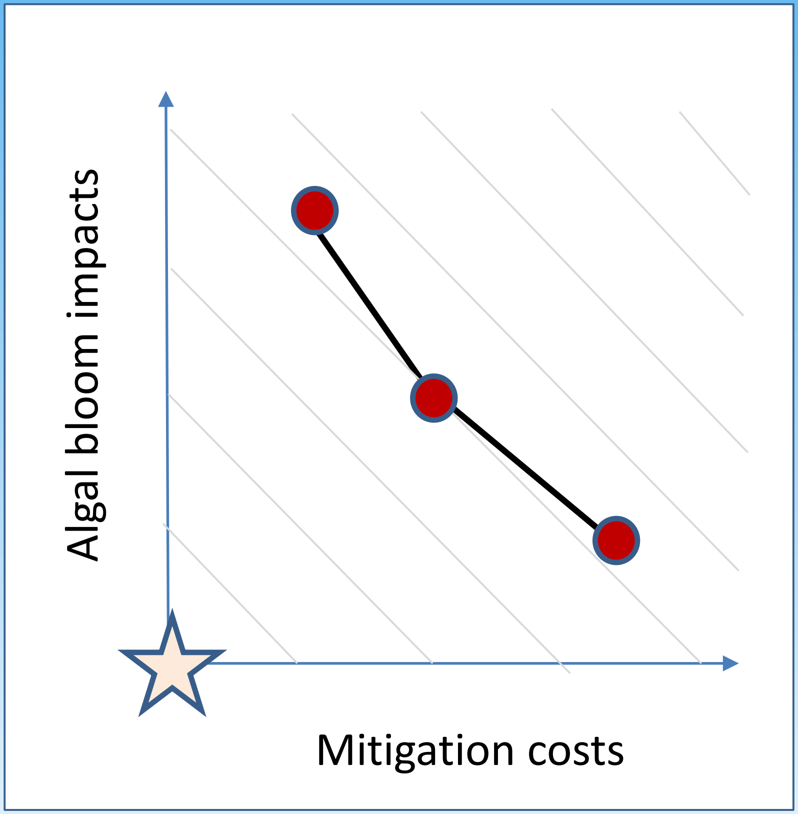
Multi-objective optimization - overarching modeling goals

- Evaluate tradeoffs between bloom mitigation costs and impacts
- Evaluate inter-sectoral and inter-generational tradeoffs
- Compare mitigation objectives:
  - Meeting total phosphorus TMDL
  - Minimizing bloom impacts, meeting total phosphorus TMDL
- Identify plans robust to plausible climatic and societal uncertainty
- Compare top-down and bottom-up governance perspectives

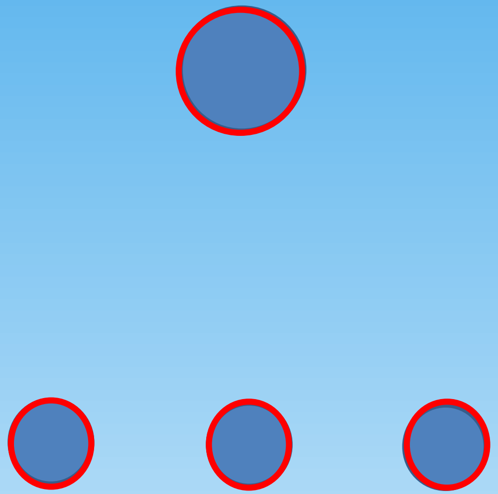


Optimization model implementation

- **Phase 1: Coarse-scale model of Vermont's Lake Champlain basins**
  - Will recommend allocation of state funds to basin-scale nutrient management efforts under present conditions
  - Leverages recent TMDL modeling work
  - Focuses on reducing phosphorus exports to Lake Champlain
- **Phase 2: Fine-scale models of Missisquoi and St. Alban's bays**
  - Coupled with BREE IAM models, including land-use model and governance ABMs
  - Account for 21st century climatic and societal uncertainty

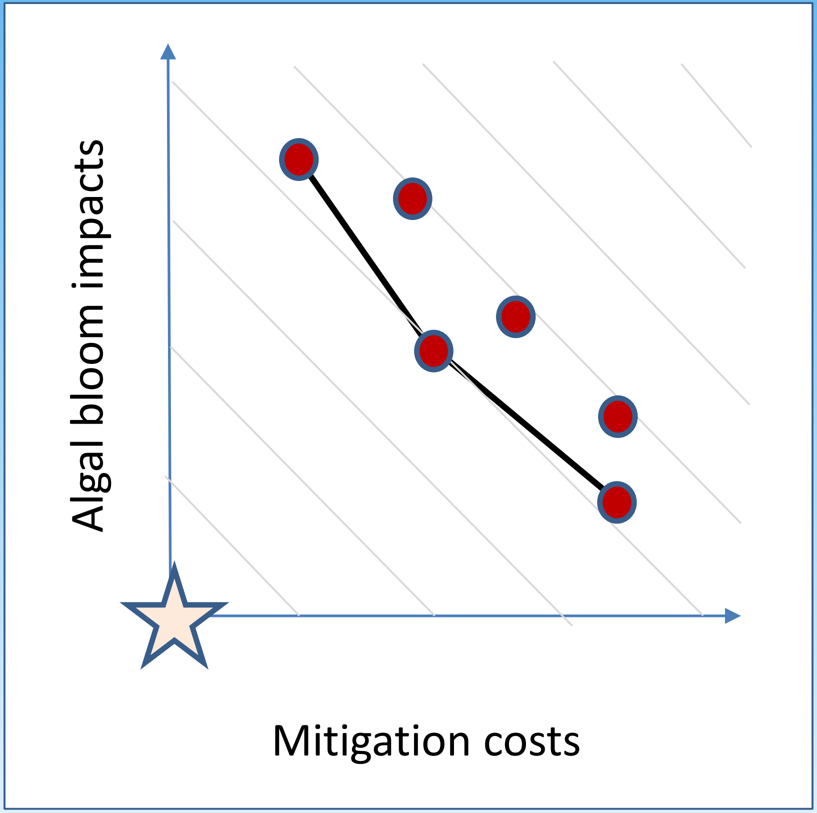
Evaluating decentralized basin planning with hierarchical optimization

- State budgets allocated to different basin-planning projects
- Tactical basin plans (TBPs) convene local stakeholders
- Stakeholder-defined TBP goals may vary from state goals
- Hierarchical optimization considers governance networks
- Emerging applications in other areas of water resources



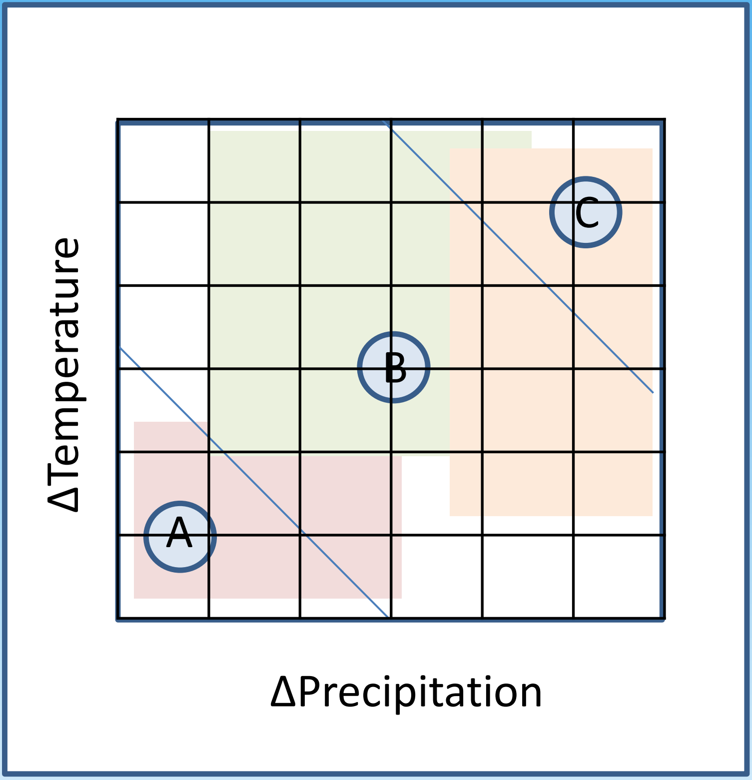
Near-optimal solutions

- "Optimal" might imply absolute best solution
- Models do not represent real-world perfectly
- "Near-optimal" solutions may be preferred
- Can reveal wide range of feasible strategies
- Encourages iterative model development with stakeholders



Identifying critical planning scenarios through Monte Carlo simulations

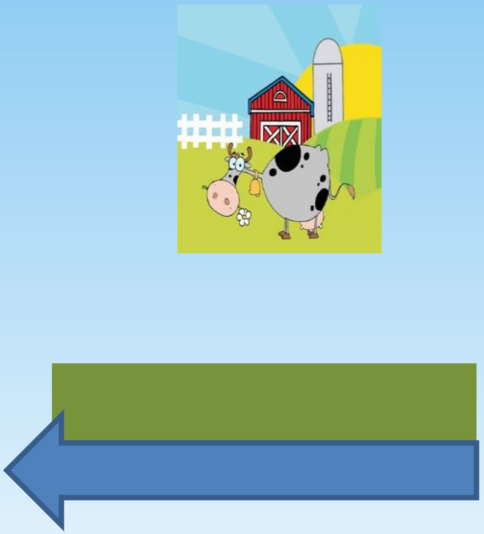
- Scenarios from cascading IAM defined by changes in:
  - Climate (emissions x GCMs)
  - Land use
  - Governance
- Computational resources limit number of scenario runs
- Sensitivity analyses guided by Latin Hypercube Sampling
- Use exploratory modeling to approximate impact thresholds
- Must simulate *sequences* of floods and droughts well!



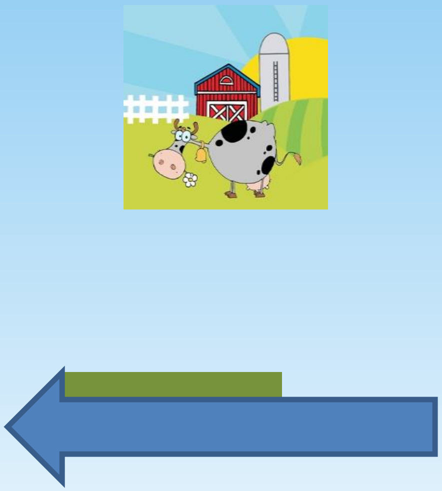
Simulating sensitivity to climate uncertainty (hypothetical example)

Identifying robust adaptation plans

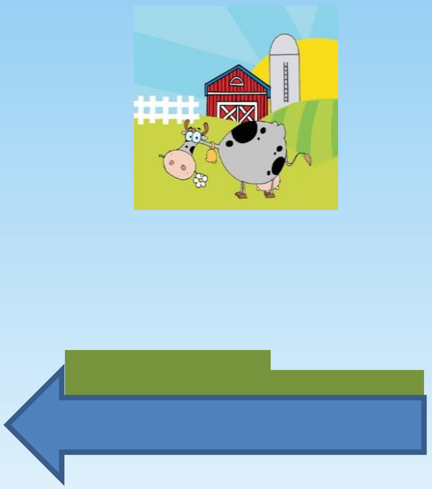
PLANNING FOR
SCENARIO A
(MAJOR CHANGE)



PLANNING FOR
SCENARIO B
(NO CHANGE)



ROBUST
PLANNING
ACROSS
SCENARIOS



Incorporating parameter uncertainty in optimization models

- Nonlinear optimization methods will be used to calibrate numerous model parameters
- Will consider synergistic effects of parameter uncertainty (e.g. Sobol sensitivity analysis)
- Can represent parameter uncertainty impacts on decisions through interval and stochastic optimization
- Bayesian meta-analyses from literature reviews provide option for characterizing BMP uncertainty

Estimating extremes with calibrated continuous simulation models

- Calibration errors often omitted from simulated data
- Can cause simulated variance to be lower than observed variance
- Can be adjusted by:
  - Reincorporating calibration errors into stochastic model
  - Calibrating to extremes
- Must track propagation of calibration errors through IAMs

SIMPLIFIED RAINFALL-RUNOFF MODEL

$$Q = a + bP + \varepsilon$$

SIMULATION MODEL

$$\hat{Q} = a + bP$$

MODEL VARIANCE

$$\sigma_Q^2 = b^2\sigma_P^2 + \sigma_\varepsilon^2$$

From Farmer and Vogel (2016)

Thank you!