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Climate Change Adaptation

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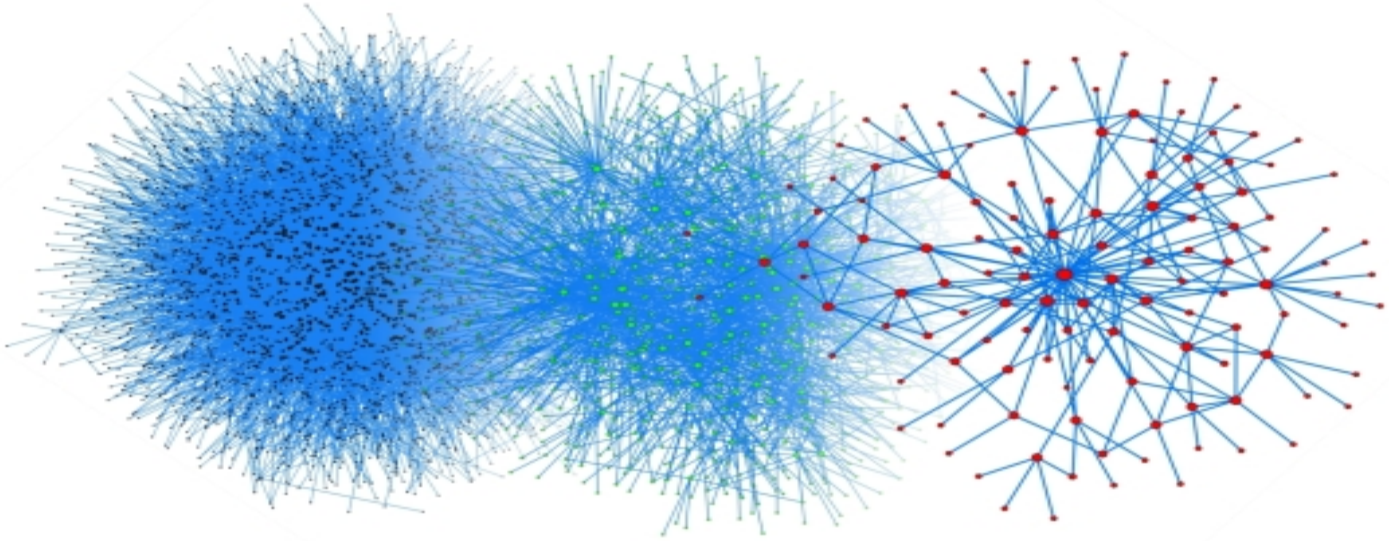
Coupled Human-Natural Systems



Multiple subsystems

Interactive

Dynamic

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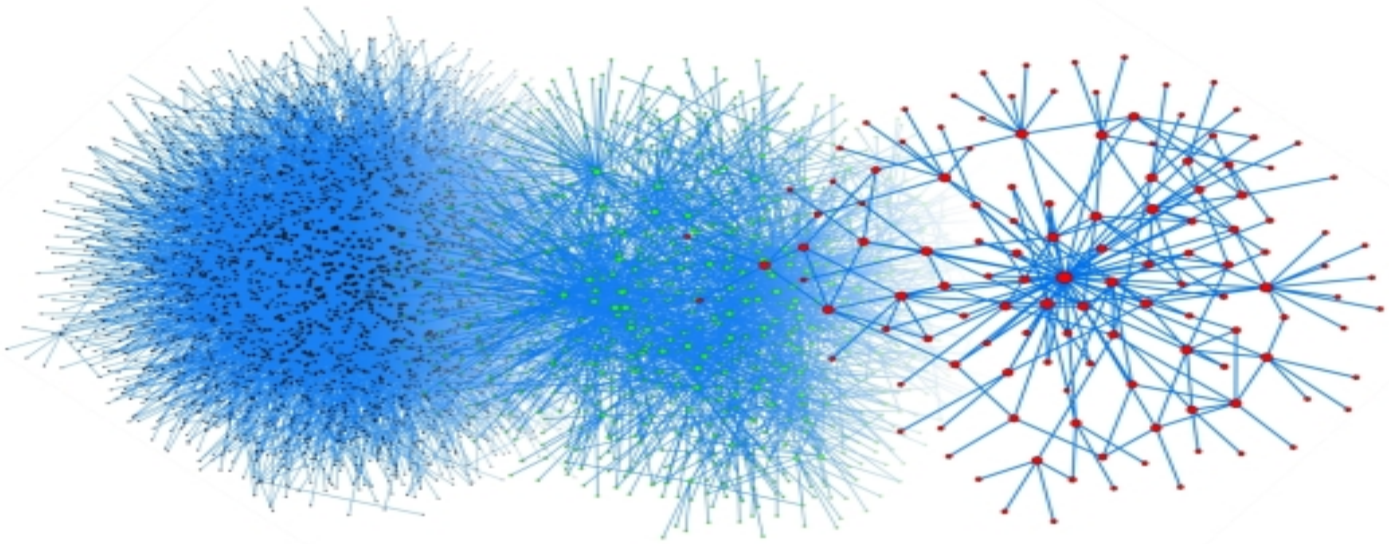
Coupled Human-Natural Systems



Multiple subsystems

Interactive

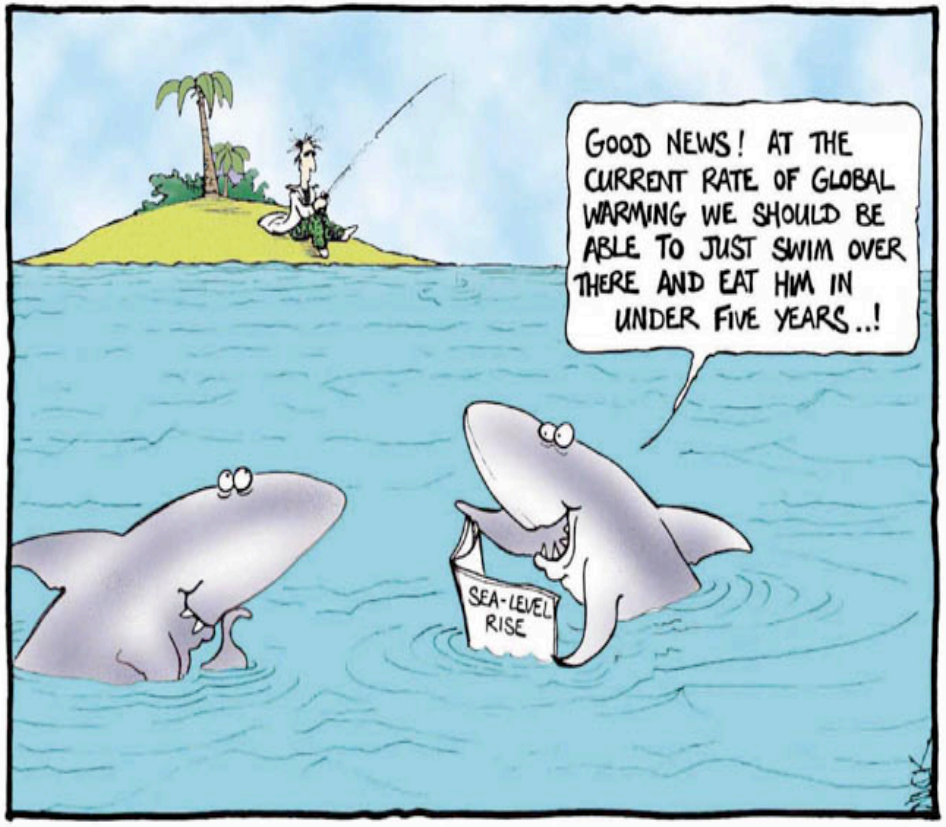
Dynamic

Uncertain

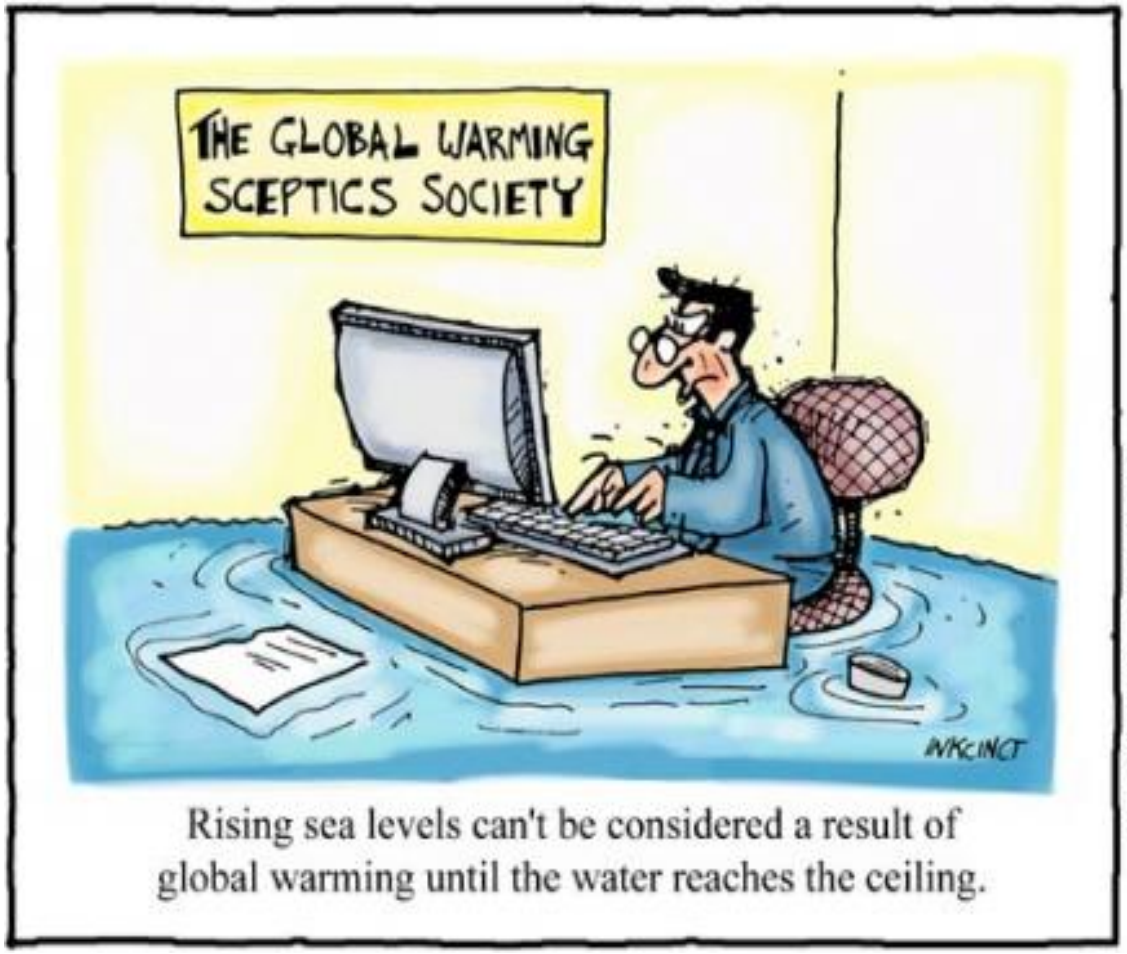
Water Management?

- Water
- Food
- Energy
- Ecosystem
- Land
- Economy
- Society
- Politics
- …

Studying Impacts vs. Adaptation



When Should We Adapt?



How Should We Adapt?

Carbon footprint:
The carbon dioxide equivalent/energy production

Water footprint:
The total amount of freshwater /energy production

Ecological/Land footprint:
The amount of land and sea area /energy production

Cost:
Levelized cost/energy production

Ignoring Trade-offs?

Global Warming (Symptom)

↑

Greenhouse gas emissions

↑

Fossil Fuels (Source)

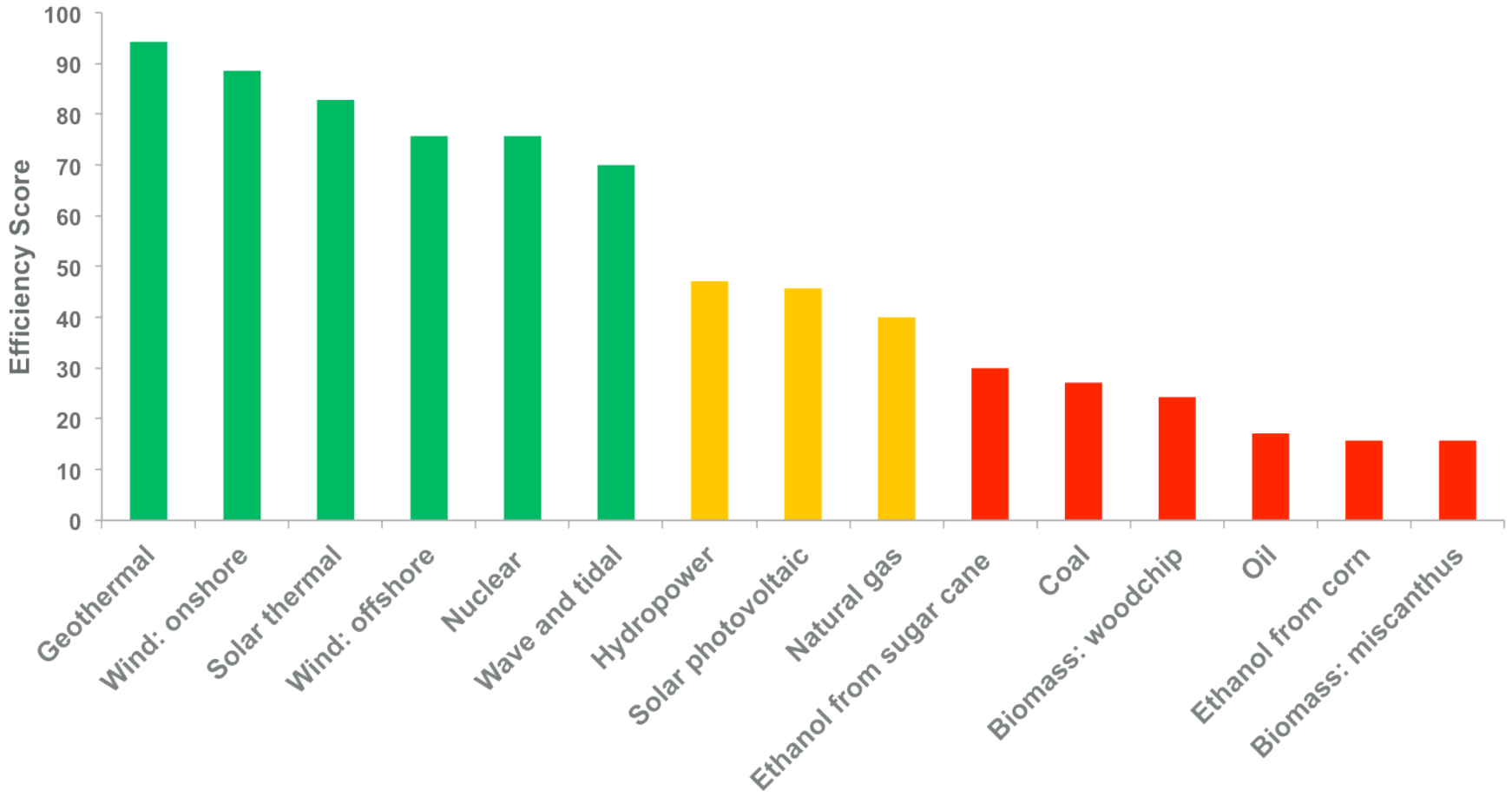
↓

Reducing carbon dioxide by any means!

Trade-offs

Energy Sources	Carbon footprint (g CO_2/kWh)	Water footprint (m^3/GJ)	Land footprint (m^2/GWh)	Cost (cent/kWh)
Ethanol from corn	81-85	78	10667-12500	2-4
Ethanol from sugar cane	19	99	9520	2-4
Biomass: wood-chip	25	42	14433-21800	4-10
Biomass: miscanthus	93	37	14433-21800	4-10
Solar thermal	8.5-11.3	0.037-0.780	340-680	4-10
Solar photovoltaic	12.5-104	0.042	704-1760	10.90-23.4
Wind: onshore	6.9-14.5	0.001	2168-2640	4.16-5.72
Wind: offshore	9.1-22	0.001	2168-2640	3.64-8.71
Wave and tidal	14-119	0.001	45-120	5-15
Hydropower	2-48	22	538-3068	3.25-12.35
Coal	834-1026	0.15-0.58	83-567	3.77-5.85
Oil	657-866	4.29-8.60	1490	8-10
Natural gas	398-499	0.1	623	5.46-11.96
Nuclear	9-70	0.42-0.76	63-93	4.55-5.46
Geothermal	15.1-55	0.005	33-463	1-8

Aggregate Performance



Some Common MCDM Methods

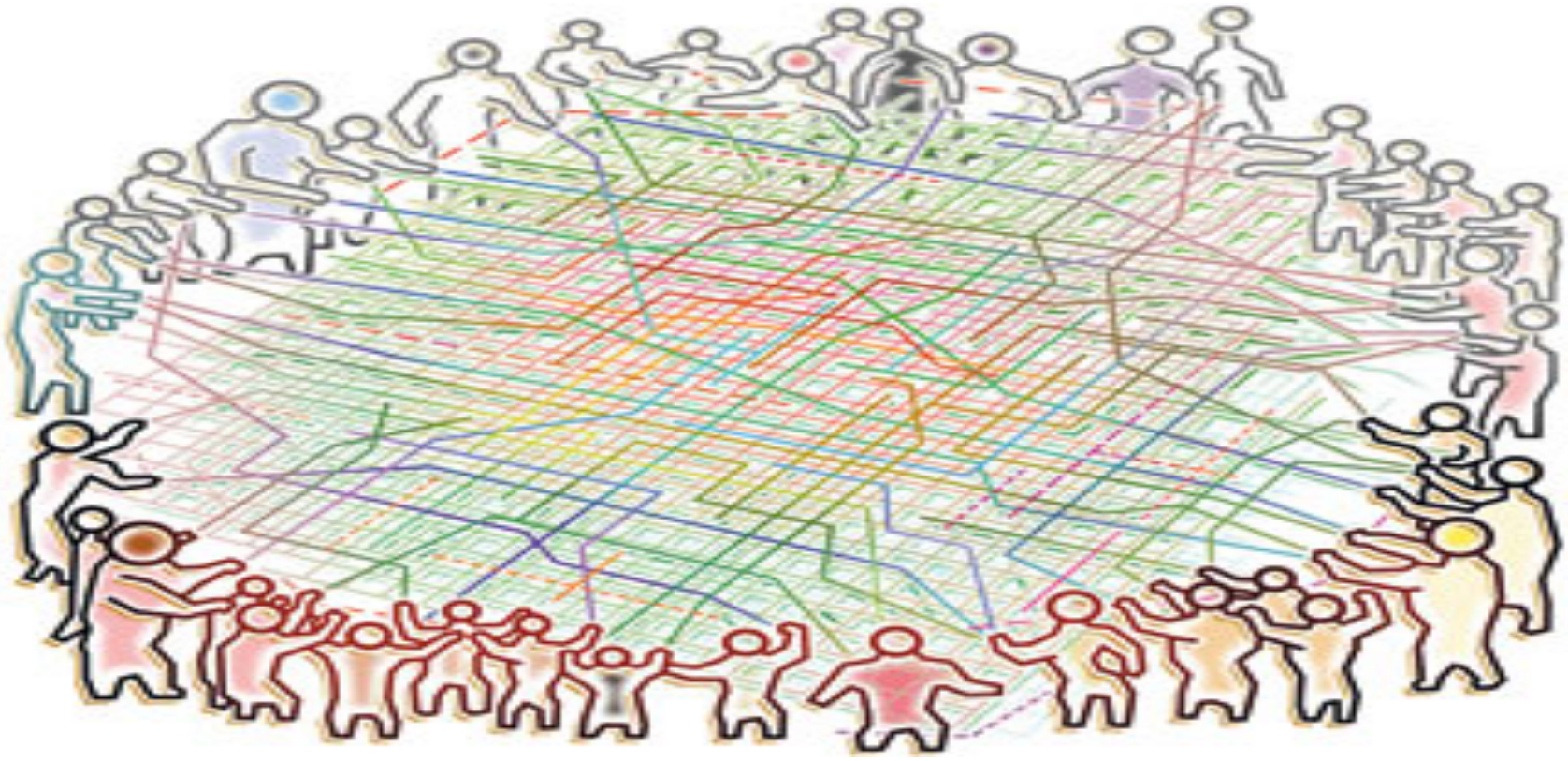
MCDM Method	Basis of Selection
Dominance (Fishburne, 1964)	Pair-wise comparison of alternatives to identify the non-dominated option
Maximin (Wald, 1945)	Maximizing the minimum satisfaction of all criteria
Lexicographic (Tversky, 1969)	The most desirable alternative for the most important criterion
TOPSIS (Hwang and Yoon, 1981)	Minimum distance from the ideal point
SAW (Churchman and Ackoff, 1945)	Highest weighted performance

Example

MCDM Method	Basis of Selection
Dominance (Fishburne, 1964)	Pair-wise comparison of alternatives to identify the non-dominated option

Consultant	Cr_1	Cr_2	Cr_3	Cr_4	Cr_5
Consultant 1	0.1	4	5	4	0.10
Consultant 2	0.15	2	2	4	0.05
Consultant 3	0.15	1	2	3	-0.05

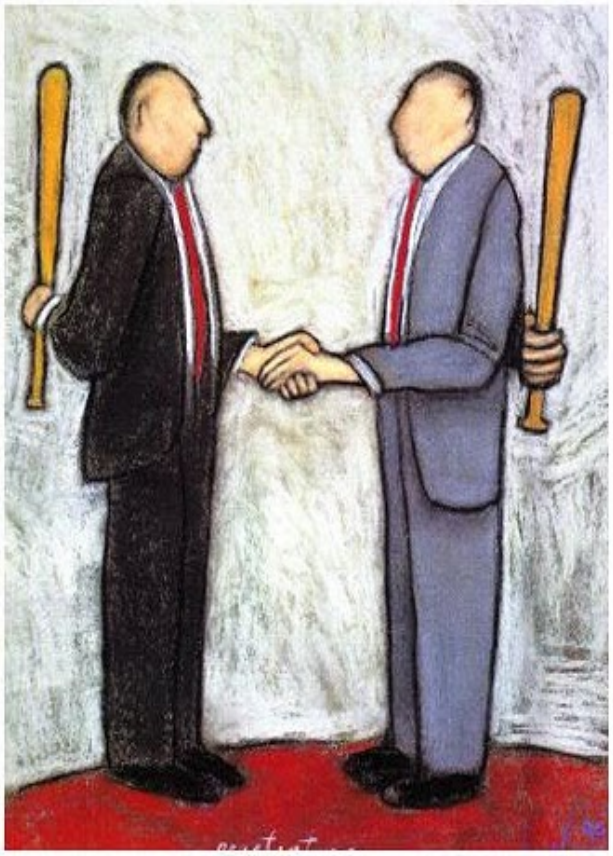
Who Manages Water?



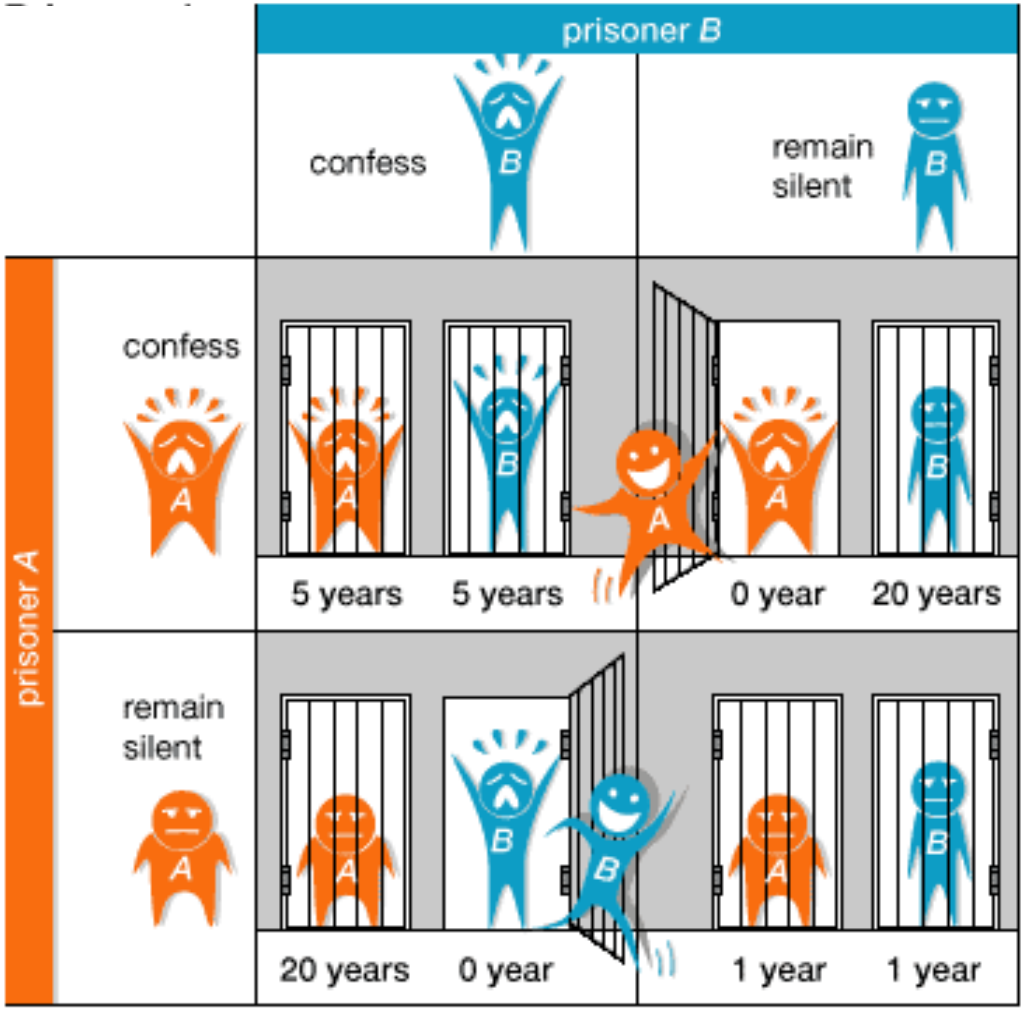
Multiple-Participants Multiple-Objective

Conflicts


IT'S AGREED! WE'LL CUT GREENHOUSE GAS EMISSIONS 50 PERCENT BY 2050!
HIGH FIVE!
OKAY, YOU GO FIRST.
NO, YOU.
INDUSTRIALIZED COUNTRIES
DEVELOPING COUNTRY
HORSEY

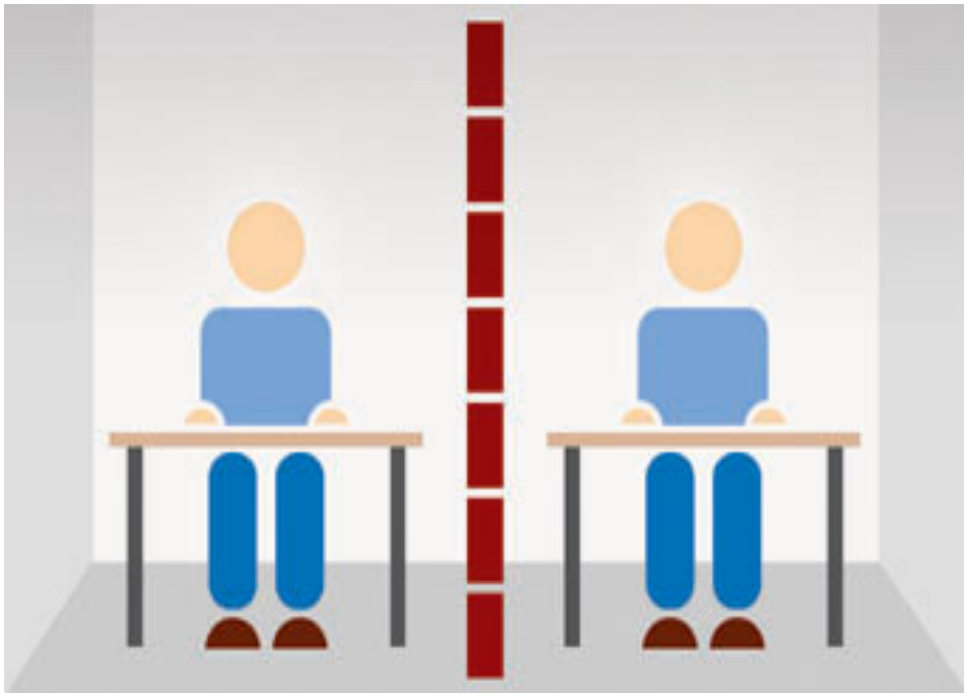


Prisoner's Dilemma



Prisoner's Dilemma

- Lack of trust
- Self-optimizer vs. system-optimizer
- Free-riding and non-cooperation is a dominant strategy



Cooperative resolution is not likely!

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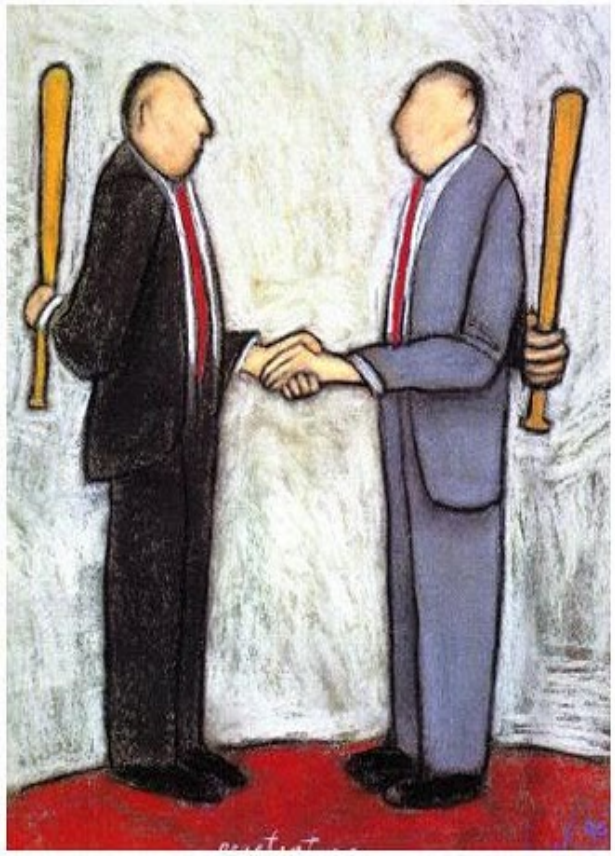
Climate Change Negotiations



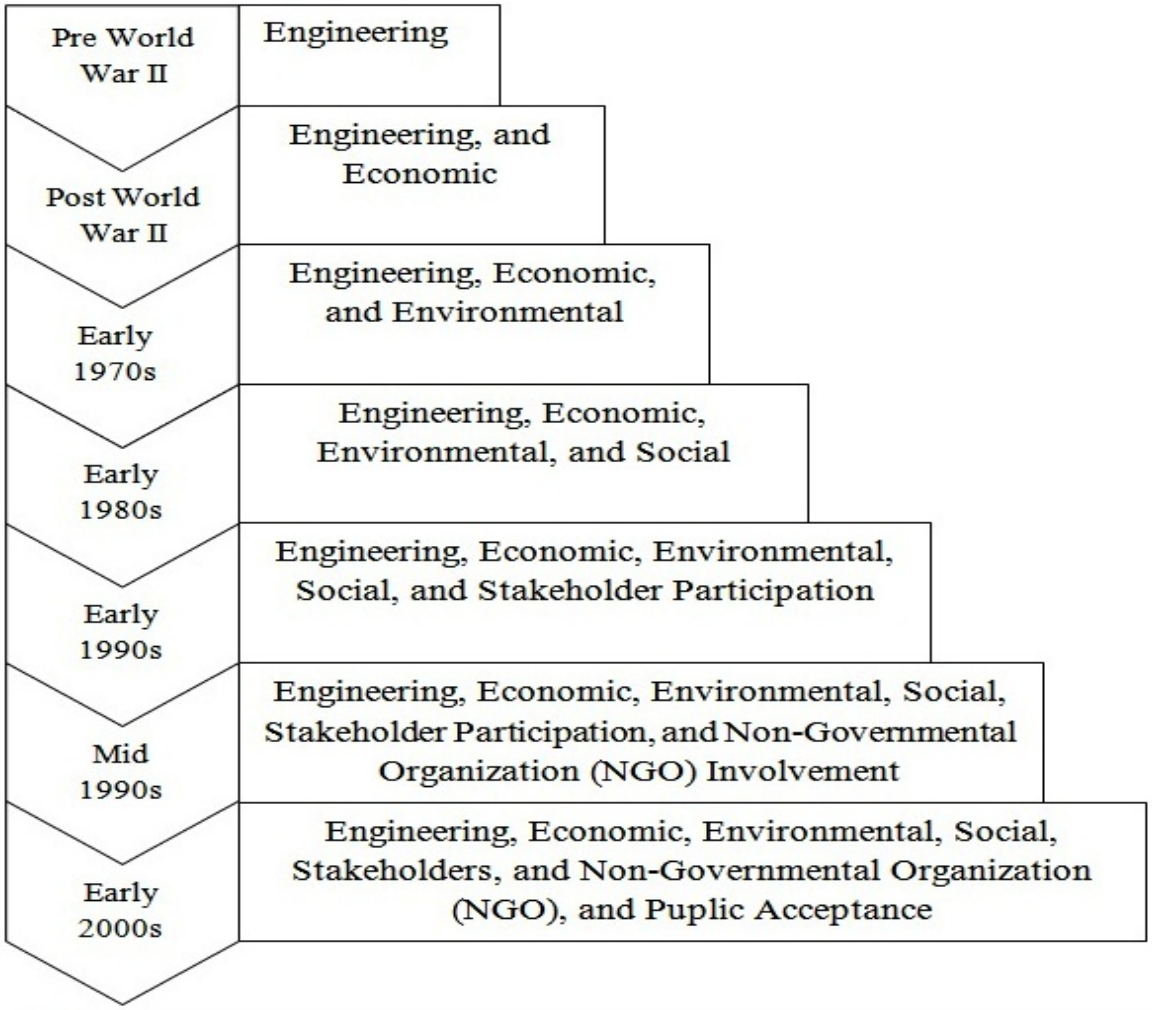
Chicken

Driver 1 \ Driver 2	S	DS
Swerve (S)	Tie, Tie	Lose, Win
Don't Swerve (DS)	Win,Lose	Crash,Crash

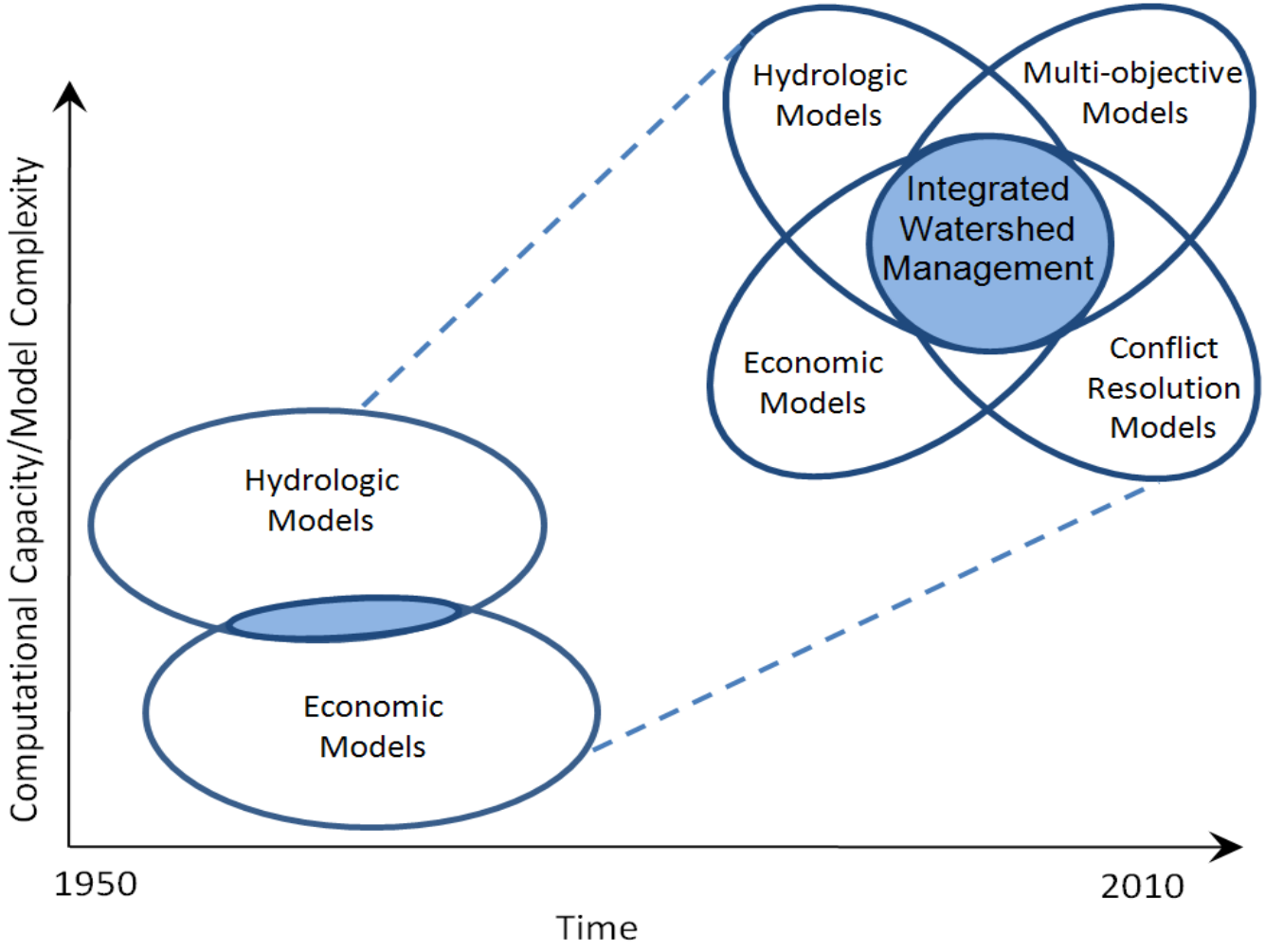
Chicken

- Little incentive for cooperation
- Free ride and doing the opposite
- One winner and one loser
- Sending strong signals
- Risk tolerance

Water Management Approaches over Time



Water Management Models over Time



Performance Evaluation

How Do You Make Decisions?

Decision	Outcome:	-$1,000	-$500	$0	$500	$1,000	$2,000
A	Probability:	0.05	0.3	0.3	0.2	0.1	0.05
B	Probability:	0	0.4	0.3	0.2	0.1	0
C	Probability:	0.1	0.1	0.2	0.3	0.3	0

- Optimistic
- Pessimistic
- Expected value
- …..

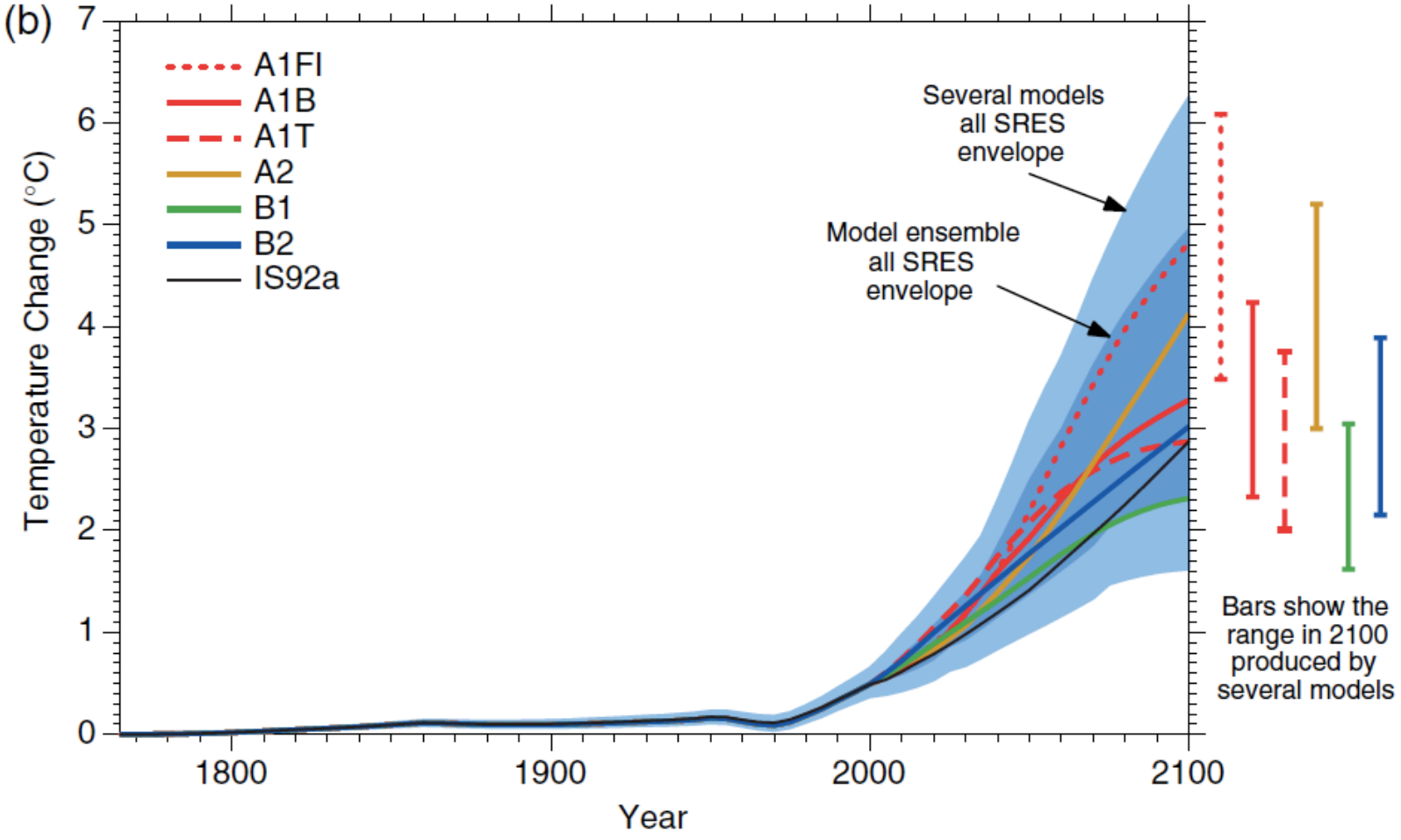
How Do You Make Decisions?

Decision	Outcome:	-$1,000	-$500	$0	$500	$1,000	$2,000
A	Probability:	0.05	0.3	0.3	0.2	0.1	0.05
B	Probability:	0	0.4	0.3	0.2	0.1	0
C	Probability:	0.1	0.1	0.2	0.3	0.3	0

- Optimistic
- Pessimistic
- Expected value
- …..

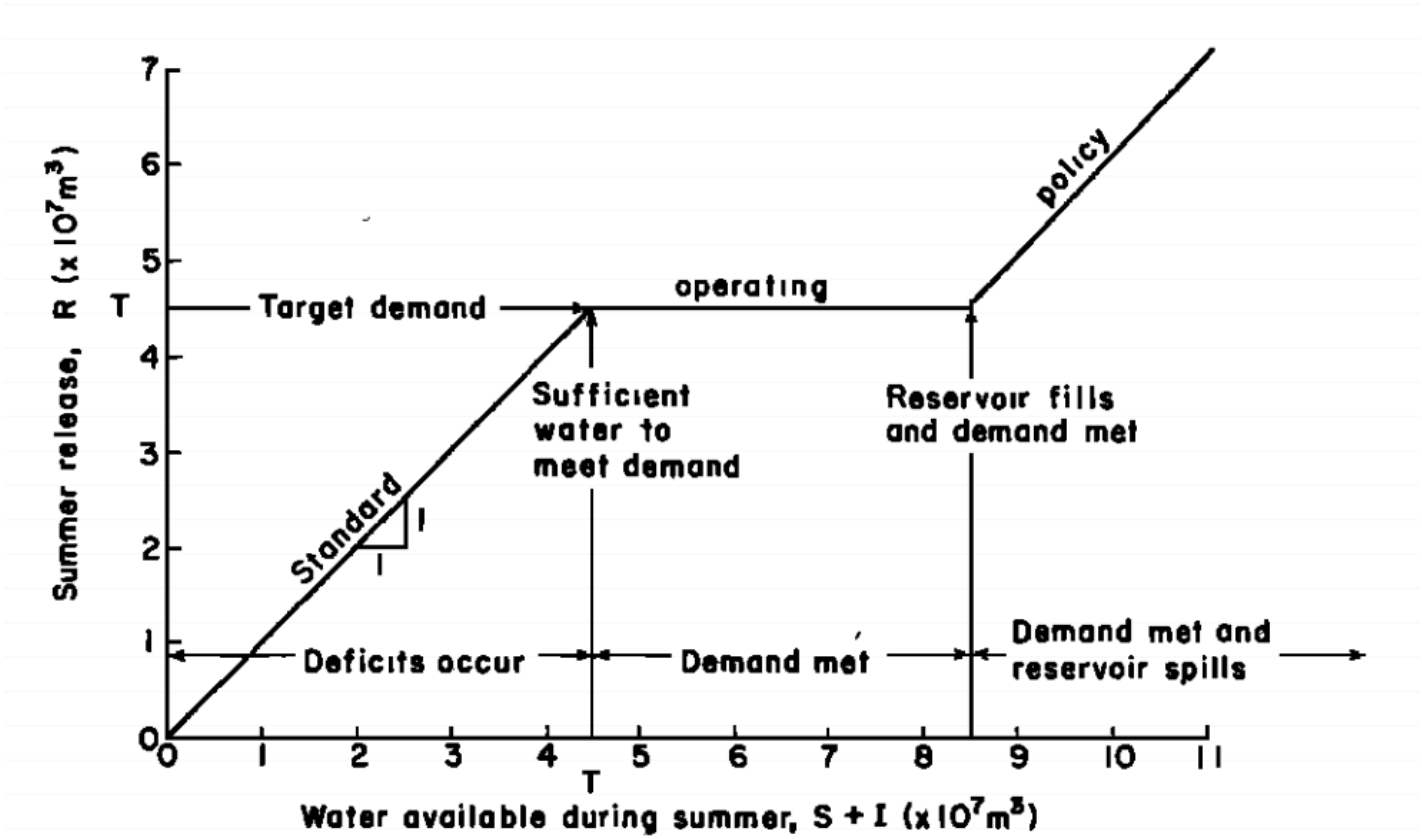
Robust Decision Making

Robust vs. Adaptable



Reservoir Operations

Rule Curve


Summer release, R (x 10⁷m³)
Water available during summer, S + I (x 10⁷m³)
Target demand
operating policy
Sufficient water to meet demand
Reservoir fills and demand met
Standard
1
1
Deficits occur
Demand met
Demand met and reservoir spills
T
T
0
1
2
3
4
5
6
7
8
9
10
11

Reliability

How often does your system fail?

Vulnerability

How significant are the likely consequences of failure?

Resiliency

How quickly can your system to a satisfactory state after a failure?

Trade-offs Again

How do you deal with the trade-offs between reliability, resiliency and vulnerability?

HEESA

Hydro-Environmental & Energy Systems Analysis

Providing Interdisciplinary & Sustainable solutions

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