Consider the role of extreme rainfall events in nutrient loss from agricultural watersheds

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STAC Workshop: ***Climate Change Modeling 2.0***

stac Chesapeake Bay Program's *Scientific and Technical Advisory Committee*

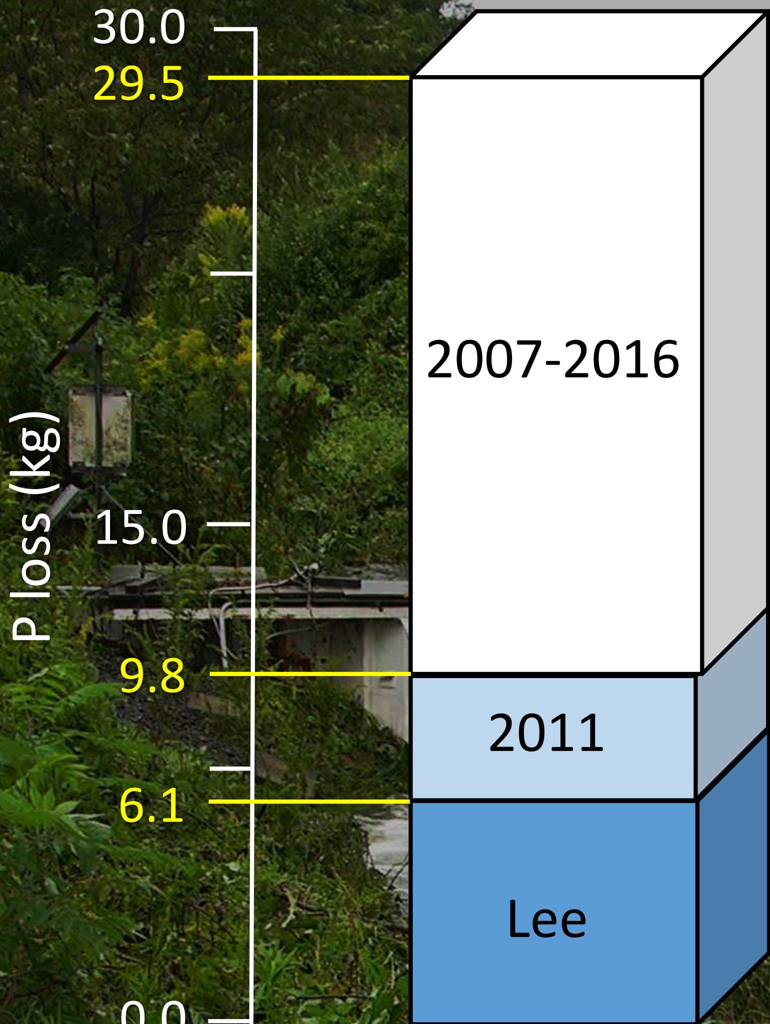
September 24-25, 2018

Crowne Plaza Hotel

Annapolis, MD

Case in point: Tropical Storm Lee in 2011

Lee contributed significantly to 2011 and decadal P loss



Tropical Storm Lee accounted for 21% of the P loss over the past decade.

Tropical Storm Lee accounted for 63% of the P loss in 2011.

Extreme rainfall greatly affects N and P loss

BMPs need to be assessed in the context of weather extremes

LIMNOLOGY AND OCEANOGRAPHY
ASLO
Association for the Sciences of Limnology and Oceanography

Extreme precipitation and phosphorus loads from two agricultural watersheds

Stephen R. Carpenter,[1*] Eric G. Booth,[2,3] Christopher J. Kucharik[3]

Biogeochemistry

Weather whiplash in agricultural regions drives deterioration of water quality

Terrance D. Loecke · Amy J. Burgin · Diego A. Riveros-Iregui · Adam S. Ward · Steven A. Thomas · Caroline A. Davis · Martin A. St. Clair

nature COMMUNICATIONS

DOI: 10.1038/s41467-017-00232-0 OPEN

Major agricultural changes required to mitigate phosphorus losses under climate change

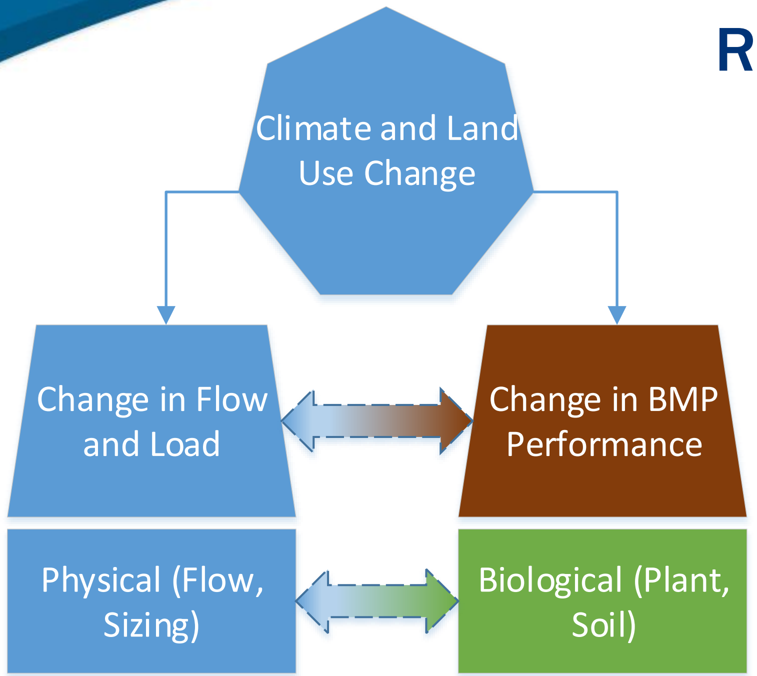
M.C. Ockenden[1], M.J. Hollaway[1], K.J. Beven[1], A.L. Collins[2], R. Evans[3], P.D. Falloon[4], K.J. Forber[1], K.M. Hiscock[5], R. Kahana[4], C.J.A. Macleod[6], W. Tych[1], M.L. Villamizar[7], C. Wearing[1], P.J.A. Withers[8], J.G. Zhou[9], P.A. Barker[1], S. Burke[10], J.E. Freer[11], P.J. Johnes[11], M.A. Snell[1], B.W.J. Surridge[1] & P.M. Haygarth[1]

Science AAAS

Eutrophication will increase during the 21st century as a result of precipitation changes

E. Sinha,[1,2*] A. M. Michalak,[1,2*] V. Balaji[3]

Resilient BMPs for a Changing Climate

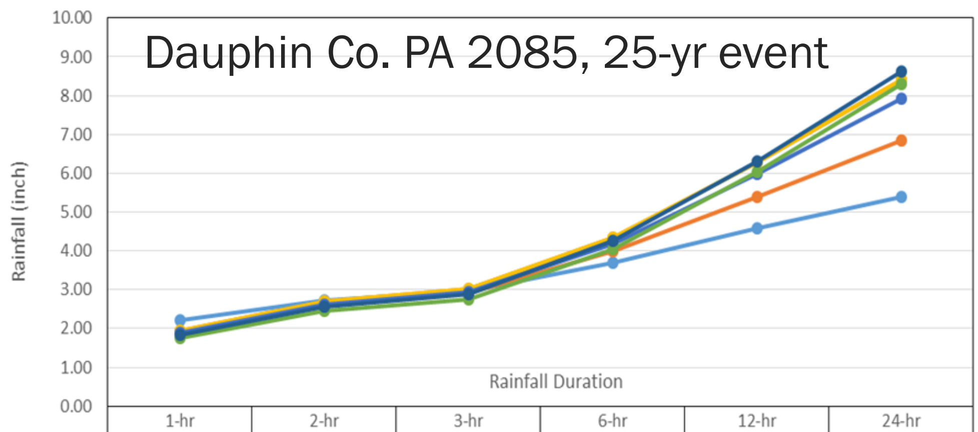


- BMPs work by a variety of physical and biological mechanisms
- These mechanisms determine how BMPs are sensitive to climate drivers (e.g., rainfall volume and intensity, temperature, soil moisture
- Evaluate climate response:
  - Simulation models
  - Space for time substitution
  - Field experiments (rare to date)

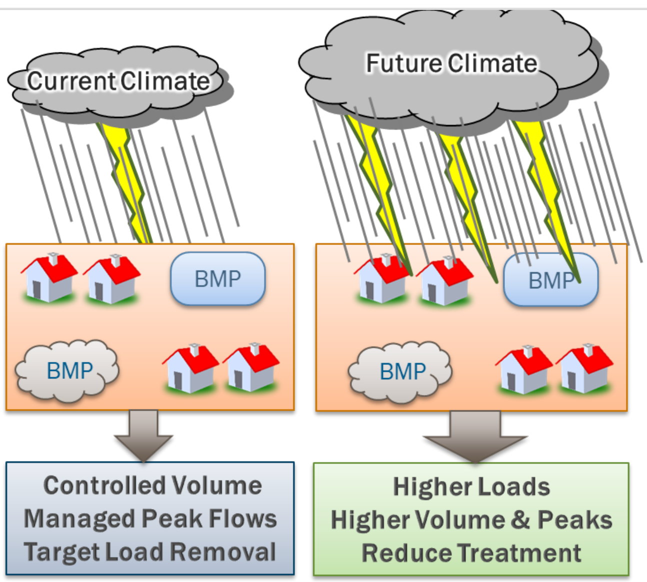
Sensitivity - Is the practice and its performance sensitive to the range of potential change?
Adaptability – Can the practice be modified to be resilient to potential changes as they emerge?
Timeliness – How short is the time line to adapt to changes?

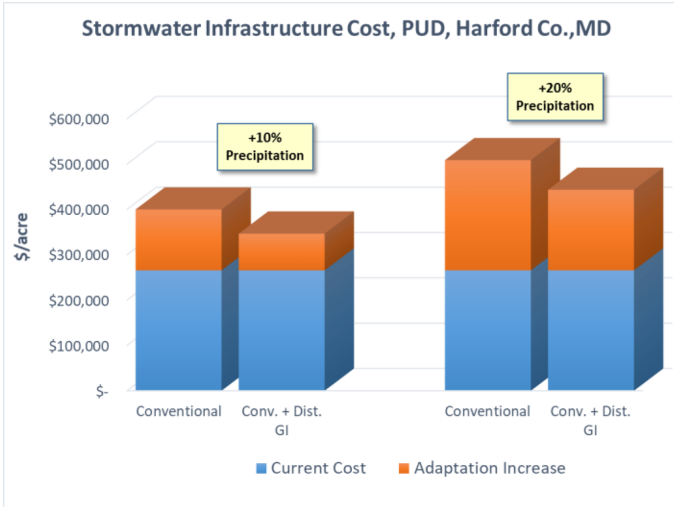
- Research sponsored by EPA ORD over the last four years

Urban BMPs

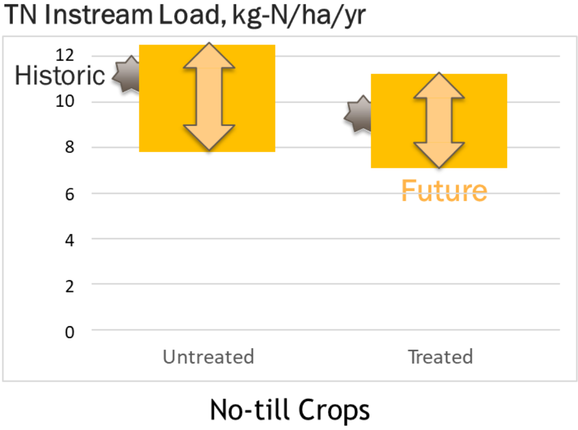


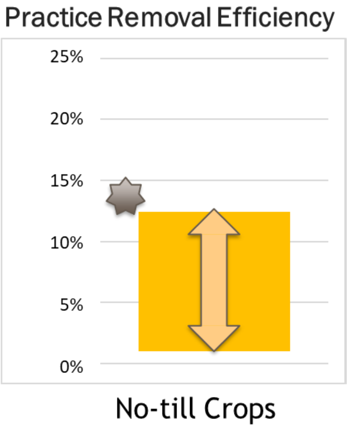
	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr
NOAA Atlas 14	2.22	2.72	2.97	3.69	4.58	5.40
HadGEM2-CC, RCP8.5	1.88	2.60	2.92	4.00	5.39	6.83
MRI-CGCM3, RCP 8.5	1.93	2.69	3.02	4.35	6.29	8.41
INMCM4, RCP 8.5	1.93	2.69	3.02	4.35	6.29	8.41
CNRM-CM5, RCP 4.5	1.89	2.63	2.95	4.19	5.97	7.93
HadGEM2-ES, RCP 4.5	1.75	2.45	2.75	4.04	6.03	8.30
BCC-CSM-1-1, RCP 4.5	1.84	2.57	2.90	4.25	6.31	8.62





Rural BMPs





Example: No-till on GA coastal plain: SWAT suggests little change in future TN load, but practice effectiveness decreases due to changes in water balance

FUNCTIONS AND SENSITIVITIES

ECOSYSTEM ANALYSIS

CLIMATE CHANGE EVALUATION

Climate resilience summary for riparian buffers

- Adaptation Strategies: Extend widths, disperse flow, increase upstream erosion control, adjust species composition
- Climate Adaptation Potential: High
- Overall Climate Sensitivity: Medium
- Timeliness: Long-term, can't quickly adjust

Ag Management Actions In Response to Climate Change

Curtis Dell, Soil Scientist,
USDA-ARS, University Park, PA
and
Agriculture Workgroup's Agriculture Modelling Subcommittee Chair

Anticipated changes in Bay watershed agricultural systems in response to changing climate

- Expanding use of winter cover crops
  - Better window for establishment after summer crop harvest
- More double cropping
  - Soybeans after small grains
  - Harvesting winter covers crops, like rye, for dairy forage
- Greater diversity of crops grown
  - Limited based on markets for crops or feed need for livestock/poultry
- Expanded use of irrigation

Possible impacts on current BMP efficiencies

- Annual management practices (largest group of ag BMPs) most flexible for adaptation to climate change.
  - For example: Nutrient management BMP give credit for adaptive approaches that improve timing and efficiency of nutrient inputs
- Efficiencies of structural BMPs (such as grassed waterways, barnyard runoff control) and vegetative buffers may be altered by changing rainfall intensities and temperature cycles.
  - Maybe biggest challenge for modeling ag BMPs

Watershed Diagnostics for Improved Adoption of Management Practices: Integrating Biophysical and Social Factors

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NIWQP: 2012-51130-20209; $631,500

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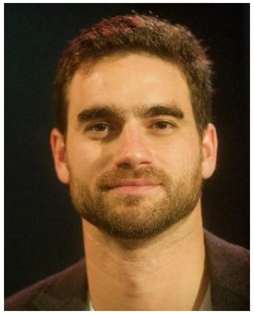

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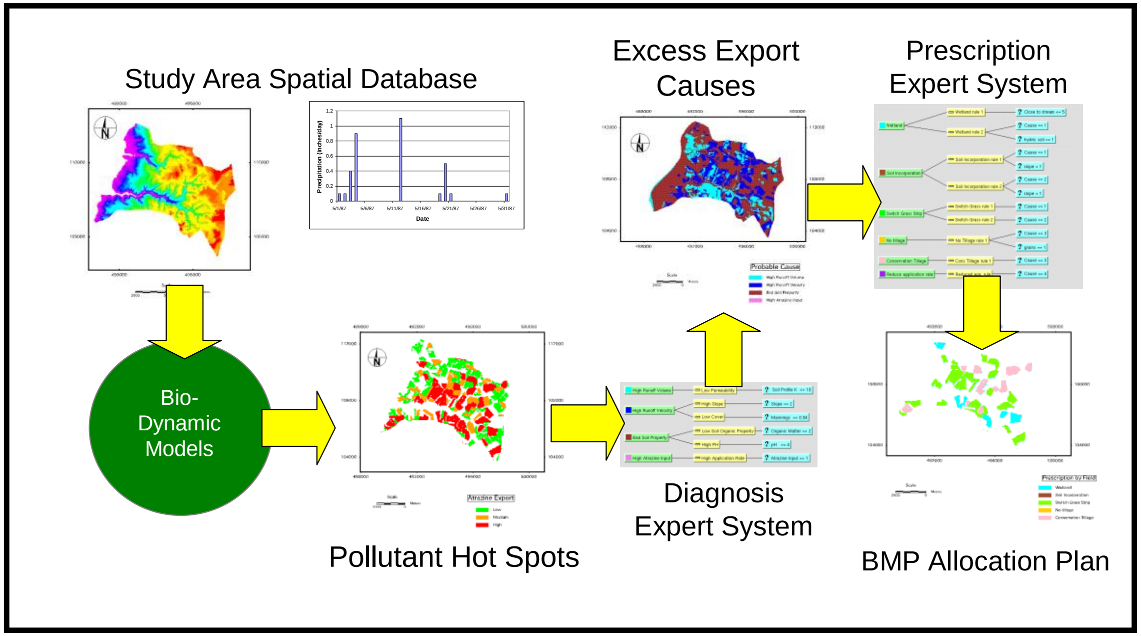
Talk Outline

1. Background
2. *Impacts of climate change on pollution Critical Source Areas (CSAs)*
3. *Impacts of climate change on Best Management Practice (BMP) effectiveness*
4. Competing views on water pollution and BMPs among stakeholders

DDSS Development



***Components**: GIS, Models, Expert Systems*

***Models**: SWAT (SUSTAIN, AQUATOX, FIBI, EPA BASINS)*

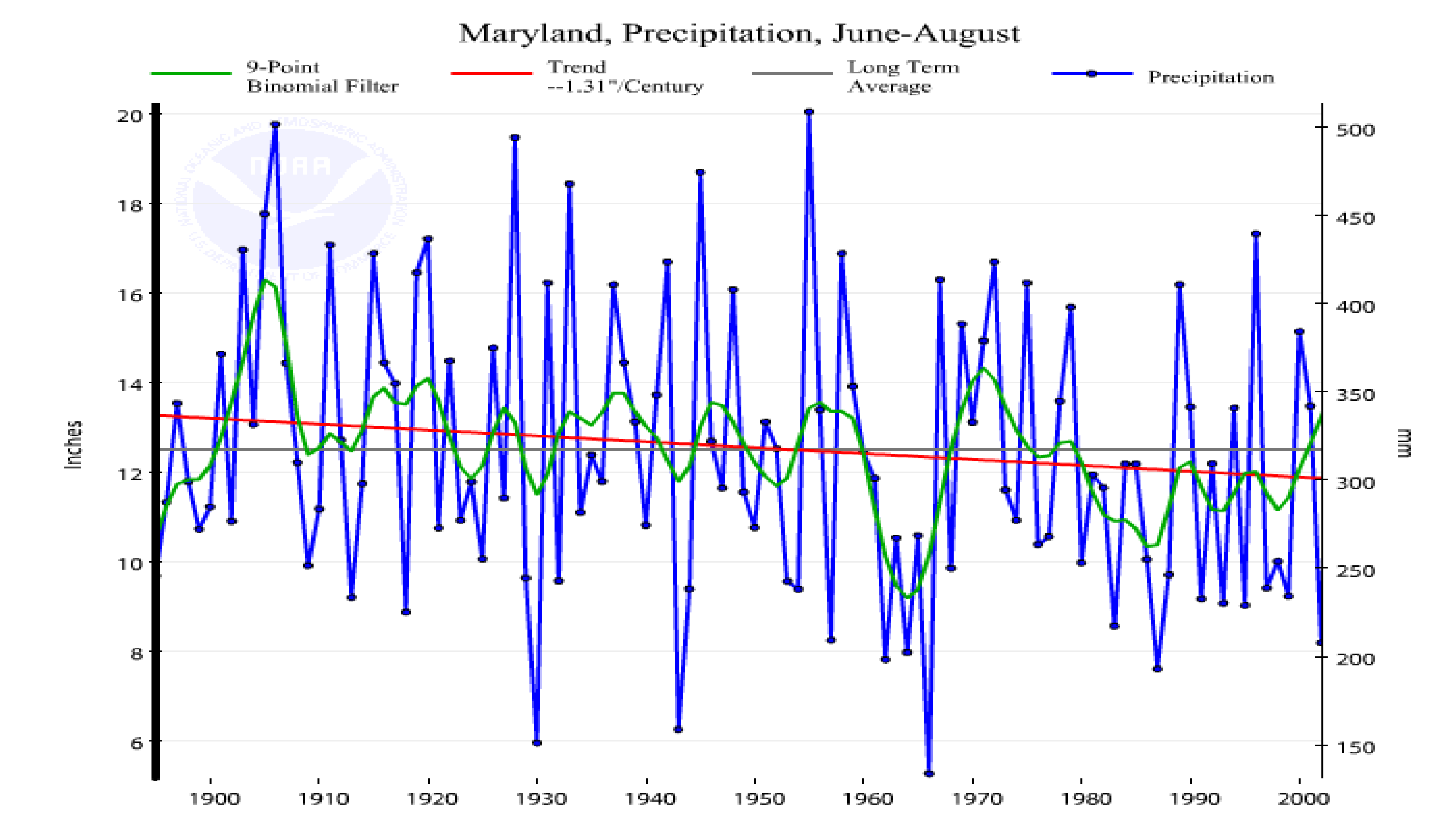
***Expert Systems**: MATLAB (predicate calculus to decision trees)*

- DDSS will rank environmental causes to pollution and prescribe a BMP allocation plan
- Geo-referenced biophysical and land management data
- Simulate watershed responses to selected stressors
- Identify CSAs & prescribe appropriate BMPs
- More “bang for the buck”

Climate Change Forecasts for the Northeastern United States

- ↑ Elevated concentrations of atmospheric CO_2
- ↑ Elevated mean temperature
- ↑ Increased mean rainfall
- ↑ Shift in seasonal rainfall patterns
  - Wetter spring
  - Drier late summer
- ↑ **Increases in extreme weather events**

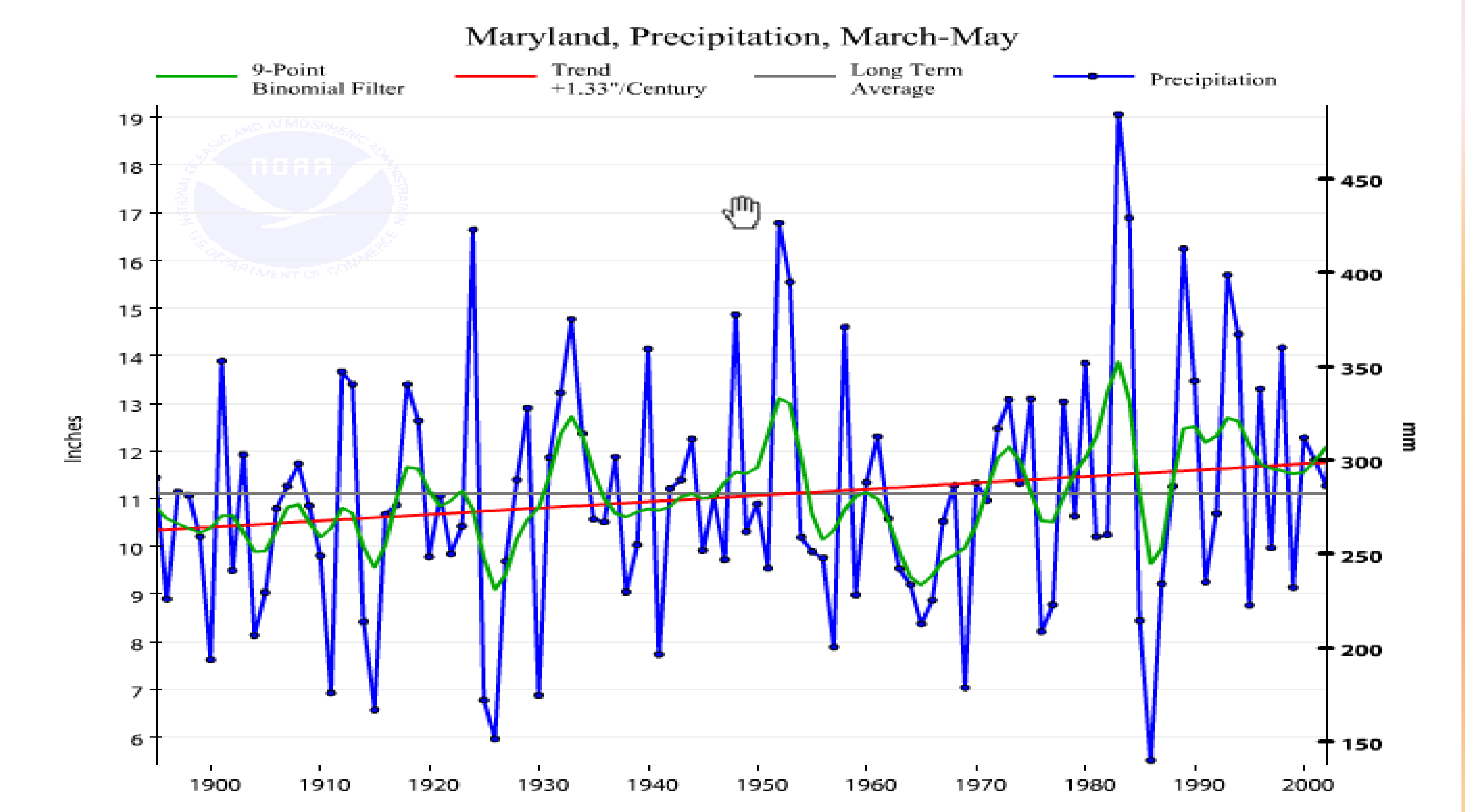
NOAA – National Climate Date Center



Cum. Change in Precipitation for June-August= -1.31” [June (-0.18), July (-0.49), August (-0.65)] per Century

http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php?parameter=pcp&month=8&year=2002&filter=3&state=18&div=0

NOAA – National Climate Date Center



Cum. Change in Precipitation for March-May = 1.33" [March (0.47), April (0.18), May (0.67)] per Century

http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php?parameter=pcp&month=8&year=2002&filter=3&state=18&div=0

Model Construction and Analysis

Data Type	Characteristics	
Topography/DEM	10 meter	HRU
Landuse/Land Cover	NLCD 2006	HRU
Soils	NRCS SSURGO	HRU
Weather (Calibration)	3 stations NCEP CFSR	
Flow, Nutrients and Sediment	1 USGS Gauging Station Greensboro	
Climate Change GFDL-CM2.1	CMIP3 (B1, A1B, A2) (Mid and End Century)	

Software	Purpose and Progression
ArcGIS	Spatial Data Analysis (Graphics and Database)
ArcSWAT	Model development SWAT input file Generation
SWAT-CUP	Model calibration (SUFI-2 Method)
SWAT	Experimental engine (SWAT.exe)

Downscaled climate predictions from global model based around 3 IPCC scenarios that lead to low, medium, and high future levels of CO_2

Model Calibration

- Warm-up (3 yrs): 1/1/1990 to 12/31/1992
- Calibration Period (15 yrs): 1/1/1990 to 12/31/2004

Model Validation

- Warm-up (2 yrs): 1/1/2005 to 12/31/2006
- Validation Period (6 yrs): 1/1/2005 to 12/31/2010

Impacts of Climate Change on Pollution CSAs

Renkenberger et al., 2016. Climate change impact on critical source area identification in a Maryland watershed. Transactions of ASABE, Vol 59 (6): 1803-1819.



Definition of a Critical Source Area (CSA)

An area that exports a target pollutant at concentrations significantly above average

Rank	SurQ (mm H20)	TSS (tonnes/ha/yr)	TN (kg/ha/yr)	TP (kg/ha/yr)
Top 10%	>406	>1.03	>24	>1.9
Top 20%	>359	>0.73	>16	>1.6

Top 10%: Value for which the top ~770 HRUs is separated from the other 7705 HRUs

Top 20%: Value for which the top ~1540 HRUs is separated from the other 7705 HRUs

Always defined a watershed area (or HRU) a CSA if it exported a given pollutant at or above these fixed thresholds

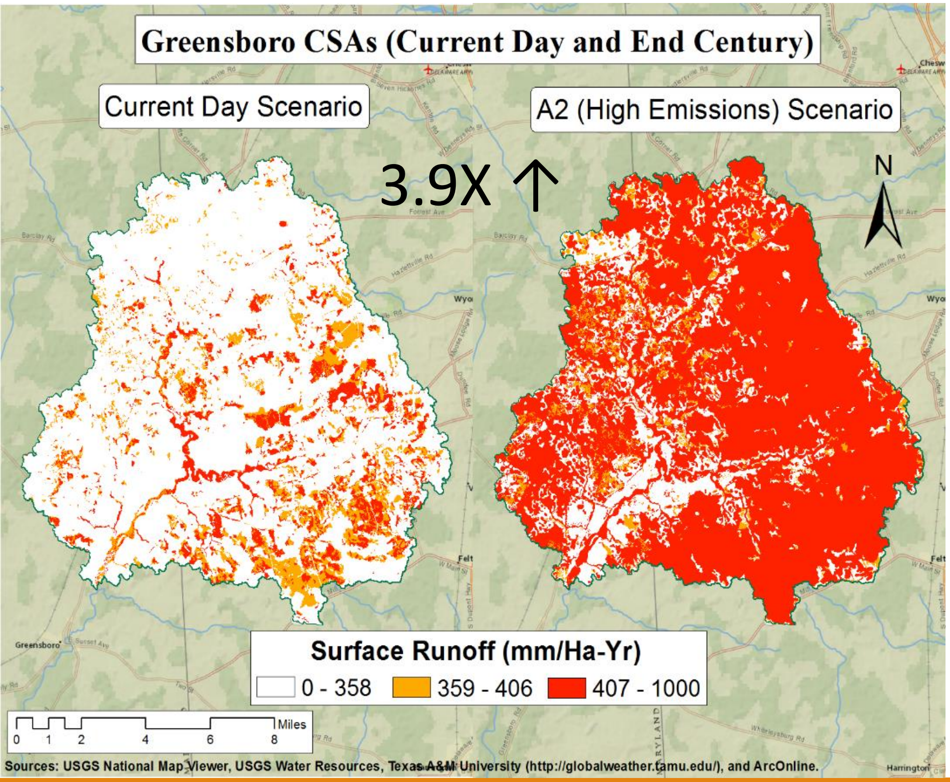
Surface Runoff & Total Suspended Solids

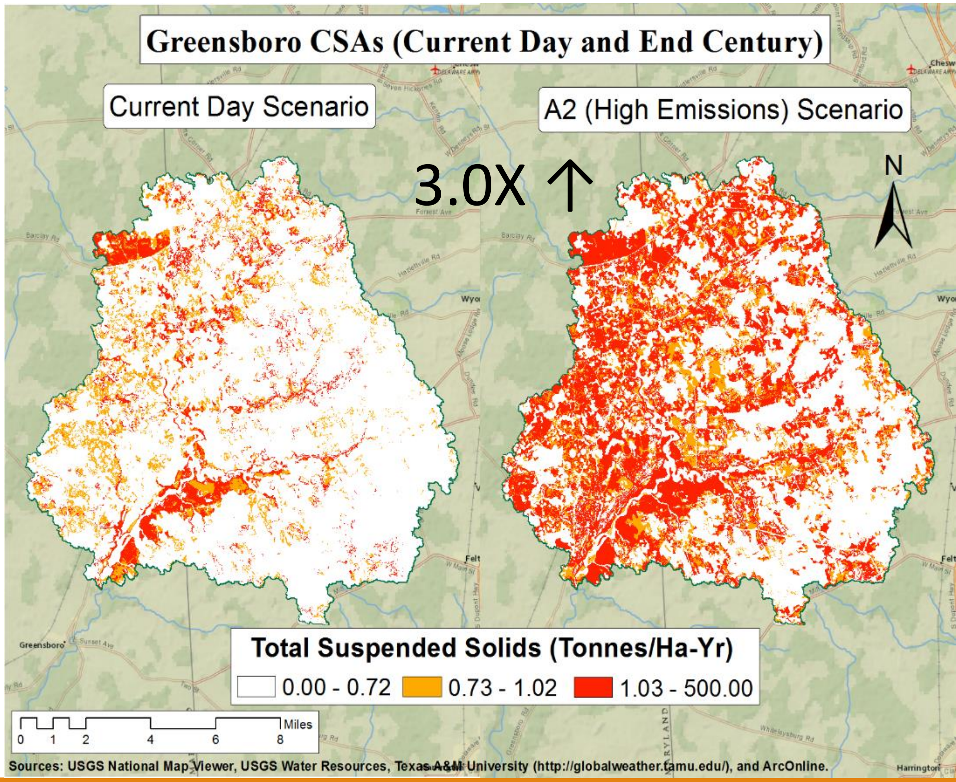
% Change in Area: SurQ: 21%-81% (3.9x), TSS: 18%-45% (2.5x)

% Change on Export: SurQ: 31%-89% (3x), TSS: 46%-81% (1.5x)

Present Day CSAs → SRES A2 → End Century CSAs

25-30% ↑ rainfall





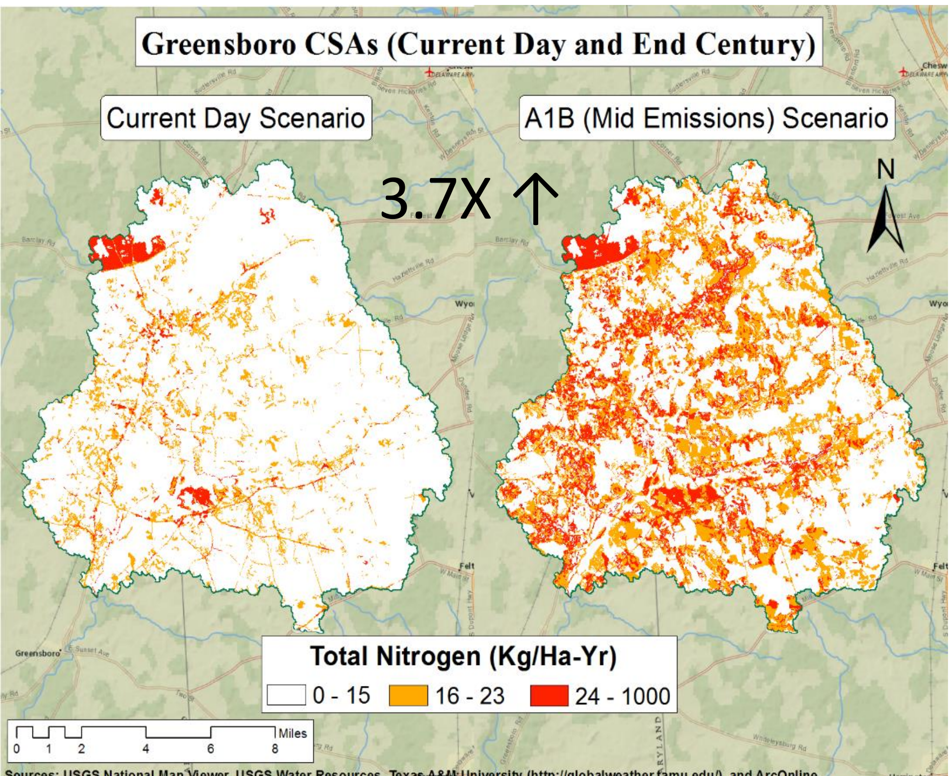
Nitrogen & Phosphorous

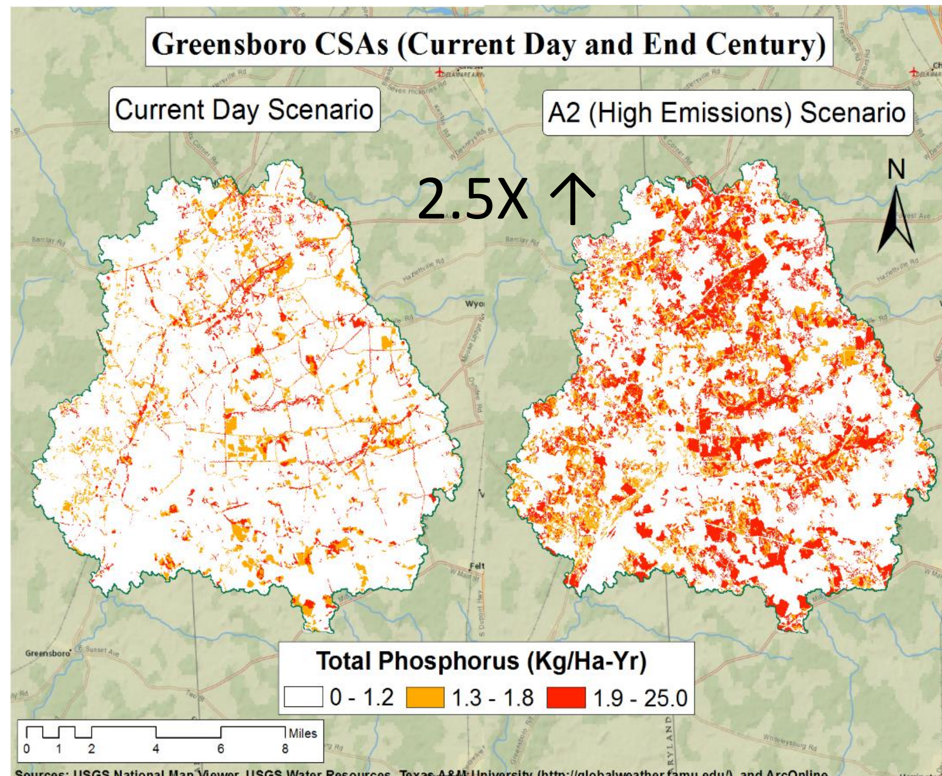
% Change in Area: TN: 11%-41% (3.7x), TP: 13%-32% (2.46x)

% Change in Export: TN: 31%-72% (2.3x), TP: 39%-66% (1.7x)

Present Day CSAs → SRES A2/A1B → End Century CSAs

25-30% ↑ rainfall



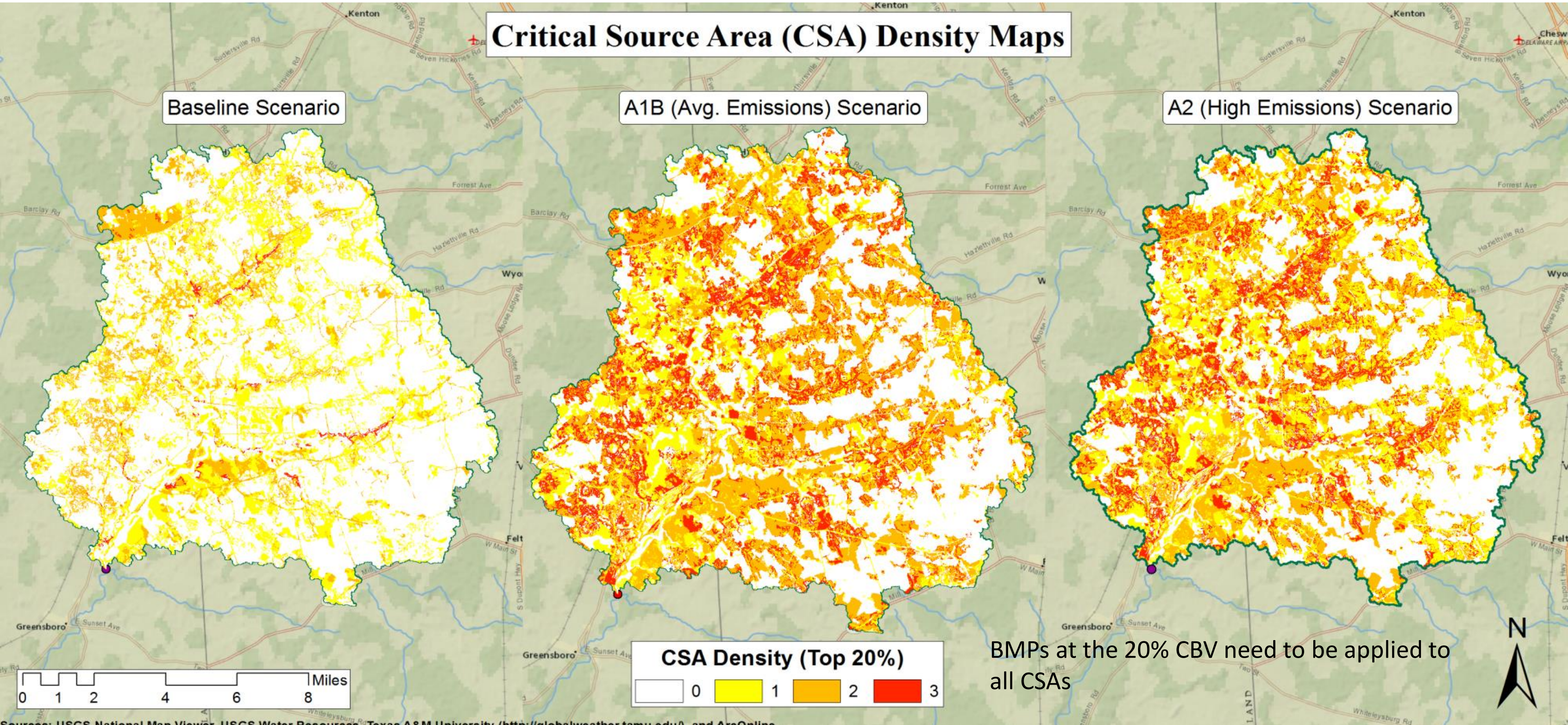


Impacts of Climate Change on BMP Effectiveness

Renkenberger et al., 2017. Effectiveness of BMPs with Changing Climate in a Maryland Watershed. Transactions of ASABE, Vol 60 (3):769-789.

Targeting Method: Dense CSAs

Critically Dense Areas at the top 20% Breakpoint Value



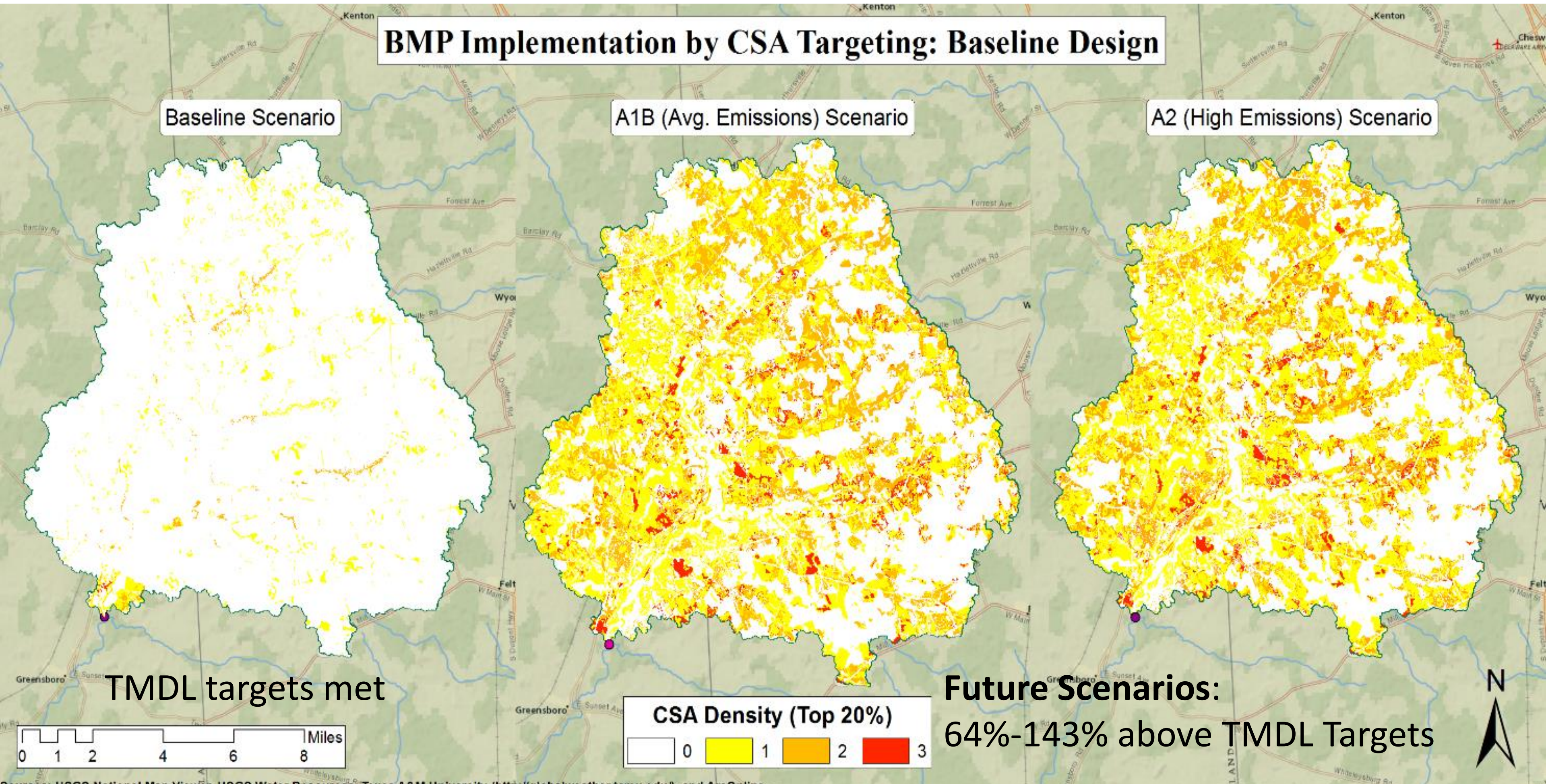
BMPs at the 20% CBV need to be applied to all CSAs

Rank	SurQ (mm H20)	TSS (tonnes/ha/yr)	TN (kg/ha/yr)	TP (kg/ha/yr)
Top 10%	>406	>1.03	>24	>1.9
Top 20%	>359	>0.73	>16	>1.6

Targeting Dense CSAs of Today

We will ***meet*** TMDL targets if we ignore CC, ***but miss*** TMDL targets by **64-143%** under Future Scenarios. We target 31% of area with BMP Eff% TSS = 61%; TN = 79%; TP = 43%

Residual CSA Density with Baseline BMP Design Subjected to Current, A1B and A2 Climate Conditions



Targeting Dense CSAs of the Future

If we target CDA under high emissions, we address CSAs now and in future and meet TMDLs. Under this option we target 58% of watershed area instead of 31 %. BMP eff. of 82%, 74% and 72% for TSS, TN and TP, respectively

Residual CSA Density with A2 BMP Design Subjected to Current, A1B and A2 Climate Conditions.