

The use of the relative risk model and Bayesian networks for the calculation of risk for the South River, VA

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Risk assessment team

Mariana Cains and Wayne Landis-Relative Risk Model (RRM)

Dr. Kim Ayre and Heather Summers-Bayesian Networks

Jonah Stinson-GIS including data analysis for RRM and Bayesian Network assessments

April Markiewicz-Management support

Goals of the risk assessment program

Perform a multiple stressor multiple endpoint ecological risk assessment for the South River region.

Create an assessment framework to calculate risk and to run scenarios to assist the planning of restoration efforts for the region.

Note: The risk calculations are preliminary.

This presentation

About the site

A very brief introduction to the relative risk model and Bayesian networks.

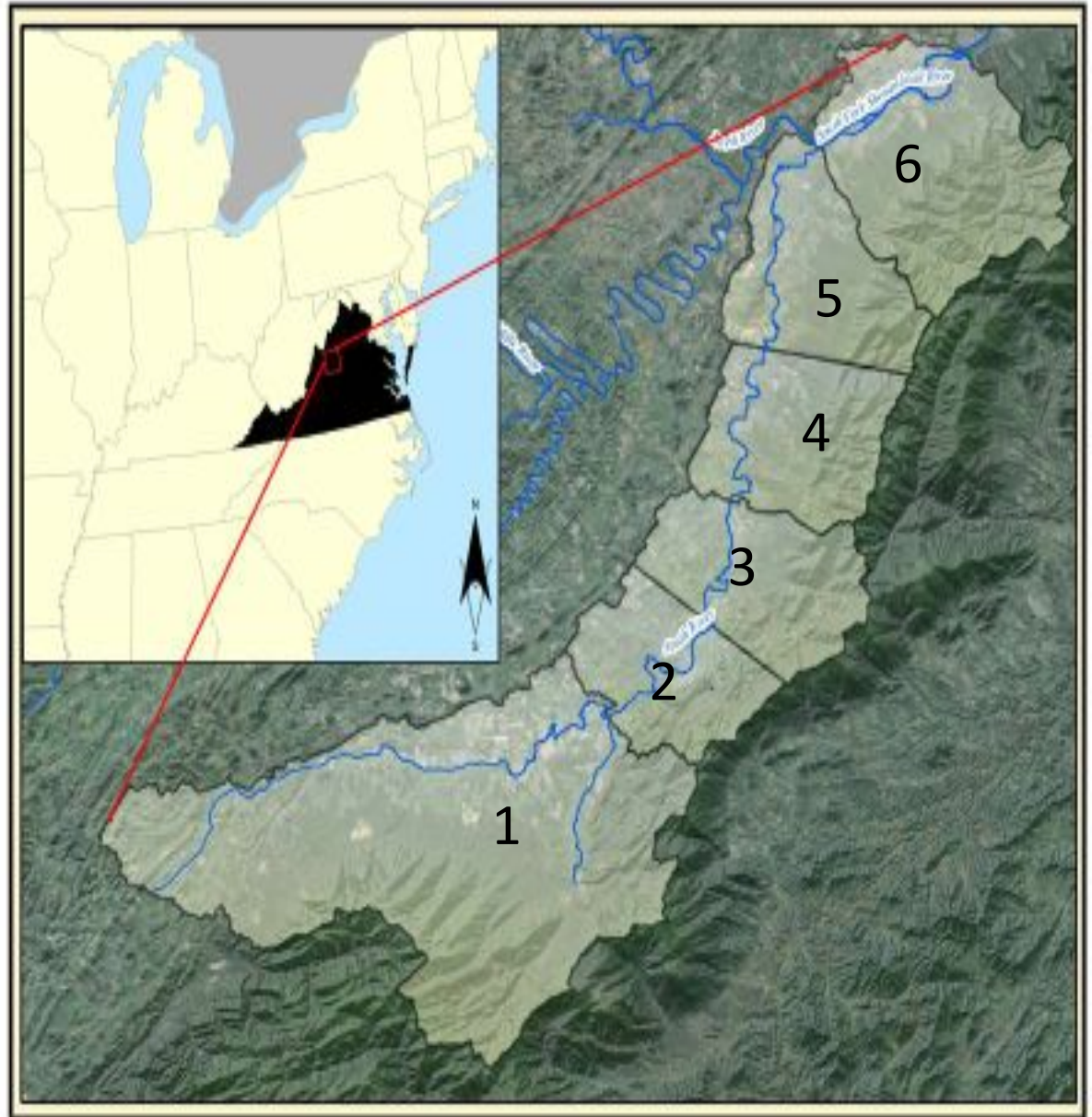
Patterns of risk in the South River

Lessons learned

Expert Solicitation

The site

Six areas designated as risk regions from upstream to include the south fork of the Shenandoah River.

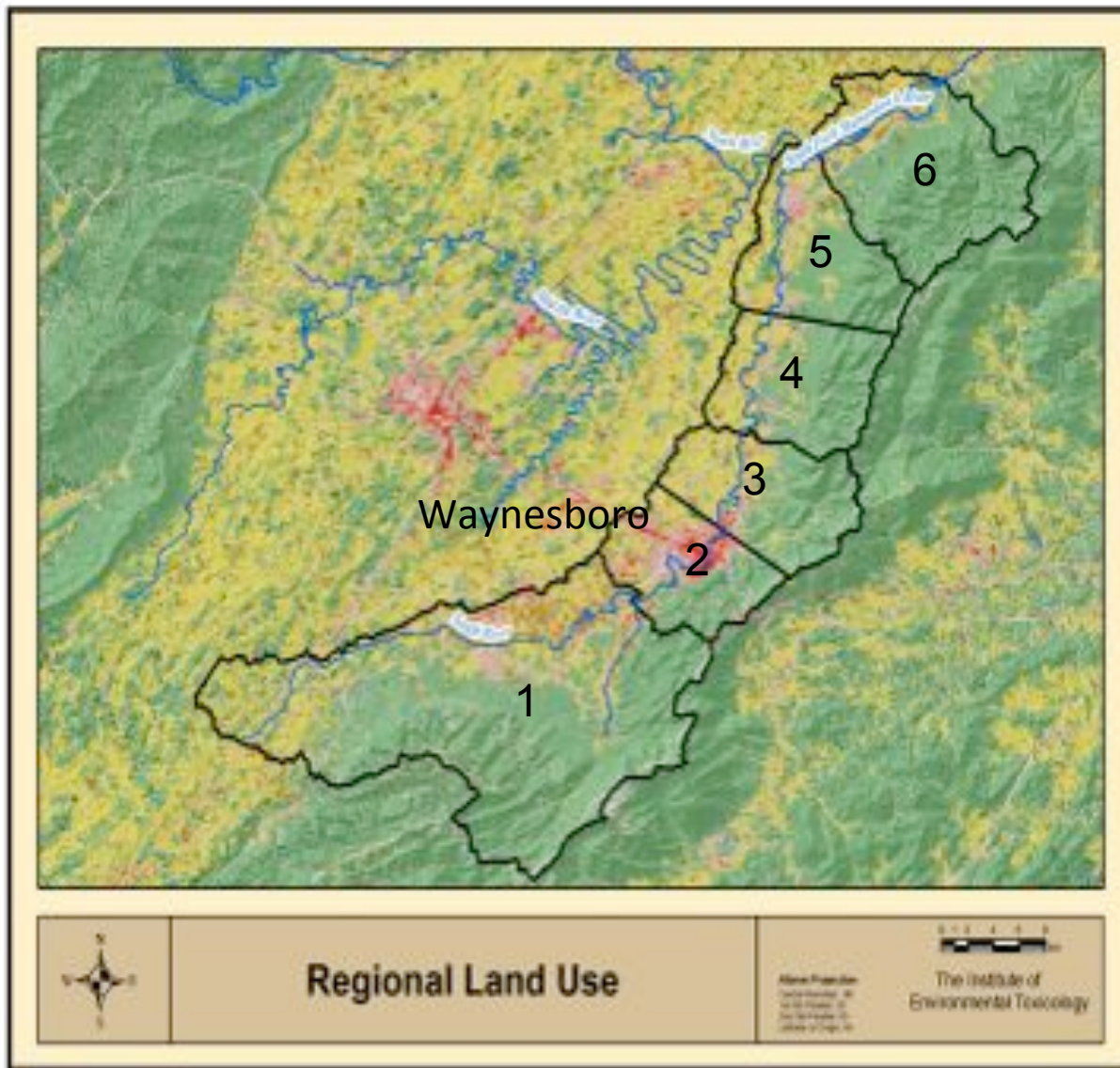


Diverse Landscape with Multiple Uses and Sources



Lots of sources of contaminants and disturbances to be taken into account.

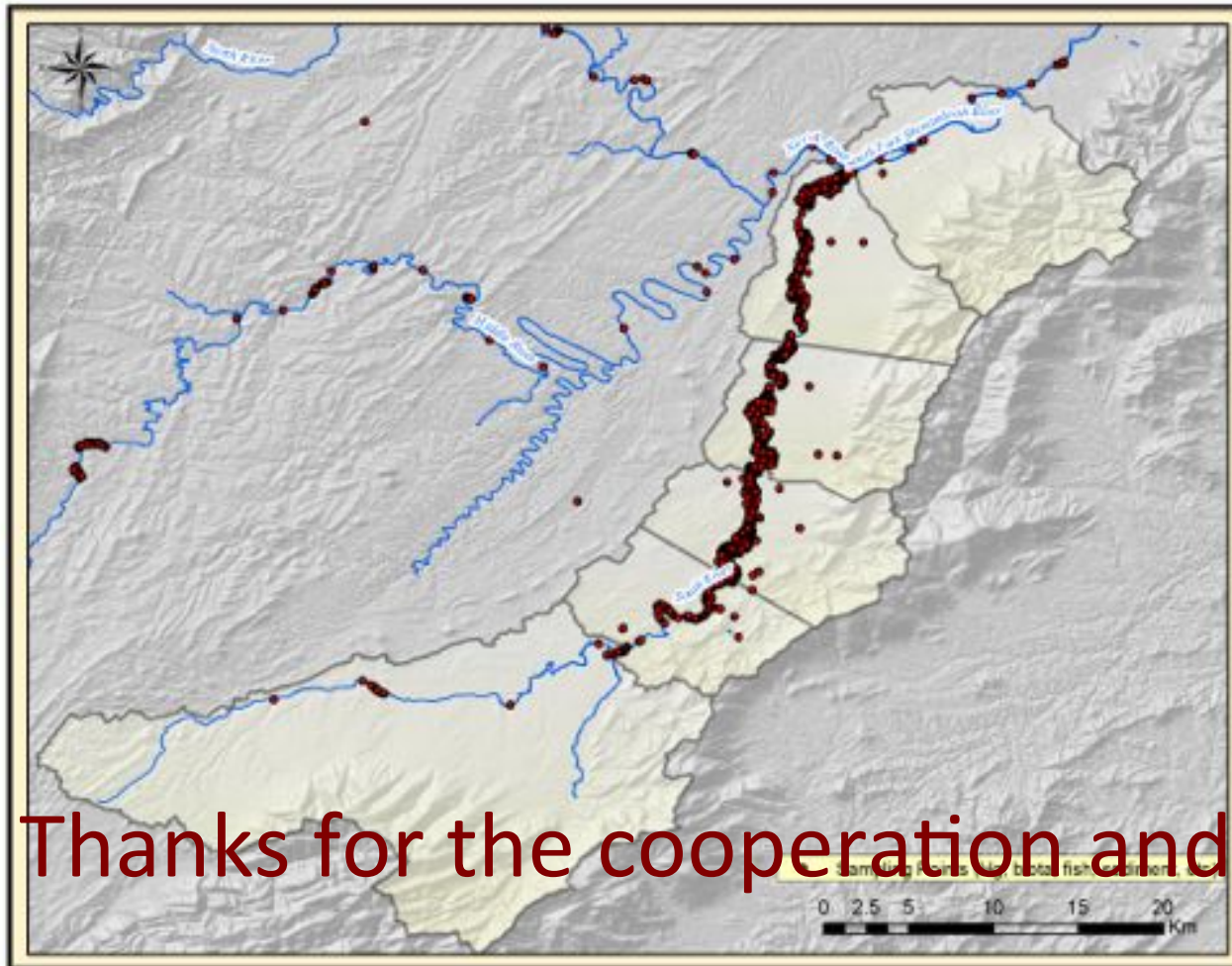
Study Area, Land Use and the Risk Regions



Legend

- Open Water
- Perennial Ice/Snow
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land (Rock/Sand/Clay)
- Unconsolidated Shore
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Dwarf Scrub
- Shrub/Scrub
- Grasslands/Herbaceous
- Sedge/Herbaceous
- Lichens
- Moss
- Pasture/Hay
- Cultivated Crops
- Woody Wetlands
- Palustrine Forested Wetland
- Palustrine Scrub/Shrub Wetland
- Estuarine Forested Wetland
- Estuarine Scrub/Shrub Wetland
- Emergent Herbaceous Wetlands
- Palustrine Emergent Wetland (Persistent)
- Estuarine Emergent Wetland
- Palustrine Aquatic Bed
- Estuarine Aquatic Bed

Data collected by the SRST along the channels



Data from the
South River
Science Team
[http://
www.southriver
scienceteam.org
/](http://www.southriverscienceteam.org/)

Thanks for the cooperation and collaboration!

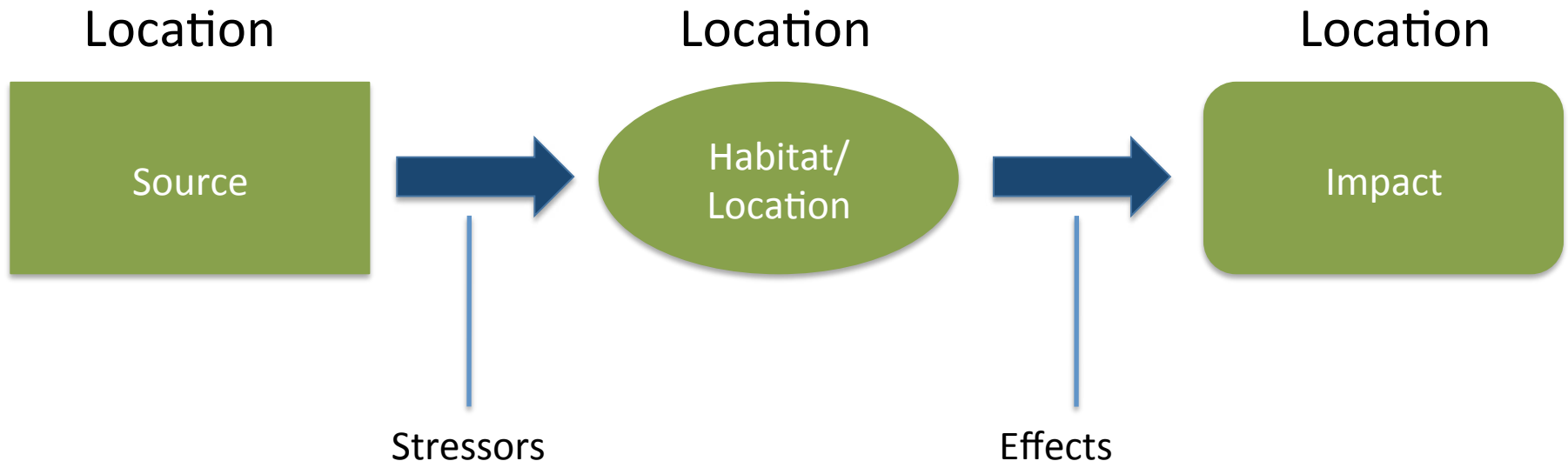
How we calculate risk, the relative risk model and Bayesian networks.

Short introduction, the RRM method can be found at Landis and Weigers 2004, Colnar and Landis 2007

The RRM and the use of Bayesian networks can be found in Ayre and Landis in press, preprint download at www.wvu.edu/toxicology

Relative Risk Model-the basics

Ranks are still used to examine multiple stressors at multiple habitats with a number of effects.



Relative risk model-Latin hypercube Monte Carlo, 10,000 iterations

**Rank
Sources
(0,2,4,6)**

**Rank
Habitats
(0,2,4,6)**

**Exposure
and
Effects
Filter
(0,0.5,1)**

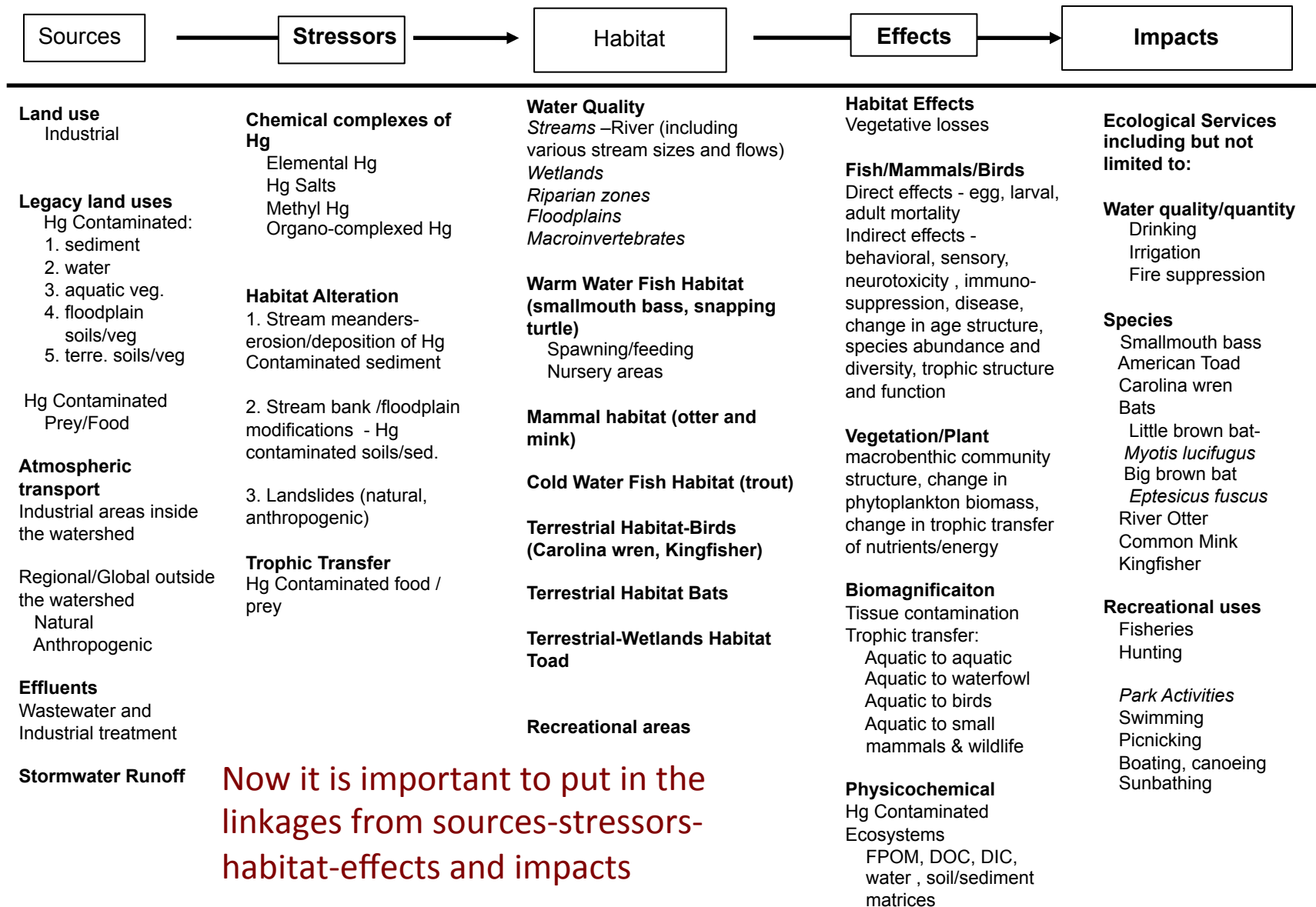
*Relative Risk
of
Effects*

Spatially explicit,
ranks determined
by clustering,
exposure-
response,
professional
judgment.

Exposure and
Effects for the
components of
the ecological
system valued by
the stakeholders

Generation of testable
predictions about
relative probabilities of
effects. Sensitivity
and uncertainty
analysis.

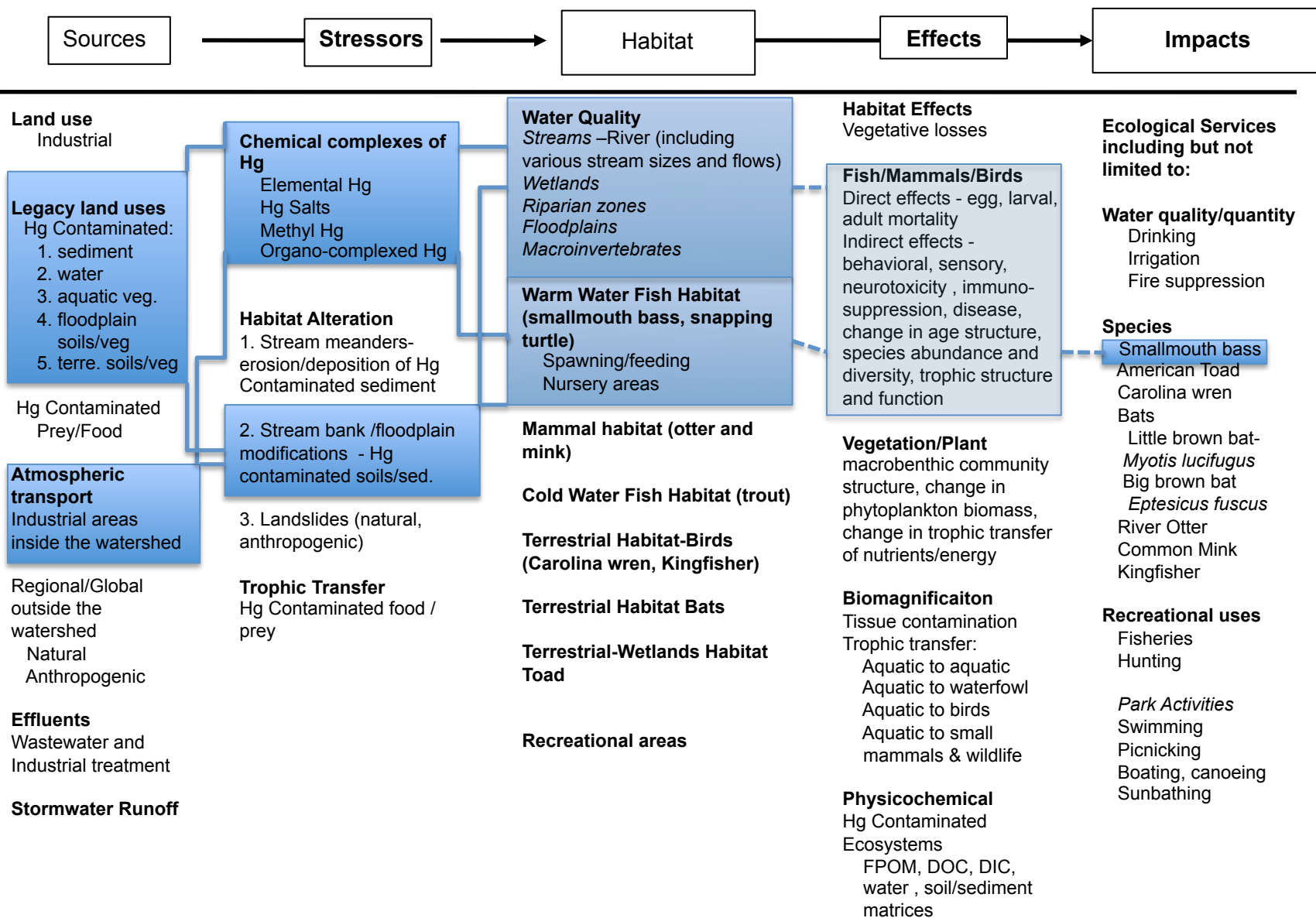
Hg Conceptual Model South River and South Fork of the Shenandoah River



Now it is important to put in the linkages from sources-stressors-habitat-effects and impacts

August 2011 South River and South Fork of the Shenandoah River Conceptual Model

Mercury: Sediment/Water and Smallmouth Bass



Notes on the setting of pathways and ranks-1

Notes:

- Pathways supported by USGS 2009 Report: Mercury Loads in the South River and Simulation of Mercury Total Maximum Daily Loads (TMDLs) for the South River, South Fork Shenandoah River, and Shenandoah River: Shenandoah Valley, Virginia
- Dillion, T., Beckvar, N., and Kern, J. (2010). Residue-based Mercury Dose-Response in Fish: An Analysis Using Lethality-Equivalent Test Endpoints. Environmental Toxicology and Chemistry. 29 (11): 2559-2565.
- Pathway “Sources to Stressors”:
 - Mercury associated with sediment accounts for 96% of annual downstream mercury load at the mouth of the South River (pdf page 15, report page 1).
 - Modeling of atmospheric deposition of the study area calculates 12.1 kg/y with 11% of atmospheric mercury upstream of Waynesboro reaching the river (pdf page 32, report page 18).
 - 84% of the mercury loading to the river downstream of the plant site is from channel margin inputs (pdf page 74, report page 60).

Notes on the setting of pathways and ranks-2

Notes:

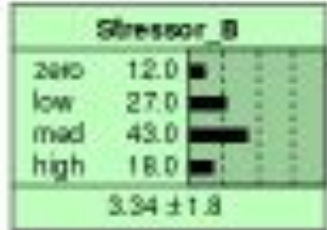
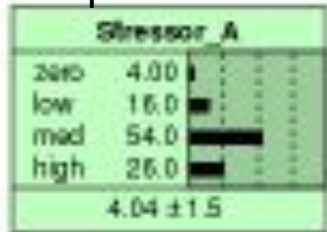
- Pathway “Stressors to Habitats”:
 - Mercury found in the surface water, groundwater, and in the floodplain with increasing concentrations downstream of Waynesboro monitoring station (pdf page 26, report page 10-12).
 - Suspended sediment concentration, turbidity, and mercury concentrations were the final data used as it provided the strongest correlation between total mercury and fish tissue methylmercury (pdf page 21-22, report page 7-8).
 - Downstream of the plant site fish tissue mercury concentration in SMB above 0.3 mg/kg.
- Pathway “Habitat to Effects”:
 - Bioaccumulation of mercury was expressed with exponential relation between aqueous total mercury and methylmercury in SMB (pdf page 15, report page 1).
 - Whole body residue-based mercury dose-response curve for lethality equivalent endpoints:
 - Mortality, severe developmental abnormalities, failure of fry to hatch, and failure of adult fish to spawn (Dillion *et al.*, 2010) *note: not site or species specific.*
- UNCERTAINTY: Confident with robust data set

Risk Assessment using Bayesian Networks

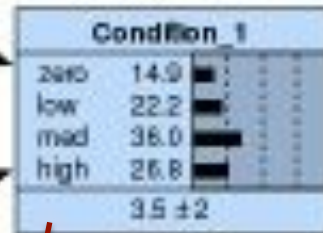
- Structure of Conceptual Model lends itself to using Bayesian Networks
- Bayesian Networks use conditional probabilities – based on the available data, models or expert opinion
- Explicit about uncertainties

Bayesian Network Model Construction

Input Nodes



Child Node

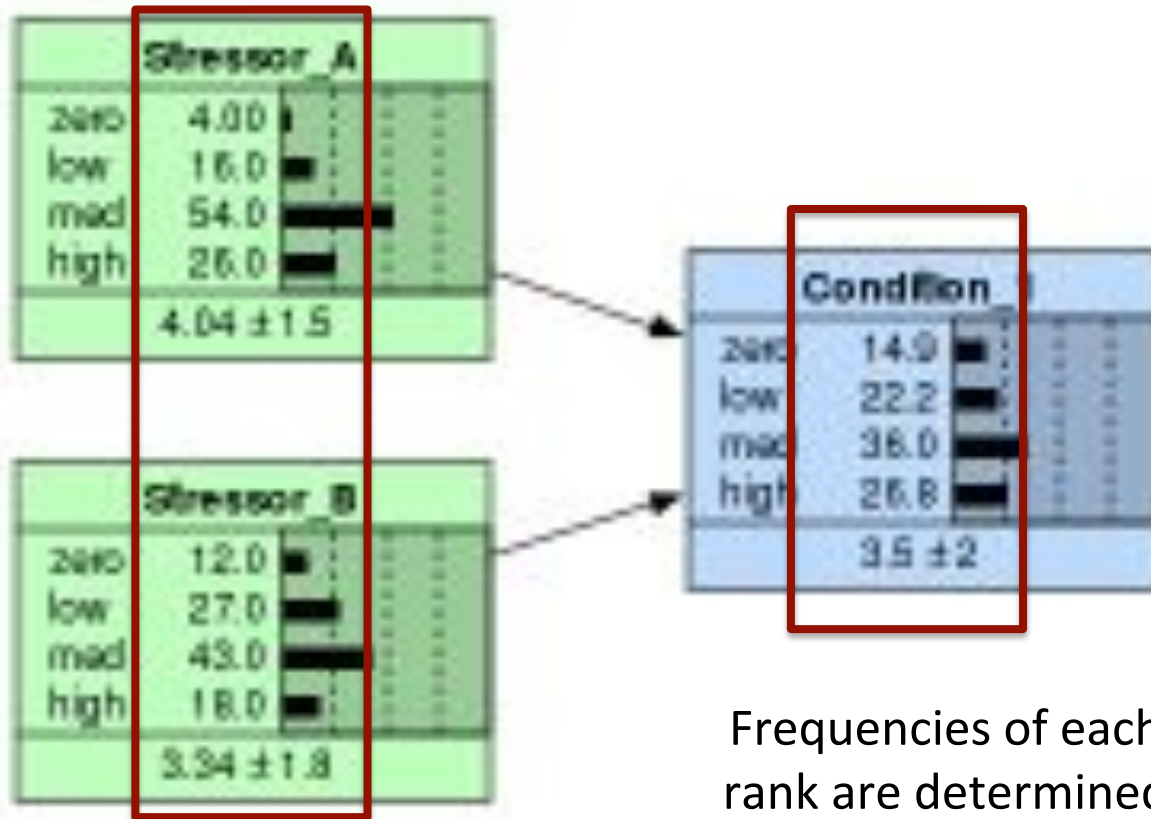


1. Each node (parameter) has 4 potential states or ranks
2. Define the ranks for each input node
3. Determine the probability distributions for each input node from available data
4. Develop conditional probability tables (CPTs) that define the relationship between input and child nodes

Stressor_A	Stressor_B	zero	low	med	high
zero	zero	100.000	0.000	0.000	0.000
zero	low	90.000	8.000	1.500	0.500
zero	med	75.000	20.000	4.000	1.000
zero	high	60.000	25.000	10.000	5.000
low	zero	75.000	20.000	4.000	1.000
low	low	50.000	35.000	10.000	5.000
low	med	25.000	35.000	30.000	10.000
low	high	10.000	30.000	45.000	15.000
med	zero	25.000	35.000	30.000	10.000
med	low	10.000	30.000	45.000	15.000
med	med	5.000	25.000	50.000	20.000
med	high	1.000	9.000	40.000	50.000
high	zero	15.000	25.000	40.000	20.000
high	low	10.000	15.000	35.000	40.000
high	med	5.000	10.000	30.000	55.000
high	high	1.000	4.000	20.000	75.000

Conditional Probability Table

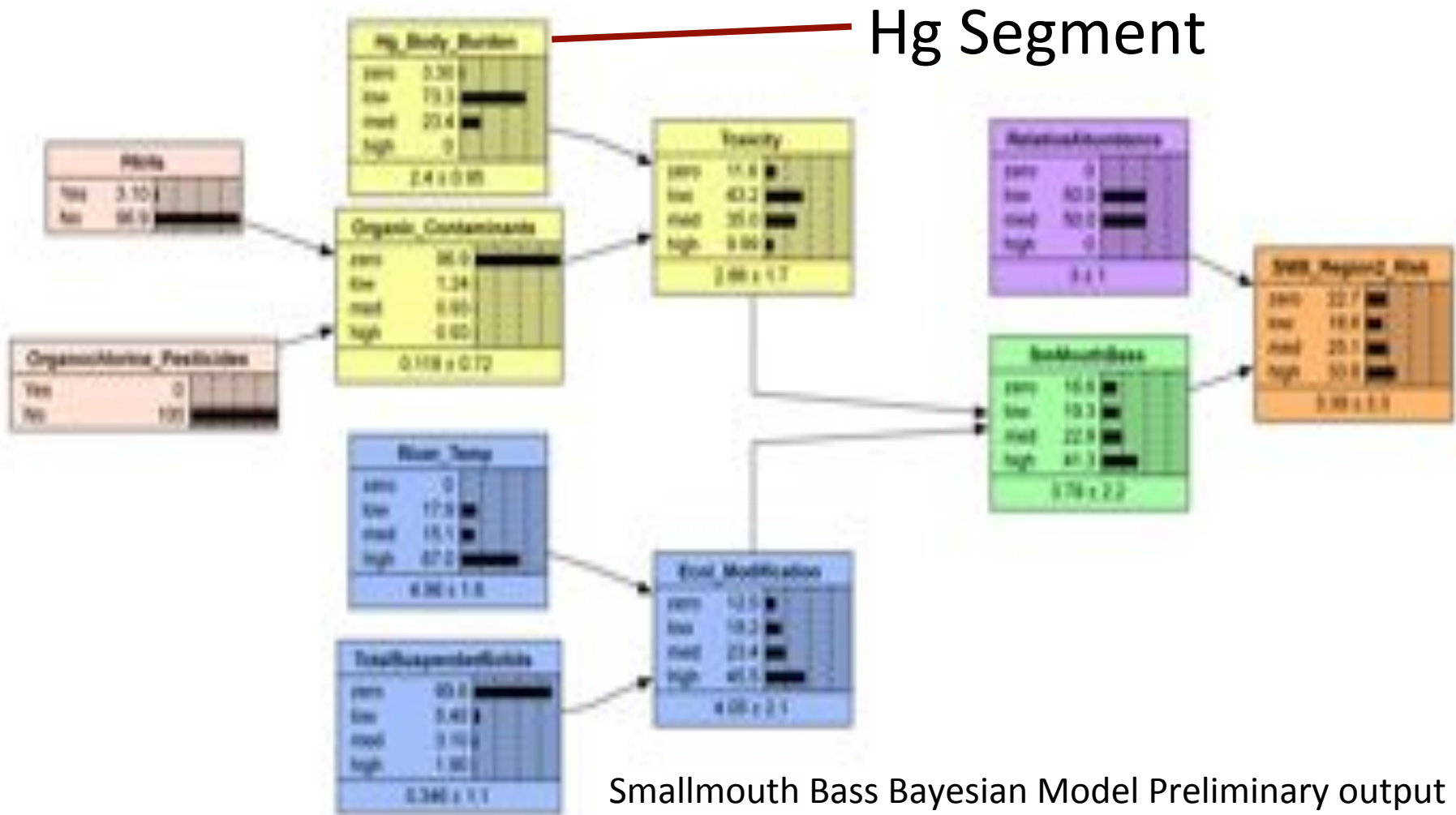
Bayesian Network Model Construction



Frequency and ranks
are determined by
Data

Frequencies of each
rank are determined
by the CPT

Step 1. Development the cause effect relationships for the Bayesian Network. Derived from the conceptual models



Smallmouth Bass Bayesian Model Preliminary output
(Risk Region 2)

Step 2. Defining Ranks

Toxicological Parameters

Variable	Description	Rank	Justification/Evidence
PAHs	Relative frequencies of sediment [PAH] with reference to NOAA Screening Quick Reference Tables (SQuiRTs) for Organics in Water and Sediment	Yes: exceeded the LEL No: lower than the LEL	Comparison with the NOAA's Low Effects Limit (LEL) Screening Reference Value
Organic Pesticides	Relative frequencies of water [pesticide] with reference to NOAA SQiRTs (mostly derived from EPA water quality criteria)	Yes: exceeded the Chronic Level No: lower than the Chronic Level	Comparison with the NOAA's Chronic Toxicological Effects Level
Mercury Body Burden	Methylmercury body burden indicative of internal mercury exposure derived from Dillion et. al, 2010.	Zero: 0.2 mg/kg Low: 0.3 - 1 mg/kg Med: 1.1 - 3.0 mg/kg High: 3.1 - 10 mg/kg	< 5% lethality or equivalent endpoints 5 - 24% lethality or equivalent endpoints 24 - 50% lethality or equivalent endpoints > 50% lethality or equivalent endpoints

Step 2. Defining Ranks

Ecological Parameters

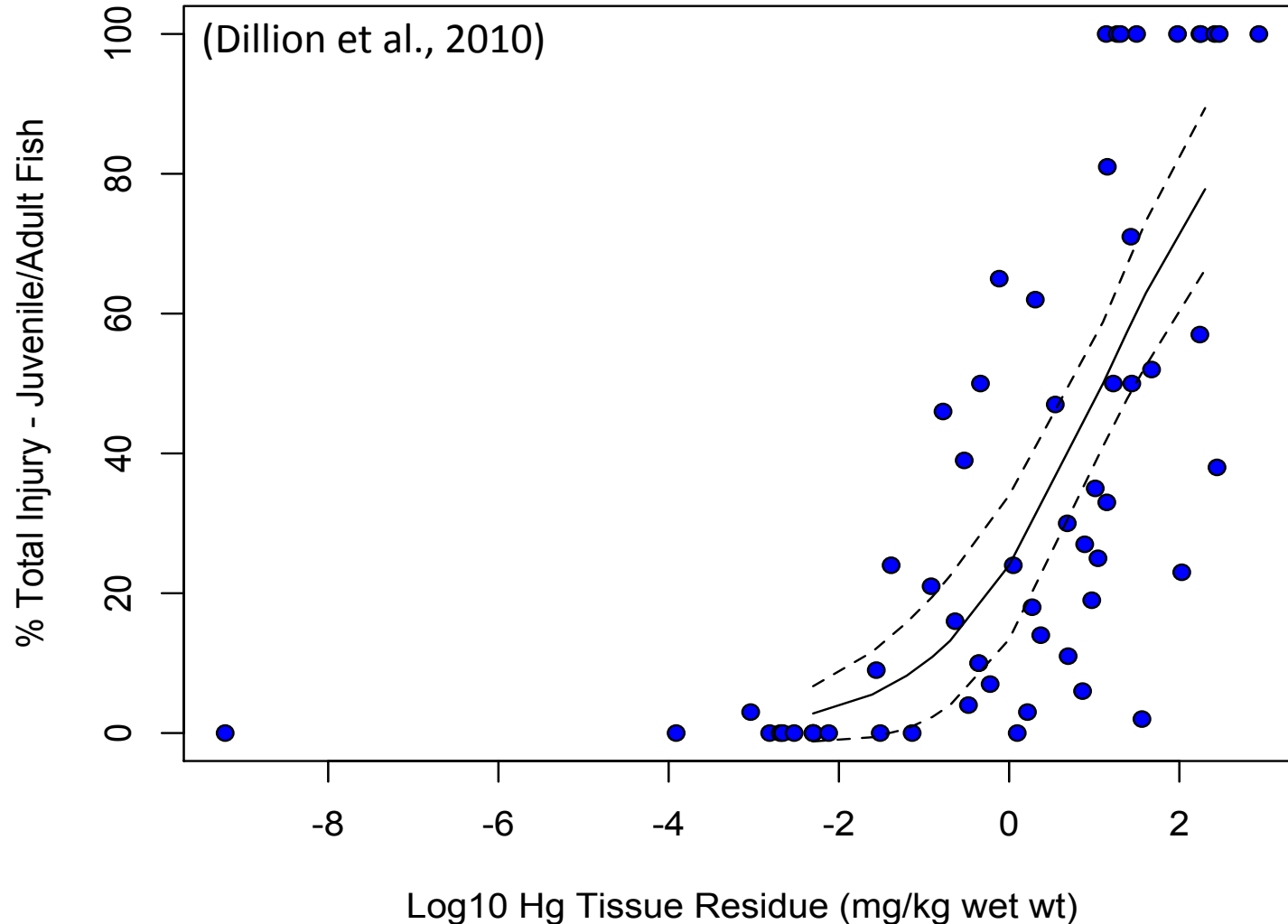
Variable	Description	Rank	Justification/Evidence
River Temperature	Relative frequencies of water temperature data from 2006 for each rank	Zero: 22-26 °C	Optimum temperature for juvenile growth & fry survival, and preferred habitat temp range
		Low: 19-21.9 or 26.1-29 °C	Growth rate reduction for juvenile fish
		Med: 16-18.9 or 29.1-31.9 °C	Estimated 30-50% growth rate reduction
		High: ≤ 15.9 or ≥ 32 °C	Upper limit for growth = 27°; no spawning or egg/fry survival
Total Suspended Solids	Relative frequencies of TSS measured in 2006 for each rank	Zero: < 25 mg/L	Preferential habitats ≤ 25
		Low: 25-80 mg/L	Prey consumption decreases above 20
		Med: 80-200 mg/L	Avoidance behavior; & coughing common in adult trout; trout egg mortality; growth retardation & reproductive impacts in largemouth bass
		High: > 200 mg/L	Onset of gill tissue damage in adult trout (no information on smallmouth bass)

Step 2. Defining Ranks

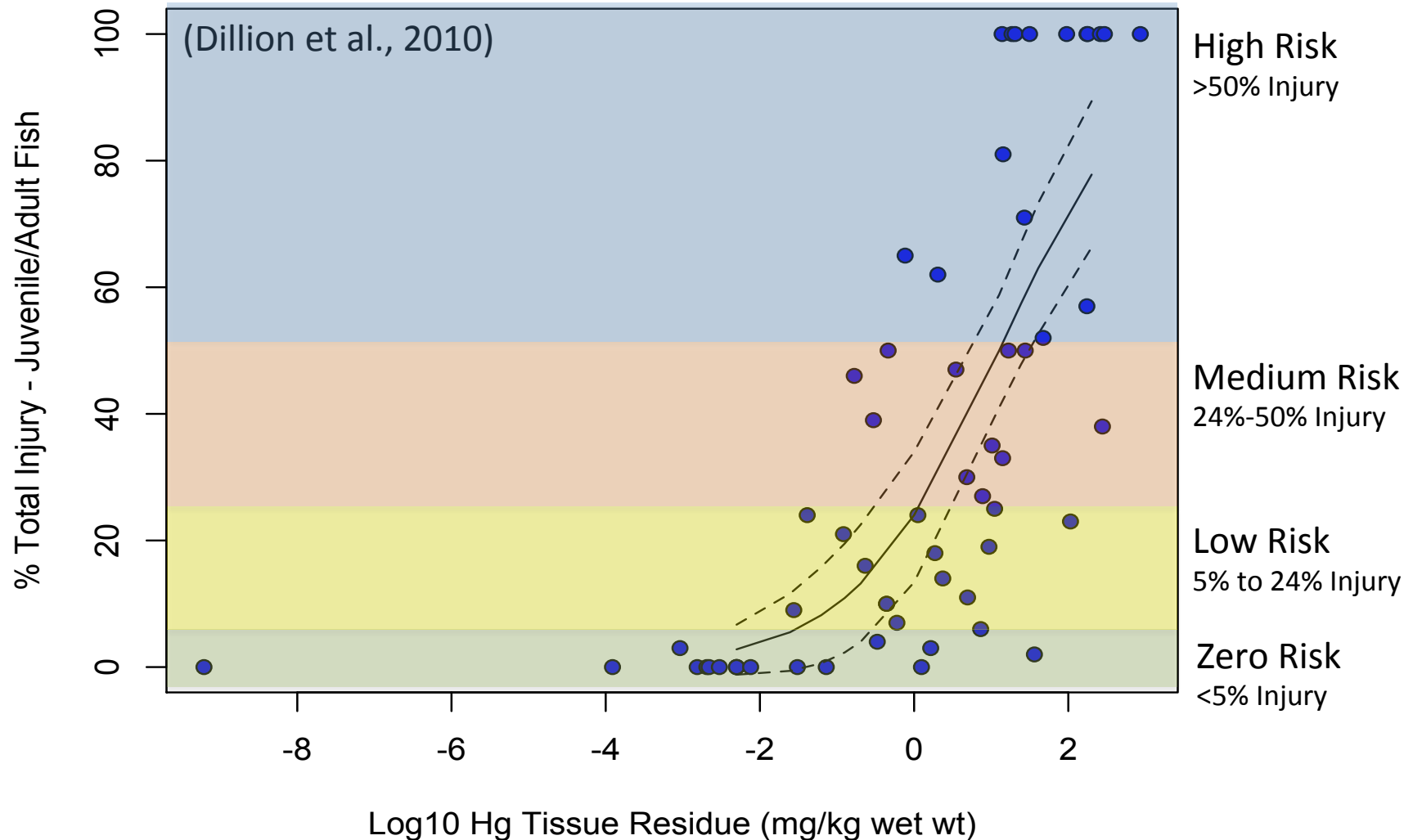
Mercury Toxicity

- Developed Risk Rankings
 - Based on Dillion et. al, 2010 – summary paper that combined fish mercury toxicity papers to create a dose-response curve for lethality equivalent endpoints (death, spawning success, and developmental abnormalities)
 - Cross-referenced and confirmed risk rankings with EPA National Lake Fish Tissue Study

Fish Whole Body Mercury Residue Dose-Response



Fish Whole Body Mercury Residue Dose-Response

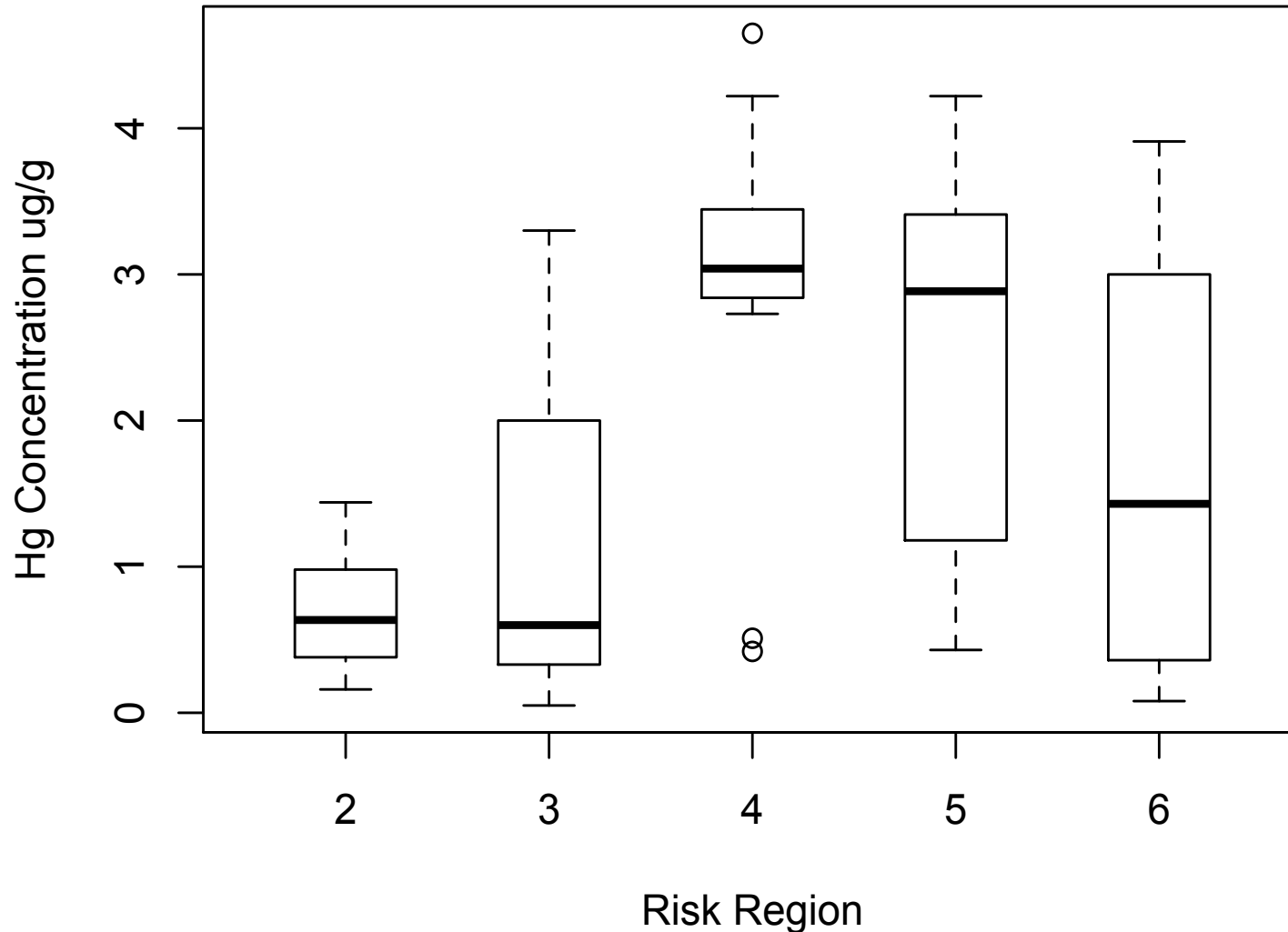


Step 3. Defining Probability Distributions

Mercury Toxicity

- Analyzed Mercury Filet data by Risk Region
 - Compared most recent data 2005 and later
 - Statistical difference in data between years – used most recent 2007 data

Smallmouth Bass Mercury Distribution (2007 data)



Step 3. Defining Probability Distributions

Mercury Toxicity

- Calculated the Frequency of Smallmouth Bass tissue concentrations within each risk level
- Calculate Frequencies

$$\frac{\text{number of data points within risk level}}{\text{Total number of data points}} \times 100\%$$

Step 4. Derivation of the Conditional Probability Tables for the nodes

Procedure:

Stressor_A	Stressor_B	zero	low	med	high
zero	zero	100.000	0.000	0.000	0.000
zero	low	90.000	8.000	1.500	0.500
zero	med	75.000	20.000	4.000	1.000
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low	med	25.000	35.000	30.000	10.000
low	high	10.000	30.000	45.000	15.000
med	zero	25.000	35.000	30.000	10.000
med	low	10.000	30.000	45.000	15.000
med	med	5.000	25.000	50.000	20.000
med	high	1.000	9.000	40.000	50.000
high	zero	15.000	25.000	40.000	20.000
high	low	10.000	15.000	35.000	40.000
high	med	5.000	10.000	30.000	55.000
high	high	1.000	4.000	20.000	75.000

1. Literature review to develop a weight of evidence based on functional relationships, model output, and theoretical insights
2. For each condition, assign a probability to the most likely state
3. Assign remaining probabilities based on the information available

Step 4. Developing CPT Toxicity Node

- Two input nodes:
 - Mercury Body Burden
 - Organic Contaminants
- Mercury body burden weighed more heavily because it is a measure of *actual* exposure
- Organic contaminants node represents *potential* exposure based on environmental measures of PAHs and organochlorine pesticides

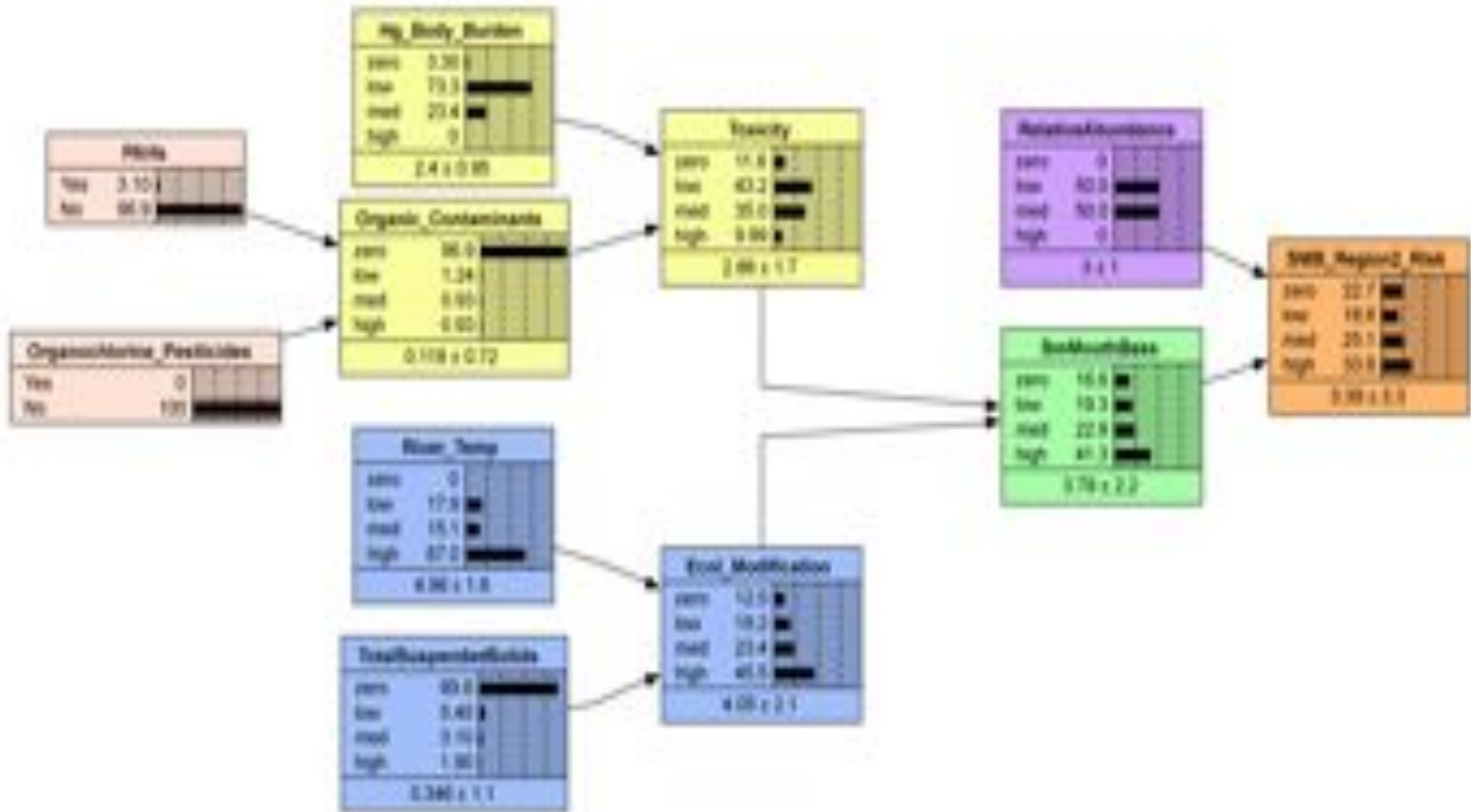
Step 4. Developing CPT Ecological Modifications

- Two input nodes:
 - Water Temperature
 - Total Suspended Solids (TSS)
- Temperature weighed more heavily
 - Species specific information
 - Effects on growth and survival of life stages
- Few studies on sub-lethal effects of TSS
 - 1 study on smallmouth bass
 - Additional information for trout or largemouth bass
 - High uncertainty

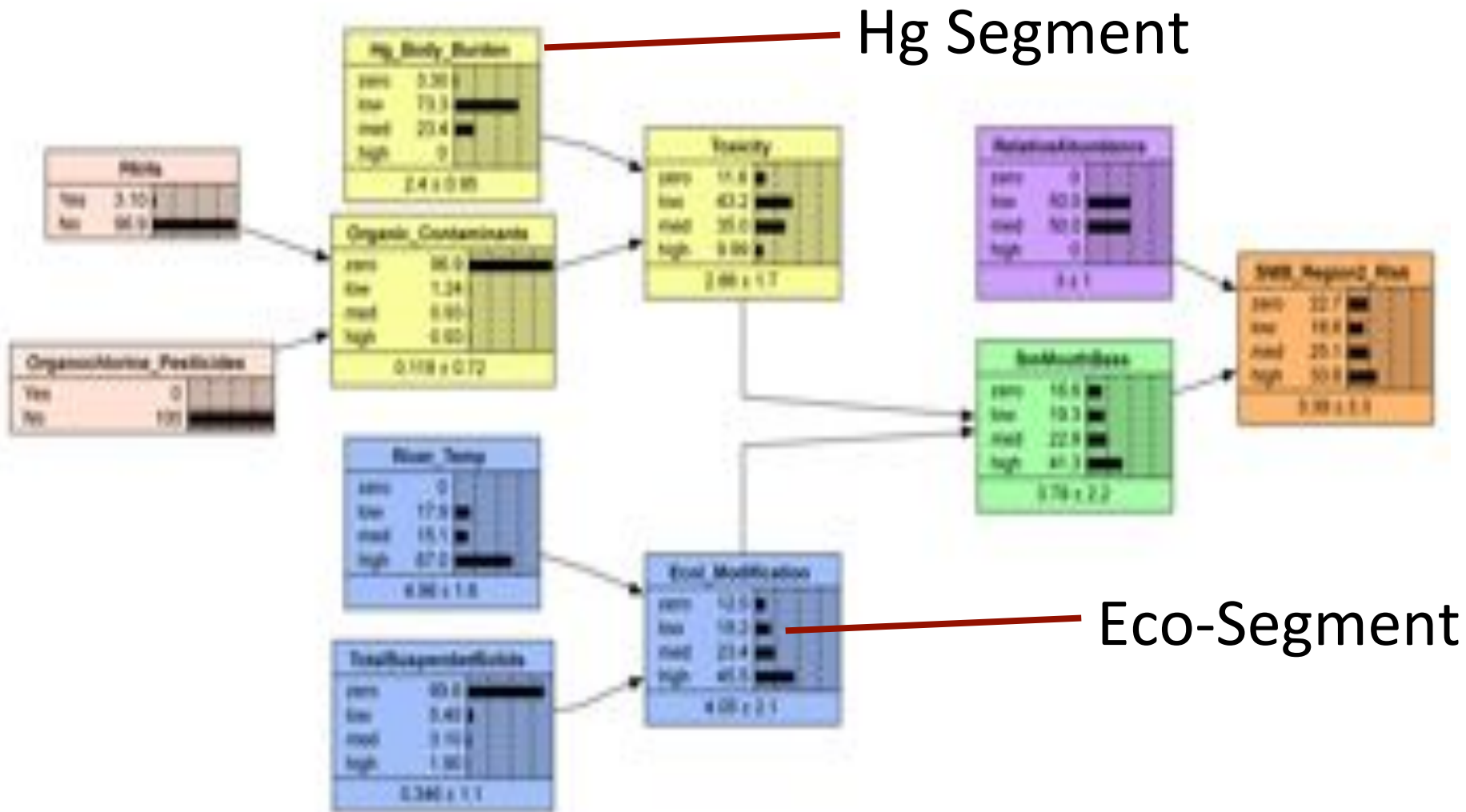
Step 5, Calculate and Plot the Output

Toxicity Smallmouth Bass Toxicity/Eco-modification model

Region 2 (Preliminary output)



Smallmouth Bass Bayesian Model Preliminary Model (Risk Region 2)

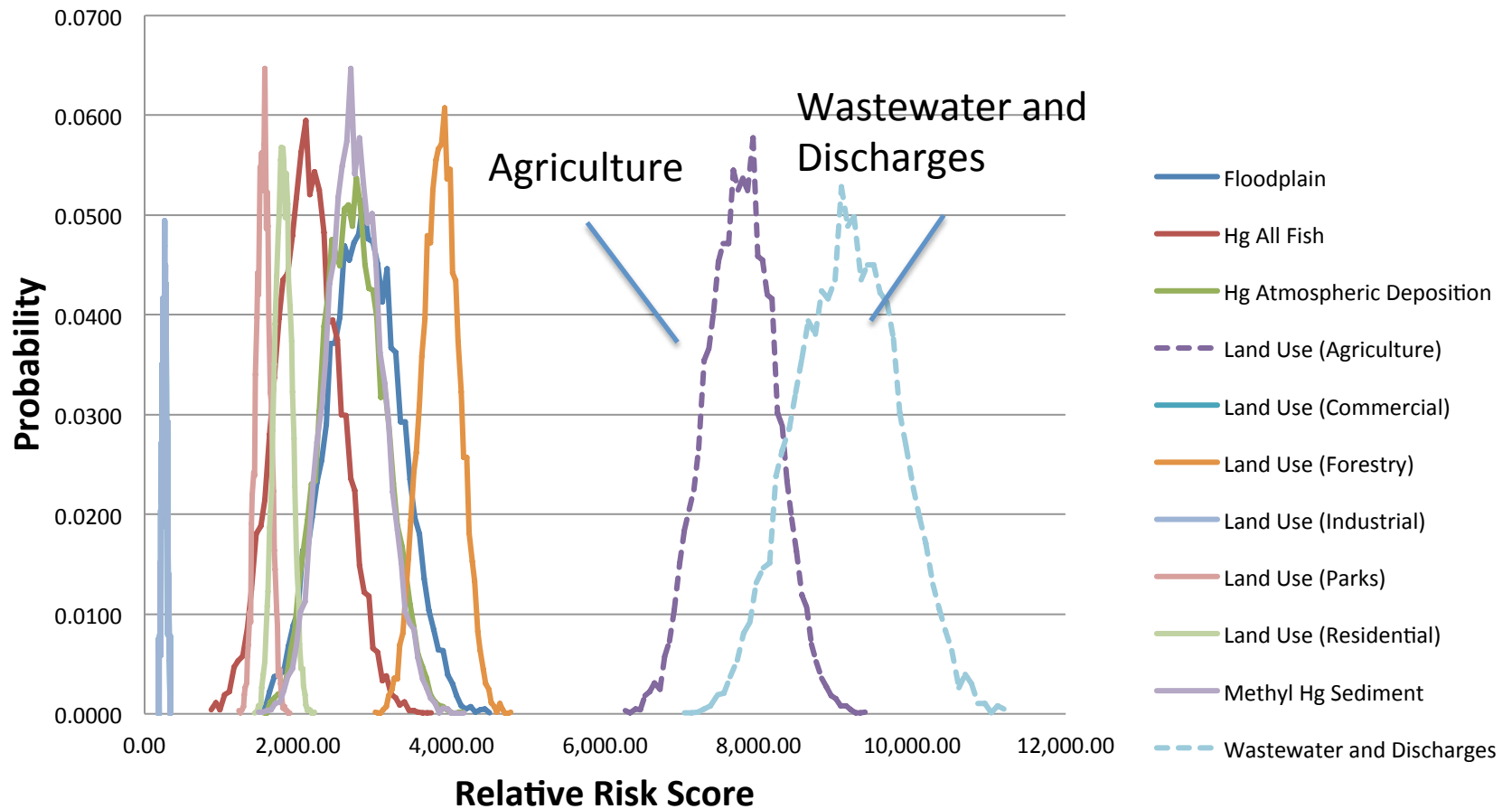


Patterns of risk in the South River and the South Fork of the Shenandoah.

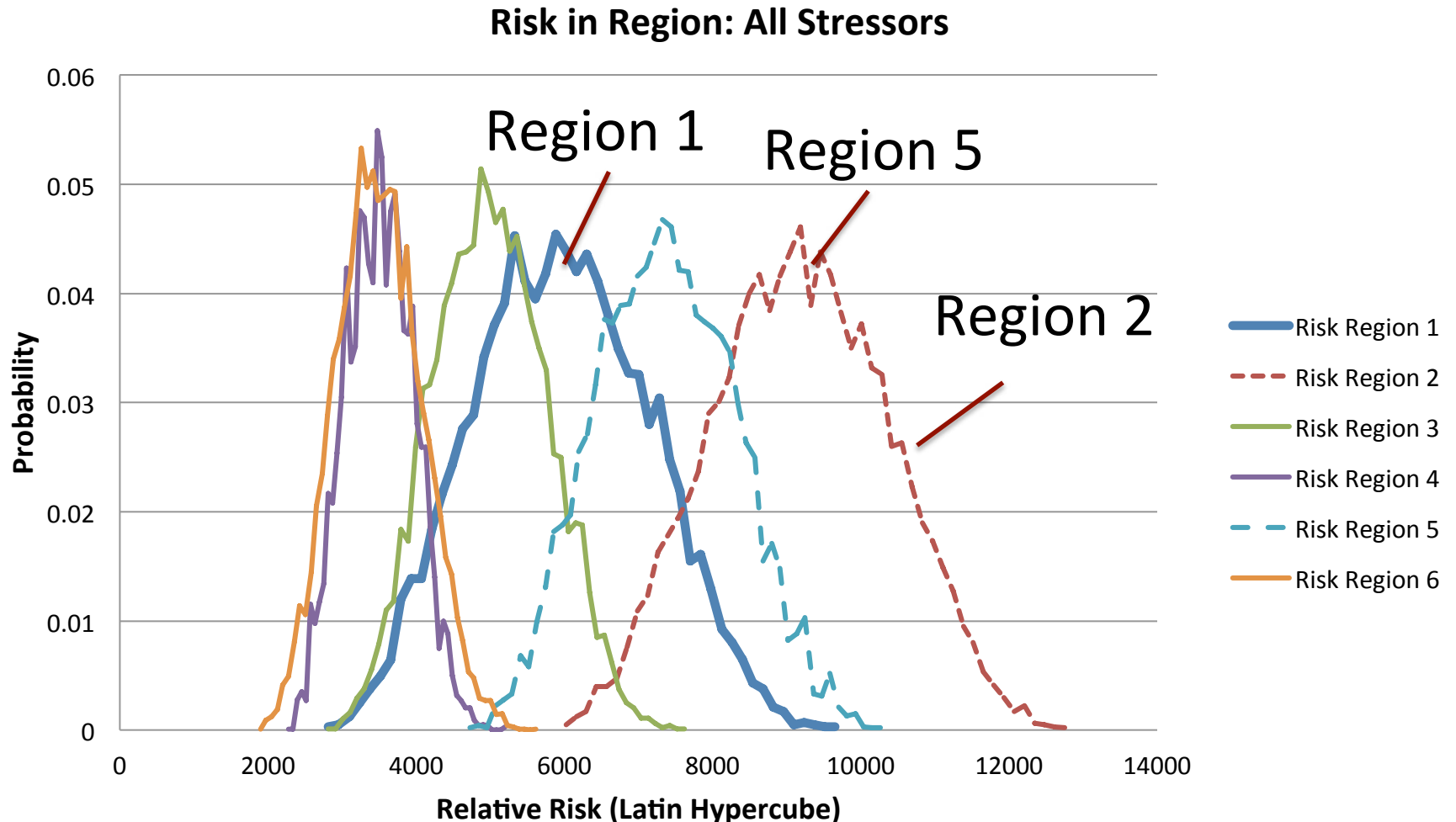
RRM Results-Incorporating all inputs and endpoints

Bayesian Results-Small mouth bass

Relative Risk Model Overall Risk Sources



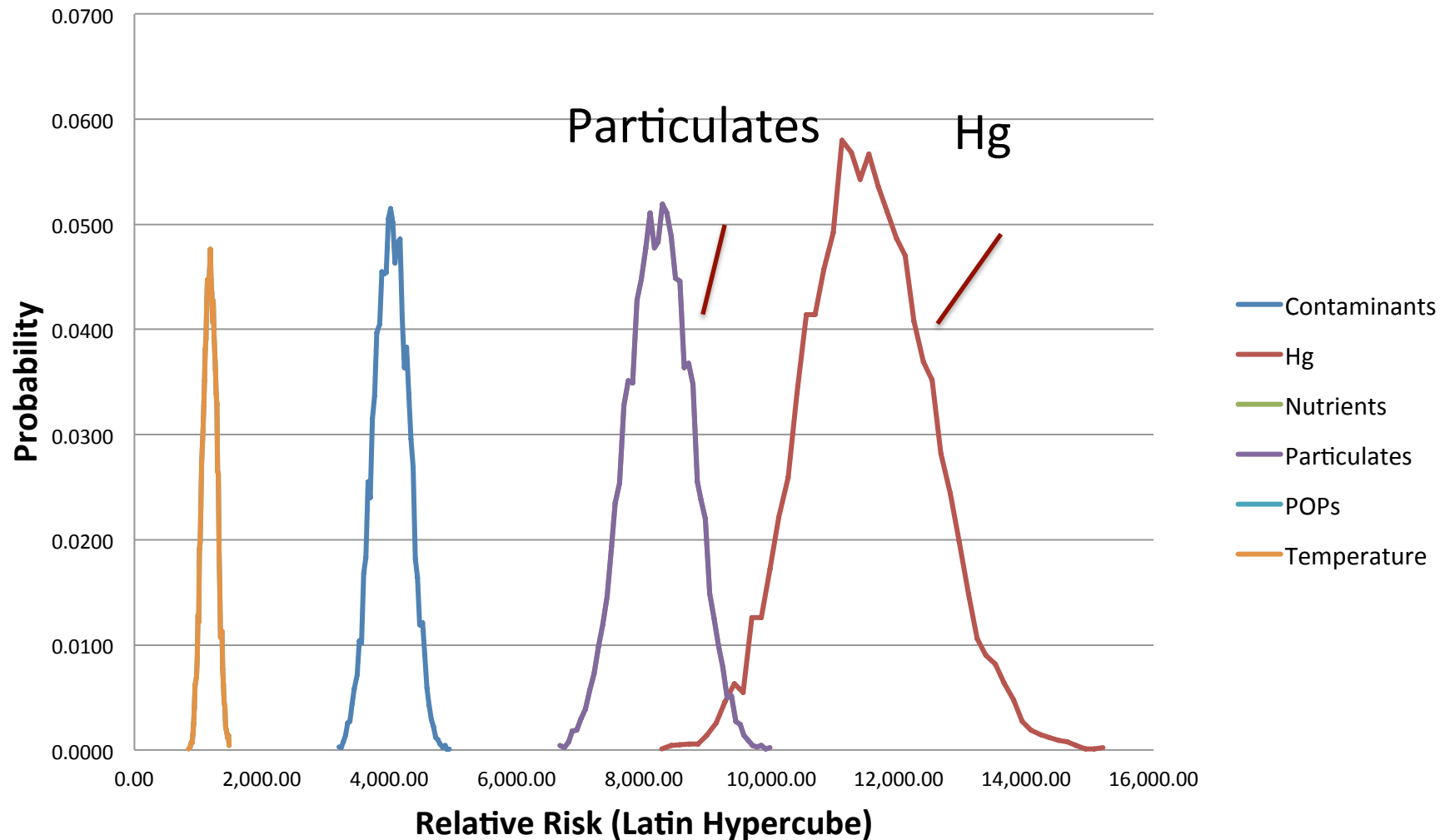
RRM-Regions 2 and 5 are the regions with the highest risk



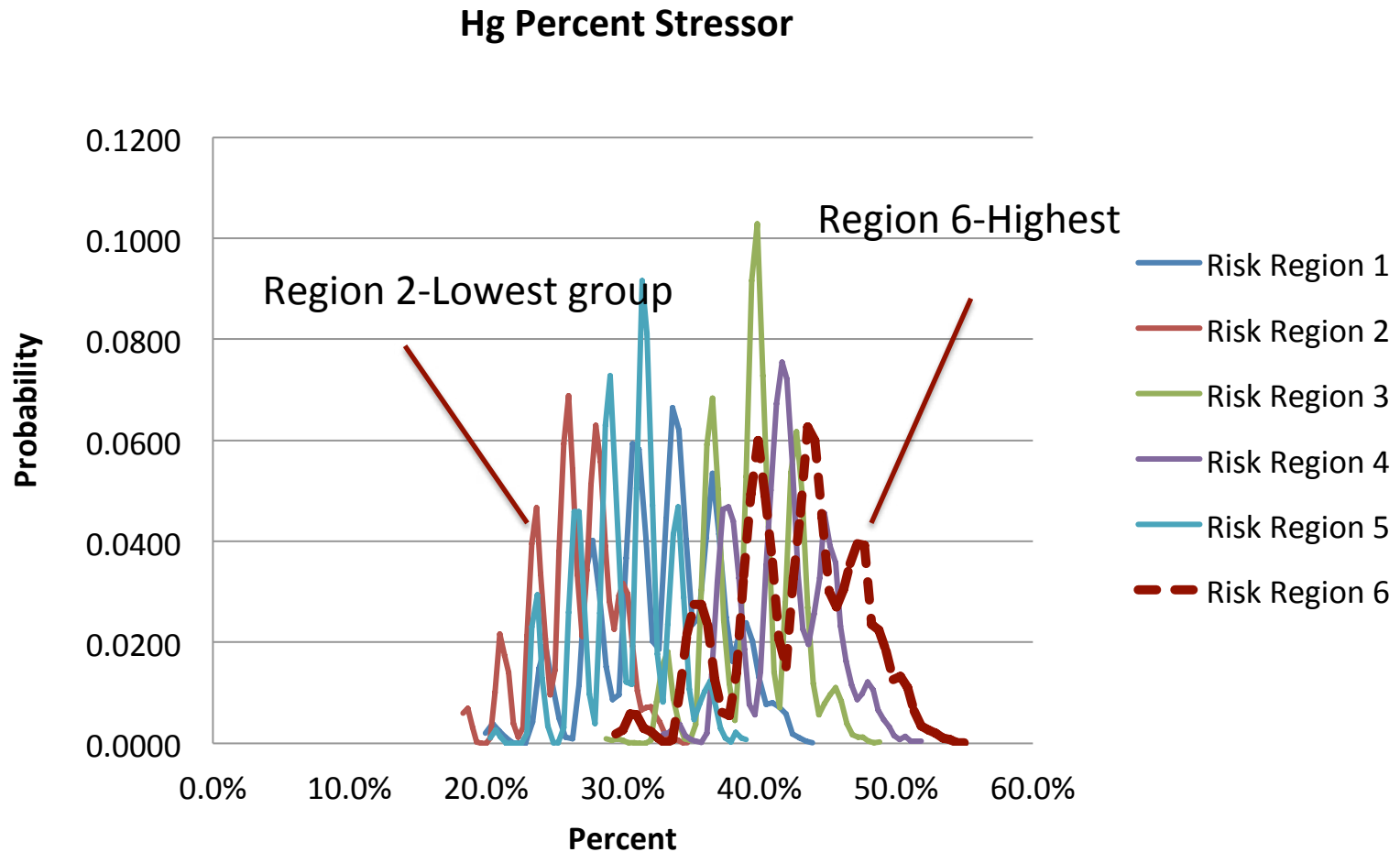
All regions have an associated risk, including region 1.

RRM-Hg is the largest contributor to risk in the region

Risk from Stressors: All Regions, Sources, Habitats, and Endpoints

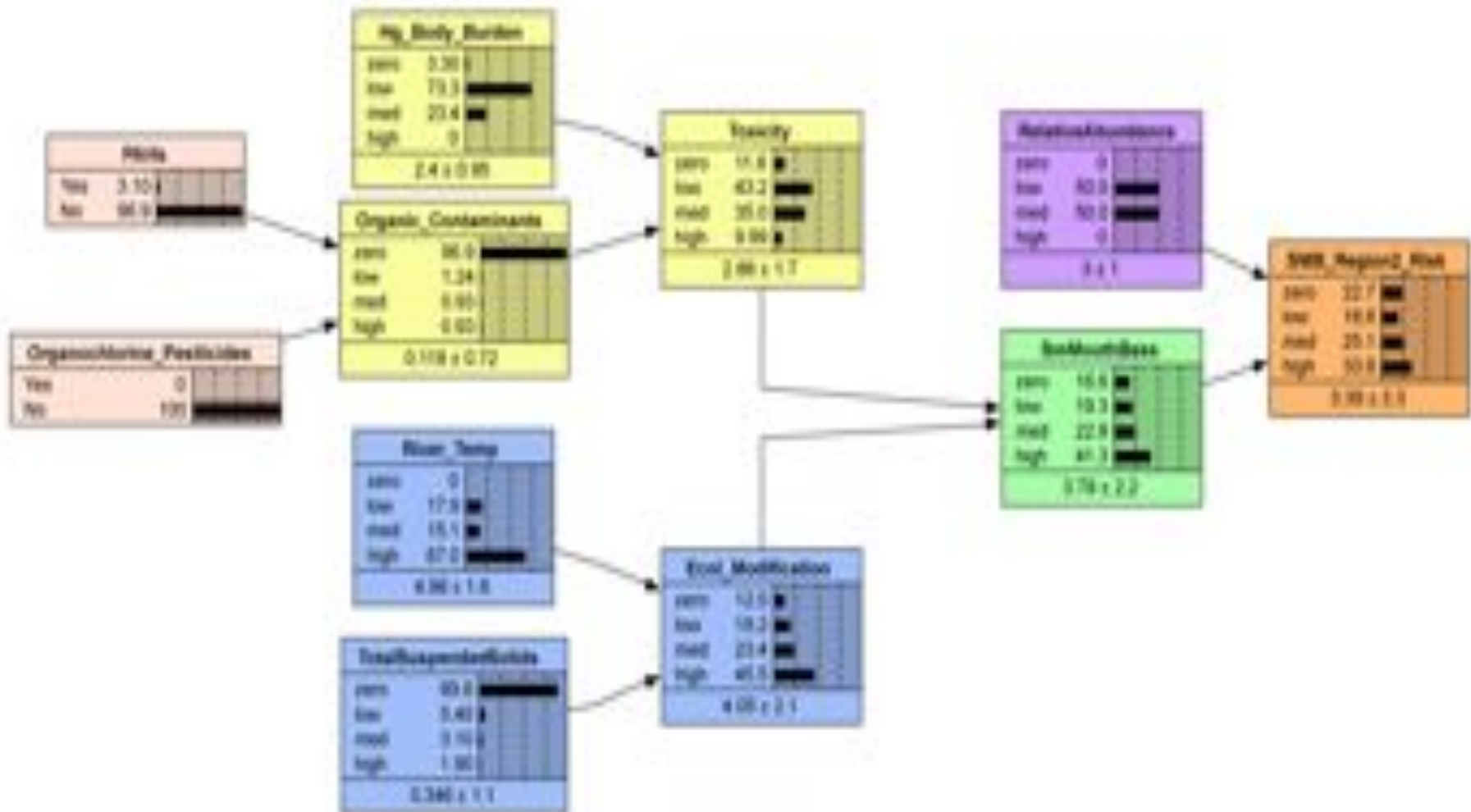


However the percent of total risk due to Hg depends on Risk Region—Counterintuitive at times



Bayesian Results

Toxicity Smallmouth Bass Toxicity/Eco-modification model Region 2



Smallmouth Bass Toxicity Risk Scores for Each Region

Highest Risk Region 5

Zero = 0
Low = 2
Med = 4
High = 6

Waynesboro

3.63

5.57

4.01

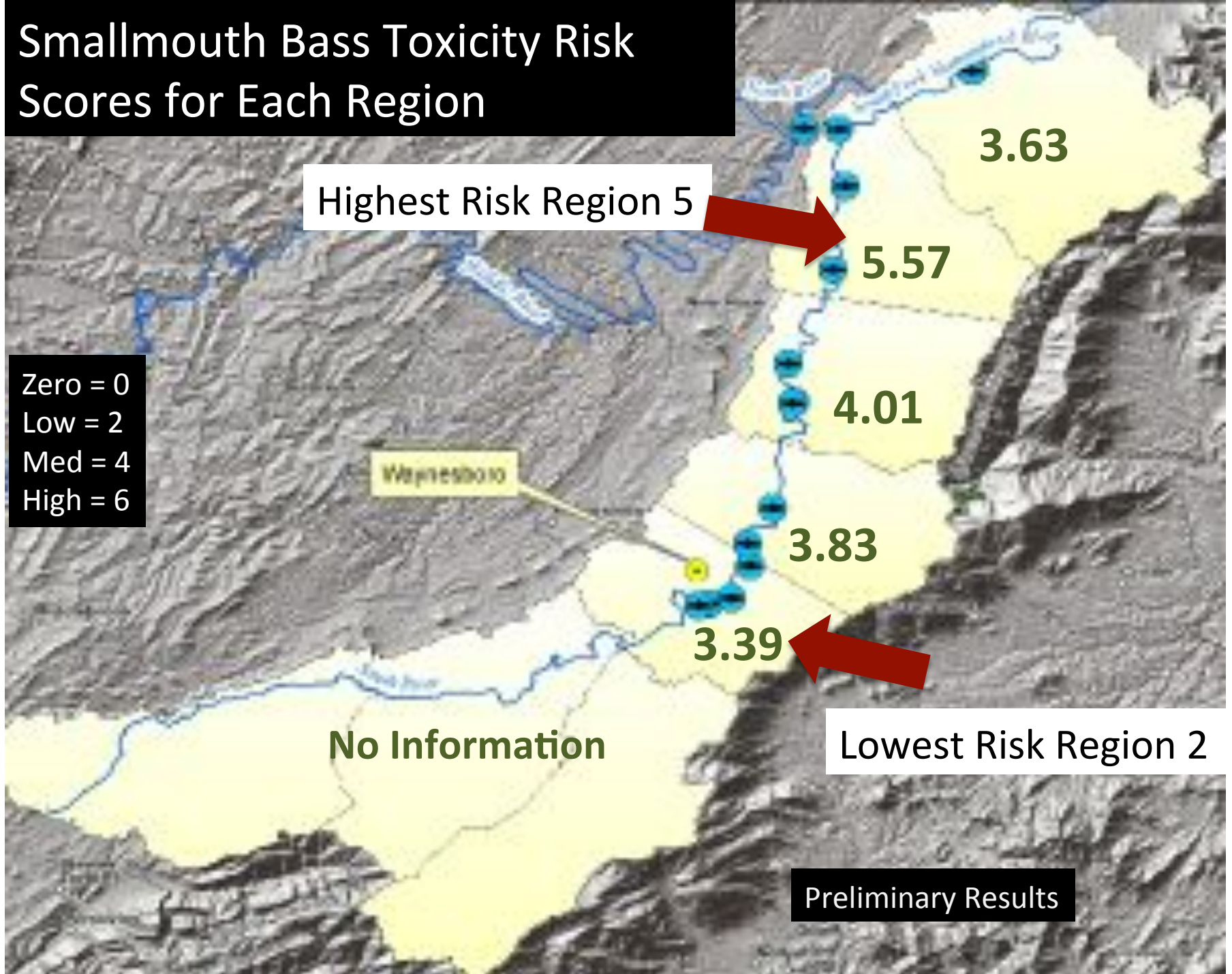
3.83

3.39

No Information

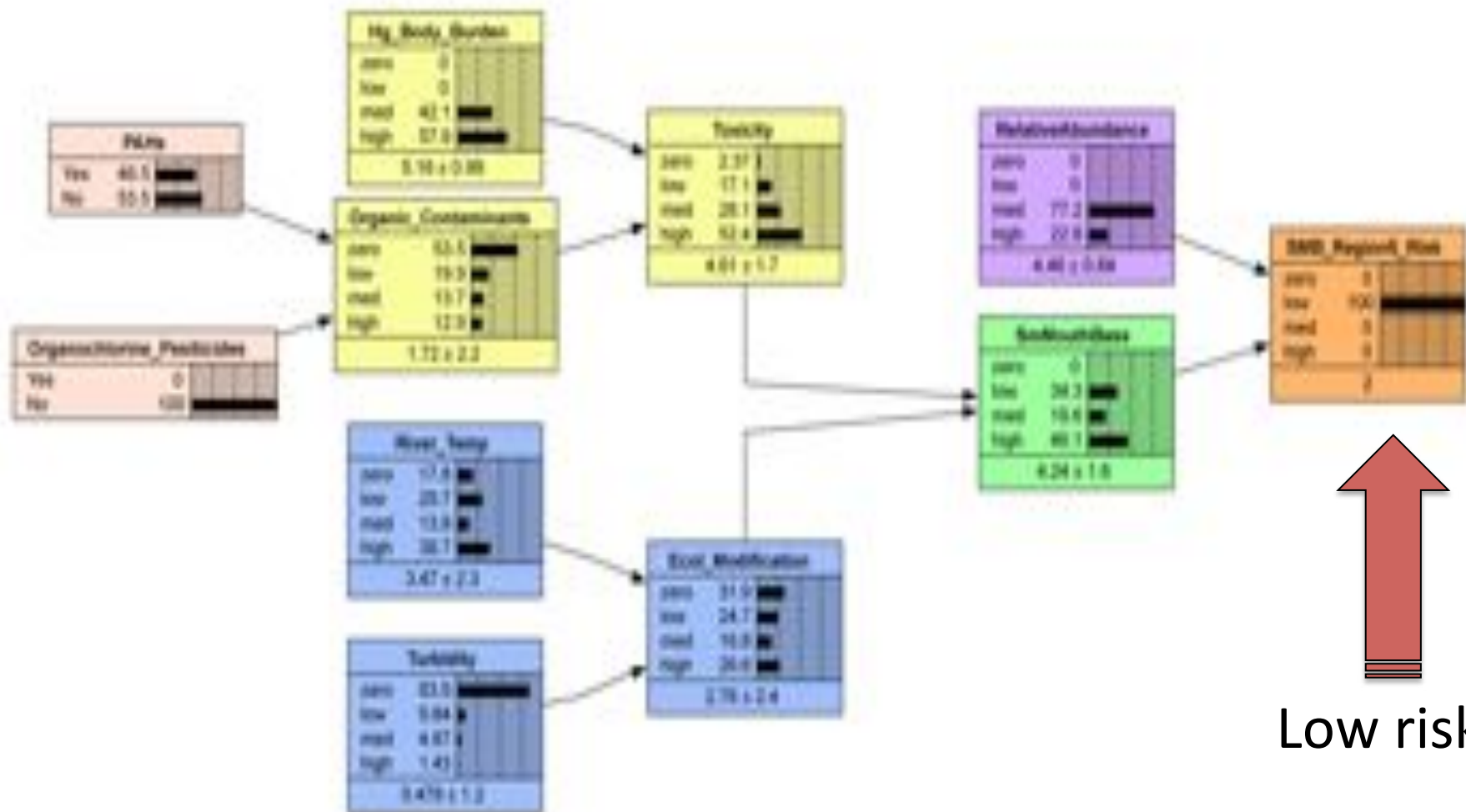
Lowest Risk Region 2

Preliminary Results



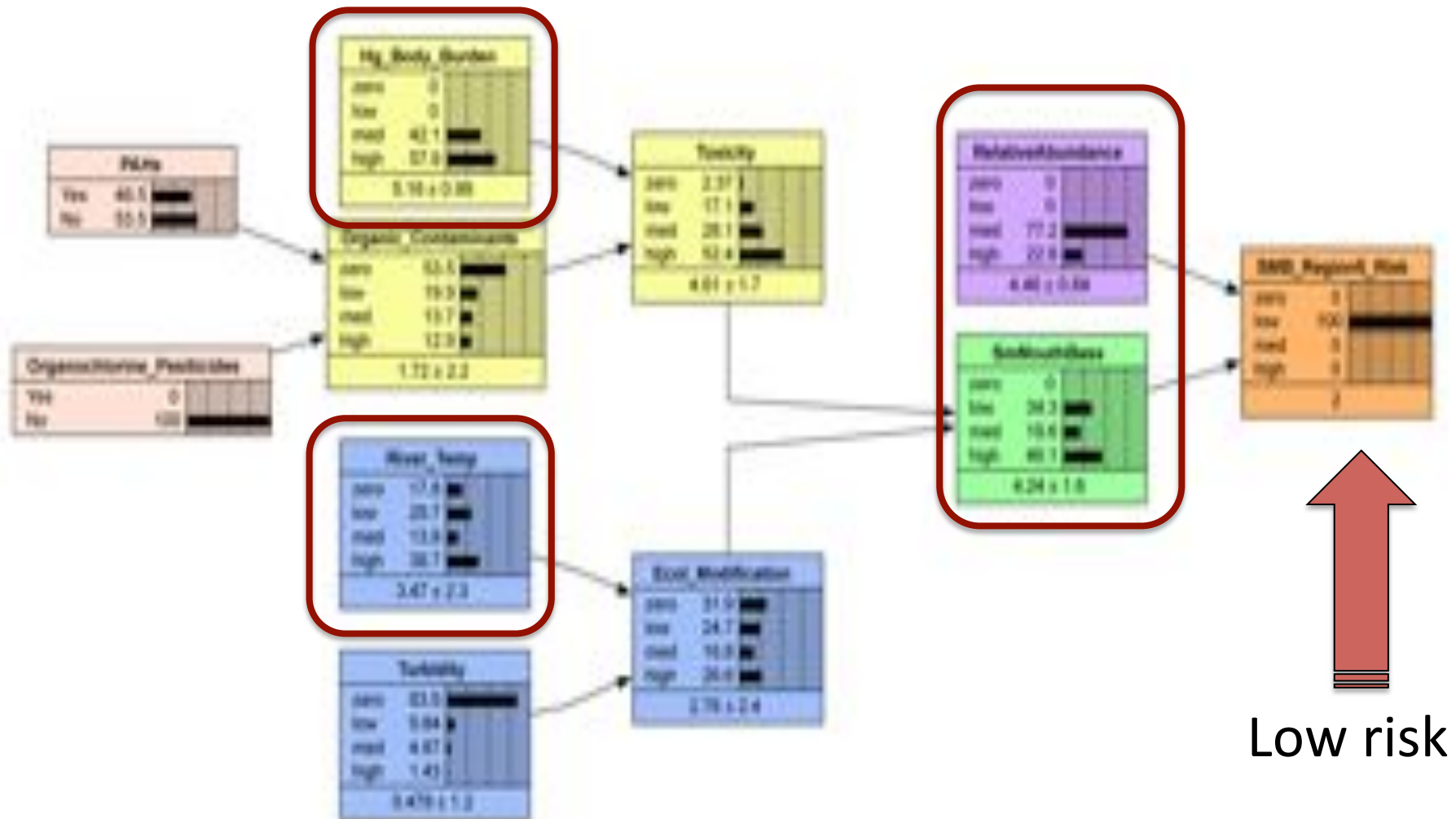
Scenario Simulation-set low risk

Smallmouth bass R5 Low Risk Preliminary Model



Parent nodes then change-Hg and River Temp

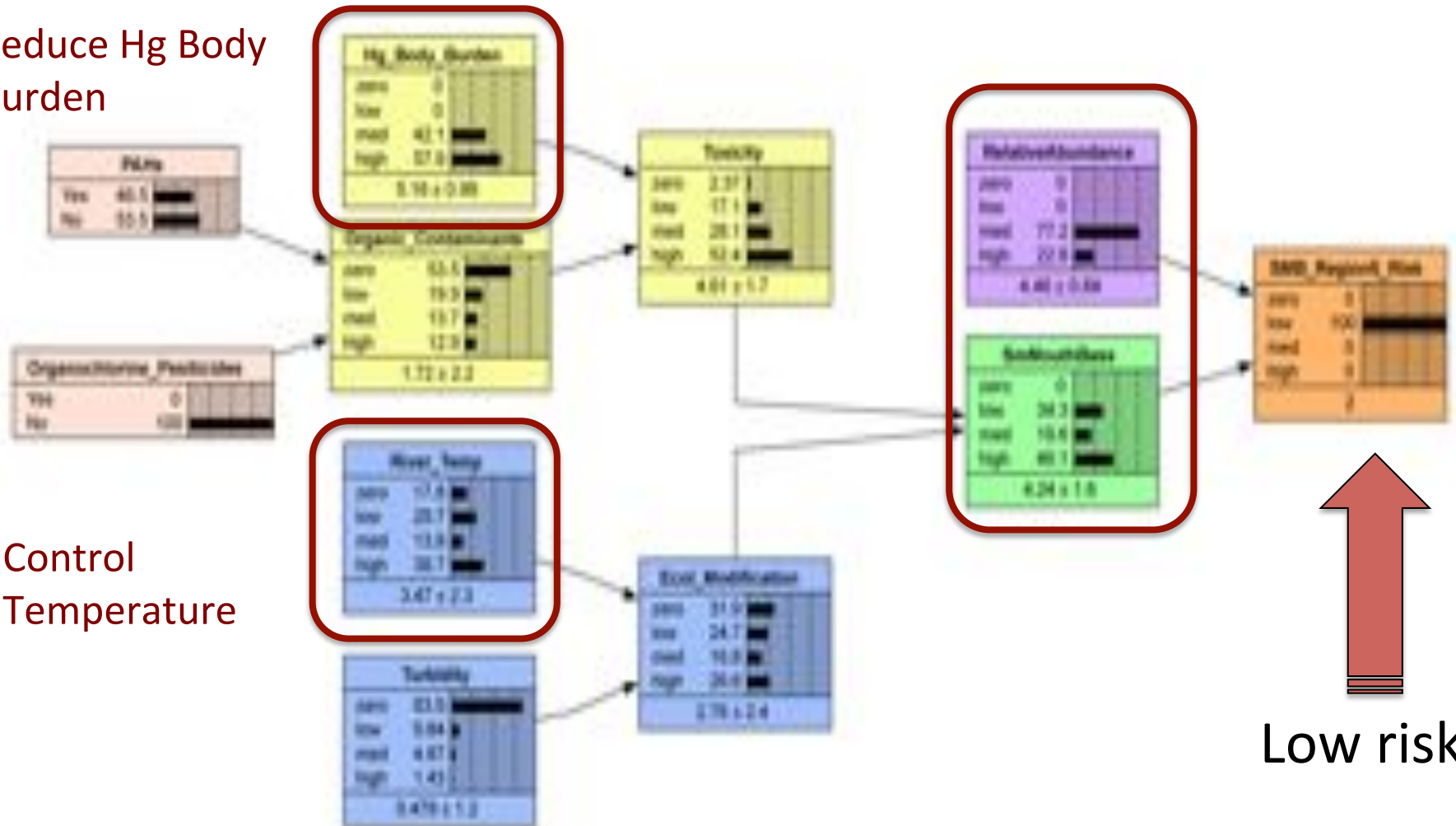
Smallmouth bass R5 Low Risk Preliminary Model



Parent nodes then change-Hg and River Temp

Smallmouth bass R5 Low Risk Preliminary Model

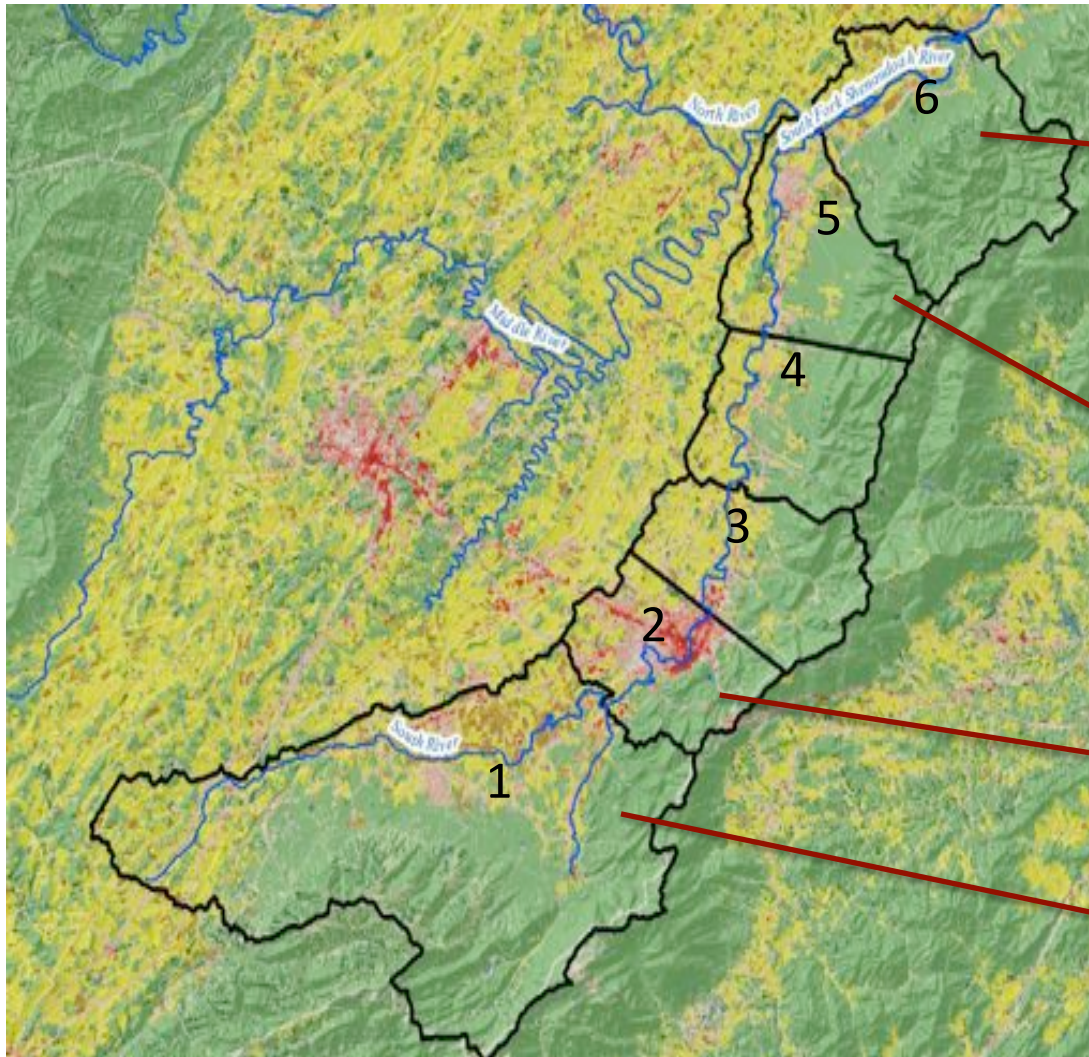
Reduce Hg Body Burden



Results to date

- It Worked! Large site with a number of stressors and endpoints.
- There are a number of patterns of risk to various endpoints and to different stressors with the South River Study area.
- The risk has moved downstream of the original source of Hg and is now combined with agriculture and other sources.

Patterns of risk in the South River Study Site



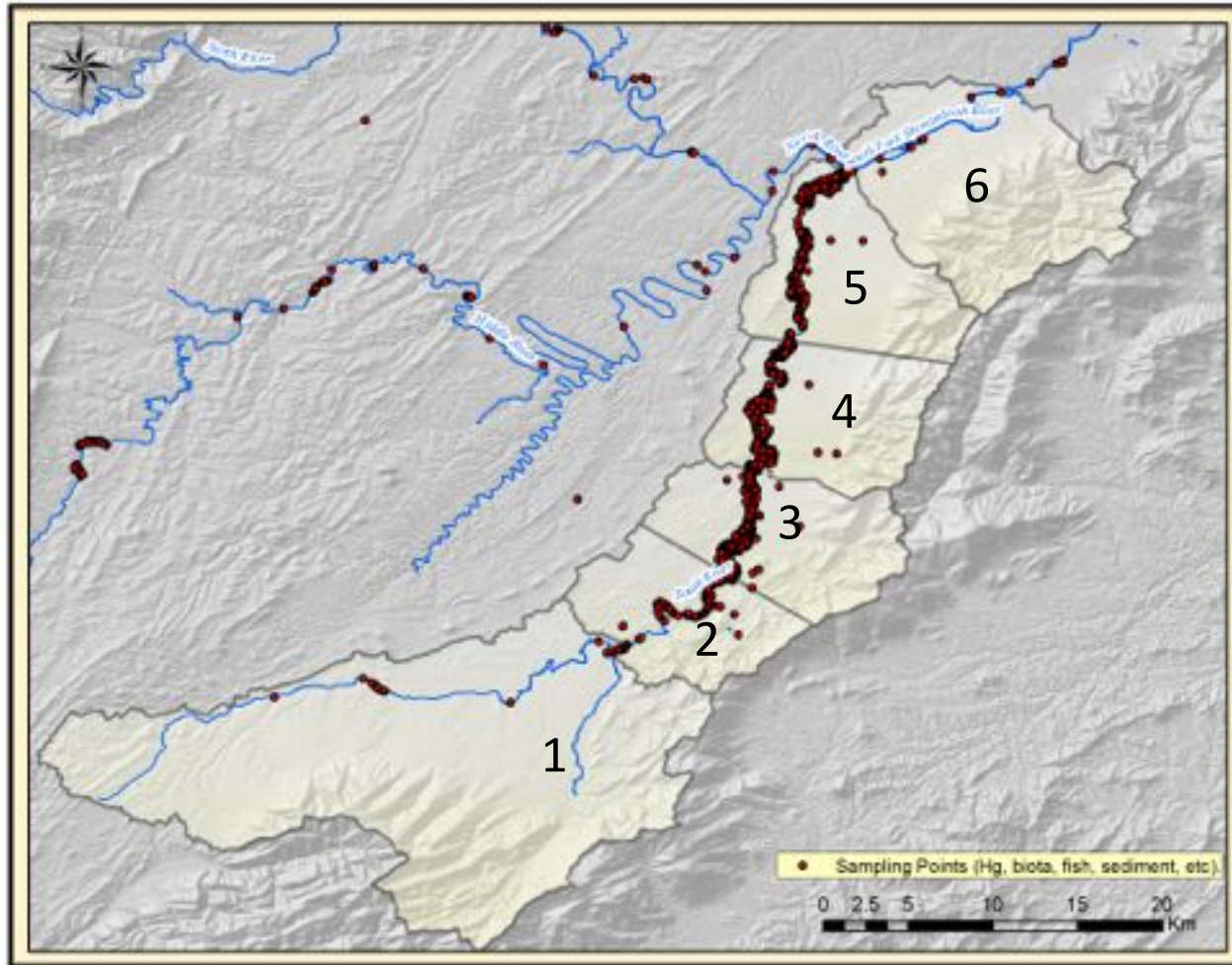
Region 6-Highest percent of risk due to Hg

Region 5-Highest risk to small mouth bass and second highest risk overall

Region 2-Highest risk overall

Region 1-Does have risk similar to Regions 3,4,6

Data Gaps exist that would have reduced uncertainty-historical artifact and common



Regions 1 and 6 with little coverage yet are part of the site.

Sampling in other rivers not useful for understanding risk in South River.

Summary-1

- The river and watershed are providing a pattern of risks analogous to a chromatography column and chemicals
- The risk assessment also allows the calculation of restoration strategies and specific goals.

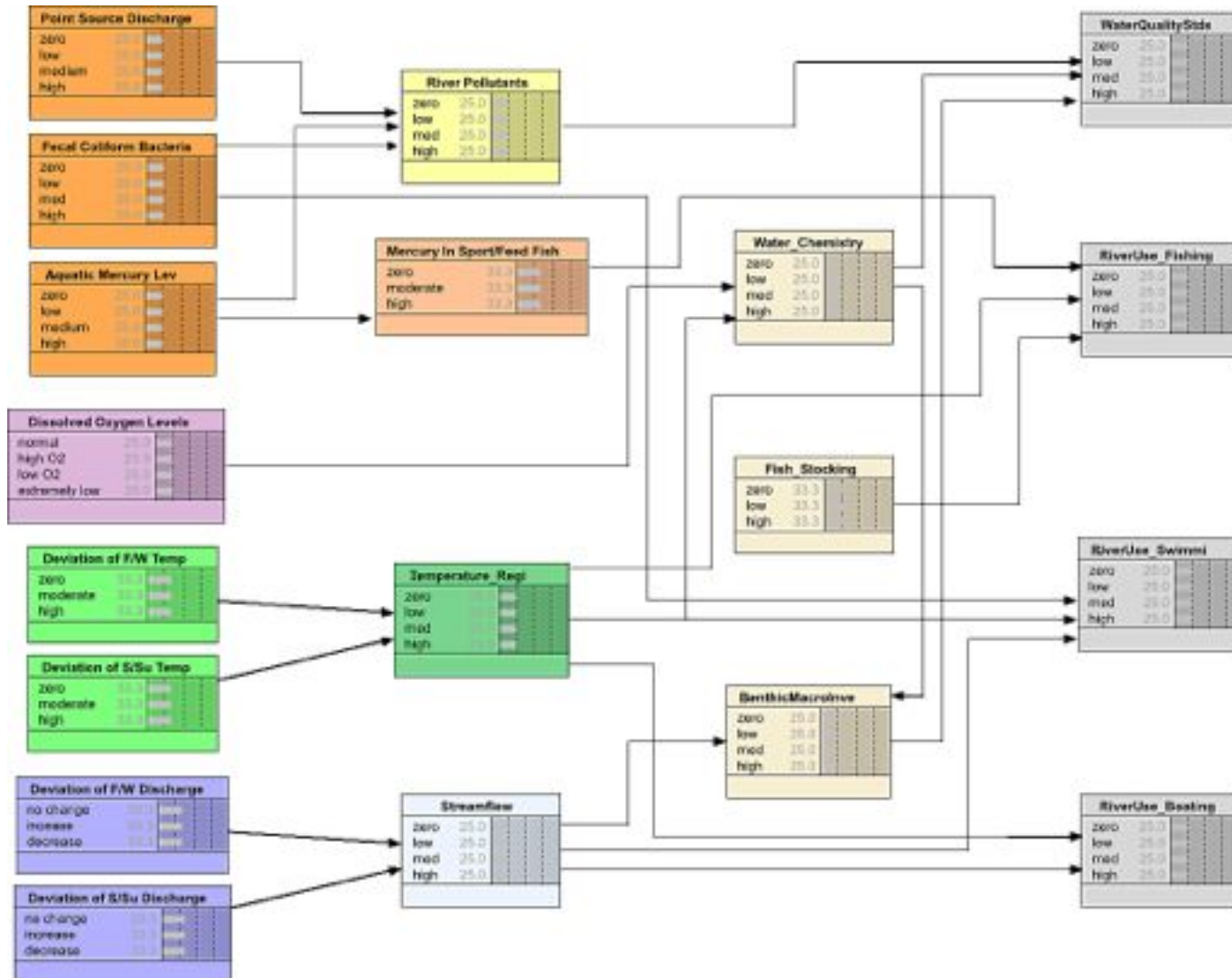
Summary-2

- The RRM provides an overview of the risk within the region with uncertainty. Requires less data but it is a trade for less specificity.
- The BN is very specific and deals very explicitly with uncertainty. The trade off is that sufficient data are required to construct a reasonable CPT.

Water Quality-Recreation Expert Solicitation

- Asking the experts to comment on model structure.
- Focused on specific problems and outcomes.

Bayesian Network-water quality and recreation



Pollution
Parameters

Point Source Discharge			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
medium	25.0	25.0	25.0
high	25.0	25.0	25.0

Fecal Coliform Bacteria			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

Aquatic Mercury Lev			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
medium	25.0	25.0	25.0
high	25.0	25.0	25.0

River Pollutants			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

Mercury In Sport/Feed Fish			
zero	33.3	33.3	33.3
moderate	33.3	33.3	33.3
high	33.3	33.3	33.3

Water Chemistry			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

Fish Stocking			
zero	33.3	33.3	33.3
low	33.3	33.3	33.3
high	33.3	33.3	33.3

Benthic Macroinverte			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

Temperature Regi			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

Streamflow			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

Dissolved Oxygen Levels			
normal	25.0	25.0	25.0
high O2	25.0	25.0	25.0
low O2	25.0	25.0	25.0
extremely low	25.0	25.0	25.0

Deviation of F/W Temp			
zero	33.3	33.3	33.3
moderate	33.3	33.3	33.3
high	33.3	33.3	33.3

Deviation of S/Su Temp			
zero	33.3	33.3	33.3
moderate	33.3	33.3	33.3
high	33.3	33.3	33.3

Deviation of F/W Discharge			
no change	33.3	33.3	33.3
increase	33.3	33.3	33.3
decrease	33.3	33.3	33.3

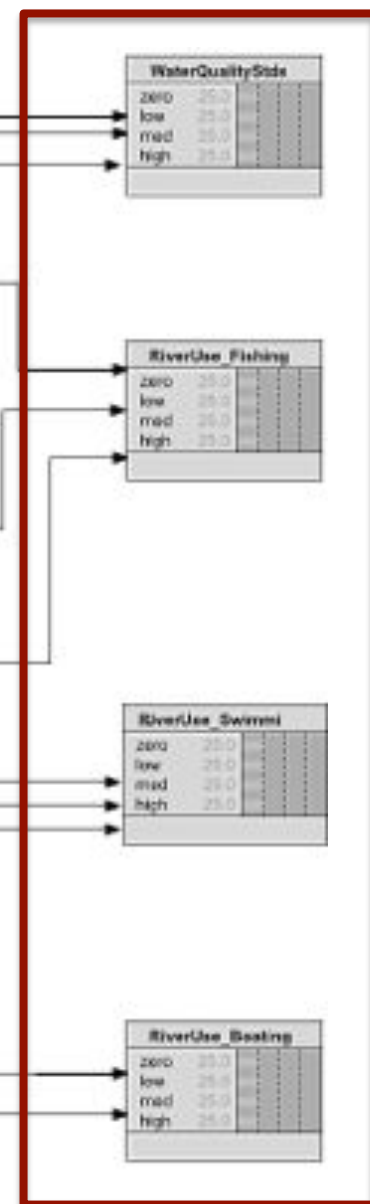
Deviation of S/Su Discharge			
no change	33.3	33.3	33.3
increase	33.3	33.3	33.3
decrease	33.3	33.3	33.3

WaterQualitySide			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

RiverUse Fishing			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

RiverUse Swimm			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

RiverUse Boating			
zero	25.0	25.0	25.0
low	25.0	25.0	25.0
med	25.0	25.0	25.0
high	25.0	25.0	25.0

Hydrologic
Parameters

Pollution Parameters

Parameter	Information Used	State	Value
Point Source Discharge	Density of effluent discharge permits within defined area	Zero	TBD
		Low	TBD
		Medium	TBD
		High	TBD
Fecal Coliform Bacteria	Concentration (CFU/100 mL) -State definitions based on Virginia bacteria standards -2005-2009 data	Zero	< 35
		Low	35 to 235
		Medium	235 to 630
		High	≥ 630
Total Mercury Content in Water (not eco-toxicological effects)	Total mercury content in water -State definitions based on mercury criteria for the protection of aquatic species -2005 – 2009 data	Zero	0 to 0.77 ppm
		Moderate	0.77 to 1.4 ppm
		High	> 1.4 ppm

Hydrologic Parameters

Parameter	Information Used	State	Value
Seasonal Temperature F/W (Oct. – March) S/Su (April – Sept.)	Deviation from 30-year average -Calculate 30-year seasonal average -Calculate deviation between daily temperatures for 2010-2011 from long-term average	No Change	0 – 2 °C
		Moderate	2 – 4 °C
		High	> 4 °C
Seasonal Discharge F/W (Oct. – March) S/Su (April – Sept.)	Deviation from 30-year average -Calculate 30-year seasonal average -Calculate % difference between daily discharge for 2010-2011 from long-term average	No Change	75% – 125%
		Increase	> 125%
		Discharge	< 75%
Dissolved Oxygen	Deviation from 30-year average -Calculate 30-year average -Calculate % difference between daily [DO] for 2010-2011 from long-term average	Normal	60 – 110%
		High	≥ 110%
		Low	40 – 59%
		Extremely Low	0 – 39%

Bayesian Networks & Solicitation of Expert Opinion

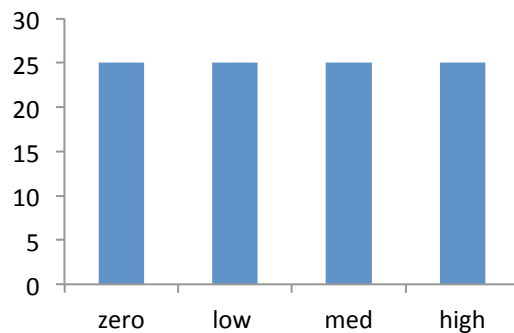
Model Structure

- Does the structure contain parameters that influence endpoints?
- Are any parameters missing?
- Are the states for each parameter reasonable?
- Are the state definitions realistic?

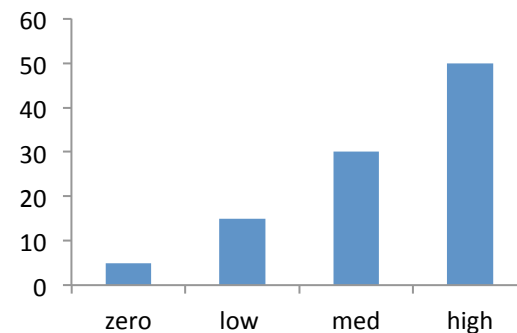
Bayesian Networks & Expert Opinion

Conditional Probabilities

- How much weight to place on parent nodes?
- Most likely outcome for each combination of parent node states?
- Least likely outcome?



Prior Probability
No Information



Consensus Expert Opinion

Bayesian Networks & Expert Opinion

[illegible]