2019 PA
Climate Change Impact
Assessment

Background

- Fourth in a series of reports mandated by the Pennsylvania Climate Change Act (PCCA), Act 70 of 2008
- Prior reports (2009, 2013, 2015)
  - Climate change in PA
  - PA climate future
  - Impacts of climate change in climate-sensitive sectors agriculture, energy, forests, human health, outdoor recreation, water and aquatic resources
- Results based on review of relevant science literature and some original work
- Literature on impacts evolves slowly

2019 Assessment

- Deeper focus on coping with climate change in climate-sensitive sectors
- Climate change creates risk management problems
- Managing climate risk requires identifying and characterizing risks and identifying and evaluating management options
- Specific risk management decision problems are especially useful assessing available information and information needs for risk management

2019 Assessment

- Chesapeake Bay TMDL (Chapters 2 and 3)
  - Livestock industry impacts & water quality pressures
  - Effectiveness of BMPs
  - Watershed management strategies
- Infrastructure (Chapter 4)
  - Energy infrastructure
  - Flooding
- Extreme precipitation risks (Chapter 5)
  - Characterization
  - Forecasting

Penn State Team

Livestock

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Review of Past and Potential Future Precipitation Changes in Pennsylvania

Robert Nicholas
with contributions from Mahkameh Zarekarizi and Klaus Keller
Earth & Environmental Systems Institute
The Pennsylvania State University

Tuesday 25 February 2020

Overall precipitation has increased in Pennsylvania, but the changes vary with season.

Fall precipitation has increased dramatically (>15%) since 1901.

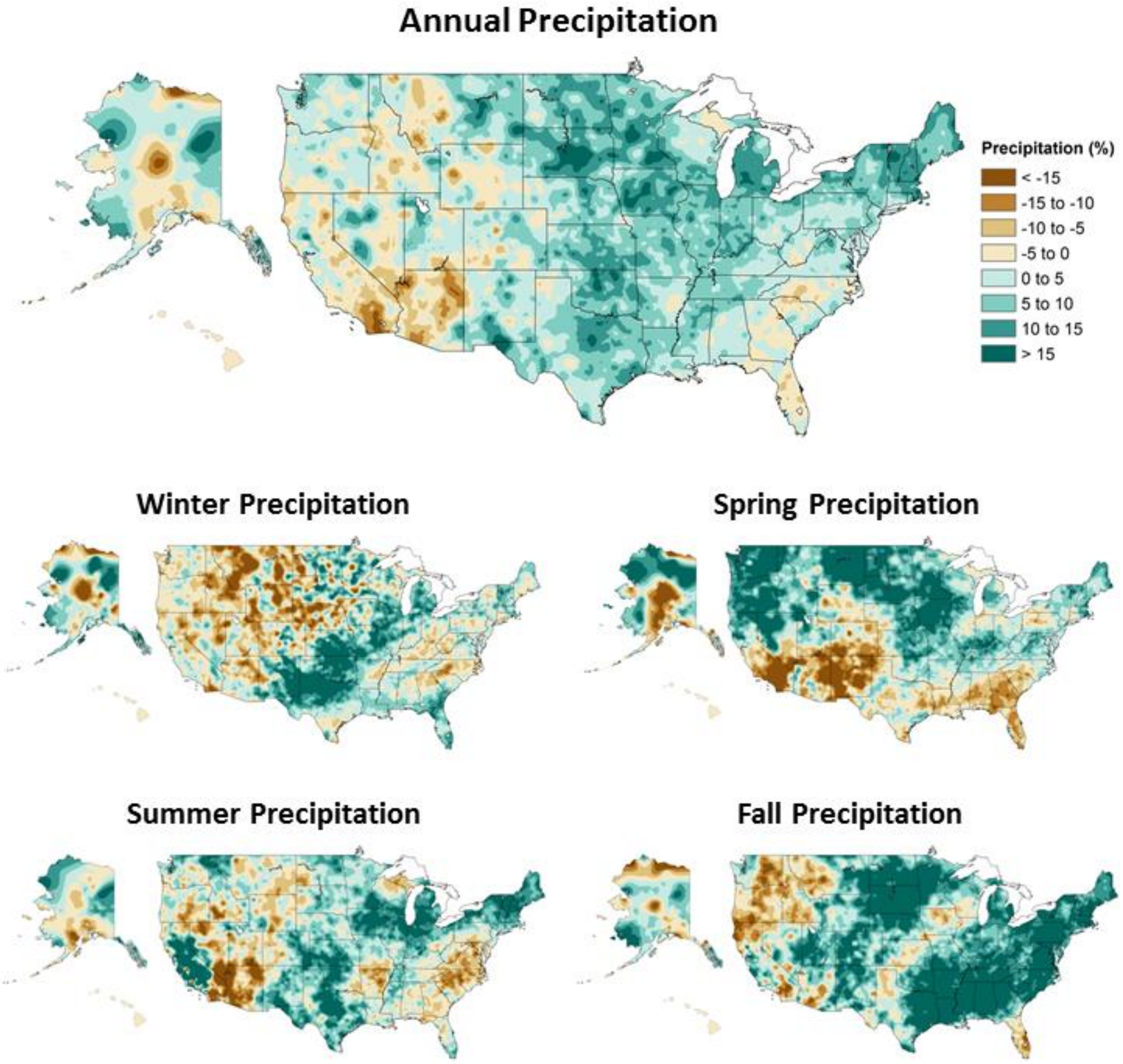


Figure 7.1: *Fourth National Climate Assessment, Volume 1*

Extreme precipitation has also increased in Pennsylvania.

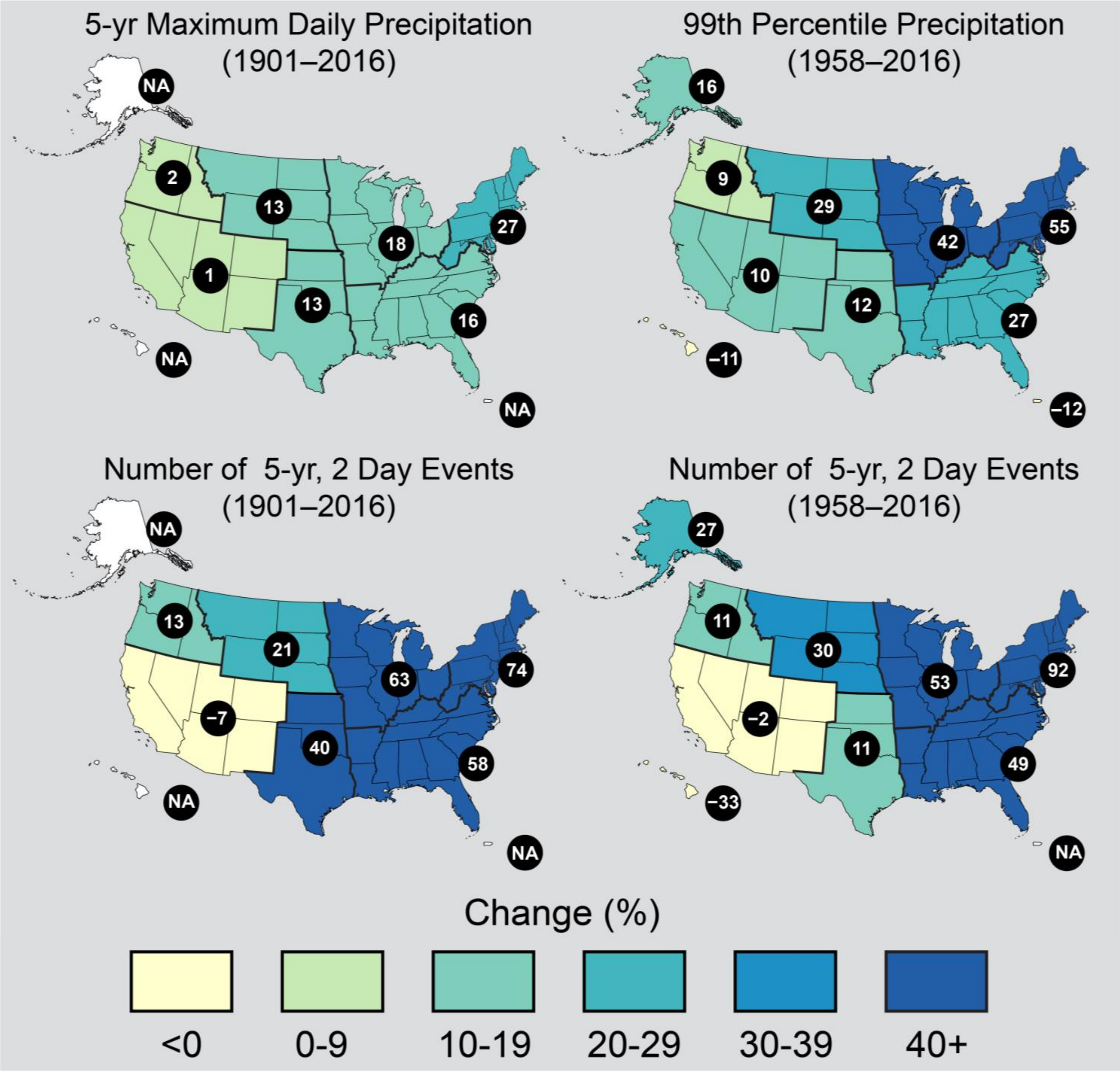


Figure 7.4: *Fourth National Climate Assessment, Volume 1*

The increases in extreme precipitation vary with season.

Observed Change in Daily, 20-Year Return Level Precipitation (1901-2016)

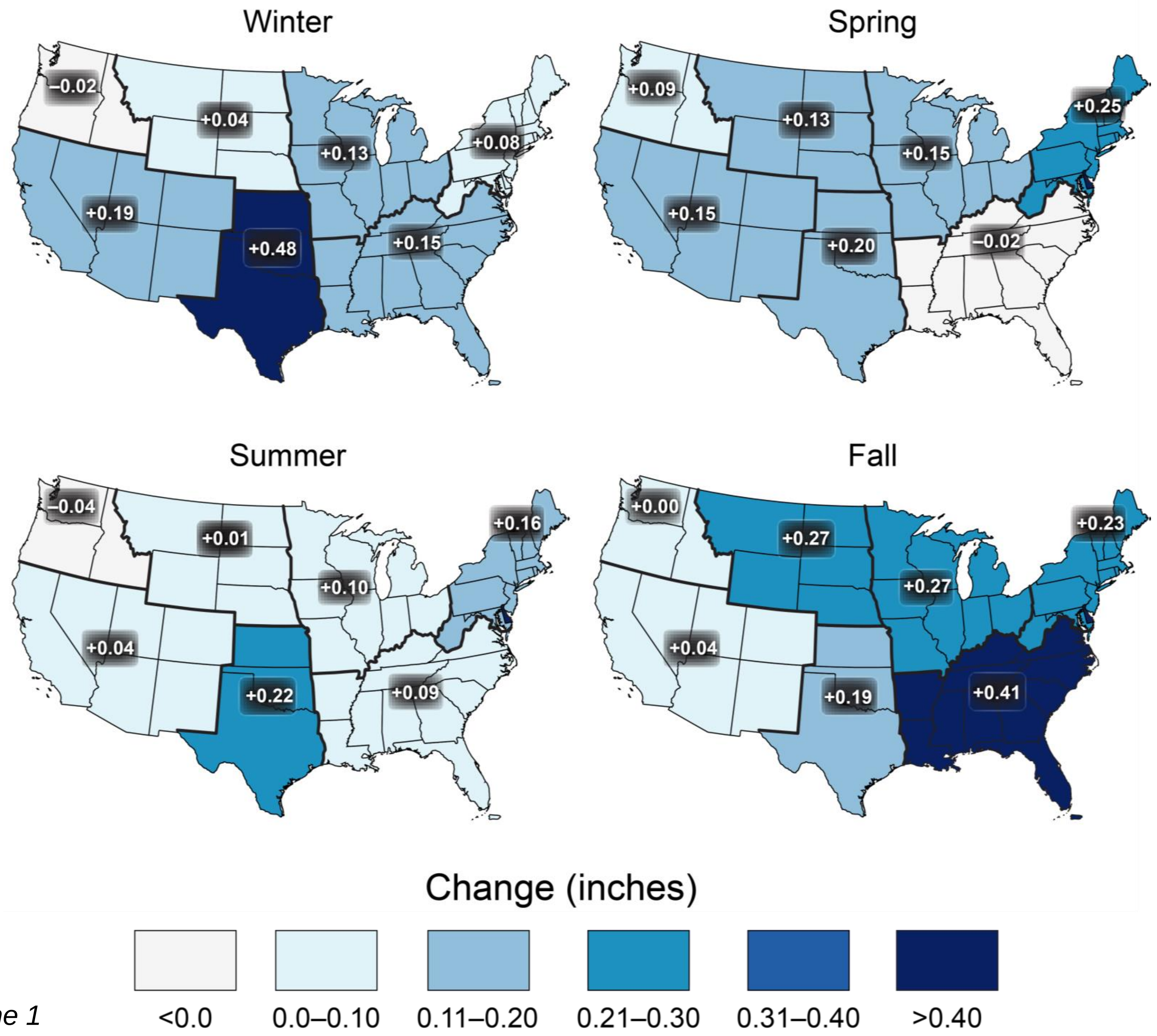


Figure 7.2: *Fourth National Climate Assessment, Volume 1*

Overall precipitation is projected to increase in Pennsylvania for all seasons.

Projected Change (%) in Seasonal Mean Precipitation to the Late 21st Century

2070-2099 relative to 1976-2005 Weighted Multimodel Mean from CMIP5 RCP8.5

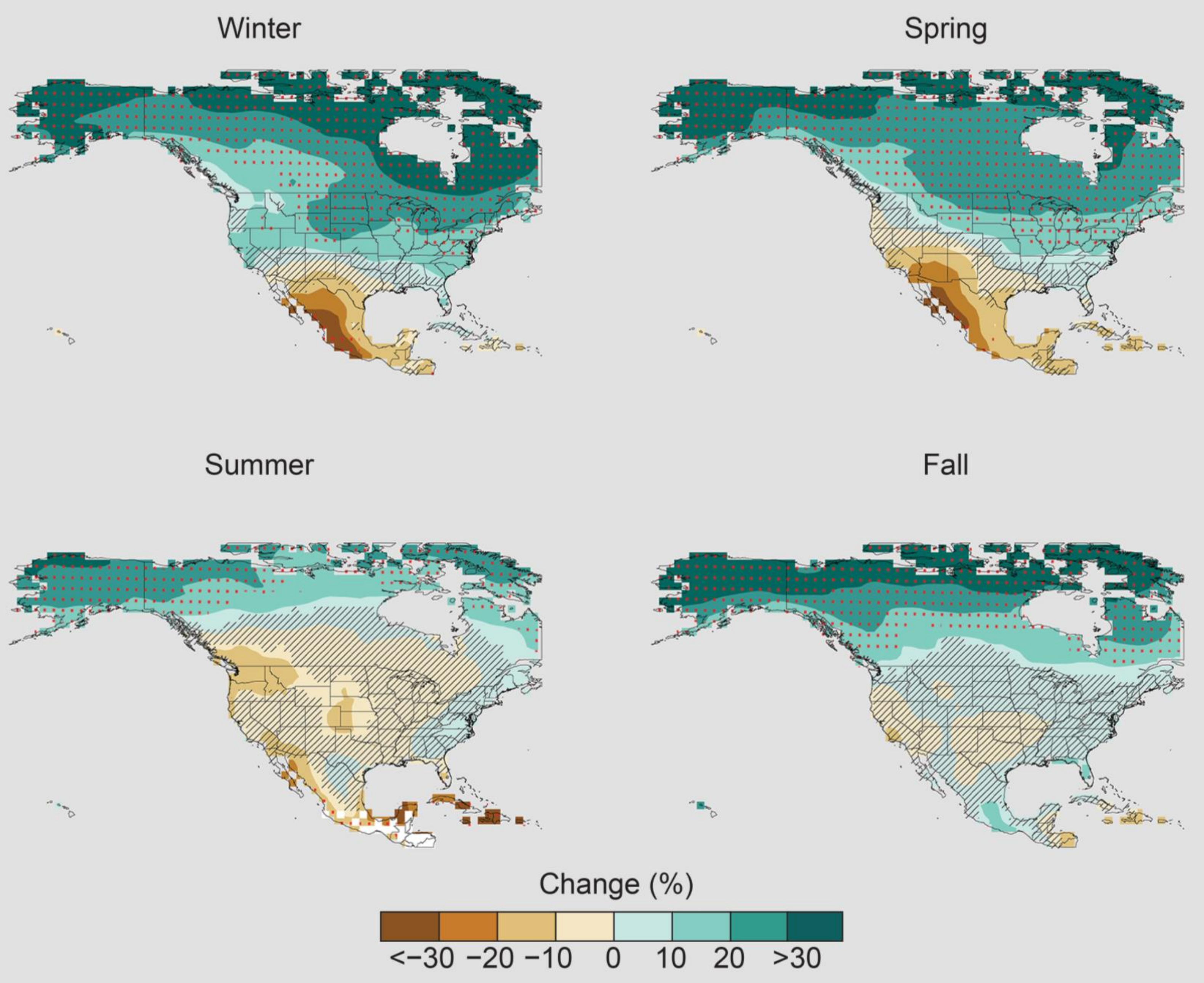


Figure 7.5: *Fourth National Climate Assessment, Volume 1*

Extreme precipitation is also expected to increase over Pennsylvania.

Projected Change (%) in
Daily, 20-Year Extreme Precipitation

Weighted Multimodel Mean from CMIP5
relative to 1976-2005

“lower emissions” = RCP4.5
“higher emissions” = RCP8.5

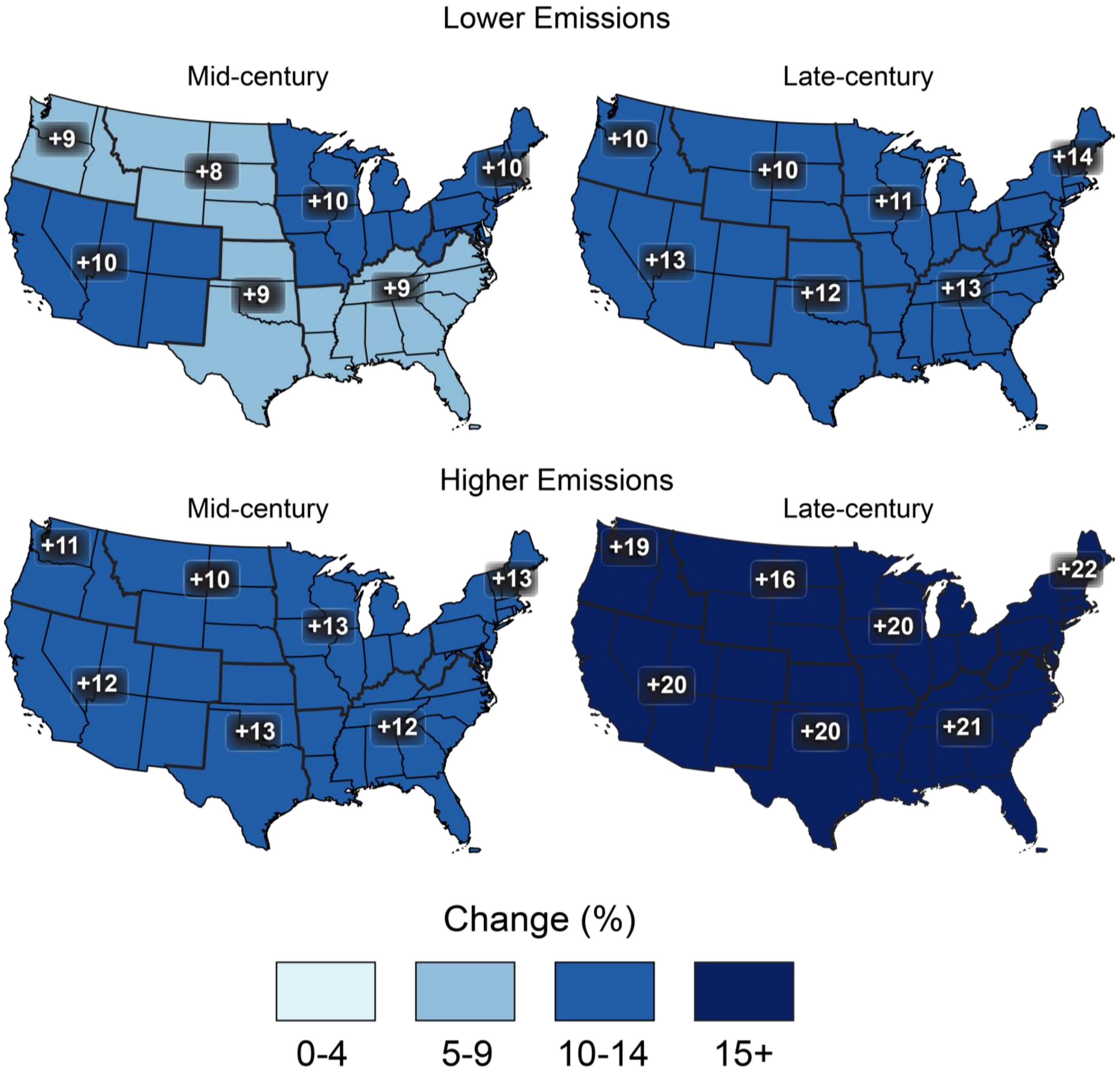


Figure 7.7: *Fourth National Climate Assessment, Volume 1*

Despite increased precipitation, soil moisture is expected to decline due to higher temperatures.

Projected Change (%) in Seasonal Soil Moisture to the Late 21st Century

2070-2099 relative to 1976-2005 Weighted Multimodel Mean from CMIP5 RCP8.5

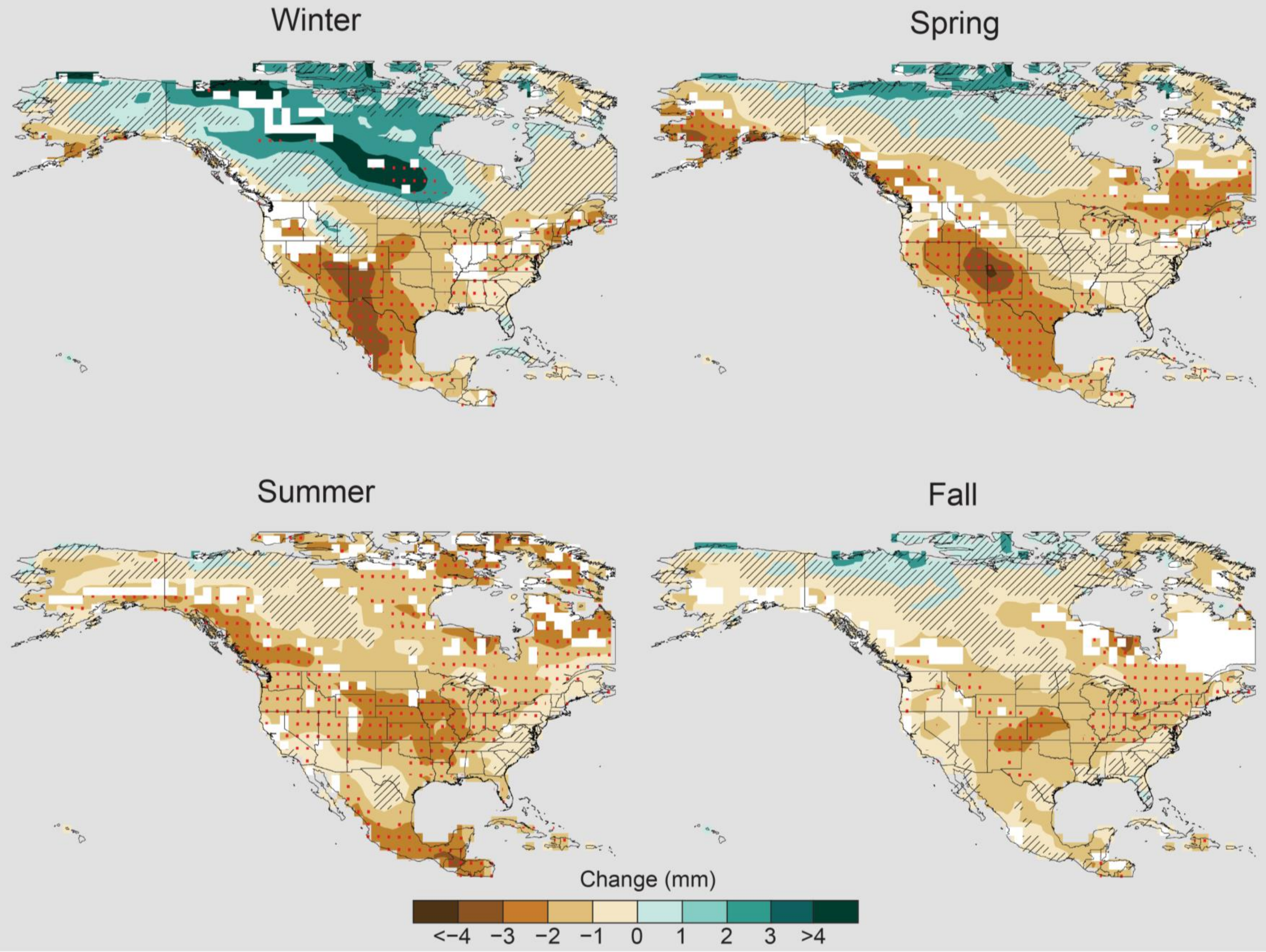


Figure 8.1: *Fourth National Climate Assessment, Volume 1*

Summary: Precipitation in PA

- Pennsylvania has seen a significant increase in precipitation since 1901, with the largest increases (>15%) coming in Fall.
- Extreme precipitation events have also increased in magnitude since 1901.
- Total precipitation and extreme precipitation are both likely to continue increasing in the coming decades (high confidence).
- Expected changes in magnitude, seasonality, and variability are less well understood. Climate policy and economic development pathways pose key uncertainties.
- Despite increasing precipitation, soil moisture is expected to decline in all seasons due to higher temperatures.

Climate Change and Livestock Production

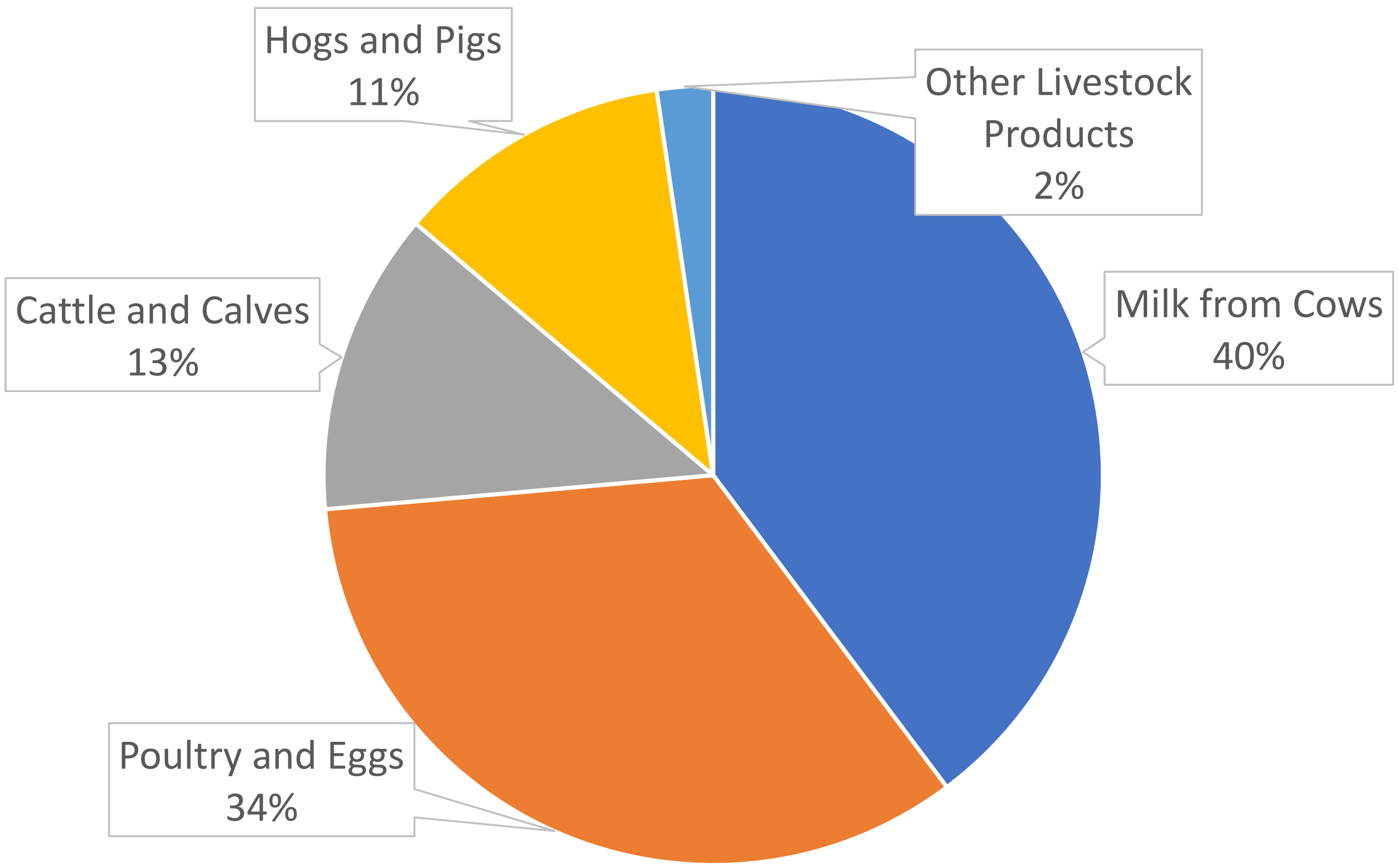
- Livestock products account for about two-thirds of Pennsylvania’s agricultural product sales
- Most of Pennsylvania farmland is in livestock feed production or pasture
- Large-scale livestock production is a nutrient concentrator on the landscape, often leading to water pollution
- Adapting to climate change requires an understanding of how Pennsylvania livestock production may change

Objectives

1. Make projections for 2050 of potential impacts of climate change on the size of Pennsylvania's livestock industry
    - Direct impacts of climate change within Pennsylvania
    - Indirect impacts of climate change on livestock industry location decisions between Pennsylvania and other parts of the U.S. and world

2. Make projections for 2050 of potential impacts of climate change on nutrients from Pennsylvania livestock production

2017 Pennsylvania Livestock Sales



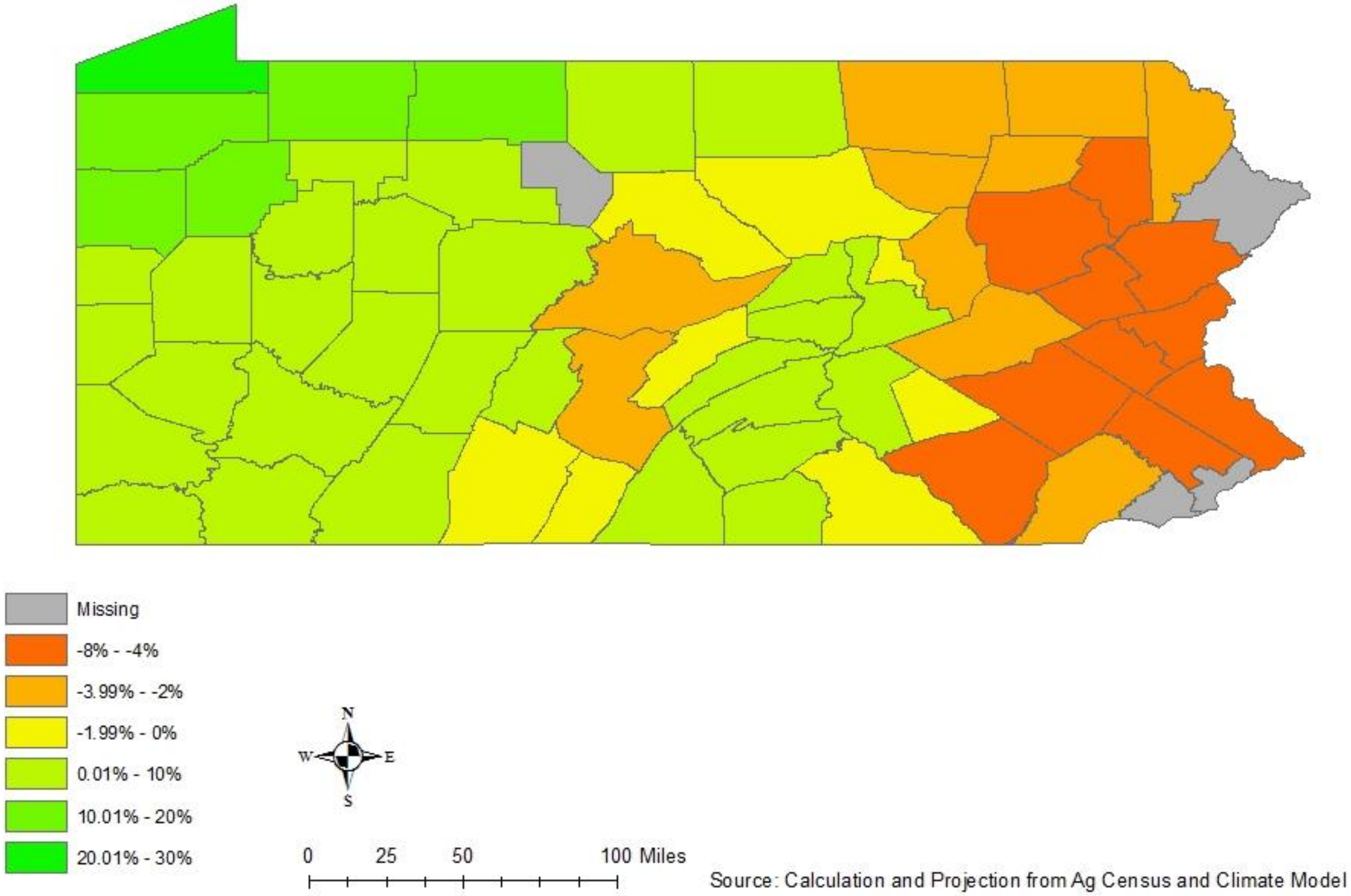
Methods

- “Climate analogue” methodology – look at other counties in the U.S. whose present-day climate is like Pennsylvania’s future climate
- Statistically analyze how climate impacts county-level inventories of dairy cows, beef cattle, hogs and pigs, and poultry, controlling for other factors impacting inventories
- Make projections of inventory changes between 2012 and 2050 due to climate change
- These projections don’t consider other factors that may be changing between now and 2050

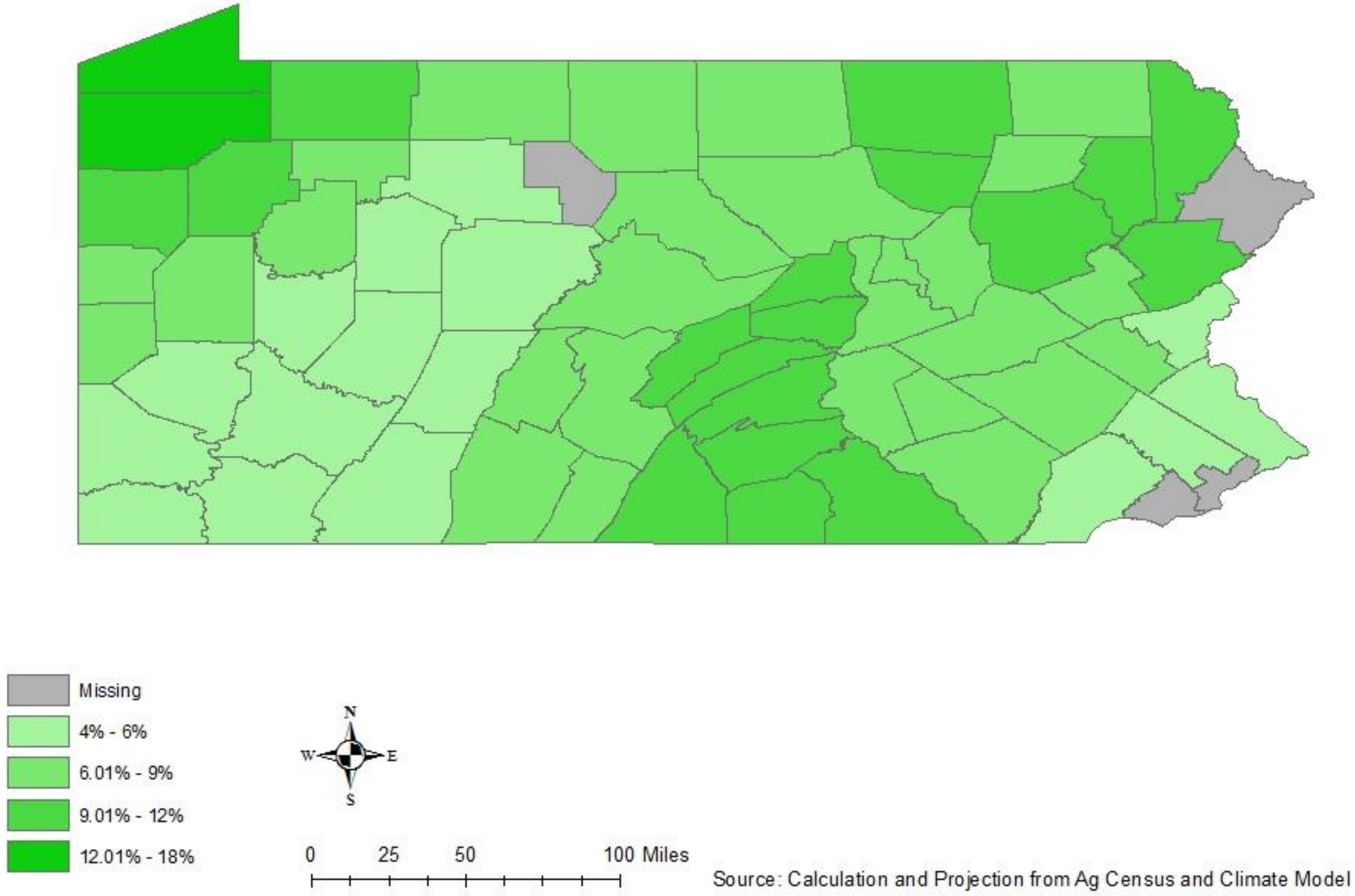
Data

- County-level data for the 48 contiguous states on livestock inventories
  - Annual farm survey data for 2009-2018
  - Census of Agriculture data for 2007, 2012, and 2017
- County-level, monthly climate data for 30-year period (1979-2008)
  - Precipitation and maximum daily temperature
  - Monthly means (climate normals)
  - Monthly standard deviations (climate variability)
- Climate projections from *2015 Pennsylvania Climate Impacts Assessment*

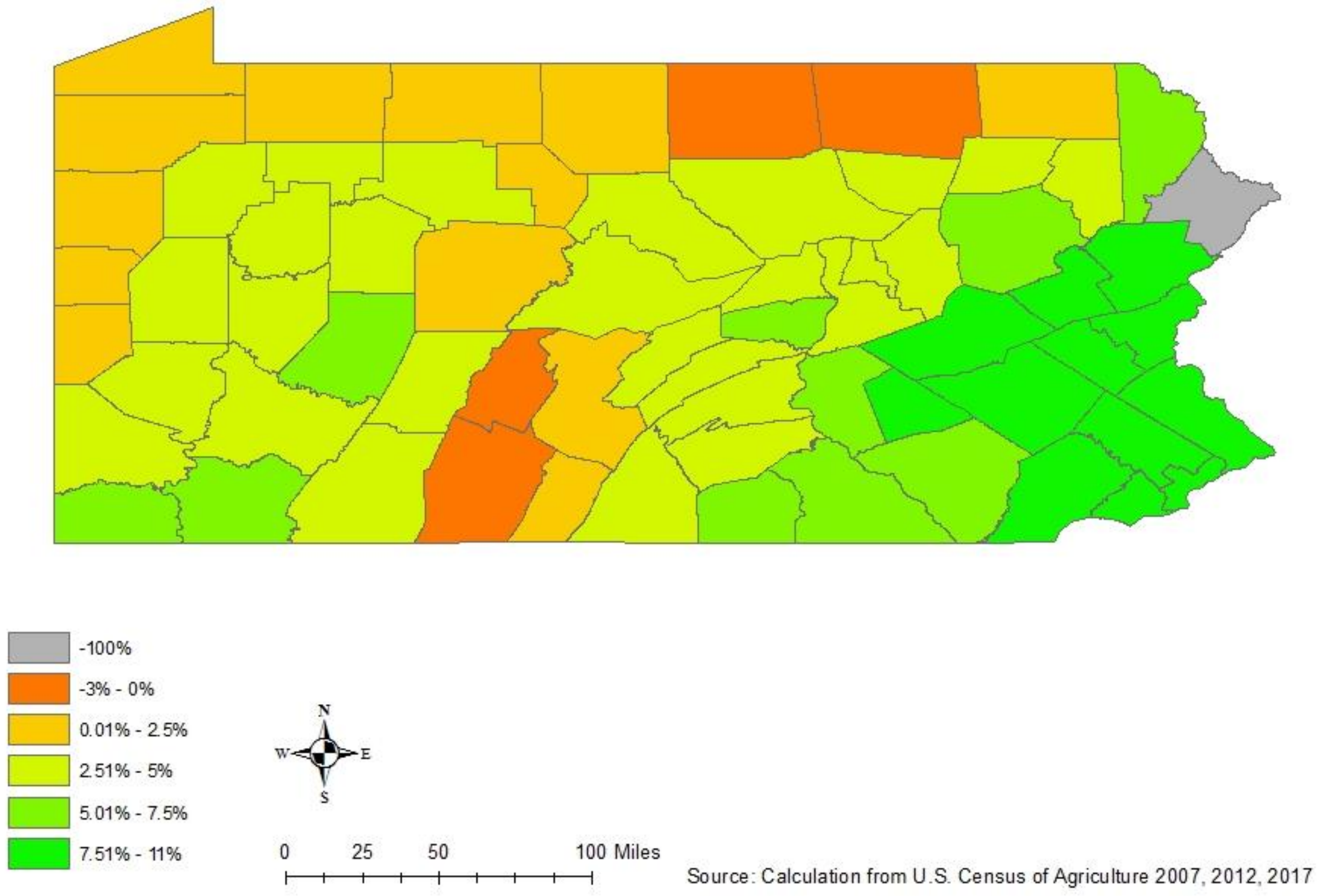
% Change in Milk Cow Inventory, 2012-2050



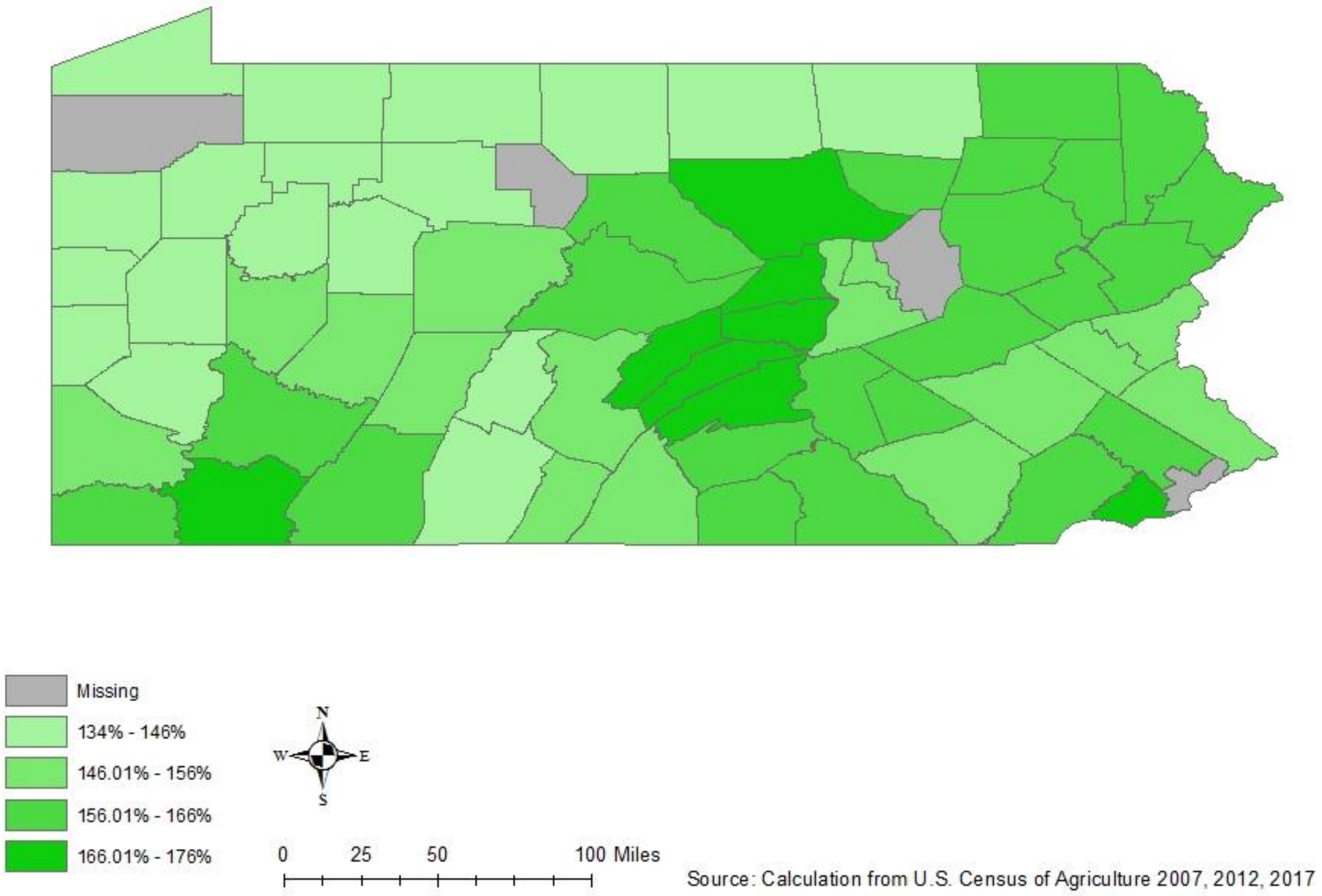
% Change in Beef Cattle Inventory, 2012-2050



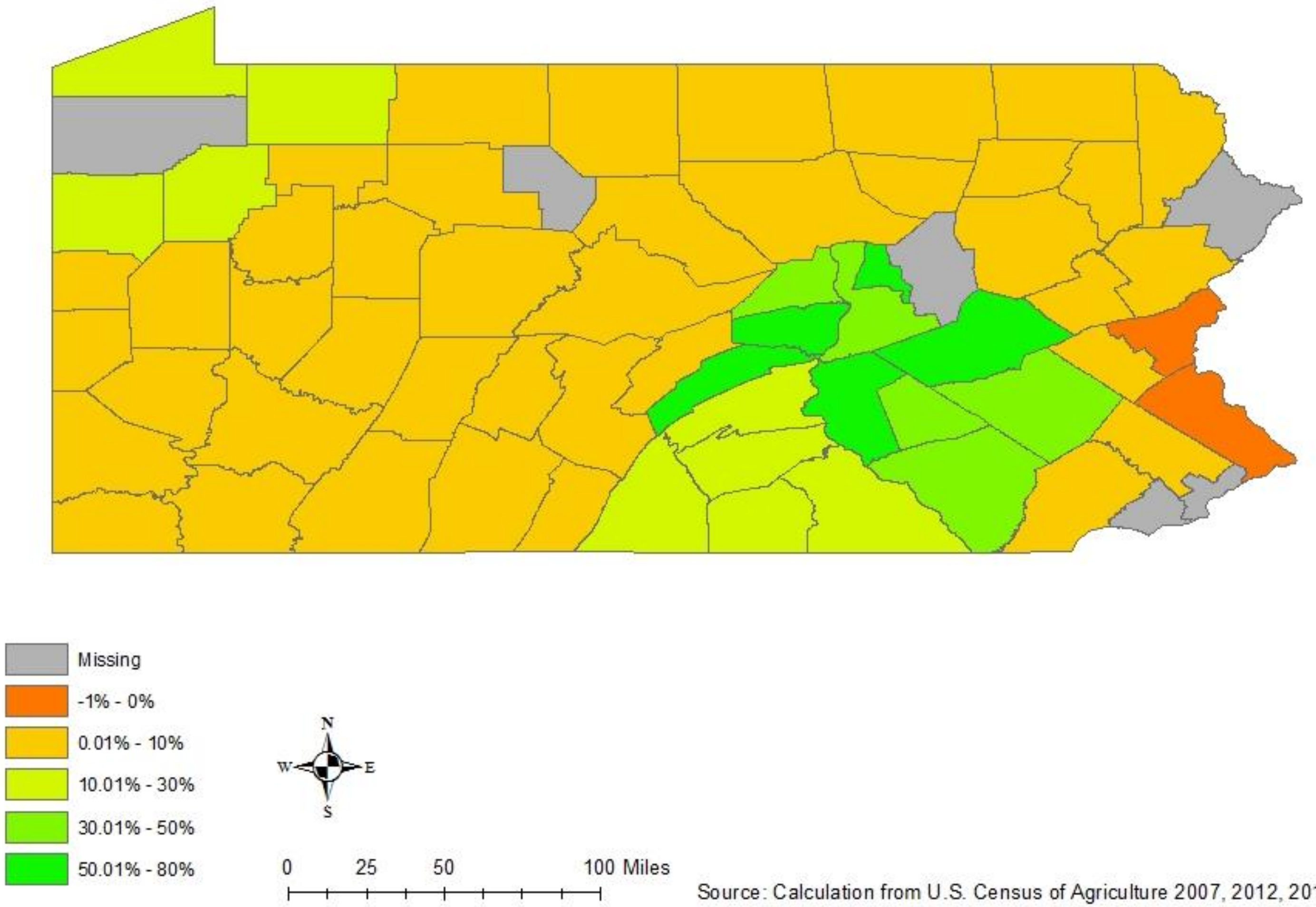
% Change in Hog/Pig Inventory, 2012-2050



% Change in Poultry Inventory, 2012-2050

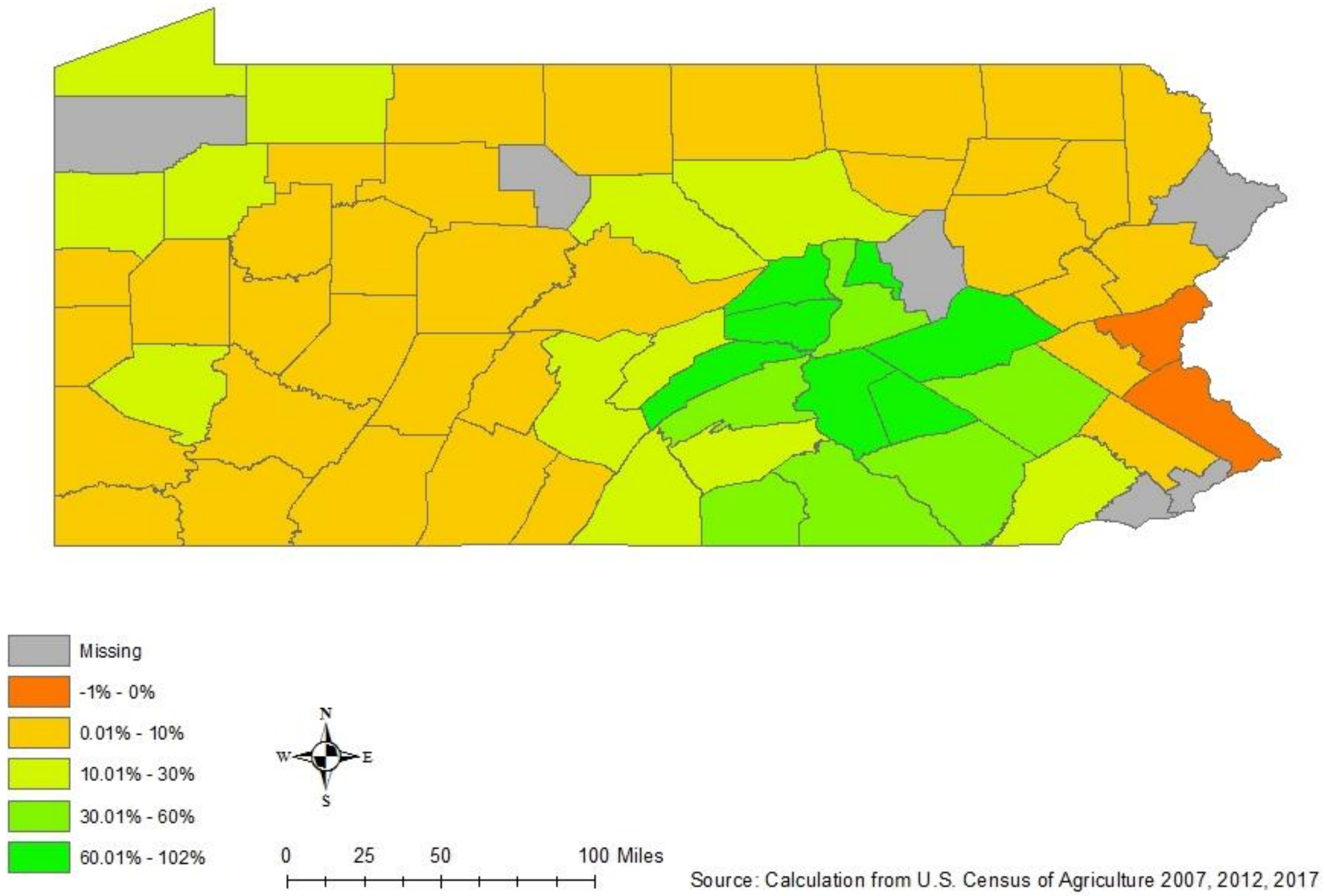


% Change in Manure Nitrogen, 2012-2050



Source: Calculation from U.S. Census of Agriculture 2007, 2012, 2017

% Change in Manure Phosphorus, 2012-2050



Livestock: Main Findings

- Pennsylvania's poultry inventory could more than double in size
- Much smaller increases in inventory could occur for beef cattle and hogs and pigs
- There could be a spatial rearranging of the dairy industry, with declines in southeast counties and increases in northwest counties
- Manure nitrogen and phosphorus could increase in almost all counties, and significantly in the south-central and southeast
- Could exacerbate water quality issues, especially in the Susquehanna and Delaware River Basins

Climate Change Impacts on Pennsylvania's Watershed Management Strategies and Water Quality Goals

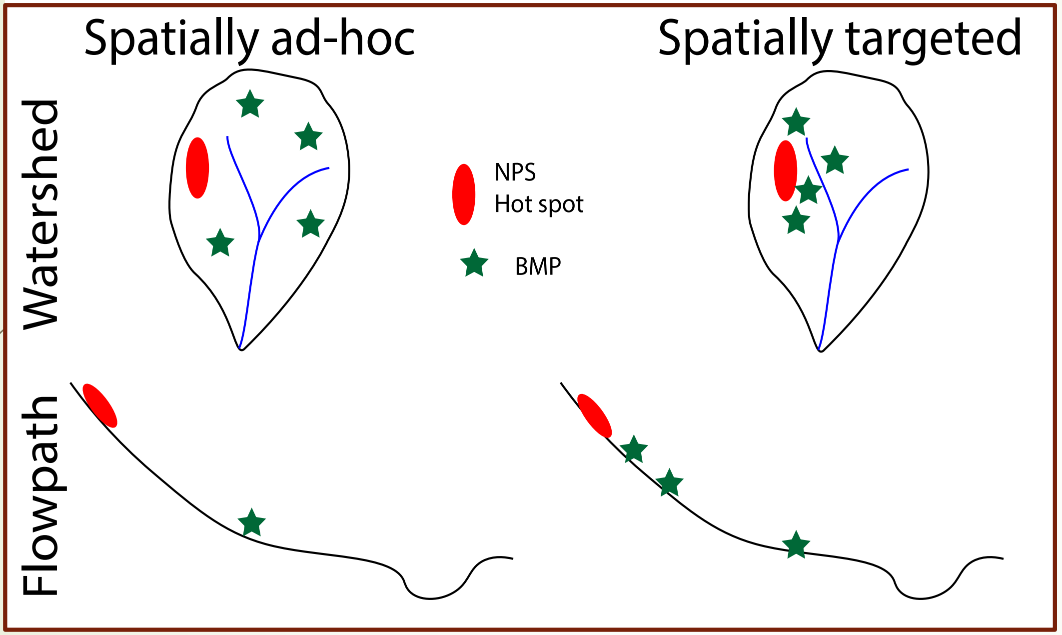
Michael Nassry, Corina Fernandez, Matthew Royer, Jon Duncan, James Shortle

Student Research Contributions: Monioluwa Adeyemo, Anthony Reed, Max Glines

Chapter Overview

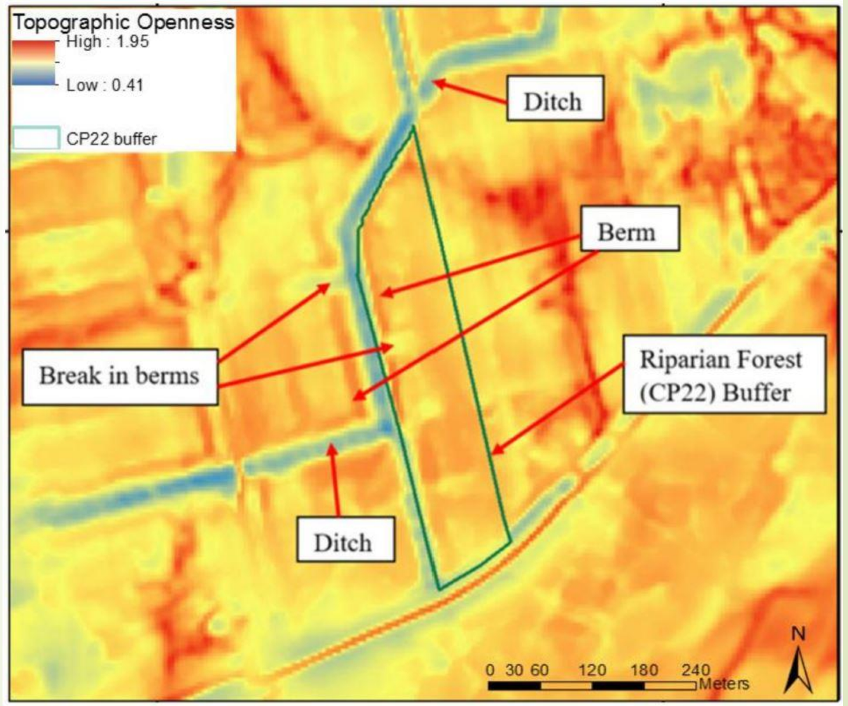
- Chesapeake Bay TMDL establishes load reductions for nitrogen / phosphorus / sediment and requires states to develop WIPs to meet these goals
- Expected climate change will increase the magnitude and variability of drivers of nonpoint source pollution (rain and runoff events)
- Climate smart adaptations to nutrient and sediment management programs as well as modifications to best management practices are needed to build climate change resilience into agricultural and urban landscapes

Updating BMP Implementation



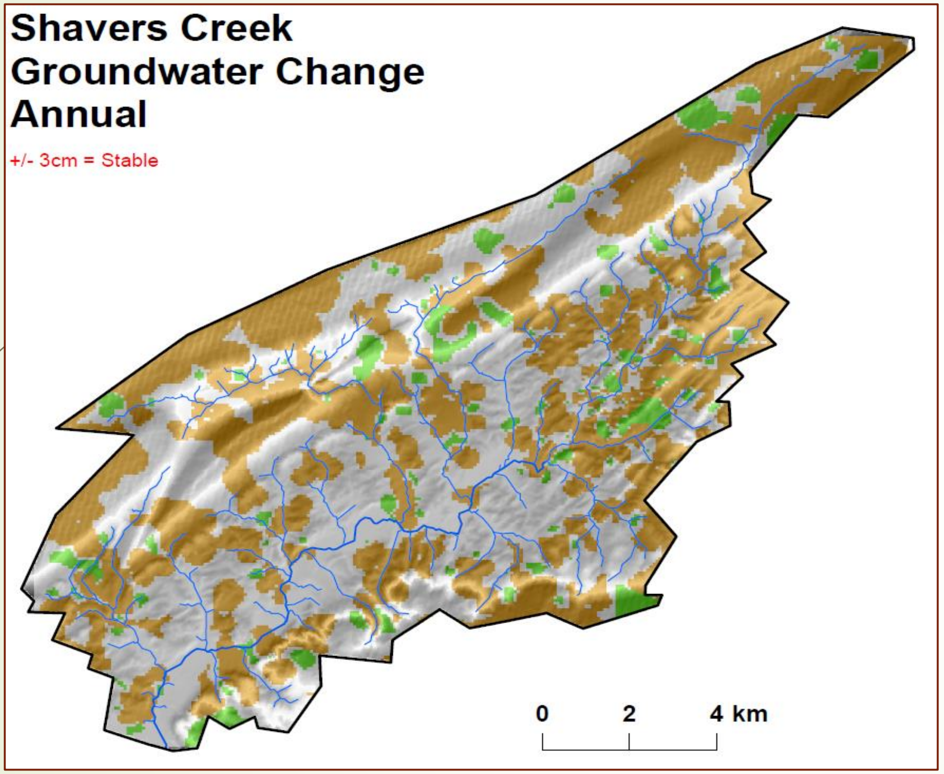
Smart BMP placement and promoting suites of practices

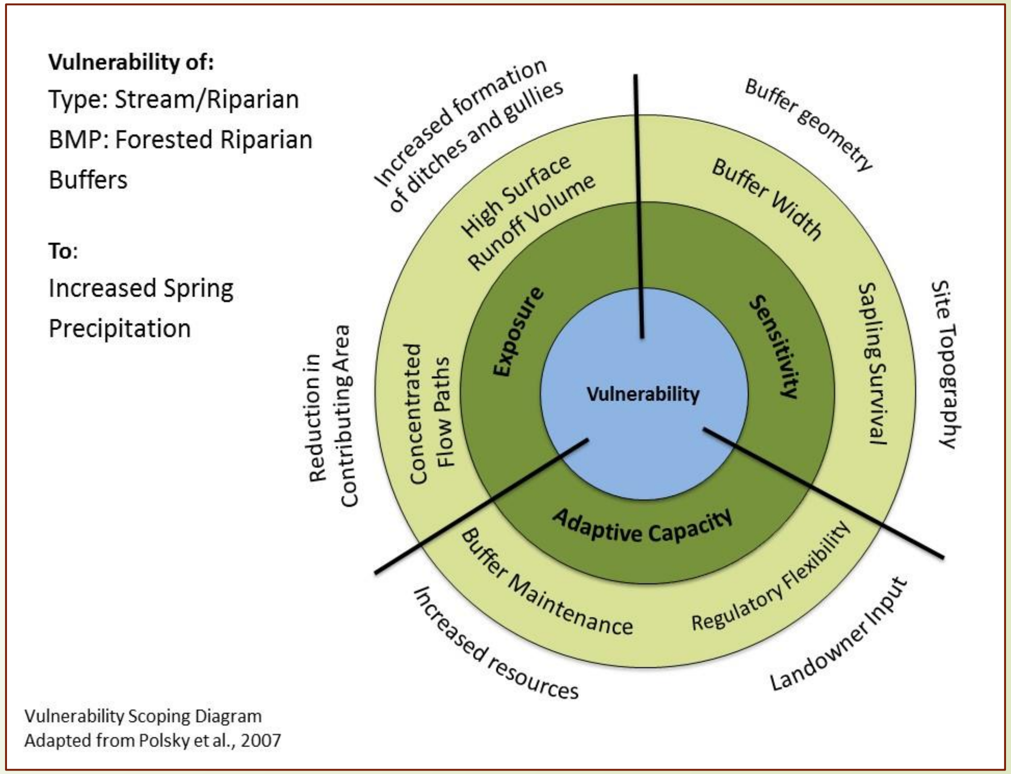
Improving BMP maintenance and using best available modeling



Wallace et al., 2018

Addressing Specific Vulnerabilities





Key Findings

- Climate change will decrease the effectiveness of some BMPs and require adaptations to BMP design, placement, maintenance.

- Landscape responses to climate change will vary across the state and within watersheds, making the identification and strategic targeting of critical source areas a requirement for cost-effective and efficient BMP placement.

- Climate change will increase local benefits of BMPs that promote resilience in agriculture and keep soil and water resources in local watersheds

Future Needs

- Additional research is needed to quantify specific BMP treatment efficiencies to changing runoff volumes and pollutant loads
- Climate resilient BMP design, maintenance and evaluation guidelines are needed to better create effective suites of management practices
- Updates to modeling and policy are needed to provide the best available information and guidelines to land managers and decision makers

Climate Change and Pennsylvania's Infrastructure

Seth Blumsack, Douglas H. Wrenn, Wenjing Su,
Mahkameh Zarakezari, Kelsey Ruckert, and KlausKeller

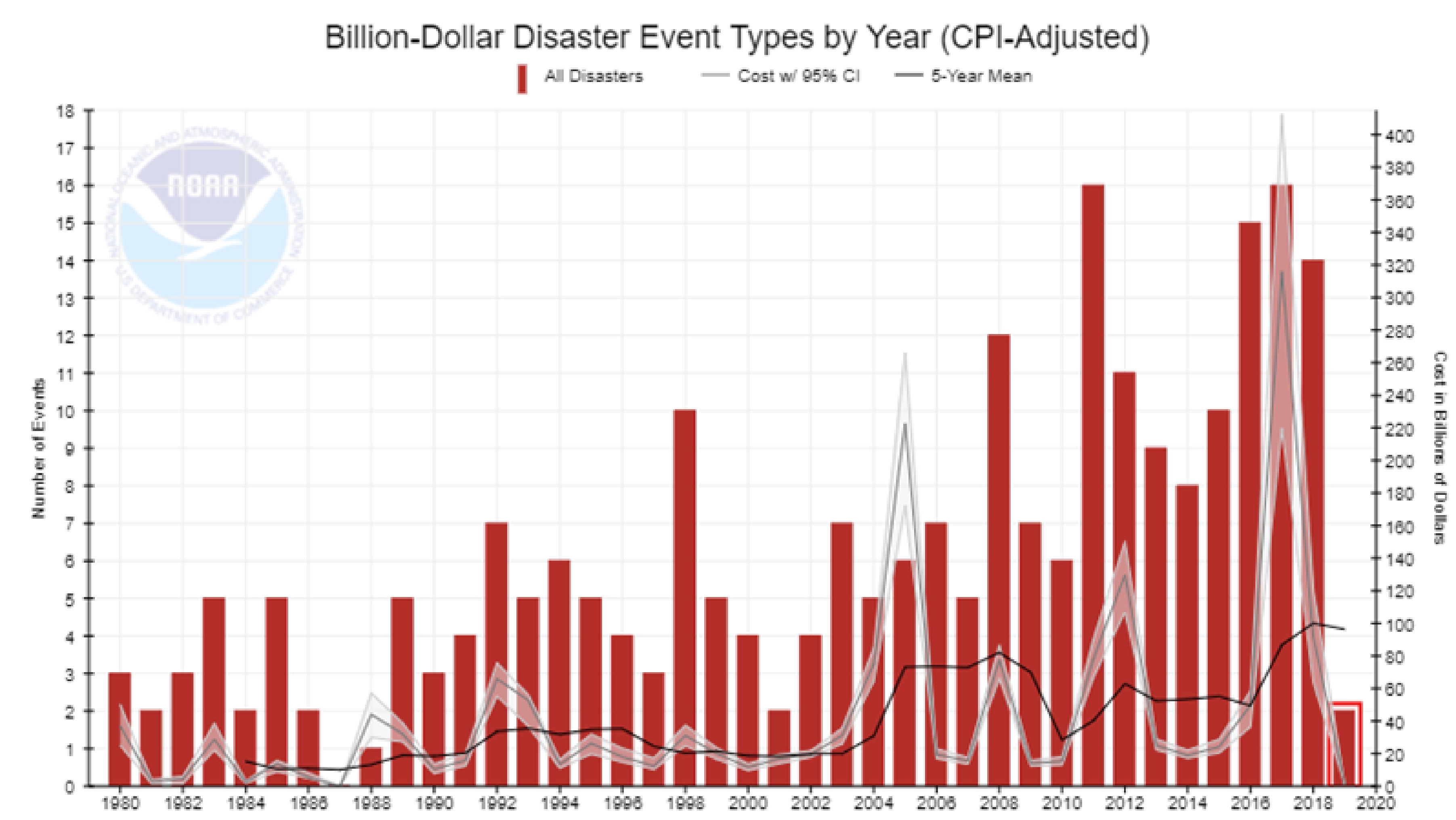
Extreme Weather and Billion-Dollar Events

Billion-dollar events to affect the U.S. from 1980 to 2018 (CPI-Adjusted)

DISASTER TYPE	NUMBER OF EVENTS	PERCENT FREQUENCY	CPI-ADJUSTED LOSSES *(BILLIONS OF DOLLARS)*	PERCENT OF TOTAL LOSSES	AVERAGE EVENT COST *(BILLIONS OF DOLLARS)*	DEATHS
Drought	26	10.7%	$247.0 CI	14.6%	$9.5	2,993[†]
Flooding	29	11.9%	$124.7[§] CI	7.4%[§]	$4.3[§]	543
Freeze	9	3.7%	$30.2 CI	1.8%	$3.4	162
Severe Storm	105	43.0%	$231.4 CI	13.7%	$2.2	1,628
Tropical Cyclone	42	17.2%	$927.5 CI	54.9%	$22.1	6,487
Wildfire	16	6.6%	$79.5 CI	4.7%	$5.0	344
Winter Storm	17	7.0%	$48.9 CI	2.9%	$2.9	1,048
All Disasters	**244**	**100.0%**	**$1,689.2** CI	**100.0%**	**$6.9**	**13,205**

[†] Deaths associated with drought are the result of heat waves. (Not all droughts are accompanied by extreme heat waves.)
[‡] Cost statistics not included for Midwest Flooding (March 2019)
[§] Flooding statistics do not include inland flood damage caused by tropical cyclone events.
The confidence interval (CI) probabilities (75%, 90% and 95%) represent the uncertainty associated with the disaster cost estimates. Monte Carlo simulations were used to produce upper and lower bounds at these confidence levels (Smith and Matthews, 2015).

Extreme Weather and Billion-Dollar Events

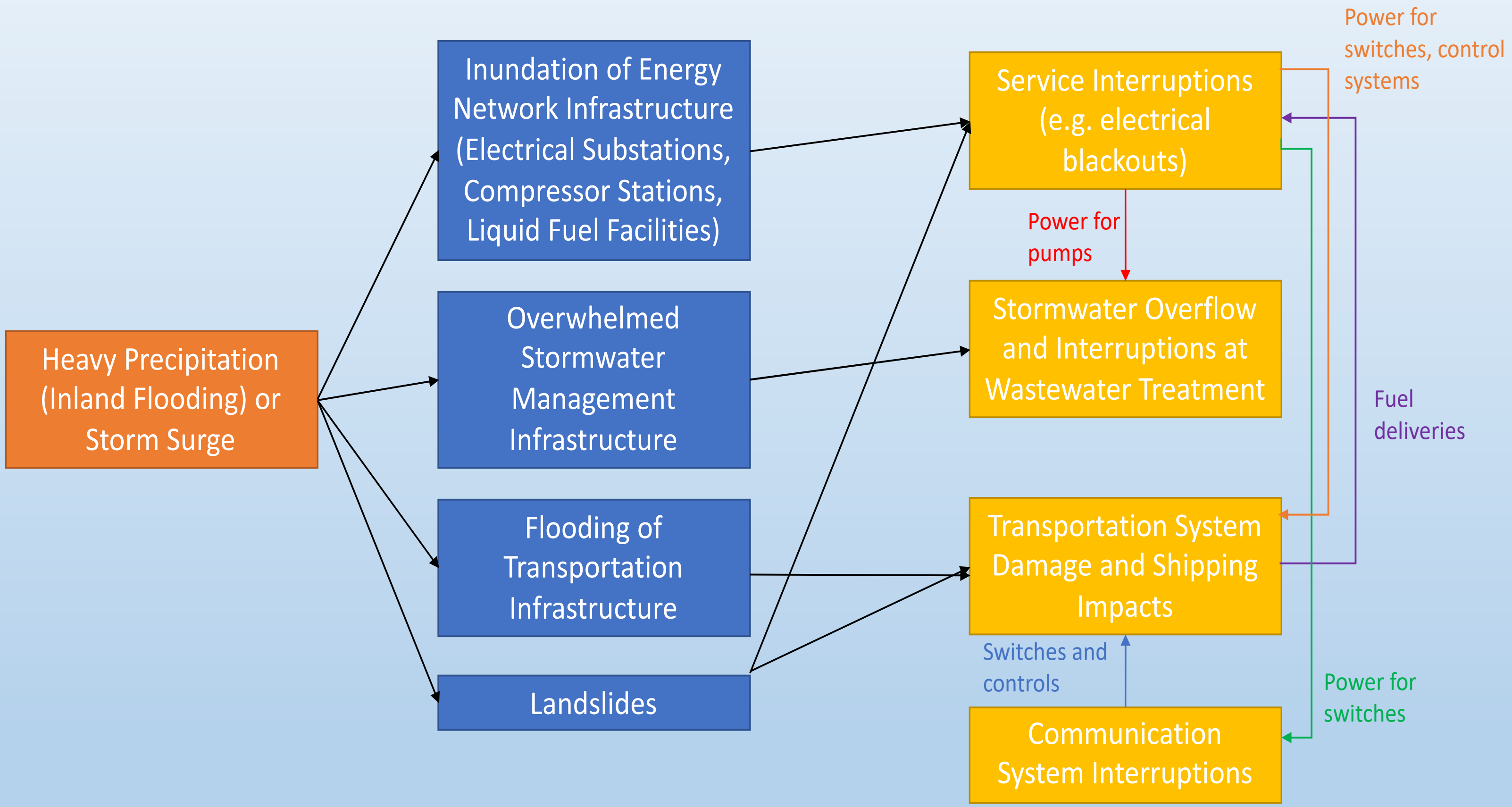


Study Methods

- Review Pennsylvania's Climate Action Plan and other assessments (e.g., DOE, DOD, etc.)
- Assess the most significant risks to infrastructure in Pennsylvania
- Review literature on infrastructure impacts from recent extreme weather specific to Pennsylvania and the Northeast region
- Use historical data (spatial and temporal) to analyze/visualize location of infrastructure systems subject to extreme weather – e.g., flooding, heat, and landslides

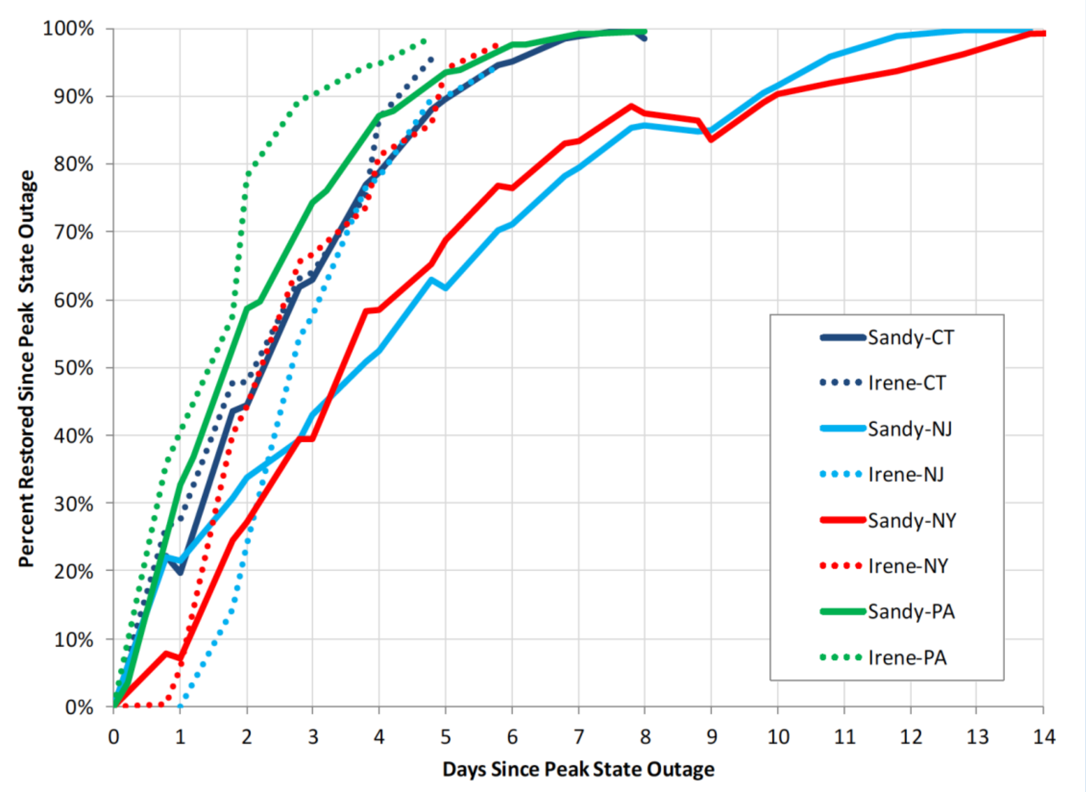
Infrastructure

Infrastructure is Critical and Interdependent



Single events can overwhelm multiple infrastructures with impacts that cascade across interconnected systems. Inland flooding, for example, can affect energy, transportation and communications systems.

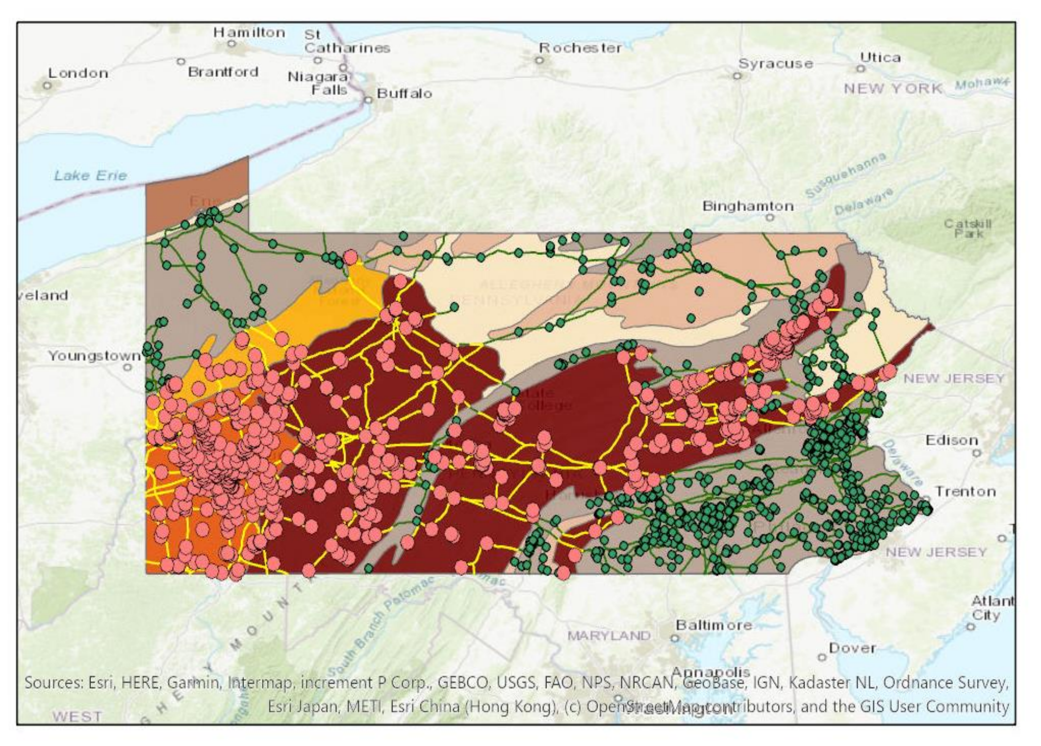
Vulnerability of Local Electric Distribution (I)



DOE, 2013

- Storms like Irene and Sandy are disruptive to electric reliability
- Half of those affected lost power for more than two days
- Impacts were primarily due to high winds and flooding affecting local electric distribution (not high voltage transmission)
- Cascading impacts on stormwater treatment facilities

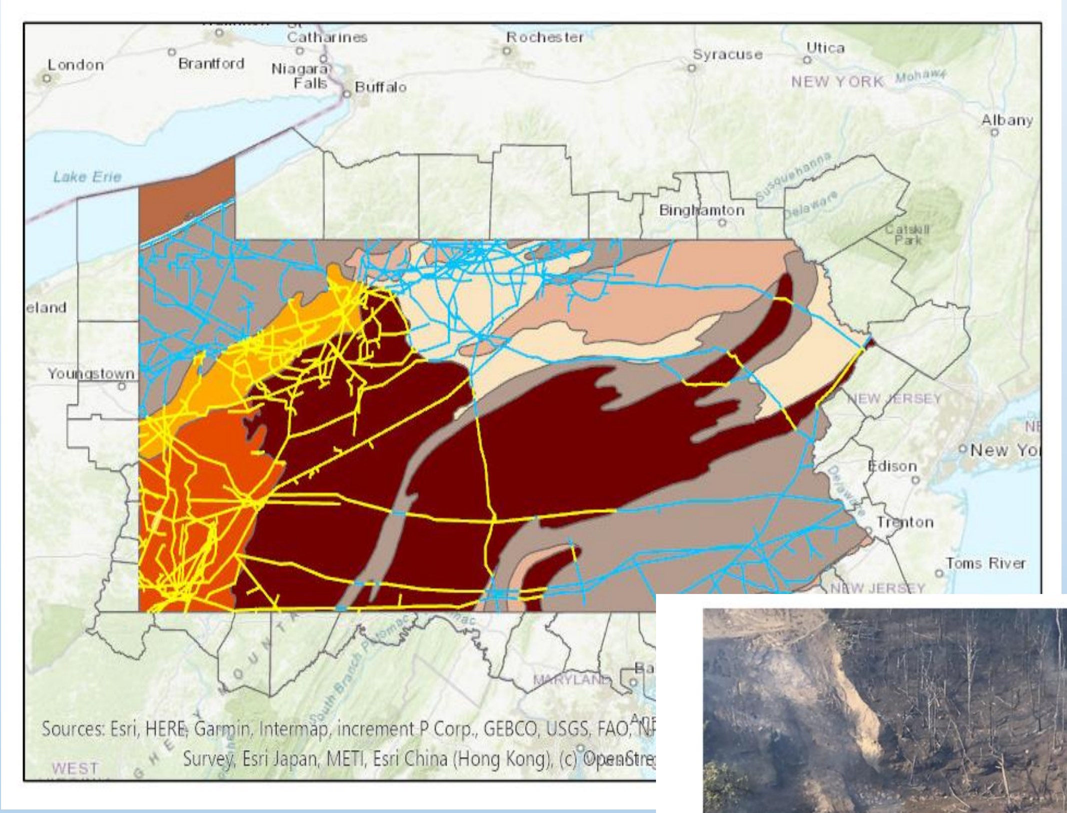
Vulnerability of Local Electric Distribution (II)



Red dots indicate substations that lie within identified landslide hazard zones. Yellow lines indicate transmission wires whose supports lie within identified landslide hazard zones.

- Heavy precipitation can induce inland flooding and landslides. Substations can be particularly vulnerable
- Nearly all the major electrical substations in Southwestern Pennsylvania lie in an identified landslide hazard zone
- Risk assessment for individual substations is difficult with existing data and tools

Vulnerability of Natural Gas Infrastructure



Landslide caused West Virginia pipeline explosion, TransCanada reports

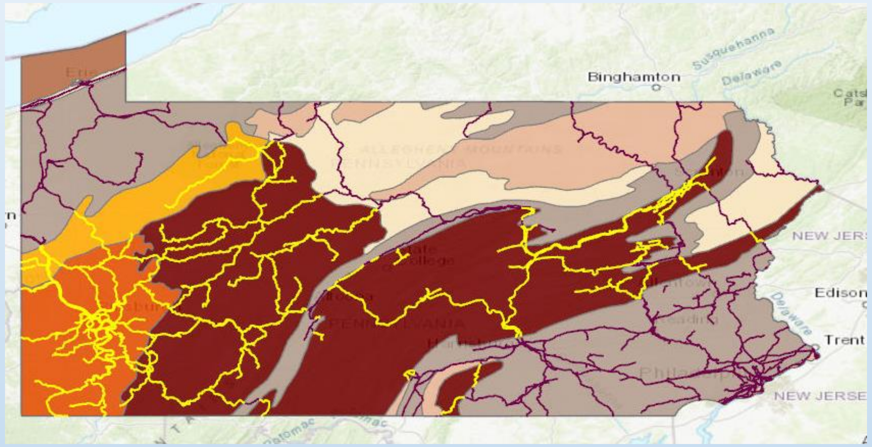
ANYA LITVAK
Pittsburgh Post-Gazette
alitvak@post-gazette.com

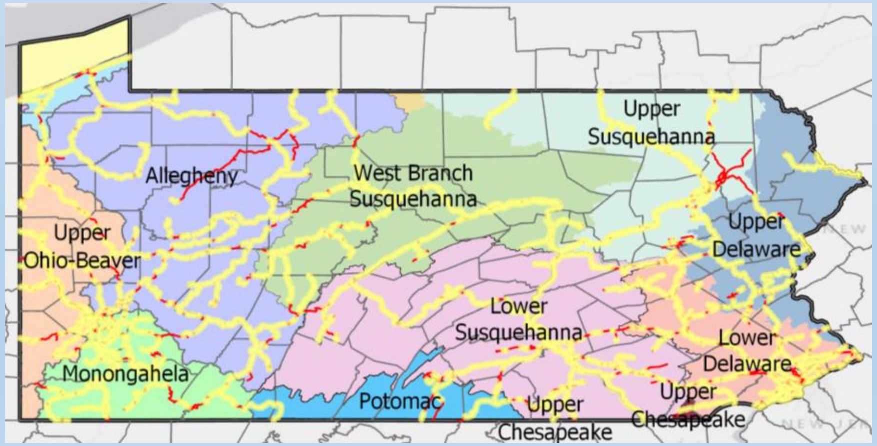
JUL 11, 2018 5:30 AM

Pittsburgh Post-Gazette

- Landslides, particularly in Southwestern Pennsylvania, are an emerging risk for natural gas infrastructure
- Even though they are subterranean, pipelines may be susceptible to small-scale seismic waves associated with landslides
- More research is needed to quantify this risk in a way that can inform pipeline safety and monitoring requirements

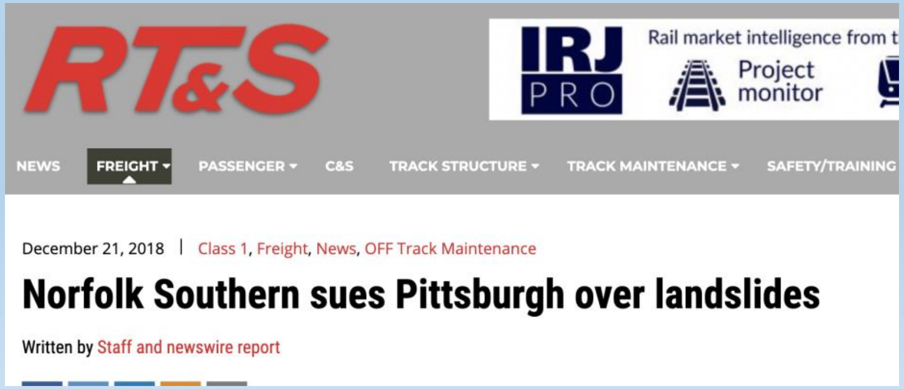
Vulnerability of Rail Infrastructure





- The location of rail infrastructure along natural contours increases vulnerability to landslides (top) and flooding (bottom)

- Slope maintenance needs and responsibility are not always clear (e.g. Norfolk-Southern v. Pittsburgh)



Property Damage and Loss of Life

Regional Comparison

Pennsylvania

Event Type	Property Damage (1)	Property Damage (2)	Fatalities (1)	Fatalities (2)	Injuries (1)	Injuries (2)
Cold	$2.05	0.001	33	0.045	1	0.000
Debris Flow	$0.08	0.000	0	0.000	0	0.000
Dense Fog	$0.00	0.000	0	0.000	13	0.006
Drought	$0.00	0.000	0	0.000	0	0.000
Flood	$1,025.05	0.255	31	0.042	107	0.046
Flood - Coastal	$0.52	0.000	0	0.000	1	0.000
Flood - Flash	$2,155.65	0.535	58	0.078	52	0.022
Flood - Lakeshore	$0.01	0.000	0	0.000	0	0.000
Hail	$6.46	0.002	0	0.000	0	0.000
Heat	$0.04	0.000	418	0.564	449	0.193
Heavy Rain	$0.00	0.000	2	0.003	4	0.002
Landslide	$0.02	0.000	0	0.000	0	0.000
Lightning	$20.23	0.005	21	0.028	214	0.092
Tropical Storm	$4.06	0.001	1	0.001	197	0.085
Wildfire	$1.72	0.000	1	0.001	0	0.000
Wind - High	$141.32	0.035	36	0.049	9	0.004
Wind - Marine High	$0.00	0.000	0	0.000	57	0.025
Wind - Thunderstorm	$236.60	0.059	23	0.031	0	0.000
Wind - Tornado	$212.75	0.053	6	0.008	248	0.107
Winter Weather	$221.09	0.055	111	0.150	972	0.418
Totals	$4,027.64		741		2,324	

Notes: This table shows weather-related property damages, fatalities, and injuries, by event type, for Pennsylvania during the period 1996-2018. All property damages are listed in millions of $2018. For fatalities and injuries, column one lists the totals by event type, and the second column gives the share associated with each event type. All results are based on data from NOAA's storm events database for the state of Pennsylvania 1996-2018.

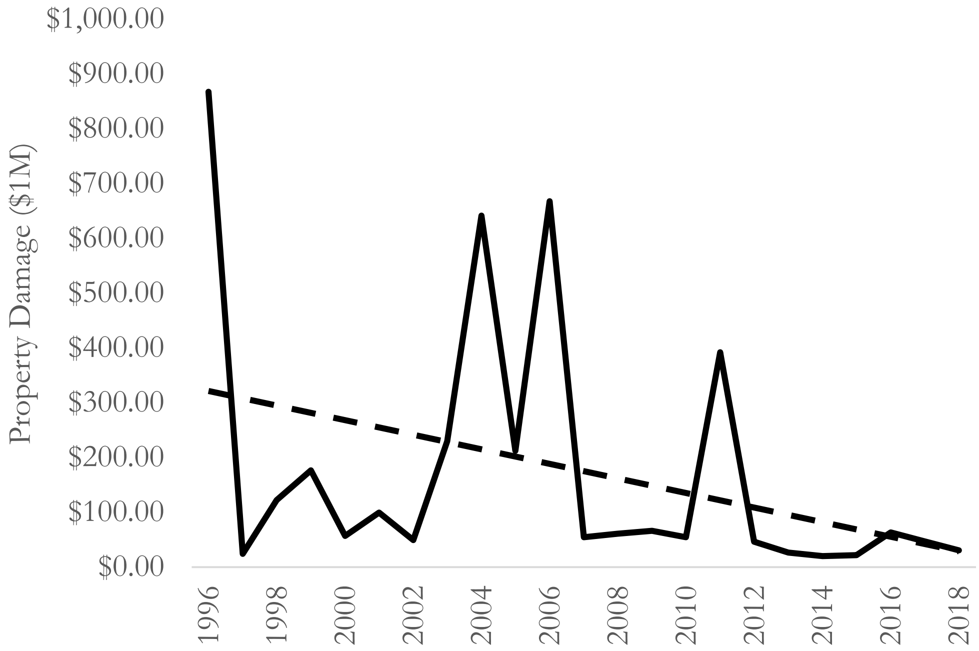
Ohio

Event Type	Property Damage (1)	Property Damage (2)	Fatalities (1)	Fatalities (2)	Injuries (1)	Injuries (2)
Cold	$26.53	0.004	10	0.048	0	0.000
Dense Fog	$0.80	0.000	6	0.029	42	0.039
Drought	$0.00	0.000	0	0.000	0	0.000
Flood	$438.25	0.061	24	0.116	9	0.008
Flood - Coastal	$9.06	0.001	0	0.000	0	0.000
Flood - Flash	$1,823.56	0.256	37	0.179	10	0.009
Hail	$1,151.33	0.162	0	0.000	4	0.004
Heat	$0.02	0.000	16	0.077	0	0.000
Heavy Rain	$0.87	0.000	2	0.010	0	0.000
Landslide	$0.00	0.000	0	0.000	0	0.000
Lightning	$18.85	0.003	24	0.116	120	0.111
Waterspout	$0.01	0.000	0	0.000	0	0.000
Wind - High	$1,045.37	0.147	18	0.087	83	0.076
Wind - Thunderstorm	$340.41	0.048	28	0.135	206	0.190
Wind - Tornado	$741.58	0.104	22	0.106	320	0.295
Winter Weather	$1,530.89	0.215	20	0.097	291	0.268
Total	$7,127.54		207		1,085	

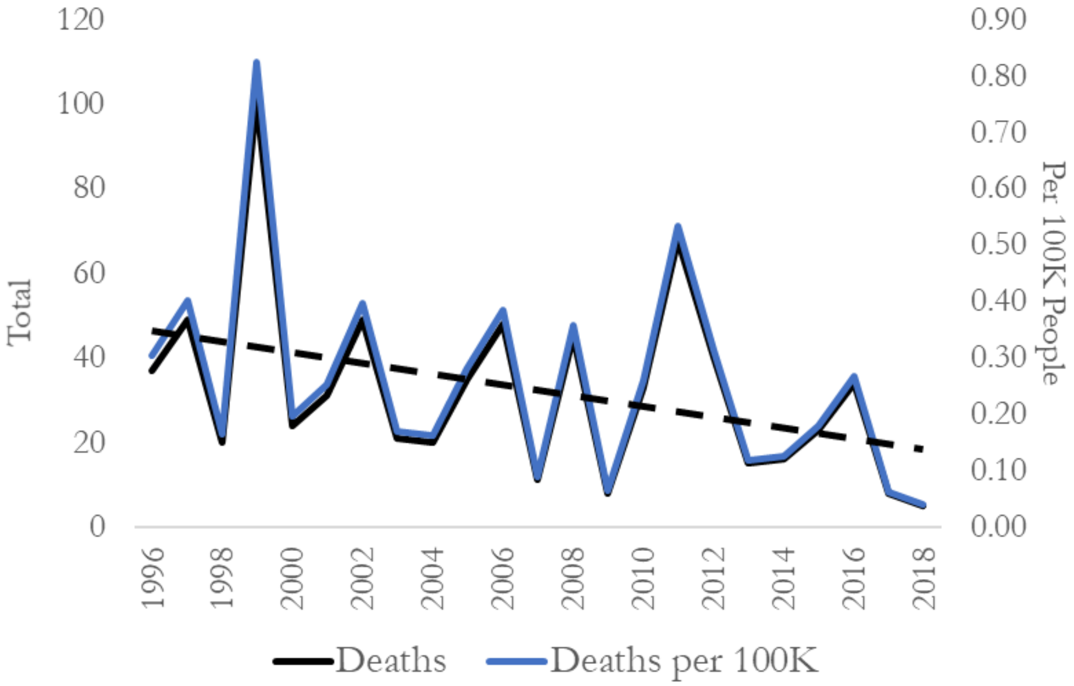
Notes: This table shows weather-related property damages, fatalities, and injuries, by event type, for Ohio for the period 1996-2018. All property damages are listed in millions of $2018. For fatalities and injuries, column one lists the totals by event type, and the second column gives the share associated with each event type. All results are based on data from NOAA's storm events database for the state of Ohio 1996-2018.

Time Trends

Property Damage

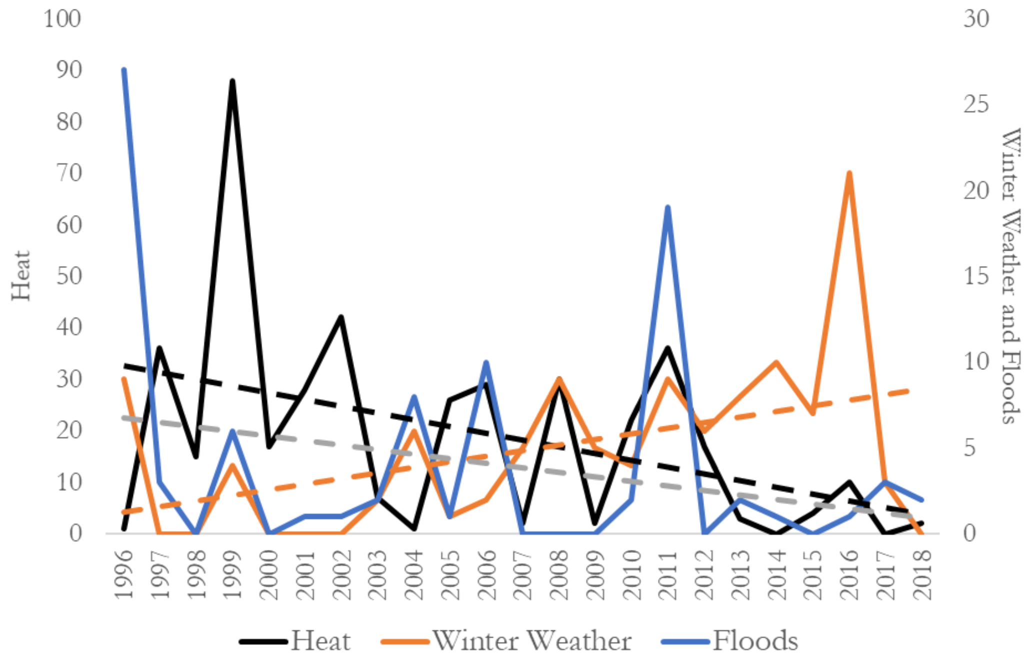


Fatalities



Fatalities

Time Trends by Event



Age Distribution by Event

	Fatalities Age Distribution by Event Type				Share Male
Event	Mean	Median	10th	90th	
Flood	45.52	45	15	76	0.65
Heat	68.97	72	49	88	0.60
Winter Weather	52.02	54	21.5	83	0.65

Notes: These data were produced by merging the NOAA storm events dataase with the NOAA fatalities database. All results are for weather events occuring from 1996-2018.

Property Damages

Total ($1M)

County	Metro	Total
Luzerne	Scranton--Wilkes-Barre	$373.26
Bucks	Philadelphia	$199.07
Wyoming	Scranton--Wilkes-Barre	$184.61
Jefferson		$167.27
Dauphin	Harrisburg-Carlisle	$165.78
Susquehanna		$158.58
Bradford	Sayre	$154.98
Montgomery	Philadelphia	$150.93
Lackawanna	Scranton--Wilkes-Barre	$136.02
Monroe	East Stroudsburg	$132.87
Wayne		$129.52
Clarion		$125.46
Allegheny	Pittsburgh	$116.55
Crawford	Meadville	$98.41
Venango	Oil City	$83.80
Pike		$75.27
Northampton	Allentown-Bethlehem	$73.73
Warren	Warren	$67.06
Beaver	Pittsburgh	$57.18
Berks	Reading	$48.51

Notes: This table lists the top 20 counties in terms of total property damages for flooding from 1996-2018. All property damages are listed in millions of $2018. The first column gives the county name, the second column lists the metro area associated with the county based on U.S. Census definitions, and the last column lists total property damages.

Per Capita ($Annual)

County	Metro	Per Capita
Wyoming	Scranton--Wilkes-Barre	$284.69
Susquehanna		$162.38
Jefferson		$160.58
Clarion		$134.82
Wayne		$111.71
Bradford	Sayre	$107.86
Sullivan		$77.29
Warren	Warren	$68.34
Venango	Oil City	$65.75
Pike		$64.37
Luzerne	Scranton--Wilkes-Barre	$50.95
Crawford	Meadville	$47.78
Mckean	Bradford	$38.93
Monroe	East Stroudsburg	$34.80
Lackawanna	Scranton--Wilkes-Barre	$27.80
Dauphin	Harrisburg-Carlisle	$27.69
Union	Lewisburg	$15.93
Lycoming	Williamsport	$15.16
Beaver	Pittsburgh	$14.51
Bucks	Philadelphia	$13.91

Notes: This table lists the top 20 counties in terms of yearly per capita property damages from flooding over the period 1996-2018. All property damages are listed in $2018.

Flood Risk and Property Damage

Location	Allegheny		Dauphin		Luzerne		Wyoming	
Panel A.								
Total Damages	$116.55		$165.78		$373.26		$184.61	
Per Capita Damages	$4.11		$27.69		$50.95		$284.69	
Panel B.	Total	Share	Total	Share	Total	Share	Total	Share
Outside 100-Year	409,628	99.02	84,342	96.45	93,939	96.45	9,013	92.26
Inside 100-Year	4,063	0.98	3,100	3.55	2,838	2.93	756	7.74

Notes: This table shows, in Panel A., total and per capita yearly property damages from flooding for four select counties in Pennsylvania. The damage values in Panel A. are taken from NOAA's stormevents database for flooding events for the years 1996-2018. Total damages are in millions of $2018 and the per capita values are yearly per-person damages for each county in $2018. In Panel B., we show counts and shares of single-family houses located inside and outside of the FEMA-designated 100-year flood zone (SFHA) for the same four counties in Panel A.

Key Conclusions

- Flooding (from extreme precipitation or coastal storms) likely poses the greatest climate-related risk to Pennsylvania's infrastructure, but drought and extreme heat are also relevant considerations for adaptation

- Flood-related damage is likely to be localized in nature, with variable potential for local events to cascade into larger disruptions

- Large portions of Pennsylvania's infrastructure are in areas susceptible to damage from flooding and landslides

- Adaptive planning for infrastructure happens at multiple scales and is at multiple stages of maturity. Stormwater management (state/local level) has been more adaptive and anticipatory than planning for power transmission and distribution (regional/national level)