



Bayesian Networks to support TANK group decision-making

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TANK Decision process

Possible Values, Objectives, Performance Measures and Management Variables For Policy Options

Values =>	Objectives =>	Performance Measures	Management Variables (for Policy Options)
Primary Production	Create new jobs in Hawke's Bay	New full-time jobs in horticulture & farming	Minimum flow; allocation regime & volume
Trout fishing	Improve river for trout fishing	Trout habitat as % of maximum	Minimum flow; nutrient levels; riparian vegetation
Mauri of river	Restore mauri of river	Cultural health index	Minimum flow; stock exclusion; nutrient levels

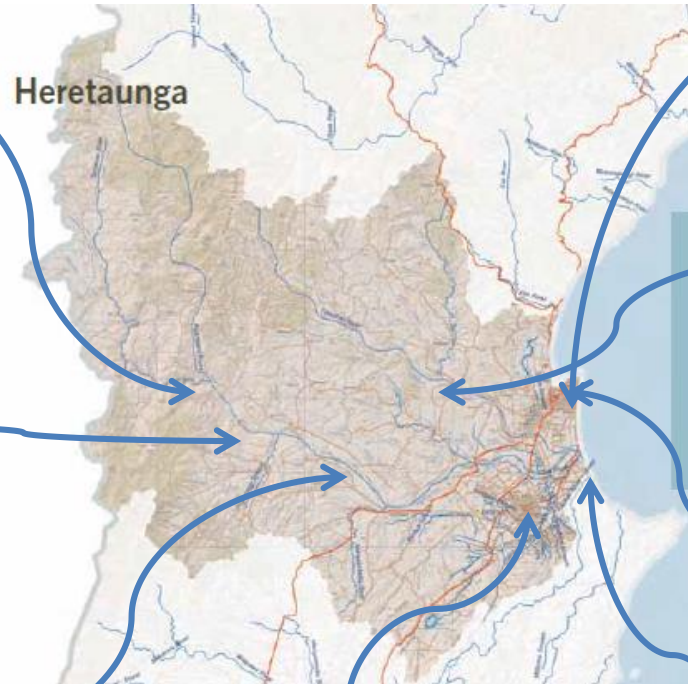
Consequences Table

Performance Measures	<i>Policy option A:</i> Raise min flow Nutrient cap	<i>Policy option B:</i> Current min flow Stock exclusion	<i>Policy option C:</i> Current min flow Stock exclusion
Full-time jobs in hort & farming	Loss of x jobs (how many?)	No change in jobs	Gain of x jobs (how many?)
Trout habitat as % of maximum	90% of habitat	70% of habitat	50% of habitat
Cultural health index	Good	Fair	Fair – Poor

* How certain are we of each consequence?

River catchments are complex systems

How to predict the effects of different management actions/policies on a range of values?



What is a Bayesian Belief Network?

- a way of determining the probability of outcome x from decision y
 - given all the knowledge and beliefs about the system.
- What can we know or believe about a system?
 - How one variable affects another.
 - The state of some variables (decisions, fixed scenarios, observations)

“if 50% of streams in the Tutaekuri catchment are fenced and planted, then there is an 80% chance that trout abundance will increase”

Bayesian Networks

- “causal-linkage” model
- Based on probabilities: represent incomplete knowledge
- Probabilities combined according to Bayes theorem: $P(A,B) = P(A|B)*P(B)$

% of river banks fenced and re-planted		
less than 50	50.0	
more than 50	50.0	

Stream phosphate conc.		
less than 5ppb	50.0	
more than 5ppb	50.0	

Algae % cover of riverbed		
less than 30pc	45.0	
more than 30pc	55.0	

Silt covering riverbed		
high	33.3	
med	33.3	
low	33.3	

Macroinvertebrate community health		
high	52.8	
med	21.6	
low	25.6	

How BNs work

Management variable
(Decision node)

% of river banks fenced and re-planted		
less than 50	50.0	
more than 50	50.0	

Intermediate node

Stream phosphate conc.		
less than 5ppb	50.0	
more than 5ppb	50.0	

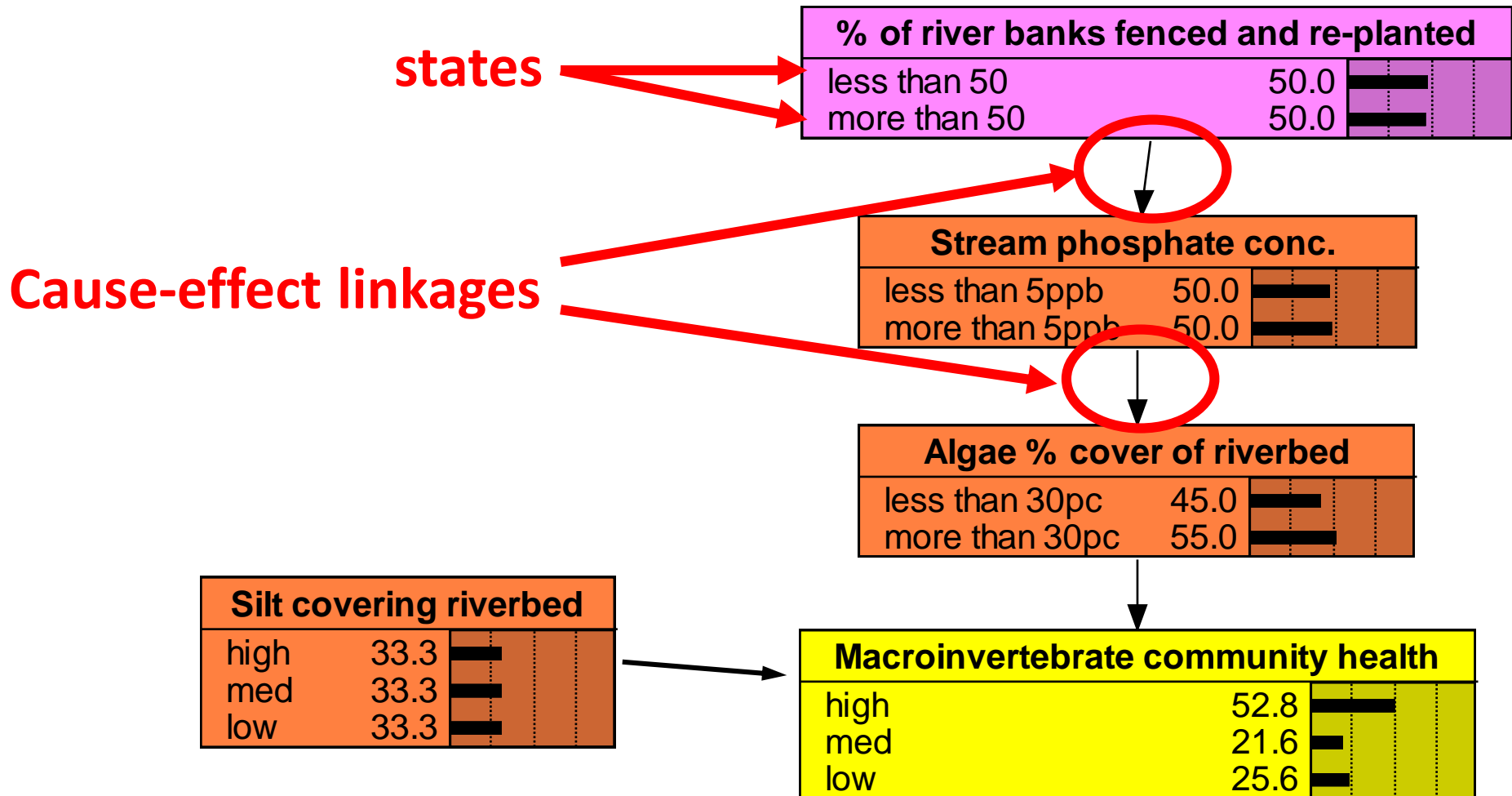
Performance measure

Algae % cover of riverbed		
less than 30pc	45.0	
more than 30pc	55.0	

Silt covering riverbed		
high	33.3	
med	33.3	
low	33.3	

Macroinvertebrate community health		
high	52.8	
med	21.6	
low	25.6	

How BNs work



Conditional probability tables

Strong dependency

		Phosphate concentration	
		<5 ppb	>5 ppb
% of banks fenced	<50%	10	90
	>50%	90	10

- Strong influence
- Few other influencing factors
- Precise knowledge

Weak dependency

		Algae cover of river bed	
		<30%	>30%
Phosphate concentration	<5 ppb	65	35
	>5 ppb	25	75

- Weak influence
- other important influences
- Knowledge poor/imprecise

CPTs combining 2 parents

Parent node 1
(2 states)

Parent node 2
(3 states)



Child node



Algae cover	Silt on river bed	Macroinvertebrate community health		
		High	Med	Low
<30%	High	60	20	20
<30%	Med	80	10	10
<30%	Low	90	10	0
>30%	High	10	30	40
>30%	Med	40	30	30
>30%	Low	50	25	25



Set manually, by equation
or by probability function




How BNs work




No prior knowledge

% of river banks fenced and re-planted		
less than 50	50.0	
more than 50	50.0	

Stream phosphate conc.		
less than 5ppb	50.0	
more than 5ppb	50.0	

Algae % cover of riverbed		
less than 30pc	45.0	
more than 30pc	55.0	

Silt covering riverbed		
high	33.3	
med	33.3	
low	33.3	

Macroinvertebrate community health		
high	52.8	
med	21.6	
low	25.6	

How BNs work

Make decision →

% of river banks fenced and re-planted		
less than 50	100	
more than 50	0	

Stream phosphate conc.		
less than 5ppb	10.0	
more than 5ppb	90.0	

Algae % cover of riverbed		
less than 30pc	29.0	
more than 30pc	71.0	

Silt covering riverbed		
high	33.3	
med	33.3	
low	33.3	

Macroinvertebrate community health		
high	45.9	
med	24.0	
low	30.1	

How BNs work

% of river banks fenced and re-planted		
less than 50	100	
more than 50	0	

Stream phosphate conc.		
less than 5ppb	4.93	
more than 5ppb	95.1	

Algae % cover of riverbed		
less than 30pc	0	
more than 30pc	100	

Macroinvertebrate community health		
high	10.0	
med	30.0	
low	60.0	

Update with data

Silt covering riverbed		
high	100	
med	0	
low	0	

Economic outcomes

Total allocable volume

Total allocable volume of surface water (a...	
pc80 current	20.0
pc90 current	20.0
current	20.0
pc110 current	20.0
pc120 current	20.0
1580 ± 220	

Security of water supply

Security of water supply	
security83pc	3.33
security84pc	3.33
security85pc	6.67
security86pc	13.3
security87pc	6.67
security88pc	6.67
security89pc	6.67
security90pc	6.67
security91pc	6.67
security92pc	10.0
security93pc	13.3
security94pc	10.0
security95pc	6.67
89.7 ± 3.5	

Minimum river flow

Minimum flow at Fernhill	
min2000L	16.7
min2400L	16.7
min2800L	16.7
min3400L	16.7
min3900L	16.7
min4200L	16.7
3120 ± 790	

Irrigation days lost

Irrigation days lost	
6 to 9	7.06
9 to 13.5	11.4
13.5 to 20.25	13.6
20.25 to 30.375	17.1
30.375 to 45.5625	10.2
45.5625 to 68.3438	14.3
68.3438 to 102.516	10.9
102.516 to 153.773	10.3
153.773 to 165	5.26
51.3 ± 45	

Type of year

Type of year	
average	25.0
one in four	25.0
one in ten	25.0
worst on record	25.0
2.75 ± 1.9	

Total profit of land sector

Total profit of land sector (\$ million/year)	
-100 to -80	6.06
-80 to -60	10.2
-60 to -40	10.8
-40 to -20	11.8
-20 to 0	16.8
0 to 10	14.0
10 to 20	15.1
20 to 30	10.0
30 to 40	5.26
-15.9 ± 36	

Profit from dairy (\$/ha/annum)

Area of dairy

Profit from sheep and beef (\$/ha/annum)

Area of sheep and beef

Profit from orchards (\$/ha/annum)

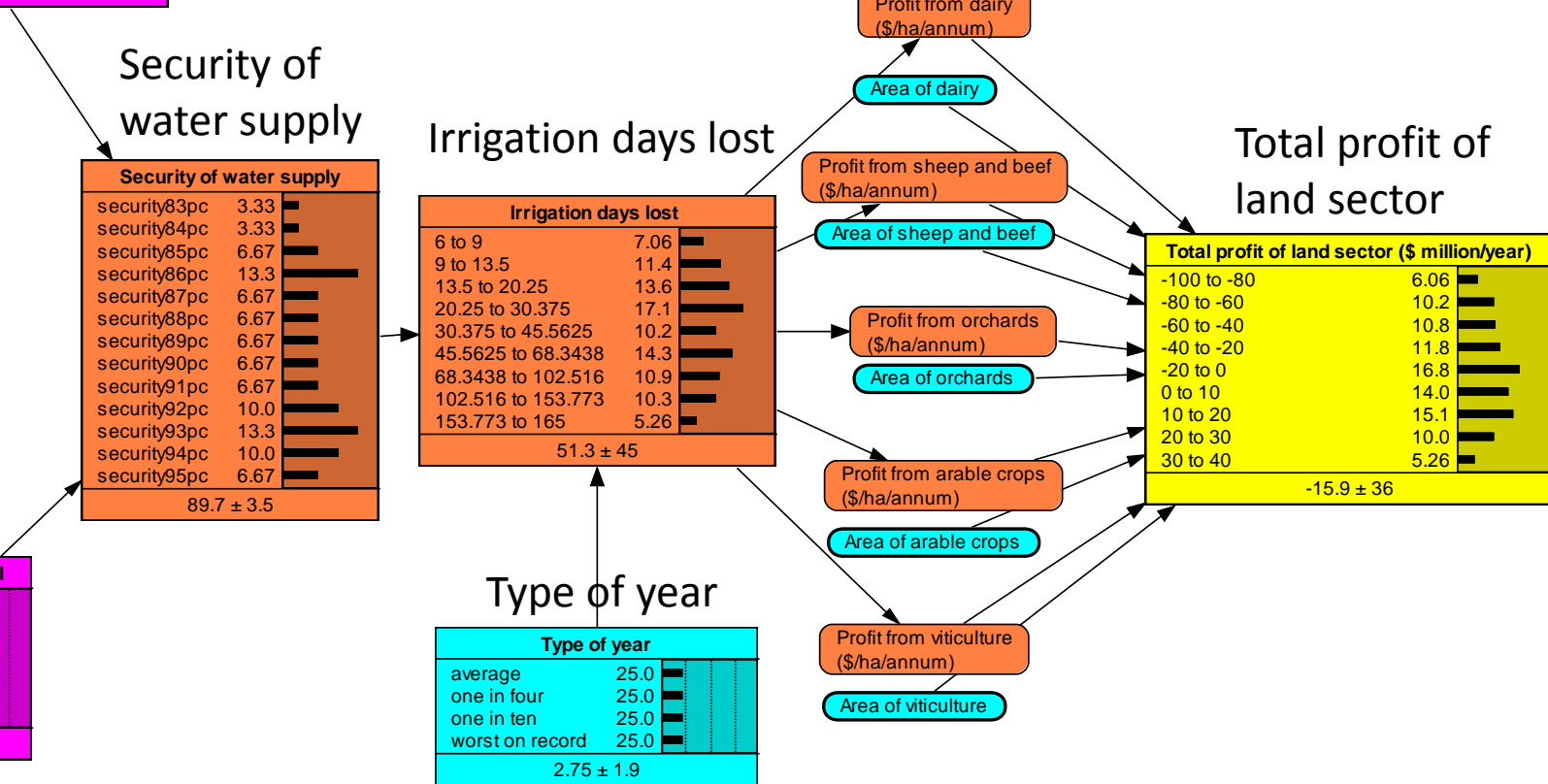
Area of orchards

Profit from arable crops (\$/ha/annum)

Area of arable crops

Profit from viticulture (\$/ha/annum)

Area of viticulture



Economic outcomes

Total allocable volume

Total allocable volume of surface water (a...	
pc80 current	0
pc90 current	0
current	100
pc110 current	0
pc120 current	0
1581	

← current

Security of water supply

Security of water supply	
security83pc	0
security84pc	0
security85pc	0
security86pc	0
security87pc	0
security88pc	0
security89pc	0
security90pc	0
security91pc	0
security92pc	0
security93pc	100
security94pc	0
security95pc	0
93 ± 0.29	

Minimum river flow

Minimum flow at Fernhill	
min2000L	0
min2400L	100
min2800L	0
min3400L	0
min3900L	0
min4200L	0
2400	

← 2400 L/s

Irrigation days lost

Irrigation days lost	
6 to 9	5.26
9 to 13.5	57.9
13.5 to 20.25	5.26
20.25 to 30.375	5.26
30.375 to 45.5625	5.26
45.5625 to 68.3438	5.26
68.3438 to 102.516	5.26
102.516 to 153.773	5.26
153.773 to 165	5.26
33.8 ± 43	

Type of year

Type of year	
average	100
one in four	0
one in ten	0
worst on record	0
1	

Profit from dairy (\$/ha/annum)

Area of dairy

Profit from sheep and beef (\$/ha/annum)

Area of sheep and beef

Profit from orchards (\$/ha/annum)

Area of orchards

Profit from arable crops (\$/ha/annum)

Area of arable crops

Profit from viticulture (\$/ha/annum)

Area of viticulture

Total profit of land sector

Total profit of land sector (\$ million/year)	
-100 to -80	5.95
-80 to -60	9.34
-60 to -40	9.81
-40 to -20	10.2
-20 to 0	12.4
0 to 10	12.4
10 to 20	19.8
20 to 30	14.9
30 to 40	5.26
-11.9 ± 37	

Economic outcomes

Total allocable volume

Total allocable volume of surface water (a...	
pc80 current	0
pc90 current	0
current	0
pc110 current	0
pc120 current	100
1897	

← Current+20%

Security of water supply

Security of water supply	
security83pc	0
security84pc	0
security85pc	0
security86pc	0
security87pc	0
security88pc	0
security89pc	0
security90pc	0
security91pc	0
security92pc	100
security93pc	0
security94pc	0
security95pc	0
92 ± 0.29	

Minimum river flow

Minimum flow at Fernhill	
min2000L	0
min2400L	100
min2800L	0
min3400L	0
min3900L	0
min4200L	0
2400	

← 2400 L/s

Irrigation days lost

Irrigation days lost	
6 to 9	5.26
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13.5 to 20.25	5.26
20.25 to 30.375	5.26
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102.516 to 153.773	5.26
153.773 to 165	5.26
33.8 ± 43	

Type of year

Type of year	
average	100
one in four	0
one in ten	0
worst on record	0
1	

Profit from dairy (\$/ha/annum)

Area of dairy

Profit from sheep and beef (\$/ha/annum)

Area of sheep and beef

Profit from orchards (\$/ha/annum)

Area of orchards

Profit from arable crops (\$/ha/annum)

Area of arable crops

Profit from viticulture (\$/ha/annum)

Area of viticulture

Total profit of land sector

Total profit of land sector (\$ million/year)	
-100 to -80	5.95
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10 to 20	19.8
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30 to 40	5.26
-11.9 ± 37	

Economic outcomes

Total allocable volume

Total allocable volume of surface water (a...	
pc80 current	0
pc90 current	0
current	100
pc110 current	0
pc120 current	0
1581	

← current

Security of water supply

Security of water supply	
security83pc	0
security84pc	0
security85pc	0
security86pc	100
security87pc	0
security88pc	0
security89pc	0
security90pc	0
security91pc	0
security92pc	0
security93pc	0
security94pc	0
security95pc	0
86 ± 0.29	

Irrigation days lost

Irrigation days lost	
6 to 9	5.26
9 to 13.5	5.26
13.5 to 20.25	5.26
20.25 to 30.375	57.9
30.375 to 45.5625	5.26
45.5625 to 68.3438	5.26
68.3438 to 102.516	5.26
102.516 to 153.773	5.26
153.773 to 165	5.26
41.2 ± 39	

Type of year

Type of year	
average	100
one in four	0
one in ten	0
worst on record	0
1	

Minimum river flow

Minimum flow at Fernhill	
min2000L	0
min2400L	0
min2800L	0
min3400L	0
min3900L	100
min4200L	0
3900	

← 3900 L/s

Profit from dairy (\$/ha/annum)

Area of dairy

Profit from sheep and beef (\$/ha/annum)

Area of sheep and beef

Profit from orchards (\$/ha/annum)

Area of orchards

Profit from arable crops (\$/ha/annum)

Area of arable crops

Profit from viticulture (\$/ha/annum)

Area of viticulture

Total profit of land sector

Total profit of land sector (\$ million/year)	
-100 to -80	5.94
-80 to -60	9.57
-60 to -40	9.79
-40 to -20	10.2
-20 to 0	14.2
0 to 10	19.7
10 to 20	16.7
20 to 30	8.61
30 to 40	5.26
-13.9 ± 36	

Why use BNs for the TANK planning process?

- BNs organise all the relevant knowledge.
- incorporate different types of knowledge:
 - expert scientific judgment, numerical model output, monitoring data and stakeholder experience.
 - Precise, imprecise
- graphical layout makes them suitable for communicating.
- Scenarios can be run quickly so implications of different management options are rapidly understood.
- The probabilities of various outcomes show stakeholders and decision makers the chances of achieving goals.

Additional benefits of BNs for the TANK process

- Identify knowledge gaps
- clarify level of detail required for decision-making

Conclusions

- BN is a decision-support tool
- It is a model that shows effects of policy decisions on the suite of agreed objectives.
- Places outputs of other models alongside other sources of knowledge in decision-making framework
- BN is information-hungry. Will require considerable effort by many people.

Conclusions

- BN is not essential, but if not used then:
 - How do you ensure shared understanding?
 - How do you compare different policy options wrt wide range of objectives?
 - How do you deliver relevant science so it is useful for decision-making
- BN provides a structured way of doing these