



Structured Decision Making for the Edwards Aquifer Recovery Implementation Program

San Antonio, Texas

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Who We Are

A Primer on SDM

Some SDM Tools

Case Study – Water Use Planning

Key Messages

How could SDM apply to EA RIP

NSF Research Grant:

Improving Deliberative Environmental Management Under Uncertainty

NSF Research Team

- **Value Scope Research/UBC – Robin Gregory**
- **Compass Resource Management**
 - Lee Failing, Graham Long,
 - Michael Harstone, Dan Ohlson
- **Others**
 - Ralph Keeney, Ellen Peters, Mark Burgman

NSF Research Areas

- Dealing with uncertainty in multi-stakeholder decisions
- Attributes of uncertainty
- Adaptive management
- Elicitation of expert judgment

NSF Approach

- Facilitate partnerships with applied decision makers
- NSF will fund methodological research and publication

Broader Interdisciplinary Experience of the Team

- Decision analysis
- Environmental risk management
- Natural resources policy, management and planning



Objective Today

- Share our experiences with use of SDM
- Discuss where/how/when SDM might be useful in the Edwards Aquifer RIP process
 - How does what we talk about today relate do the Mini-SDM Workshop in January?
 - Would SDM be a useful organizing framework for your work?



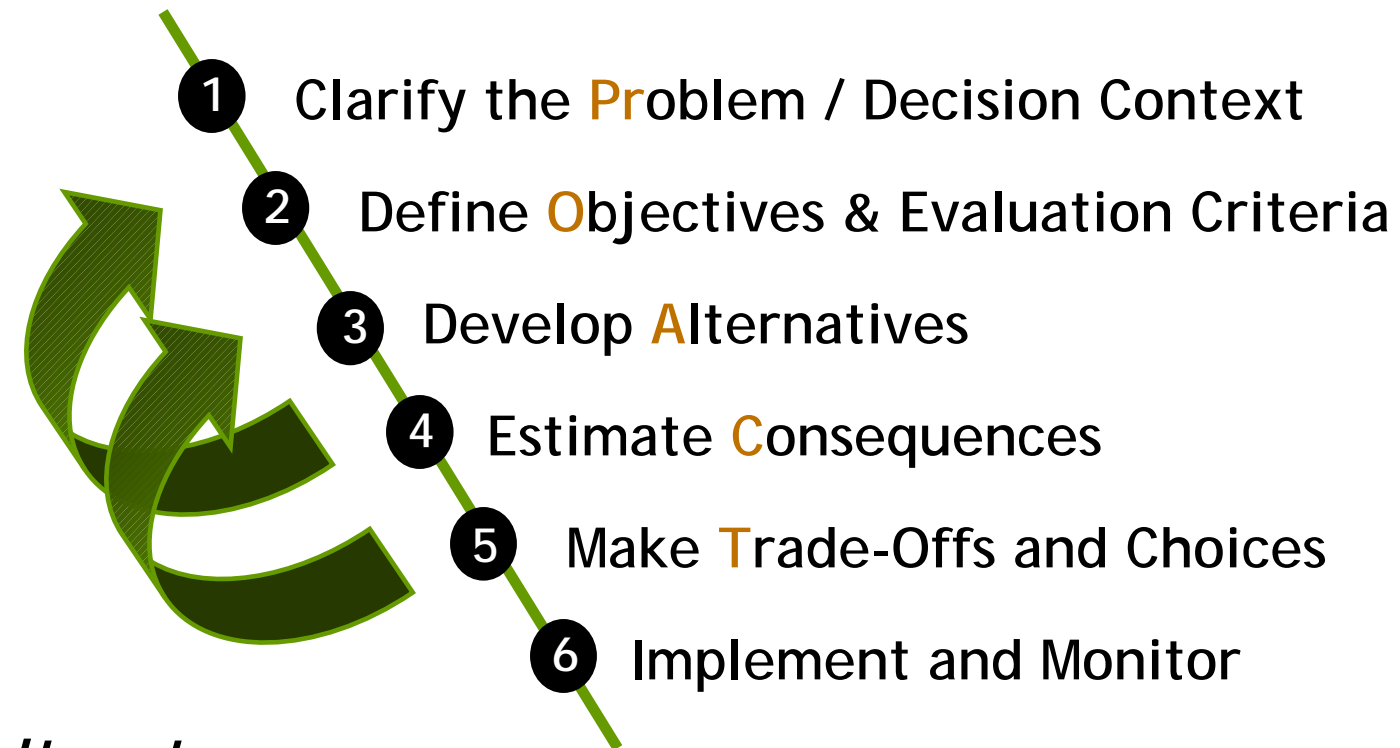
What is SDM?

“A formalization of common sense for decision problems which are too complex for informal use of common sense.”

(Ralph Keeney on “Decision Analysis”)

An organized and transparent framework for identifying and evaluating creative options and making defensible choices in difficult situations

- A set of core steps
- Set of structuring tools from the decision sciences
- Integration of analysis and deliberation
- Flexible and iterative



*Iterate as
required*

“... your own mind may be your worst enemy....”

The Hidden Traps in Decision Making

(Hammond et al, HBR 1998)

- Structuring and analysis tools from the decision sciences
 - **Objectives hierarchies**
 - Means-ends diagrams
 - **Influence diagrams**
 - **Bayesian Networks**
 - Value-focused thinking
 - **Strategy tables** and portfolio builders
 - **Consequence tables**
 - **Structured expert judgment**
 - **Risk profiles and risk tolerance**
 - **Multi-attribute trade-off analysis**
 - Adaptive management

Science
won't make
choices

- Rigorous treatment of *both*
 - **Facts/Analysis** (impact hypotheses, estimated consequences, uncertainties)
 - **Values / Dialogue** (priorities, preferences, choices)
- Integration of
 - **Technical/scientific analysis**
 - **Socio-economic analysis**

- **Flexible**
 - Adapt methods to the stakes and resources
- **Iterative**
 - Walk through whole process at scoping level
 - Identify key trade-offs and uncertainties
 - Allocate resources/effort accordingly



A Simple Example – Choosing a Flight

Issues

- I don't want to spend much money
- I don't want hidden fees
- I don't want to spend an extra day in Vancouver

- I want a direct flight
- I want easy check-ins

- I want decent leg room
- I want an aisle seat
- I want friendly service

- I am concerned about all the airline crashes recently
- I am not comfortable flying with a new airline

Objectives

- ➔ Minimize Cost

- ➔ Minimize Travel Time

- ➔ Maximize Comfort

- ➔ Maximize Safety

Evaluation Criteria

\$ CAD

Hours

Index (0-5)

Incidents per million take-offs (5-year average)

Consequences and Trade-offs

	Units	A Air Canada	B Transat	C Vintage Air	D Easy Jet
Cost	\$	\$2,000	\$1,500	\$400	\$2000
Travel time	Hours	8-9	13-15	12-64	16
Comfort	(5 = best, 0 = worst)	4	4	3	3
Safety	# Incidents per million take-offs	3.8	3.6	4.0	4.8
Flexibility	5 = fully refundable 0 = non refundable	5	5	5	5

Focusing on Key Trade-offs

Dominance

	Units	A Air Canada	B Transat	C Vintage Air	D Easy Jet
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Insensitivity

Iterative approach to refining alternatives and criteria



What might this look like for the EARIP?

Objective	Units/Metric	A	B	C
Species at Risk -Texas Wild Rice -Comal Springs Beetle	Change in Area Occupied (%) Likelihood of Survival (%)			
Water Supply -Urban -Agricultural				
Commercial Tourism - Annual Revenue?				
Implementation Cost -State -Other				
Other?				



What's different about SDM?

Relative to other frameworks (CBA, ERA, etc.), **SDM**:

- Focuses on **what matters**, even if it's hard to quantify
- Improves the quality and transparency of **judgments**
- Generates creative **alternatives**
- Explores **trade-offs and uncertainties**
- Ensures a **decision-relevant** information base
- Integrates **analysis with deliberation**
- Promotes structured **learning**



What's different about SDM?

Bottom line....

It's the **organizing framework** within which other evaluation tools are applied

It's **not a formula** – design something that works for you

It focuses on **what decision makers need** to make defensible decisions – if you start out by approaching it as a multi-dimensional decision problem rather than a science problem or a risk assessment, you allocate resources and effort differently

Quality and Defensibility

- Best practices in decision making

Transparency and Accountability

- A road map (where are we going?) and audit trail (how did we get here?)

Efficiency

- Upfront investment in structuring pays off in streamlined information gathering and decision making

Relationship Building

- Meaningful involvement, trust, collaboration of stakeholders

Learning and Capacity Building

- Dealing with uncertainty, building capacity for future decisions

Results!

- Meeting core objectives

Who's using it?

EPA, DOE,
DFO, EU,
HM
Treasury,
MOE/BC,
BCH

- Developed in the decision sciences
- Initially applied in desk exercises
- Now used in on-ground decisions with stakeholders and technical teams
 - **Water use plans**
 - **Species recovery plans**
 - **Ground water management plans**
 - Fish and wildlife allocation/harvest policy
 - Climate change and adaptation planning
 - Government decision making guidelines
 - Drinking water supply
 - Hydropower investments
 - Pine beetle management (Forest Management)
 - Park planning and wildfire management

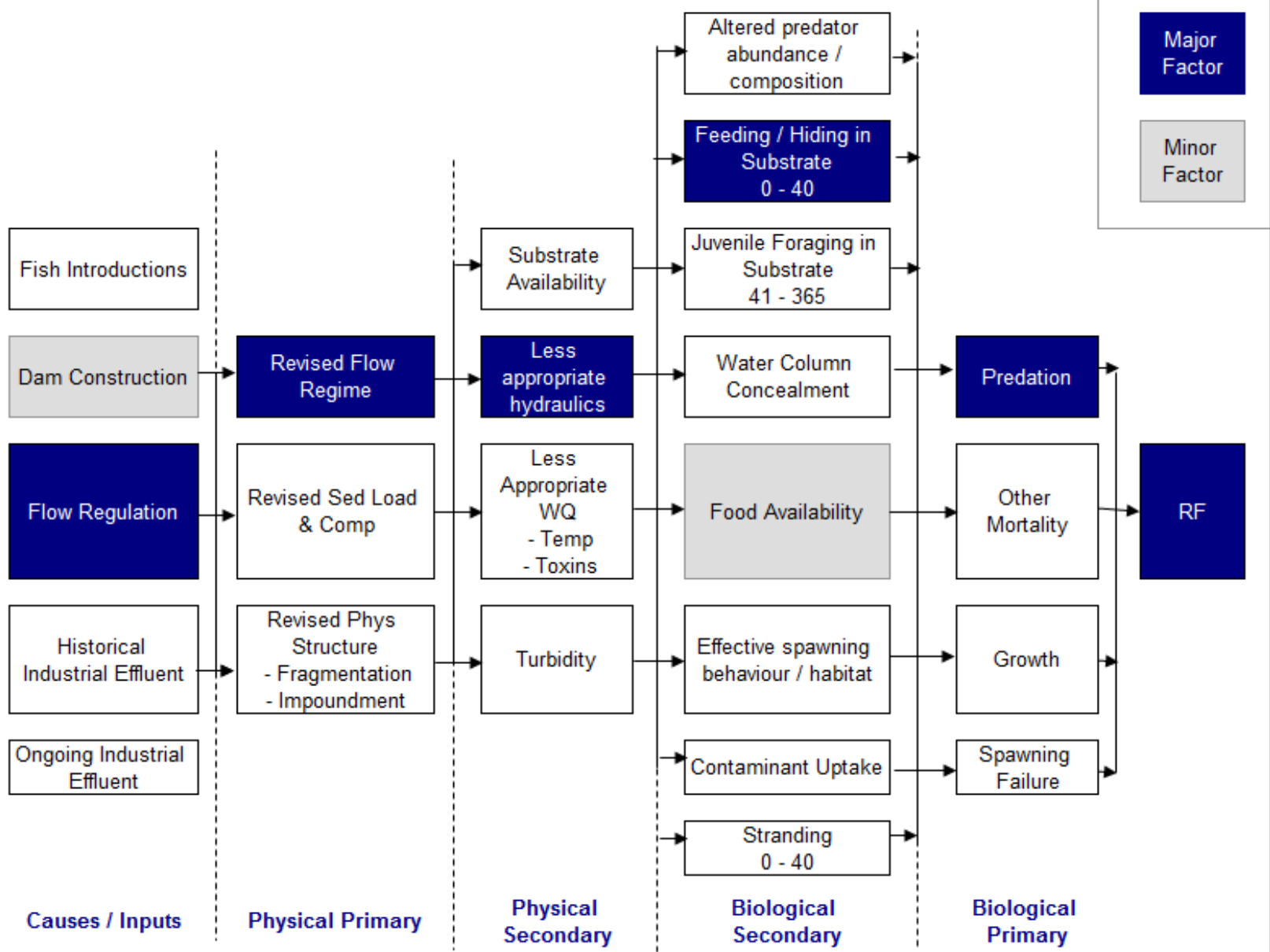
Some SDM tools and techniques

1. Influence diagrams (decision-focused)
2. Dealing with uncertainty and risk tolerance
3. Eliciting expert judgment
4. Strategy tables
5. Trade-off analysis tools

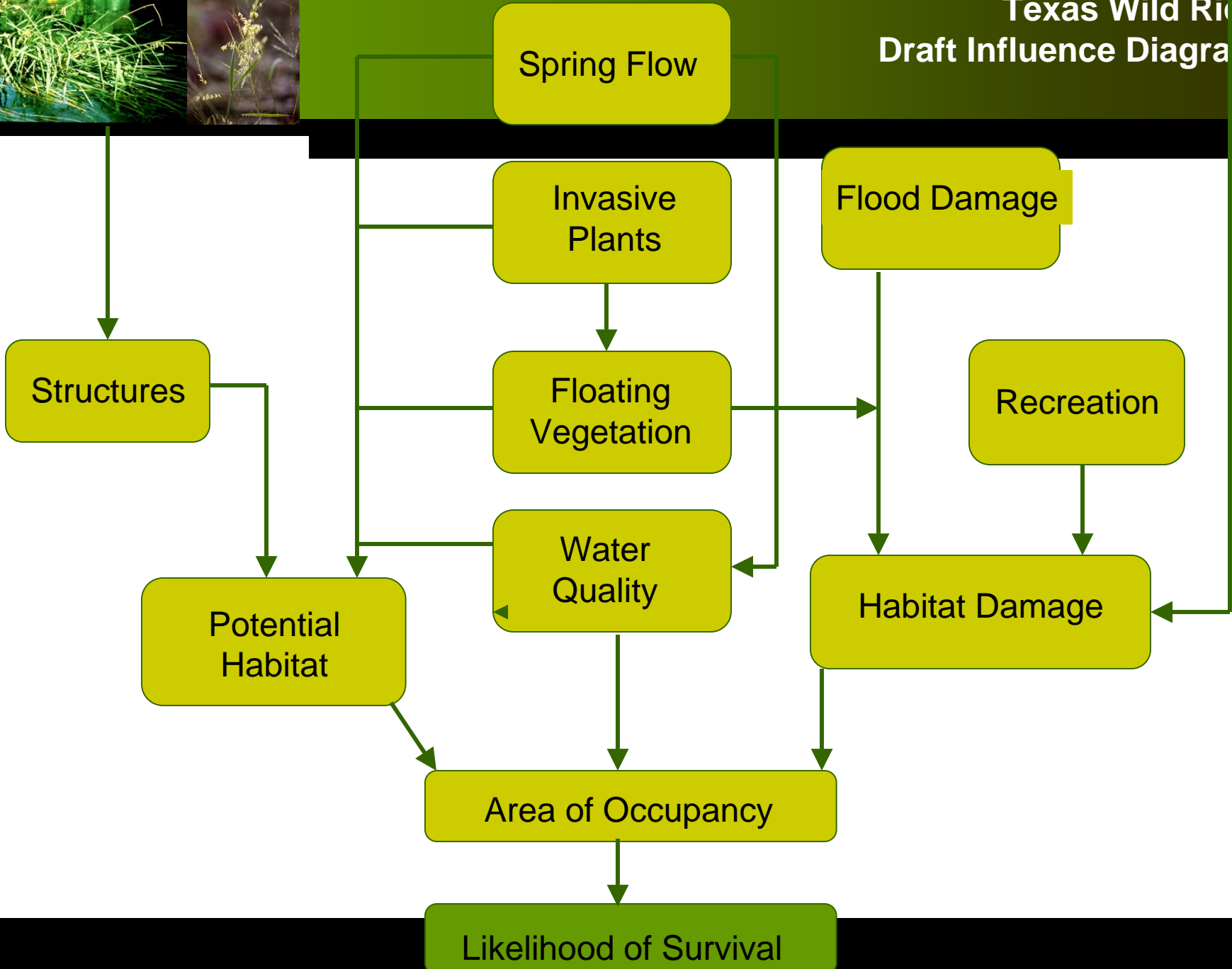
1. Influence Diagrams

- Conceptually link the things you can control (management actions) to the things that people care about, so as to make relationships visible
- Assist in clarifying competing hypotheses
- Assist in developing endpoints and evaluation criteria
- Example: Columbia River White Sturgeon recruitment failure...

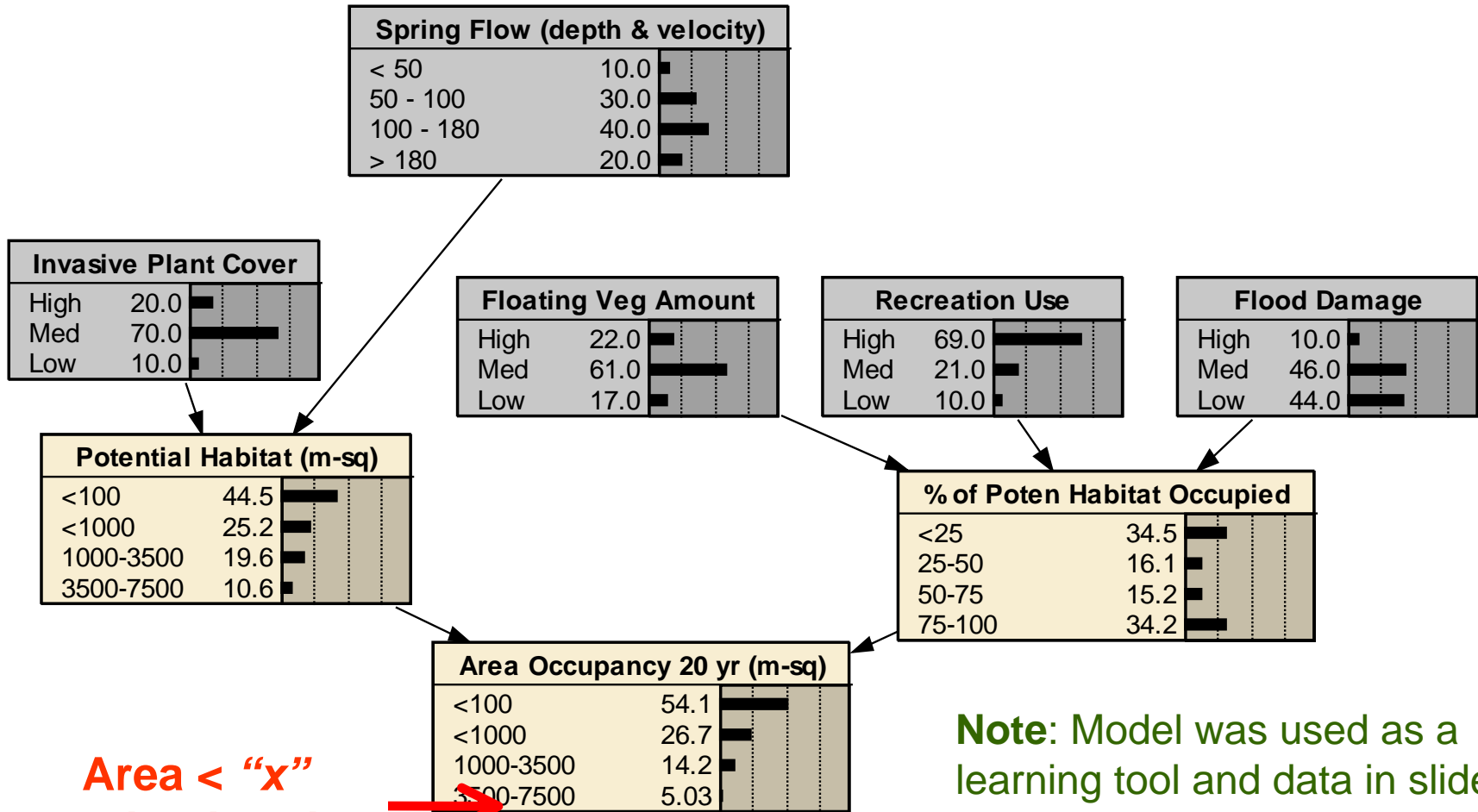
LC1: Movement to habitat, Age: 0-15



Texas Wild Rice Draft Influence Diagram



Texas Wild Rice Draft Hypothetical Belief Net Model



Area < "x"
~ extinction risk

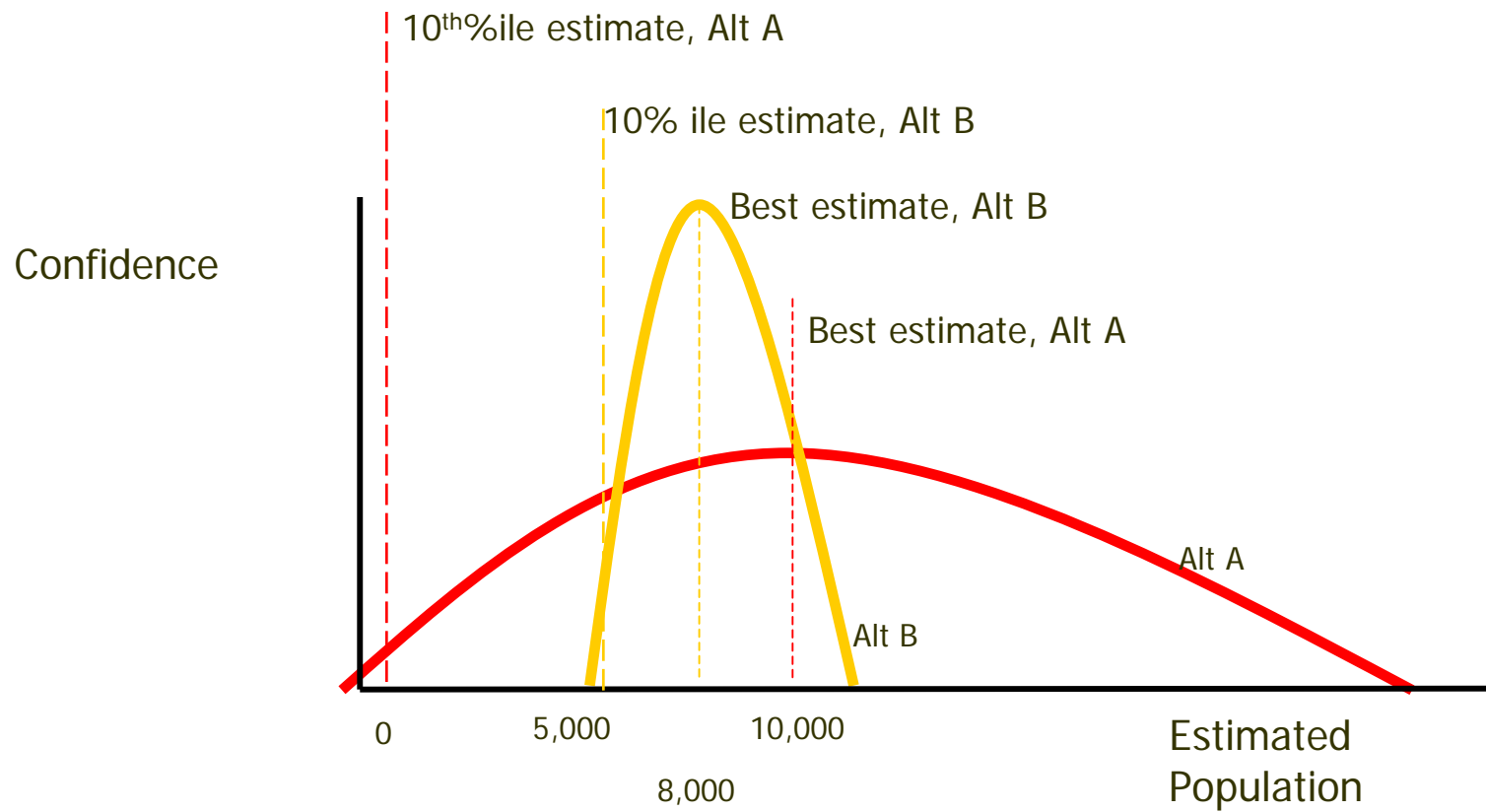
Note: Model was used as a learning tool and data in slide should only be interpreted as such

2. Uncertainty and Risk Tolerance

- Example: which alternative is best?

	Alternative A	Alternative B
Best estimate of species X population	10,000	8,000

Tools - Risk Tolerance



Now which alternative is best?

	Alternative A	Alternative B
Median (50 th %ile) estimate of species X population	10,000	8,000
Low (10 th %ile) estimate of species X population	0	5,000

3. Expert judgment elicitations

Done poorly...

- Fail to question fundamental assumptions
- Lead to phenomenon of “dueling experts”
- Leads to court cases and litigation

DON'T MOVE, or I'll fill you full of LEAD!!!

HAAA!! I happen to know that the lead in bullets is in the METALLIC form! This chemical form of lead has an intrinsically low bioavailability and toxicity!!

YES, but EARP et al (1886) have recently reported that the gunpowder-assisted acceleration of this form of lead to 1000 ft/sec substantially enhances its ability to penetrate biological membranes, effectively making it a whole lot MORE toxic!!!

I don't believe I've read that paper...

ENVIRONMENTAL SCIENTISTS IN THE WILD WEST

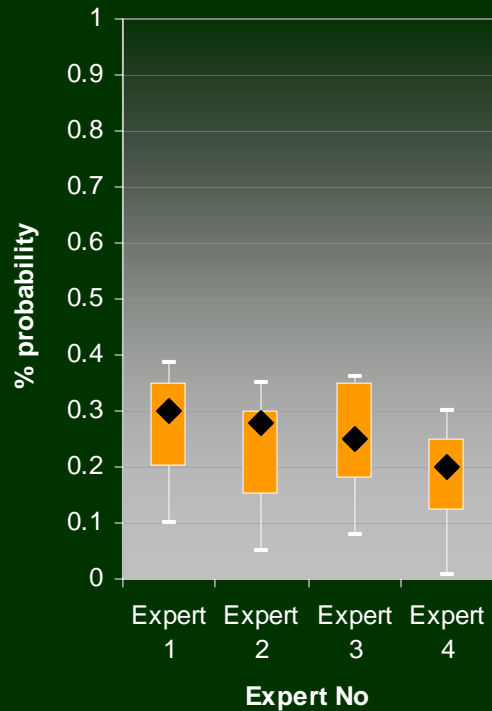
- Expert judgment elicitations

Done well...

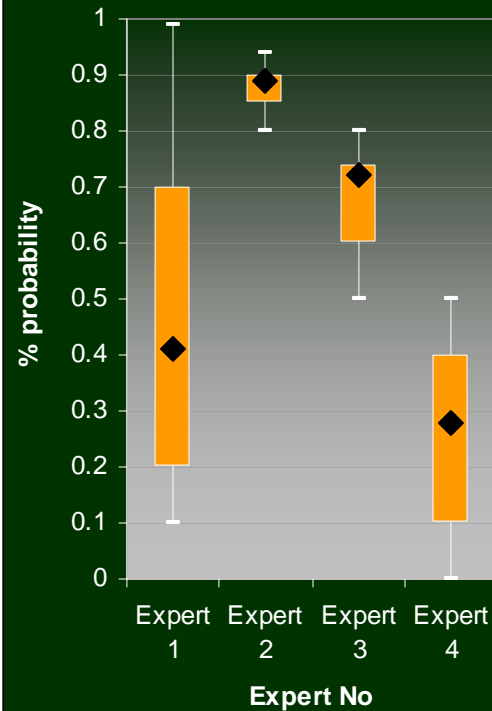
- Expose fundamental assumptions
- Encourage experts to reach agreement
- Facilitate learning and incorporation of knowledge from different sources
- Identify useful management actions
- Widely used – recognized “best practices”

Tools – Expert Judgment

Estimate of % probability of Catastrophic Breeding Failure under Condition X



Estimate of % probability of Moratorium under Condition X



Wide range of judgements...

– priority for research?

- improved info on stakeholder risk tolerance?

4. Strategy Tables

A "strategy" is a logically consistent set of individual actions combined to create a comprehensive management response. Usually there are several categories of possible management actions, and creating a strategy involves selecting one or more actions from each category and combining them to create a comprehensive strategy, normally with a recognizable theme or approach.

Tools - Strategy Tables

Cultus Exploitation Rate %	Enhancement	Freshwater projects options
5	None	None
10	Current Captive Brood	Current Milfoil Removal
20	Double Current Capacity	Current Pikeminnow
30	Maximum Enhancement	Large Milfoil Removal
40		Large Pikeminnow Removal

Alternative 1: "Status Quo"

Tools - Strategy Tables

Cultus Exploitation Rate %	Enhancement	Freshwater projects options
5	None	None
10	Current Captive Brood	Current Milfoil Removal
20	Double Current Capacity	Current Pikeminnow
30	Maximum Enhancement	Large Milfoil Removal
40		Large Pikeminnow Removal

Alternative 2: "Spread the Pain 2"

5. Trade-off analysis tools

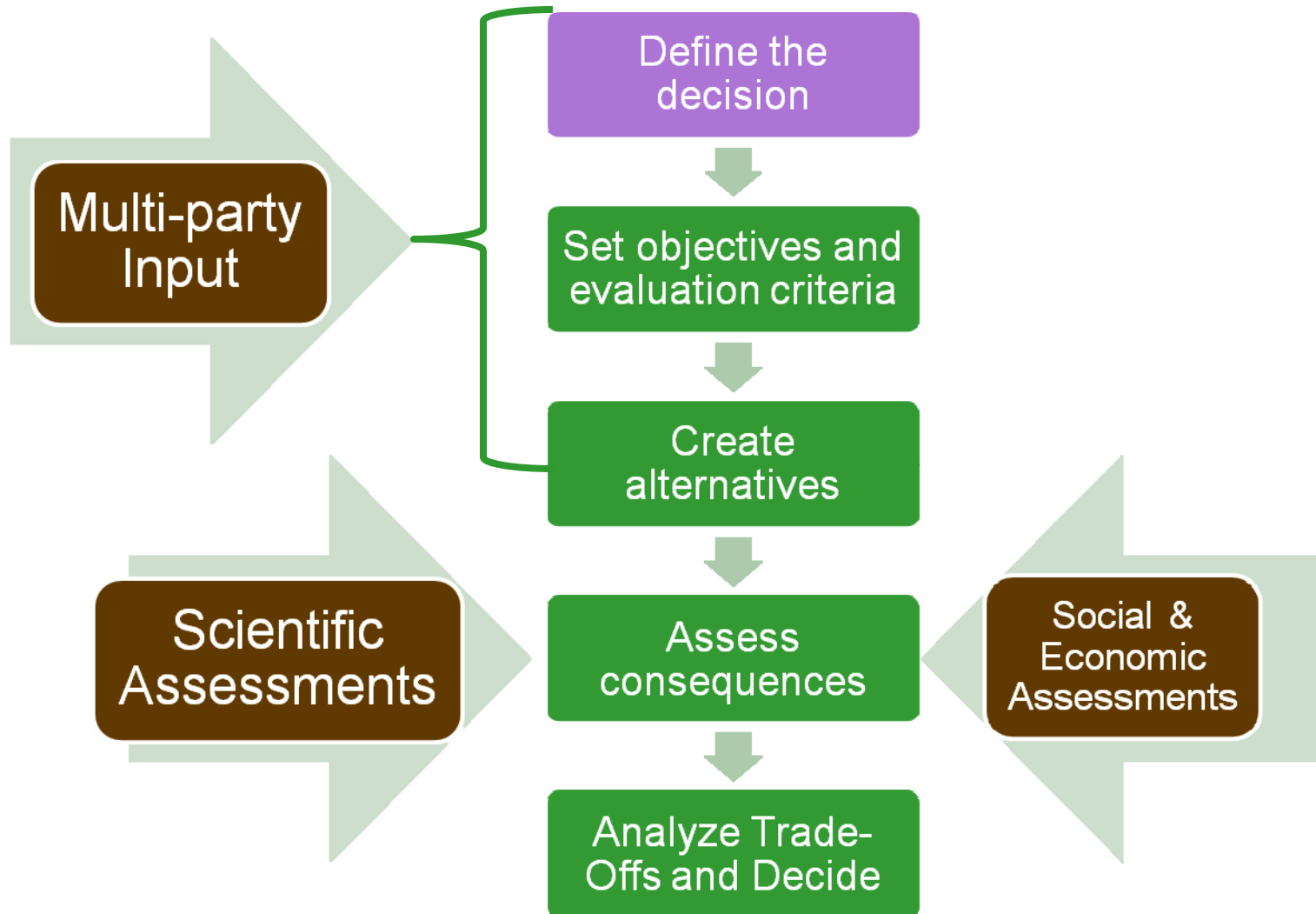
- Understanding the trade-offs between complex alternatives can be challenging
- Value elicitation tools can help structure values just as we structure facts...
- Structuring values helps to inform and clarify when situations require unfamiliar choices or decisions across multiple dimensions
- Examples in Bridge WUP case study...

Water Use Planning In British Columbia

- Most BC hydro water licenses granted pre-1962
- Little consideration of environmental & social values
- From 1960s to mid-1990s, shift in public values, major conflicts and legal challenges
- Charges for regulatory violations, federal orders constraining operational flexibility
- BC Hydro in court, challenged by First Nations, loss of public consent to operate

- BC Hydro response: Water Use Planning

Steps in Good Decision Making



Bounds

- Water use, not footprint
- Budgets, timelines
- Consultation, not consensus

▪ **Guiding Principles**

- Recognition of multiple objectives
- Trade-offs within constraints (legal / regulatory)
- Structured framework for discussions
- Inclusiveness
- Access to information
- Flexibility and periodic review

▪ **Road Map**

- WUP Guidelines that outlined the SDM process



Facilities

- Three impoundment dams
- Three reservoirs/rivers
- Four powerhouses - 500 MW

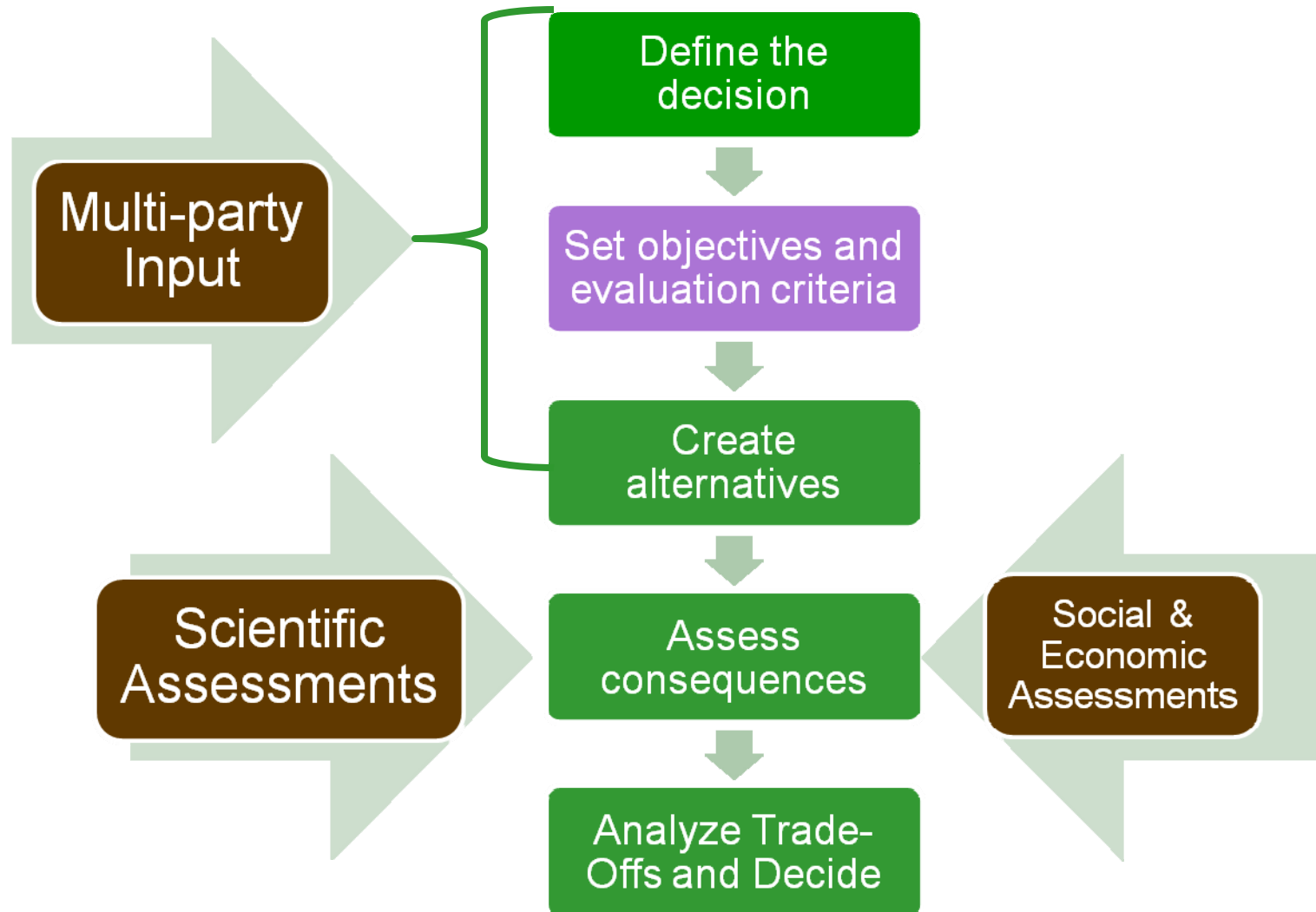
Conflict

- Parties in court over fish impacts
- Volatile relations with First Nations
- Consultative committee made up of
 - Utility, provincial regulators, federal fisheries regulator, communities, NGOs and First Nations

The Process

- Consultative Guidelines and Committee
- SDM process
- Two years, multiple meetings
- (Other WUPs conducted in 1-4 meetings)

Steps in Good Decision Making





Bridge River WUP - Structuring Objectives

Flood Damage

- Minimize risk of catastrophic dam failure
- Minimize damage to property from periodic flooding (3)

Fish

- Maximize abundance and diversity of fish in reservoirs (3)
- Maximize abundance and diversity of fish in rivers (3)

Vegetation

- Maximize the quality and quantity of vegetation on reservoirs (3)

Recreation

- Minimize impacts on boat launches on Seton Reservoir
- Maximize aesthetics on Carpenter and Downton Reservoirs

Water Quality

- Minimize turbidity (TSS) in Seton Reservoir

Power / Financial

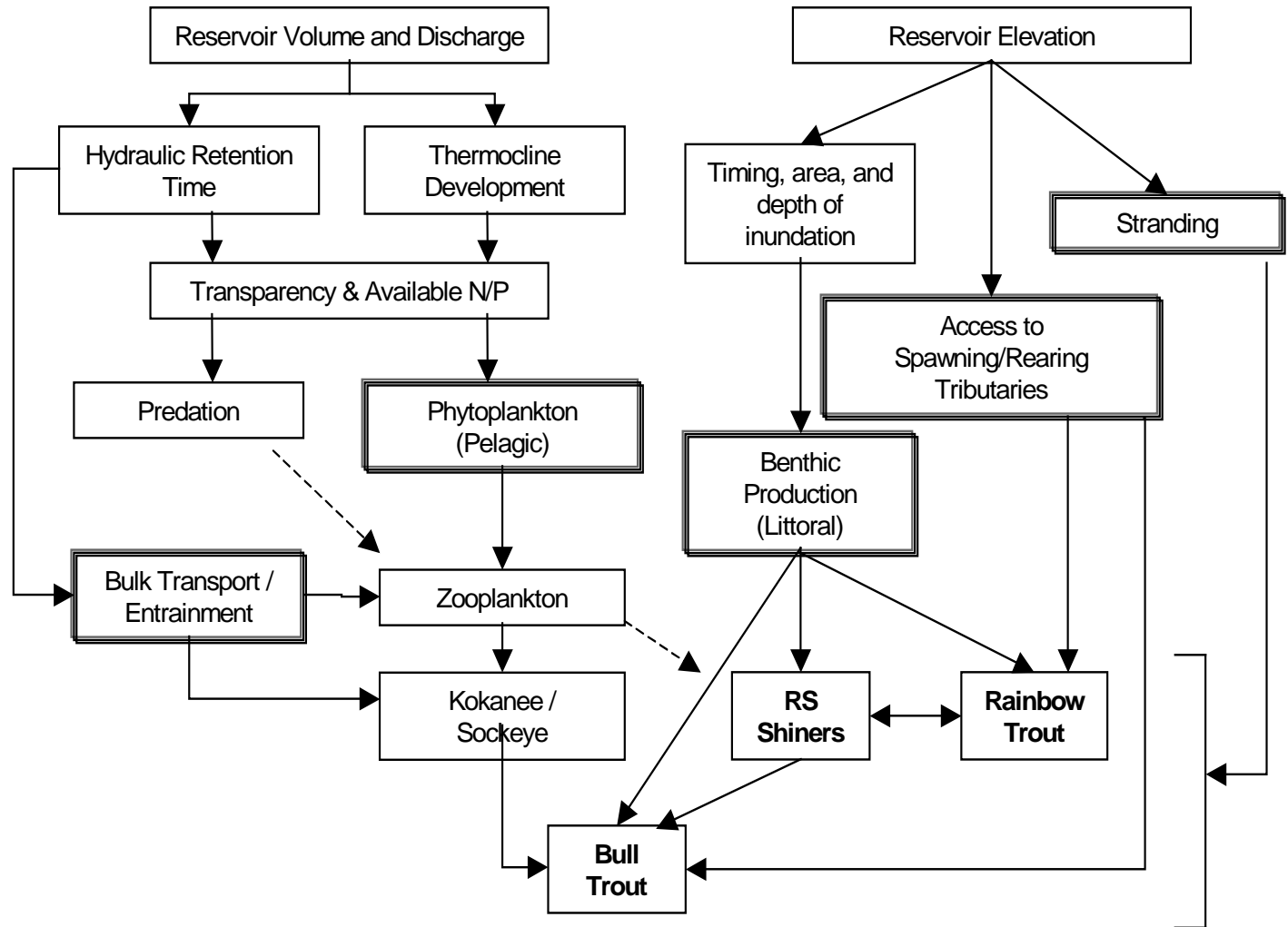
- Maximize financial benefits of power
- Minimize reliability impacts on ancillary services

Bridge River WUP - Influence Diagrams

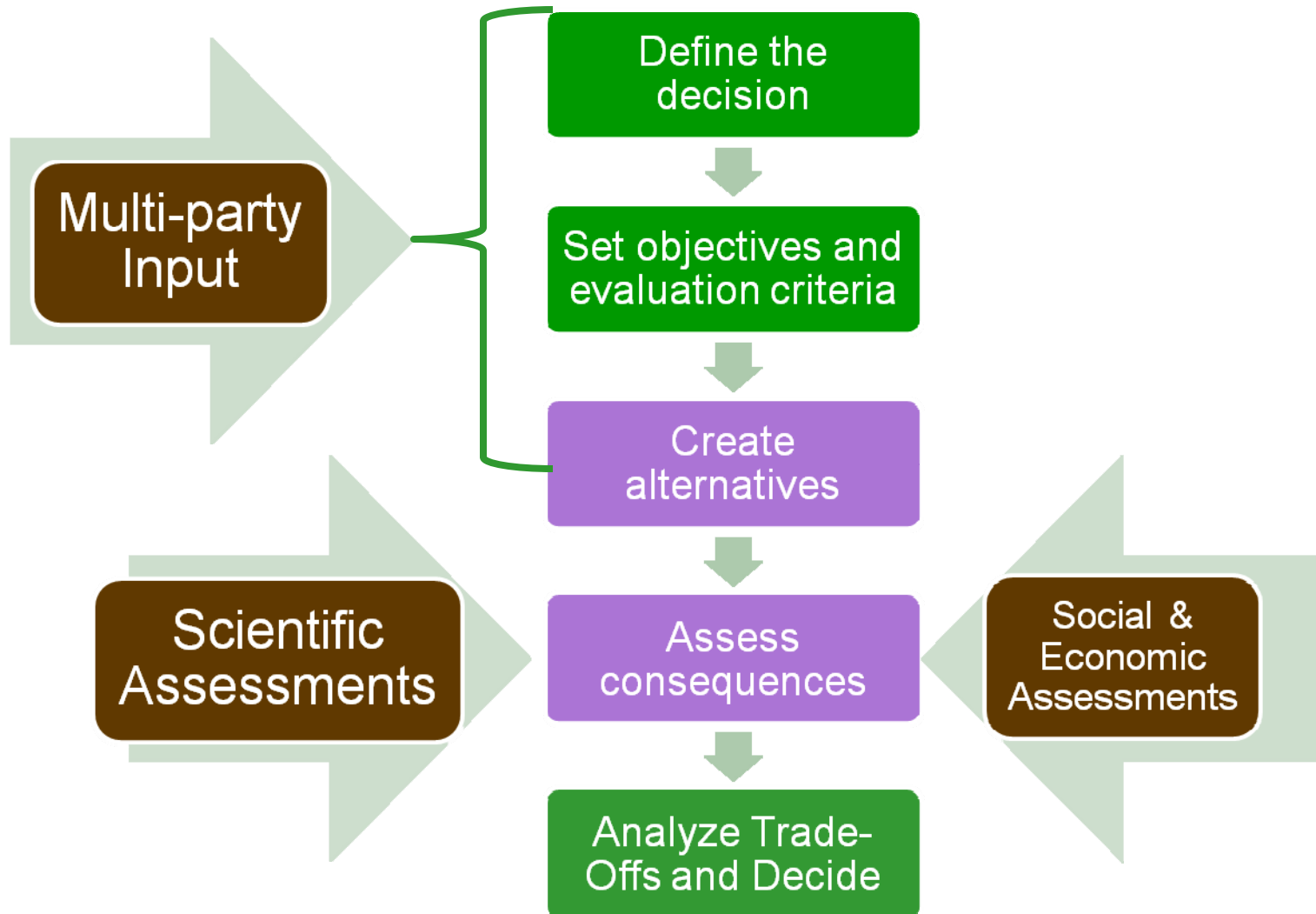
Build Common Understanding

Explore Competing Hypotheses

Select & Model Evaluation Criteria

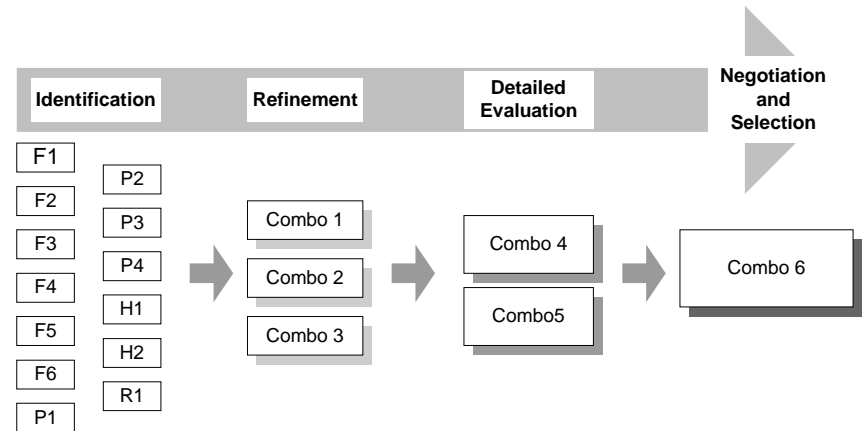


Steps in Good Decision Making



Bridge River WUP - Alternatives

- Began with over 40 criteria
- Explored over 20 alternatives



- Iteratively reduced decision to fundamental trade-offs:
 - Eliminate dominated alternatives
 - Eliminate insensitive criteria
 - Eliminate or combine attributes that co-vary
 - Aggregated grouped criteria into indices

Develop a **decision-relevant** information base

- Focus data collection and modeling around the evaluation criteria
- Build decision-focused models
- Use expert judgment
- Uncertainty/sensitivity analysis

Bridge River River WUP

			A	B	C	D	E	F	G
Flood	Failure	Risk scale	0	0	0	0	0	0	0
	Flood	d/yr	1	4	5	7	8	3	0
FISH	CAR	Entrain	0.7	0.8	0.4	0.8	0.8	0.6	0.6
		Strand	400	500	400	450	480	350	370
		Spawn	380	480	440	320	650	300	320
		Littoral	1200	1550	2200	1850	2190	3320	3500
		Pelagic	8600	8800	9800	10500	11800	9800	7500
		INDEX	65	70	40	40	30	30	40
VEG	DOW	Wtd ha	225	230	320	315	295	150	250
	CAR	Wtd ha	750	520	750	560	600	400	500
	SET	Wtd ha	50	50	50	50	30	30	50
WQ	SET	TSS t/yr	80	76	90	80	75	100	80
REC	Boat	# days	5	5	5	5	5	5	5
	Aesth	Wtd Ha	700	500	700	500	550	350	450
POW	Rev	\$M/yr	190	150	210	185	190	\$200	\$250
	Anc	Scale	None	None	None	None	None	None	None

In insensitive

Expert Judgment

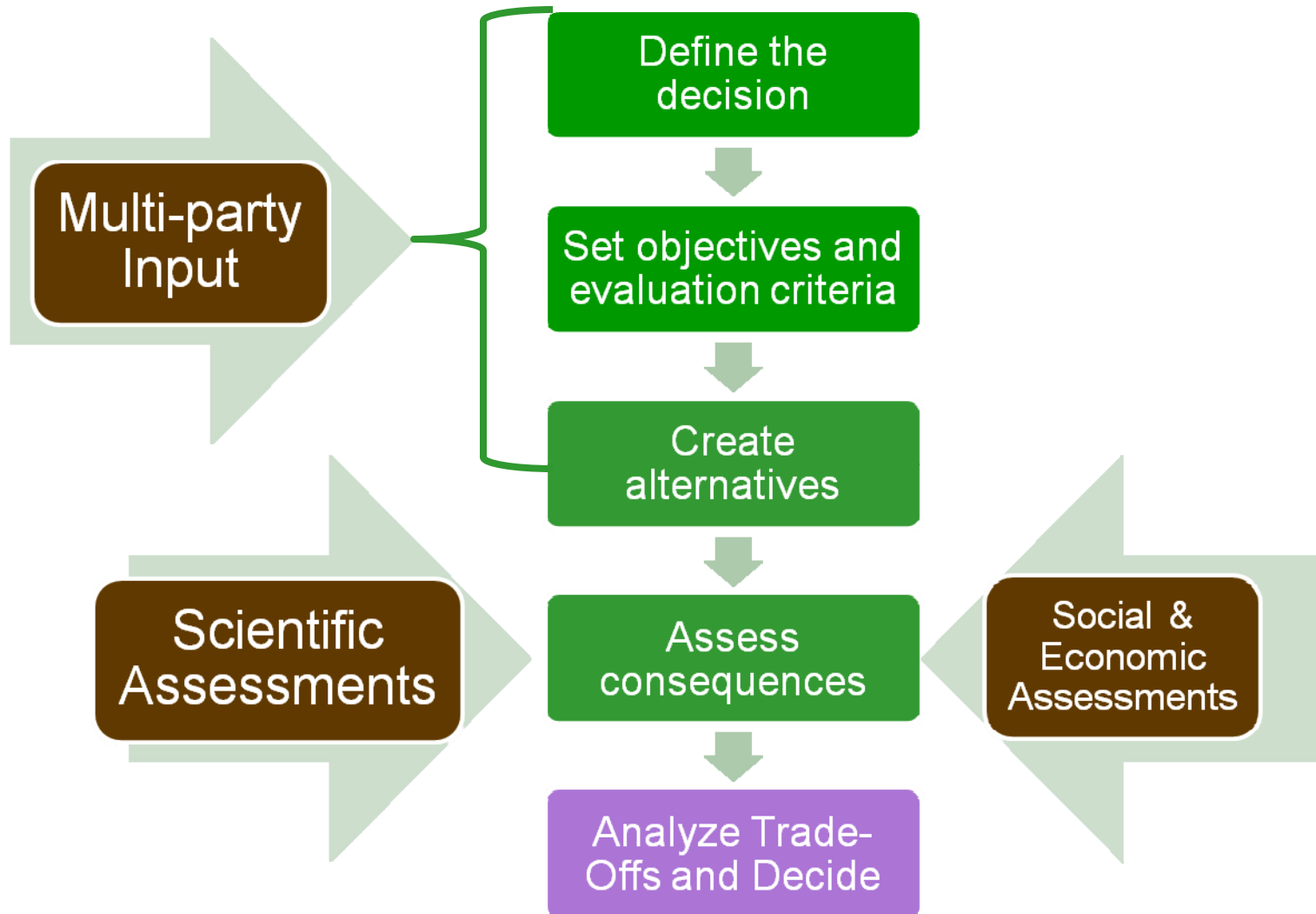
In insensitive

Dominated

Bridge River River WUP - Consequence Table

Objective	PM	Units	M2	M5	L2	N2	I3	B
FLOOD	Flood	Days per year	1	1	0	0	0	0
FISH	LBR	Scale	1	1	1	1	1	0
	SET	Scale	2	2	2	2	1	0
	DOW	Index	42	70	48	69	65	69
	CAR	Index	69	71	41	41	29	29
WATER QUALITY	TSS	Tonnes per year	94	89	77	84	108	78
VEGETATION	DOW	Weighted ha	223	231	322	313	295	300
	CAR	Weighted ha	759	522	758	520	602	600
	SET	Weighted ha	48	48	48	48	48	33
POWER	Revenue	Dollars per year	144	145	146	148	144	145

Steps in Good Decision Making



Bridge River River WUP- Trade-offs



Suppose you've set objectives, identified alternatives, and estimated consequences. You've eliminated unnecessary information and eliminated "losers". But you still have complicated choices – multiple objectives, many alternatives, complicated trade-offs and no obvious solution.

What now?



Bridge River River WUP- Trade-offs

Two day MATA workshop (Multi-Attribute Trade-off Analysis)

- Review objectives and criteria
- Review consequence table
- Discuss
- Complete questionnaires (weighting)
- Review results and discuss
- Revise preferences holistically



Bridge River River WUP- Trade-offs

Stakeholders answer two questionnaires using two different methods for value elicitation.

Direct ranking asks people to simply rank alternatives directly.

Name: _____

Alternative	Rank	Points
M2		
M5		
L2		
N2		
I3		
B		

Bridge River River WUP- Trade-offs

Swing weighting
delivers weights
for individual
criteria, resulting
in ranks and
scores for the
alternatives

	PM	Director	Units	Worst	Best	Rank	Points
Flood Damage	Flood	L	Days per year	1	0		
Fish	Fish - LBR	H	Scale	0	1		
Fish	Fish - SET	H	Scale	0	2		
Fish	Fish - DOW	H	Index	42	70		
Fish	Fish - CAR	H	Index	29	71		
Water Quality	TSS	L	Tonnes per year	108	77		
Vegetation	Veg - DOW	H	Weighted (ha)	223	322		
Vegetation	Veg - CAR	H	Weighted (ha)	520	759		
Vegetation	Veg - SET	H	Weighted (ha)	33	48		
Power	Revenue	H	Dollars per year	144	148		

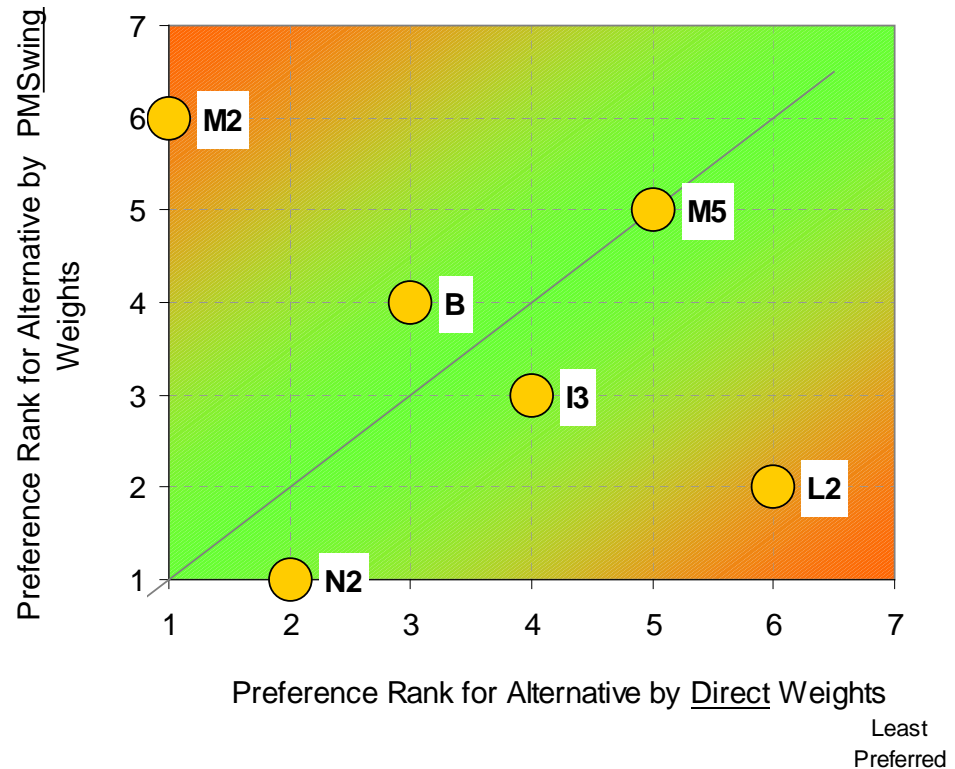
Bridge River River WUP- Trade-offs

Value elicitation is intended to aid decision making – not a black box!

Stakeholders can see how consistent their direct ranks are with their swing weighted ranks.

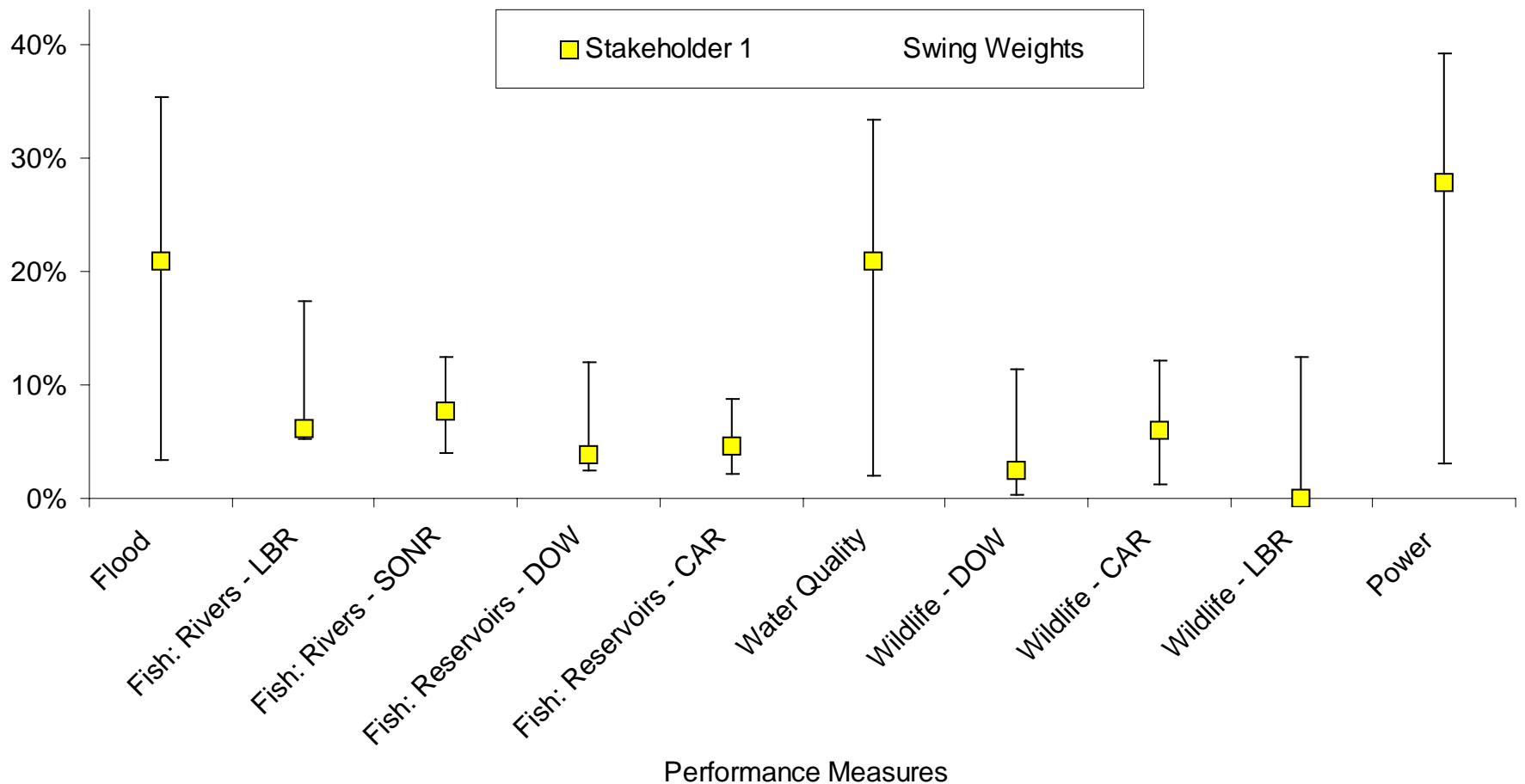
This person may want to reconsider M2 and L2.

Person1's Relative Preference for Alternatives Using Two Weighting Techniques



Bridge River River WUP- Trade-offs

**Selected Individual Weights (square point)
Compared to the
Range of Weights Across All Stakeholders (up-down line)**



Bridge River River WUP- Trade-offs

Consensus on
N2 with
compensatory
planting of
drawdown
zone

		Rank of Alternatives by Stakeholder and by Method											
Alternatives	Weighting Method	CC Members											
		1	2	3	4	5	6	7	8	9	10	11	12
M2	Swing	4	4	3	3	2	2	4	3	2	4	3	4
M2	Paired Comparison	4	4	4	2	2	2	4	4	2	4	4	5
M2	Direct	4	4	1	3	3	3	4	2	1	4	2	2
M5	Swing	3	3	4	4	4	4	3	4	4	3	4	3
M5	Paired Comparison	3	3	3	3	4	4	3	3	4	3	3	3
M5	Direct	2	2	6	2	2	2	3	5	4	2	4	3
L2	Swing	1	1	1	1	1	1	2	1	1	2	1	1
L2	Paired Comparison	1	2	1	1	1	1	2	1	1	2	1	2
L2	Direct	3	3	3	4	4	4	2	4	3	3	3	4
N2	Swing	2	2	2	2	3	3	1	2	3	1	2	2
N2	Paired Comparison	2	1	2	4	3	3	1	2	3	1	2	1
N2	Direct	1	1	2	1	1	5	1	3	5	1	1	1
I3	Swing	5	5	5	5	5	5	5	5	5	5	5	5
I3	Paired Comparison	5	5	5	5	5	5	5	5	5	5	5	4
I3	Direct	5	5	4	5	5	1	6	1	2	5	5	5
B	Swing	6	6	6	6	6	6	6	6	6	6	6	6
B	Paired Comparison	6	6	6	6	6	6	6	6	6	6	6	6
B	Direct	6	6	5	6	6	6	5	6	6	6	6	6



Indicates an alternative with a rank = 1

Indicates an alternative with a rank = 2

Indicates an alternative with a rank = 6

Why bother with structured trade-off methods?

- Improve ability to deal with complexity
- Avoid errors and biases
- Encourage performance-based dialogue
- Focus deliberations in constructive areas
- Provide diagnostic tool for disagreements
- Provide opportunity for equal input to all
- Improve transparency

No method is right... goal is *Insight*

- People learned
- People made surprising choices
- Preferences depend on the alternatives
- Agreement depends on a mutual understanding of consequences
- Very often the key trade-offs were not those anticipated before the process
- Different choices are often rooted in different risk tolerances



WUP - What made it work?

- **Structure and rigor**
 - A road map that everyone agreed to – explicit evaluation framework
 - Rigorous, defensible treatment of facts and values
- **Bounds**
 - Consensus sought, not required
 - Operating impacts, not footprint
- **Emphasis on learning**
 - During and after the process
 - About objectives, alternatives, uncertainties, trade-offs
- **Collaborative exploration of alternatives**
 - Only when the best alternatives had been explored did people make difficult trade-offs



Other Applications

- Cultus Lake Sockeye Salmon
- White Sturgeon Recovery Planning
- Atlantic Salmon
- Eastern Nile Joint Management Plan
- Glen Canyon Dam Adaptive Management Plan
- Columbia River Water Use Plan
- Mackenzie Basin Transboundary Waters Agreement
- Langley Ground Water Management Plan
- More...



Key Messages

Key Success Factors

- All players at the table
- Agreement by all to the SDM process/structure
- Written SDM guidelines – road map
- Independent decision analysis/facilitation
- Upfront commitment of time / resources

- Treat the problem as a **multi-dimensional** decision problem from the beginning
- Be explicit about the role and limits of **science**
- Establish explicit **objectives/criteria** and framework for evaluating options
- Develop **decision-relevant** models that focus on evaluating alternatives
- Use best practices in the use of **expert judgment**
- Know that hard decisions will depend on **risk tolerance**
- Be practical about “**adaptive management**”
- Use the same rigor for **values** as for facts

- SDM is a way of thinking about and guiding decisions. It provides a focus for analysis and a framework for constructive dialogue. It does not “make” decisions.
- While there are some recognized best practices, SDM is not a formula – every decision and every group of decision makers is different.

- SDM Guidelines
- Objectives / evaluation framework
- Identify range of alternatives
- Links to models / risk assessment
 - Focus on identifying and evaluating alternatives



Thanks!

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