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Bayesian Belief Networks (BBNs): A Tool to Integrate Expert Opinion into Land Use Planning

Presented at: *BC's Coastal Forests: Planning for
Sustainability in a Dynamic Landscape Workshop*
Nanaimo, March 7th, 2006

Presented by: Adrian Walton, Landscape Modeling
Biologist, BC Ministry of Forests.

Presentation Overview

- What are Bayesian belief networks?
- Why Are They Useful for Land use Planning?
- Why are they called Bayes nets?
- Where have they been used?
- How to create a Bayesian belief network
 - Building the network structure
 - Entering Findings
 - Testing using case files
 - Learning (updating) from case files
- Examples and online resources

What is a Bayesian Belief Network?

- A multivariate model (i.e. an attempt to explain the interactions between multiple factors)
- For example, what is the relationship between recreation value, cultural value, timber value and forest management strategy?

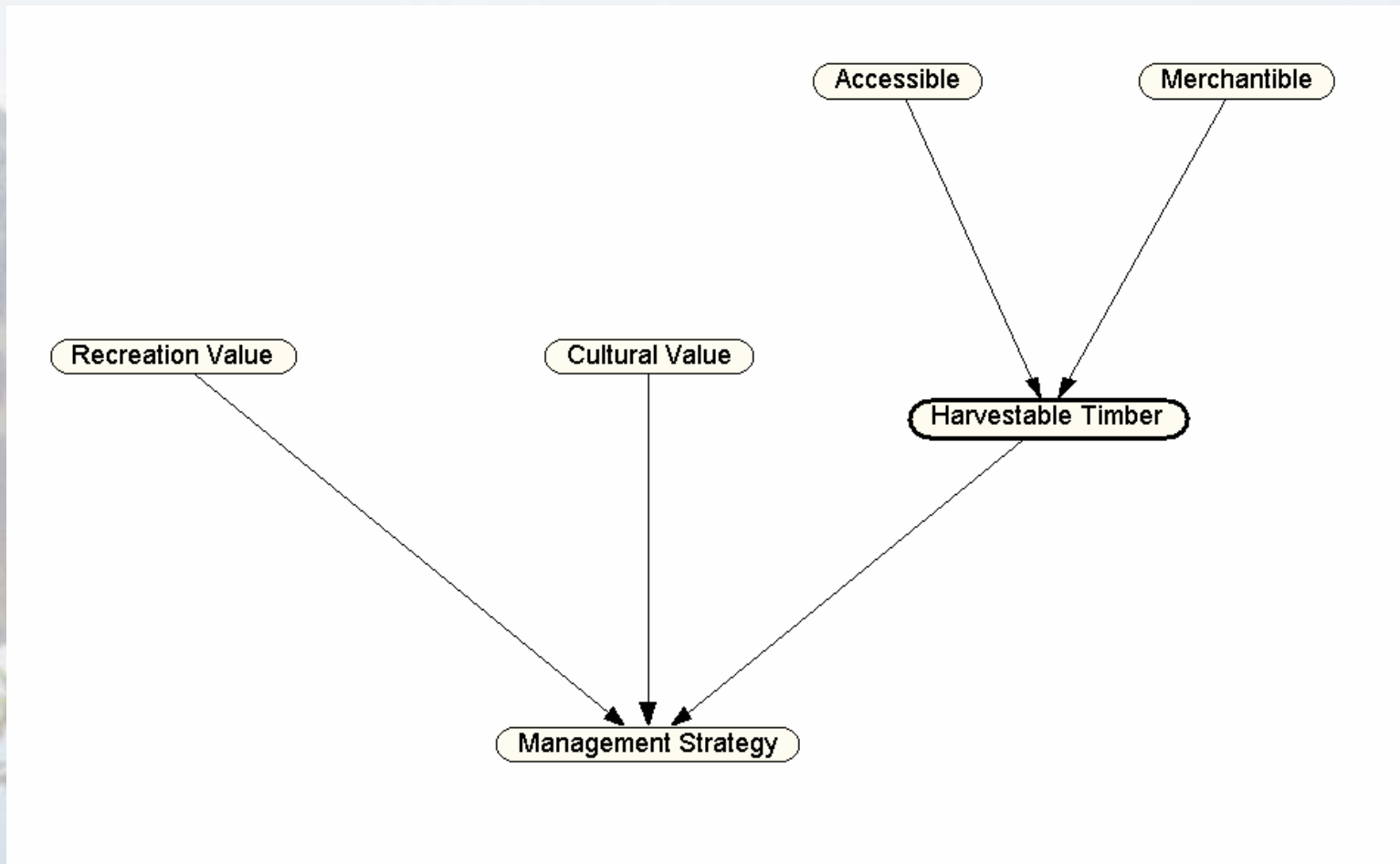
$$Y = b_0 + b_1P + b_2Q$$

$$Y = b_0 + b_1P + b_2P^2 + b_3Q + b_4Q^2 + b_5R$$

$$Y = b_0 + b_1P + b_2P^2 + b_3Q + b_4Q^2 + b_5R + b_6R^2 + b_7P^*Q + b_8P^*R + b_9Q^*R$$

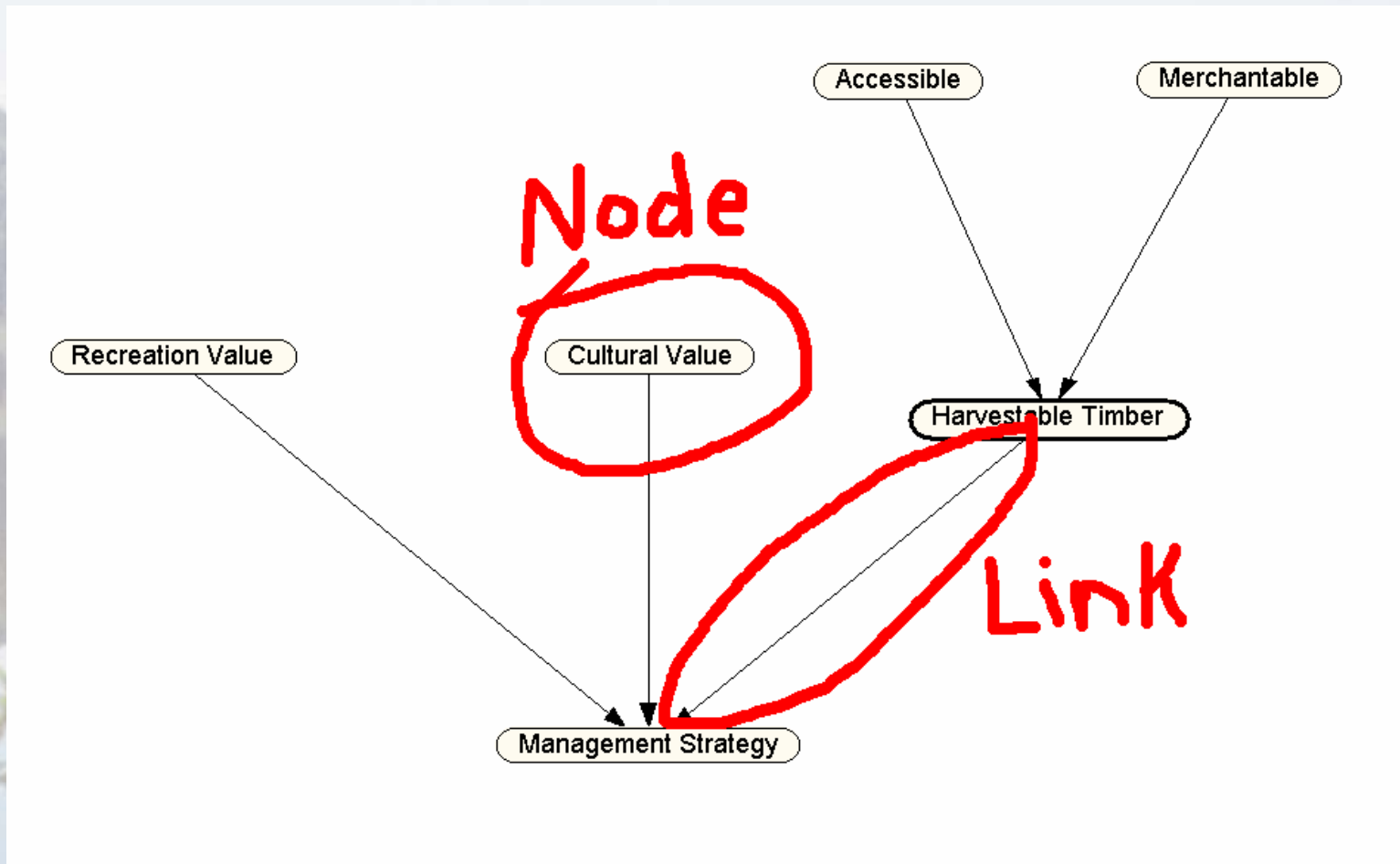
What is a Bayesian Belief Network?

- A graphical network



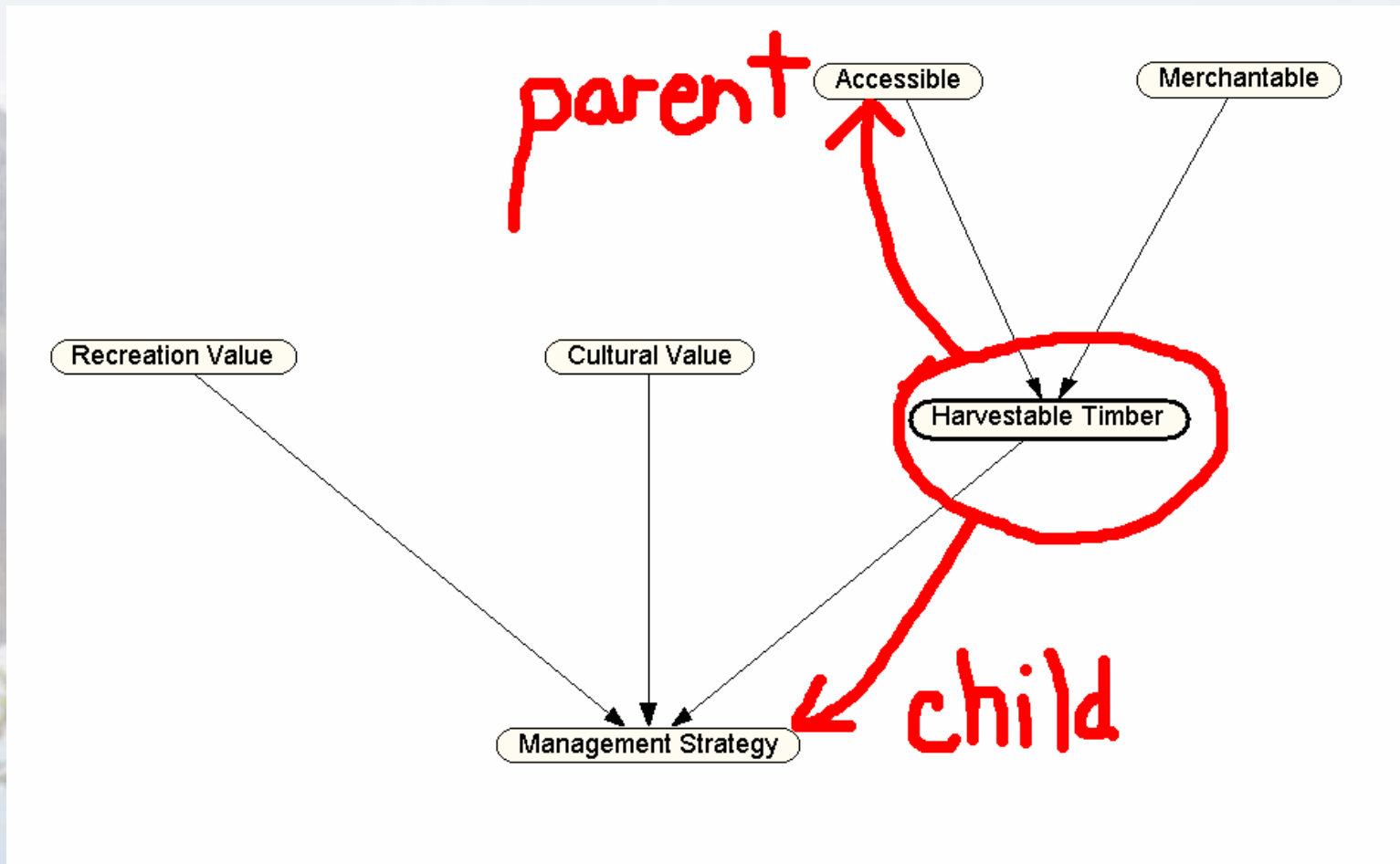
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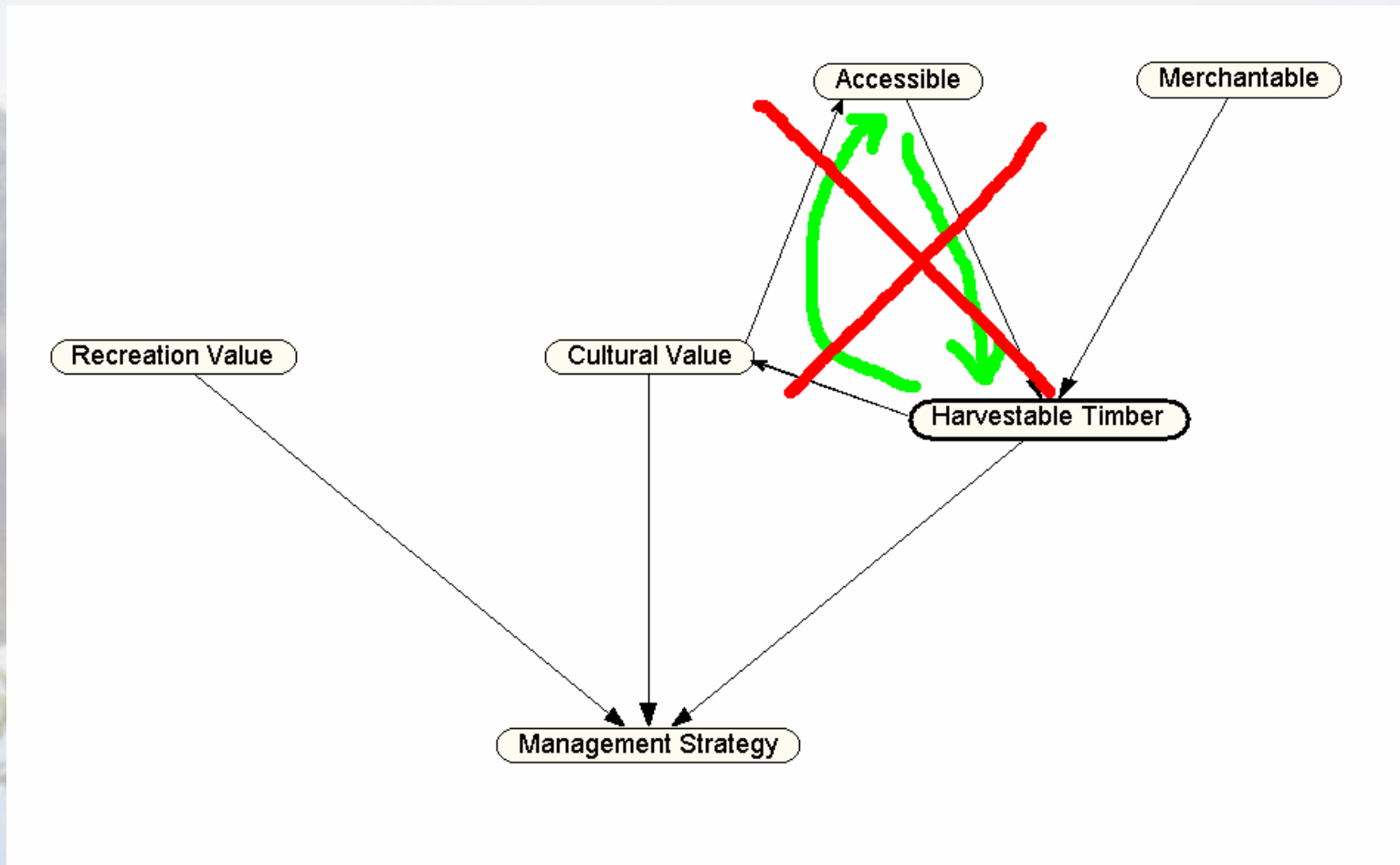
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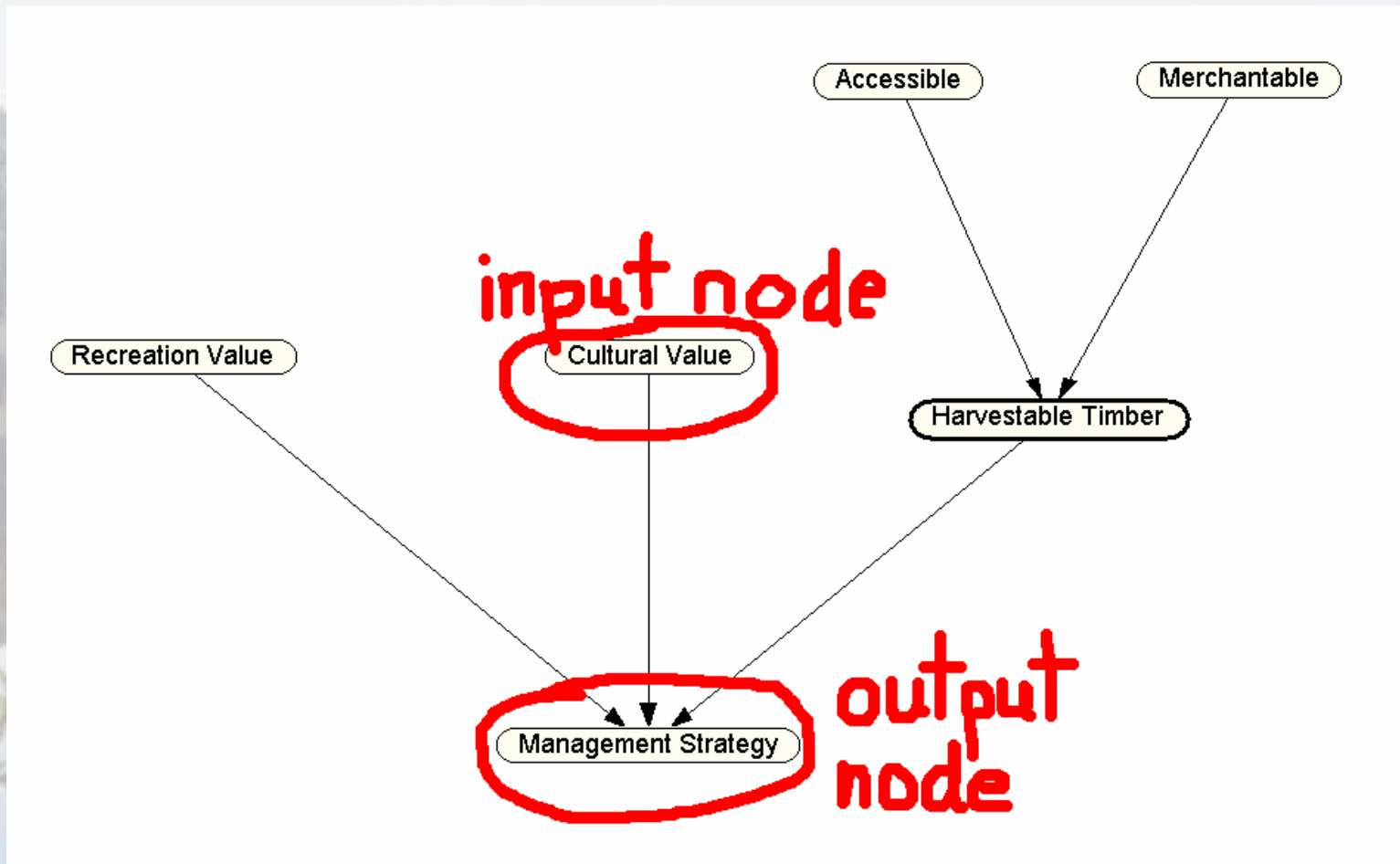
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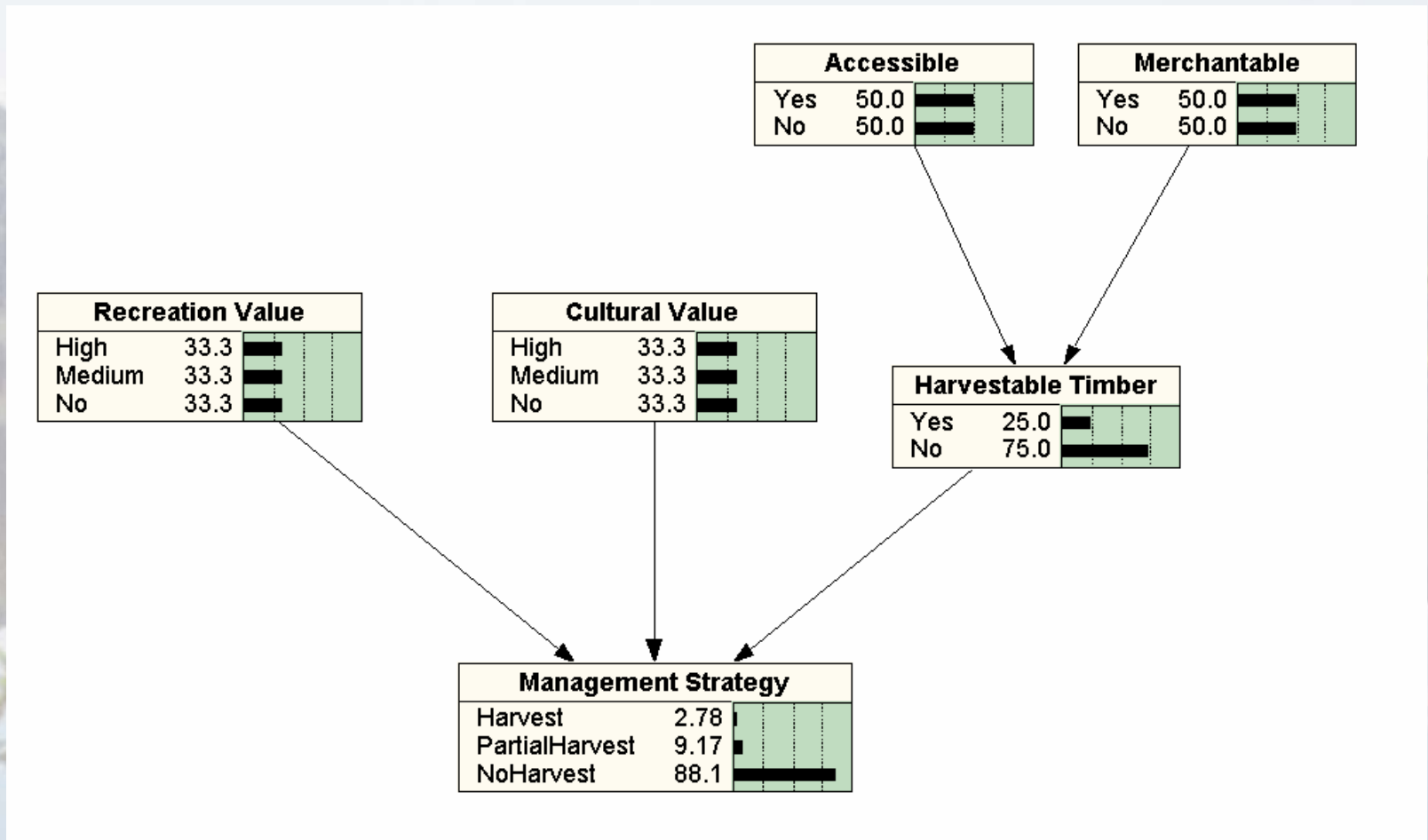
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What is a Bayesian Belief Network?

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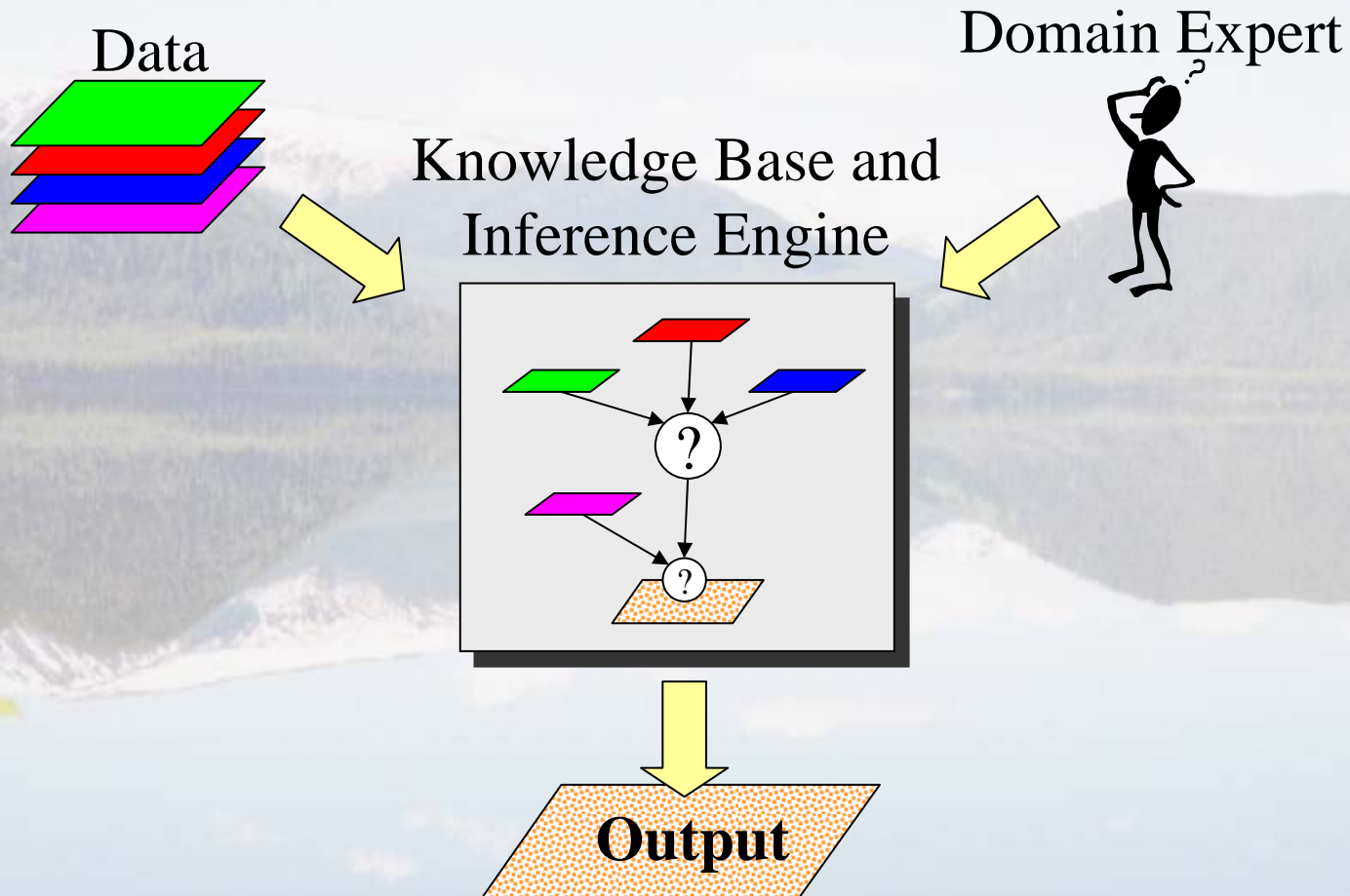
What is a Bayesian Belief Network?

- A graphical network

Recreation Value	Cultural Value	Harvestable Timber	Harvest	PartialHarvest	NoHarvest
High	High	Yes		5.000	95.000
High	High	No			100.00
High	Medium	Yes		50.000	50.000
High	Medium	No			100.00
High	No	Yes		50.000	50.000
High	No	No			100.00
Medium	High	Yes		25.000	75.000
Medium	High	No			100.00
Medium	Medium	Yes		25.000	75.000
Medium	Medium	No			100.00
Medium	No	Yes		100.00	
Medium	No	No			100.00
No	High	Yes		25.000	75.000
No	High	No			100.00
No	Medium	Yes		50.000	50.000
No	Medium	No			100.00
No	No	Yes	100.00		
No	No	No			100.00

What is a Bayesian Belief Network?

- A type of knowledge base used in an expert system



Why Are They Useful for Land Use Planning?

- Can incorporate expert opinion
- Can include qualitative and/or quantitative information

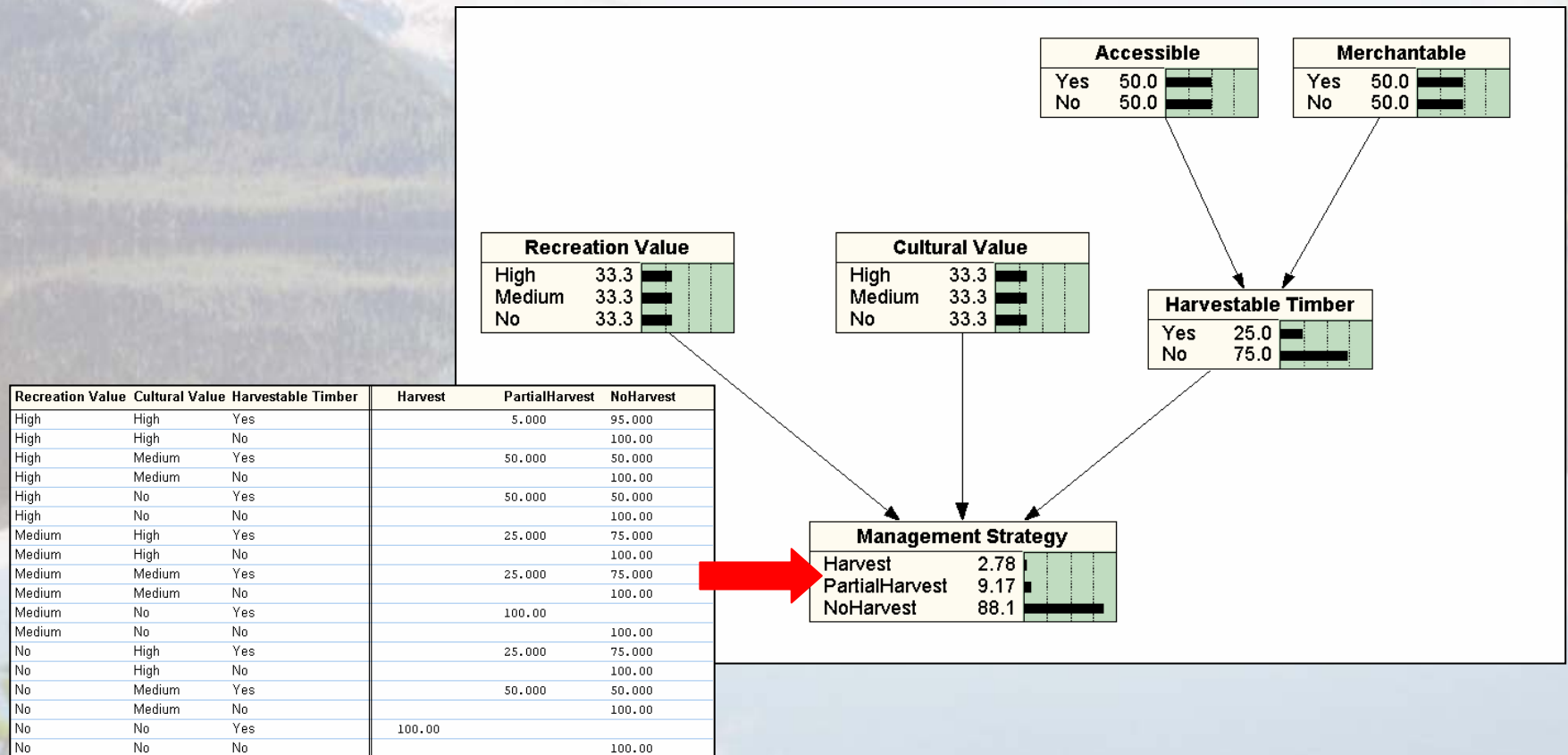
Slope Percent		
Slope 0 to 10	20.0	█
Slope 11 to 20	20.0	█
Slope 21 to 40	20.0	█
Slope 41 to 100	20.0	█
Slope 100 plus	20.0	█

Slope Grade		
Flat	20.0	█
Gentle	20.0	█
Moderate	20.0	█
Steep	20.0	█
Extremely Steep	20.0	█

Why Are They Useful for Land Use Planning?

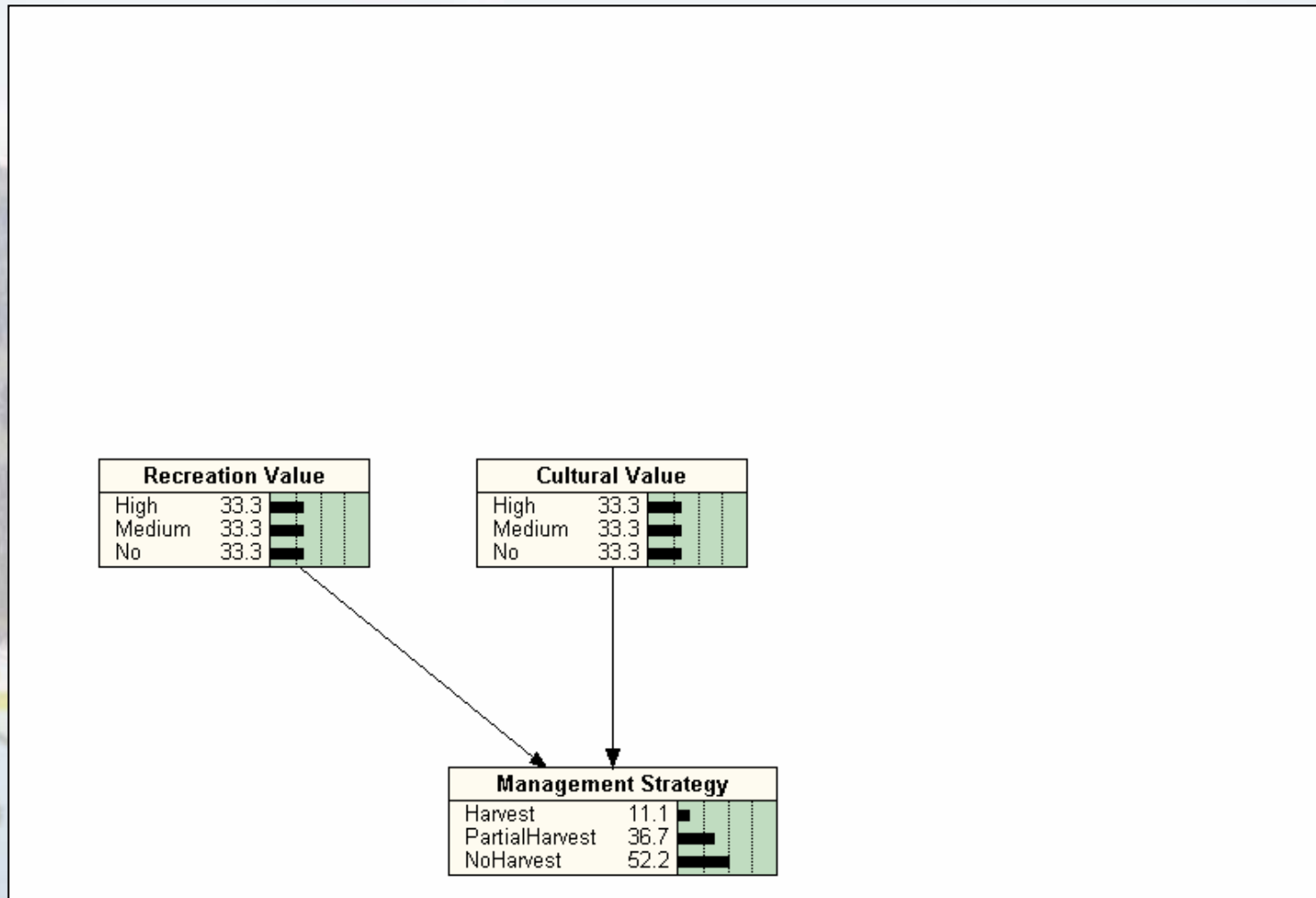
- Transparent

- Variables, classes and relationships are clearly presented.



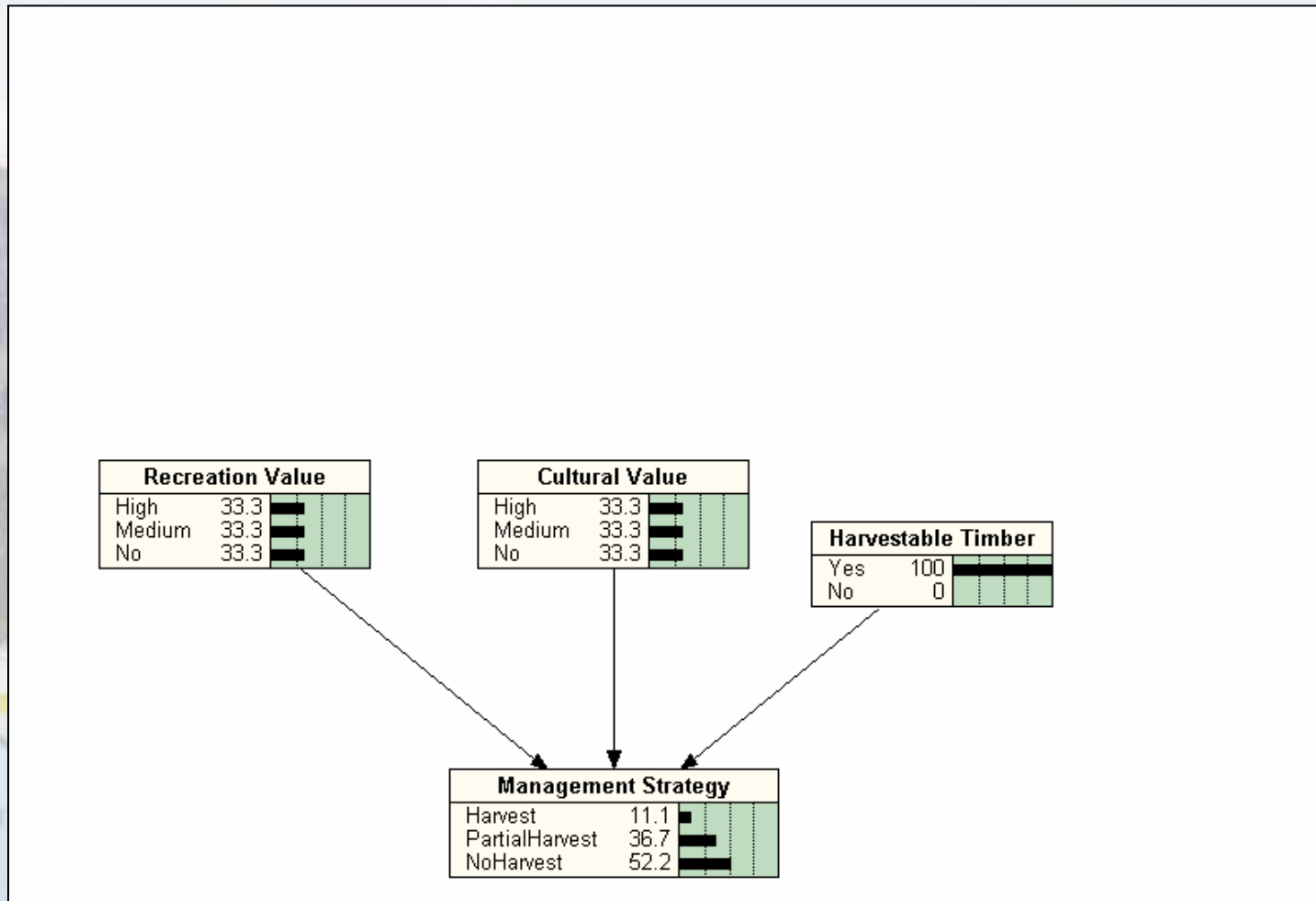
Why Are They Useful for Land Use Planning?

- Adaptable



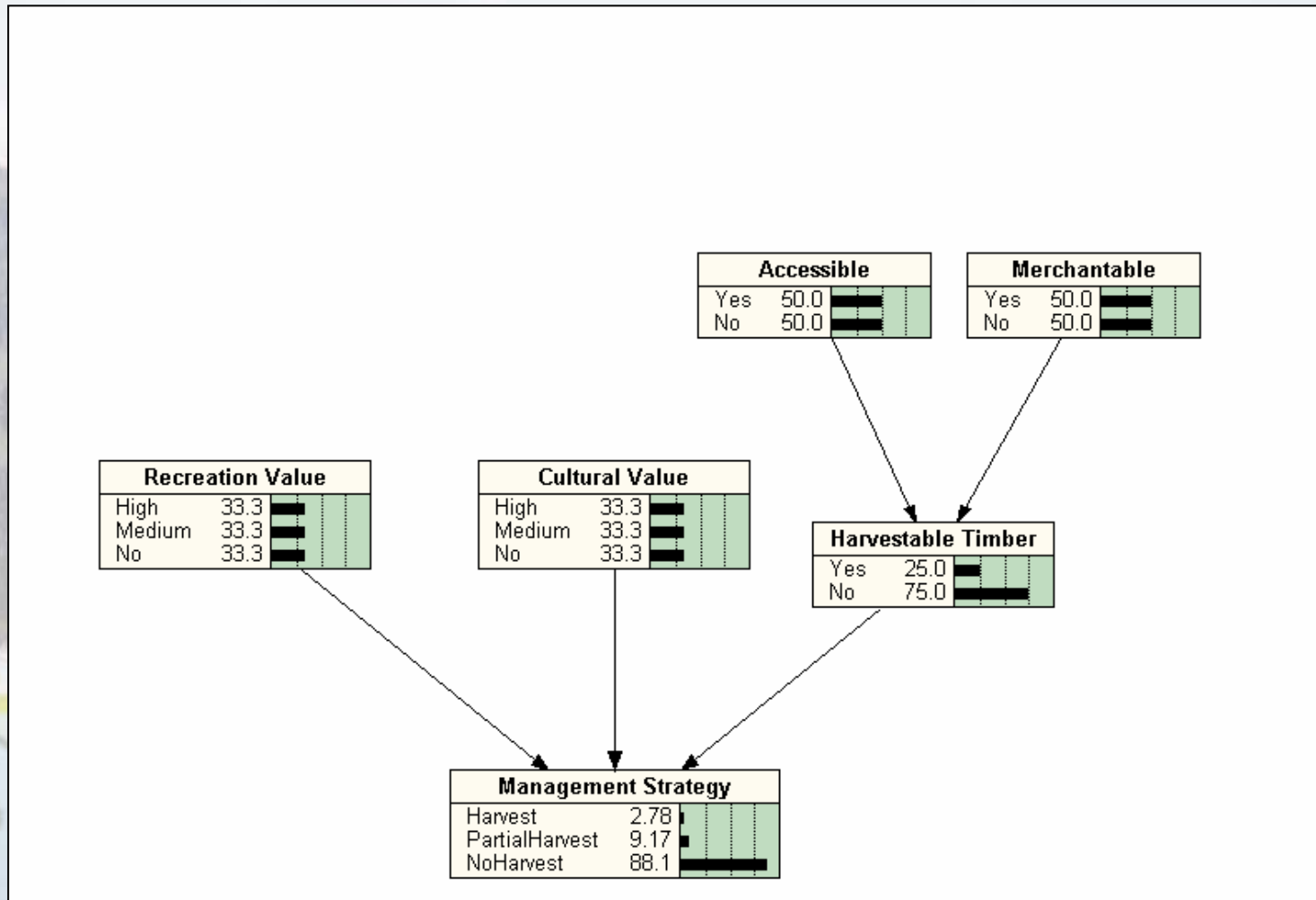
Why Are They Useful for Land Use Planning?

- Adaptable



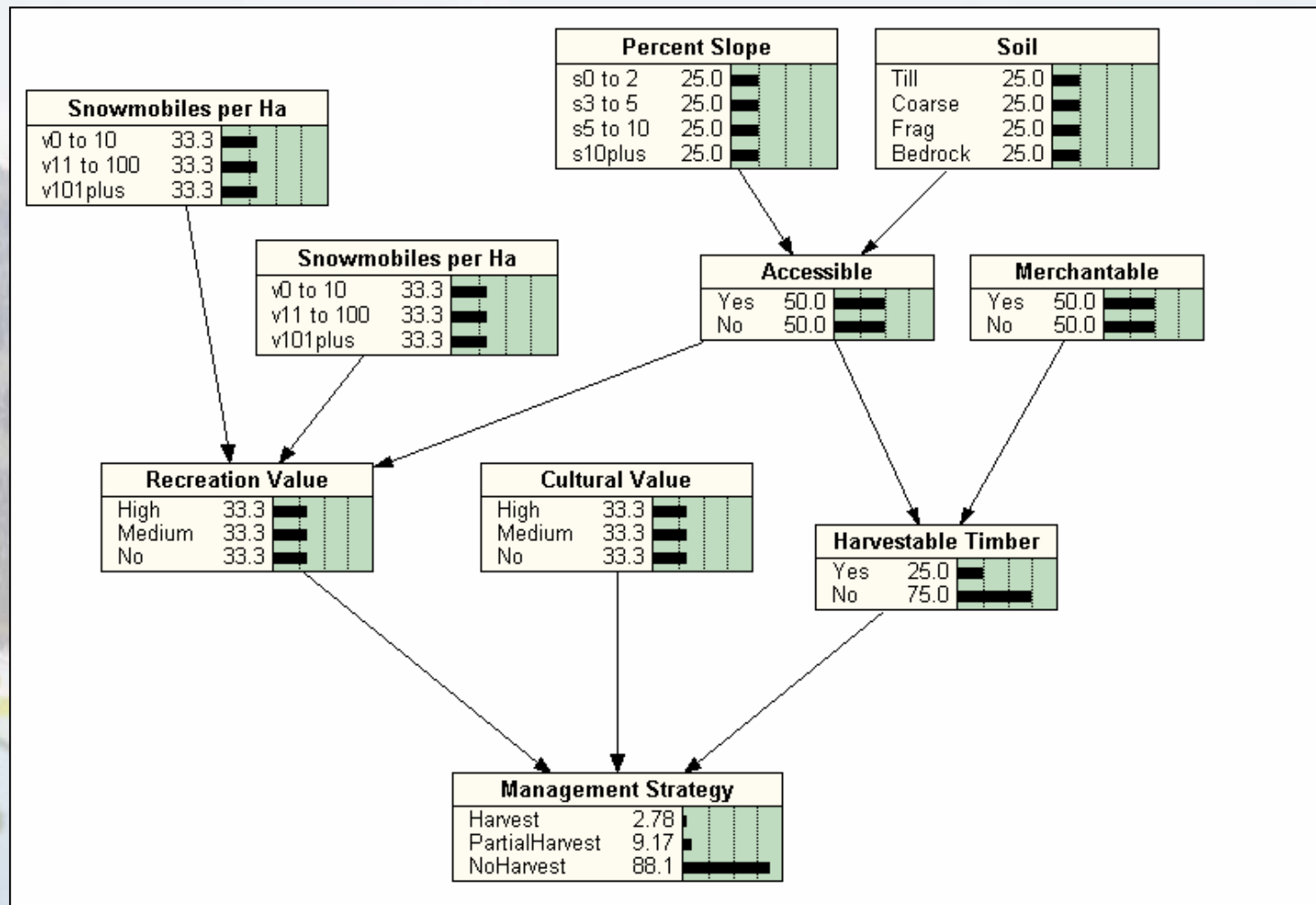
Why Are They Useful for Land Use Planning?

- Adaptable



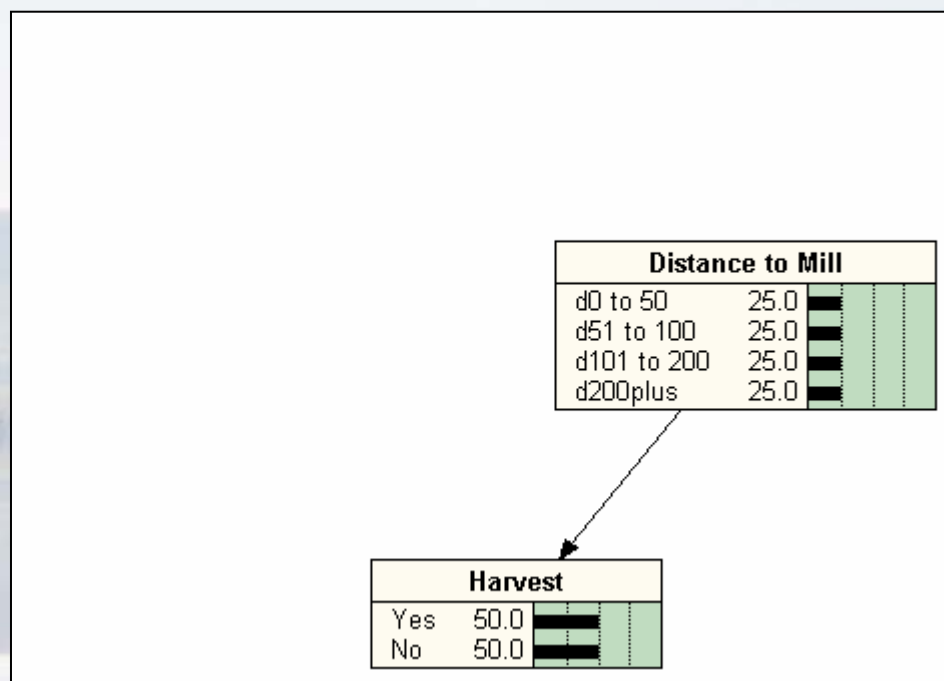
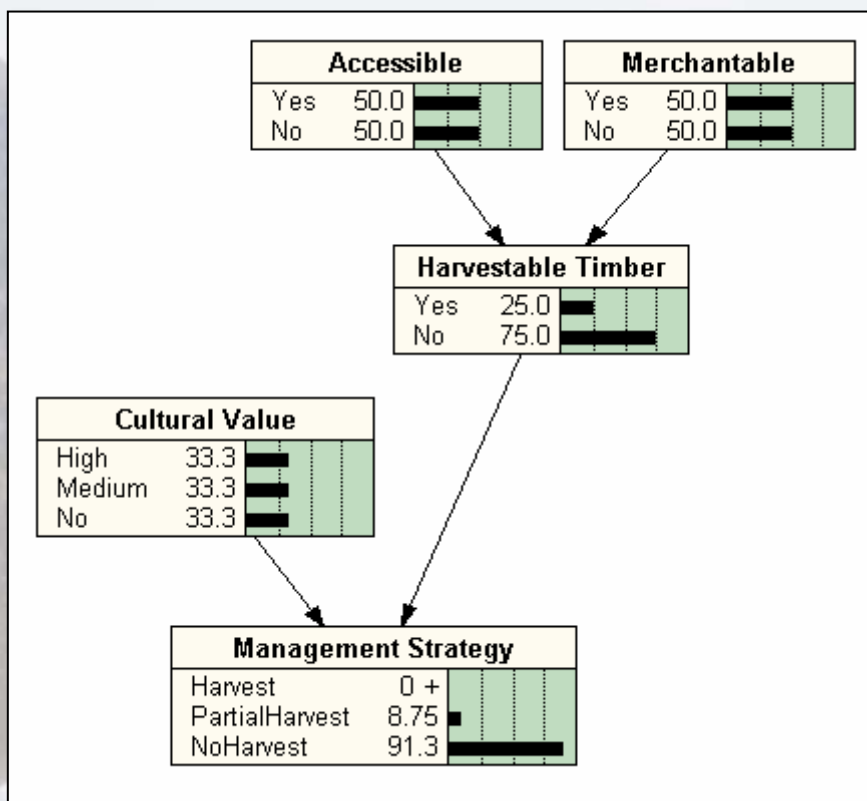
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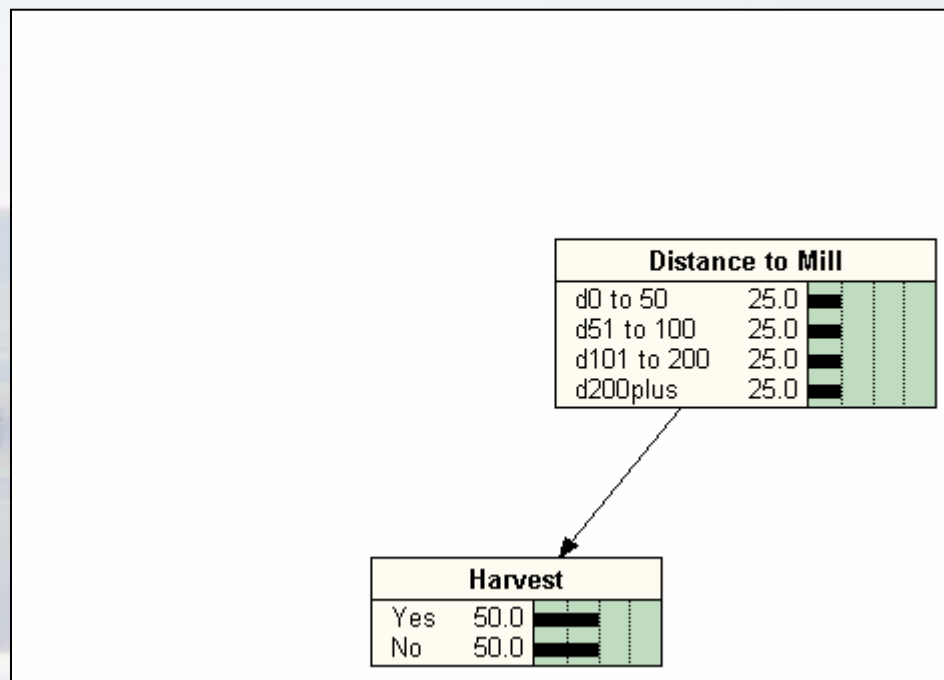
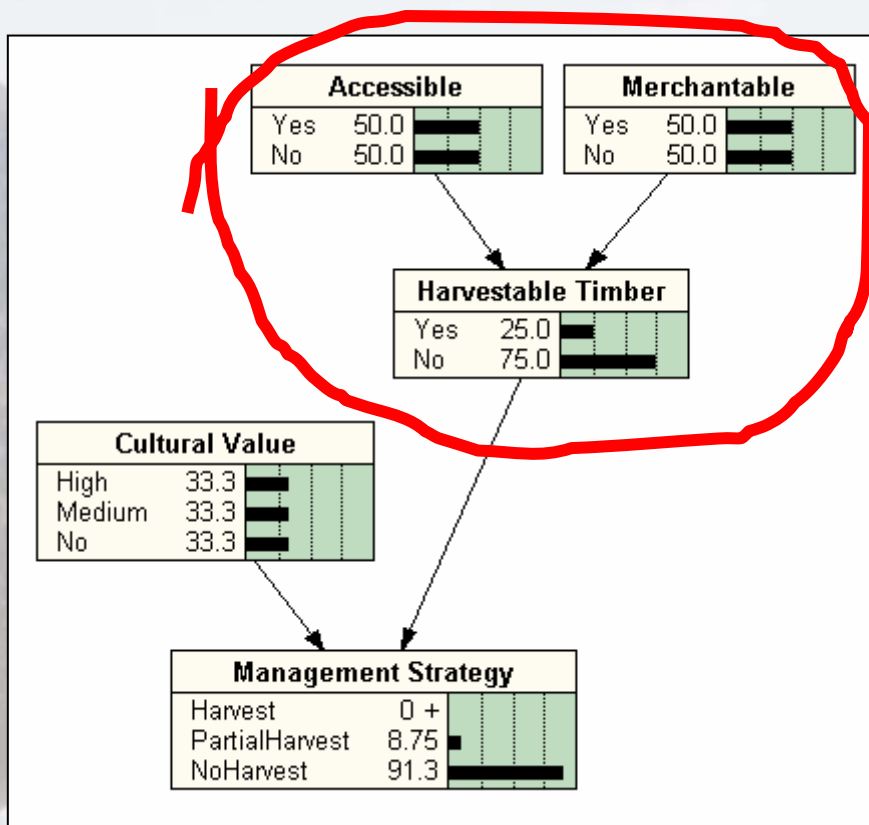
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- Adaptable



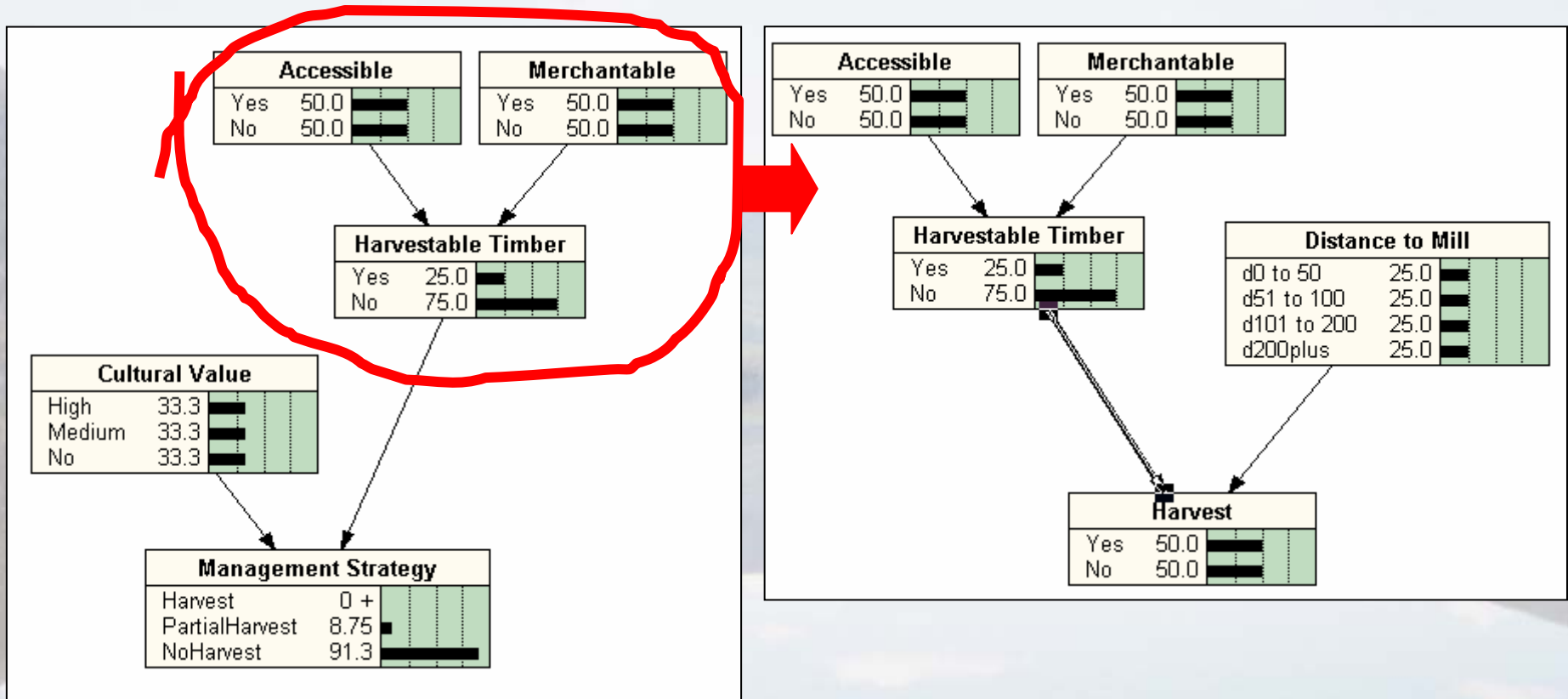
Why Are They Useful for Land Use Planning?

- Adaptable



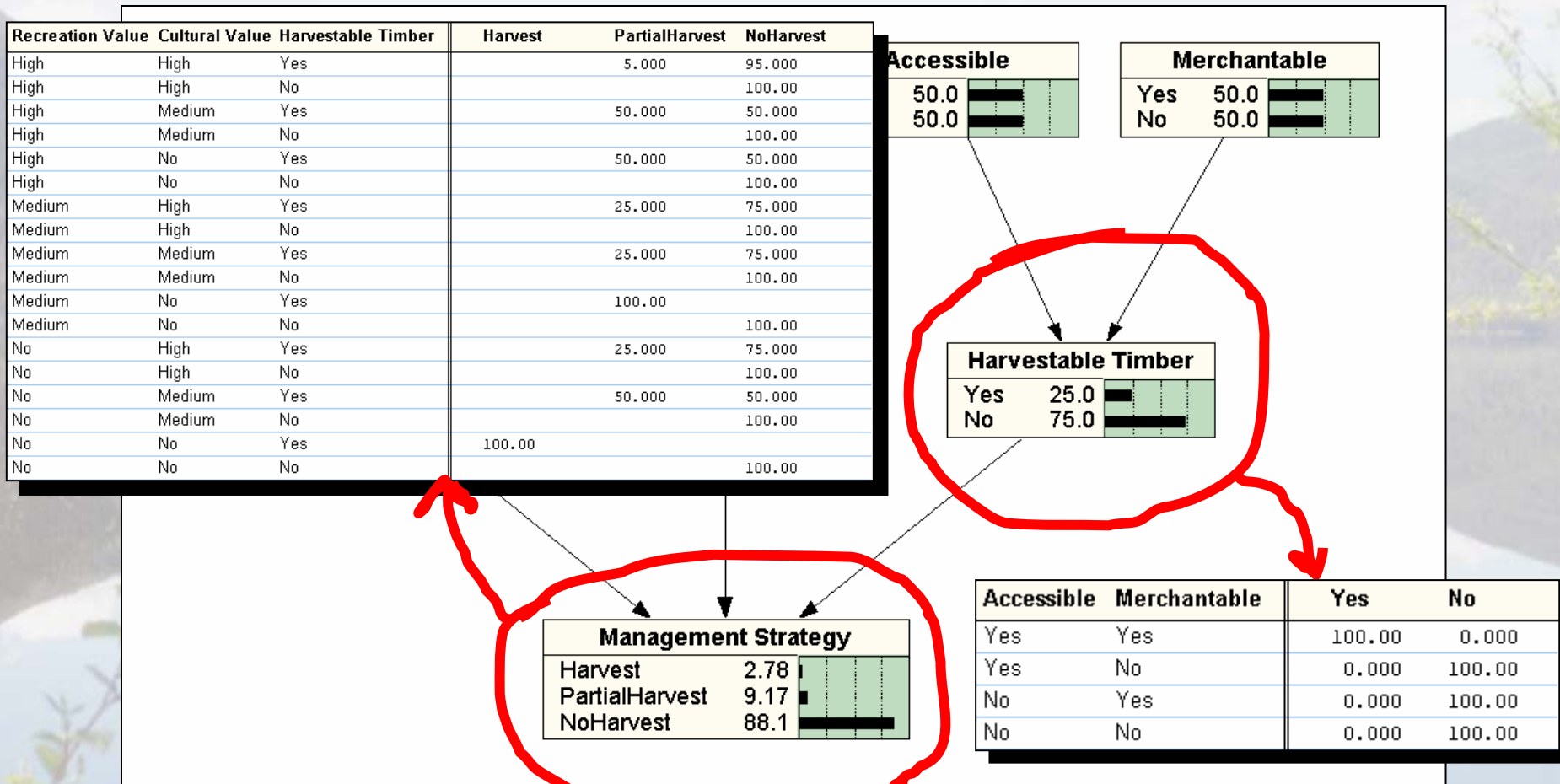
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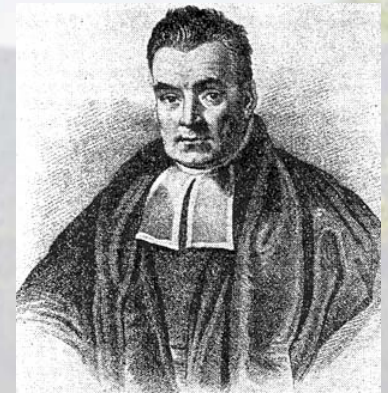
Why Are They Useful for Land Use Planning?

- Divide the problem into more manageable chunks



Why Are They Called Bayes Nets?

- Commit to Bayes' rule for probabilistic inference
- Rule developed by Reverend Thomas Bayes
 - Belief that an event will occur is based on the number of times the event has occurred in the past given similar conditions
- Allows network probabilities to be updated when only one piece of information changes



Where Have BBNs Been Applied?

- Ecology

- Forest soil mapping
- Forest ecosystem mapping
- Wildlife population viability
- Wildlife habitat mapping
- Integrated natural resource management

- Medical

- Disease surveillance
- Diagnosis
- Cancer classification

Where Have BBNs Been Applied?

- Other

- consumer help desks
- nuclear reactor diagnosis
- tissue pathology
- pattern recognition
- credit assessment
- computer network diagnosis

Building a BBN

(using Netica v2.17)

- **Creating Nodes**
 - One node for each variable
 - Input nodes typically at the top
 - Output nodes at the bottom
 - Intermediate, or summary, nodes in the middle
- **Creating Links**
 - Define the causal relationship

Building a BBN

(using Netica v2.17)

- Defining Node States
 - Literally or with numerical ranges
 - Must be mutually exclusive
 - Keep number of states low if possible
- Defining Node Relationships
 - Manually
 - From an equation
 - From a case file
 - A list of evidence or observations
 - Missing data is acceptable

Entering Findings into a BBN

(using Netica v2.17)

- Manually

- Node will appear grey once findings have been entered
- Possible to enter negative findings
- Can also enter likelihoods

- Case file

- Use in conjunction with a *control file*
- A *control file* indicates which node beliefs will be reported

BBN Testing

(using Netica v2.17)

- Purpose:

- See how well the BBN predictions match real observations
- Identify which nodes are weakly correlated with reality

- Product:

- Confusion matrix
 - Compares BBN prediction against observation for each node state
- Overall error rate

BBN Updating (Learning) from Case Files

(using Netica v2.17)

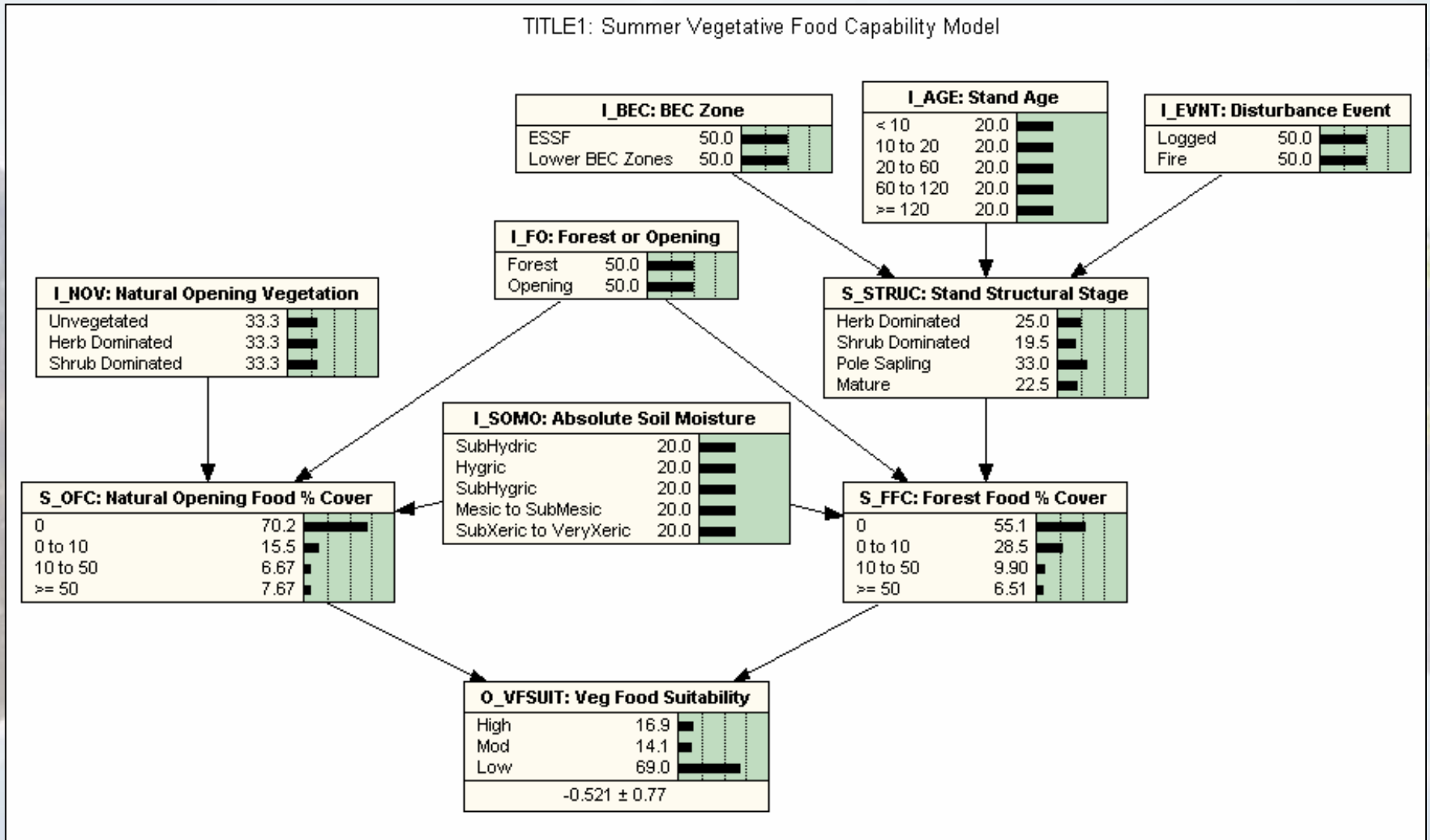
- Automated adjustment of probabilities based on new evidence
 - Use *experience* to weight how strongly node-relationship updating adheres to the existing probabilities
 - Different methods of learning
 - True Bayesian, gradient, expectation maximization

Examples of Bayesian Networks for Resource Management

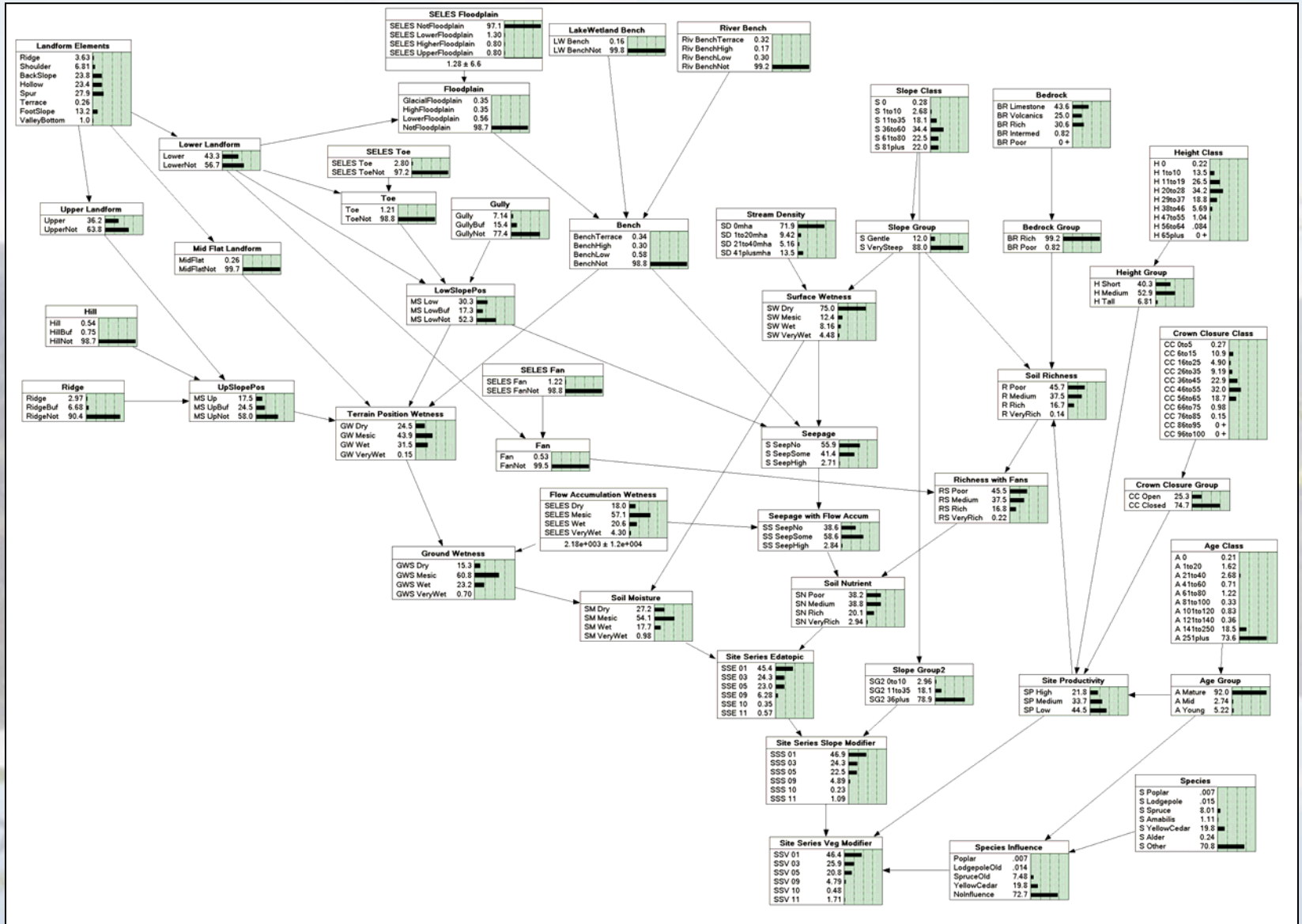
A scenic landscape photograph of a mountain valley. In the foreground, a river flows through a valley, reflecting the surrounding environment. The middle ground is dominated by dense, green forested hills. In the background, more mountains are visible, some with patches of snow or light-colored rock. The sky is bright and slightly hazy. The overall scene is peaceful and natural.

Grizzly Bear Summer Vegetative Foods Suitability

TITLE1: Summer Vegetative Food Capability Model

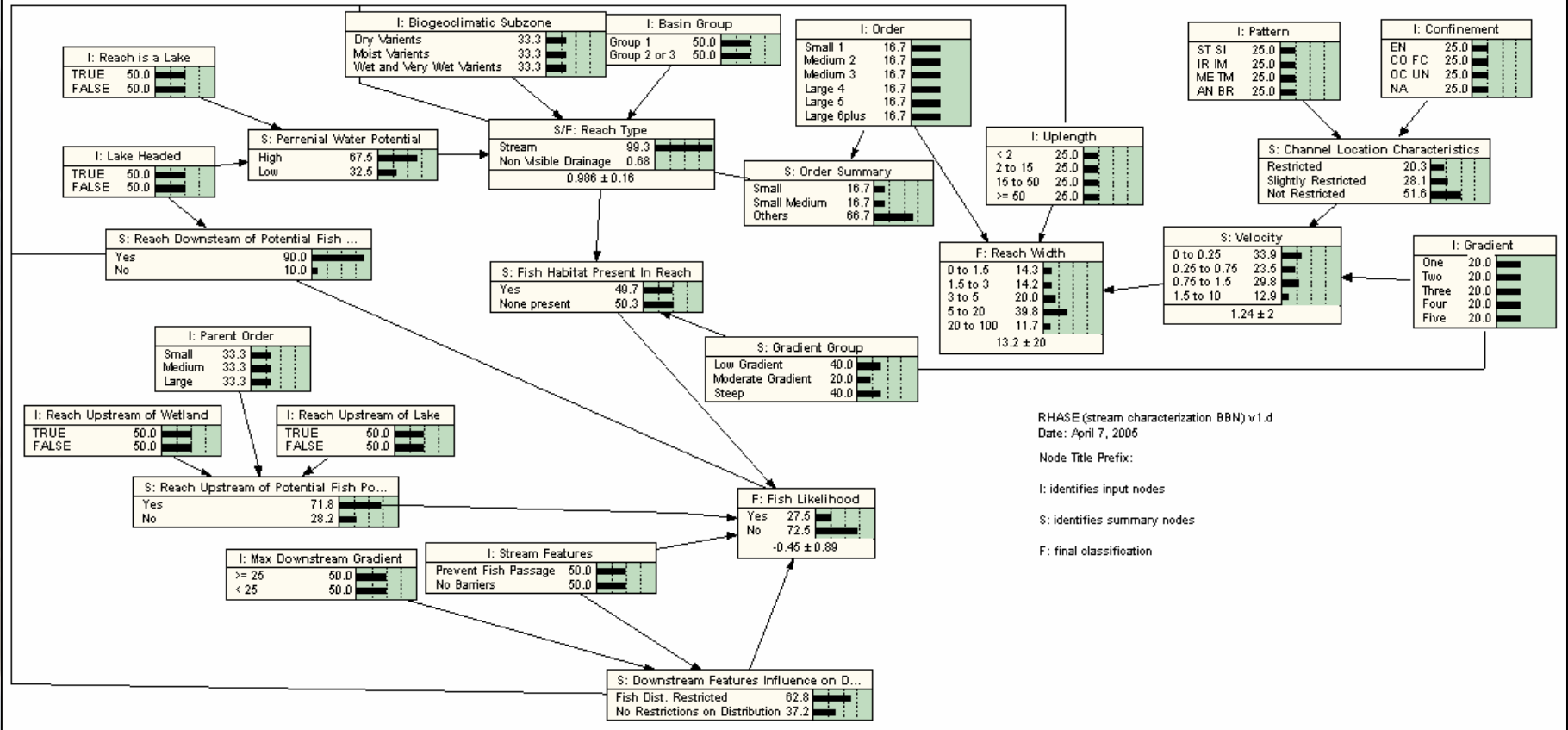


Predictive Ecosystem Mapping



Riparian Habitat Assessment

Riparian Habitat Assessment and Supply Estimator (Stream Characterization BBN)



RHASE (stream characterization BBN) v 1.0
Date: April 7, 2005

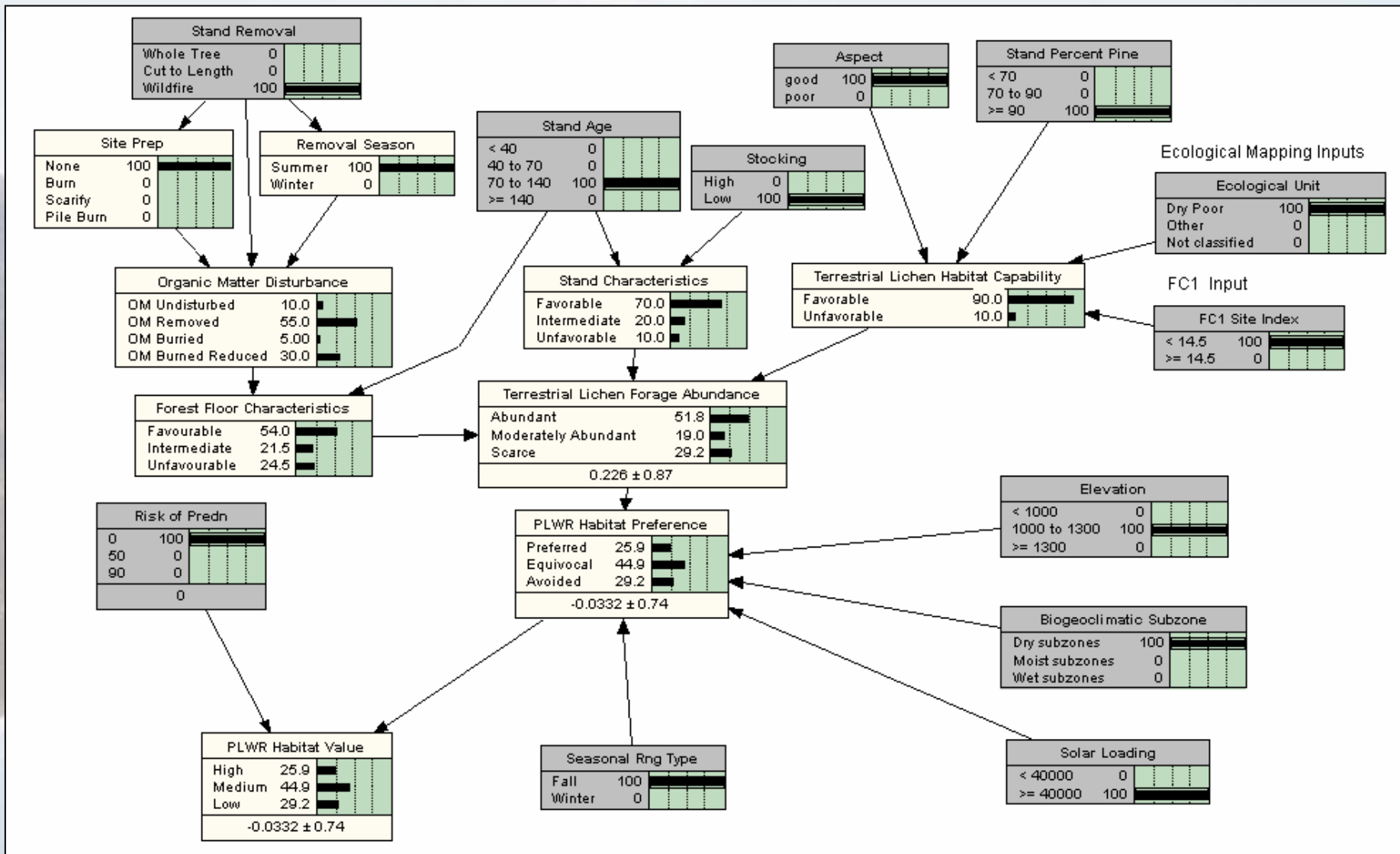
Node Title Prefix:

I: identifies input nodes

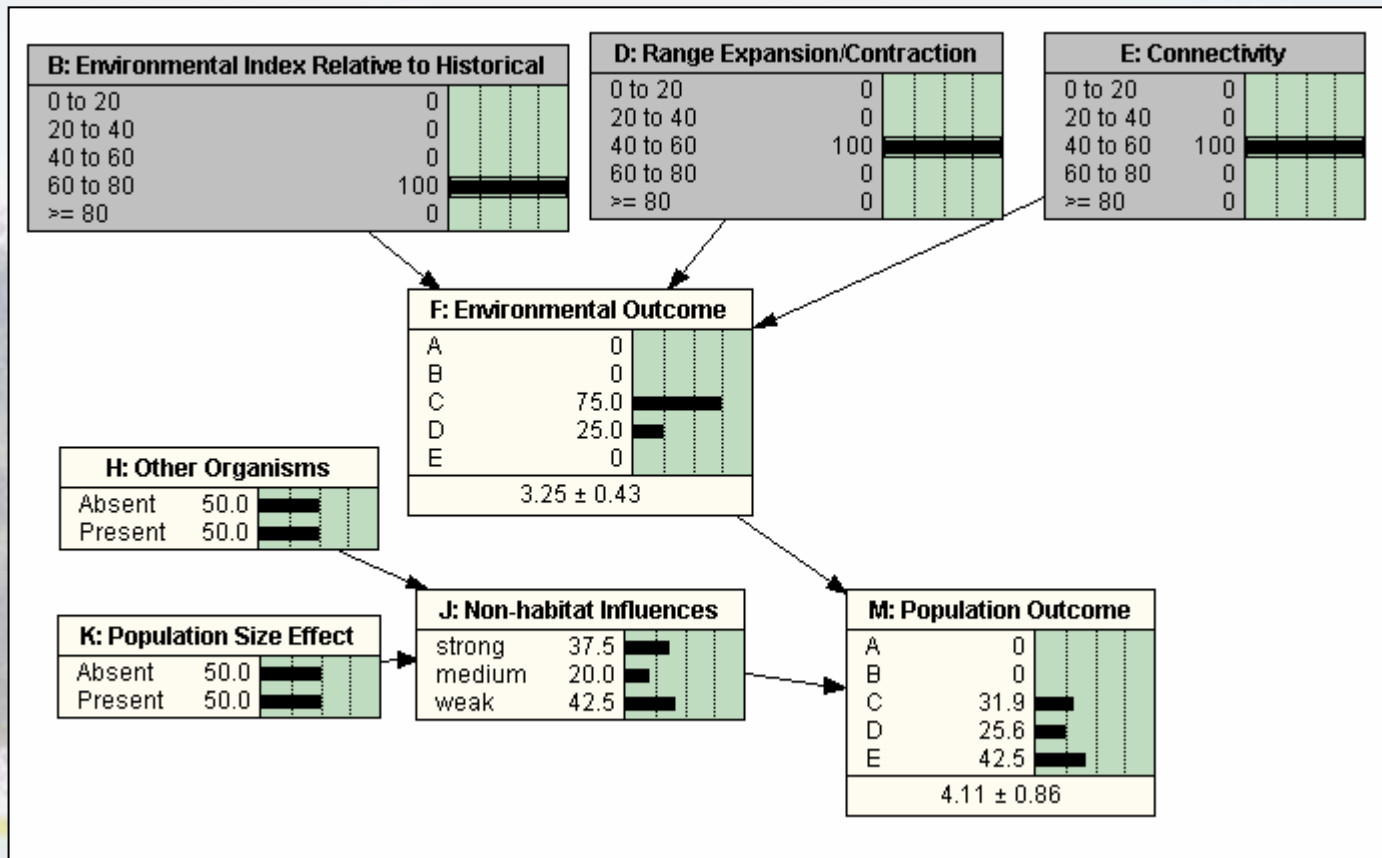
S: identifies summary nodes

F: final classification

Caribou Pine Lichen Winter Range



Wildlife/Fish Population Viability Under Land Management Alternatives



Source: Marcot, B. G., R. S. Holthausen, M. G. Raphael, M. Rowland, and M. Wisdom. 2001. Using Bayesian belief networks to evaluate fish and wildlife population viability under land management alternatives from an environmental impact statement. *Forest Ecology and Management* 153(1-3):29-42.

BBN Online Resources

Creator of Netica BBN Software: <http://www.norsys.com>

Introduction to BBNs for integrated resource management:
<http://merit-eu.net/downloads/Guidelines.pdf>

Mathematical explanation of Bayes nets:
<http://www.cs.ubc.ca/~murphyk/Bayes/bnintro.html>