Conceptual Bayesian Networks for Supporting Contaminated Site Ecological Risk Assessments and Remediation Management

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Contaminated sites and EPA

- **Superfund- 1,600+ NPL sites**
  - Sites that due to size, toxicity or contamination and/or geological complexity, pose a higher risk
- **RCRA sites**
  - Sites that store or treat hazardous and non hazardous wastes, USTs
- **State programs**
- **Brownfields**
  - Former used industrial sites
  - Not necessarily contaminated
  - Require assessment or redevelopment
- **Federal facilities**
  - Nuclear weapons facilities, military installations

https://www.epa.gov/superfund/superfund-cleanup-process
Contaminants

- Metals
  - Often Cd, Pb, Cr, As, Hg

- Organic contaminants
  - Chlorinated solvents, PCBs, PAHs

- Radionuclide contaminants
  - Uranium, strontium, iodine, caesium

- Emerging chemicals
  - PFOS
  - PFOA


https://www3.epa.gov/hudson/photos.html

Framework for Ecological Risk Assessment

Framework encourages iterative methods

Balances exposure (concentrations) and effects (toxicity)

Risk can be expressed as probabilities based on the overlap of exposure with effects

Conceptual site model

- Used throughout the site assessment process
  - Risk assessment
  - Monitoring
  - Remediation
- Characterizes what is known about a site
- Traces sources of contamination to receptors
- Updated with knowledge over time
Bayesian networks

• Qualitative (graphical) portion can be advantageous for
  • Detailed expert-developed causal models
  • Rapid “on the fly” development to capture workshop conversations

• Judea Pearl- we think about the world like this

• We set out to investigate how conceptual Bayesian networks might benefit the contaminated site assessment and remediation process?
Use of Bayesian networks will (likely) increase in the future

“I now consider it “data scientific malpractice” to be designing studies, analyzing data, and adjusting for confounders without using causal models. Human brains are wired to resist new paradigms. Be intellectually wise and humble and read this book—you will not regret it!”

-Tomas Aragon, Amazon review
Risk assessment network

Sediment concentration

Surface water concentration

Trout mortality

Chance nodes (random variables)
Risk assessment network

Source media
- Sediment concentration

Exposure media
- Surface water concentration

Consequence
- Trout mortality

Risk system (from source to receptor)

Causal connection (arcs)
Causal (conditional) independence

Is lake water concentration causally independent of soil concentration given groundwater concentration?

OR

Notion of mediation
Notion of blocking
Causal (conditional) independence

Is lake water concentration causally independent of soil concentration given groundwater concentration?

No
Causal (conditional) independence

Is lake water concentration causally independent of soil concentration given groundwater concentration?

No
Correlation & causation

A = contaminant concentration, B = fish abundance, C = water flow, D = prey species abundance
Integrated model?

Water flows
Contaminant loadings
Fish in area
Observed concentrations
Crustacean mortality
Observed fish
Fish mortality from contam
Controlling factors

- Sediment concentration
  - Surface water concentration
    - Trout mortality

Controlling factor: Water flows
Controlling factors

- Sediment concentration
- Surface water concentration
- Trout mortality
- Avoidance reaction
- Water flows

Controlling factors

Avoidance reaction
Sediment concentration
Surface water concentration
Trout mortality

Water flows
Causal pathway analysis
Causal pathway analysis

Initial variable - Creek sediment quality

Target variable - Avian mortality
Causal pathway analysis
Causal pathway analysis
Risk management

- Dredging
- Sediment concentration
- Surface water concentration
- Avoidance reaction
- Trout mortality

Intervention
Intervention Types

Is this intervention intended or unintended?
- Intended- effect on C that intervention was meant to do
- Unintended- an effect from the intervention occurs that was unintended
Intervention Types

Is this intervention overwhelming or underwhelming?

- Overwhelming - Makes C independent of B
- Underwhelming - Makes C still dependent on B

Intervention Types

Is this intervention deterministic or stochastic?
- Deterministic- know the outcome of C
- Stochastic- probabilities on C

Intervention Types

Is this intervention independent or interactive?

- Independent - under complete control
- Interactive - affected by other components
  - Other interventions (coordination)
  - Other variables (information)
Intervention Types

Is this intervention targeted or indiscriminate?

- Targeted- only impacts C
- Indiscriminate- affects C and other nodes

Indiscriminate intervention

What are the additional costs and benefits of this intervention?

Intervention cost considerations
- Failures
- Financial costs
- Ecological injuries
Causal pathway analysis

Initial variable - Waste rock extent

Target variable - Avian mortality
Causal pathway analysis

Intervention-
dam construction

- Dam construction
- Waste loadings
- Subsidence
- Rainfall
- Waste rock extent
- Runoff quality
- Creek sed quality
- Creek WQ
- Dissolution amount
- Benthos contam
- Benthic integrity
- Fish pop size
- Avian mortality
- Riparian quality
- Subsidence
Causal pathway analysis

Intervention-dam construction

Intervention-capping

Dam construction

Capping

Waste loadings

Creek sed quality

Subsidence

Riparian quality

Dissolution amount

Benthos contam

Rainfall

Runoff quality

Waste rock extent

Fish pop size

Benthic integrity

Avian mortality

Creek WQ

Intervention-dam construction

Intervention-capping
Why use Bayesian networks for contaminated site remediation?

• Advantages of graphical structure
  • Knowledge representation
  • Communication tool

• Imparts rigor and logical thinking

• Decision support through intervention inclusion

• Platform for quantitative modeling

• Enhances causal inferences

• Uncertainty evaluation
Thank you for listening!

Questions?

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