Risk-Based Scenario Analysis and Construction Using Bayesian Networks

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Coming attractions

Short Outline

- The Natural Resource Management landscape
- Decisions to be made-using risk as a metric
- A short background on Bayesian networks
- The use of Bayesian networks to make decisions and to interact with stakeholders
- Questions

Broad management mandate

Scale of Responsibilities

- Manages 75 percent of the lands in the United States with the US Forest Service of USDA most of the remainder.
- US Park Service
- Science Agencies-US Fish and Wildlife Service, US Geological Survey
- Manages Natural Resources and resource extraction.
- Interactions with US Tribes

Multiple stakeholders

Broad range of stakeholders in the use of public lands

- Tribes and States
- Mining and Energy interests
- Environmental Protection of land and sea interests
- Other Federal/State/Local land management and environmental protection agencies

Never any controversy…….

Critical Resources

Wide Range of Consequences…

Energy resources from Alaska are refined in Washington along the Puget Sound. Jobs are created, taxes paid, and product is shipped across the country. Who would have thought Washington as an Energy extraction dependent economy.

Pier for BP oil refinery, Cherry Point near Ferndale Washington-Crude from Alaska

Decisions to be made.

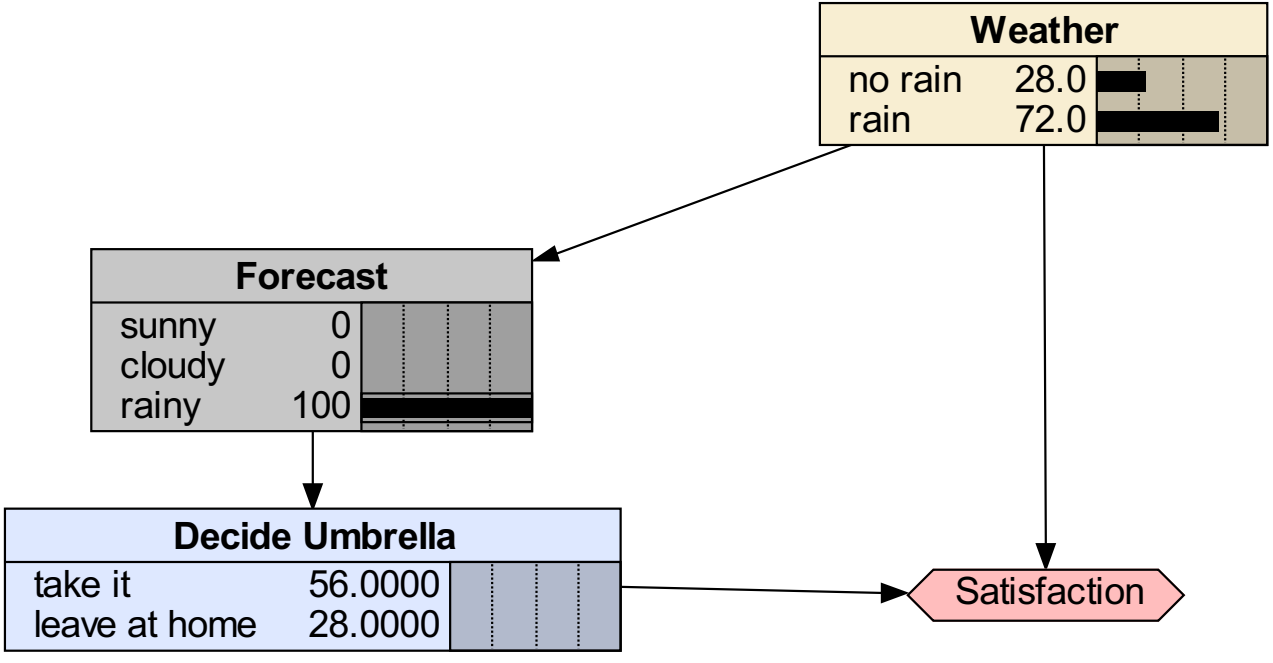
How to make decisions regarding the use of natural resources and the consequences of the activities?

We use Bayesian networks to calculate risks, evaluate alternatives, and to adaptively manage the resources.

Bayesian networks have been applied by the US Forest Service to management a variety of resources since the mid 2000s. (B. Marcot et al papers).

The tool is extensively used in economics, medicine and by the Tech industry to predict and classify data to facilitate decision making.

The question boils down to…should I take my umbrella to work today.



https://www.norsys.com/netlibrary/index.htm

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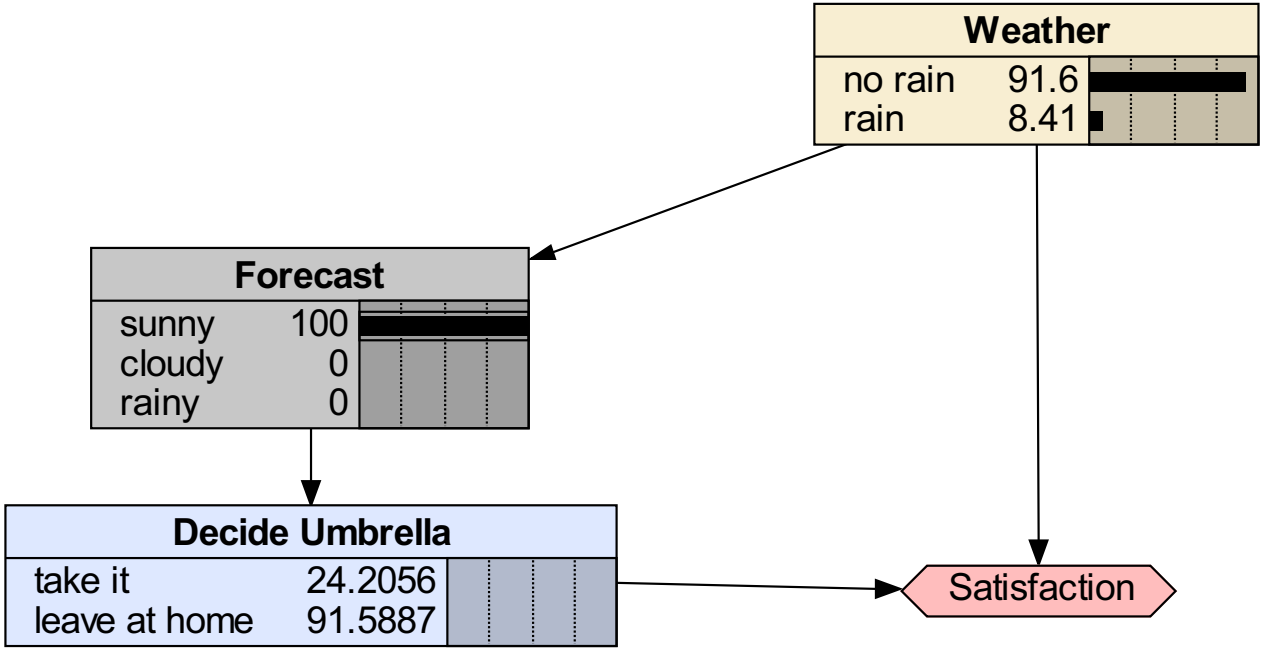

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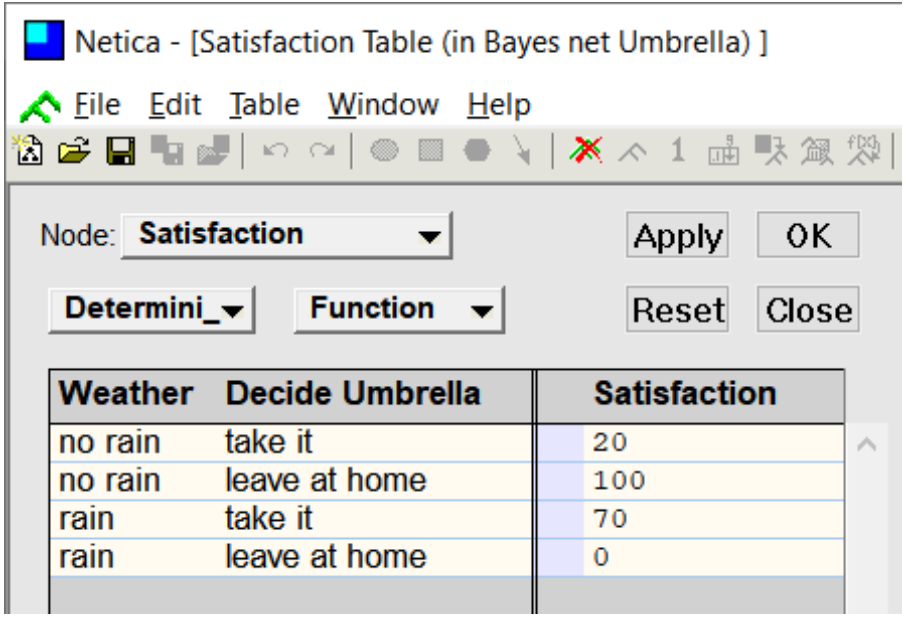
The question boils down to…should I take my umbrella to work today.

Here is a table of the satisfaction of the owner depending on the scenario.

Or if you live in the Northwest you never take the umbrella and just gear up from November until March.

Note that the table is easily accessed by double clicking on the model node.

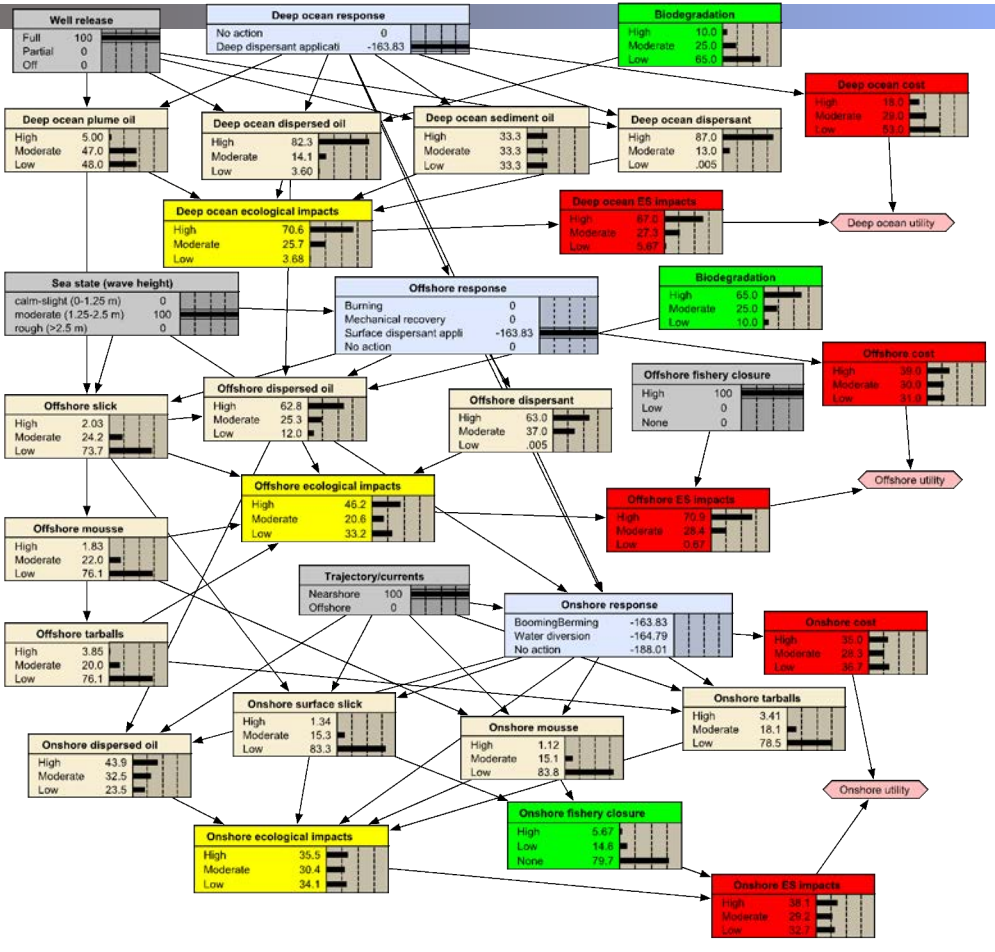


Weather	Decide Umbrella	Satisfaction
no rain	take it	20
no rain	leave at home	100
rain	take it	70
rain	leave at home	0

https://www.norsys.com/netlibrary/index.htm

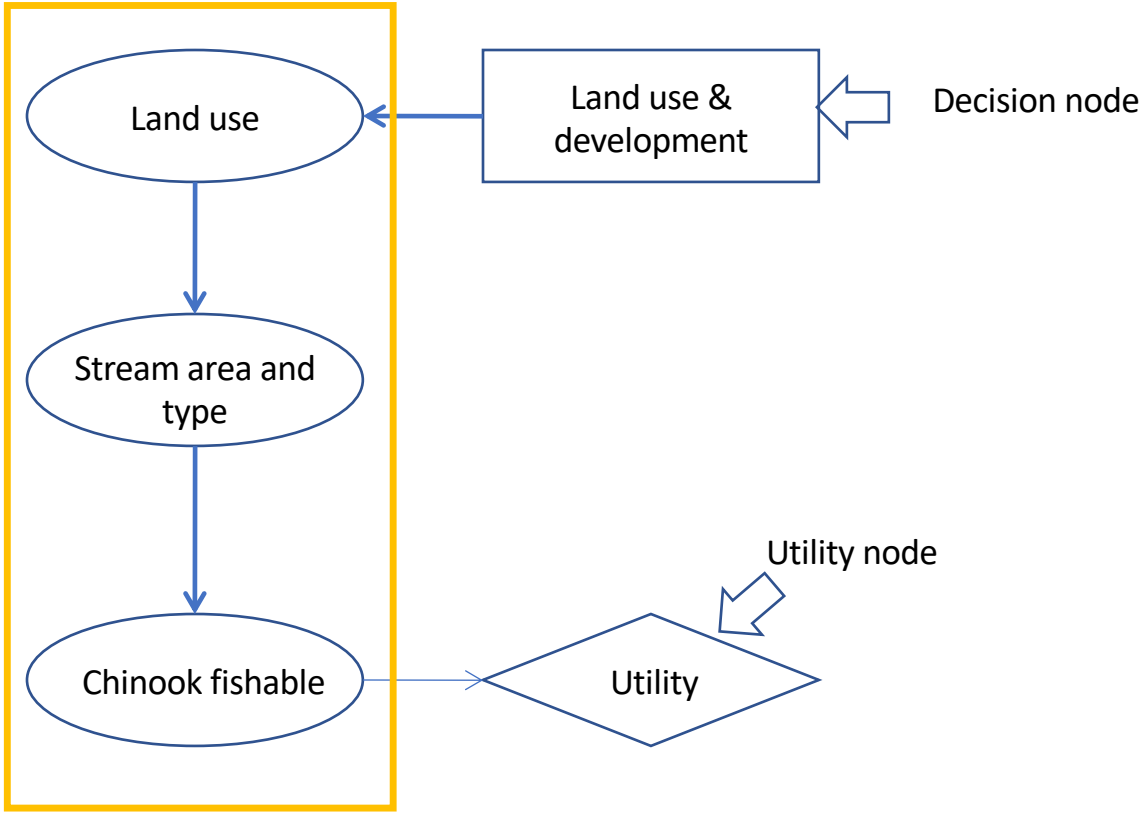
The question boils down to…should I take my umbrella to work today.

Deepwater Horizon was a bigger umbrella-and a classic study



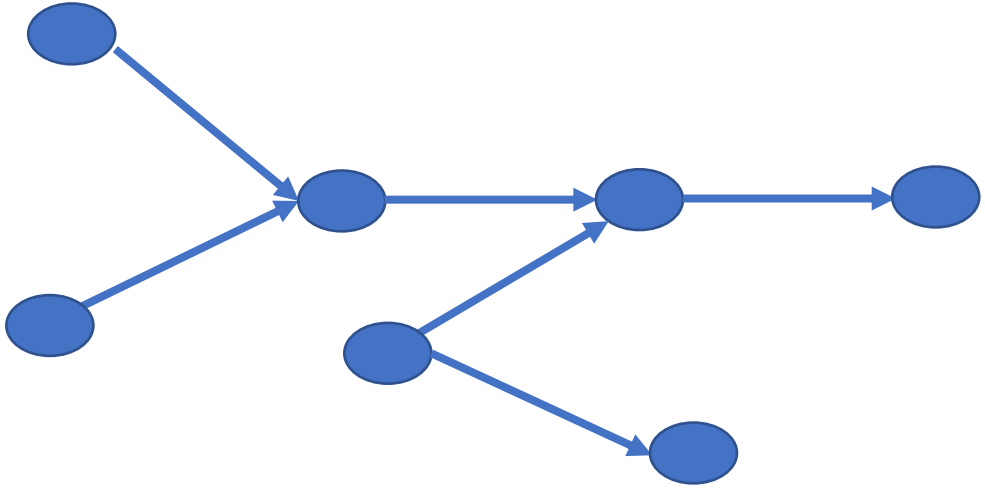
Carriger, J.F. and Barron, M.G., 2011. Minimizing risks from spilled oil to ecosystem services using influence diagrams: The Deepwater Horizon spill response. *Environmental Science & Technology*, *45*(18), pp.7631-7639.

A very simple model-but illustrates the point.



A short background on Bayesian networks

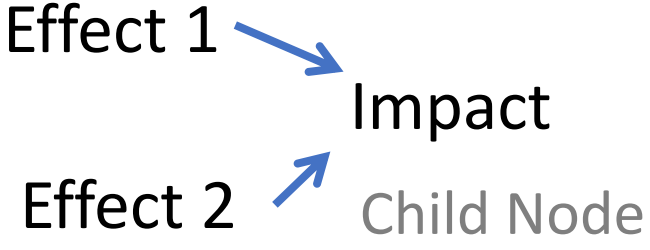
Directed Acyclic graph-left to right-some draw them vertical.



Bayesian networks (BN) are directed acyclic graphs

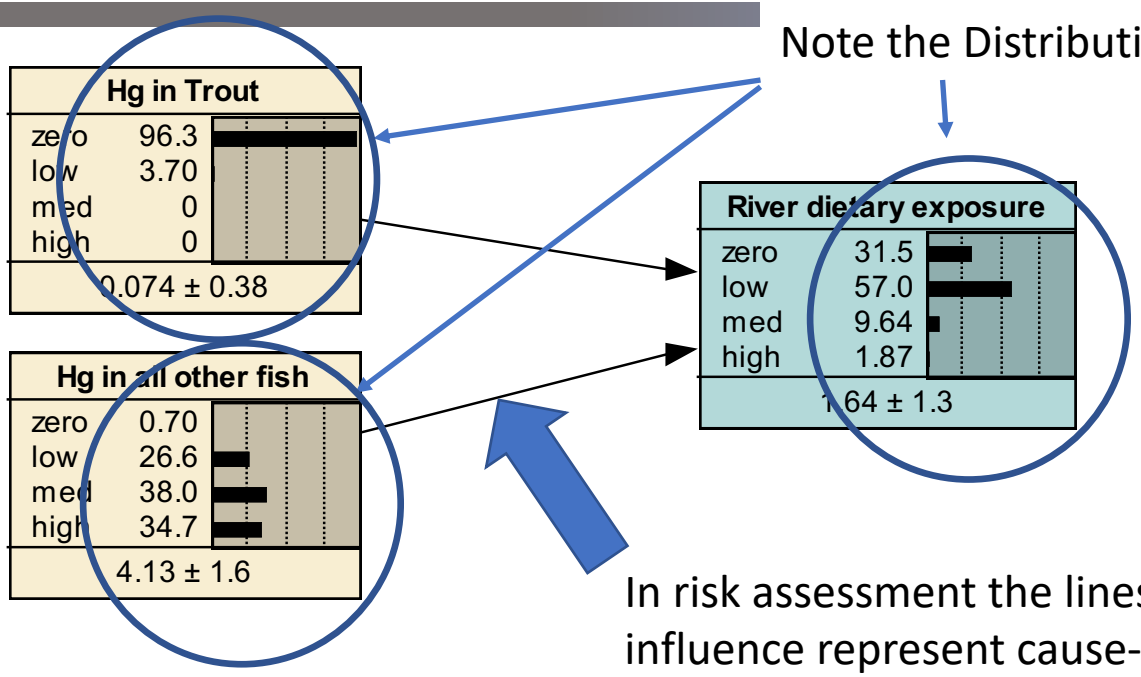
Bayesian Networks (BNs)-even shorter introduction-

Parent Nodes



The result in the child node is determined by a conditional probability table (CPT).

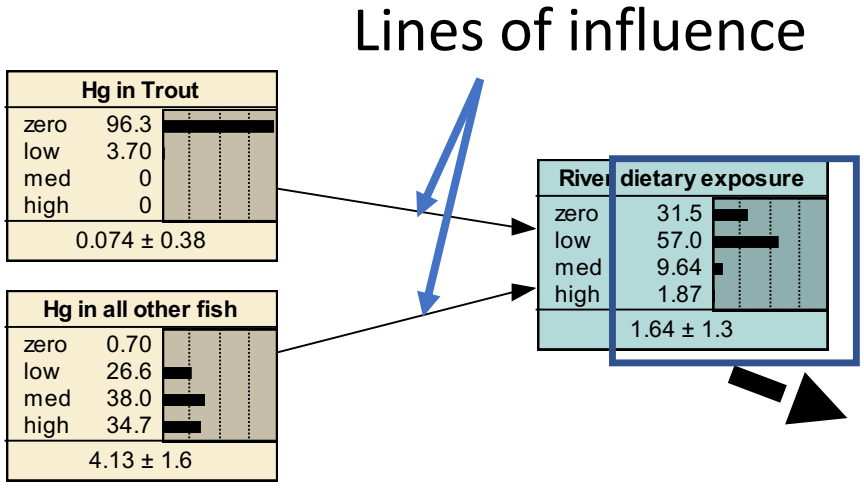
Bayesian network calculations



In risk assessment the lines of influence represent cause-effect pathways.

We use the Netica software
https://www.norsys.com/download.html

The Conditional Probability Table (CPT) is the probability calculator

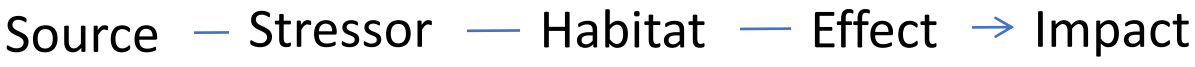


Conditional probability table describes dietary exposure

Hg in all other fish	Hg in Trout	zero	low	med	high
zero	zero	100	0	0	0
zero	low	30	50	20	0
zero	med	5	15	75	5
zero	high	0	0	10	90
low	zero	50	50	0	0
low	low	20	60	20	0
low	med	0	15	80	5
low	high	0	0	10	90
med	zero	25	60	15	0
med	low	10	60	25	5
med	med	0	10	80	10
med	high	0	0	10	90
high	zero	25	60	10	5
high	low	10	60	20	10
high	med	0	0	80	20
high	high	0	0	0	100

Another directed acyclic graph

Relative risk model cause-effect framework



A risk assessment-first a definition

Technical definition: The ***probability*** of an effect on one or more specific endpoints due to a specific stressor or stressors.

In other words, risk reflects how often a specific change or changes in the environment will affect something of value to society, such as human health, outdoor recreation, or the survival of an endangered species.

Here is our example…Landis et al 2020

Chinook salmon in four watersheds in Washington State

Organophosphate as the pesticide chlorpyrifos

Water quality (DO and Temp) as additional stressor

Population model used to estimate populations to year 50.

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Health & Ecological Risk Assessment

Integration of Chlorpyrifos Acetylcholinesterase Inhibition, Water Temperature, and Dissolved Oxygen Concentration into a Regional Scale Multiple Stressor Risk Assessment Estimating Risk to Chinook Salmon

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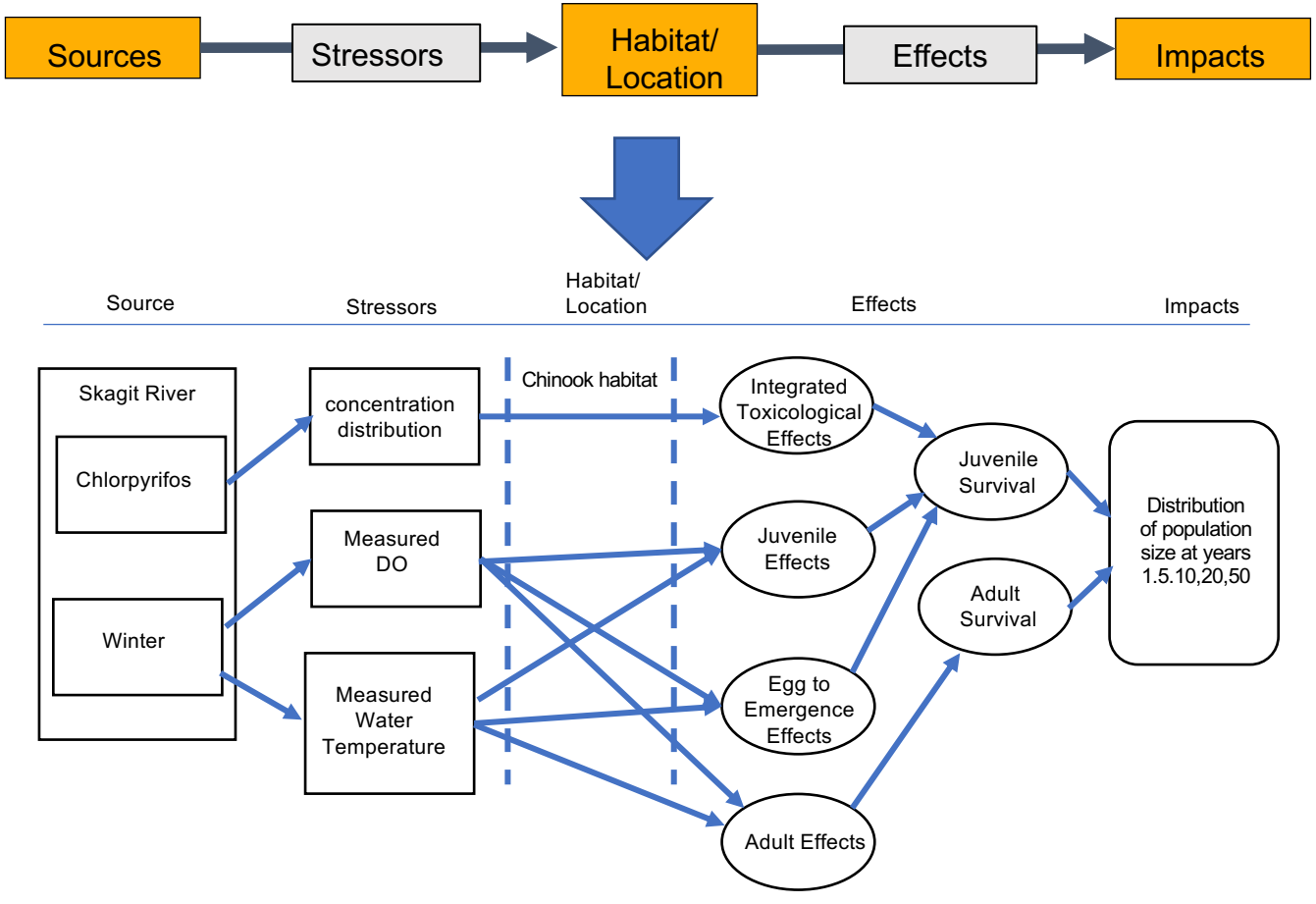
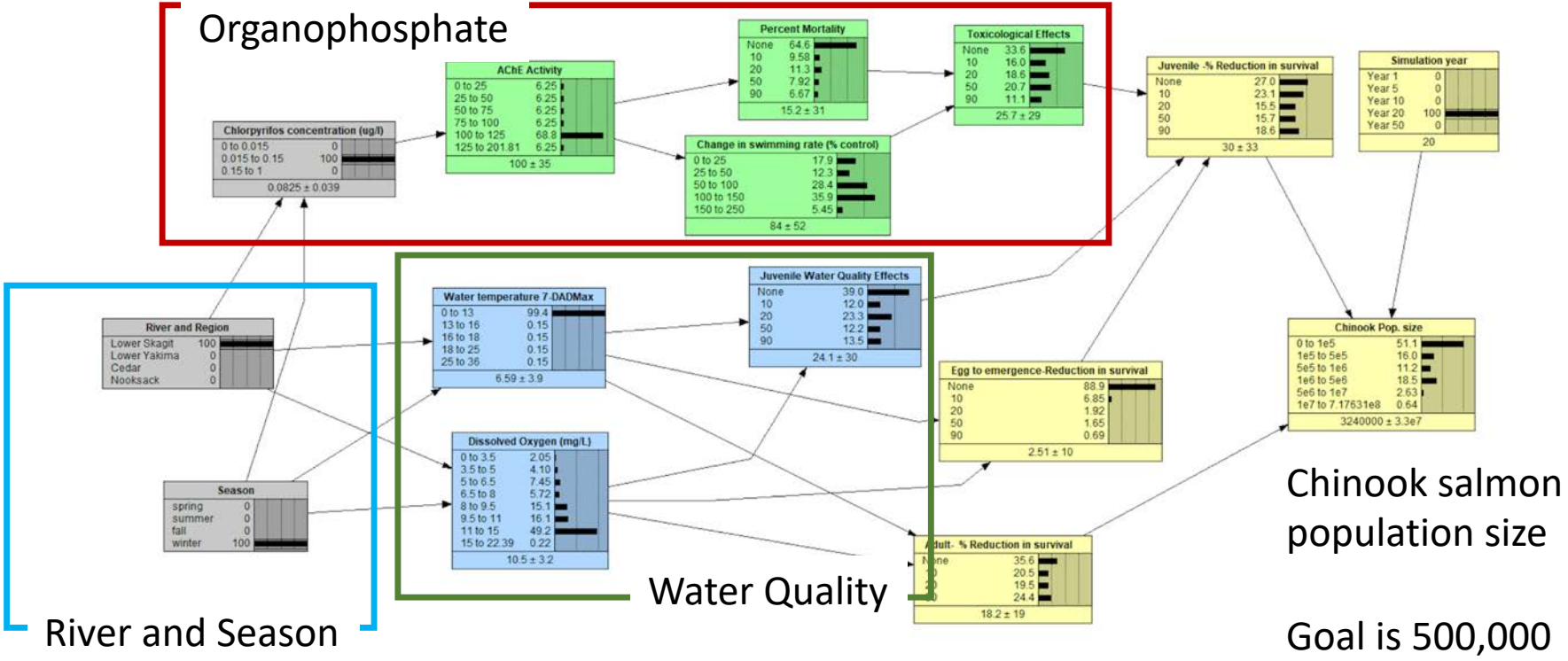
§Center for Health and the Global Environment, Harvard University, TH Chan School of Public Health, Boston, Massachusetts, USA

The simple diagram is turned into a conceptual model…..



…..which is then turned into a Bayesian network



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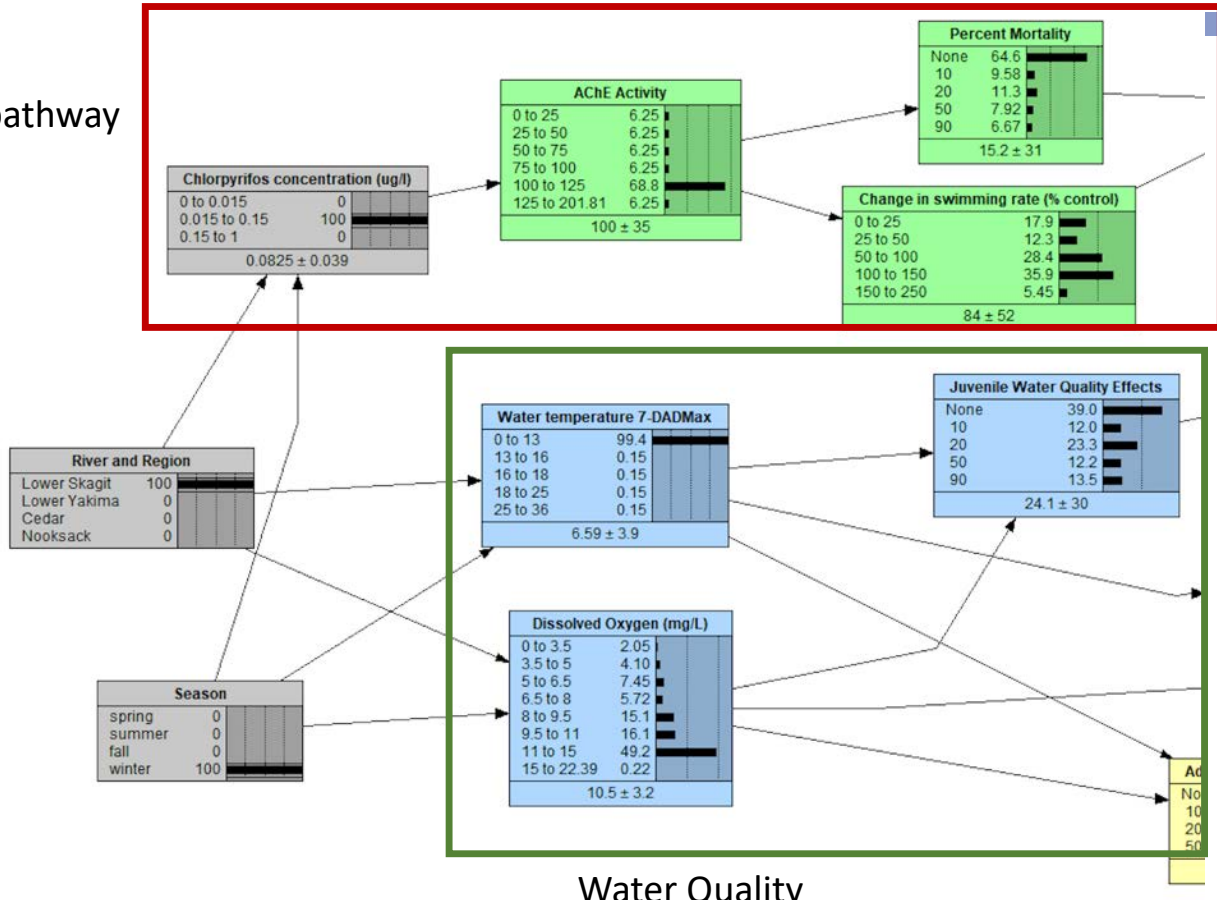
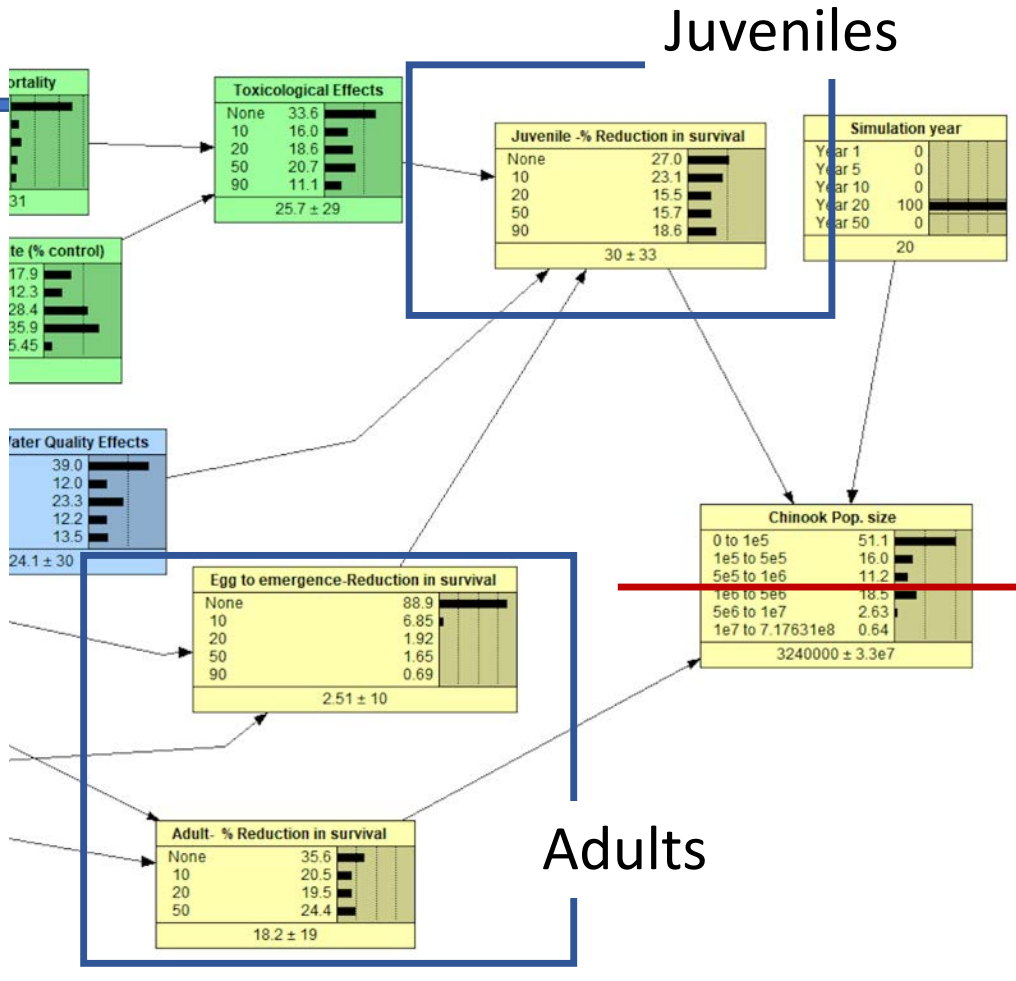
Pesticide pathway



Water Quality

…..which is then turned into a Bayesian network

Each step in the model is transparently presented and the details are observable by double clicking on the node.



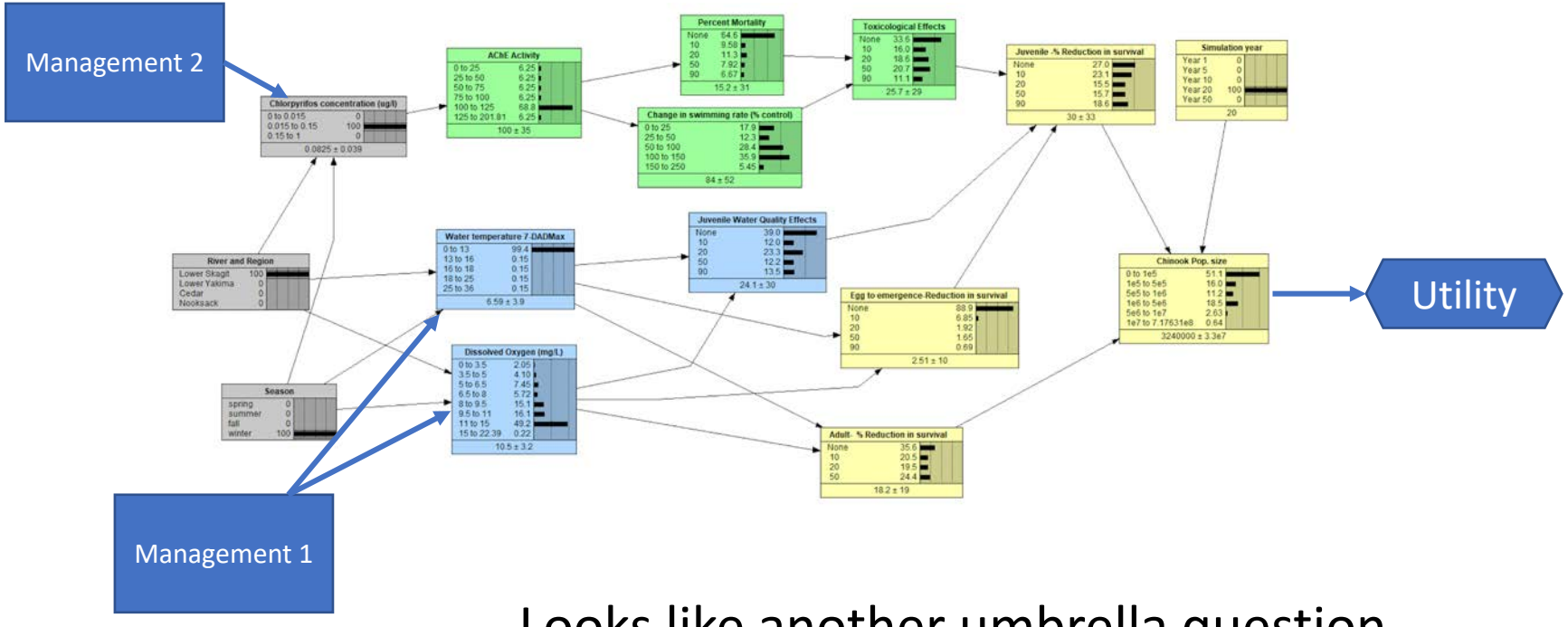
Population Node Chinook Salmon based on Baldwin model with uncertainty included (C. Mitchell)

We can now compare the factors contributing to risk

Scenario	Risk	No OP	Change in risk	OP Percent Risk	Ecological Percent Risk
Skagit-winter	67.3	54.7	12.6	18.7	81.3
Skagit-summer	80.2	72.7	7.5	9.4	90.6
Nooksack-winter	67.3	55.0	12.3	18.3	81.7
Nooksack-summer	92.4	89.9	2.5	**2.7**	97.3
Cedar-winter	64.5	51.3	13.2	**20.5**	79.5
Cedar-summer	81.8	74.8	7.0	8.6	91.4
Yakima-winter	65.8	53.1	12.7	19.3	80.7
Yakima-summer	85.3	79.8	5.5	6.4	93.6

Now we can calculate the contribution to risk due to each pathway-water quality pathway is the largest contributor.

Now to include management options and a utility node.



Looks like another umbrella question.

Now to include management options, and an ecosystem service.

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

An introduction to Bayesian networks as assessment and decision support tools for managing coral reef ecosystem services

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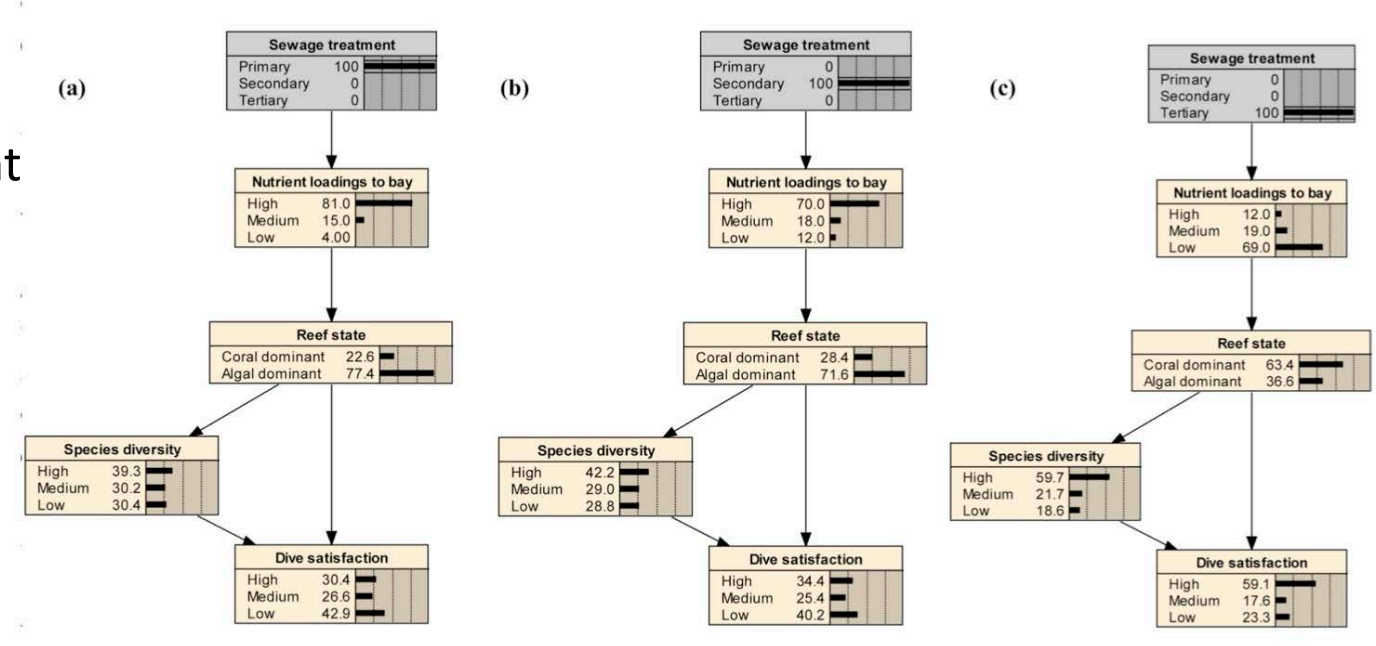
[c] U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, United States

Easy to update the initial node by point and click

Ocean and Coastal Management 177 (2019) 188–199

Sewage treatment and scuba dive satisfaction.



BNs have been used in multiple cases to evaluate management options.

Carriger, J.F. and Barron, M.G., 2011. Minimizing risks from spilled oil to ecosystem services using influence diagrams: The Deepwater Horizon spill response. *Environmental Science & Technology*, *45:*7631-7639.

Ayre KK, Landis WG. 2012. A Bayesian approach to landscape ecological risk assessment applied to the Upper Grande Ronde watershed, Oregon. *Human and Ecological Risk Assessment.* 18:5 946-970

Johns, AF, Graham SE, Harris MJ, Markiewicz AJ, Stinson JM, Landis WG. 2017. Using the Bayesian Network Relative Risk Model Risk Assessment Process to Evaluate Management Alternatives for the South River and Upper Shenandoah River, Virginia**.** *Integr Environ Assess Manag*. 13:100-114

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Graham SE, Chariton AA, Landis WG. 2020. Using Bayesian networks to predict risk to estuary water quality and patterns of benthic environmental DNA in Queensland. *Integr Environ Assess Manag*. 15:93-111.DOI: 10.1002/ieam.4091

Stakeholders-multiple scenarios and criteria

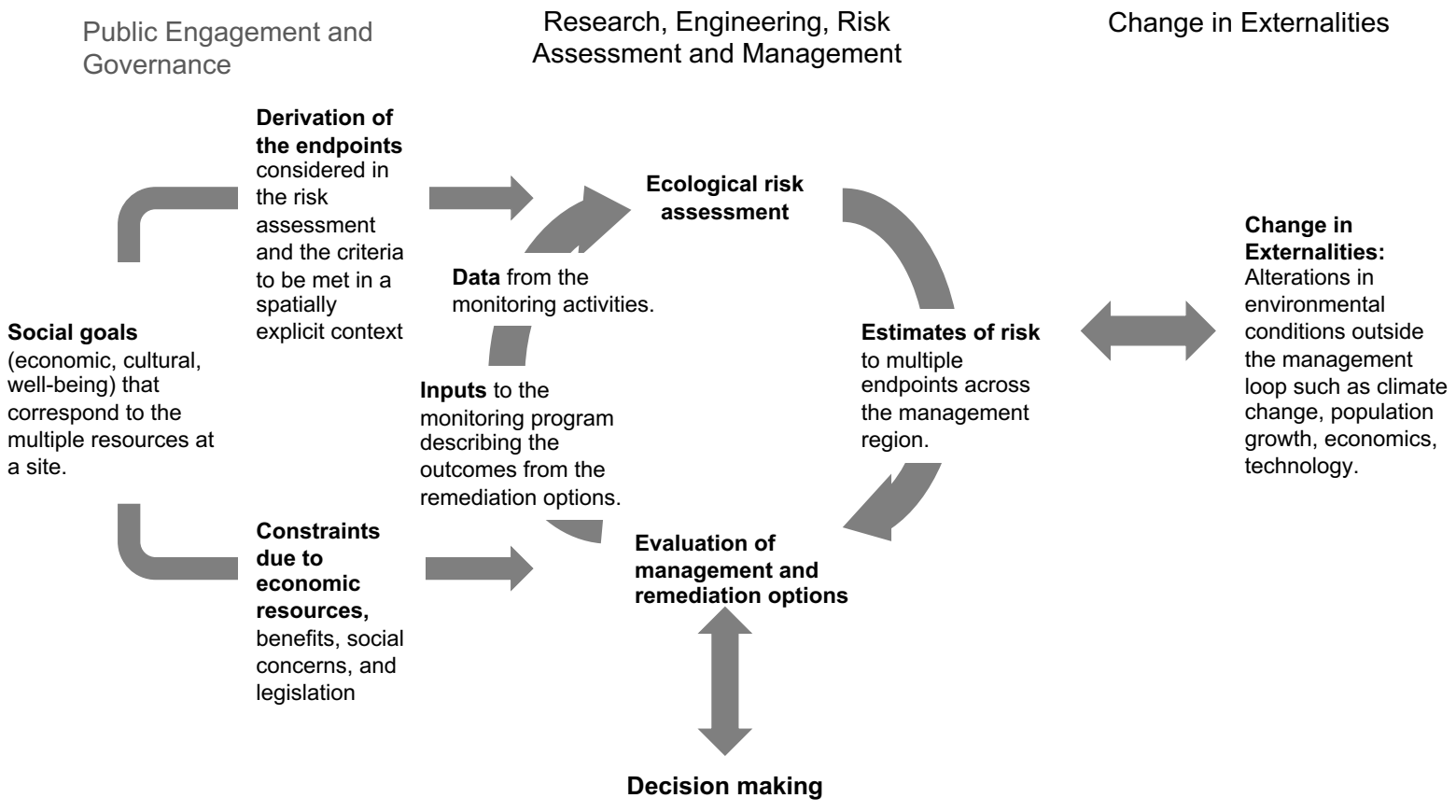
USFS with the INLAS Forest-USFS managers

Whirling Disease-Fish and Wildlife Regional managers

South River, VA-Virginia DEQ, USFW, USEPA, City of Waynesboro, South River Science Team

Upper San Francisco Estuary-State Water Contractors, Metropolitan Water District, Delta Project, California Department of Pesticide Regulation, Department of Wildlife, Cal EPA

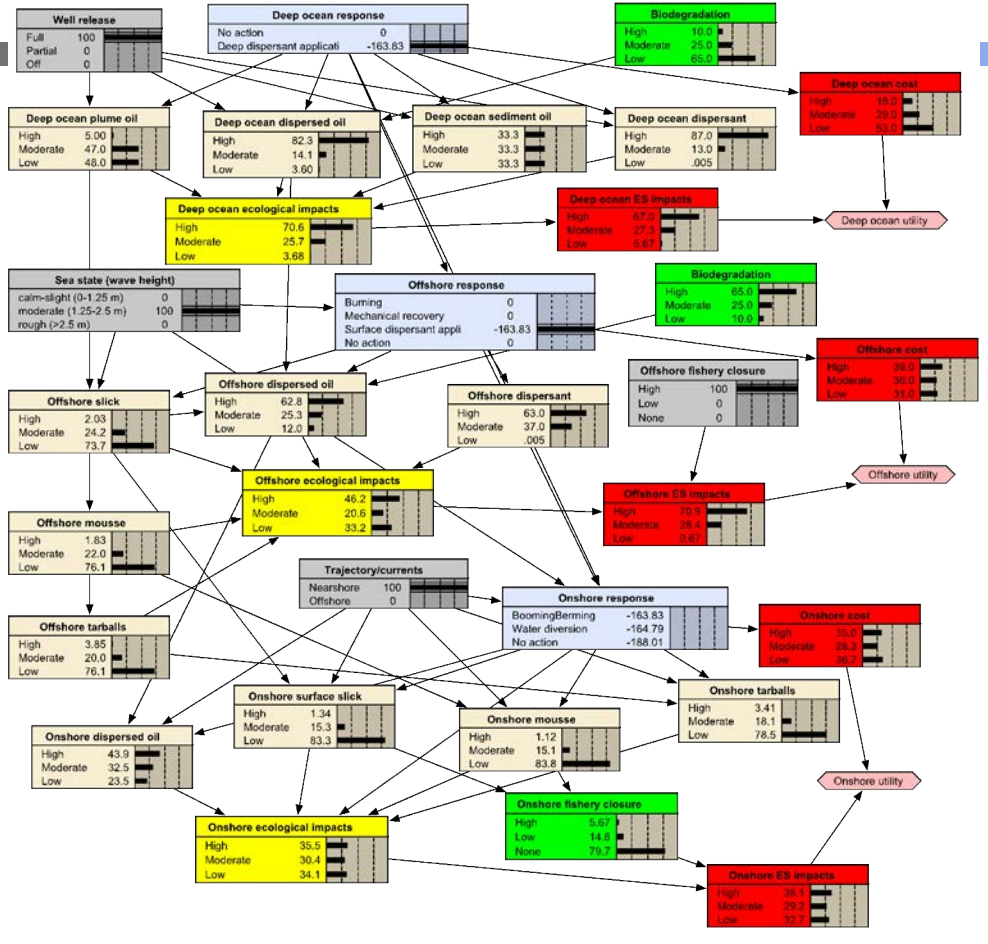
Adaptive Management-Landis et al 2017



Questions and Comments?

Now to include management options and a utility node.

Much more detail and a number of management options and utility criteria



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