Managing Water Quality In the Face of Uncertainty:

A Robust Decision Making Demonstration

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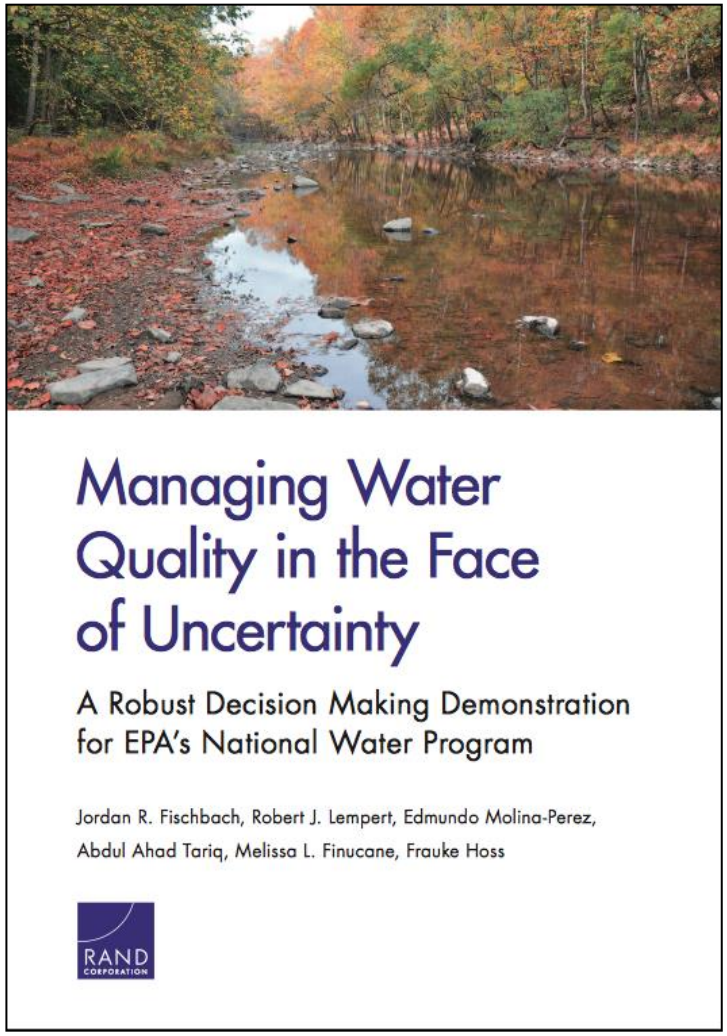
This Project Explored Application of RDM for EPA Water Quality Implementation and Adaptive Management



http://www.rand.org/pubs/research_reports/RR720.html

Three case studies:

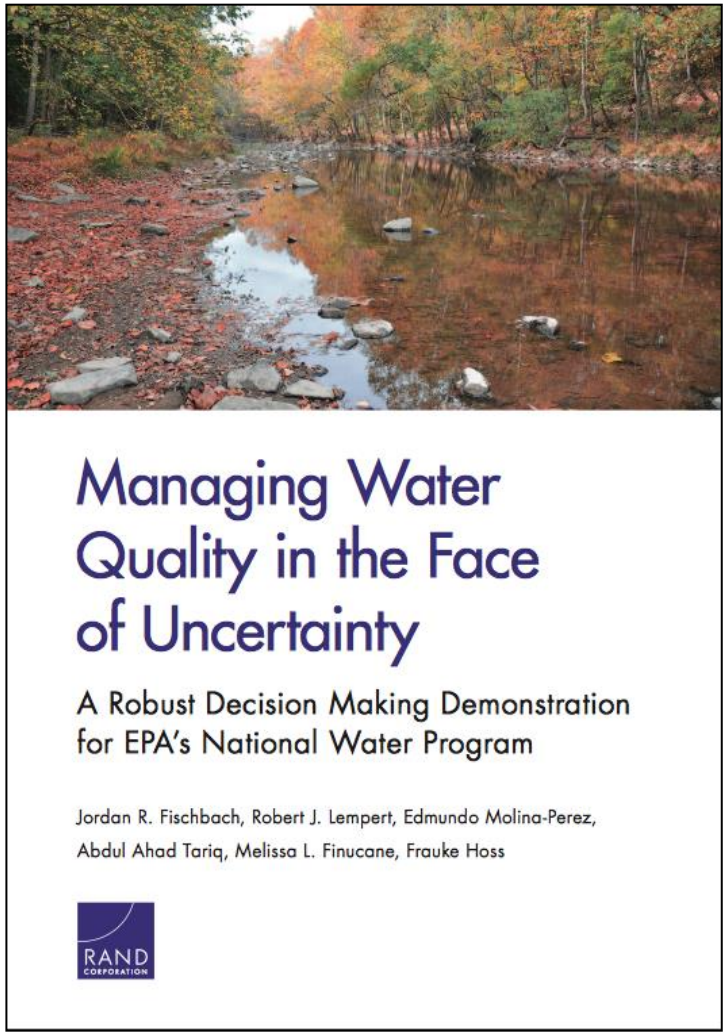
I. Urban stormwater management in Maryland's Patuxent River

II. Agricultural runoff in the Illinois River

III. BMP implementation in Los Angeles (Tujunga Wash)

Special thanks to: Susan Julius and Tom Johnson (USEPA ORD)

Today's Briefing Highlights Uncertainty Analysis From Two Case Studies



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Three case studies:

I. **Urban stormwater management in Maryland's Patuxent River**

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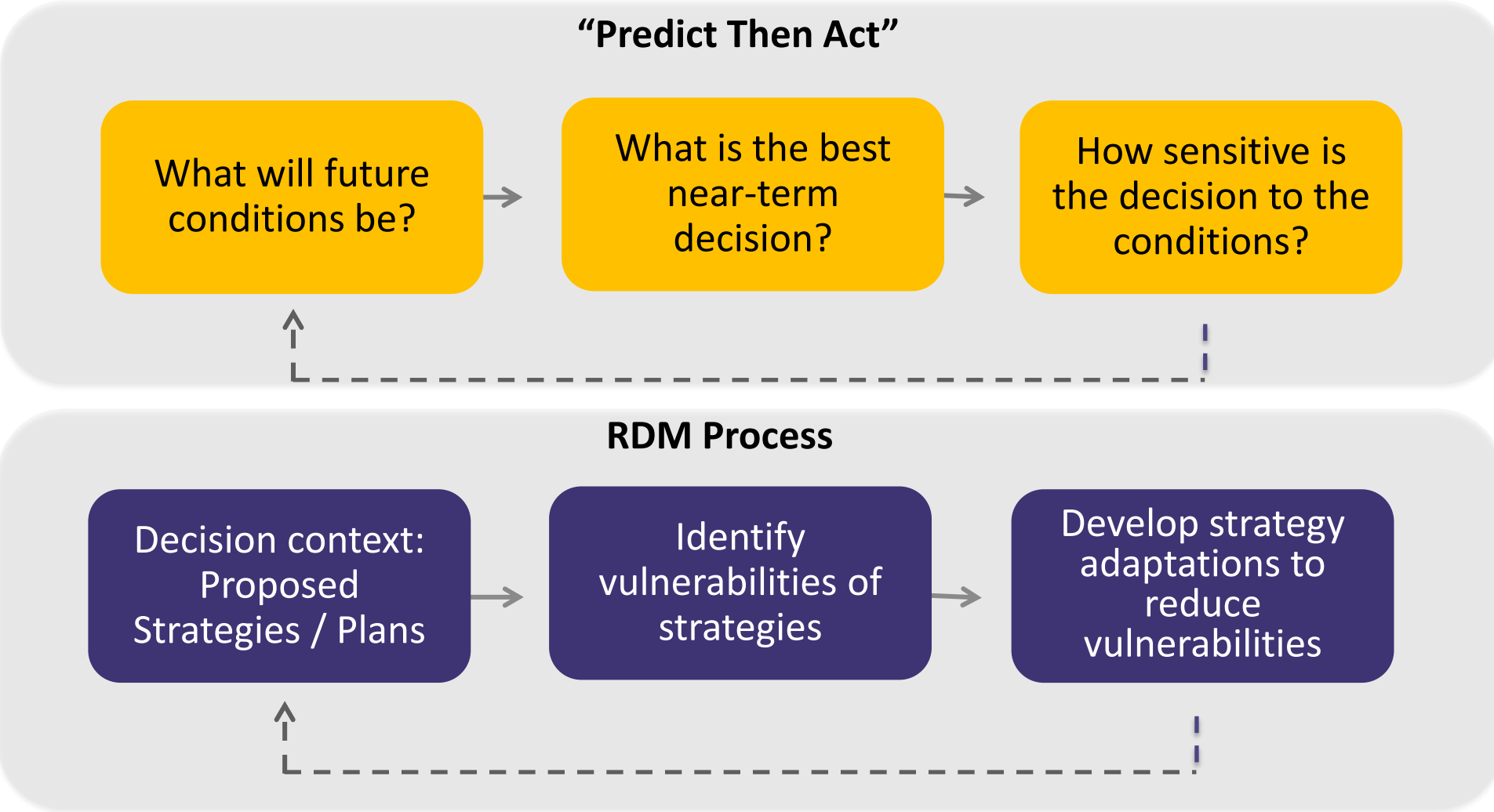
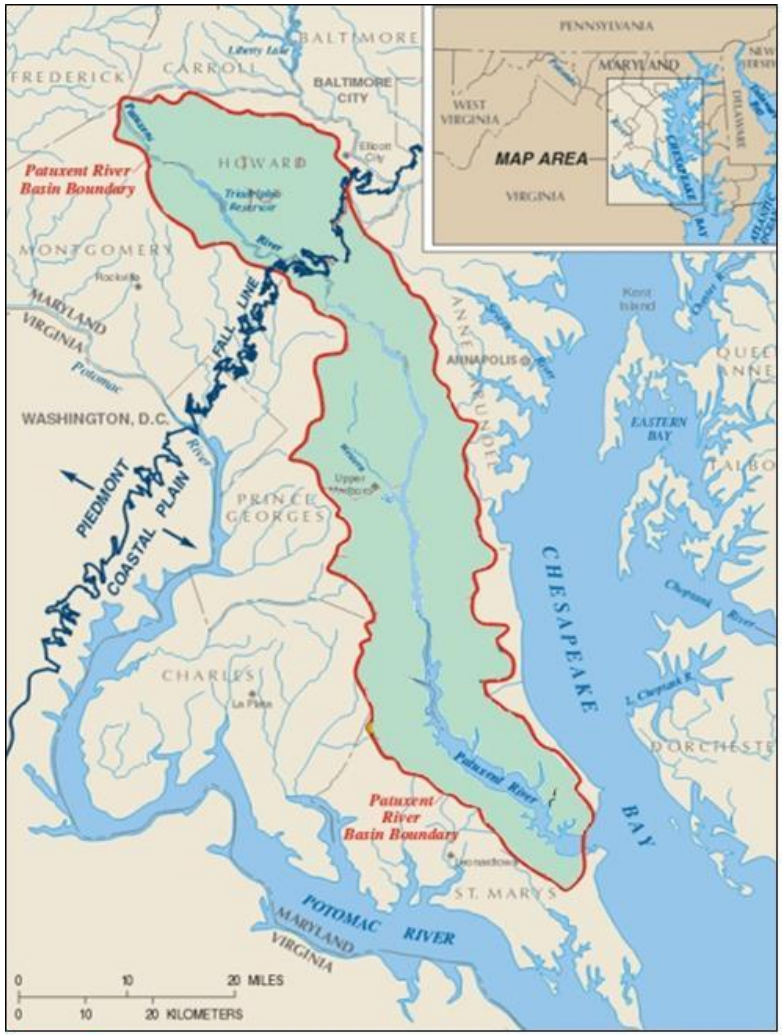
Robust Decision Making (RDM) Works Under Deep Uncertainty by Running the Analysis Backwards



The Patuxent is a Highly Urbanized Watershed With Stormwater Management Challenges

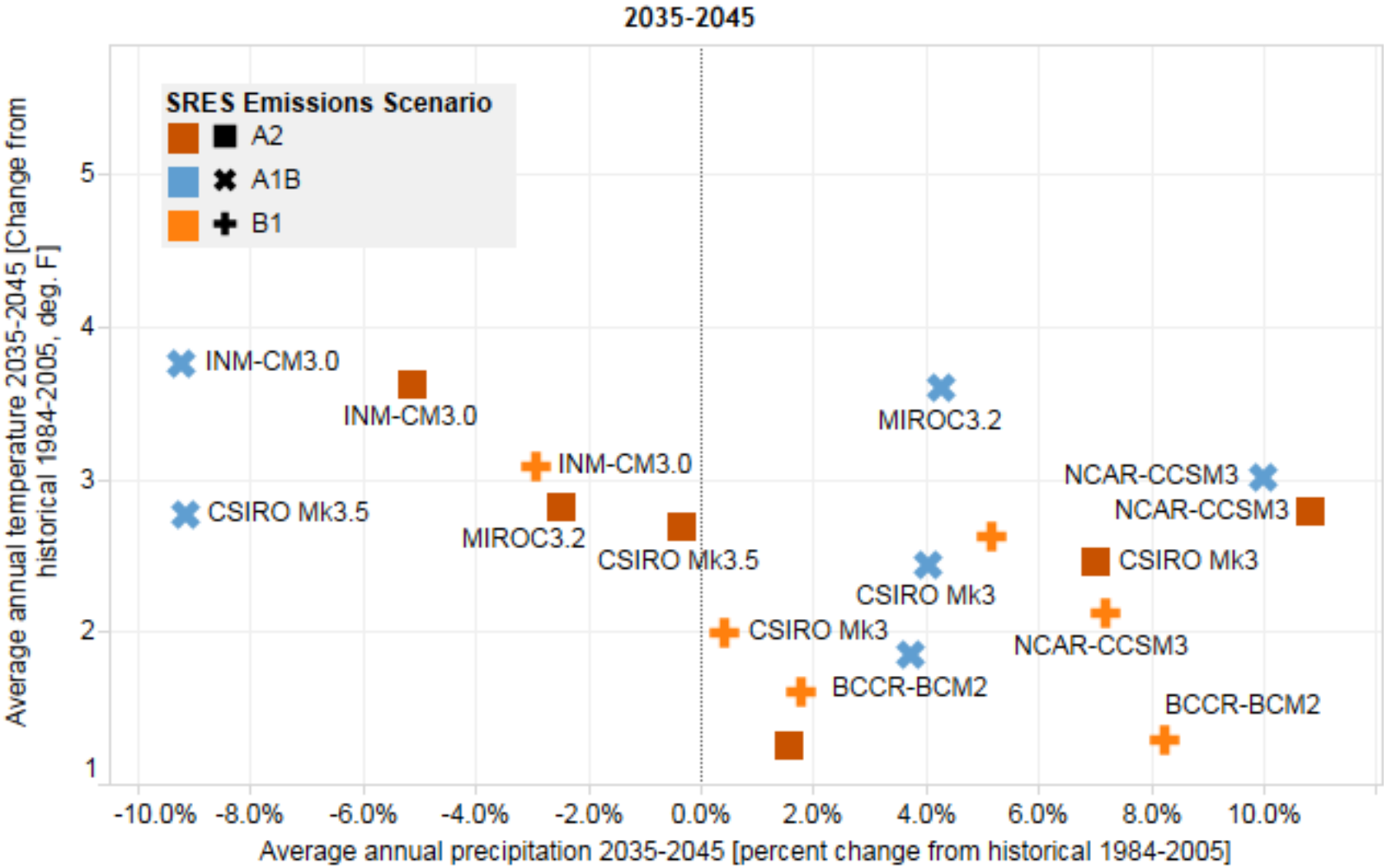
- Urban runoff pollutes the Patuxent River
- Contaminants create harmful conditions for fish, shellfish, and other key species
- Climate change and urban growth can exacerbate these challenges



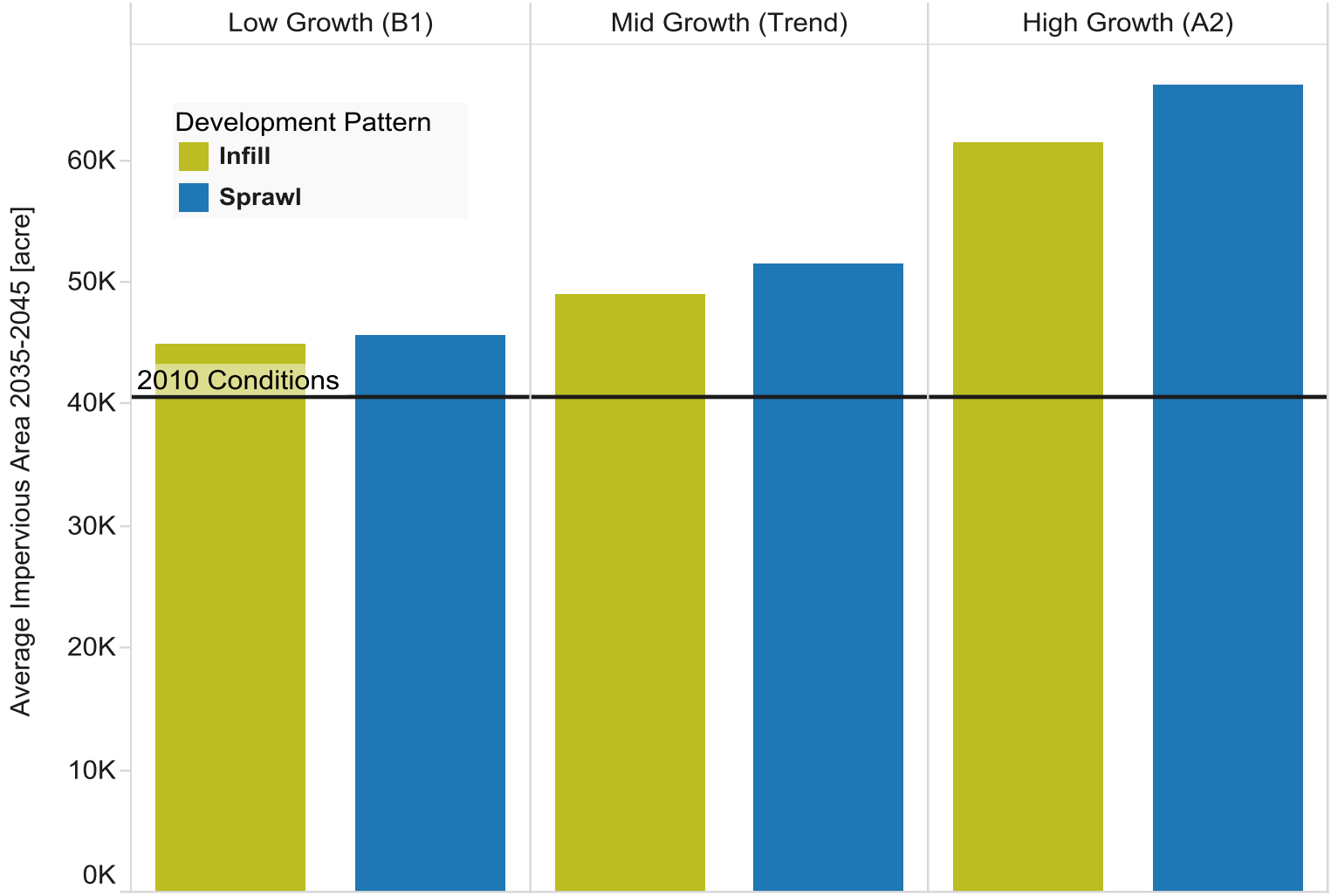
“XLRM” Framework Helps Organize Key Factors Considered in the Analysis

Uncertain Factors (X)	Policy Levers (L)
Hydrology and climate change • Observed historical hydrology • Downscaled climate scenarios ***Land use*** • Population growth (2010-2050) • Infill, sprawl ***Evapotranspiration model parameters***	***MDE Phase II Watershed Implementation Plan BMPs, including:*** • Stormwater management-filtering practices • Stormwater management-infiltration practices • Urban stream restoration • Urban forest buffers
System Model Relationships (R)	**Performance Metrics (M)**
Phase 5.3.2 Chesapeake Bay Watershed Model • Airshed model • Land use change model • Watershed model	***Metrics*** Nitrogen delivered loads Phosphorus delivered loads Sediment delivered loads Implementation costs (extended analysis only) ***Targets:*** Phase II WIP TMDLs

Climate Projections for Future Patuxent Basin Hydrology Vary Widely



We Considered Six Land Use Change Scenarios with Varying Population and Sprawl Assumptions

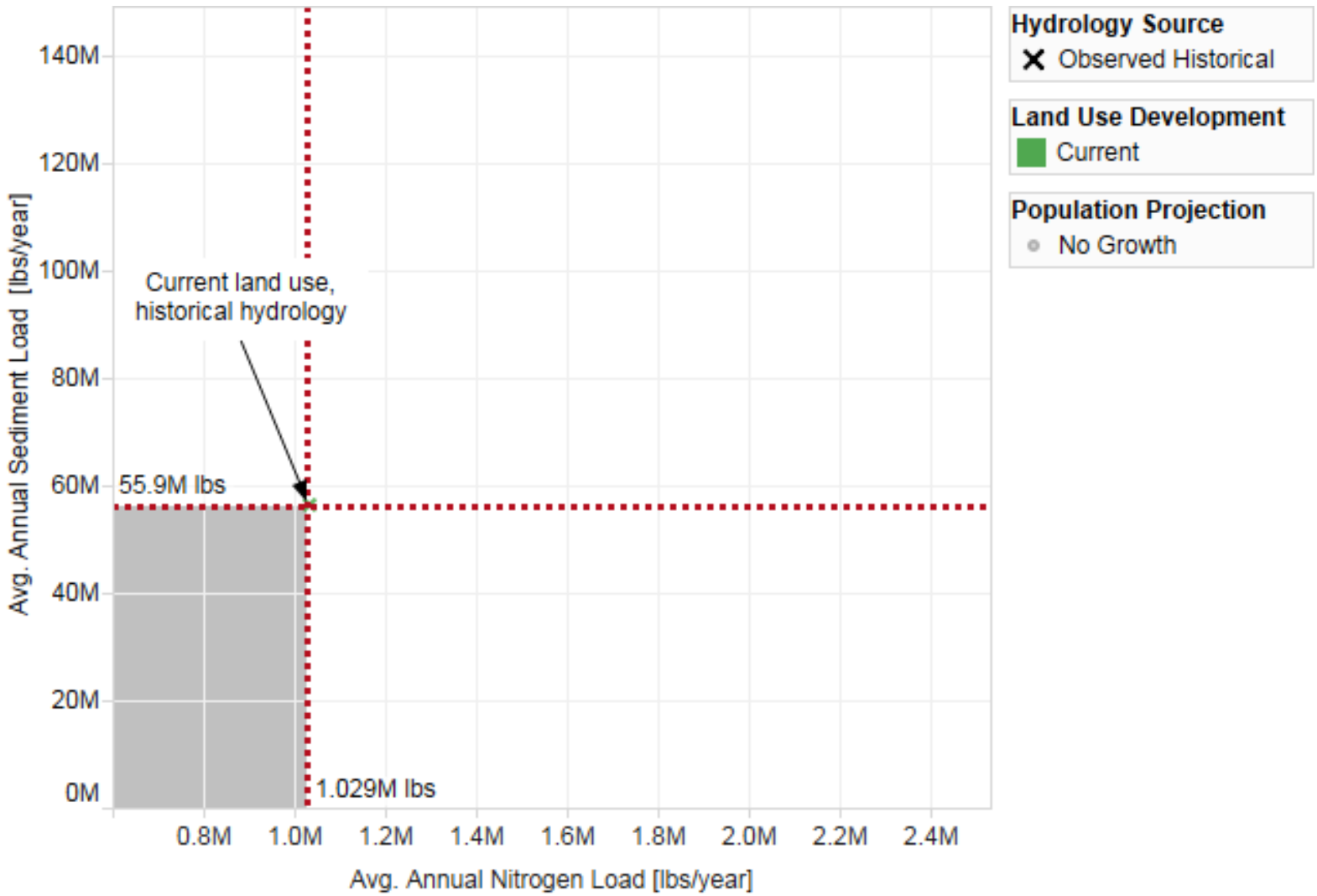


Maryland's Watershed Implementation Plan (WIP) Identified Stormwater Targets for the Patuxent

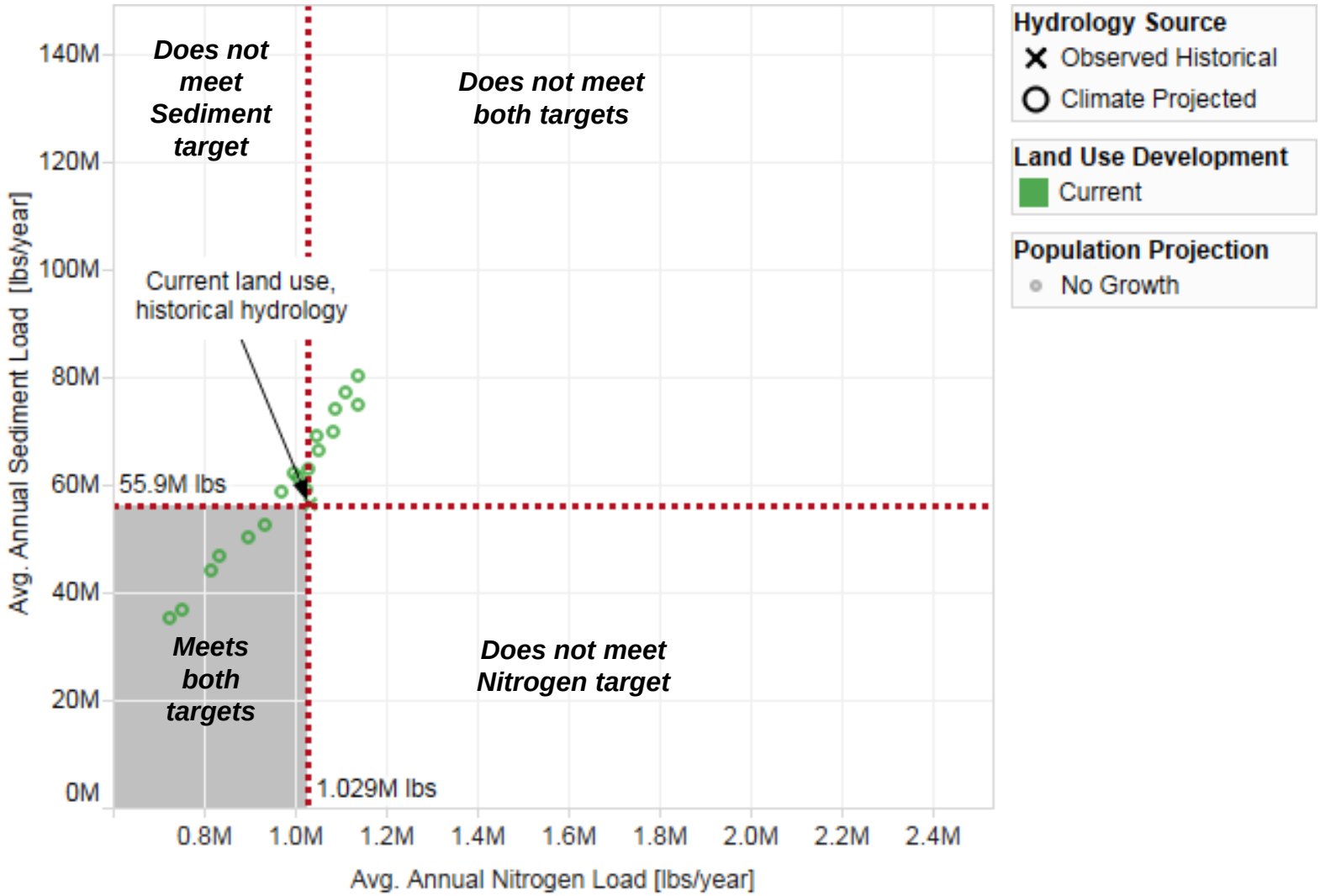
Pollutant Type	**Annual Target (million pounds/year)**		
	Phase I	**Phase II 2017 Interim**	**Phase II 2025 Final**
Nitrogen	2.740	1.029	1.029
Phosphorous	0.210	0.078	0.078
Sediment	85	52	55.9

Source: Maryland Department of the Environment (2012). Note that these thresholds are adjusted to the calibration runs of the Phase 5.3.2 model, and differ somewhat from those listed in the Phase II WIP report.

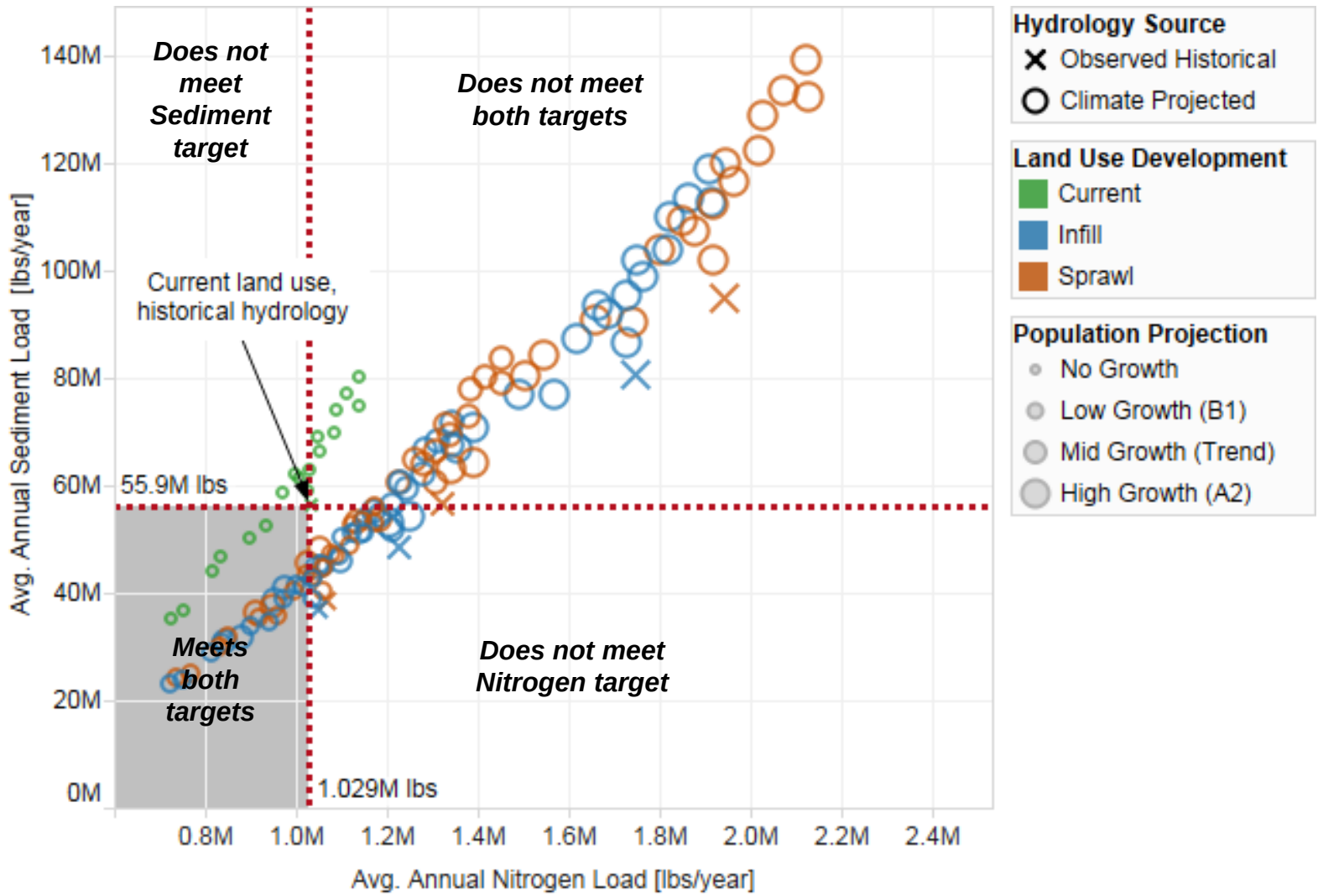
Phase II WIP Strategy Meets Intended Target In Current Conditions



Climate Projections Affect Attaining Targets in Some Futures (2035-2045)



Under Phase II WIP, Climate and Land Use Lead to Stressing Futures



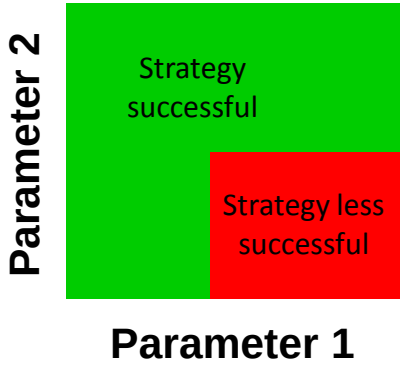
We Identified Sets of Vulnerable Futures for Two BMP Portfolios

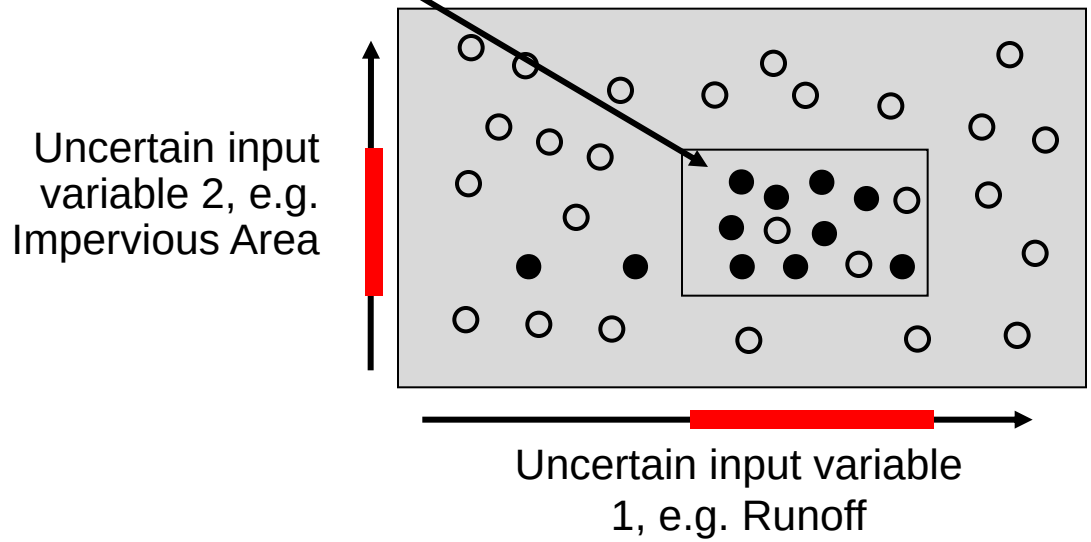
Vulnerability Type	Number of futures exceeding the Phase II target (2035-2045 hydrology)	
	2010 Progress	**Phase II WIP Strategy**
Nitrogen target	114 (93%)	91 (72%)
Phosphorous target	120 (95%)	84 (67%)
Sediments target	111 (88%)	67 (53%)
Exceeding all three targets	109 (87%)	62 (49%)

Scenario Discovery Provides an Approach for Computer-Assisted Scenario Development

Clusters represent scenarios and driving forces of interest to decision makers

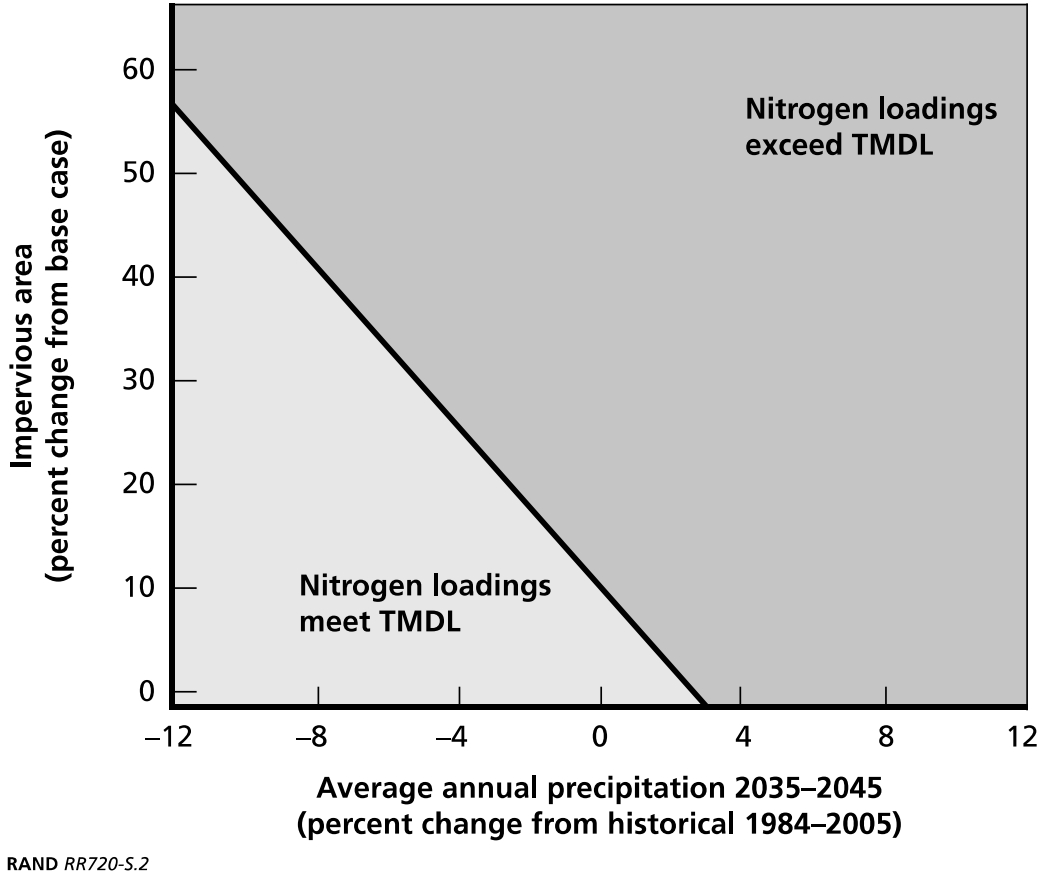
1. Indicate policy-relevant cases in database of simulation results
2. Statistical analysis finds low-dimensional clusters with high density of these cases





Most Vulnerability Explained by Increase in Impervious Runoff (2035-2045)

- Nitrogen vulnerability in MD's Phase II WIP:
  - Higher precipitation increases runoff, leads to higher nitrogen loads
  - Impervious area growth leads to missing target even if average precipitation declines
  - Must have low impervious area growth *as well as* precipitation declines to meet target

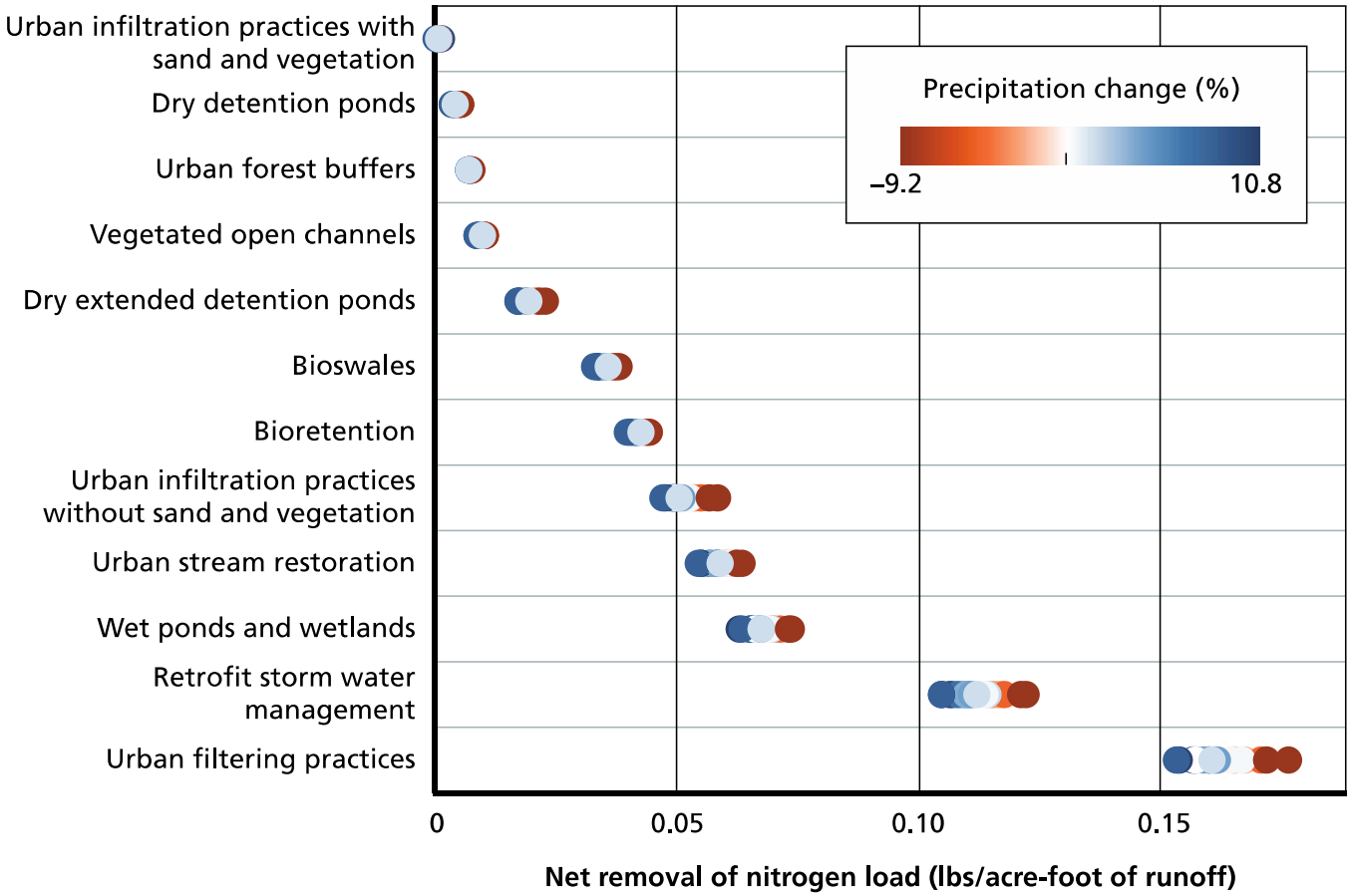


*Impervious Area Change (%) + 5.05 * Precipitation Change (%) > 11%*

OR

Impervious Runoff > 115 acre feet/year

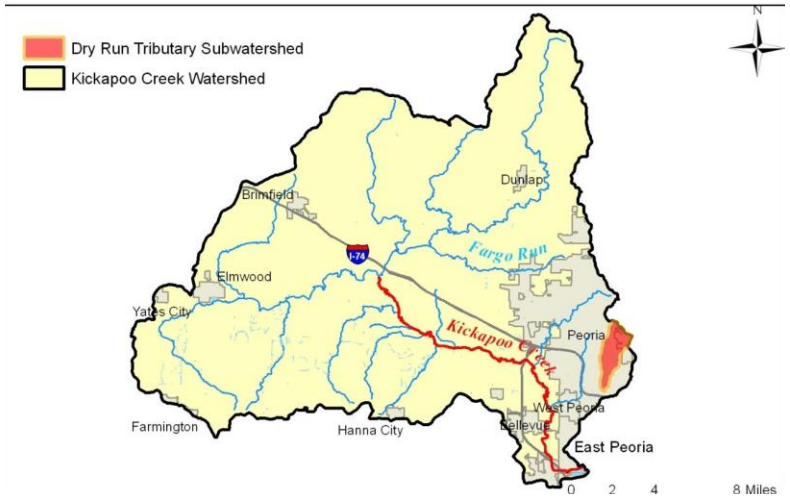
We Compared Net Pollutant Reduction by BMP Type With Rainfall Uncertainty as an Initial Next Step

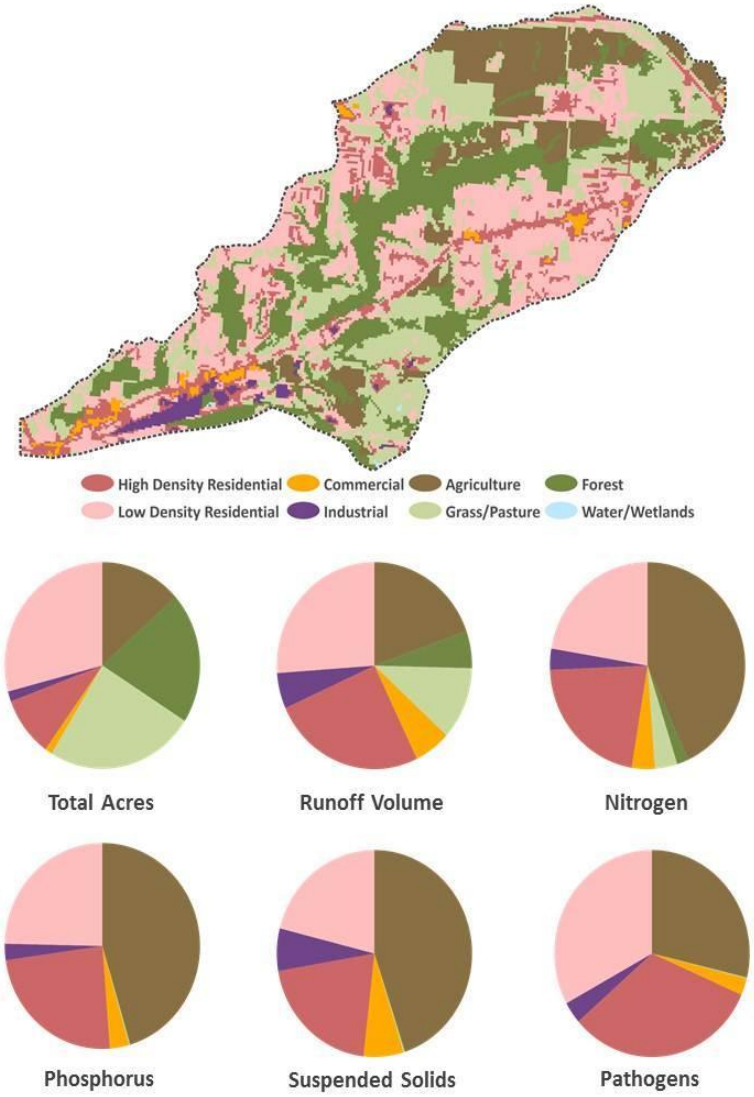


NOTE: In this chart, zero precipitation change is relative to the historical average. BMP types not applied to impervious areas are omitted.

Illinois River: How Might Climate Change Affect North Farm Creek Implementation Plan?

- State of Illinois developing TMDL's for middle Illinois River
- This study builds on Dec 2012 load reduction strategy and BMP implementation plan for North Farm Creek Watershed





“XLRM” Framework Helps Organize Key Factors Considered in the Analysis

Uncertainty Factors (X)	Policy Levers (L)
• Effects of climate change on stream flows - Six projections from North American Regional Climate Change Assessment Program (NARCCAP) • BMP effectiveness - Intrinsic performance - In response to climate change	• Draft Implementation Plan, some structural management options: - Riparian area management (filter strips) - Green infrastructure - Grassed waterways - Conservation tillage - Adaptive management policy responses
Relationships (R)	**Performance Metrics (M)**
• SWAT model of North Farm Creek, calibrated to meet current water quality	• TMDL compliance for: - Nitrogen - Phosphorus - Suspended solids

Initial Analysis Considers Four Important Structural BMPs from Implementation Plan

Implementation plan includes

- Structural and non-structural management options
- Implementation in three phases:
  1. Non-structural (Years 0-3)
  2. Structural (Years 3-10)
  3. Monitoring and adaptive management (Years 10-20)

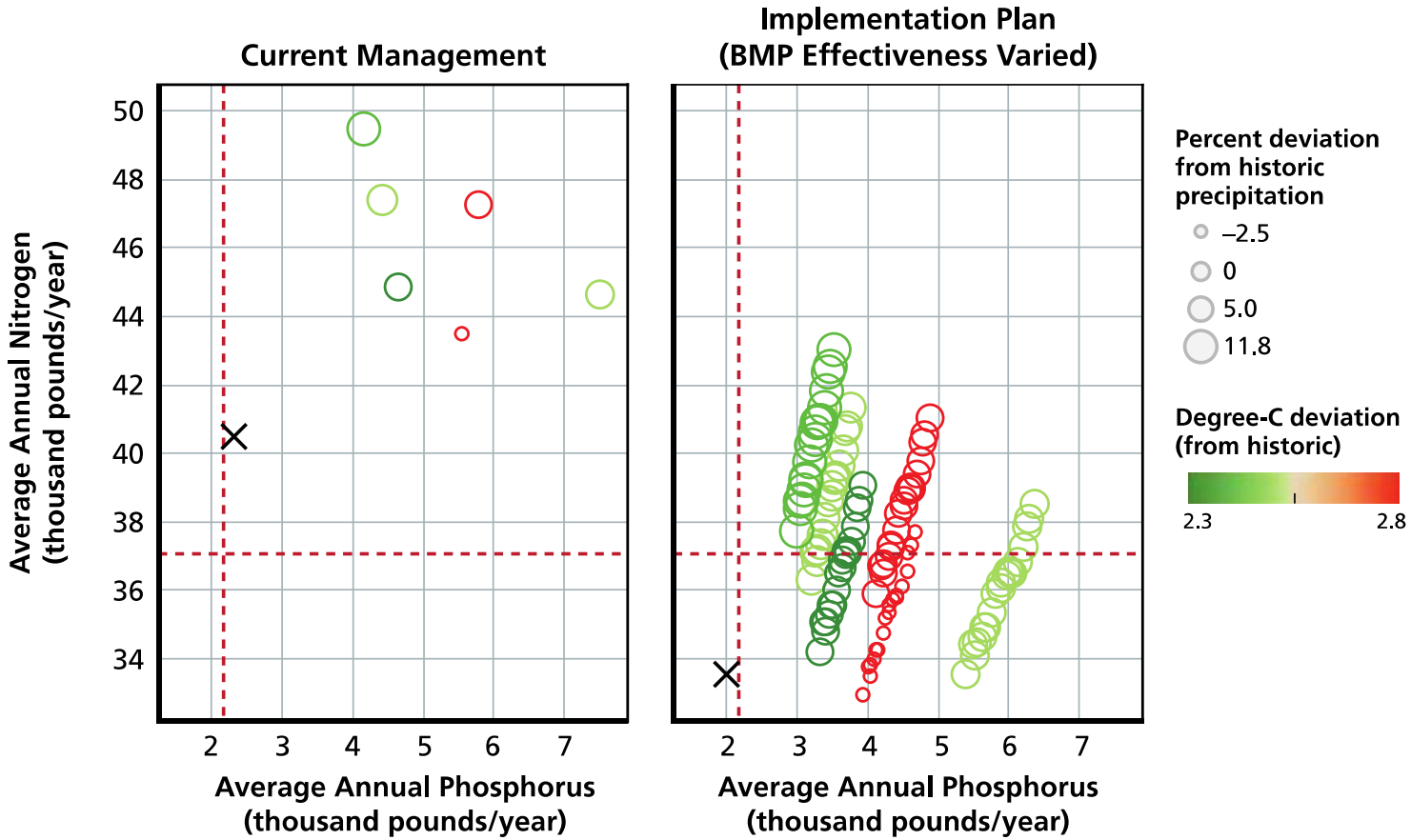
Activity	Critical area	Phasing I/II/III	Pollution removal	Cost
Nonstructural Management Options				
Education and pollution prevention programs	Watershed wide	H/C/C	Moderate	Low
Ordinance development	Watershed wide	H/C/C	Moderate	Moderate
Street & parking lot sweeping	Impervious surfaces	H/C/C	Moderate	Moderate
Pet waste education and outreach campaign	Residential areas	H/C/C	Moderate	Low
Wildlife implementation practices	Riparian areas	H/C/C	Moderate	Low
Salt management plan	Impervious salted areas watershed wide	H/C/C	High	Low
Structural Management Options				
Green infrastructure refitting	Impervious areas	M/H/C	High	High
SSO Control	East Peoria Oakwood Ave outfall	H/C/C	High	High
Disinfection of primary sewage plant effluents	Sundale Sewer Corp-Highland	H/C/C	High	High
Stabilize erosion of steep slopes	Storm sewer outfalls, steep slopes	H/C/C	High	Moderate-High
Stream bank restoration	Eroding steam banks	L/H/H	High	High
Riparian area management	Riparian areas	H/H/C	High	Moderate
Grassed waterways	Cultivated agricultural areas	H/M/L	High	Low
Conservation tillage	Cultivated agricultural areas	H/M/L	High	Low

BMP Removal Efficiencies and Uncertainty Range Adapted from Plan Assumptions and Previous Literature

Structural BMP	Land Use (HRU)	BMP Removal Efficiency (%)
Green infrastructure retrofitting	Urban	Phosphorus = 47 Nitrogen = 48 Sediment = 52
Grassed waterways	Cropland (corn, soy); **pasture**	Phosphorus = 75 Nitrogen = 70 Sediment = 65
Riparian area management (filter strips)	Cropland (corn, soy); pasture; **rangeland**	Phosphorus = 75 Nitrogen = 70 Sediment = 65
Conservation tillage	**Cropland (corn, soy)**; pasture	Phosphorus = 45 Nitrogen = 55 Sediment = 75

BMP removal efficiency uncertainty: 50 to 100% of estimate

BMP Effectiveness Assumptions Greatly Influence Nutrient Loadings, Especially Nitrogen



NOTE: Figure shows nitrogen and phosphorus loadings for current (left panel) and Modeled Implementation Plan (right panel) for each future considered in the analysis. Dot size shows future precipitation, dot color shows future temperature, and x indicates historic climate. Dashed red lines show TMDLs.

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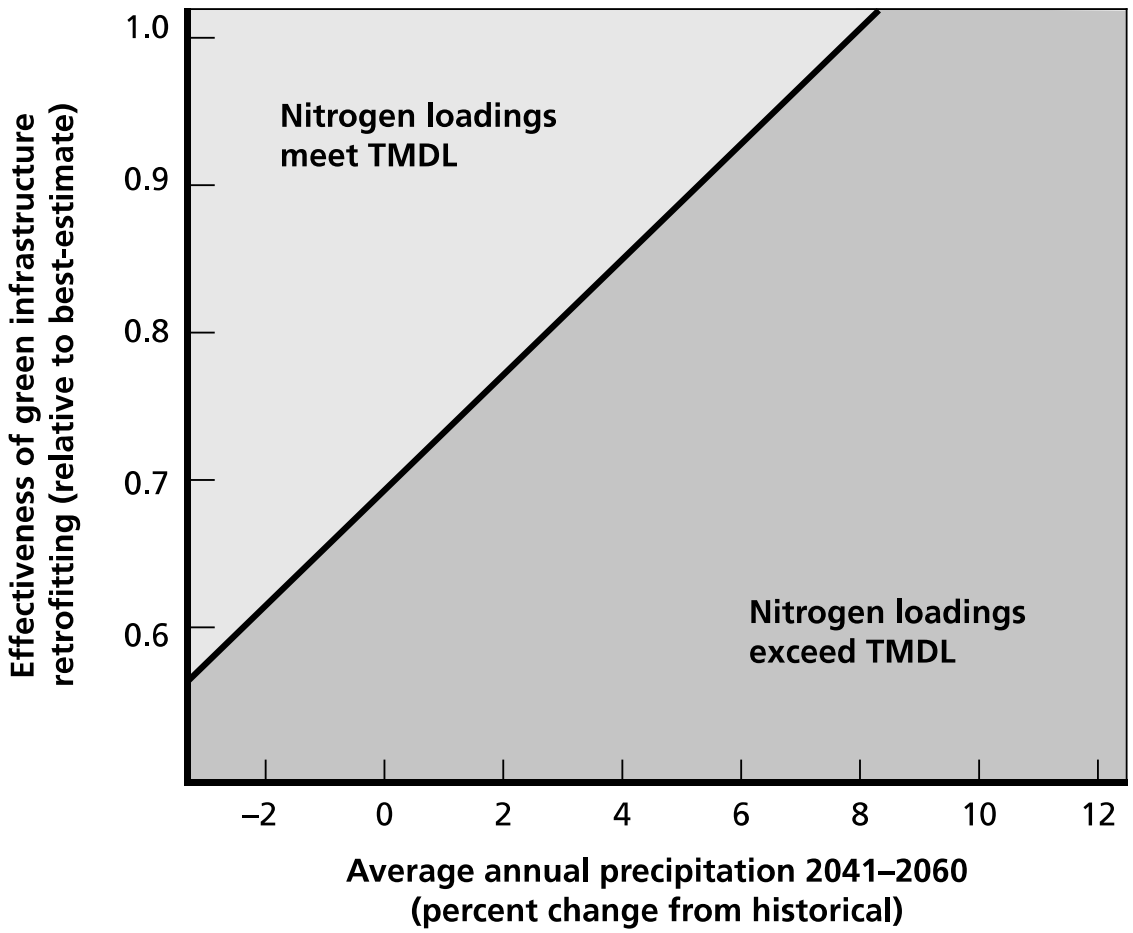
Most Vulnerability Explained by Combination of Lower BMP Efficiency and Increased Precipitation



Range of six NARCCAP climate projections

Conclusions

- Climate and other uncertainties could have a significant impact on the success of water quality plans
- TMDL plans evaluated with simulation models do not meet standards over a range of plausible future climate conditions
- Other uncertainties could also be key drivers
  - An increase in the amount of impervious area cover
  - Worse-than-anticipated BMP removal efficiency

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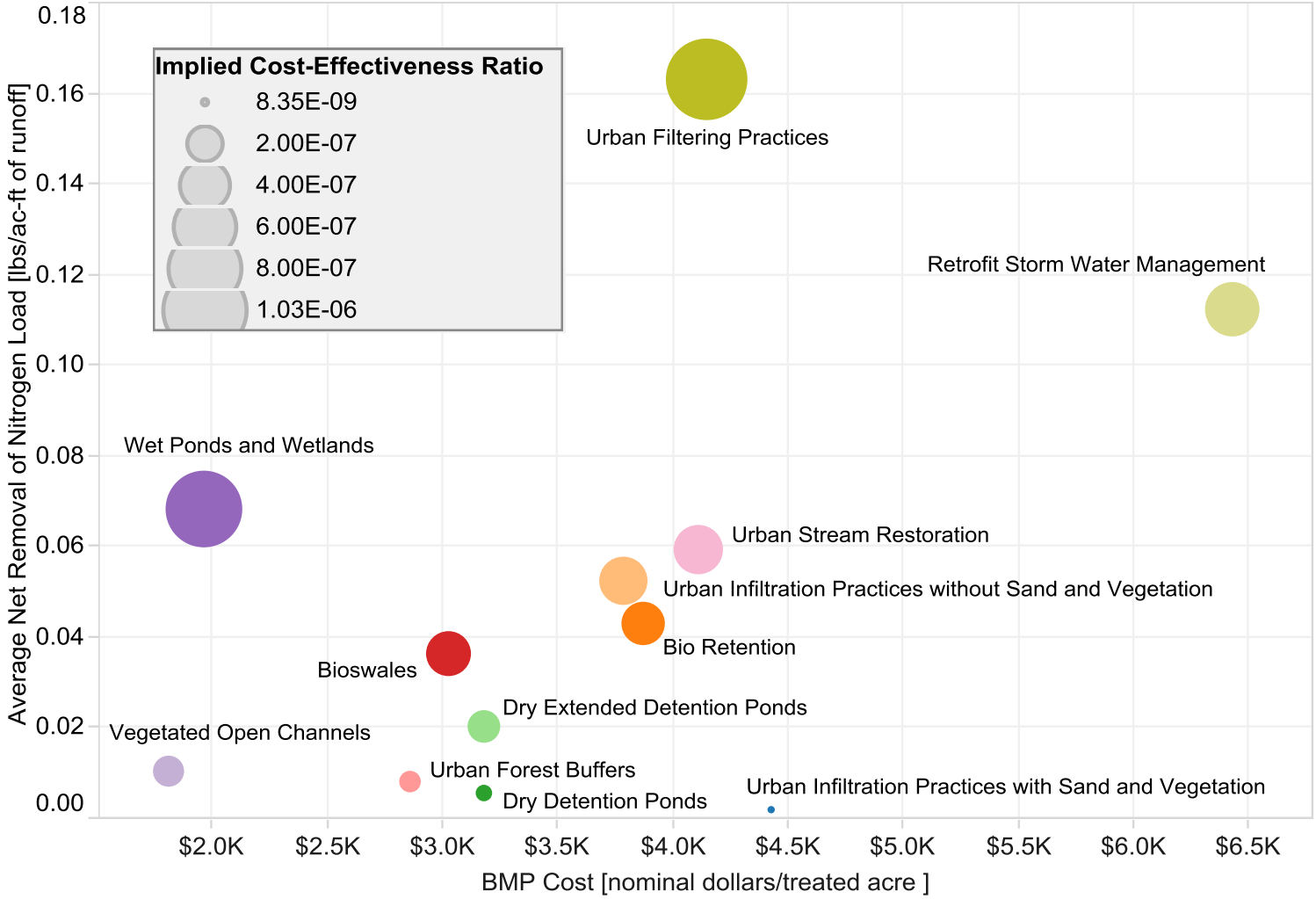
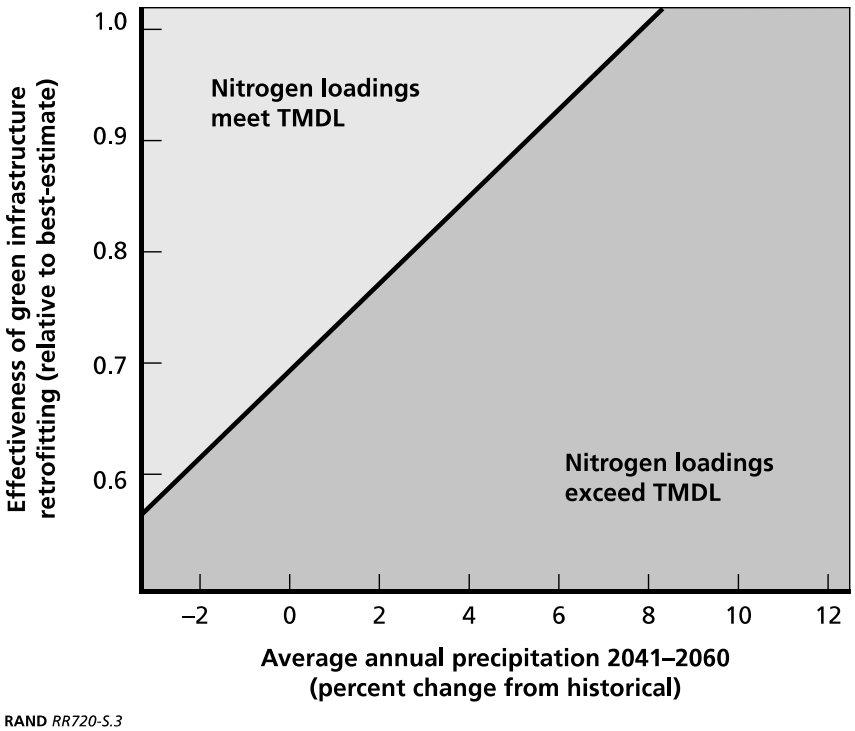
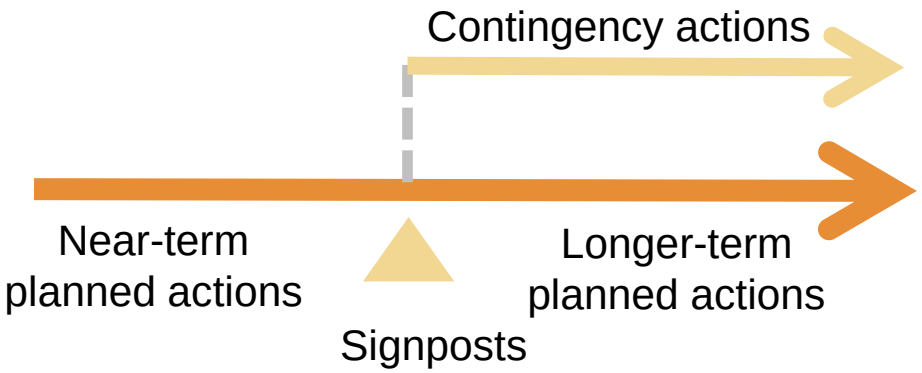
Maryland's WIP Also Identified a Series of Best Management Practices (BMPs) Designed to Meet Targets

We Identified Additional Cost-Effective BMPs to Help Mitigate Nitrogen Vulnerability as an Initial Next Step



Scenario Maps Can Help Inform Adaptive Management Strategies



For adaptive management, monitor:

- Climate
- BMP effectiveness