National Centre for
Groundwater Research and Training

sustaining a vital water resource

Thinking beyond the aquifer: integrating policy, socioeconomics, ecology and interest groups into groundwater management through model-based processes

Tony Jakeman and Baihua Fu

iCAM
Fenner School of Environment and Society
Australian National University and NCGRT

tony.jakeman@anu.edu.au; groundwater.com.au

Why groundwater? Why now?

- Many aquifers ***vital*** but over-exploited, some parts non-renewable (groundwater ***mining***)
- Is a hidden resource - Managers often ***flying blind***
- Groundwater taken for granted and ***underpriced***
- ***Competition*** for water intensifying
- ***Quality*** affects use
- Time to reach ***tipping points*** longer than those of societal decision making
- ***Transcends*** sector, state or even national issues

\- a human issue requiring an ***integrated*** approach

- ***Precautionary Principle!***

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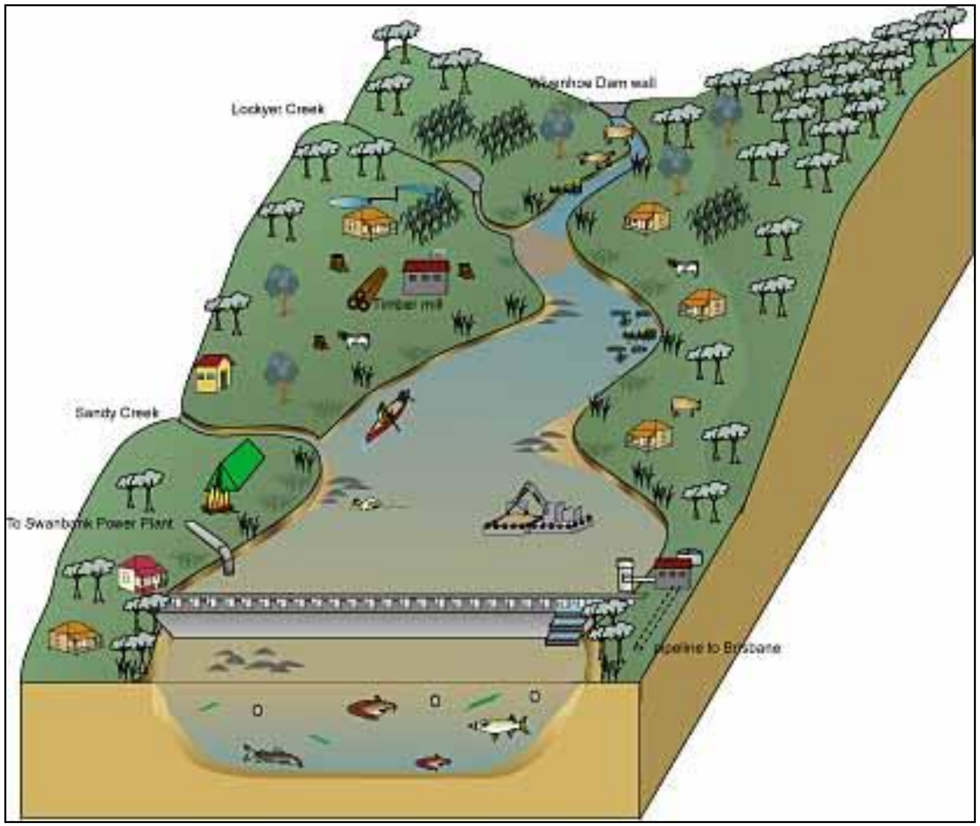
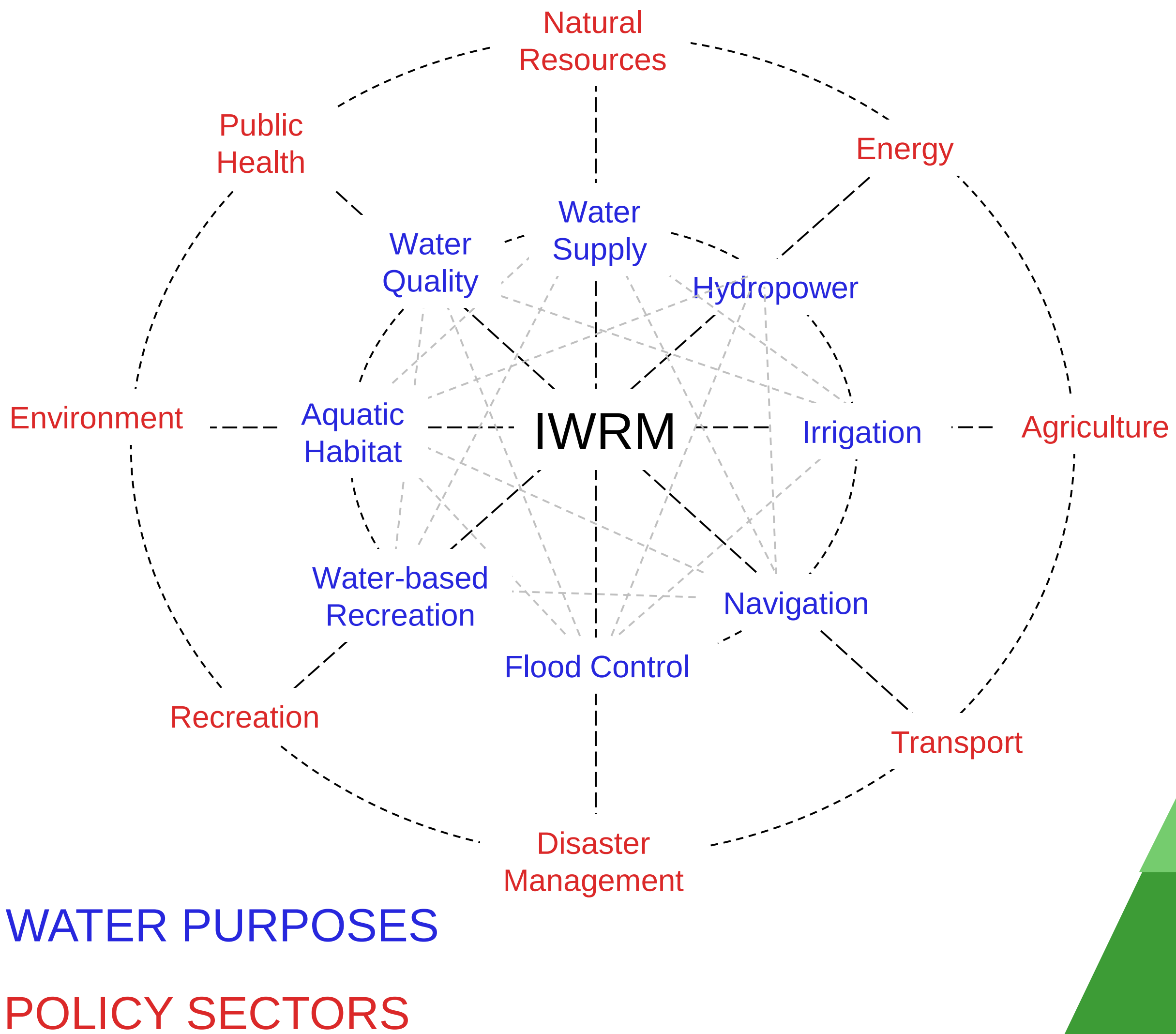
The ‘messiness’ of IWRM and environmental decision making

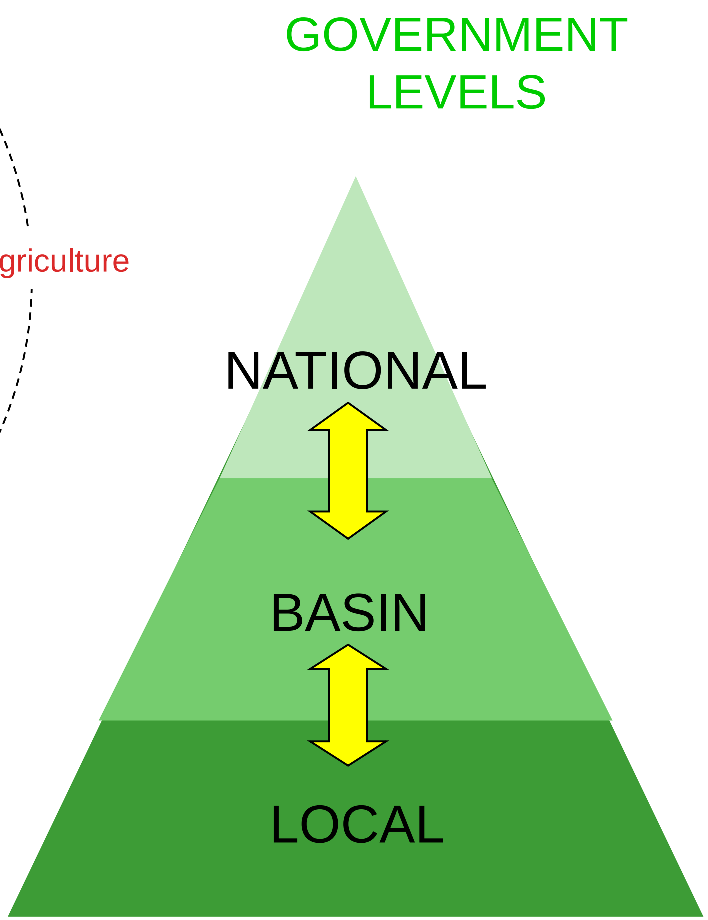


- Multiple EVERYTHING!

Uses/functions, Stakeholders & Competing goals, Decision makers, Legal frameworks, Problem severity, Resource resilience, Timescales of importance, Degrees of Complexity and Uncertainty

- No stopping point





(adapted from Grigg 2008)

IGM definition

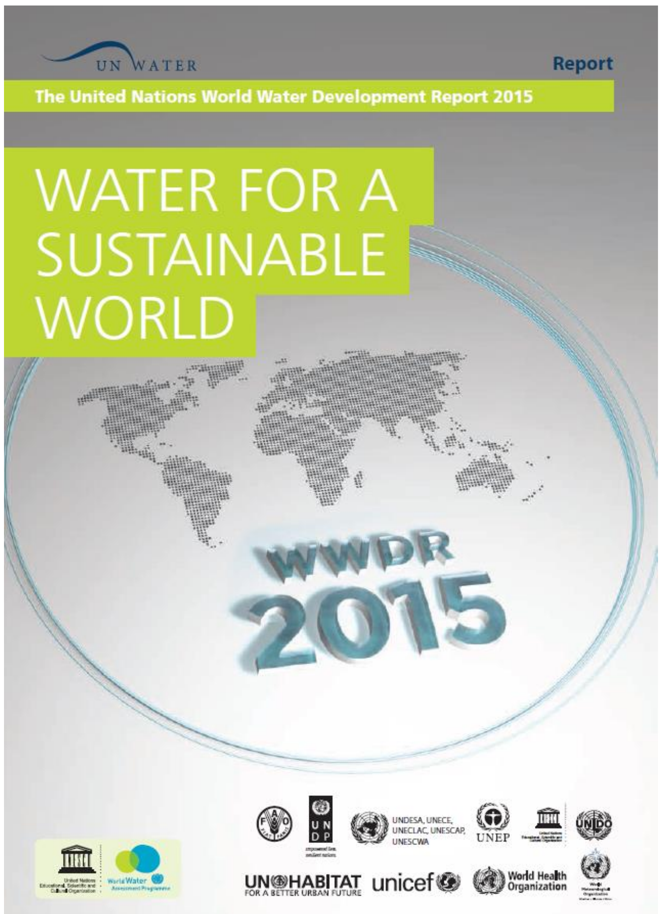
Jakeman, Barreteau, Hunt, Rinaudo, Ross (2016)*

"Integrated groundwater management is…a structured ***process*** that promotes the coordinated management of groundwater and related resources…taking into account…policy interactions…to achieve balanced economic, social welfare and ecosystem outcomes over space and time."

*Free download of Springer book on Integrated Groundwater Management

http://link.springer.com/book/10.1007%2F978-3-319-23576-9

UN World Water Development Report 2015

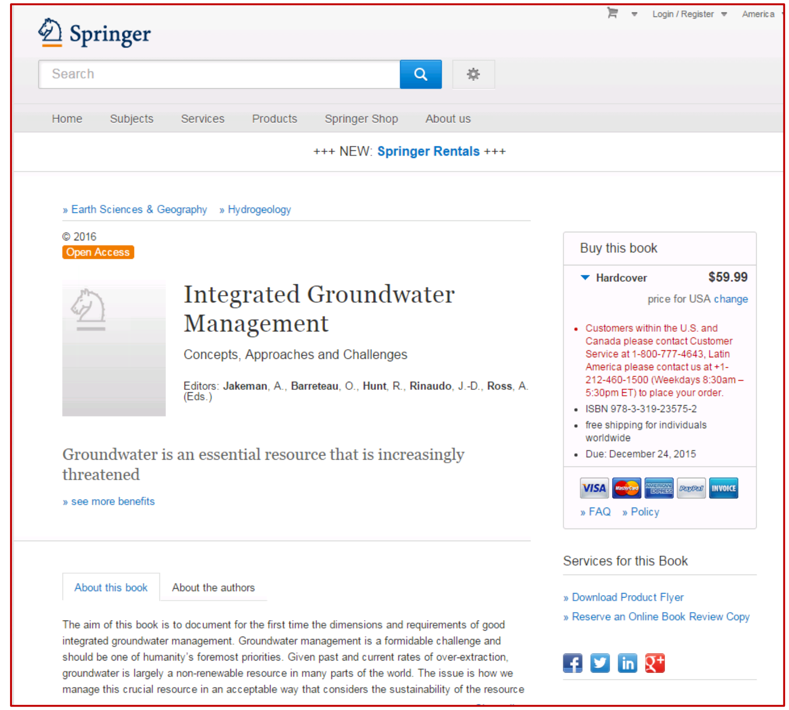


Vision 2050: water in a sustainable world

"In a sustainable world that is achievable in the near future, water and related resources are managed in support of human well-being and ecosystem integrity in a robust economy… Integrated approaches to water resources development, management and use – and to human rights – are the norm…"

The (big) Book

- 5 Parts
- 28 Chapters
- 74 Authors



- Not distilled for this part of the talk! Will focus on *examples* to illustrate presentation style and approach

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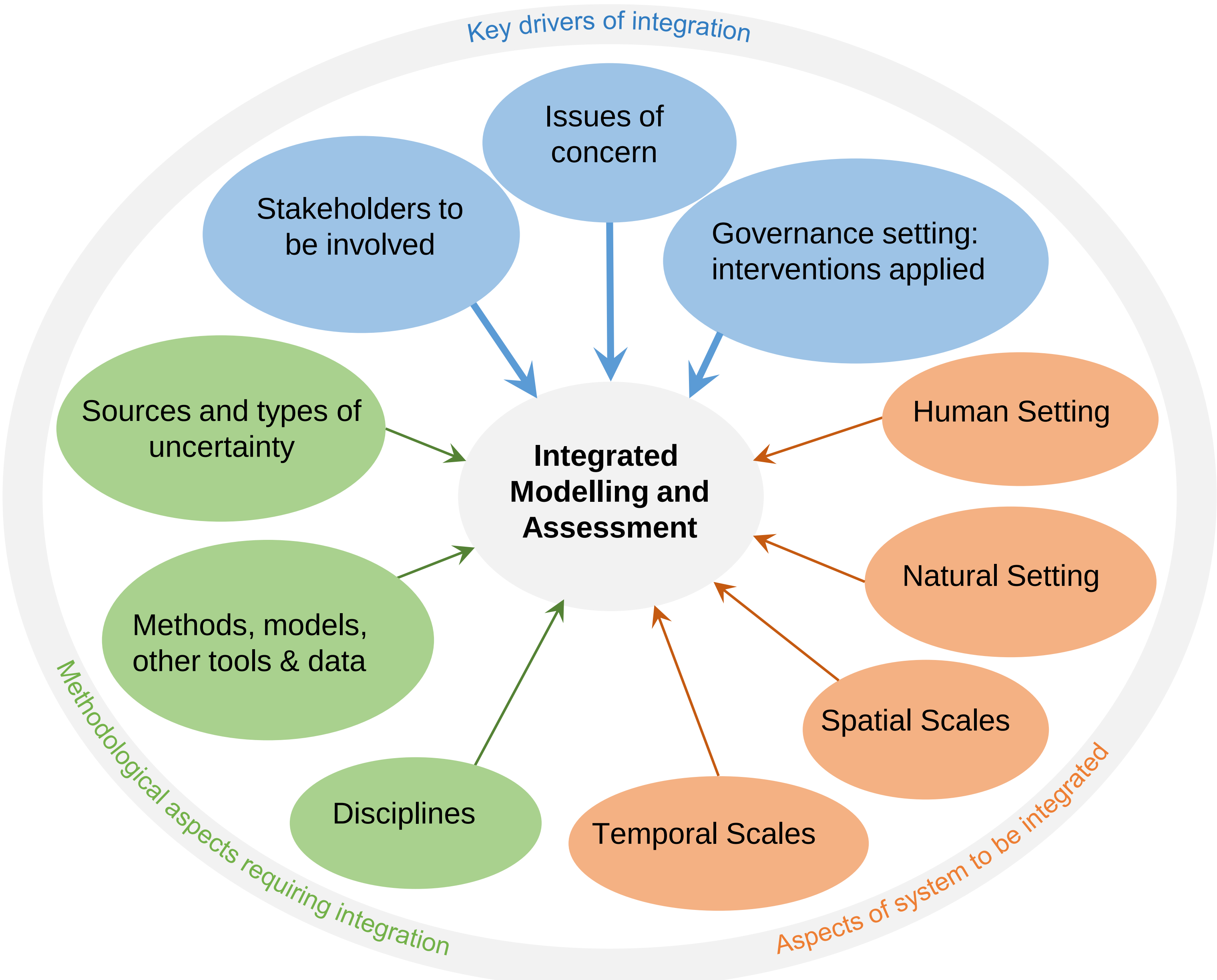
Part I example: Introduction

- Managing groundwater is a grand challenge problem in its severity, pervasiveness and importance for future generations
- There are opportunities and new threats: managed aquifer recharge, conjunctive use, climate change, water-energy-food nexus…
- Conceptual framework proposed to deal with complexity of interactions
- We have many of the tools and processes but we must learn how to select and combine them

Ten dimensions of integration in IMA

Hamilton, S., El Sawah, S., Guillaume, J.H.A., Jakeman, A.J. & Pierce, S.A. (2015) Integrated modeling and assessment: an overview and synthesis of its salient dimensions. *Env. Mod. & Software*.



Part II: Governance messages

- Strengths and weaknesses of governance in Australia, EU and USA
- Legal principles and challenges including in a cross-boundary and cross-sectoral context
- Examines policy frameworks for integrated management and planning, indicating the living nature of IGM as new information and experience is gained
- Crisis driven: e.g., conjunctive mgmt through coordinated action by governments and water users
- Justice for equitable and reasonable utilization of gw; experience shows farmers influenced by their perception of policy legitimacy and feasibility

Part III: Biophysical messages

- Non-hydrological factors commonly most critical for determining gw availability, sustainability & mgmt
- Need response function of ecosystems to gw extraction
- Water quality concerns change over time, can eclipse quantity issues
- Salinization of groundwater need strong integration with policy
- MAR (in theory) can be economic and can augment supply, aid conjunctive use and water security, and improve water use efficiency
- MAR (in practice) is a challenge due to site specifics and legal frameworks

Part IV: Socioeconomics messages

- Case studies in China, North Africa, France, Australia, USA etc.
- Social scientists to be involved from the outset: stakeholder engagement, social impact assessment, identifying collaborative approaches
- Groundwater markets require a level of regulatory and institutional setup. Efficiency versus social concerns
- Addresses contingent valuation methodology for present and future generations (i.e., bequest value)
- Evaluates strategies for IGM through economic instruments and presents innovative approaches

Part V: Modeling and Decision Support

- Systems thinking needed including all important aspects of IGM: hydrology + social, economic, science, legal
- Examples of successful decision support systems (DSS) still rare (but still provides process, methods and tools to deal with otherwise intractable problem)
- Holistic hydroeconomic DSS needed but challenges arise from incorporating model/social complexity, uncertainty
- Data mgmt challenges of IGM as new technologies in monitoring, developing, QA/QC, storing, curating, maintaining discoverability and accessibility
- Effective IGM tools require ***comprehensive pragmatism***: eliminating the impossible and low-probability potential outcomes, "crash testing", elucidating/exploring alternatives

Using a scenario analysis process to investigate uncertainty in water resource management

Baihua Fu[1], Joseph Guillaume[2,1], Mike Asher[1], Tony Jakeman[1]

[1]: National Centre for Groundwater Research and Training (NCGRT) and Integrated Catchment Assessment and Management (iCAM) centre, Fenner School of Environment and Society, Australian National University, Canberra, ACT 0200, Australia

[2]: Water & Development Research Group (WDRG), Aalto University, Finland

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Murray-Darling Basin

- Agricultural centre, ecological hotspots
- Basin Plan: ensuring a balance between the water needs of communities, industries and the environment
- “environmentally sustainable level of take” to determine “sustainable diversion limits”
  - 10,873 GL/yr surface water
  - 3,324 GL/yr groundwater

Source: en.wikipedia.org/wiki

Source:
www.murrayriver.com.au

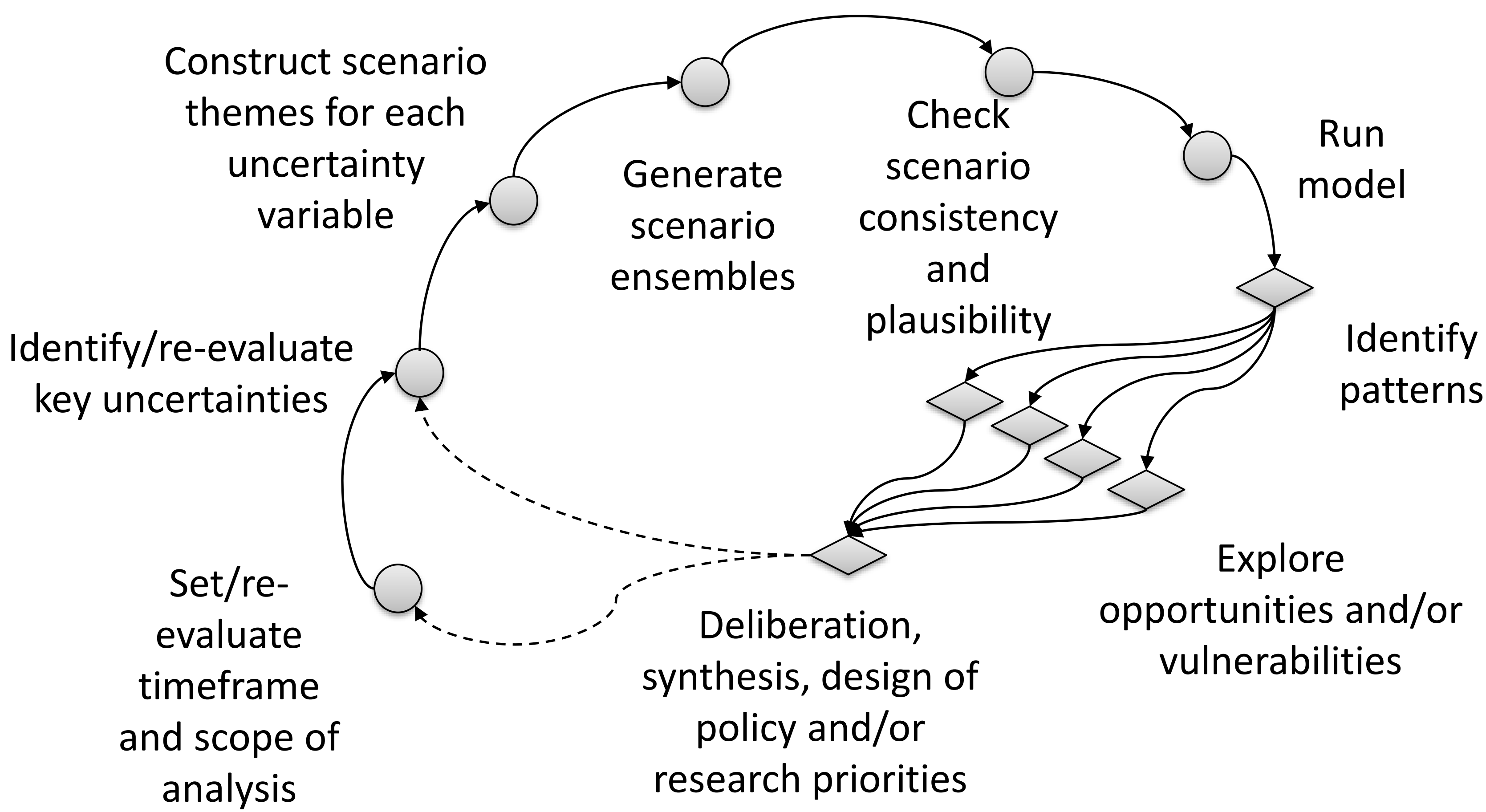
A controversial planning process

- *“**What were the assumptions** that went into the modelling of …”*
- *“Is the methodology … **robust scientifically or assured of success** given the large number of factors other than flows that threaten river and floodplain ecosystem health”*
- Deep uncertainty: “Fundamental disagreement about the **driving forces** that will shape the future, the **probability distributions** used to represent uncertainty and key variables, and **how to value alternative outcomes**” (Lempert 2002)

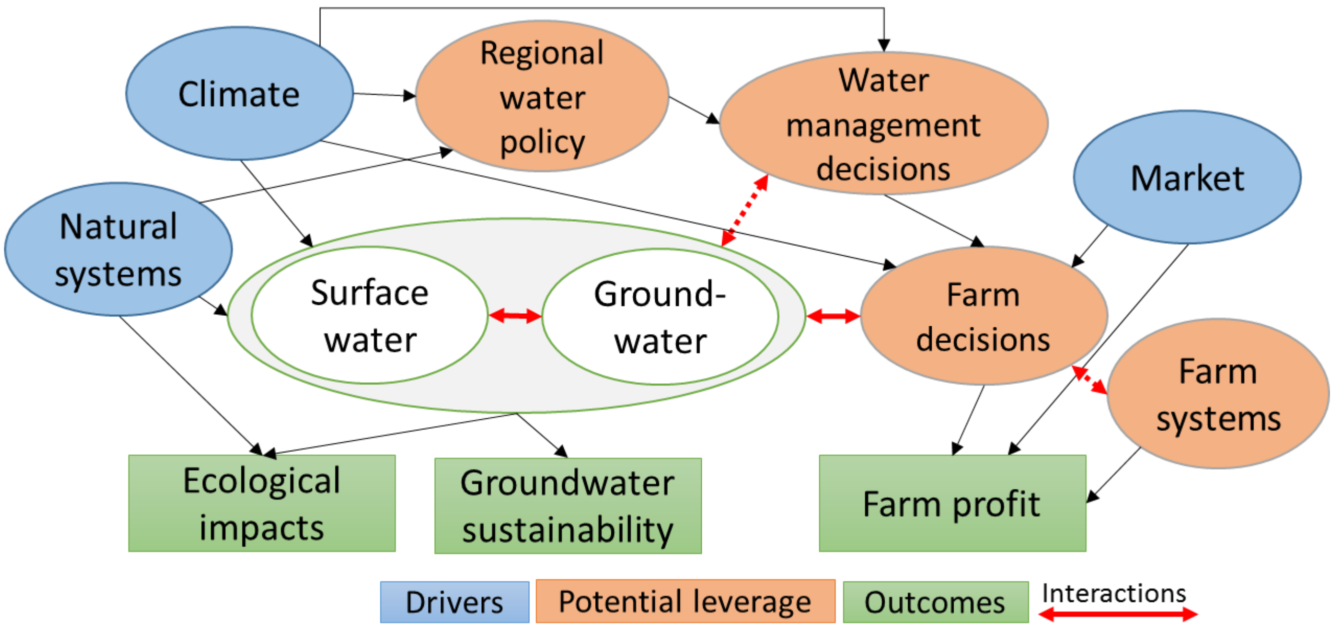
A solution?

- Exploratory modelling (vs. consolidative modelling) Bankes (1993)
  - Explore implications of various assumptions within broader analytical context
  - vs. consolidating knowledge to create a surrogate of a system
  - i.e. using scenarios as coherent descriptions of alternative hypothetical futures, arising from different assumptions
- Case study analyzing ensembles of scenarios
- Related to:
  - Scenario discovery: summarizing plausible future states of the world that illuminate key vulnerabilities
  - Robust decision making: identifying interventions that achieve goals in the face of uncertainties

Exploratory Scenario Analysis Workflow



Prototype integrated model – "Namoi" subcatchment case study



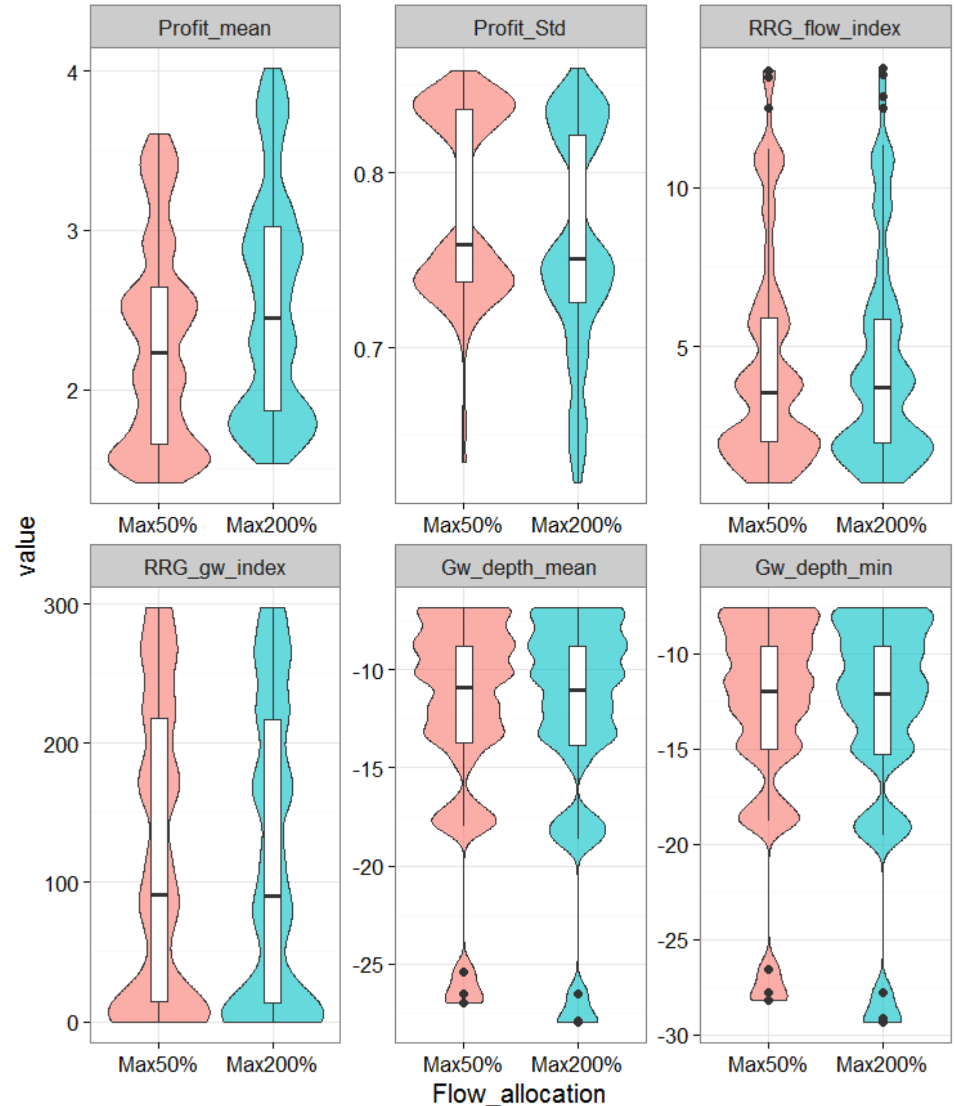
	Scenario assumptions	Interventions considered
Regional (or above)	• Climate • Market	
Catchment zones	• Surface water hydrology • Groundwater hydrogeology	• Surface water max allocation • Groundwater max allocation • Conjunctive use options*
Farm		• Irrigation efficiency choice (flood, spray) • Farmer’s adoption of new technology
River reach	• Commence to flood level • Requirements of flood attributes* • Relative importance of flood attributes* • Requirements in groundwater depth*	

*: Categorical data

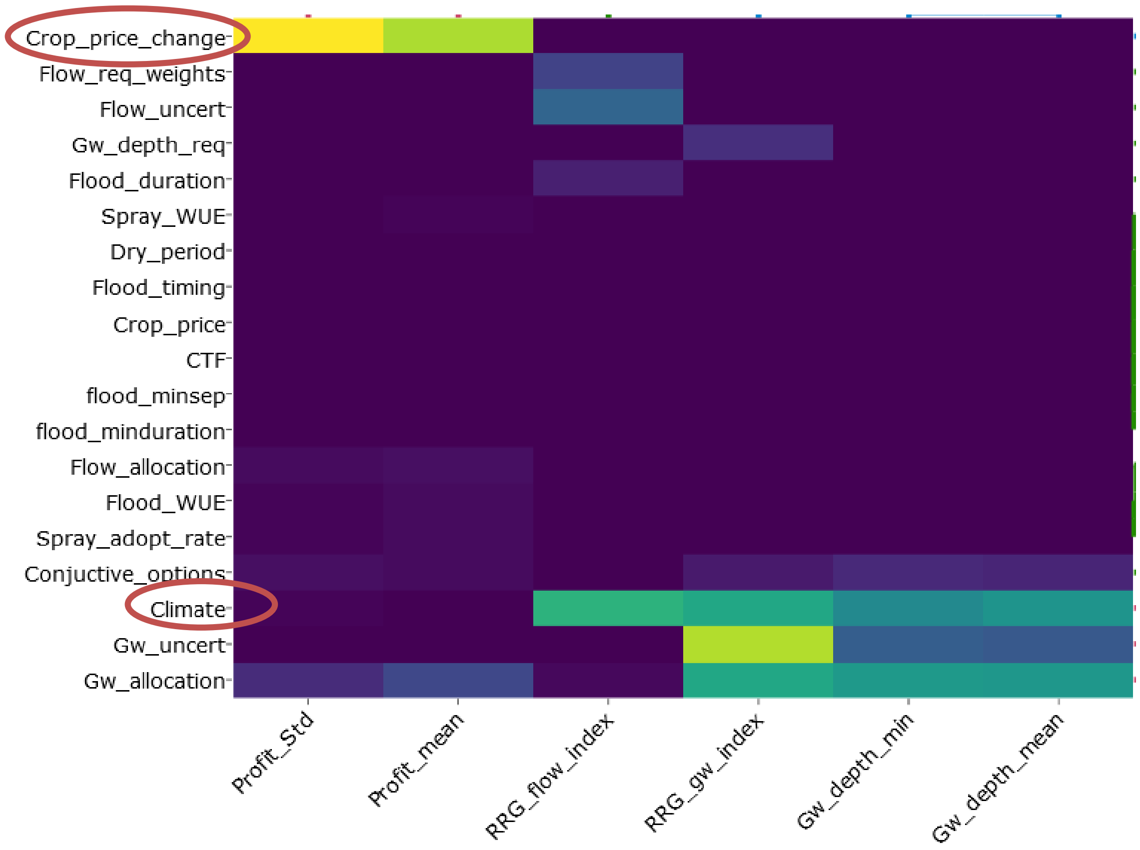
For continuous data, upper and lower bound values were selected for scenario runs

Initial exploration of interventions using violin and box plots

- Outcomes of different flow allocation policy options (and other interventions) plagued by uncertainties in the system
- Other things are in play
- We need to identify bigger patterns and search for the effective interventions within these patterns



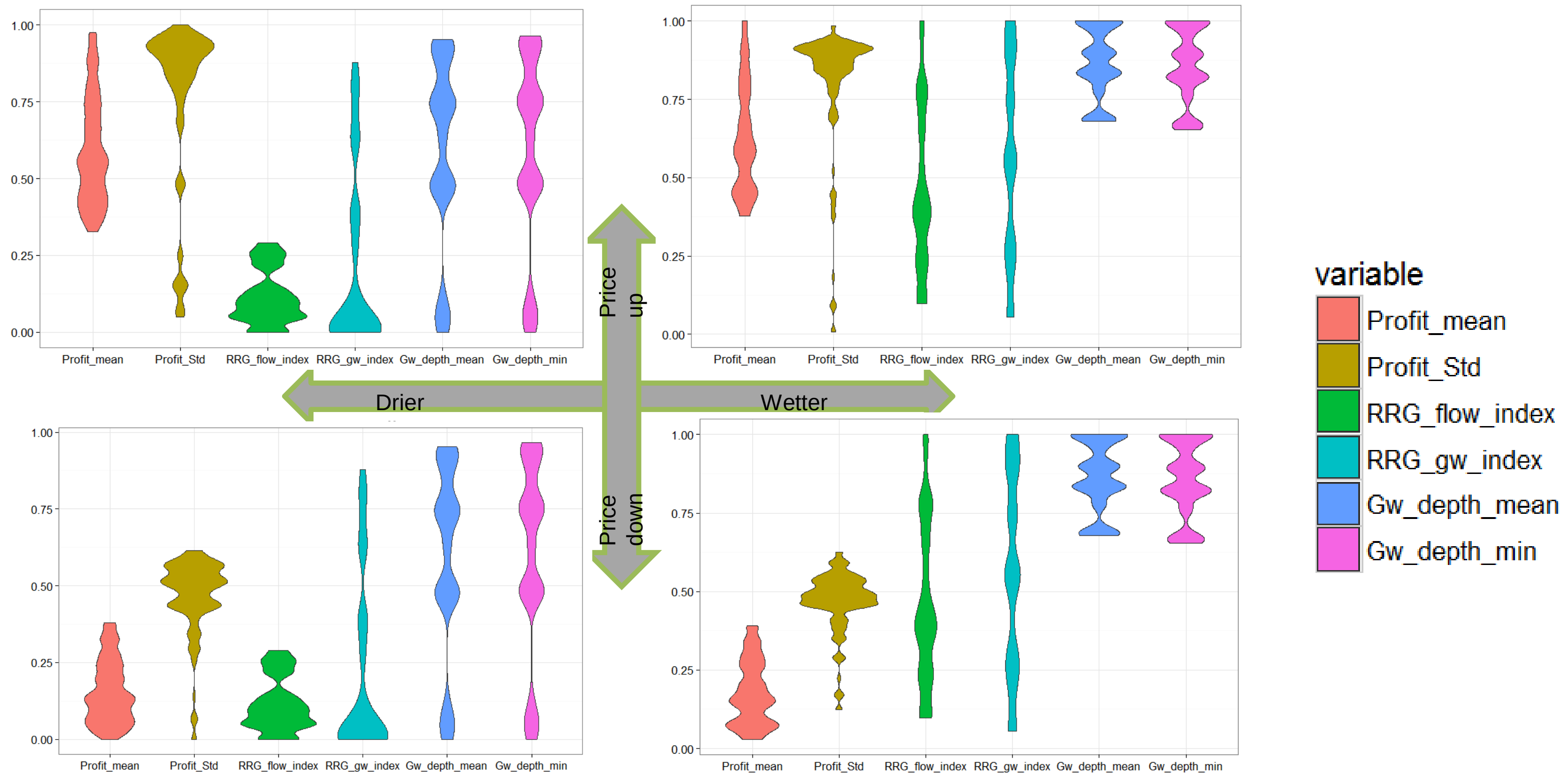
What variables are in play?



- Variable importance analysis (via *cforest* and *varimp* in R) suggests some key uncertainty factors.
- K-means clustering (not shown) also suggests crop price change and climate the key variables for clustering

USE 1: SITUATION AWARENESS

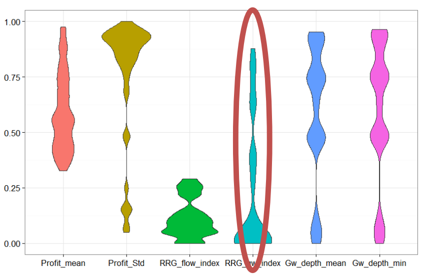
Identifying patterns considering uncertainty



USE 2: DIAGNOSIS

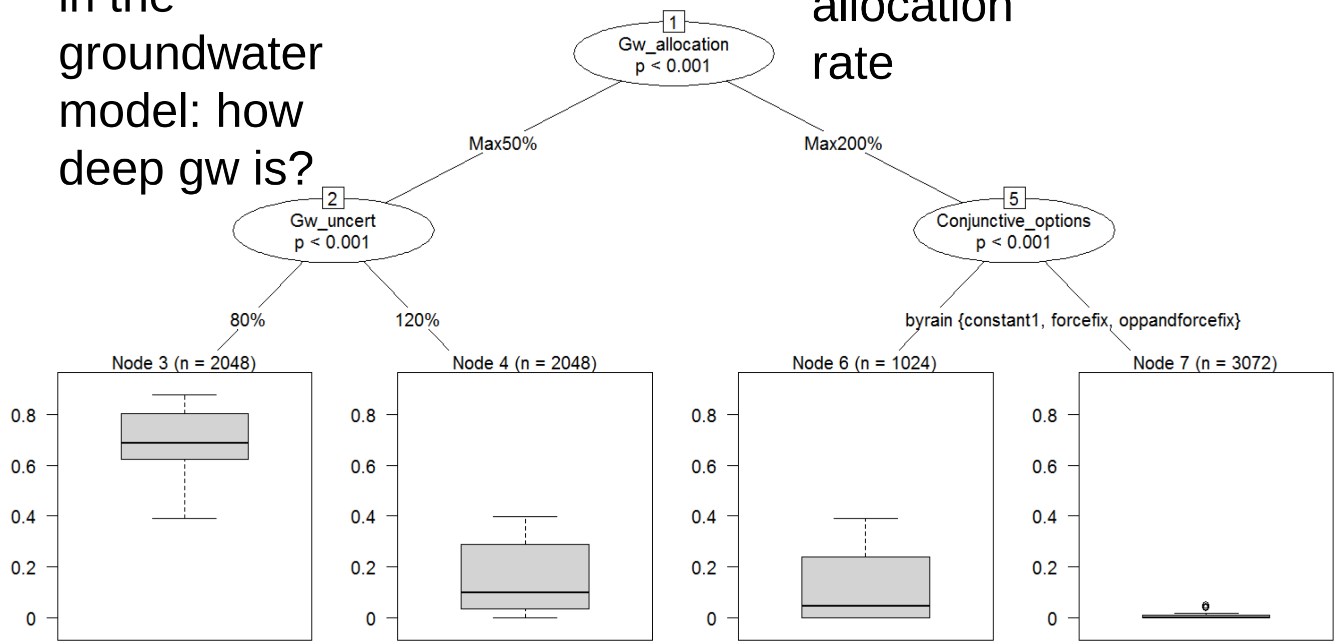
Examining state of knowledge

What contributes to the uncertainty in groundwater suitability outcomes for river red gum in dry climate?



Uncertainty in the groundwater model: how deep gw is?

Maximum groundwater allocation rate

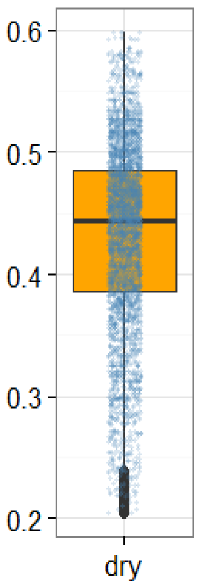


Method: recursive partitioning via *ctree*, party package in R

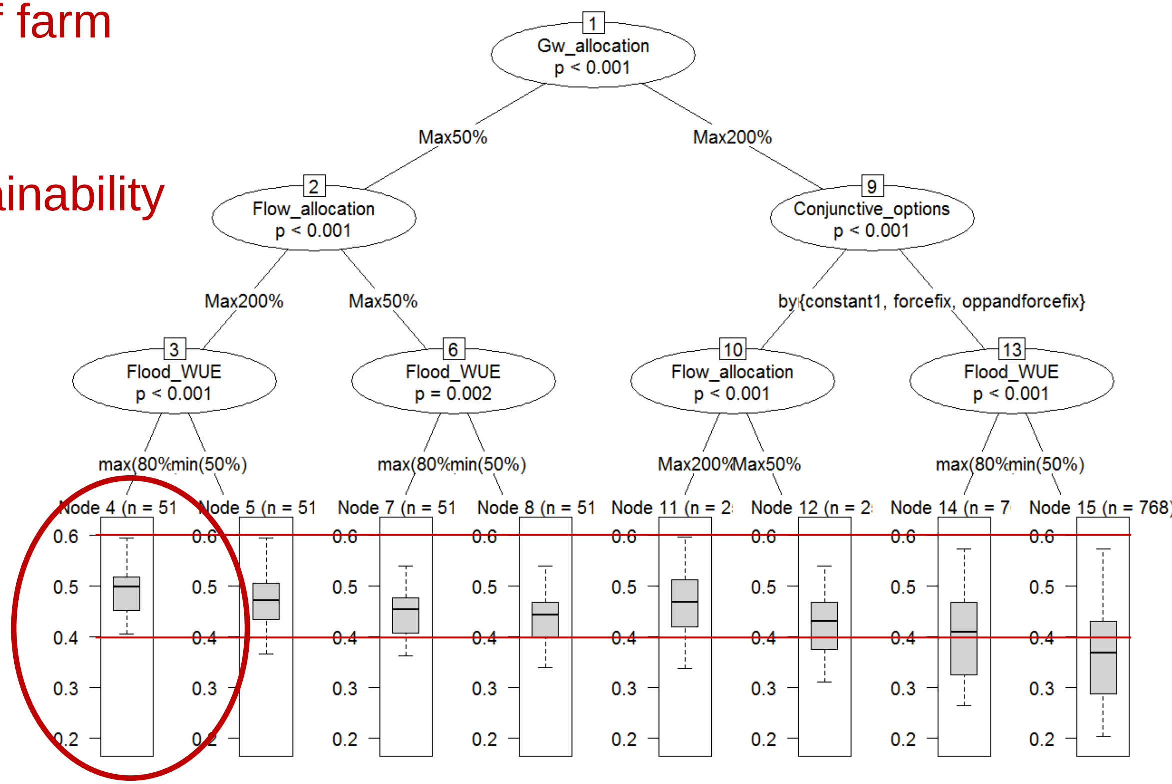
USE 3: OPTION AWARENESS

Identifying effective combination of interventions

- Dry climate & good markets
- Equal weighting of farm profit, ecological outcomes and groundwater sustainability



Overall distribution

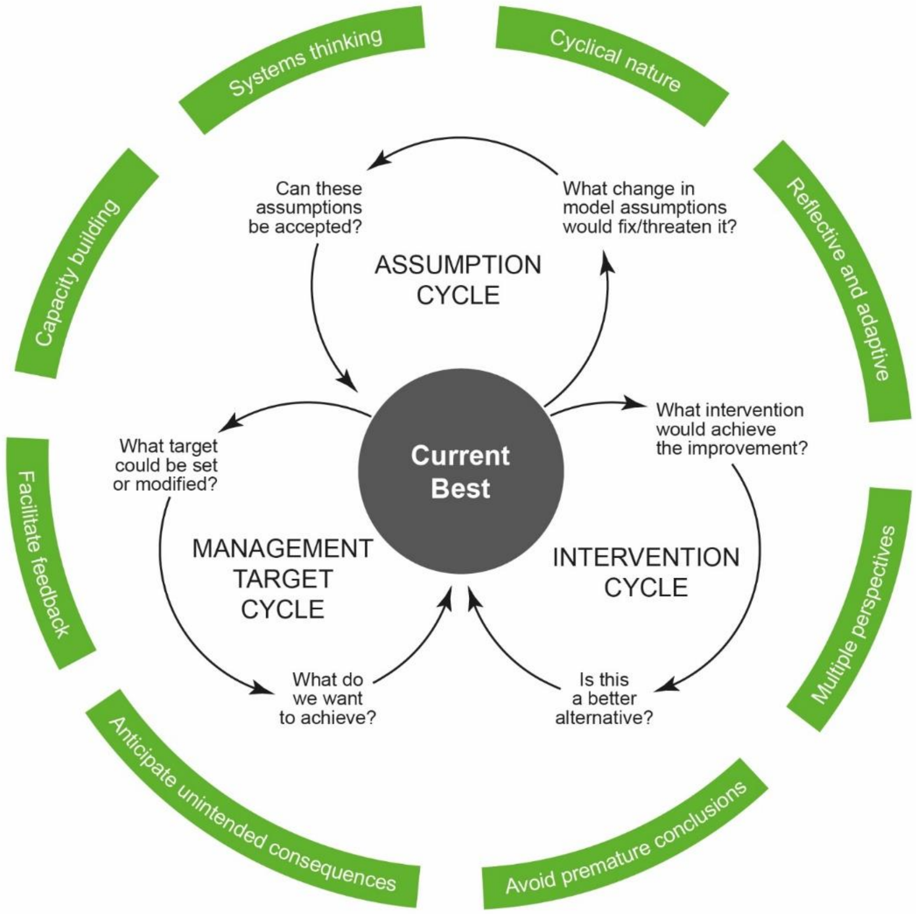


Method: recursive partitioning via *ctree*, party package in R

USE 4: DELIBERATION

Promoting discussions

Iterative Discovery



Fu, B., Guillaume, J. H., & Jakeman, A. J. (2015). An iterative method for discovering feasible management interventions and targets conjointly using uncertainty visualizations. *Environmental Modelling & Software*, *71*, 159-173.

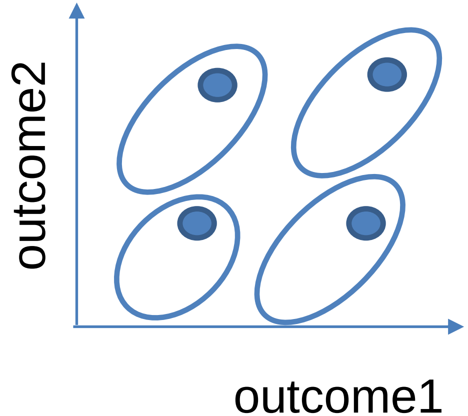
Synthesis: what interventions are most effective?

When profits, ecological outcomes and groundwater sustainability are equally weighted:

Climate	Market	Max groundwater allocation	Max flow allocation	Flood irrigation WUE	Conjunctive use
Dry	Up	Low (50%)	High (200%)	High (80%)	
Dry	Down	Low (50%)	High (200%)		By rain/constant/opportunity fix
Wet	Up	High (200%)	High (200%)	High (80%)	
Wet	Down		High (200%)	High (80%)	

When profits outweigh other outcomes:

Climate	Market	Max groundwater allocation	Max flow allocation	Flood irrigation WUE
Dry	Up	High (200%)	High (200%)	High (80%)
Dry	Down	High (200%)	High (200%)	High (80%)
Wet	Up	High (200%)	High (200%)	High (80%)
Wet	Down	High (200%)	High (200%)	High (80%)



Concluding remarks

- Effectiveness of interventions can be overshadowed by uncertainties in the system. Consistent with exploratory modelling, we can address this by searching for useful interventions within broader patterns (which define context)
- Social studies inform integrated assessment through identifying new ideas/opportunities and providing boundaries for the integrated modelling
- Demonstrated case study using decision tree methods
- Coupled with integrated modeling and appropriate participatory exercises, scenario analyses have great potential for:
  - **Situation awareness**: identifying big picture uncertainty-related patterns
  - **Diagnosis**: examining state of knowledge of why a result occurs
  - **Option awareness**: visualization of robustness of options
  - **Deliberation**: using visualization to promote discussion

Extra slides

- Moved to the end instead of deleting

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Conclusions

1. Social studies inform integrated assessment through identifying new ideas and providing boundaries for the integrated modelling

2. Integrated modelling and exploratory analysis will allow us to conduct computational experiments to reveal the implications of prior knowledge, assumptions, hypotheses and uncertainties.

3. Two key Lessons learnt so far include: 1) Component model building takes time and requires considerable investment; 2) Implementing policy in integrated models requires considerations of time scale, communication between the models, and levels of complexity warranted

Integrated Assessment

- ***Integrated Assessment (IA) is the interdisciplinary process (meta-discipline) of integrating knowledge from various disciplines and stakeholder groups in order to evaluate a problem situation from a variety of perspectives and provide support for its (re)solution***

- ***IA supports learning and decision processes and helps to identify desirable and possible options***

- ***It therefore builds on two major pillars: approaches to integrating knowledge about a problem domain, and understanding policy and decision making processes***

» *www.tias-web.info*

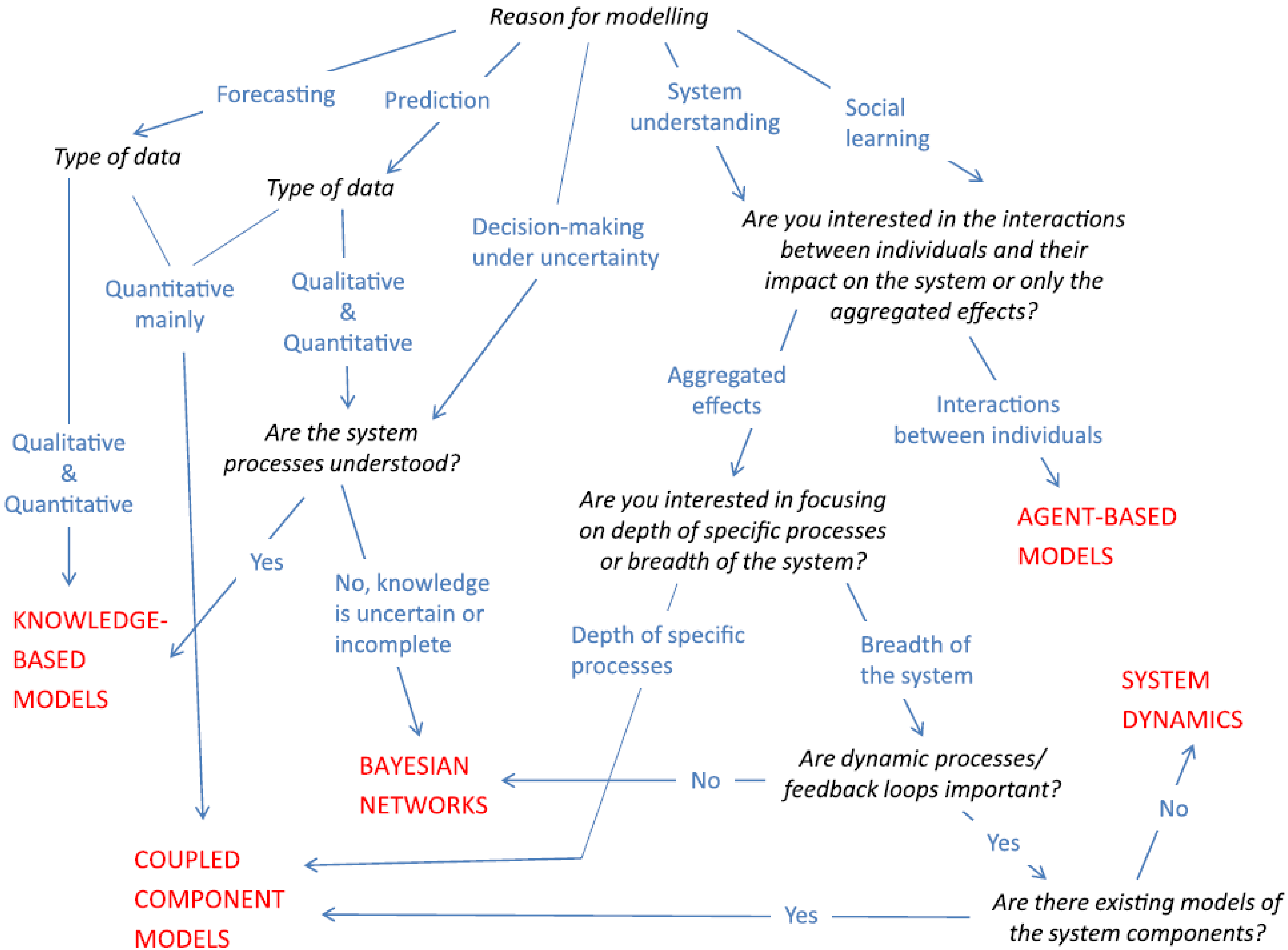
Integrated Modelling Approaches or Paradigms

- System dynamics
- Bayesian networks
- Coupling complex models
- Agent-based models
- Hybrid expert systems

Kelly, R.A., Jakeman, A.J. and 11 others (2013) Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling and Software*, 47: 159-181.

Tools to support the IMA process

Tool Category	Examples of tools	Application	Purpose
Exploratory tools	statistical analysis, data mining, multivariate exploratory techniques, data-based models	Search for **patterns** in data and **relationships** between variables	• Improve system understanding • Identify indicators and criteria
Knowledge representation tools	process-based models, integrated models such as Bayesian networks, decision trees, conceptual models, mind maps, spatial analysis, mapping	**Summarize** and represent what is understood about the system by **integrating** or encoding knowledge and data	• Improve system understanding • Communication of knowledge • Social learning • Identify knowledge gaps
Optimisation tools	multi-objective optimisation models, genetic algorithms, cost-benefit analysis	Find the solution that **optimises the objective function** based on a single criterion, or finds the set of solutions at the **Pareto frontier** when multiple criteria are involved	• Improve system understanding • Screen or evaluate alternative management options
Participatory tools	participatory modelling, focus groups, scenario analysis, stakeholder workshops, role playing games	Constitute interactive or deliberative approaches where stakeholders contribute by **expressing their knowledge, ideas, preferences and/or values**	• Identify objectives, issues, preferences, management options • Obtain information from stakeholders • Improve system understanding • Social learning • Support negotiation, reduce conflict and build trust
Prediction tools	data-based models, process-based models, integrated models	Estimate **impacts** of alternative scenarios on criteria of interest	• Improve system understanding • Evaluate alternative management options
Trade-off tools	integrated models, MCDA	Explore trade-offs involved with different alternatives based on **two or more criteria**	• Improve system understanding • Evaluate alternative management options • Facilitate negotiation and conflict resolution



Kelly (Letcher) et al. (2013). Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling and Software*, **47**, 159-181