Using a Bayesian Network Approach to Model the Effects of Urbanization on the Condition of Benthic Macroinvertebrate Assemblages in the Northeast U.S. as Defined by the Biological Condition Gradient

Roxolana Kashuba,
Thomas F. Cuffney, Gerard McMahon, Song Qian,
Kenneth Reckhow, Jeroen Gerritsen,
and Susan P. Davies

Seventh National Monitoring Conference; Denver, CO; April 27, 2010

Decreased infiltration/
Increased runoff

Contaminants
(human waste, pesticides, chemicals)

Sedimentation/Habitat disruption

Decreased canopy cover/
Destroyed riparian buffer

Channel incision/
Disconnected floodplain

Pictures: Woods Hole Research Center, USGS GA Water Science Center, Urban Creeks Council (CA), CDM Milwaukee

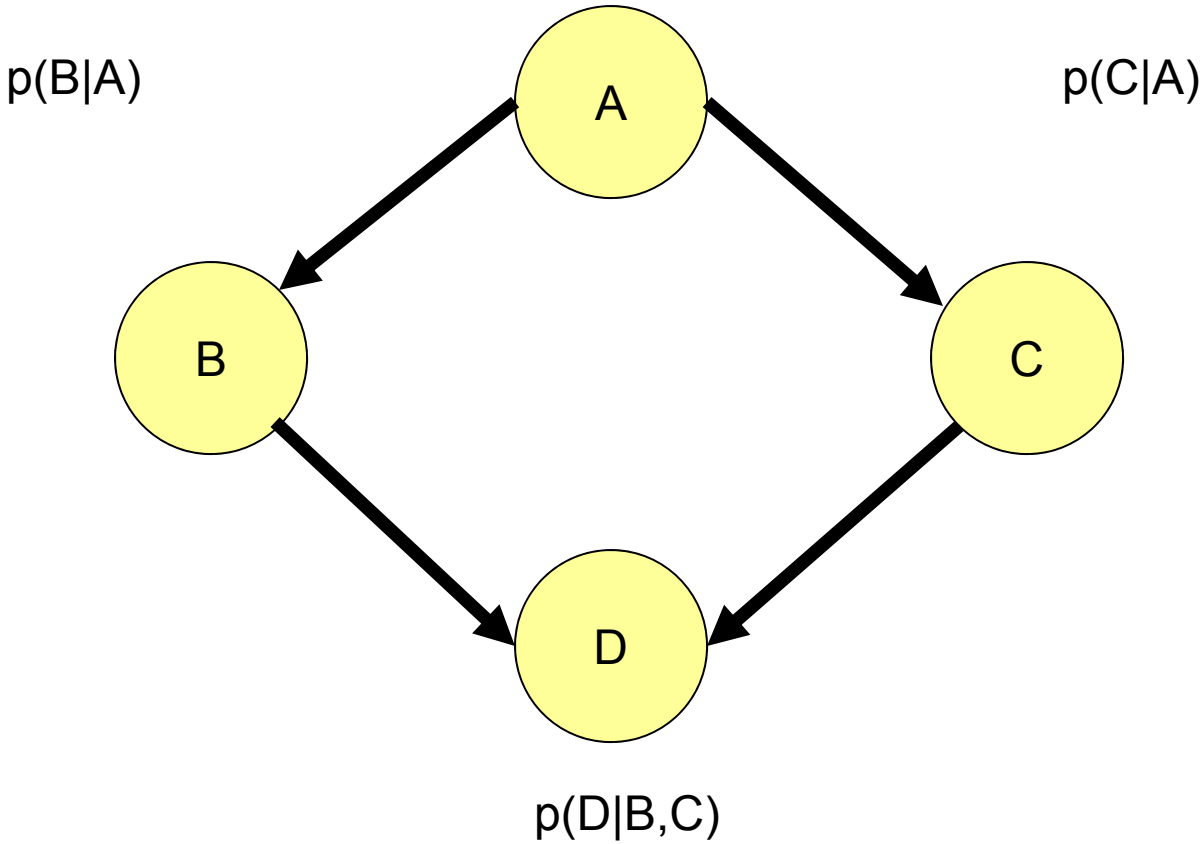
Modeling Dilemmas

- Address influences of **multiple stressors** acting simultaneously
- Incorporate **knowledge** of teams of subject matter experts and **data** into model construction
- Link effects of urbanization to **management endpoint**
- **Rank** management options incorporating science and uncertainty

Solution: Bayesian network

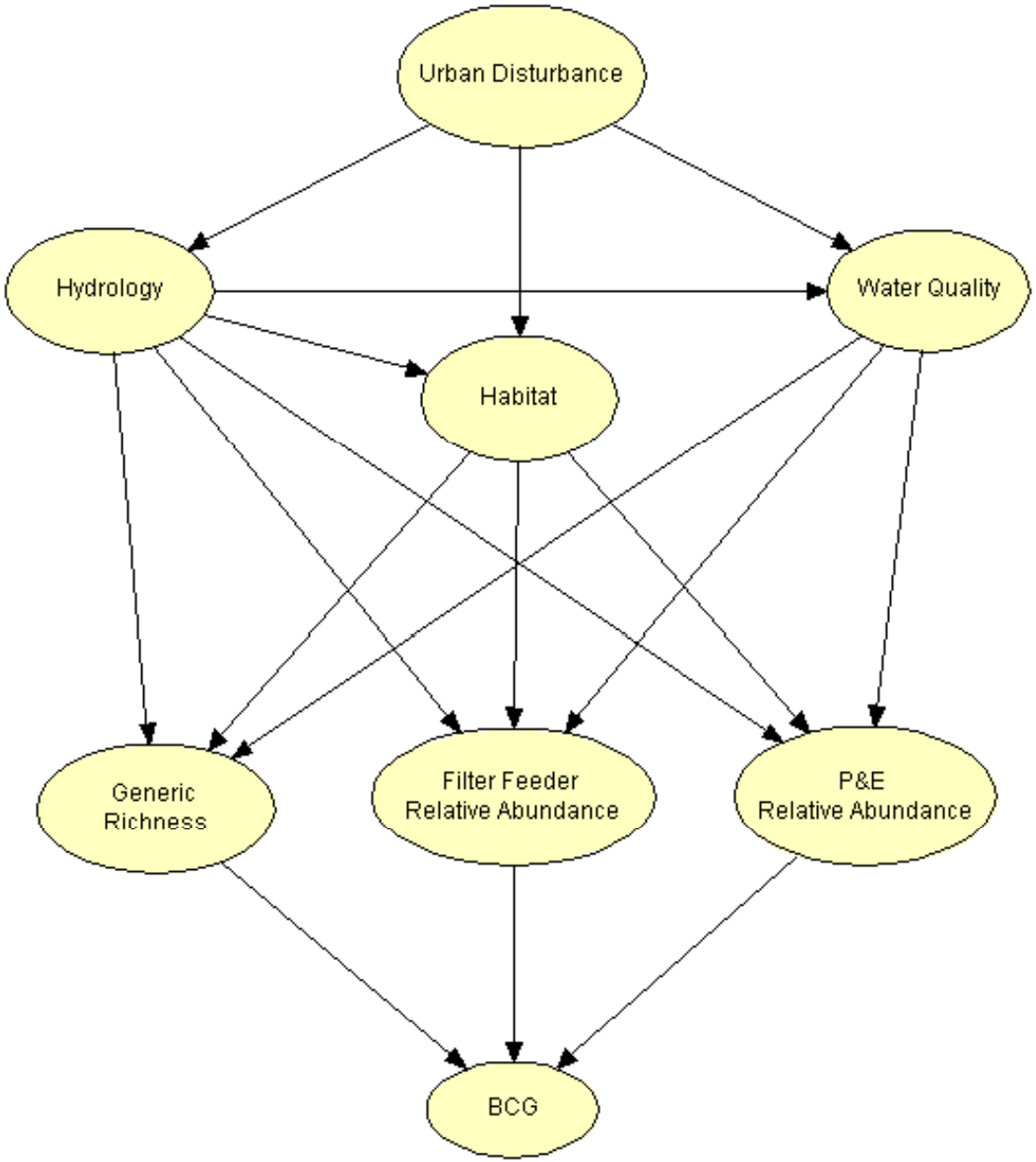
- Model **system** of urbanization affecting biological condition using nodes-and-arrows graphical interface
- Flexible to parameterize; Use Bayes Theorem to combine and appropriately weight expert **knowledge and data** measurements
- Translate BCG framework into quantifiable **management endpoint**
- Run model **evaluation diagnostics** to probabilistically rank management actions

Bayesian network



$$p(A,B,C,D) = p(D|C,B)*p(C|A)*p(B|A)*p(A)$$

Northeast Model Structure



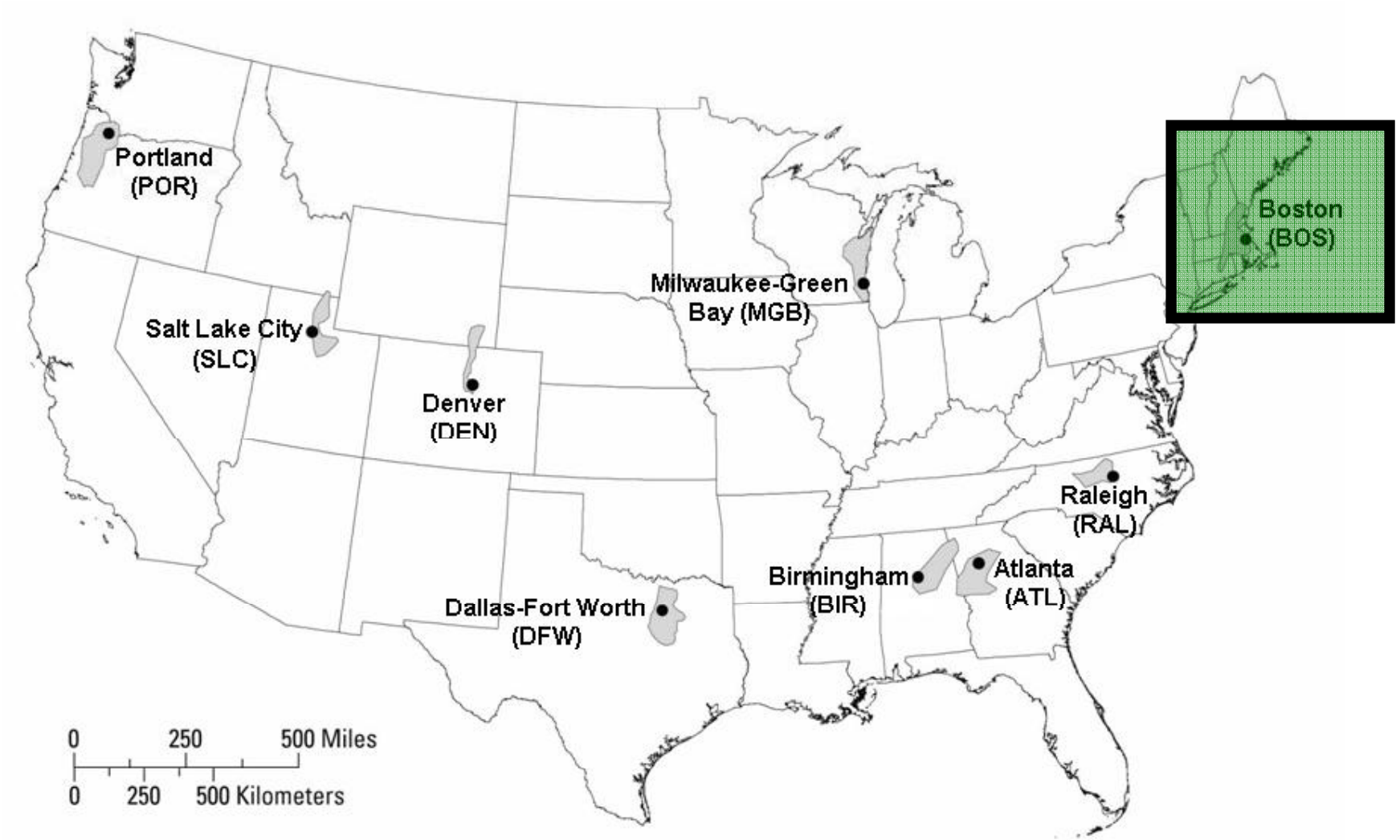
Expert Elicitation

- Develop model structure
  - Describe chain of events that link urbanization to aquatic invertebrate communities
  - Graphically represent using nodes and arrows
- Develop conditional probability tables
  - Quantify relationships between parent and child nodes
  - Quantify uncertainty in those relationships

Experts:

- **Susan Davies**, Maine DEP
- **Dave Courtemanch**, Maine DEP
- **Tom Danielson**, Maine DEP
- **Jeroen Gerritsen**, Tetra Tech Inc.
- **Jim Coles**, USGS
- **Tom Cuffney**, USGS
- **Jerry McMahon**, USGS
- **Paul Sturm**, Center for Watershed Protection
- **Bill Stack**, City of Baltimore, Department of Public Works
- **Kernell G. Ries**, USGS
- **Ronald Bowen**, Anne Arundal County, Department of Public Works
- **Janis Markusic**, Anne Arundal County, Department of Public Works
- **Chris Victoria**, Anne Arundal County, Department of Public Works
- **Joe MacDonald**, American Planning Association
- **Ken Reckhow**, Duke University
- **Song Qian**, Duke University

EUSE: Effect of Urbanization on Stream Ecosystems



USGS
science for a changing world

Bayes Theorem

expert prior

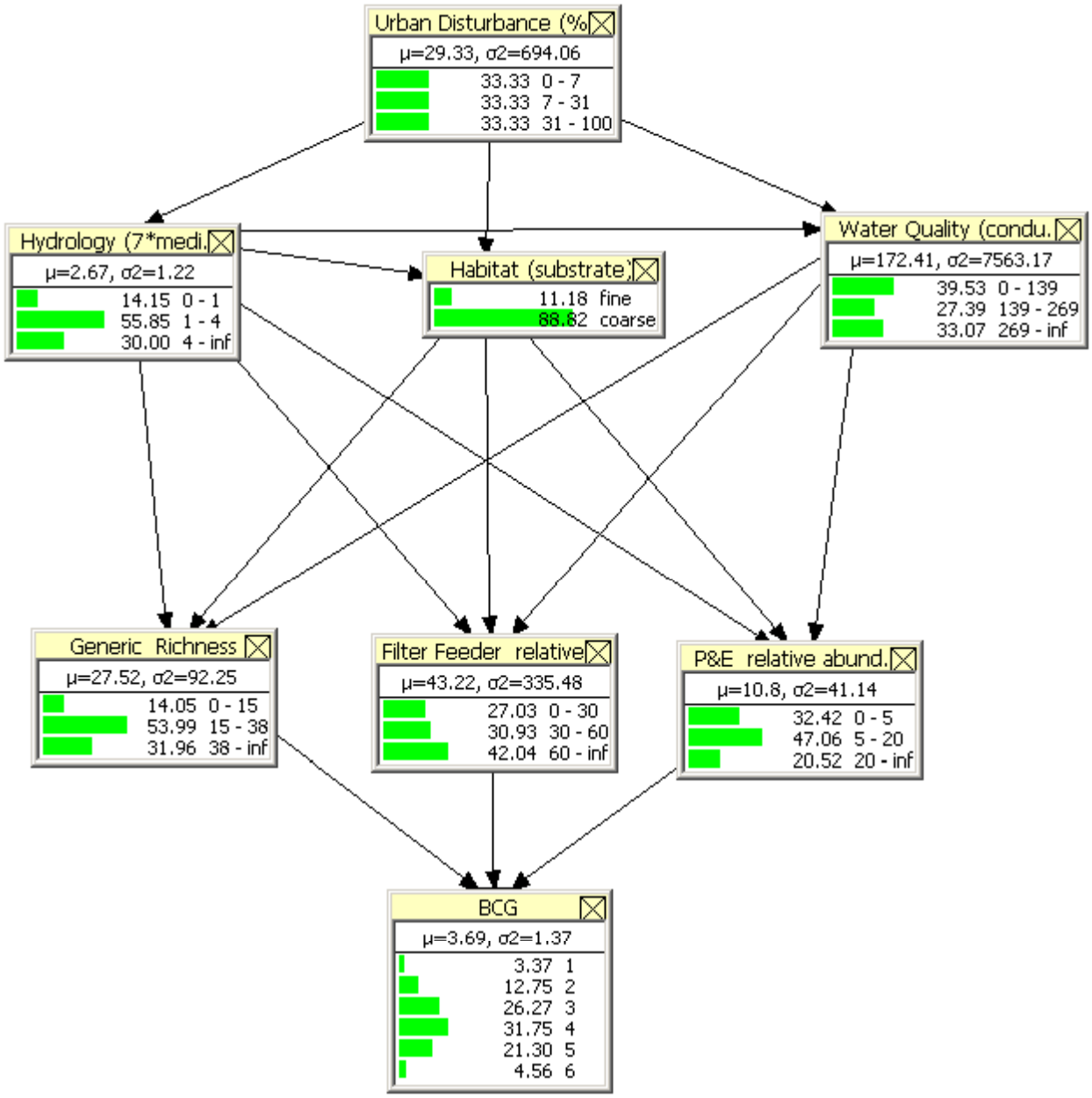
measured data

$$p(\theta|x) \propto p(\theta)p(x|\theta)$$

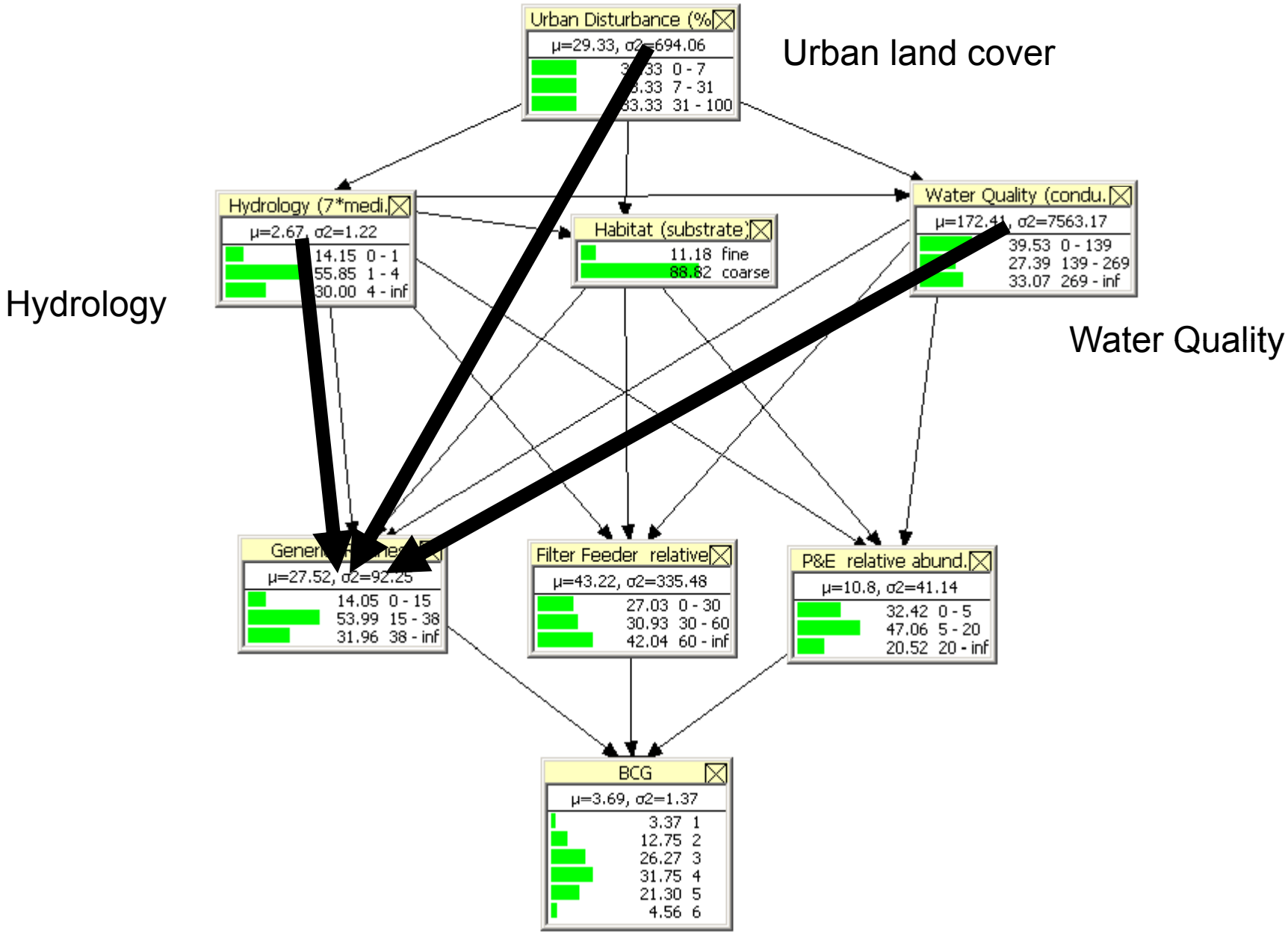
posterior

[Θ is parameter; x is data]

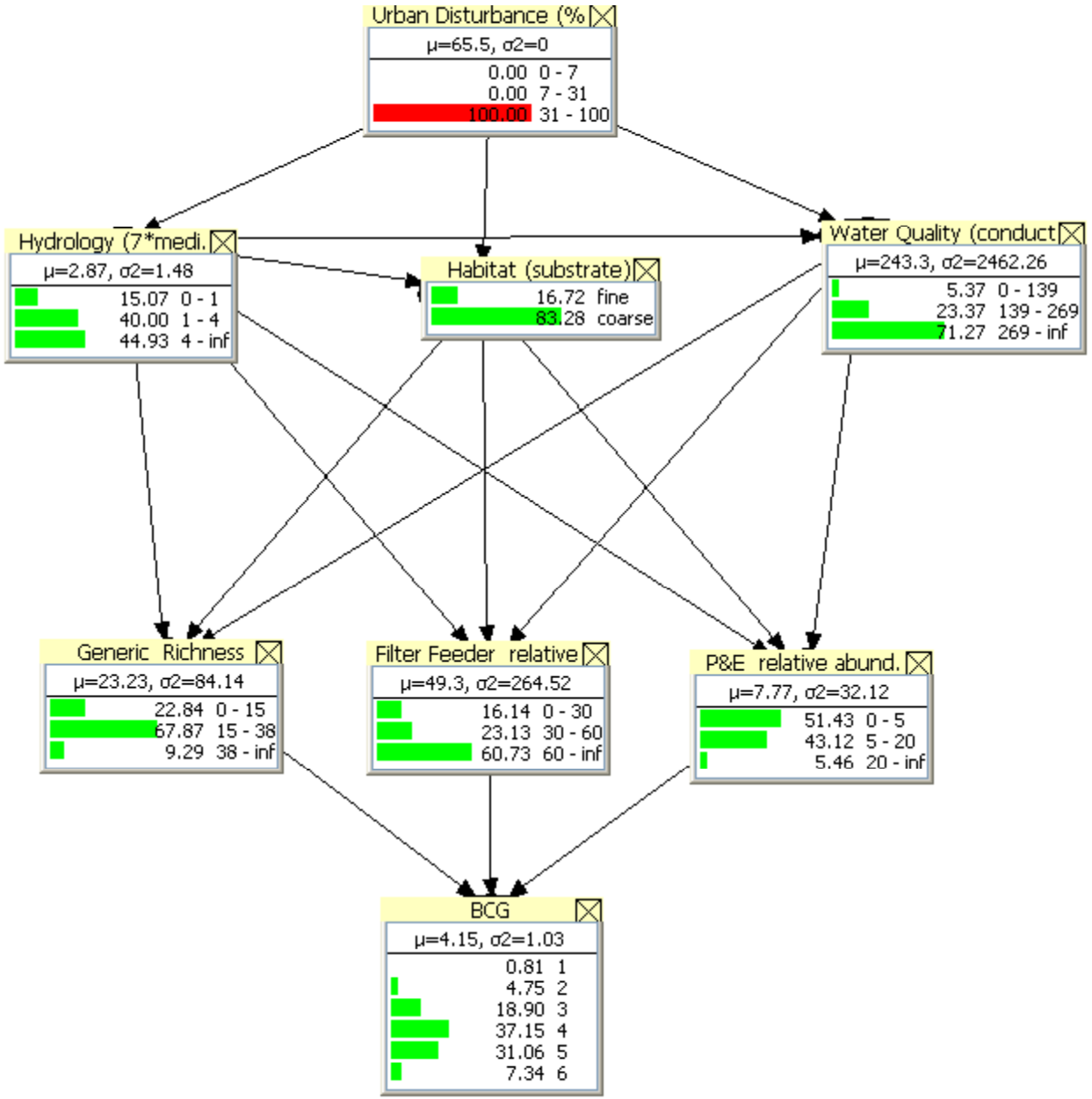
Northeast Posterior Model



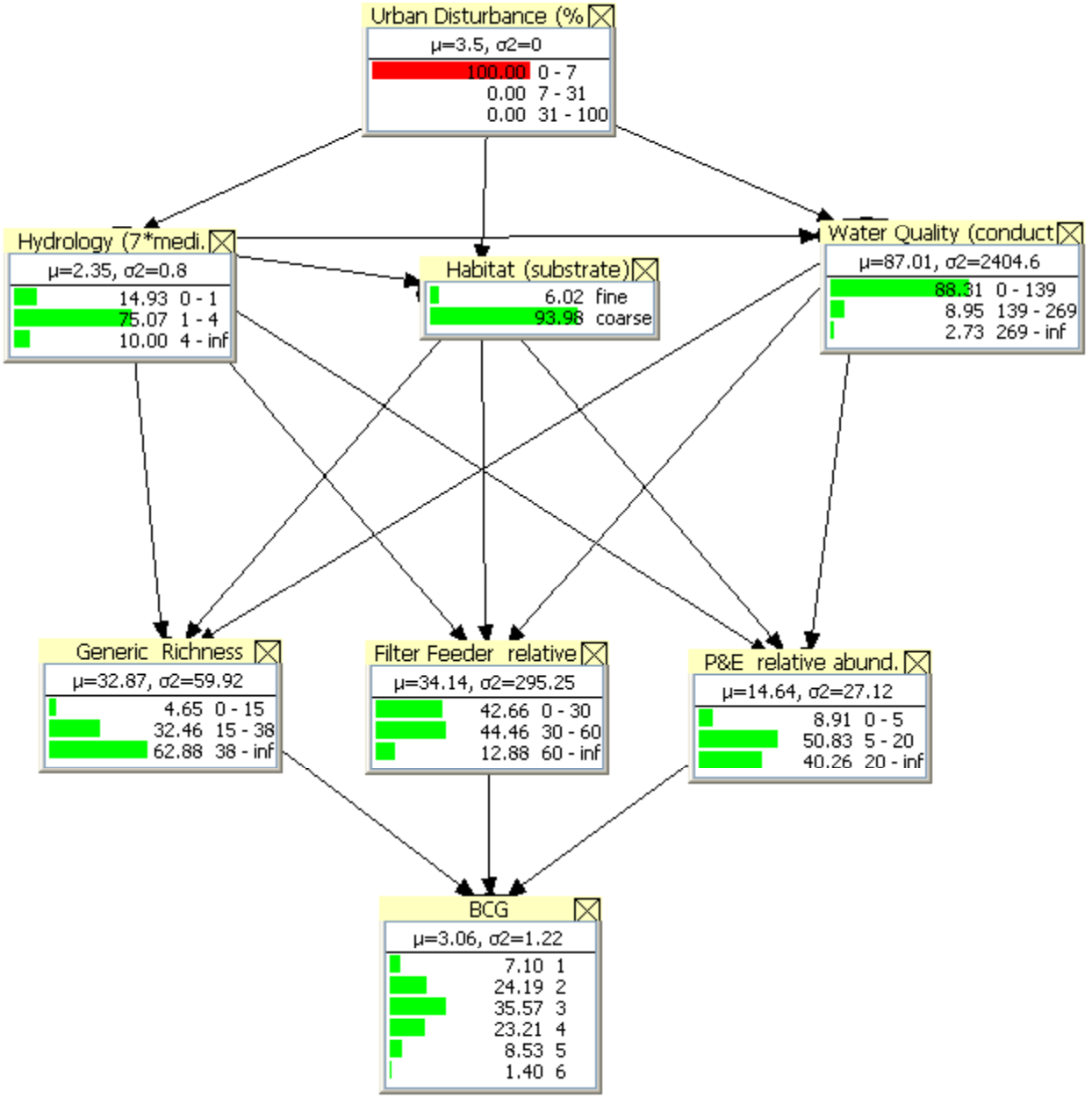
Bayesian network benefits



Posterior predictive: high urban



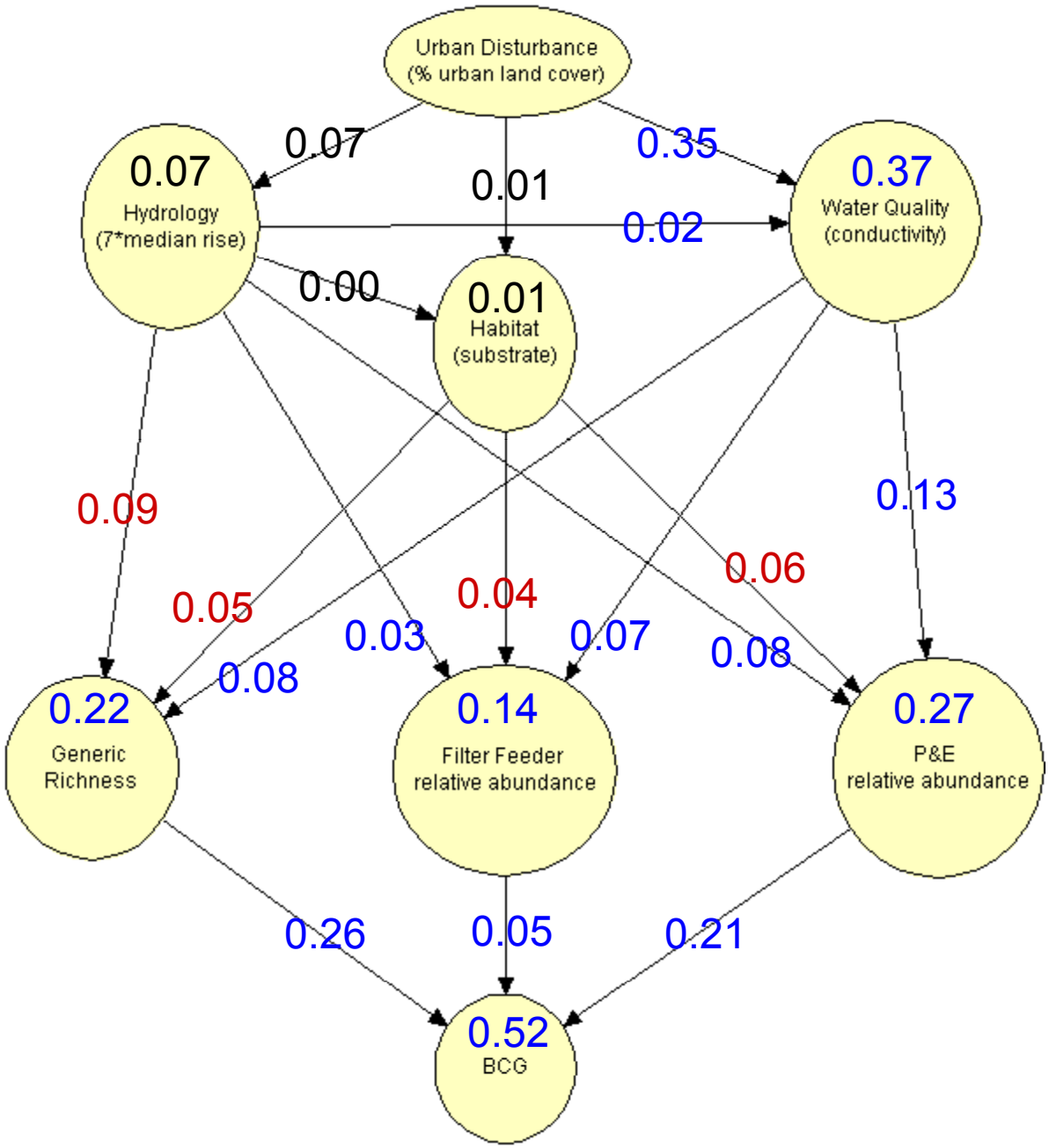
Posterior predictive: low urban



Comparing prior to data: mutual information

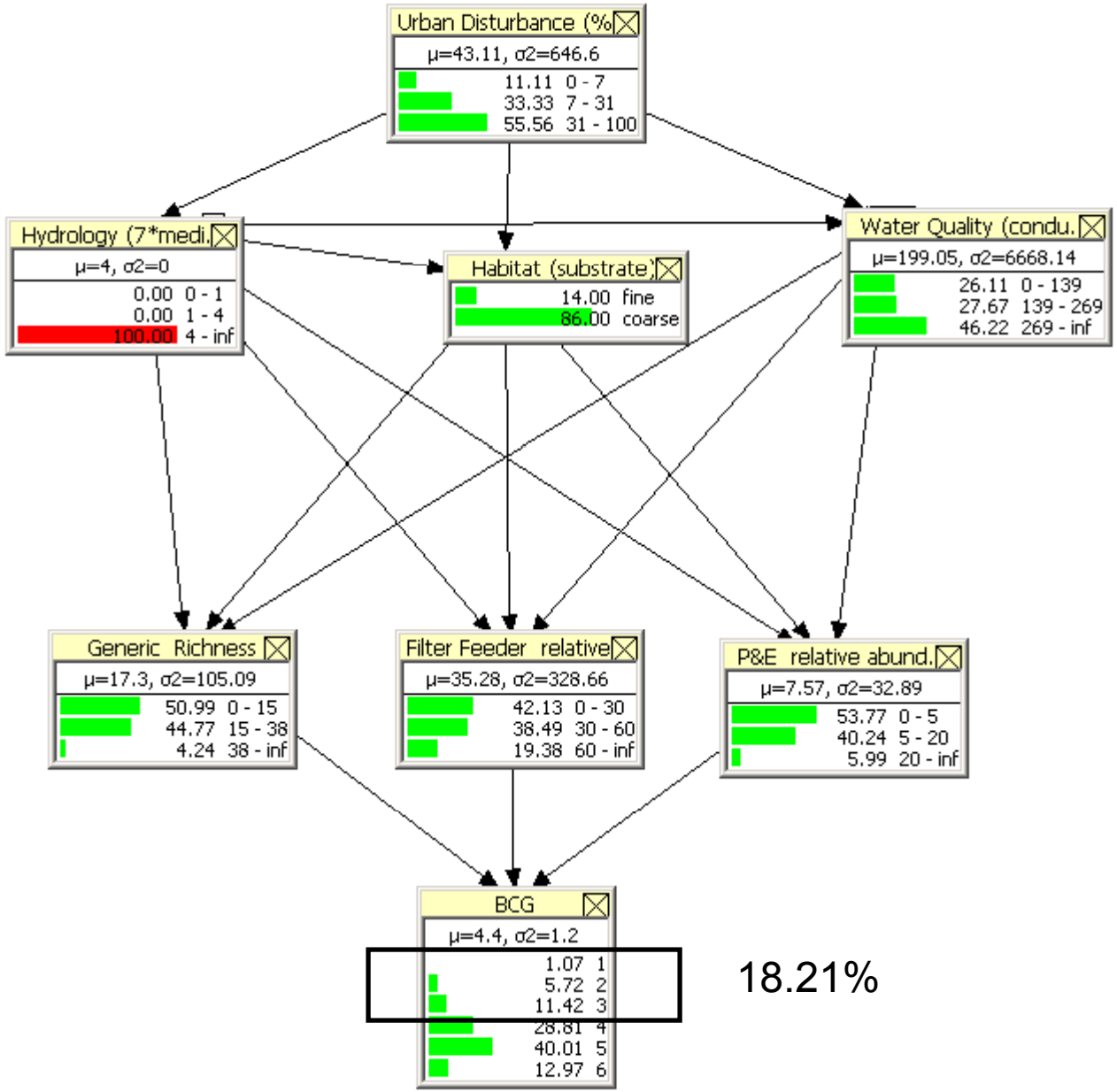
More mutual dependence in:

- prior
- data
- same



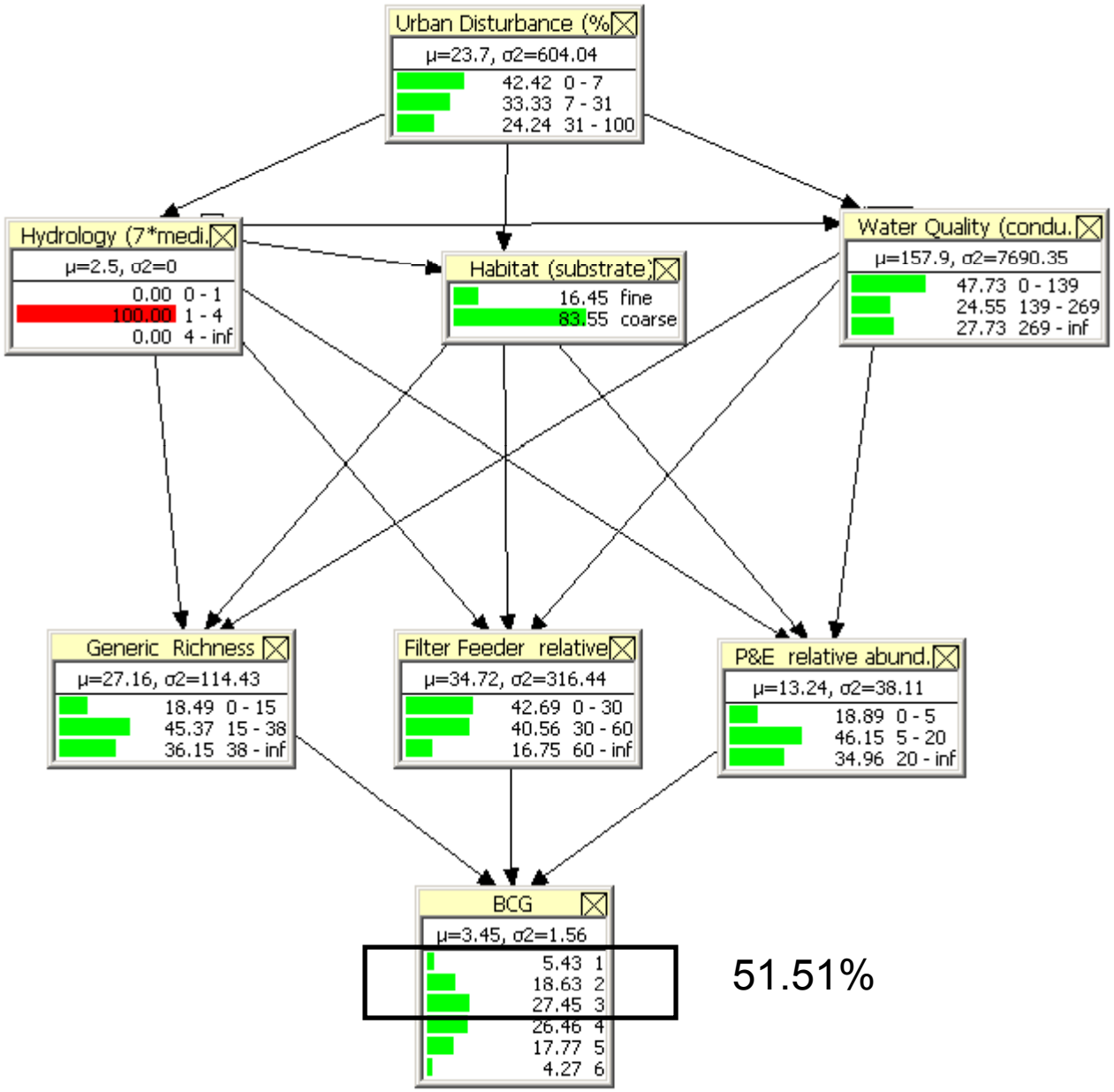
PRIOR MI

Sensitivity Analysis: Decreasing flashiness from high….



18.21%

… to medium,



51.51%

…increases likelihood of BCG Tier 3 or better from 18% to 52%.

	Possible stream condition improvements increases likelihood of achieving BCG Tiers by:		
	Flashiness high to medium	Substrate fine to coarse	Conductivity high to medium
BCG Tier 1	1.07% → 5.43% Δ = 4.36%	0.83% → 4.33% Δ = 3.50%	0.65% → 2.87% Δ = 2.22%
BCG Tier >2 (i.e., 1 & 2)	6.79% → 24.06% Δ = 17.27%	5.56% → 19.57% Δ = 14.01%	4.57% → 13.95% Δ = 9.38%
BCG Tier >3 (i.e., 1, 2, & 3)	18.21% → 51.51% **Δ = 33.30%**	14.06% → 45.00% Δ = 30.94%	16.63% → 37.03% Δ = 20.40%

Decreasing flashiness one bin has greater effect on BCG Tier attainment likelihood than managing substrate or conductivity

-Can also evaluate and compare joint management actions or find the driver combination that results in the best BCG (diagnostic probabilities)

Northeast Bayesian Network Model

Conclusions:

- Can use this model to rank likelihood of attaining desired management endpoint given different management actions (in this case, managing flashiness more likely to improve BCG than managing substrate or conductivity)

- Model supports EUSE urbanization regression work but does so in more integrated, comprehensive framework

- Shows BCG can be modeled from small set of invert metrics, in terms of probability of attaining each BCG Tier

- Major contributions to literature: (1) Parameterization of BCG relative to urban stressors and (2) Introduce new framework for urbanization management modeling

Northeast Bayesian Network Model

Benefits of new framework:

- Increase conceptualization of environmental and ecological processes (network of relationships between variables)
- Able to analyze entire system together (acknowledge that biological response driven by many factors)
- Interactive end product; easy for users to understand without necessarily being bogged down with complex mathematics
- Flexible modeling construct; can incorporate a variety of possible management actions and predict effects probabilistically
- Enormous potential for use in environmental management decision making


Thank you!
Questions?
U.S. Department of the Interior
U.S. Geological Survey