Effect of Potential Future Climate Change on Cost-Effective Nonpoint Source Pollution Reduction Strategies in the UMRB

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Upper Mississippi River Basin (UMRB)

- 189,000 square miles in seven states,
- dominated by agriculture: 67% of total area,
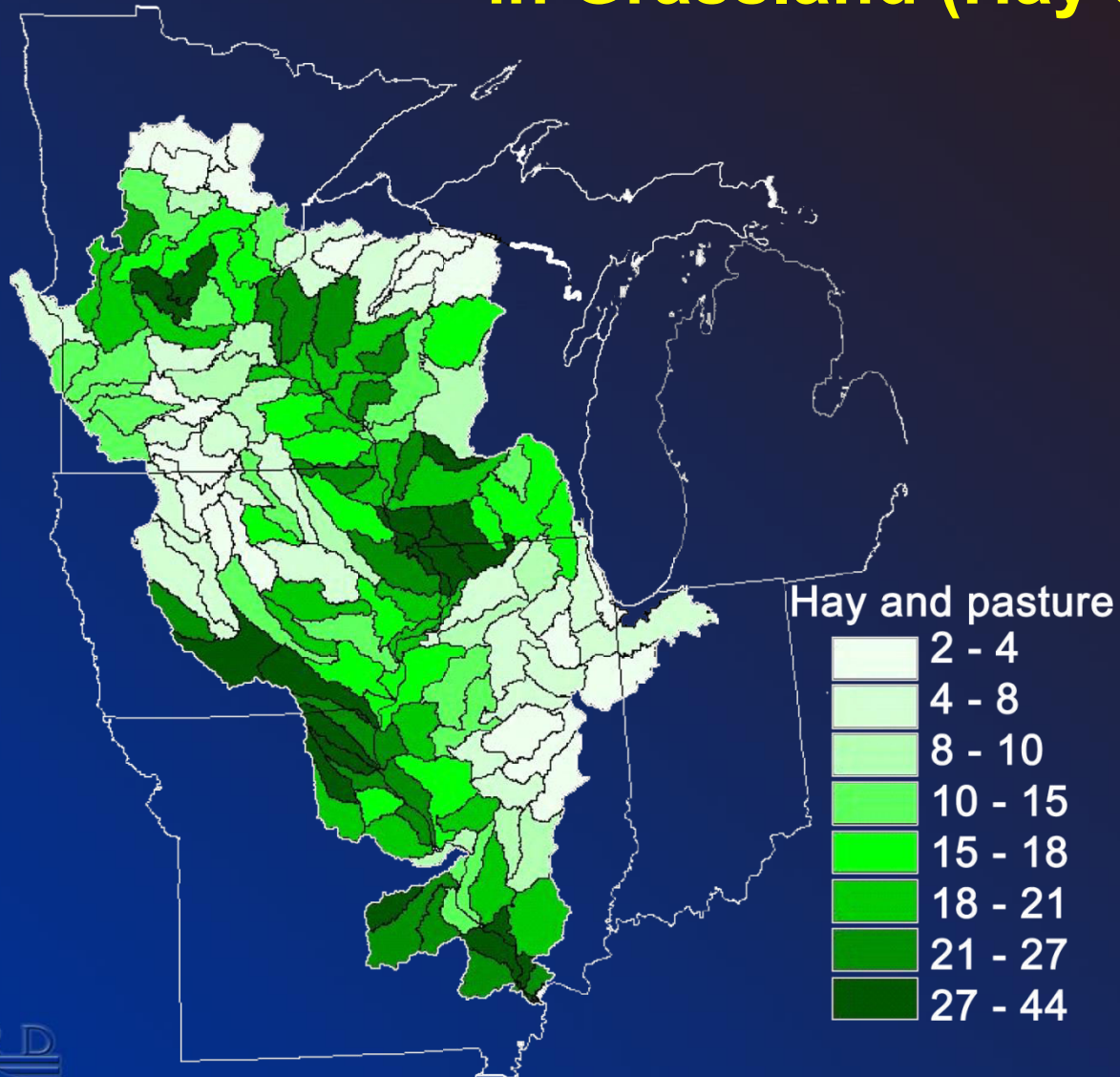- > 1200 stream segments and lakes on EPAs impaired waters list,

UMRB Modeling Framework

- Soil and Water Assessment Tool (SWAT)
- Interfaces: ArcSWAT and i_SWAT
- Input databases:

(spatial GIS, survey, field, and laboratory data)

      Topography (DEM)

      Land use data

      Soil data

      Fertilizer rates and tillage data

      Conservation practices data

      Climate data

% of 8-Digit Watershed Areas in Cropland (Corn and Soybean)
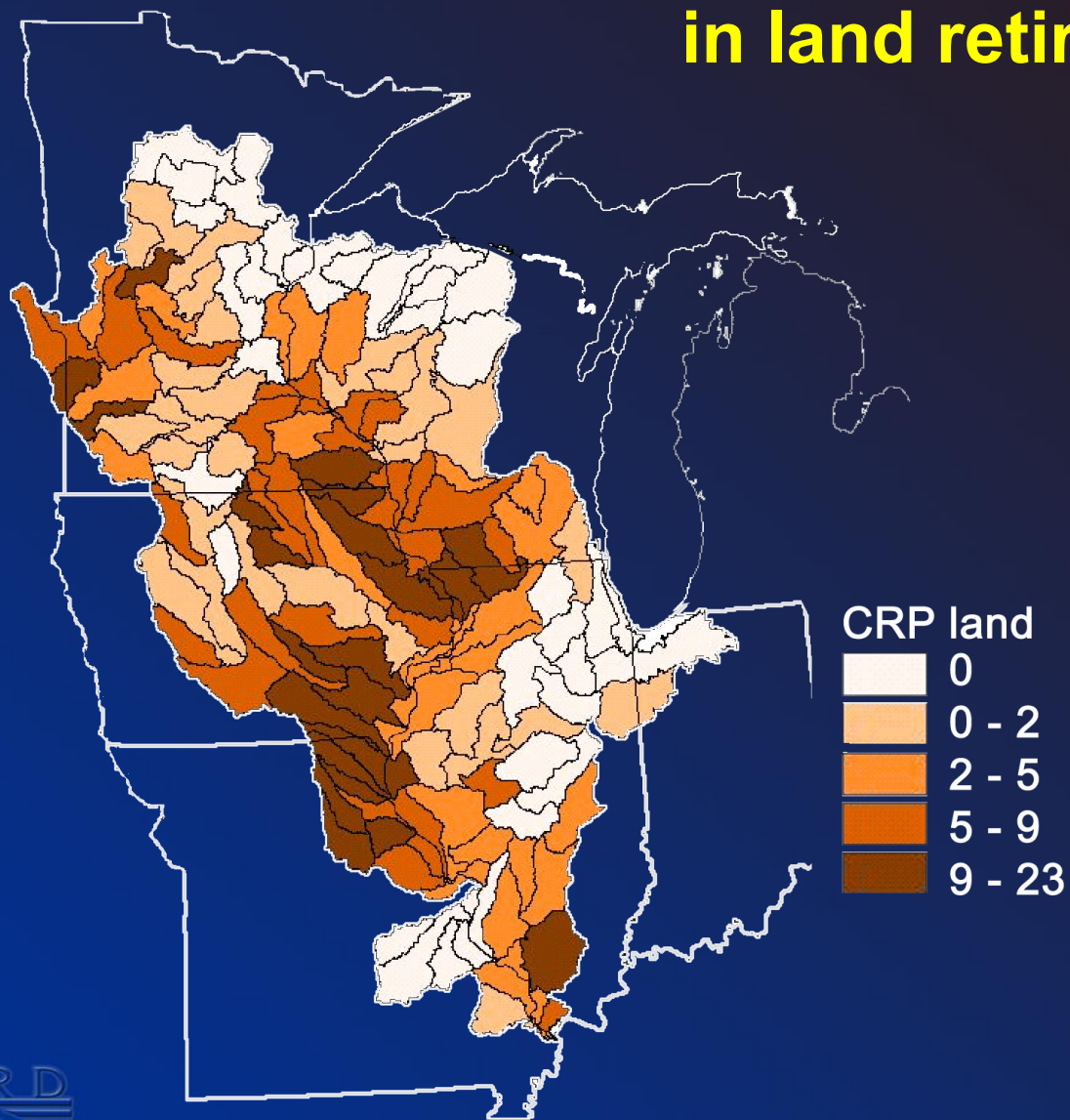

Cropland (CS)

- 0
- 1 - 4
- 4 - 9
- 9 - 20
- 20 - 41
- 41 - 54
- 54 - 71
- 71 - 91
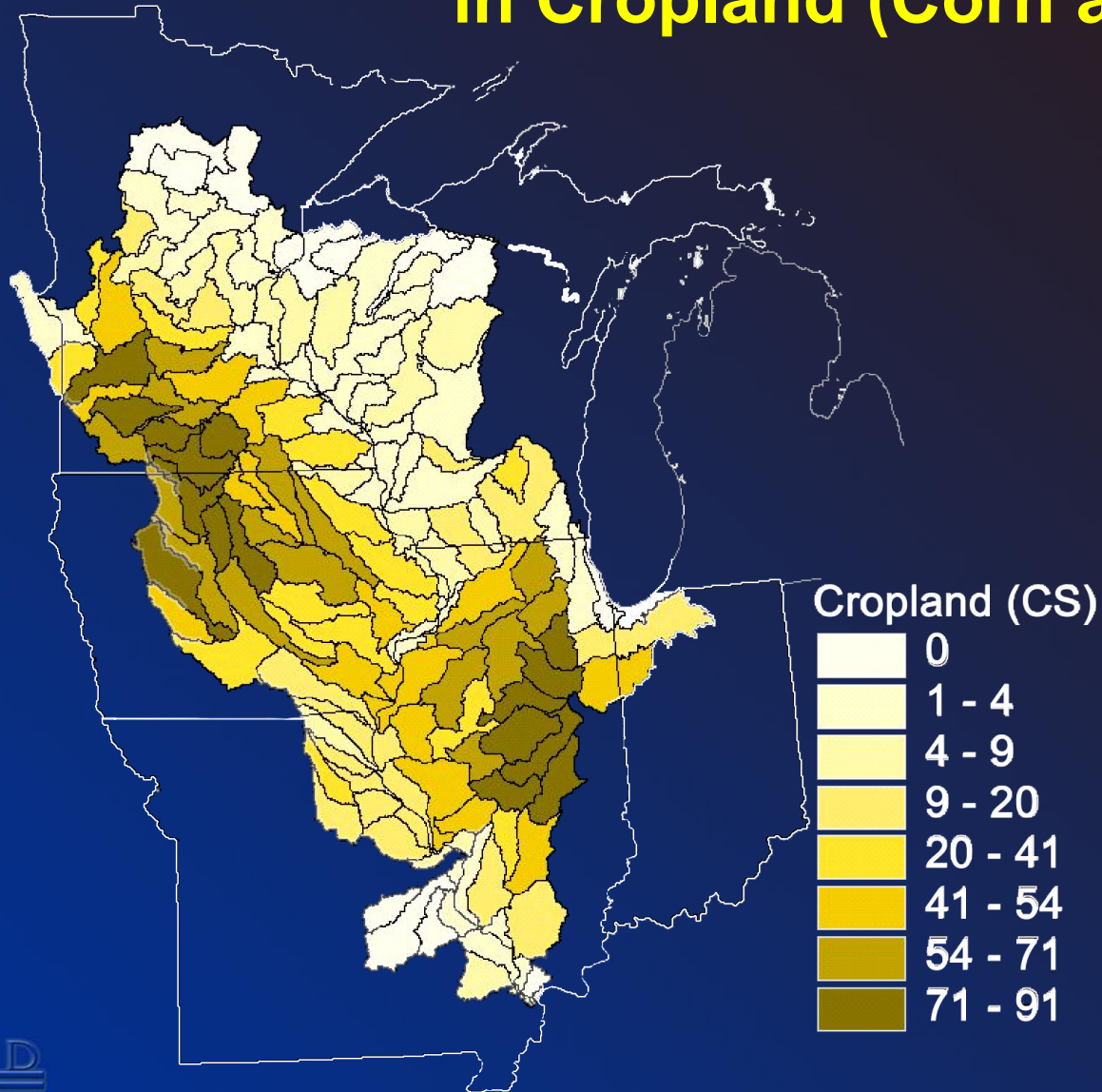
% of 8-Digit Watershed Areas in Grassland (Hay and Pasture)

Hay and pasture

- 2 - 4
- 4 - 8
- 8 - 10
- 10 - 15
- 15 - 18
- 18 - 21
- 21 - 27
- 27 - 44

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% of 8-Digit Watershed Areas in land retirement (CRP)

CRP land
- 0
- 0 - 2
- 2 - 5
- 5 - 9
- 9 - 23

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Calibration Results

Hydrologic balance of the watershed

(average annual values for 1981-2003)

Precipitation = 939 mm

Snowfall = 131 mm
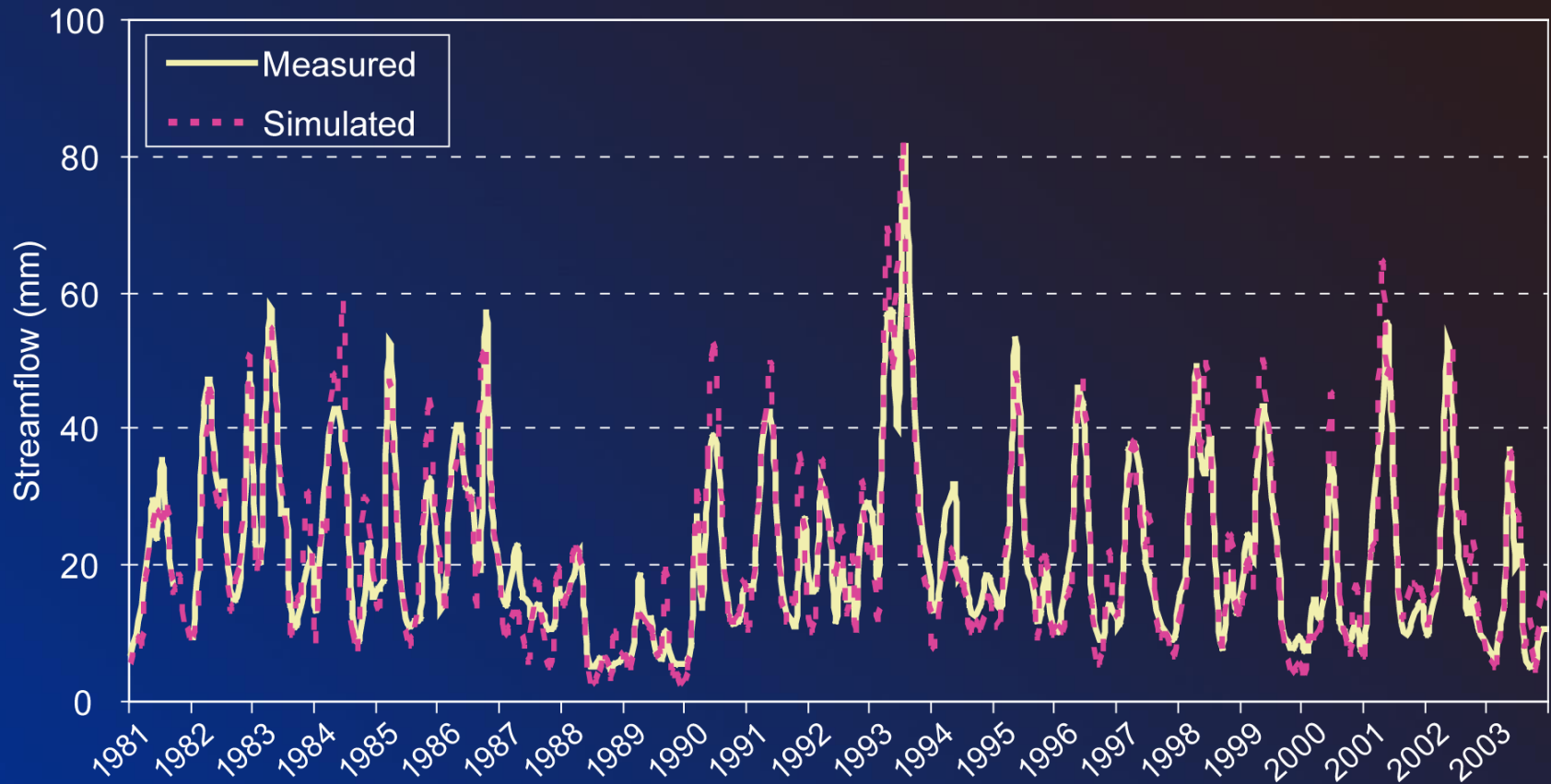
Surface runoff = 84 mm

Tile flow = 12 mm

Groundwater = 170 mm

Baseflow = 182 mm (70% of streamflow)

Evapotranspiration = 583 mm (62% of precipitation)

Monthly Streamflow

Calibration (1981-1992)
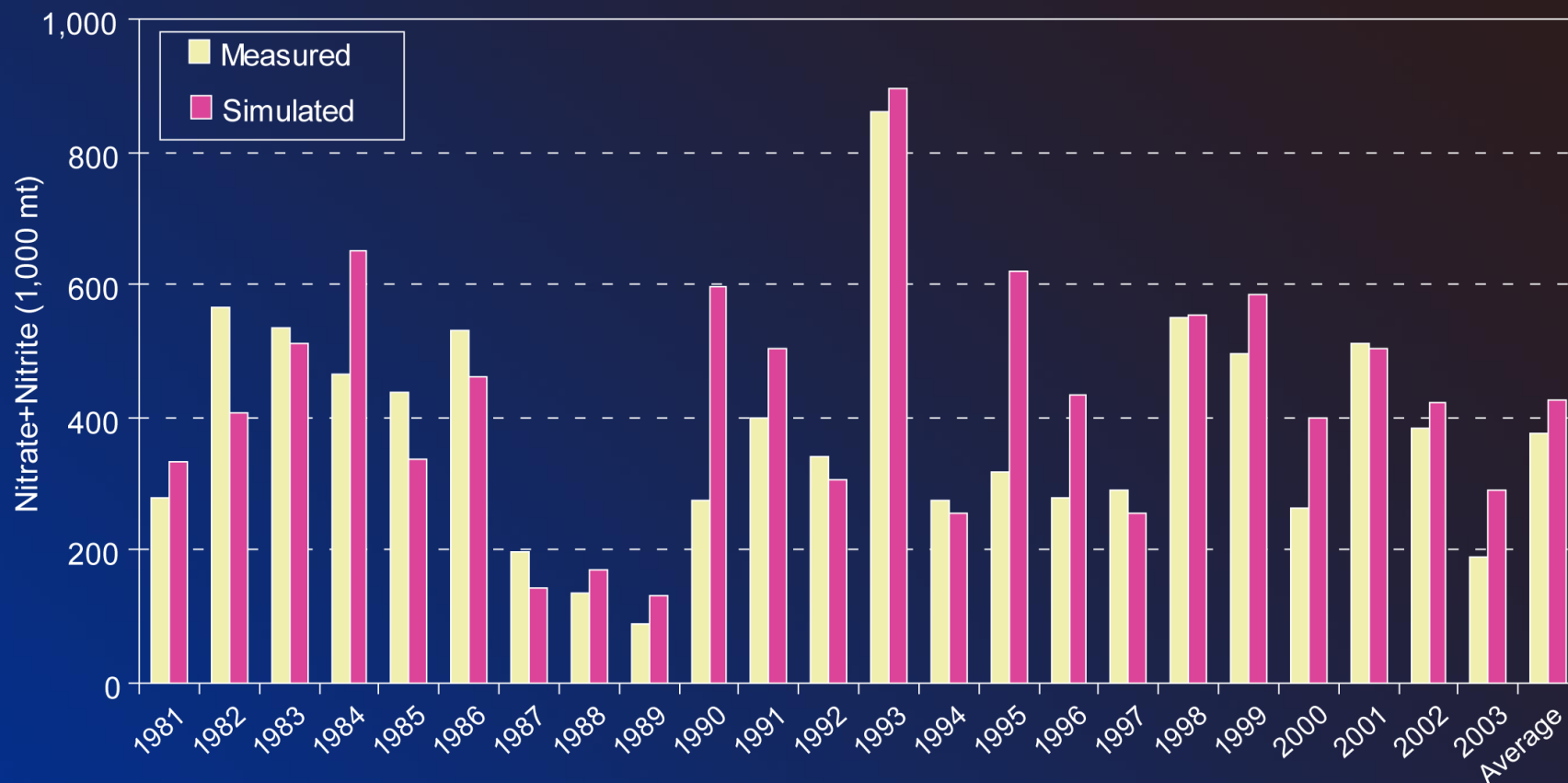
$R^2 = 0.81$

E = 0.77

Validation (1993-2003)

$R^2 = 0.85$

E = 0.83

Annual Nitrate
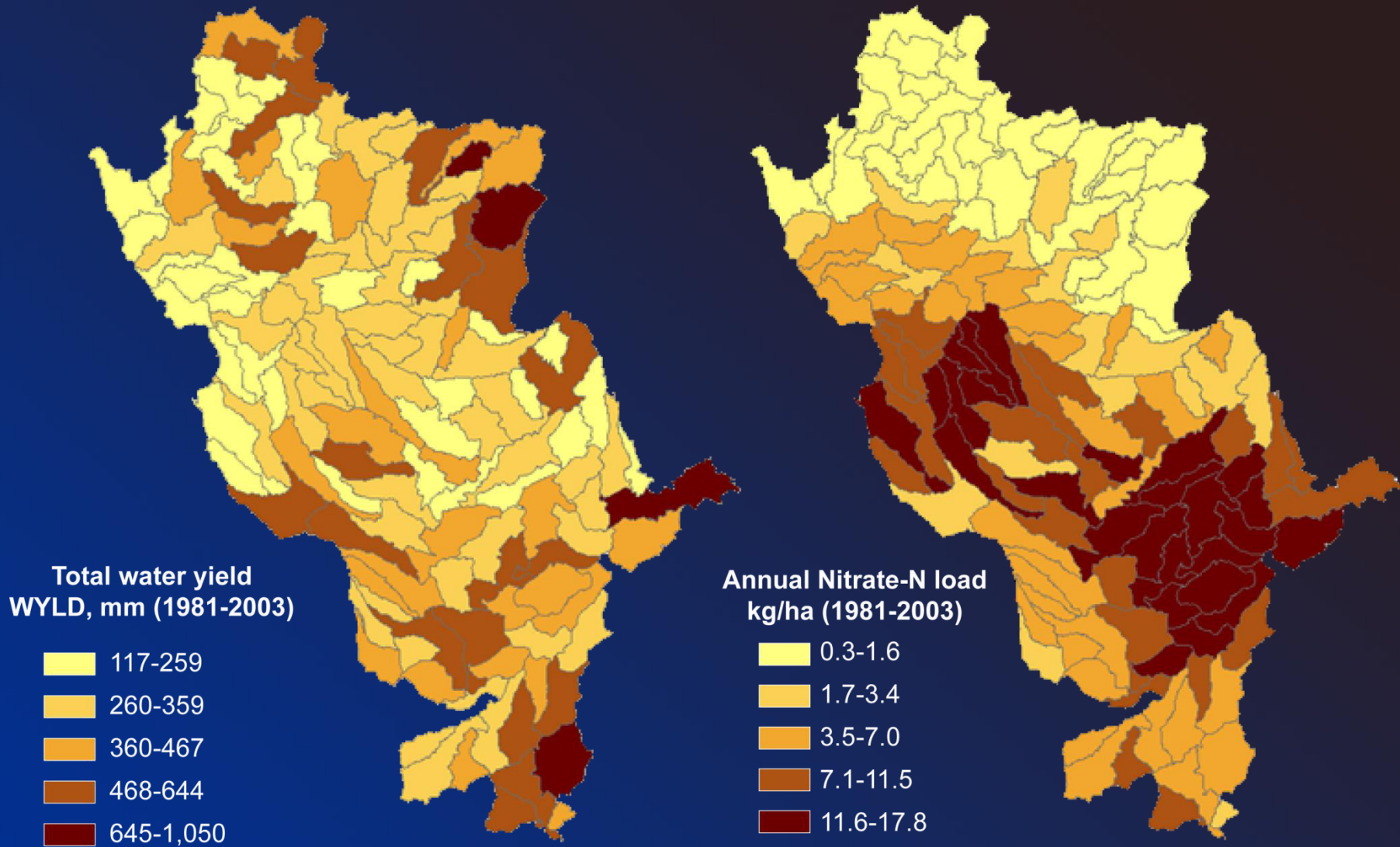

Calibration (1981-1992)

$R^2 = 0.48$

$E = 0.29$

Validation (1993-2003)

$R^2 = 0.74$

$E = 0.57$

# Spatial distribution of baseline water yield and nitrate-N load

Total water yield WYLD, mm (1981-2003)

- 117-259
- 260-359
- 360-467
- 468-644
- 645-1,050

Annual Nitrate-N load kg/ha (1981-2003)

- 0.3-1.6
- 1.7-3.4
- 3.5-7.0
- 7.1-11.5
- 11.6-17.8

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Nitrate-N loading that yields 30% nitrate-N and 36% P loading reduction

Annual additional cost: $ 1.4 billion

Nitrate loadings (fraction of baseline)

- 0.07-0.36
- 0.37-0.47
- 0.48-0.63
- 0.64-0.81
- 0.82-1.00

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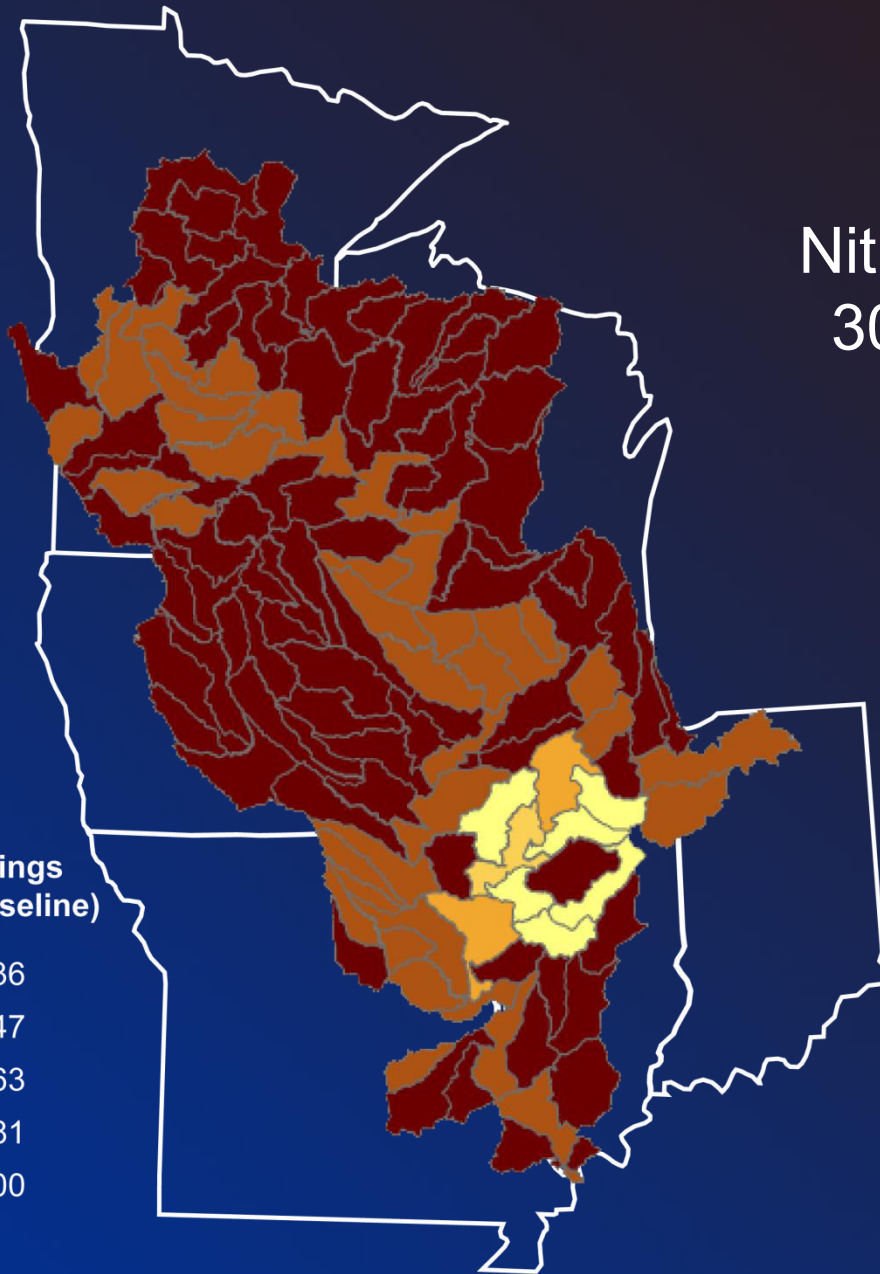
Effects of potential future climate change

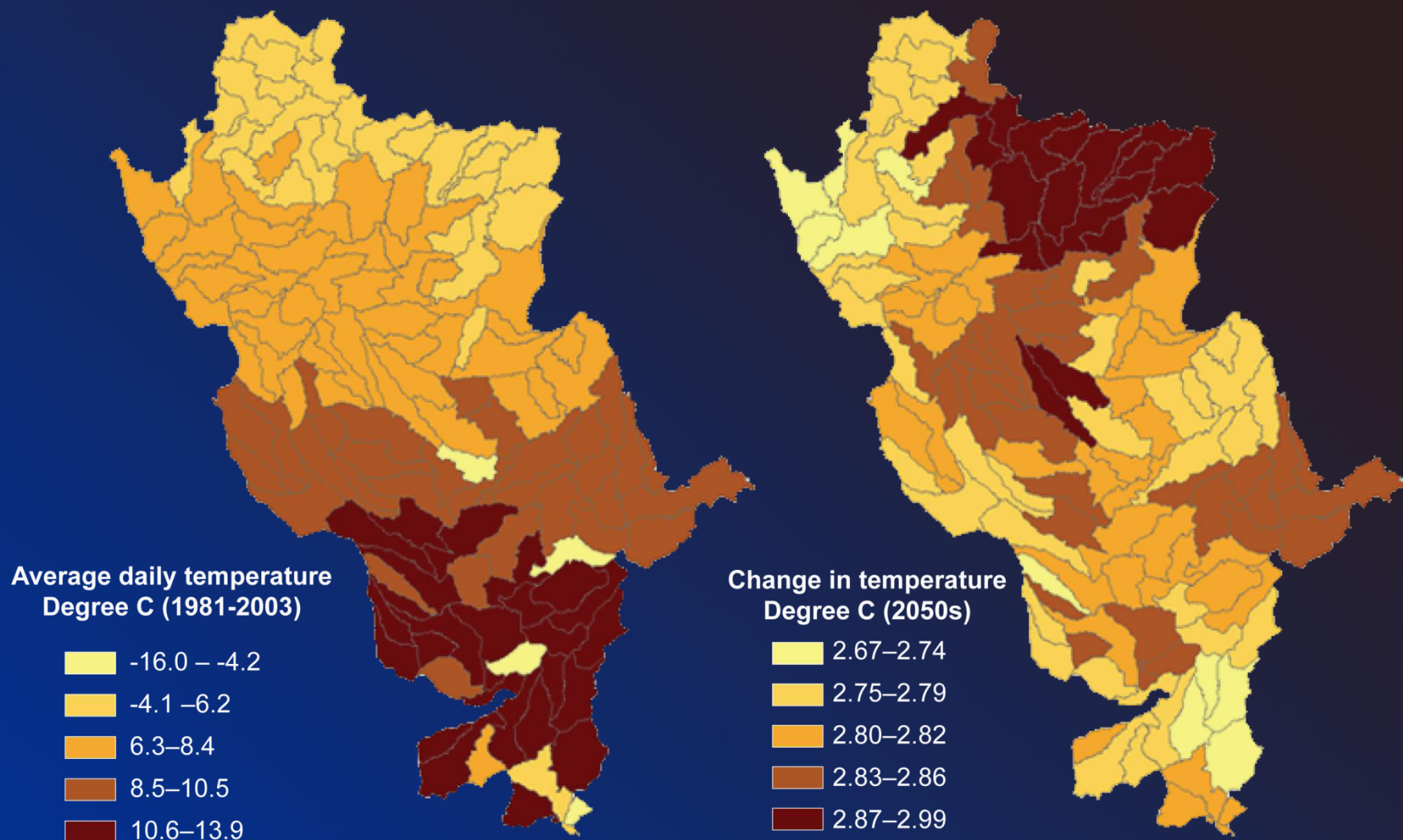## Change in precipitation predicted by the ensemble of 10 GCMs

**Annual precipitation
mm (1981–2003)**

- 642–761
- 762–874
- 875–976
- 977–1,105
- 1,106–1,322

**Change in precipitation
mm (2050s)**

- -2 – -1
- 0–2
- 3
- 4
- 5–6

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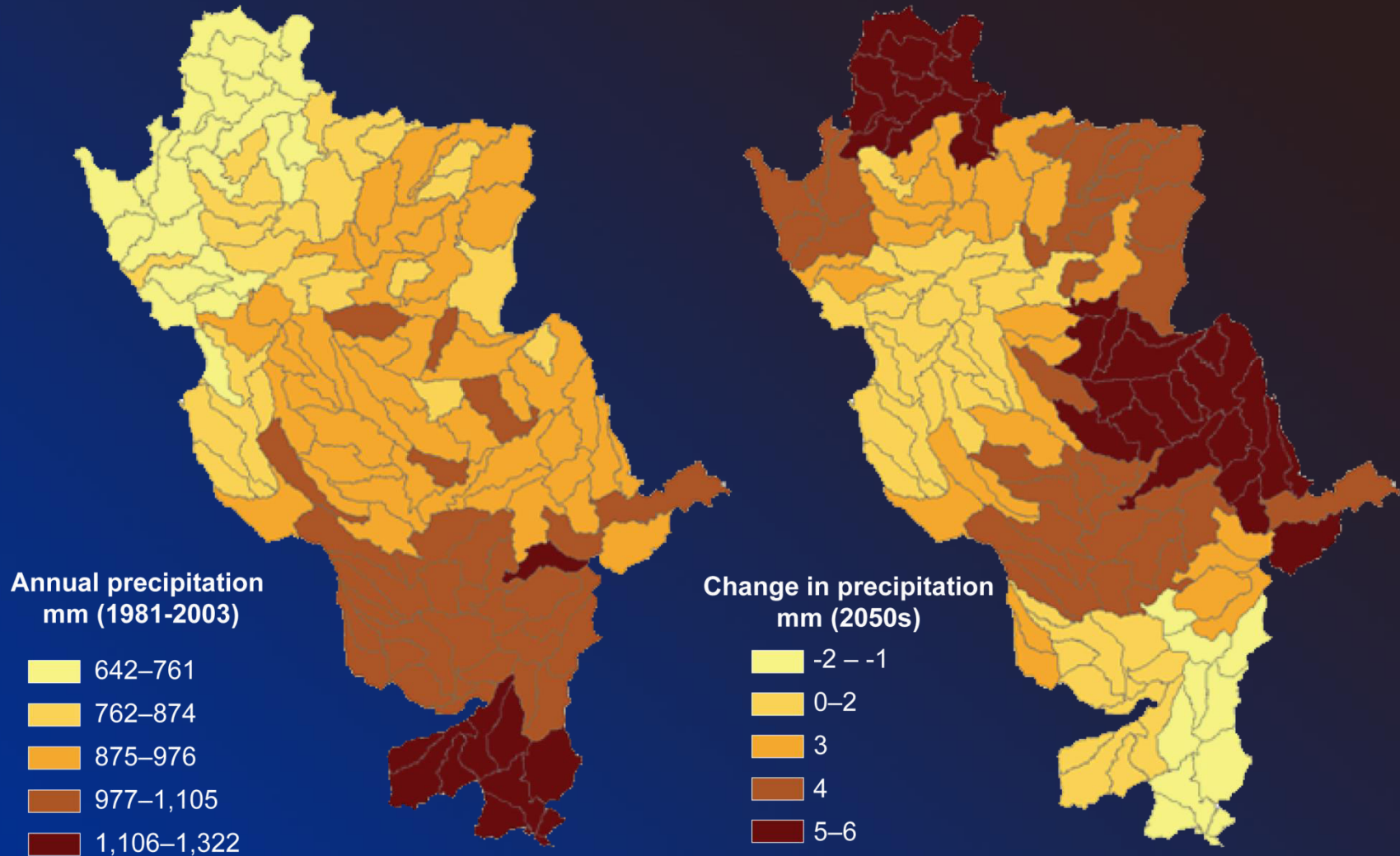
Change in aver. temperature predicted by the ensemble of 10 GCMs

Average daily temperature
Degree C (1981-2003)

- -16.0 – -4.2
- -4.1 –6.2
- 6.3–8.4
- 8.5–10.5
- 10.6–13.9

Change in temperature
Degree C (2050s)

- 2.67–2.74
- 2.75–2.79
- 2.80–2.82
- 2.83–2.86
- 2.87–2.99

C A R D

Total water yield (mm)

Total water yield WYLD, mm (1981-2003)

- 117–259
- 260–359
- 360–467
- 468–644
- 645–1,050

Change in WYLD mm (2050s)

- -56– -34
- -33– -15
- -14–1
- 2–16
- 17–54

C A R D

Nitrate-N Load (kg/ha)

Annual nitrate-N load kg/ha (1981-2003)

- 0.3–1.6
- 1.7–3.4
- 3.5–7.0
- 7.1–11.5
- 11.6–17.8

Change in WYLD mm (2050s)

- -2.7– -0.9
- -0.8–0.5
- 0.6–2.0
- 2.1–4.3
- 4.4–7.6

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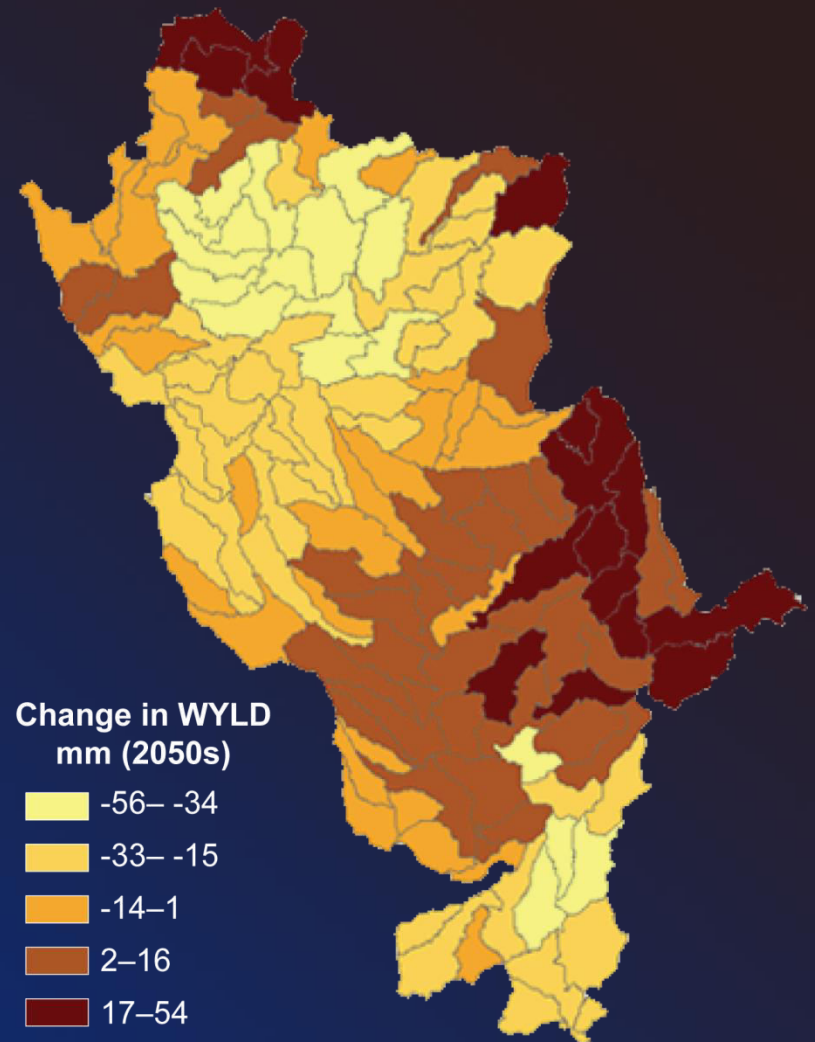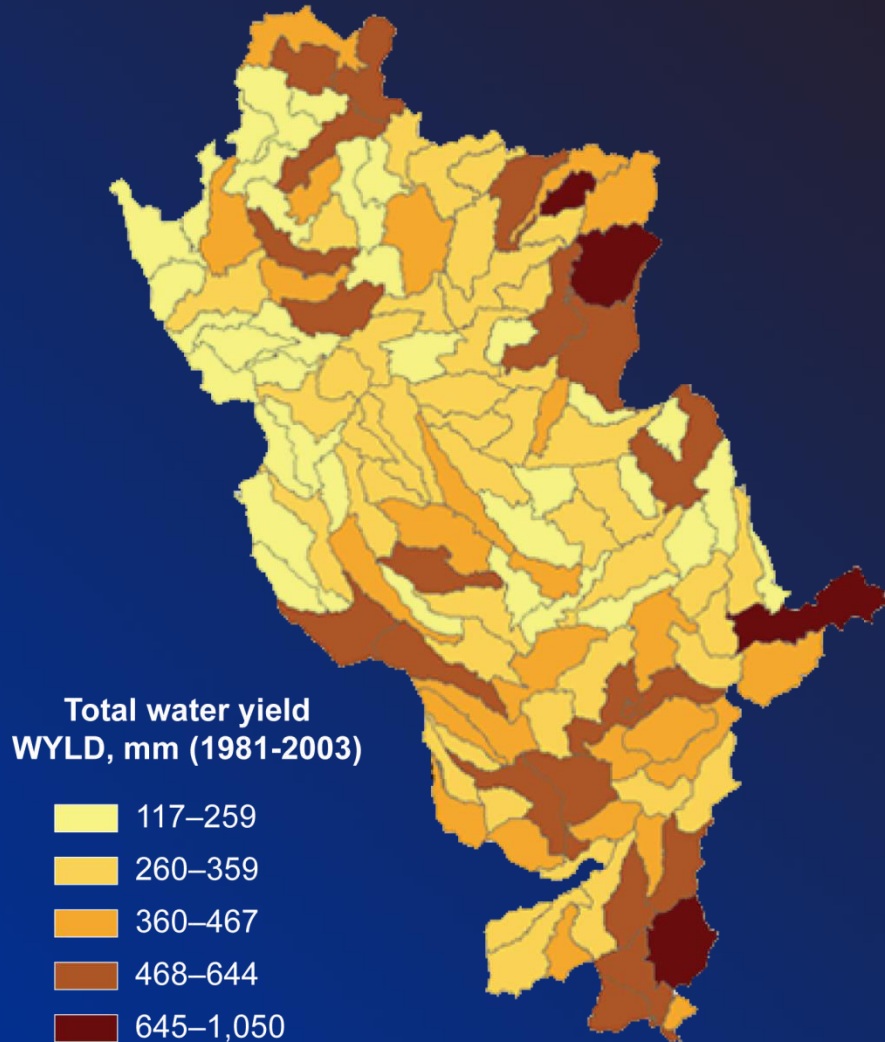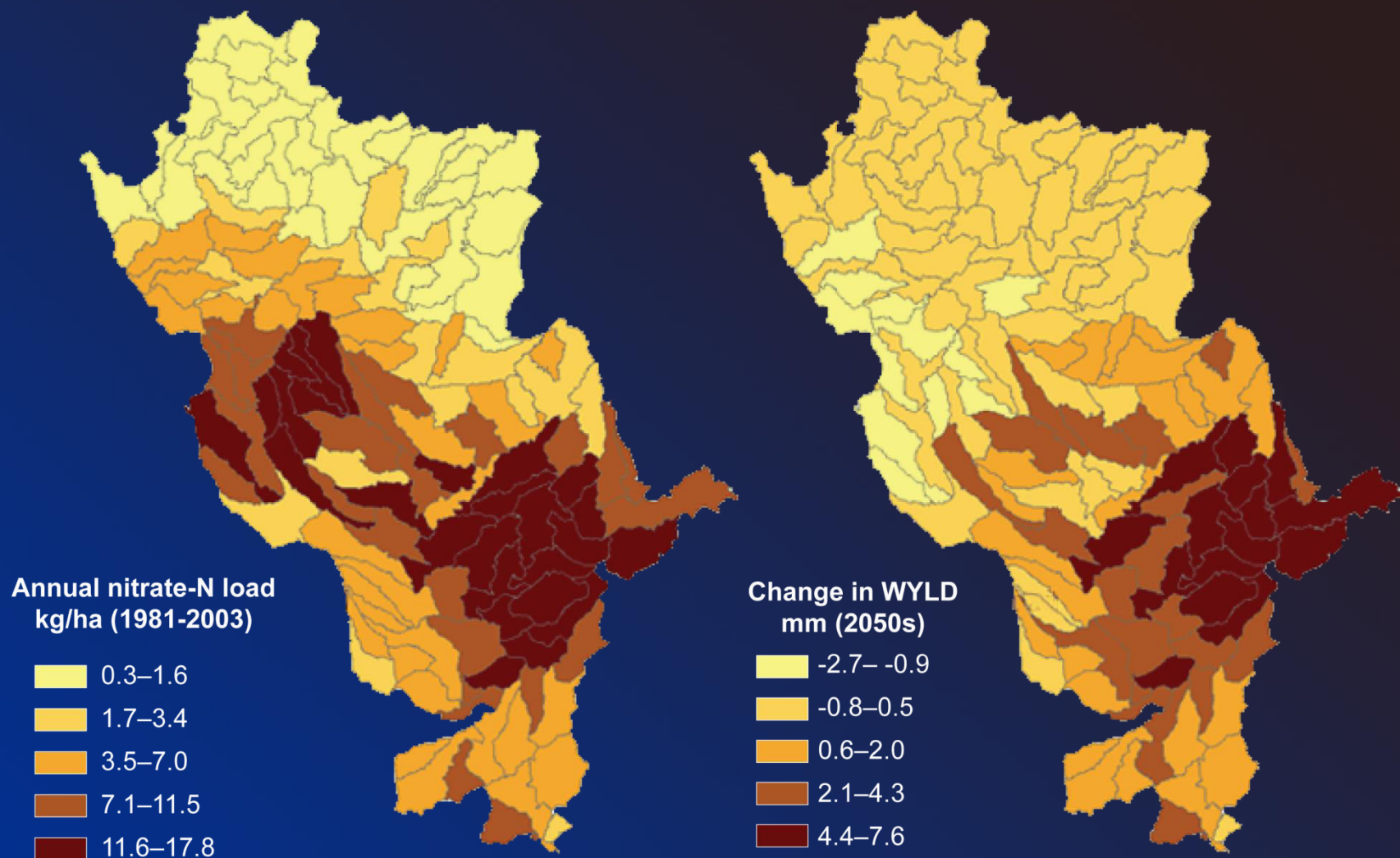
Simulation-Optimization

- Basic questions:

  - Where to put conservation practices so as to meet water quality improvement objectives at least cost?

  - What are the trade-offs between costs and water quality improvements?

- If there are N conservation practices possible for adoption on each field and there are F fields, this implies a total of possible N^F configurations to compare

  - 30 fields, 2 options $\rightarrow$ over 1 billion possible scenarios

- Genetic Algorithm provides approximate solution

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Genetic Algorithm (GA)

1) Approximate a least-cost frontier for pollutant of interest, where each point on the frontier represents a distinct conservation practice placement scenario.

2) SPEA2 (Strength Pareto Evolutionary Algorithm 2) is used to evaluate alternatives based on the resulting pollution and cost levels:

- selects those that are preferred

- subsequently attempts to create better solutions through the process of recombination and mutation, until the full frontier is reasonably identified.
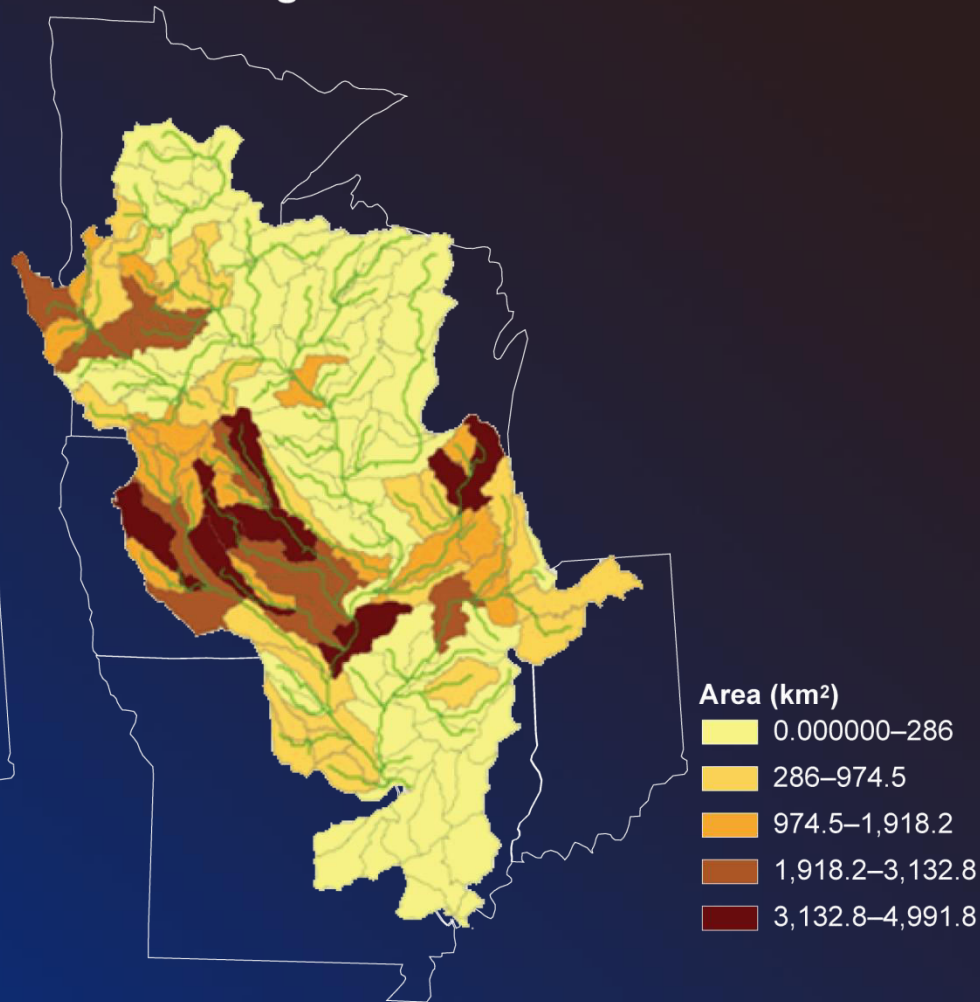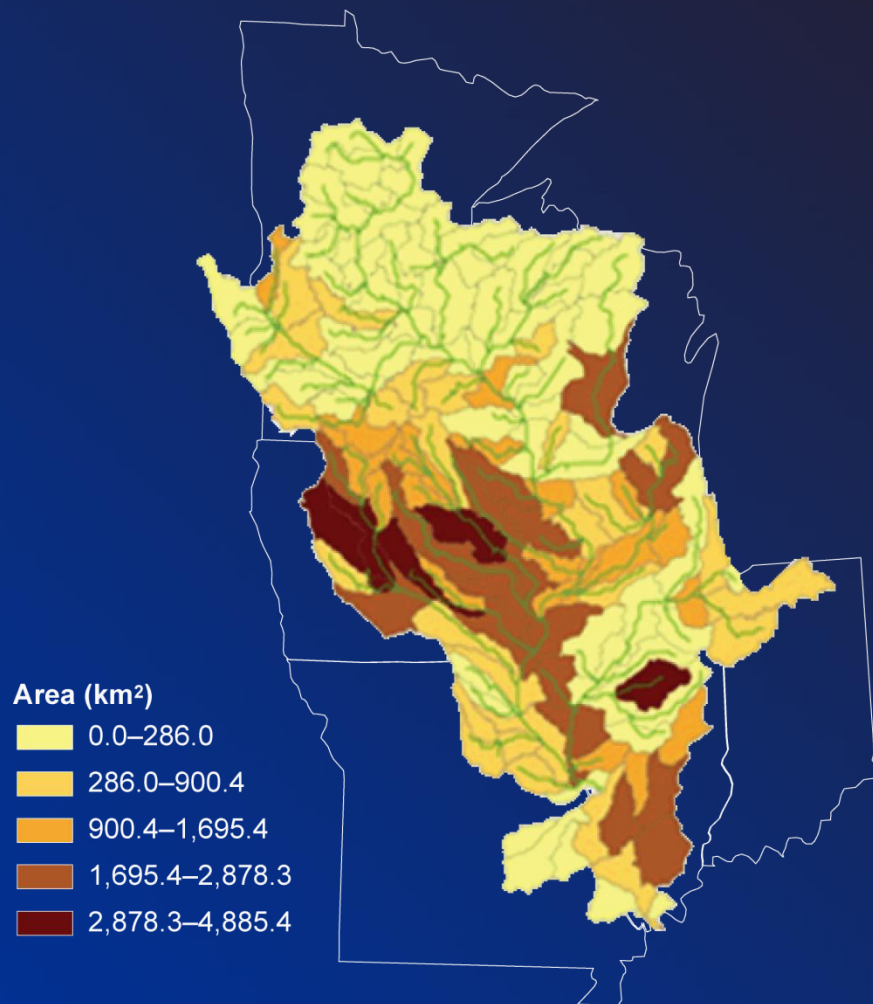
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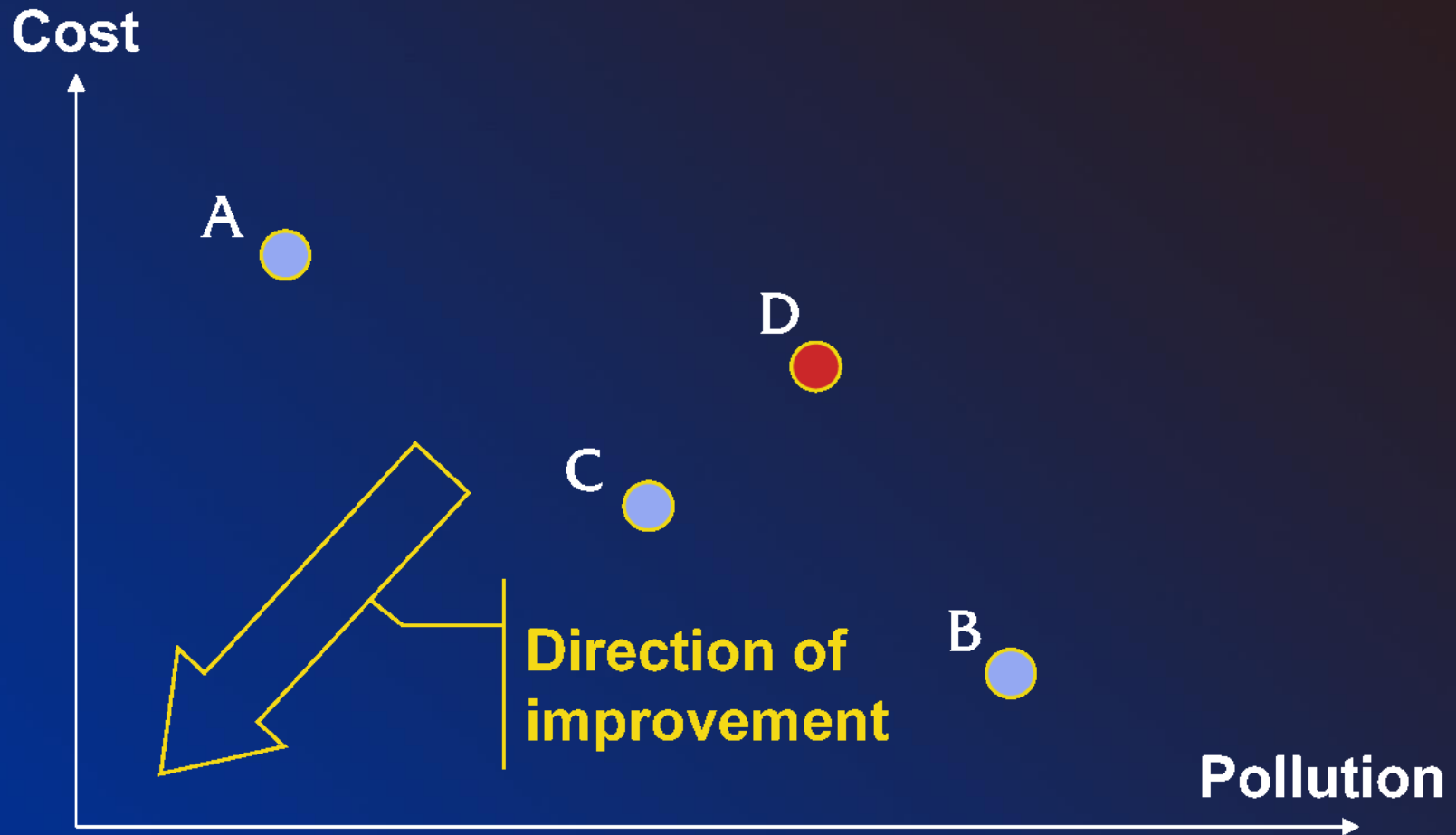
Pareto frontier: UMRB
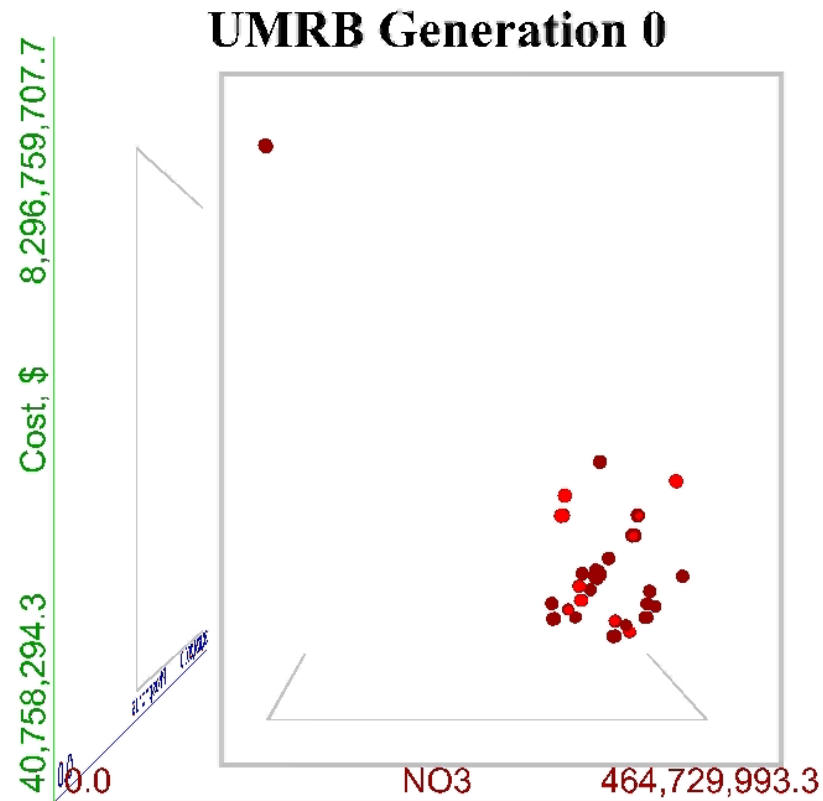
Spatial distribution of selected practices*
(30% NC reduction and 36% P reduction)

Historical climate

Climate Change Scenario

Area (km²)
- 0.0–286.0
- 286.0–900.4
- 900.4–1,695.4
- 1,695.4–2,878.3
- 2,878.3–4,885.4

Area (km²)
- 0.000000–286
- 286–974.5
- 974.5–1,918.2
- 1,918.2–3,132.8
- 3,132.8–4,991.8

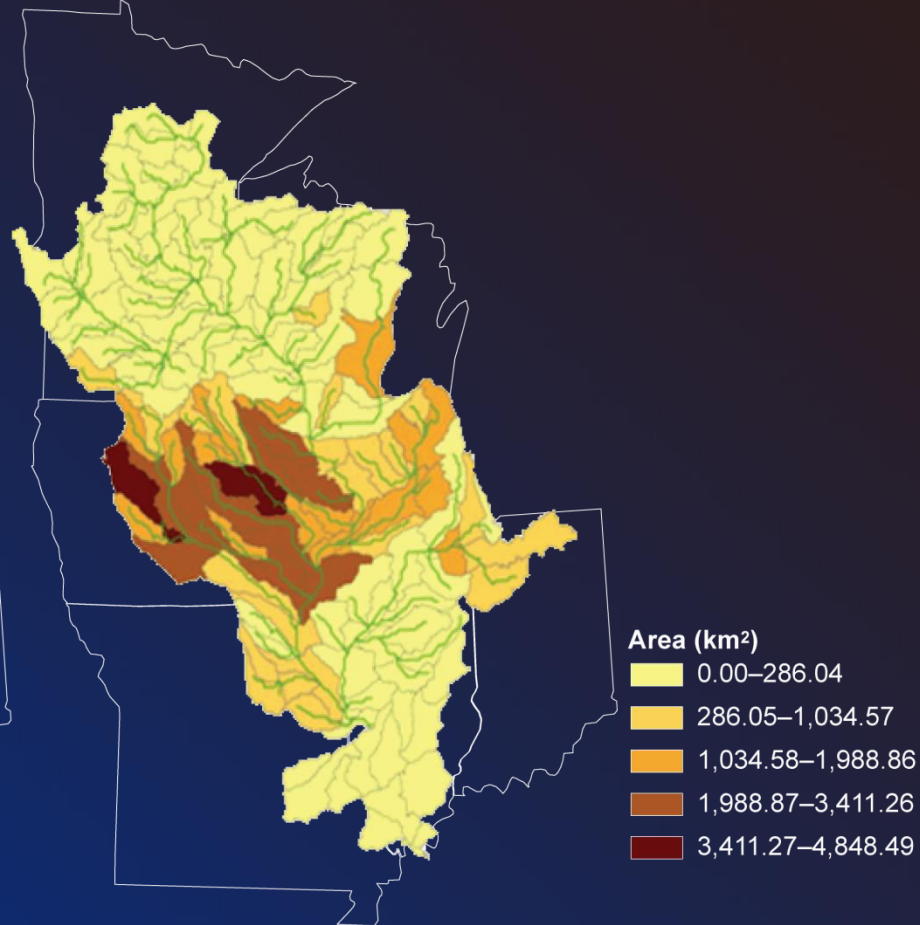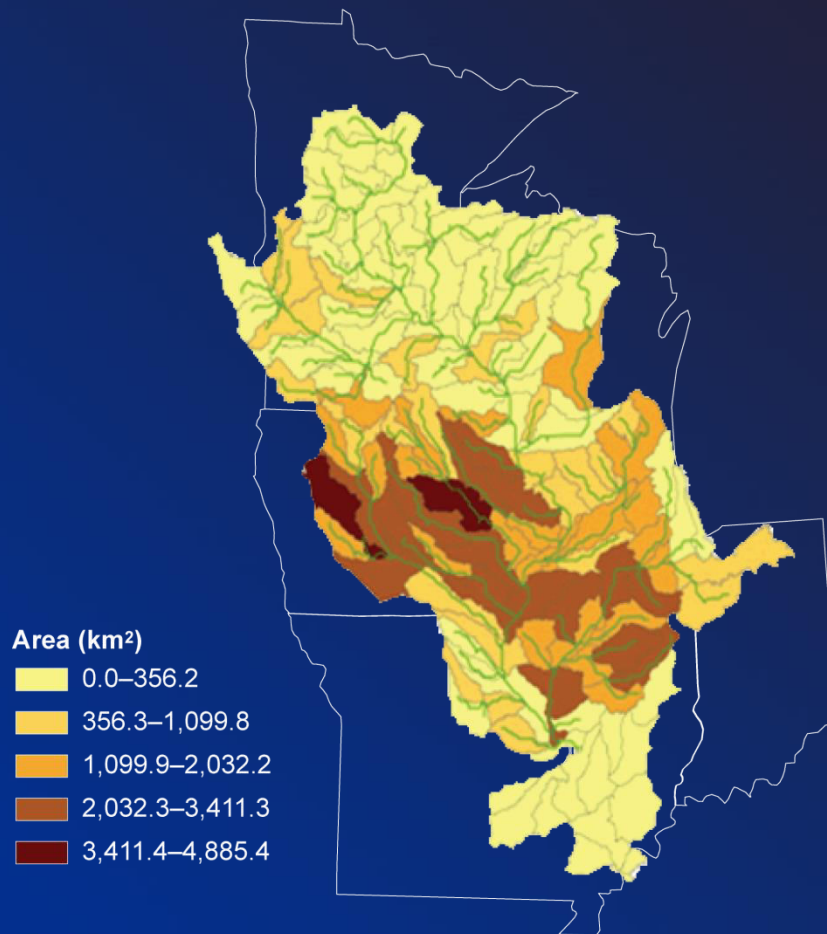*Conservation practices applied: Conservation tillage + Grassed waterways +20% N fertilizer reduction

Spatial distribution of selected practices*
(9% N reduction and 30% P reduction)

Historical climate

Climate Change Scenario

Area (km²)
- 0.0–356.2
- 356.3–1,099.8
- 1,099.9–2,032.2
- 2,032.3–3,411.3
- 3,411.4–4,885.4

Area (km²)
- 0.00–286.04
- 286.05–1,034.57
- 1,034.58–1,988.86
- 1,988.87–3,411.26
- 3,411.27–4,848.49

*Conservation practices applied: Conservation tillage + Grassed waterways

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Some Model/Data/Scale Issues

- Lumped units within subwatersheds (HRUs) are not spatially defined.

- Simulation of important conservation measures such as filter strips and wetlands are limited

- Fertilizer application rates: sales data vs. survey data

- Manure application rates

    - how should nutrient crediting be represented?

- Choice of land use data; crop rotation development

- Monitoring data – nutrient sampling

- Spatial scale of biophysical model vs. climate models

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Conclusion

- Optimization techniques such as genetic algorithm can be combined with the hydrologic modeling system to inform policy makers for cost-effective placement of conservation practice

- 30% reduction in nitrate-N loading (concomitant 36% P reduction) at Grafton, IL could be achieved at an annual additional cost of $1.4 billion under the selected list of conservation practices and assumption of cost of their placement

- Effects of potential future climate change predicted by the UMRB SWAT setup driven by the ensemble of 10 GCMs indicated some nitrate load reduction in Iowa basins but worse condition for Illinois basins.