National Centre for
Groundwater Research and Training
sustaining a vital water resource

Modelling and Decision Support for Integrated Groundwater Management

Tony Jakeman
iCAM, Fenner School of Environment and Society
The Australian National University

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Pressures upon water resources

Issues include:

- Variations in climate and rainfall patterns
- Increasing demand upon water resources for ecological requirements, to service a growing human population, and an increased demand for food production ; groundwater a demand difficult to turn around
- Socio-economic and political issues surrounding the past over-allocation of water resources for irrigated agriculture
- A potential decrease in available water if carbon offsets increase perennial ground cover
- Current political efforts to regain flows for ecological health and equity throughout catchments
- Complex problem requires an integrated approach to assess the social, economic and environmental trade-offs.

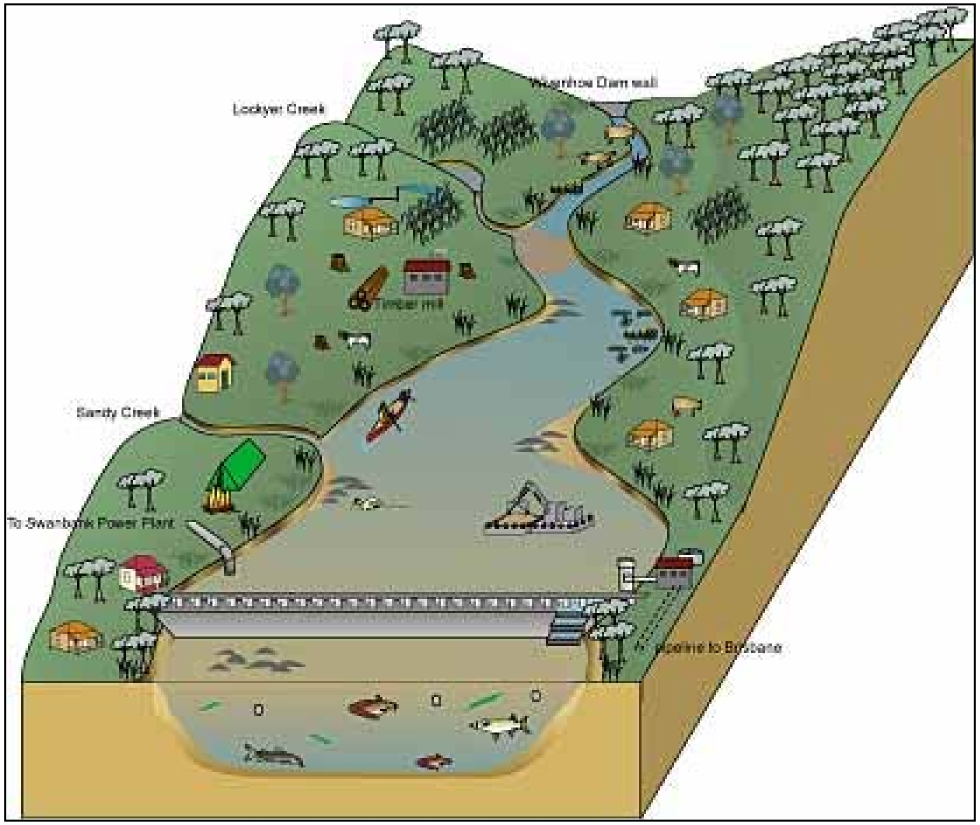
Questions for the talk

- What are the characteristics of water resource management problems?
- And what is different about groundwater?
- What is the essence of an integrated approach to resolution?
- Do we need modelling and if so what kind?
- Do we have frameworks and tools for doing the modelling? How do we select among them?
- How do we deal with scale issues?
- What are the knowledge and information gaps?
- How do we deal with uncertainty?

‘Sustainability’ of ‘basin health’: the bad news…

- A “wicked” or “messy” problem
- No definite formulation: lack of clarity, ambiguity
- No right or wrong solution: multiple and conflicting pressures, functions and goals, no ultimate test
- Compromises across scales
- Knowledge limited, complexity and uncertainty pervasive
- Moving target – e.g. preferences evolve
- Every problem unique, resources limited
- Implementing a management intervention may create a new set of problems
- No final solution stopping point

Water Resources



- Multiple uses/functions
- Multiple stakeholders
- Competing goals
- Multiple decision makers
- Multiple pressures
- Limited resources
- Complexity
- Uncertainty

What makes groundwater different?

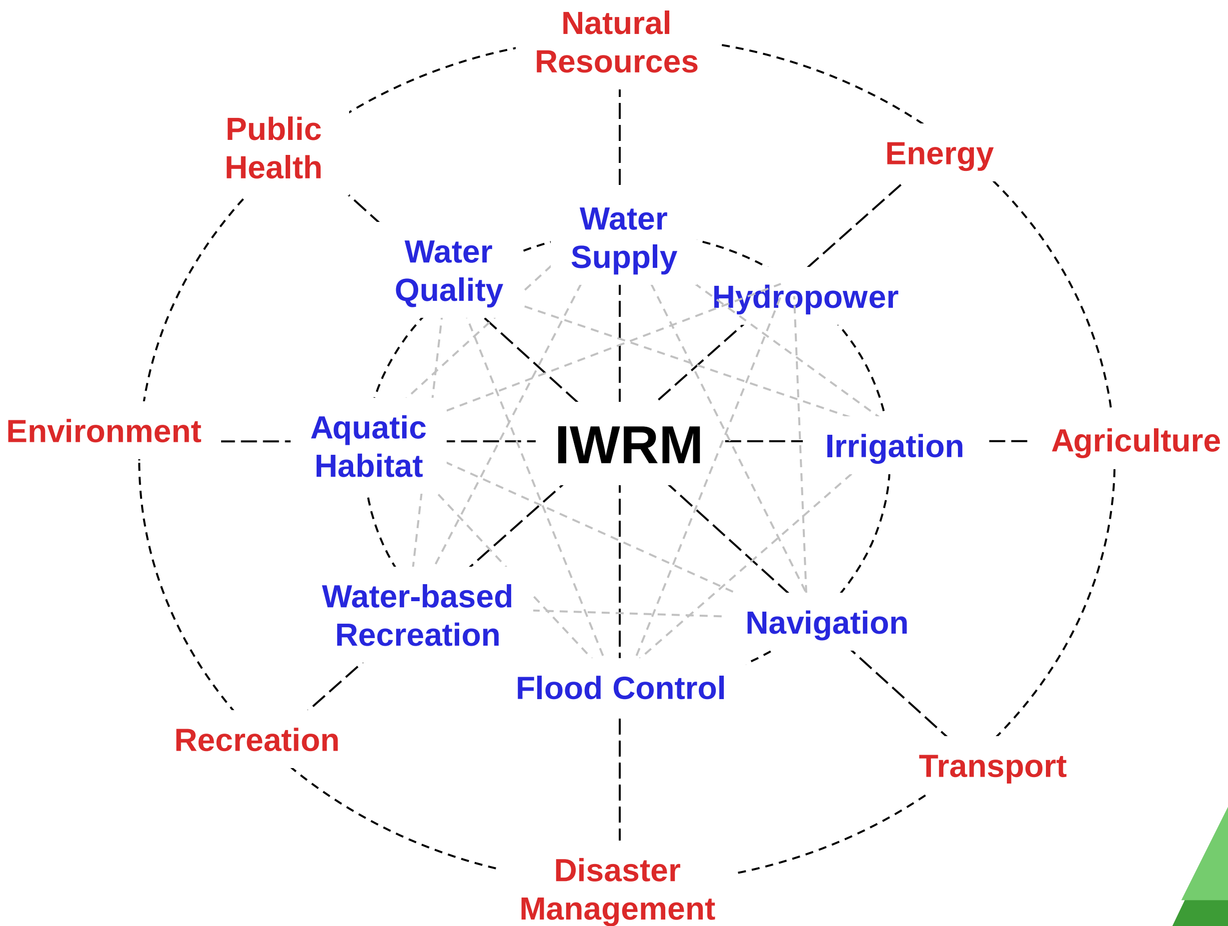
- Less knowledge about managing for sustainability
- Largely a non-renewable resource
- Often linked physically with surface water; can’t be considered in isolation
- Delivery different – pumped out, costs
- Less visible – compliance lower, social norms less influential
- Relations between surface and groundwater less intuitive; treated differently by policy in practice
- Groundwater quality – technical issues, dilution effects
- Long turnover times and exaggerated storage
- Monitoring inadequate for understanding the ‘resource’
- Groundwater models can be computationally intensive

Integration required: its dimensions

- Issues
  - Human, water and land-related
  - Water quantity and quality, ecosystems
- Parts of river basin
  - Land, waterway, floodplain
  - Surface water, groundwater
  - Upstream, downstream
  - Spatial and temporal scales
- Major drivers
  - Uncontrollable – e.g. climate, commodity prices, some other sector policies
  - Controllable – e.g. policy instruments, education

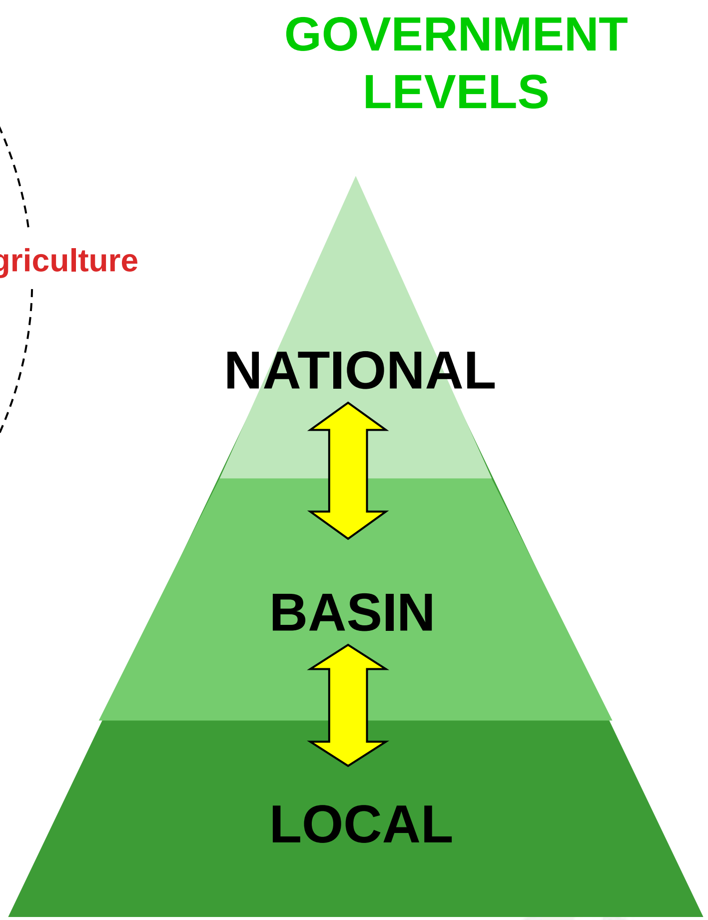
Dimensions of Integration

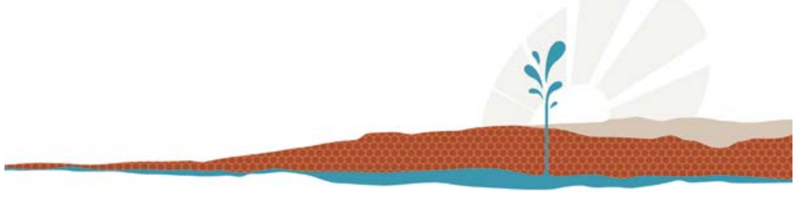
- Disciplines
  - Economics, ecology, engineering, sociology, hydrology, earth science etc
- Stakeholders
  - Government at various levels
  - Industry groups, community, environmental sector etc
- Models, data & other info
  - Range of methodologies – participatory approaches, predictive models, MCA, CBA etc
  - Integration tools & modelling and software frameworks



WATER PURPOSES

POLICY SECTORS





(adapted from Grigg 2008)

Integrated Assessment: a metadiscipline for messy problems

- ***Integrated Assessment (IA) is the interdisciplinary process 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 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*

Premise of the talk

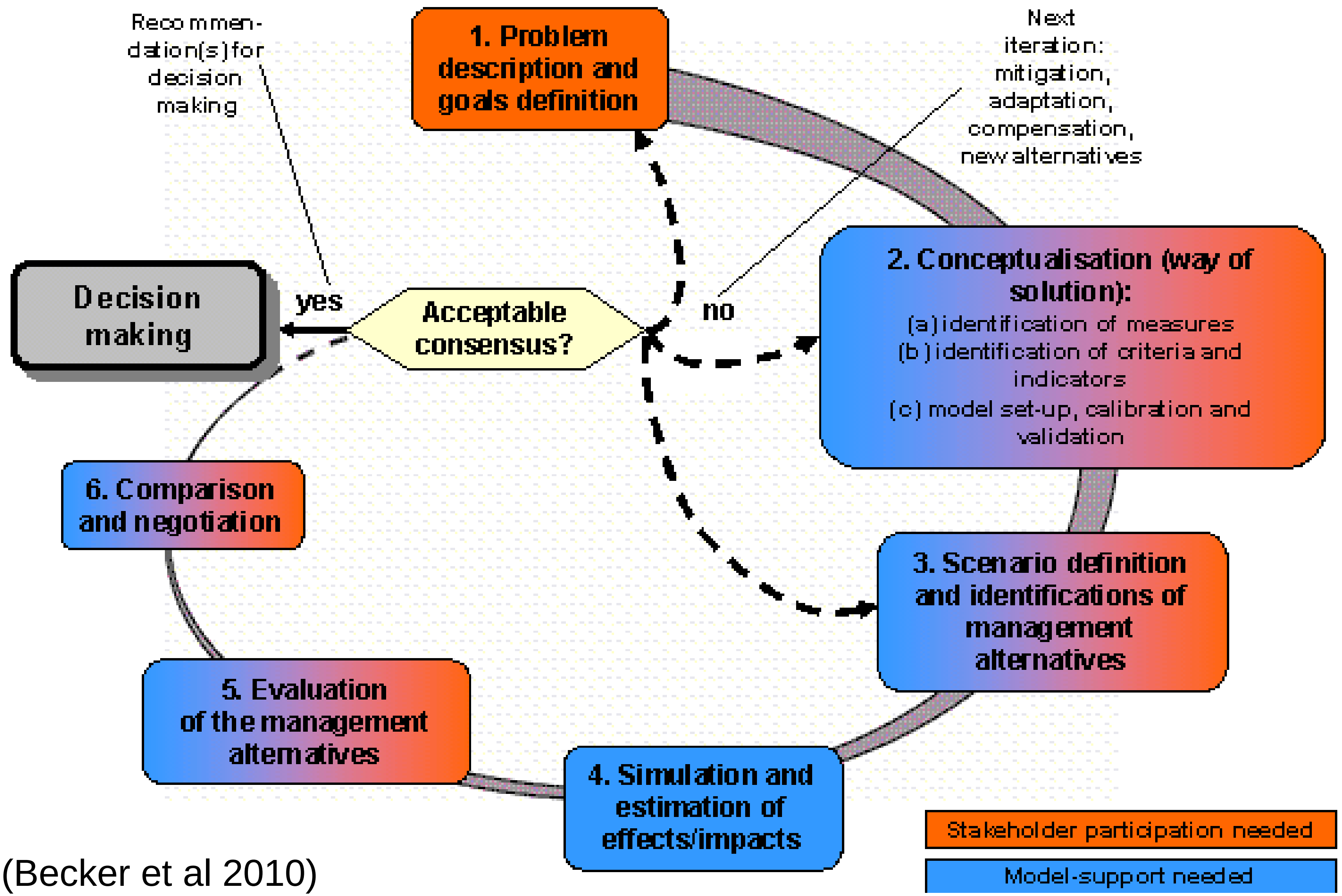
‘Modelling’ is essential for -

- Systematically integrating our knowledge on a messy/wicked problem such as occurs in Integrated Water Resources management (IWRM)
- Predicting outcomes to assess tradeoffs
- Exploring opportunities for improvements
- Assessing some of the uncertainties

‘Modelling’ is also useful for –

- Aiding transparency, developing trust, sharing and communicating knowledge and views
- Clarifying and focusing on the issues – problem framing
- Facilitating adoption
- Managing uncertainties

The steps: Modelling & Stakeholder participation



(Becker et al 2010)

Tools to support IWRM

1. Integrated Modelling frameworks or paradigms

2. Other tools and processes

Integrated Modelling (simplified)

Assumptions/

Alternatives

- Climate
- Shocks
- Demography
- Policy drivers
- Adaptation options
- External drivers

→ **Environmental System** →

'Sustainability' or 'basin health' indicators

- Economic
- Social
- Environmental

Assess tradeoffs to balance & compare alternatives

Step	Tasks involved	Tools
1. Identify objectives	•Identify issues, concerns •Build consensus on the problem(s) to be addressed	•Participatory methods
2. Problem framing	•Understanding the problem(s) •Define boundaries/scope	•Exploratory analysis •Visualisation tools (e.g. conceptual models, mind maps) •Participatory methods
3. Identify performance measures	•Identify criteria to be used to compare and evaluate alternatives •Gather value judgments	•Participatory methods
4. Identify alternatives	•Identify potential management options based on objectives	•Participatory methods •Scenario tools
5. Evaluate alternatives	•Evaluate each alternative based on how it is predicted to affect the performance measures •Explore tradeoffs •Narrow options	•Predictive/Simulation models (e.g. disciplinary tools) •Integrated models (e.g. Bayesian networks, coupled component models, system dynamics, hybrid expert systems) •Expert elicitation •Optimisation tools (e.g. heuristic search methods, Pareto-optimal tradeoff curves) •Decision trees
6. Rank/select final alternative	•Compare and rank different outcomes •Select satisficing option	•Multi-criteria analysis •Cost-benefit analysis •Bayesian decision methods •Risk Analysis •Participatory methods

Sources of Uncertainty

Uncertainties accumulate throughout the model building process, and hence within the model and decisions based on it

Examples throughout the decision making process:

Decision prompt

Identification

Scope

- Boundaries of analysis

Identify data and knowledge

- Measurement error
- Representativeness
- Imprecision
- Inaccuracy

Choose methodology

- Experience of modeller
- Assumptions
- Technical issues

Development & Evaluation

Frame

- How inputs and outputs are represented in the model

Search

- Avoiding locally optimal solutions
- Missed alternatives

Deliberate

- Attitudes of stakeholders
- Political climate
- Relation between stakeholders
- Communication
- Ranking

Analyse

For integrated modelling:

- Model structure
- Model parameters
- Calibration method
- Validation method
- Technical
- Integration

Commitment to action

Action

Monitor & evaluate

- Treating emerging concerns
- Identifying need for change

Implement

- Adoption
- Compliance

Commonly discussed uncertainties in modelling are shown in red

Uncertainty in decision support models

Uncertainty can be considered in 3 dimensions:

1) ***Source*** – where the uncertainty manifests itself within the model and the process that created it

2) ***Level*** – in how much detail can the uncertainty be expressed

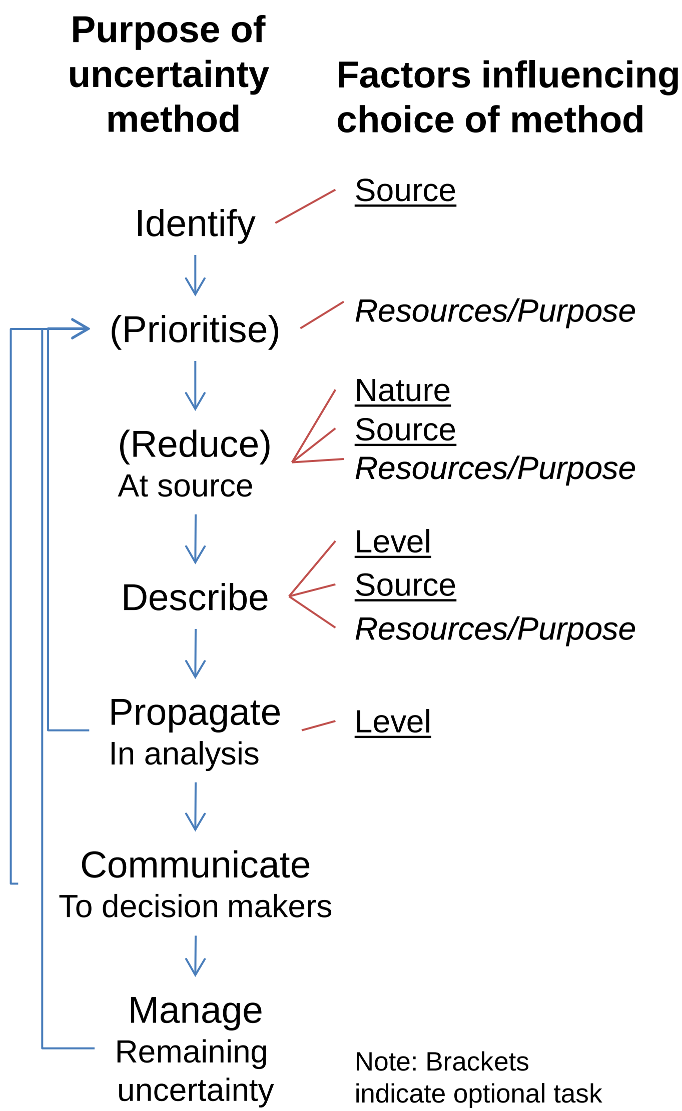
3) ***Nature*** of uncertainty
    1) Variability "accepting not to know"
    2) Limited knowledge "knowing too little"
    3) Contradiction "knowing too differently"

<u>Level:</u>
A continuum of detail of knowledge of uncertainty

- Certainty
- Distribution
- Bounds
  Incl. extreme case scenarios
- Scenario
  Where not all possible outcomes are known
- Recognised ignorance
- Unrecognised unknowns

(Guillaume et al, 2010) Also see (Walker et al. 2003; Brugnach et al, 2008)

Managing Uncertainty



- Main actions needed for dealing with uncertainty in the modelling process
- Methods to use for each action depends on
  - Resources
  - Purpose of the analysis
  - Type of uncertainty in 3 dimensions

(Guillaume et al, 2010) Also see (Refsgaard et al. 2007)

Approaches to assess & manage uncertainty

Purpose of uncertainty method	
Identify	•Proper processes and protocols, good practice guidelines eg NUSAP •Benchmark against standard, catalogue & rank uncertainties
(Prioritise)	•Significance for decision, risks incurred •Sensitivity assessment → simplifying model/problem
(Reduce) At source	•Inverse modelling •Data acquisition planning
Describe Propagate In analysis	•Monte Carlo and related analyses inc Bayesian methods •Scenario simulation •Analysing model components then linkages
Communicate To decision makers	•Extended peer review & stakeholder involvement
Manage Remaining uncertainty	•Adaptive management

Uncertainty Management

- Uncertainty is unavoidable
- Need to consider, rank and wherever possible quantify all relevant types and sources of uncertainty
- Uncertainties from each of the decision making process steps must be appropriately managed, propagated and communicated

Integrated Modelling Approaches

The main types of integrated models with different strengths and weaknesses in particular situations:

- **Systems dynamics**
- **Bayesian networks**
- **Coupling complex models**
- **Agent-based models**
- **Hybrid/expert systems**

Essential perspectives on advancing Integrated Water Resource Management

- Problem context should guide all analysis and data collection
  - Cling to context & purpose for tractability, realism & cost
  - Balance top-down policy with bottom-up engagement

- Problem should be captured by (credible and participatory) ‘modeling’, which can help with the rest of the analysis
  - ‘Model’ and analyse for: priority setting of ‘boundaries’, representing sufficient complexity (e.g. multiple stressors), integration generally, sharing knowledge, developing trust, valuable monitoring & trade-off identification
  - Manage major sources of uncertainty through all stages of the decision process
  - Tailor model components to needs of the integrated problem esp hydrology

- Learn integration by doing real studies
  - Use key studies to motivate the less obvious core science and social science research and data needs (obvious inc. climate, flows, water use, vegetation data)

Why seek problem context for integration?

- Policy and institutional settings change with the case
- To identify policy and adoption impediments, <u>and</u> innovations
- Indicators of catchment ‘health’ change
- The stakeholders to engage become more apparent

- Scales of interest and analysis are more identifiable
- Boundaries are clearer – what to include, exclude & integrate
- The minimum data to develop and evaluate the ‘modelling,’ and for IWRM program evaluation and compliance, can be sought

Socioeconomic & environmental impacts of climate change, technology and water policy drivers in the Namoi catchment – adaptation opportunities

Tony Jakeman, Jenifer Ticehurst, Rachel Blakers, Barry Croke, Baihua Fu, Patrick Hutchings, Wendy Merritt, Darren Sinclair, Neil Gunningham, Joseph Guillaume, Andrew Ross (ANU)

Allan Curtis and Emily Sharp (CSU)

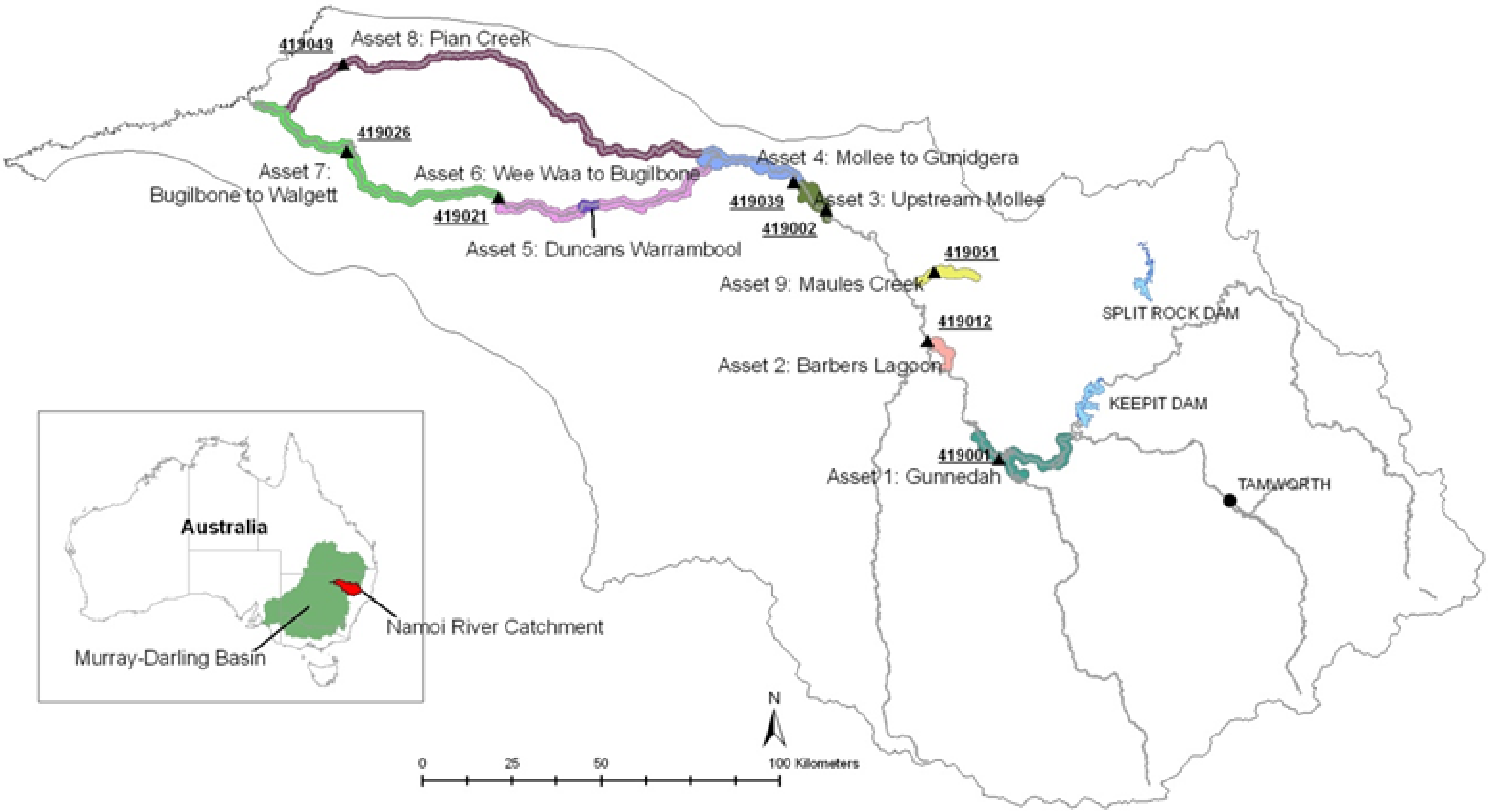
David Pannell, Alex Gardner, Alison Wilson and Madeleine Hartley (UWA)

Cameron Holley (UNSW)

Rebecca Kelly (iSNRM and ANU)

Steering Committee: State and local agencies, Namoi Water (irrigators)

Cotton Catchment Communities CRC



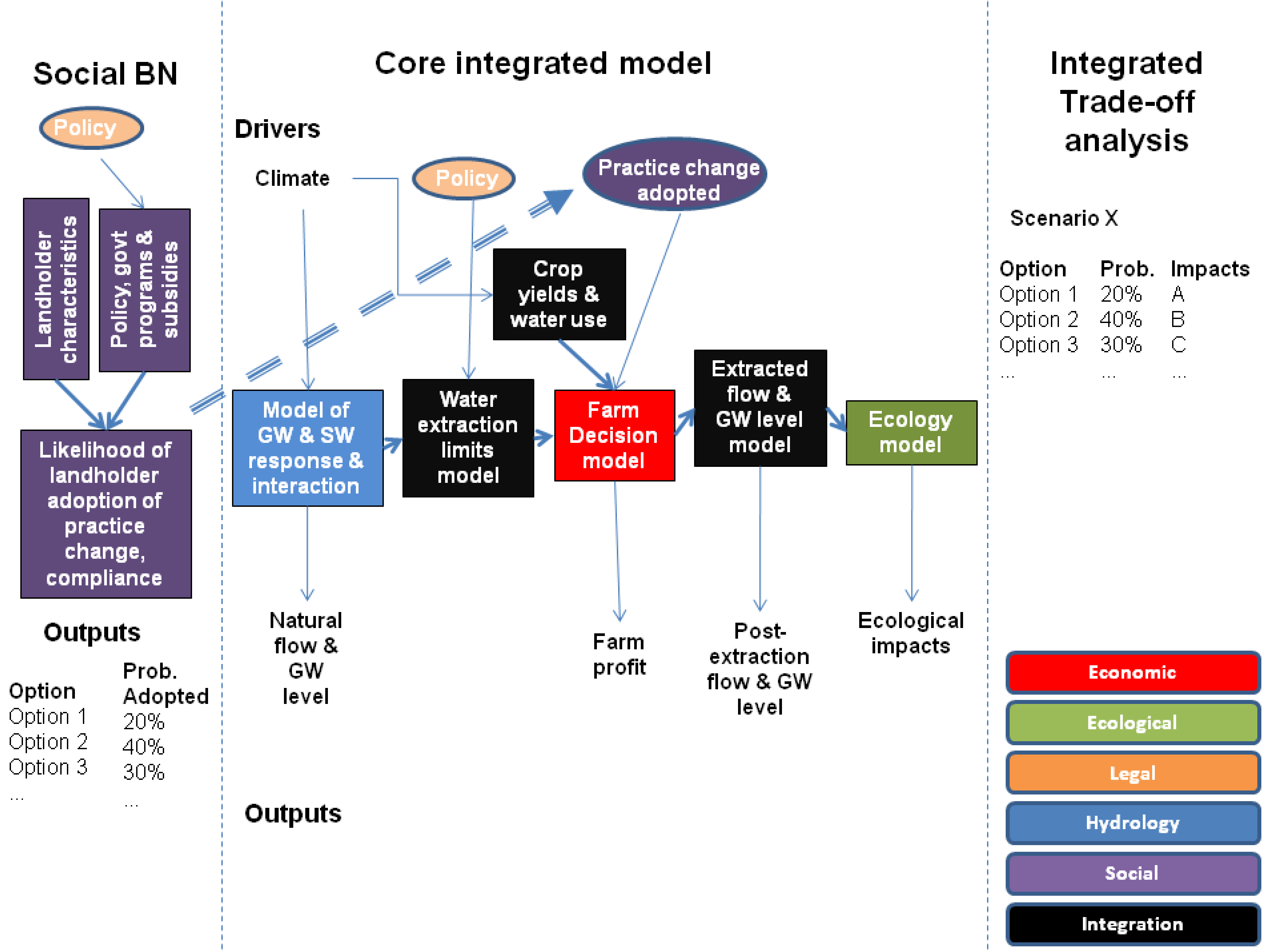
Asset 8: Pian Creek
419049
419026
Asset 7:
Bugilbone to Walgett
Asset 6: Wee Waa to Bugilbone
419021
Asset 5: Duncans Warrambool
Asset 4: Mollee to Gunidgera
419039
Asset 3: Upstream Mollee
419002
419051
Asset 9: Maules Creek
419012
Asset 2: Barbers Lagoon
SPLIT ROCK DAM
KEEPIT DAM
419001
Asset 1: Gunnedah
TAMWORTH
Australia
Namoi River Catchment
Murray-Darling Basin
N
0
25
50
100 Kilometers

Three pillars of the National Water Initiative (Australia)

- Regulation
  - e.g. water shares to the environment
- Markets especially water trading
  - issues include third party impacts, impediments
- Water planning
  - devolution of responsibilities through engagement of interest groups

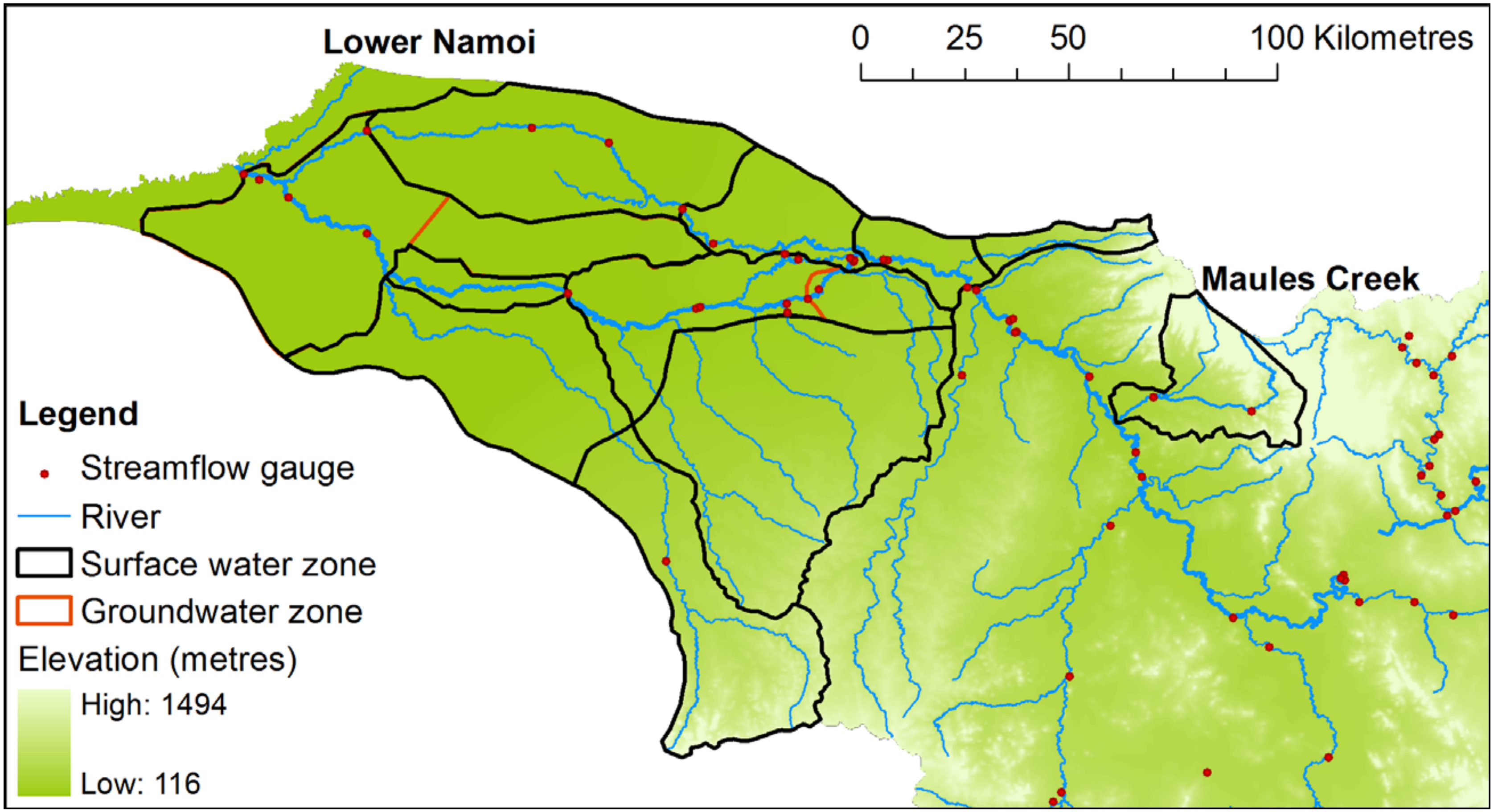
Integrated Model

- Integrates the work of each of the disciplinary sub-teams
- Three components
  - Social Bayesian Network using results of the social survey
  - Core integrated deterministic model
    - Simulates hydrogeological system, constraints on extraction, farmer decision making, crop yields and ecological impacts
    - With inputs of the possible practice changes , climate change scenarios and water allocation policies
  - An integrated trade-off analysis


Social BN
Policy
Landholder characteristics
Policy, govt programs & subsidies
Likelihood of landholder adoption of practice change, compliance
Outputs
Option
Prob. Adopted
Option 1 20%
Option 2 40%
Option 3 30%
… …
Core integrated model
Drivers
Climate
Policy
Practice change adopted
Crop yields & water use
Model of GW & SW response & interaction
Water extraction limits model
Farm Decision model
Extracted flow & GW level model
Ecology model
Natural flow & GW level
Farm profit
Post-extraction flow & GW level
Ecological impacts
Outputs
Integrated Trade-off analysis
Scenario X
Option Prob. Impacts
Option 1 20% A
Option 2 40% B
Option 3 30% C
… … …
Economic
Ecological
Legal
Hydrology
Social
Integration

Spatial Scale

Hydrological model zones



Social Research – Sharp and Curtis

- What **innovative practices** are landholders adopting now and who plans to do so in the future?
- What are the key drivers influencing landholder **adoption of innovative practices** and/or changes in land use in the Namoi catchment?
- Survey data for modelling in other project teams

- How trustworthy do licence-holders rate the state water agency (NoW) and their staff?
- How does the **trustworthiness of agency staff** influence perceptions of **agency trustworthiness** and licence-holders' willingness to rely on NoW?

Collective management of GW
-Sinclair and Holley

- General support for collective management of GW
  - 69% agreed that collective management at local scale would ensure operating rules are appropriate to local conditions and environmental circumstances
  - 61% indicated it would be desirable to have govt oversee operating rules developed with landholder input

    - Respondents with pro-conservation values and beliefs, altruistic values and beliefs more likely to support collective governance arrangements
    - Older licence holders less likely to express support
    - More acceptable if it has the strong support of practitioners on-the-ground whom licence holders find more trustworthy than the agency itself

Aquifer Storage and Recovery - a win-win opportunity?

- 65% agreed that Aquifer Storage and Recovery (ASR) based on intercepting large flood events is a good idea

- Some respondents uncertain about the use of ASR
  - Concerns about water quality, environmental impacts and implications for GW entitlements
  - Existing information needs to be suitably conveyed

GW licence compliance

- General agreement that they and others in their management zone did their best to comply with the conditions of their water licence
  - 87% agreed important to comply with licence conditions
  - 94% did their best to comply with maximum allowable volume of water they can pump under their licence allocation

- 67% thought other respondents in their zone complied with reporting requirements
  - 80% in Lower Namoi, 63% in Upper Namoi

- Extraction metering alone is not sufficient for evaluation

Development of the social BN for the Namoi

Ticehurst, Sharp and Curtis

Predicting adoption of land management practices

Identifying levers to influence land management

Management Practices

- Data from the survey: Reasonable level of uptake, Covered a variety of costs & knowledge to implement; note that Census and land use data too large scale, too infrequent or error-prone

- Actions taken or considered in the past 5 years, and the next 5 years
  - Change to spray irrigation
  - Implement soil moisture mapping
  - Modify flood irrigation approach
  - Deepen farm storage dams
  - Measure dam evaporation losses
  - Buy water on the temporary market
  - Buy water on the permanent market

Convert to BN variables

Beliefs and Views

Dominant beliefs about the Namoi	
Egotistic	11.1
Altruistic	58.5
Biospheric	12.9
Egotistic & Altruistic	8.29
Egotistic & Biospheric	1.84
Altruistic & Biospheric	5.53
Equal	1.84

Personal norms	
None	3.83
1) Community GW	3.63
2) Group GW	2.76
3) Personal GW	2.33
4) Carbon Emission	1.82
1 & 2	4.71
1 & 3	5.88
1 & 4	1.88
2 & 3	7.27
2 & 4	1.57
3 & 4	1.50
1, 2 & 3	18.8
1, 2 & 4	1.94
1, 3 & 4	8.20
2, 3 & 4	5.08
All	28.8

Personal values	
Biospheric	63.5
Egoistic	13.7
Biospheric & Egoistic	22.7

Over allocation	
Problem	39.4
Not a problem	60.6

Carry_over	
Too small	44.2
Just right	43.5
Too large	12.4

Belief in MBD Plan	
None	12.5
SDL science	12.5
Adapt to GW reduction	12.5
Adapt to SW reduction	12.5
SDL & GW reduction	12.5
SDL & SW reduction	12.5
GW & SW reduction	12.5
All	12.5

Water sharing plan process	
None	49.0
Meaningful participation	9.71
Input helped shape plan	11.2
Process was fair	1.46
Participation and shape plan	13.1
Participation and fair process	1.46
Shape plan and fair process	2.91
All	11.2

Response to surface water	
No change	25.0
Change cropping	25.0
Enter water market	25.0
Change technology and met…	25.0

NoW trustworthiness	
High org, High individ	4.82
High org, Low individ	23.6
Low org, High individ	3.03
Low org, Low individ	68.6

Trust in NoW	
Can't rely, no monitor	14.5
Can't rely, yes monitor	66.3
Can rely, no monitor	6.92
Can rely, yes monitor	12.3

Trends in weather and climate	
No change	25.0
Change cropping	25.0
Enter water market	25.0
Change technology and met…	25.0

MPs & end points

Likely compliance level	
High	33.3
Moderate	33.3
Low	33.3

Deepend dams & measure evaporation	
Yes	33.3
No	33.3
Not applicable	33.3

Buy water (temp or perm)	
Yes	33.3
No	33.3
Not applicable	33.3

SMM & flood irrigation	
Yes	33.3
No	33.3
Not applicable	33.3

Change to spray irrigation	
Yes	33.3
No	33.3
Not applicable	33.3

Physical

Groundwater management zone	
Lower Namoi	29.0
Zone 1, 6, 7, 10	10.1
Zone 2, 9	10.1
Zone 3	9.68
Zone 4	18.0
Zone 5, 11	11.1
Zone 8	12.0

Property_size	
0 to 2000	76.3
2000 to 6000	18.7
>= 6000	4.99

Irrigated_area	
< median	49.8
> median	50.2

Cultivated_area	
< median	49.8
> median	50.2

Total_dam_capacity	
< median	55.1
> median	44.9

Other model variables

Belief_summary	
Business focused	50.0
Environmentally focused	50.0

Property scale	
Small	36.4
Moderate	11.9
Large	38.0
Not likely	13.6

License_holder_type	
MCFB	50.0
MCES	50.0

Scenarios

Compliance Scenario	
Decrease	0
Current	100
Small increase	0
Large increase	0

Water theft compensation	
None	25.0
25% compensation	25.0
50% compensation	25.0
100% compensation	25.0

Climate scenario	
No change	25.0
Small change	25.0
Moderate change	25.0
Large change	25.0

Water efficiency compensation	
None	25.0
25% compensation	25.0
50% compensation	25.0
100% compensation	25.0

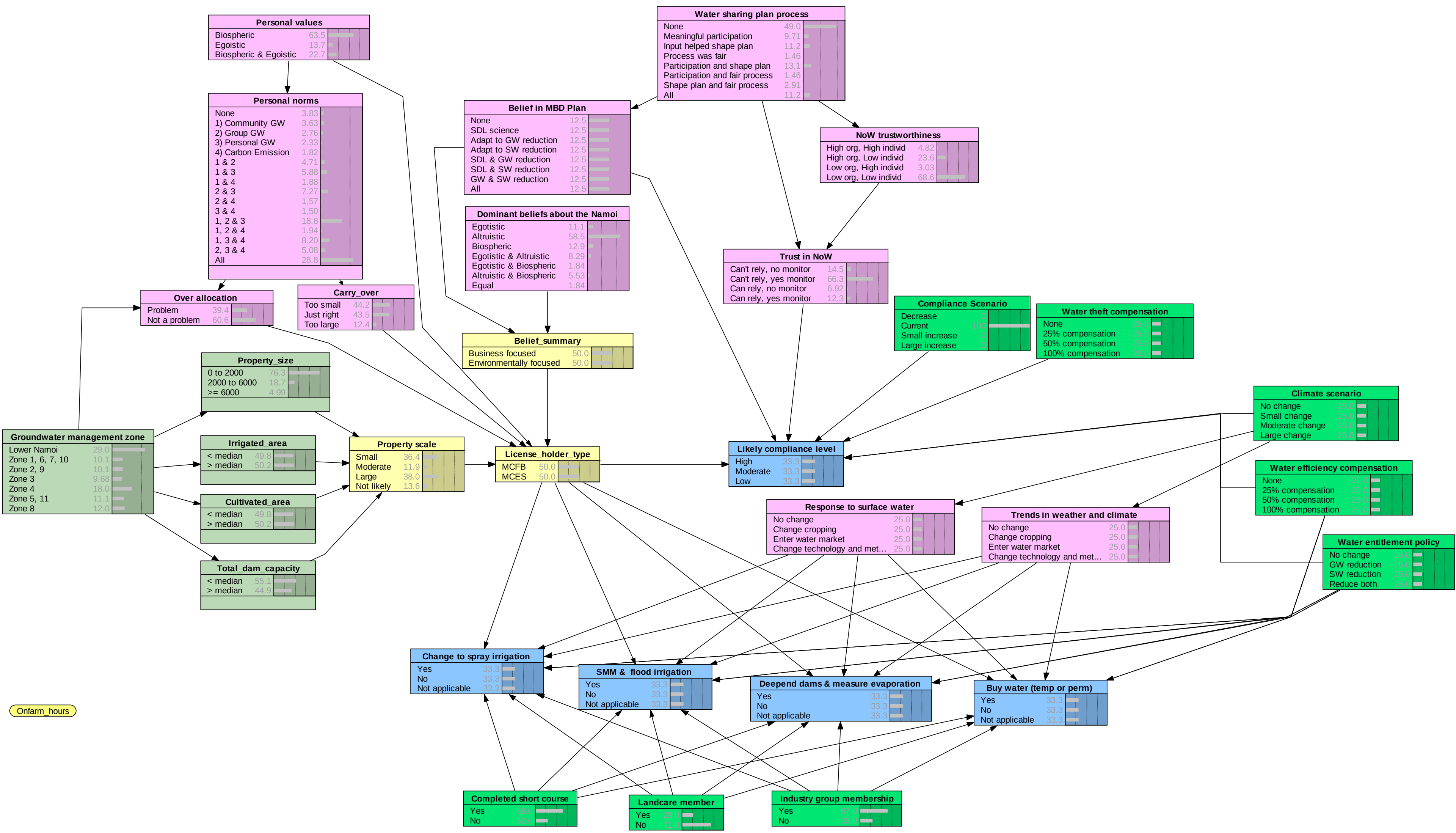
Water entitlement policy	
No change	25.0
GW reduction	25.0
SW reduction	25.0
Reduce both	25.0

Industry group membership	
Yes	67.0
No	33.0

Landcare member	
Yes	29.0
No	71.0

Completed short course	
Yes	68.0
No	32.0

Develop into an influence diagram



Economic questions – Wilson and Kelly

- What is the **current agricultural production and profitability** for cotton producing farms? This establishes a **baseline for later analyses**.

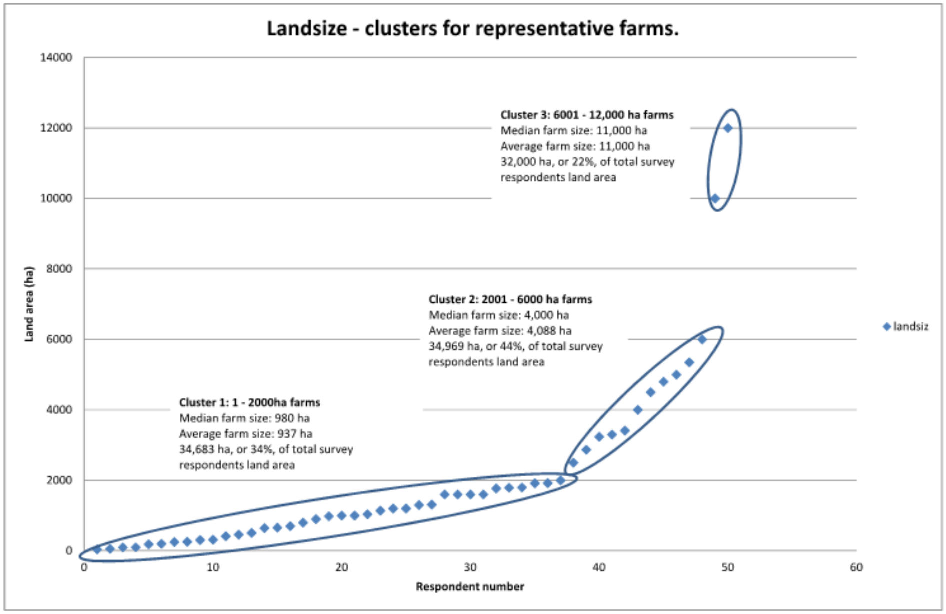
- What is the likely **impact of the adoption of water-use adaptations** on agricultural production and profitability for cotton-producing farms?

- What is the likely impact of the adoption of water-use adaptations on agricultural production and profitability with **changed government policy (water allocations and efficiency incentives)** for cotton producing farms?

- For the 3 scenarios above, what is the likely **impact of climate change** on agricultural production and profitability for cotton producing farms?

Economics – Letcher et al.

- Developing a set of representative farm models
- Using data from social survey and interviews with farmers
- No suitable ongoing monitoring



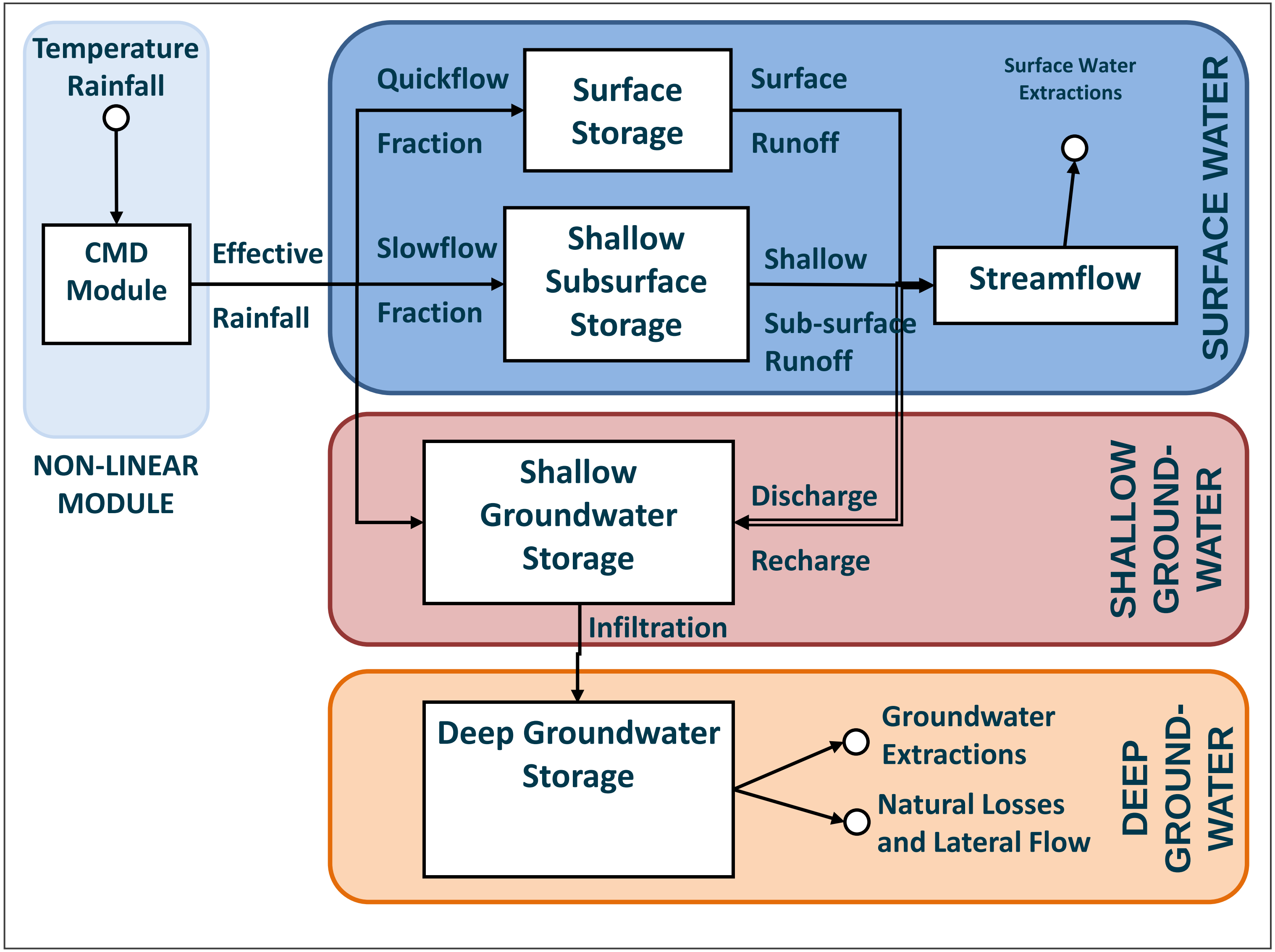
Crop yield model - Hutchings

- Metamodel of the APSIM model obtained through sensitivity analysis
  - A two layer model estimating soil moisture content (SMI) using the available inputs to improve the estimate of evapotranspiration (ET) and show the available water for crop use after considering runoff, infiltration and ET
  - Runoff determined by the soil moisture content of the top layer (SMI_1) at the time of rainfall
  - Empirical relationship between yield, PET, rain, soil moisture and temperature

Hydrological Model Development – Blakers and Croke

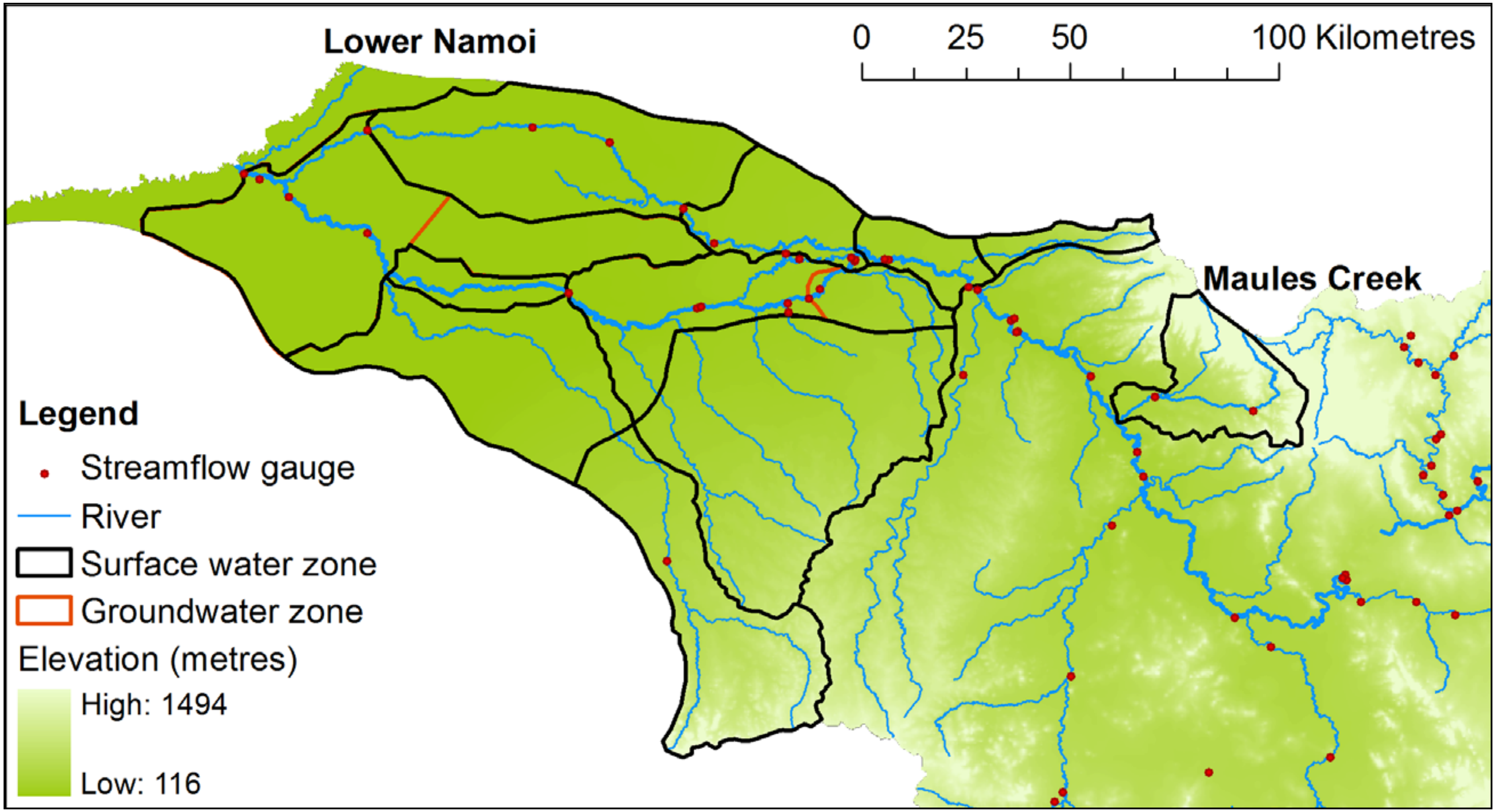
- A key challenge was the choice of hydrological model structure, including:
  - Surface-groundwater, groundwater level and routing sub-modules needed
  - Which hydrological processes should be simulated?
  - The spatial resolution
  - The level of process detail – conceptual or physics-based?
- The driving consideration was the needs of the Integrated Assessment Project

Model Structure



Spatial Scale

Hydrological model zones

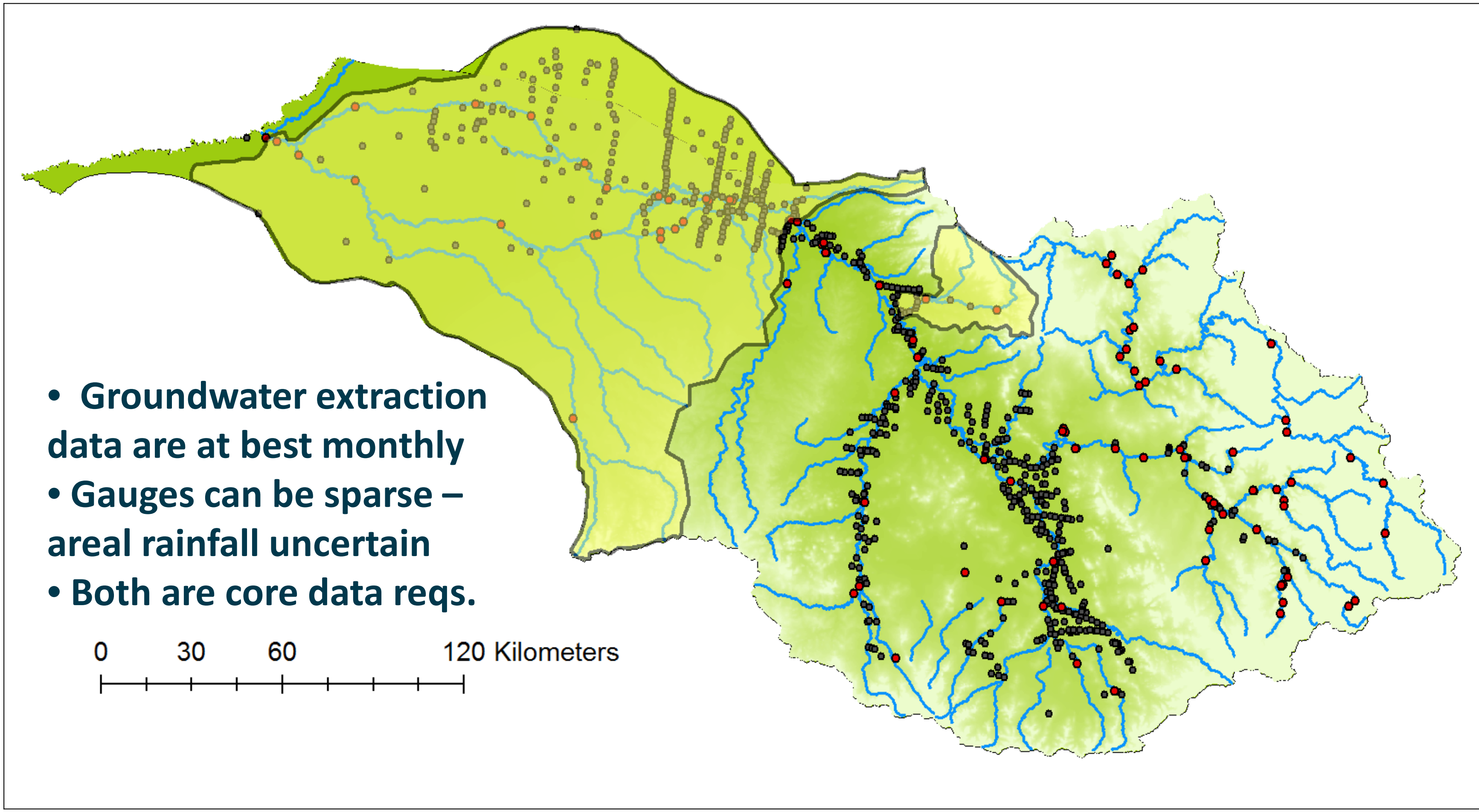


Model Complexity

- Three considerations favoured a parsimonious approach:
  1. The model outputs were only required at the scale of management zones
  2. The need to limit the computational complexity of the integrated model
  3. The available data was insufficient to support a detailed, physics/cell-based model

Main data improvement required – irrigation abstractions

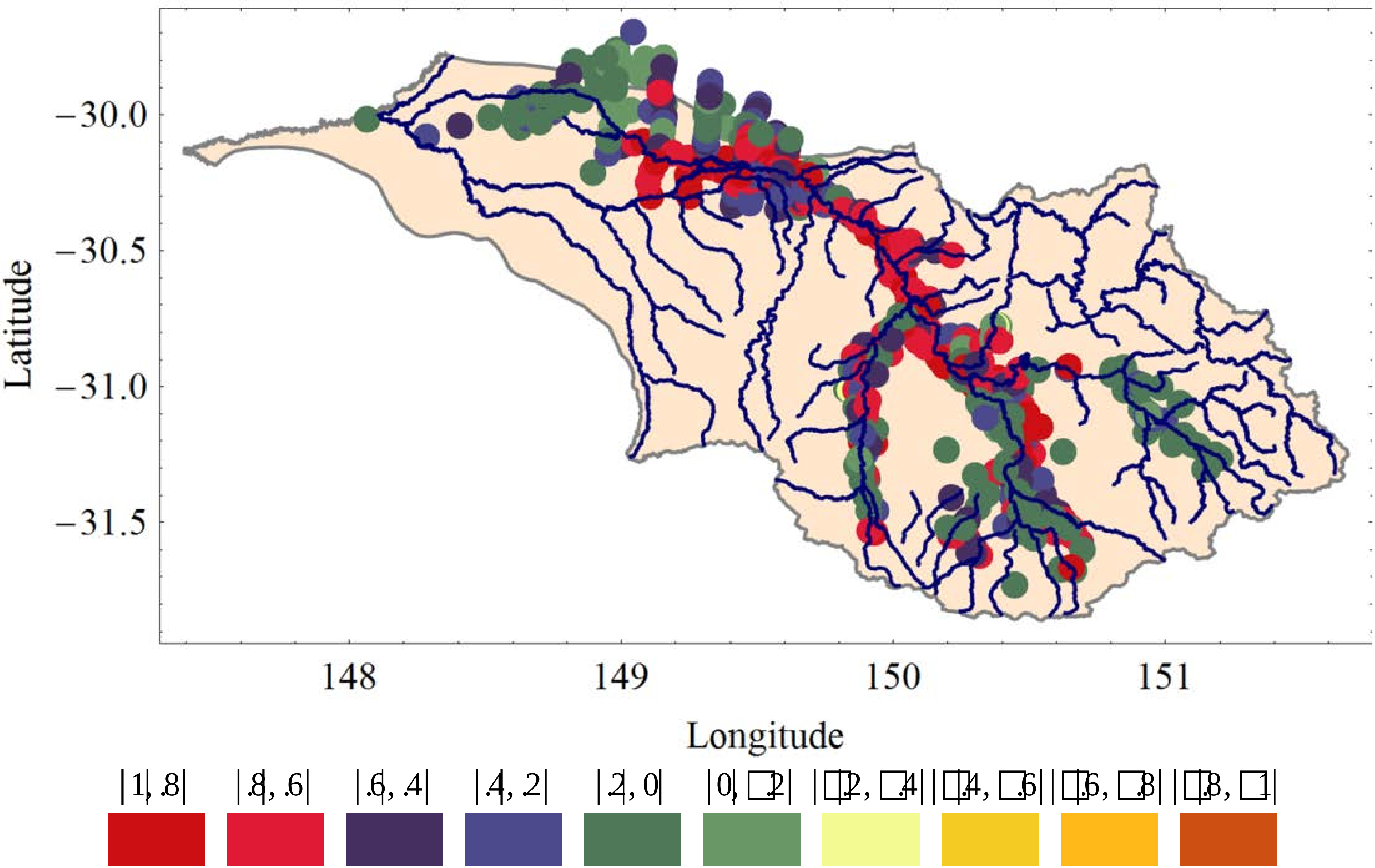
Monitoring Data



- Groundwater extraction data are at best monthly
- Gauges can be sparse – areal rainfall uncertain
- Both are core data reqs.

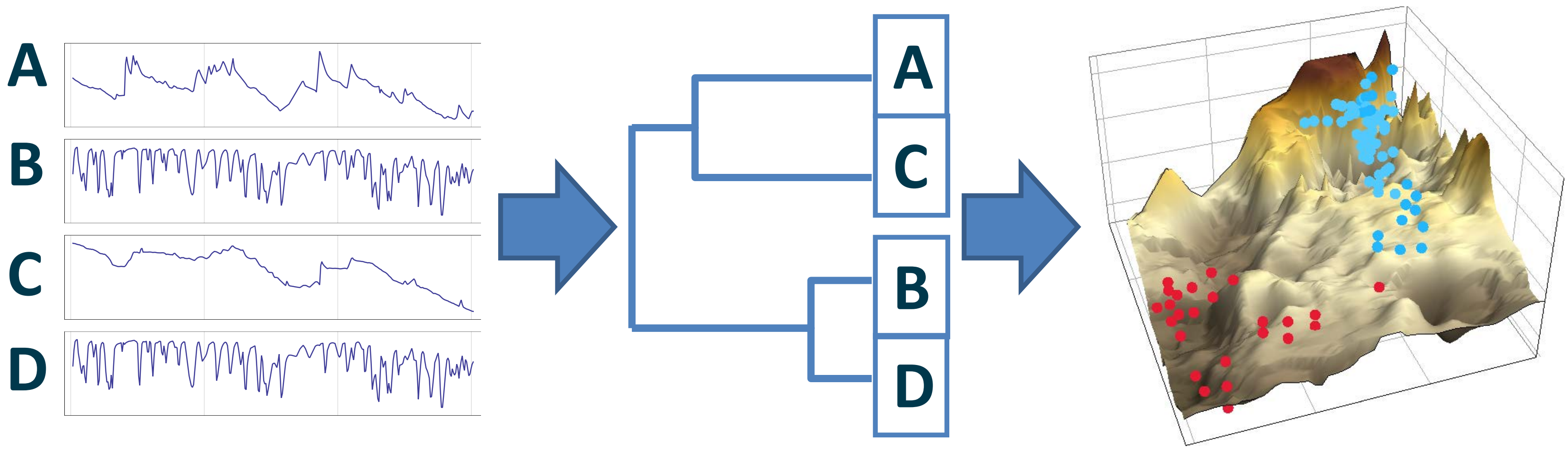
Making greater use of existing data

Streamflow – Groundwater Level Correlation

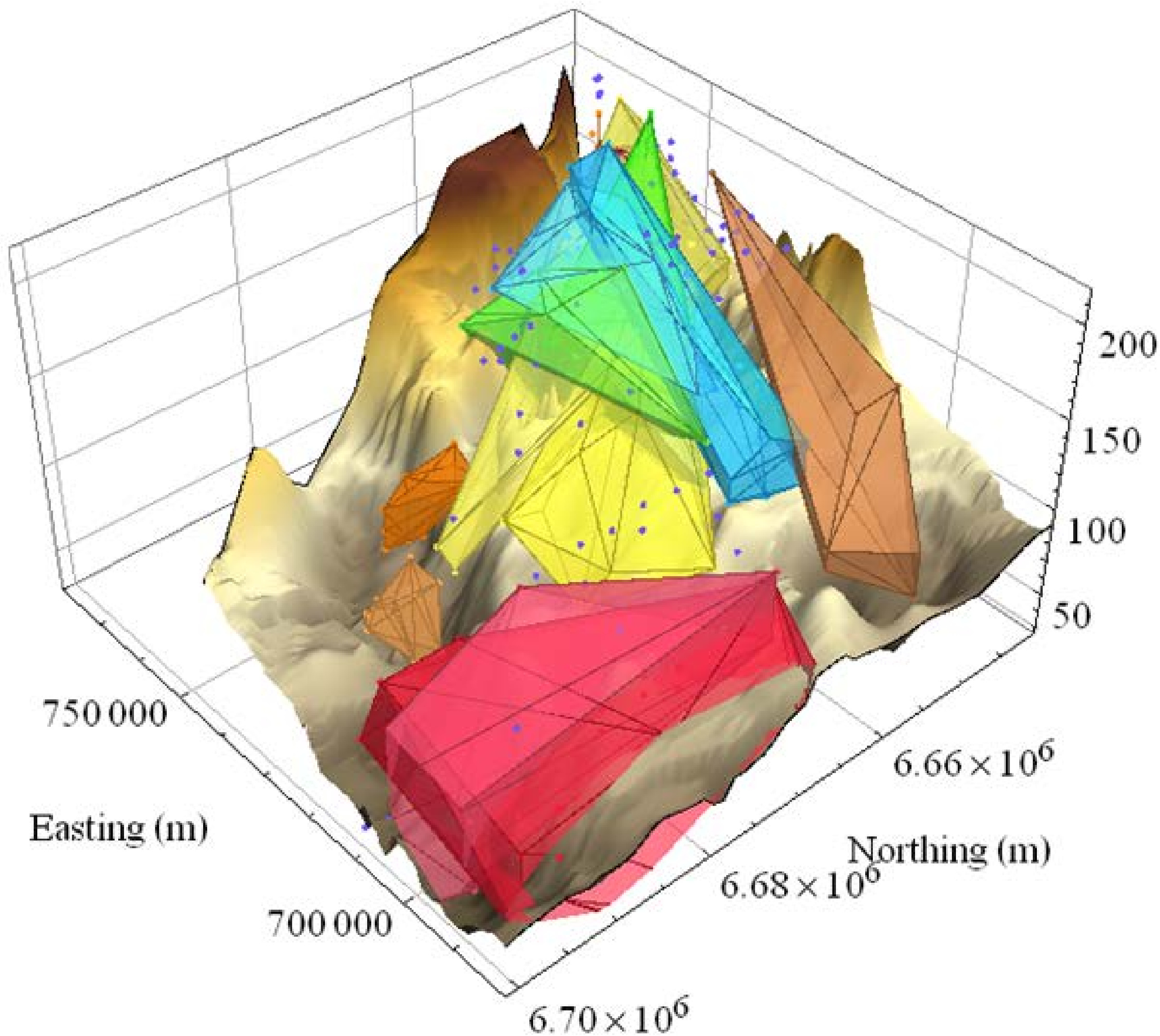


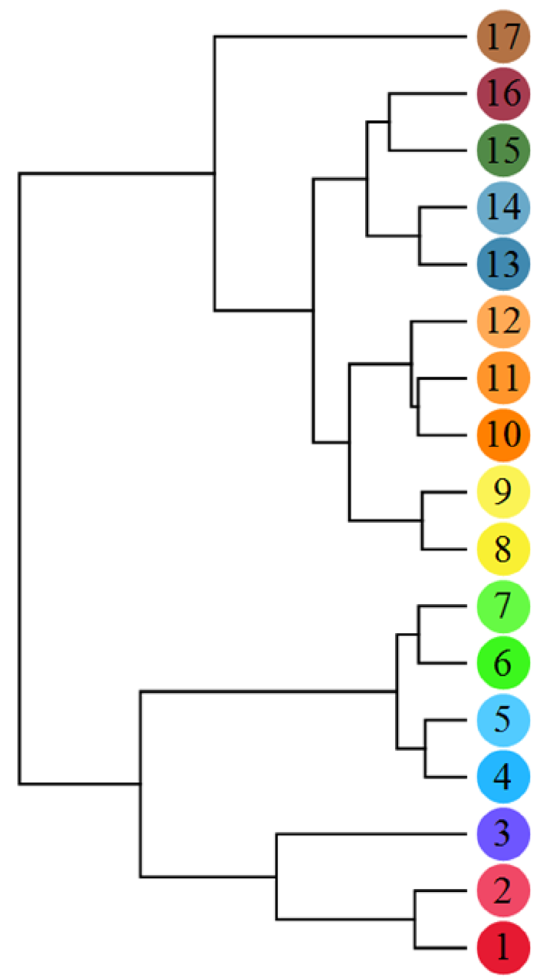
Groundwater Data Clustering

- **Cluster boreholes based on the distances between groundwater level time-series and then visualize the spatial locations of the resulting clusters.**



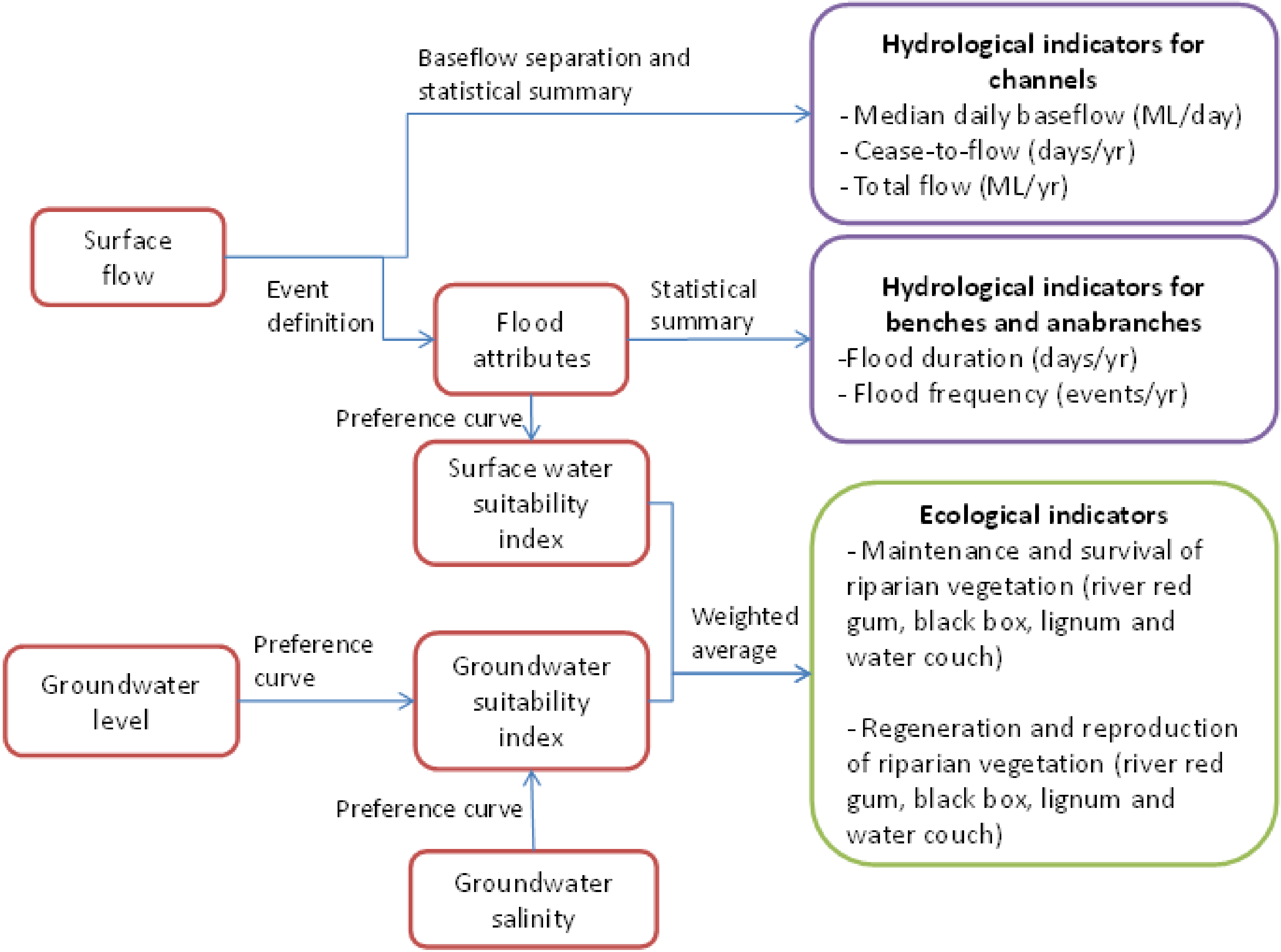
Groundwater Level Cluster Analysis





Ecology - Fu

- For 9 ecological assets, focus is on:
  - a sustained level of base flow which provides refuges during drought
  - regular flushing at various levels of benches and anabranches in order to increase habitat areas and transport nutrients and organic carbon to the river system
  - regular flooding to sustain the growth of riverine vegetation and support regeneration
  - suitable groundwater and salinity levels to allow the access to water by riverine vegetation, particularly during drought
- These management-relevant concepts are implemented by multiple indicators


Surface flow
Baseflow separation and statistical summary
Hydrological indicators for channels
- Median daily baseflow (ML/day)
- Cease-to-flow (days/yr)
- Total flow (ML/yr)
Event definition
Flood attributes
Statistical summary
Hydrological indicators for benches and anabranches
-Flood duration (days/yr)
- Flood frequency (events/yr)
Preference curve
Surface water suitability index
Weighted average
Ecological indicators
- Maintenance and survival of riparian vegetation (river red gum, black box, lignum and water couch)
- Regeneration and reproduction of riparian vegetation (river red gum, black box, lignum and water couch)
Groundwater level
Preference curve
Groundwater suitability index
Preference curve
Groundwater salinity

Data gaps

- Knowledge gaps for model development
  - Ecological interactions between flood attributes, access to groundwater and surface water - would benefit from hypothesis testing
  - Relation between flow and flood extent

- Inadequate information for validation
  - No suitable time series of large scale vegetation mapping

Integrated trade-off matrix

- Primary output of integrated model: visualisation options for communication of trade-offs under consideration
- Accounts for likelihood of the adoption of various practices under each scenario
  - Compliance
  - Adoption of WUE – deepen farm dams (or split into cells), convert to spray irrigation, improve furrow irrigation
  - **Trading, Carryover rules, Conjunctive use and Aquifer Storage innovations to follow (ie flexible policy mix)**
- Impacts simulated from each of the integrated model components
  - Natural flow and groundwater level
  - Farm profit
  - Post extraction flow & groundwater level, and
  - Ecological impacts

Uncertainty assessment: Could the answer be wrong?

Uncertainty Management Action	Audit by falsification of conclusions
Identify	• What choices were made? What uncertainty arises from that choice? • Often insufficiently documented for existing models and data • Keep whole of system view, but analyse model components and then linkages
Prioritize	• Rank uncertainties and consider uncertainties with greatest risk first.
Reduce	• Select model components and paradigms suited to the uncertainty in the whole model • Only reduce uncertainty further if the answer could be wrong. • Target efforts. Data collection can be valued by its contribution to reducing uncertainty
Describe	• What alternative choices would be considered plausible?
Propagate	• Choose a plausible counter-example that might falsify the conclusion
Communicate	• Answer: Could the conclusion be wrong? • Describe counter-examples tested, including link between indicators and management
Anticipate	• Monitor whether conditions outside plausible boundary judgements are observed • Monitor early warning signs of conclusion being wrong

Conclusions: Be purposeful and sensitive to context

- We need to be structured, purposeful and eclectic in integrating
- Profound investigation of the situation context is the foundation
  - Simplifies tasks (monitoring, modelling, engagement, uncertainty assessment)
  - Higher impact results
  - Problem needs determine model requirements
  - Problem and model requirements, incl. uncertainty, determine data needs. Core data does need extensive monitoring
- Socio-economic data is marginalised - either ad-hoc collection or at too large a scale
- Current monitoring often unsuitable for evaluation (and compliance), incl. socio-economic impacts and ecological modelling

Conclusions : Embed research in management

- Learn integration by doing and seek the lessons for transferability; monitoring needs will become apparent; science and institutional aspects also
- Disciplinary research requires focus, inc. away from unnecessarily sophisticated models: our ecological knowledge is crucially limiting – data and studies needed
- Allow expense to plan for reuse of models and data – make available and document, incl. uncertainty
- Sensitive engagement demands many facets and products: be prepared to devote a major component of time to it!
- (Formal) Water Planning is an entrée to capacity building

A John Tukey quotation

"The data may not contain the answer.

The combination of some data and an aching desire for an answer does not ensure that a reasonable answer can be extracted from a given body of data."

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