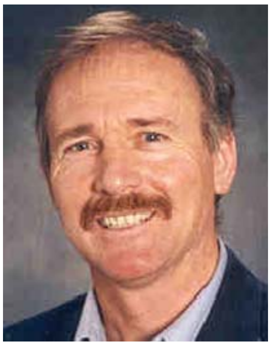


Prof Tony Jakeman
tony.jakeman@anu.edu.au
Australian National University

Day 2, 1.20pm

Area of work: Environmental modelling

Specialty: Integrated assessment and modelling of water resources issues

Take-home messages:

1. Natural resource management is characterized by wicked problems (high levels of uncertainty, conflicting values and interests, no right answers).
2. Integrated Assessment (IA) is a response to these challenges, using an open approach to building models that reflect our current understanding of how natural systems work from established knowledge, expert opinion, and empirical data.
3. Landscape Logic is using IA approaches to develop decision support tools with catchment managers in 6 of Australia's NRM regions to explore the likely impact of interventions on water quality and vegetation condition.
4. Key lessons in this application have been establishing clear goals amongst all parties from the start, maintaining clear lines of communication, distinguishing between research challenges and procedural tasks, recognising the differing time cycles of research and management, and identifying the value of collaboration for all parties involved, and recognising that IA takes time.

Integrated Assessment of options for improving resource condition

Integrated Assessment (IA) is a meta-discipline that offers a way forward for addressing the wicked problems that pervade natural resource management. IA is a 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 resolution. Necessarily it involves modelling.

Models are essential for wicked problems in order to systematically integrate and capture our understanding, taking into account uncertainties and characterising them as far as possible. In the case of NRM, IA modelling is typically about how changes in management, climate, demographics and other factors affect selected indicators of system health so that the consequences of management options can be clarified. In line with the principles of IA, transparency, accountability, engagement of stakeholders and knowledge elicitation need to be properties of the ongoing process. Increasingly, decision support systems, usually incorporating models, are being adopted as a facilitating mechanism in IA exercises.

To this end, modelling and its incorporation in information or decision support systems can aid the development of:

(i) ways to gather, record and share conventional and unconventional environmental system information;

(ii) improved tools to capture and express qualitative as well as quantitative knowledge;

(iii) methods for testing knowledge, identifying gaps and designing experiments;

(iv) monitoring techniques able to distinguish the effects of changed management practices from the large natural variations associated with most systems; and

(v) approaches to screening and testing a broad range of alternative policies

The presentation will illustrate a range of experiences in undertaking IA and summarise the key lessons to take us forward in NRM.

Relevant publications

Jakeman AJ, Voinov A, Rizzoli A and Chen S (Eds) (2008) *Environmental Modelling, Software and Decision Support: state of the art and new perspectives*. Elsevier series on Integrated Environmental Assessment, 369pp.

Giupponi C, Jakeman A, Karssenberg G and Hare M (Eds) (2006) *Sustainable Management of Water Resources: an Integrated Approach*. Edward Elgar Publishing, Cheltenham, UK, 361 pp.

Jakeman AJ and Letcher RA (2003) Integrated Assessment and Modelling: Features, Principles and Examples for Catchment Management. *Environmental Modelling and Software*, 18: 491-501.

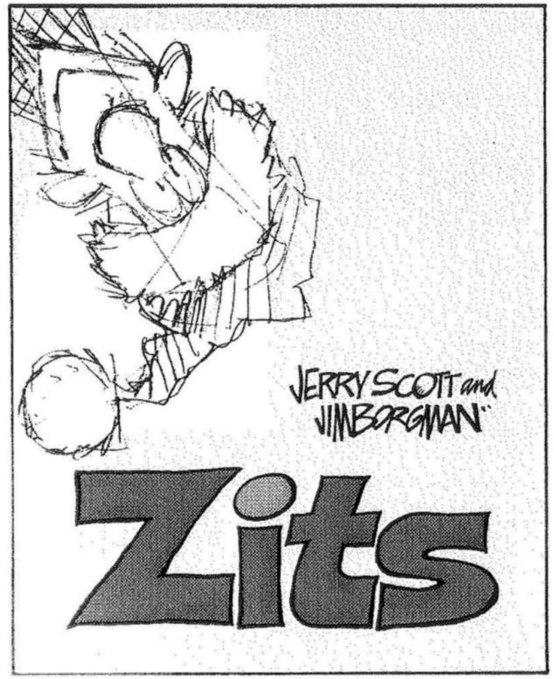
Croke BFW and Jakeman AJ (2001). Predictions in catchment hydrology: an Australian perspective. *Mar. Freshwater Res*, 52: 65-79.

Jakeman AJ, Letcher RA and Norton JP (2006). Ten iterative steps in development and evaluation of environmental models. *Environmental Modelling and Software*, 21: 602-614.

Integrated Assessment of Options for Improving Resource Condition

Tony Jakeman, Barry Croke, Susan Cuddy, Natasha Herron, Rebecca Kelly, Ted Lefroy, Wendy Merritt, Lachlan Newham, John Norton, Carmel Pollino, Jenifer Ticehurst

2009 Fenner Conference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THE BEARER TO ONE
DRIVING-FREE
SATURDAY

Main points of the talk

- The IA and decision support process for messy problems
- Focus here on “integrated modelling frameworks” versus “tools”
- Guiding selection of an integrated modelling framework
- Examples
- Comments on uncertainty and communication
- Take home messages

NRM: the bad news…

- Often a “wicked” or “messy” problem
- No definite formulation: lack of clarity
- No right or wrong solution: conflicts rife, no ultimate test
- Compromises across scales
- Knowledge limited, uncertainty pervasive
- Moving target/evolves – eg preferences evolve, issues change
- Every problem unique
- No solution stopping point

NRM: the good news…

- A “wicked” problem but with crafting of many good-enough options to consider for resolution
- No right or wrong solution but solutions can be better or worse
- Compromises across scales which can be elucidated
- Uncertainty pervasive but can be managed better
- Every problem unique but not its components
- Best seen as a process of resolution: of engagement, learning and adaptation

Some requirements for good environmental decision making

- Effective, strategic, targeted "investment" in NRM
- Linking the science to policy and management
- Identification of interest groups
- A shared understanding of the issues and tradeoffs
  - Spatial, temporal, sectoral
- A knowledge of the 'relevant' uncertainties
- Ways forward to reduce relevant uncertainties that make the decision clear enough for good enough options - satisficing
- Best seen as an adaptive, transparent process of learning that builds trust, enhances adoption and in the long run is more efficient than piecemeal approaches

Integrated Assessment

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- *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*

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Modelling Cause and Effect (simplified)

Scenarios

Assumptions

- Climate
- Episodes
- Demography
- Policy drivers
- External drivers

→ **Environmental System** →

Sustainability indicators

- Economic
- Social
- Environmental

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But why model?

- System understanding: banking for the future, capturing and documenting our knowledge
- Discovering and reducing the relevant uncertainty limitations, inconsistencies and gaps
- Management and decision-making***
- Social learning among interest groups***
- Prediction or simulation***

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The IA Modelling and Decision Support Engagement Process

- Problem framing: definition of issues, policy options, uncontrollable drivers, human activities, interest groups
- Model conceptualisation: system boundaries, interactions, process knowledge, scales, data, state and endpoint indicators of satisfactory outcomes, scenarios
- Selecting modelling approach and methods: consider complexity of issues, type of data, interest groups, uncertainty
- Selecting software and visualisation platform(s) & methods
- Populating, calibrating and evaluating models
- Calculating (relative) impacts and evaluating tradeoffs for alternative scenarios
- Characterising uncertainty: scientific and perceptual
- Monitoring and reflection: Identify ‘data and experiments’ to reduce decision uncertainty and implement adaptive management

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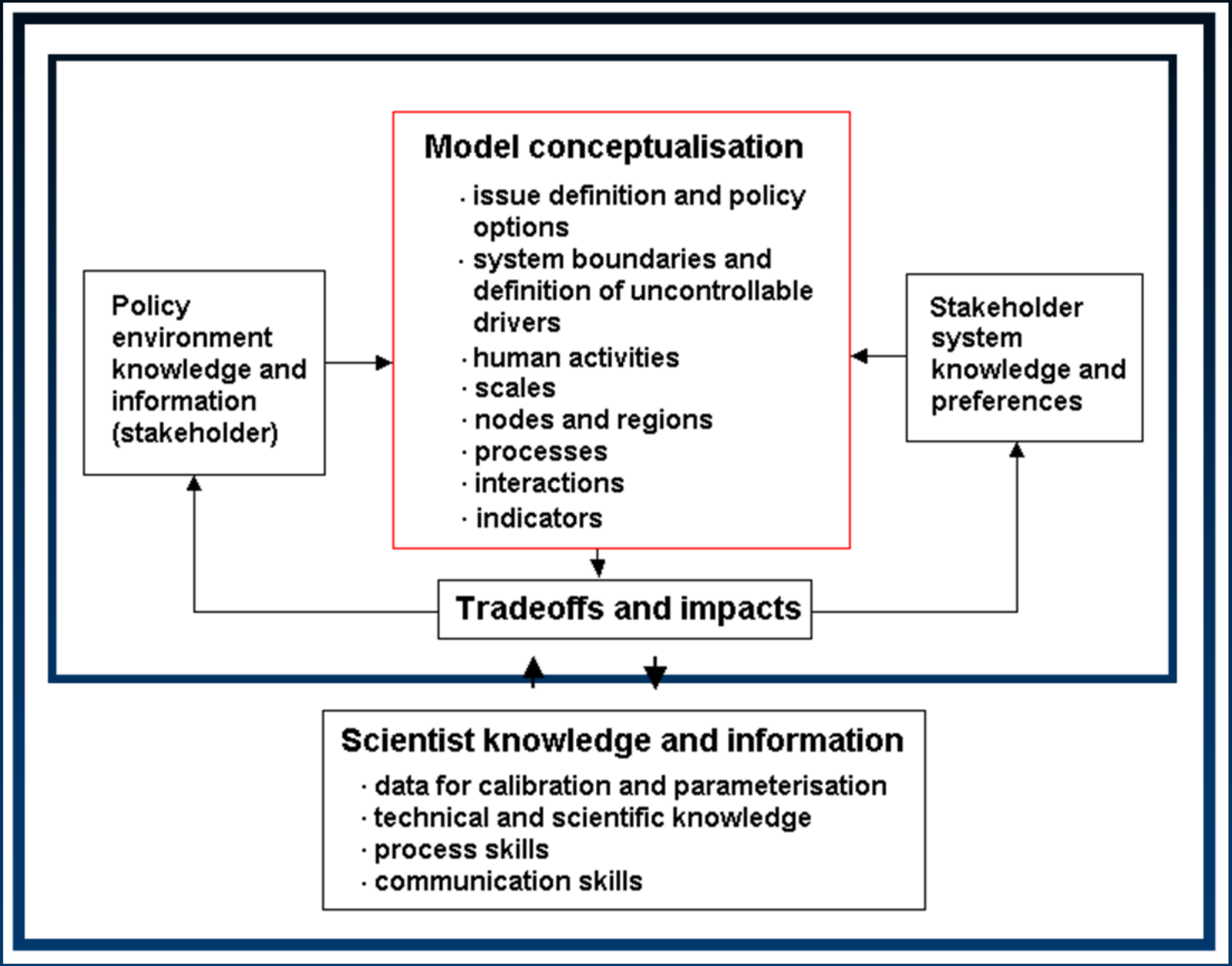

Step	Tasks involved	Tools
1. Identify objectives	•Identify issues, concerns •Build consensus on the problem(s) to be addressed	•Participatory methods
2. Problem framing	•Understanding the problem(s) •Define boundaries/scope	•Exploratory analysis •Visualisation tools (e.g. conceptual models, mind maps) •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, optimisation models, 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 models •Participatory methods

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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

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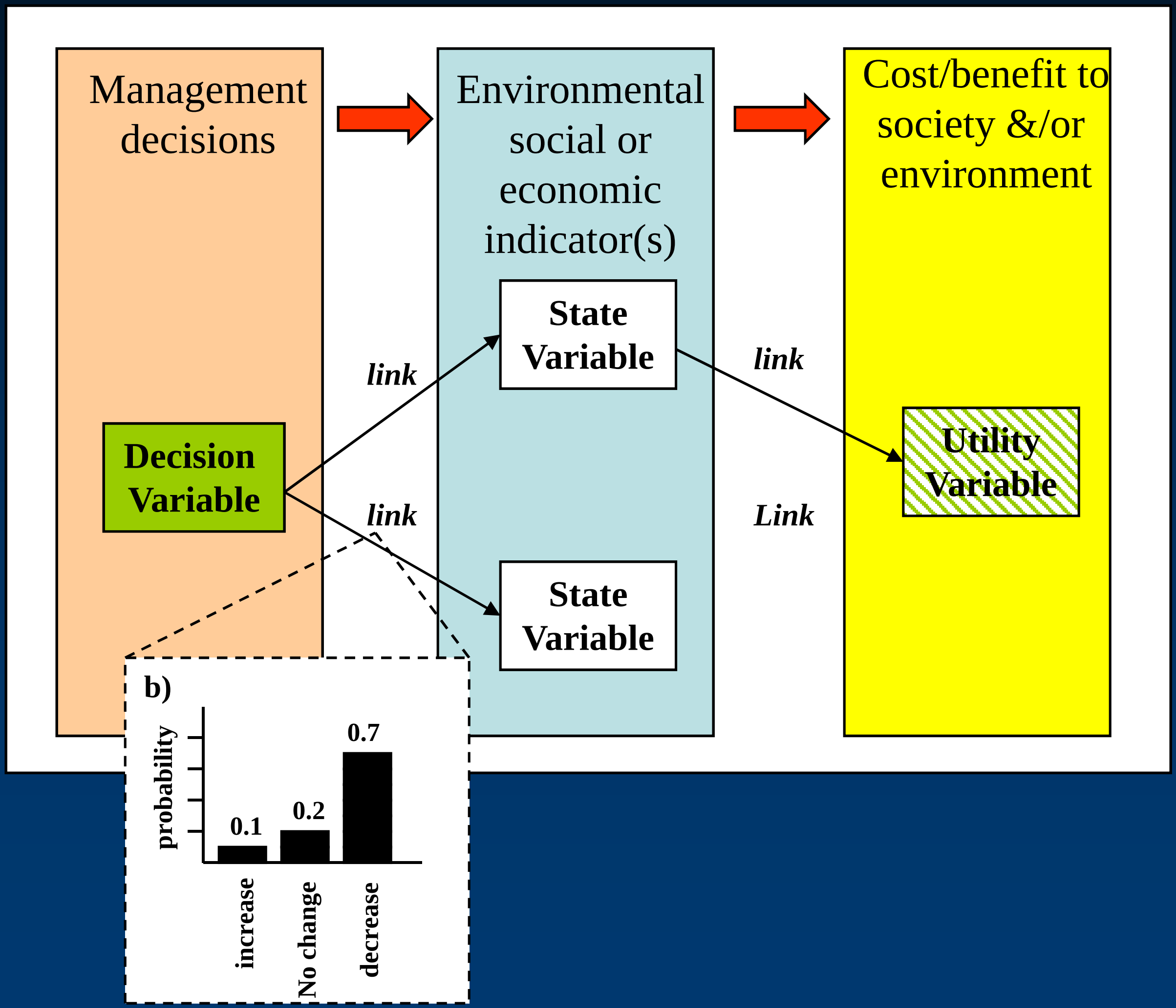
Bayesian Networks

- A fundamental modelling tool for decision-making and management where key considerations are:
  - wide-scale issue and knowledge integration
  - knowledge is of varying quality and type
- Uses conditional probabilities as a common basis to link cause and effect – ie to determine likelihood of different outcomes
- Conditional probabilities derived from:
  - many (1000's) of runs of component models
  - expert elicitation
  - stakeholder surveys
  - observed data – categoric and numeric
- Good availability of technical/analytic tools

Bayesian Decision Networks: linking nodes



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Coupling Complex Models

- Direct combination of complex models from different disciplines
- Can be loosely coupled or fully integrated
- Require comprehensive model testing to understand data and model structure uncertainty: ‘single answer’ for each run
- Can facilitate very complex scenarios in space and time
- Restricted to a modest number of component complex models

Examples: spatially-distributed hydroeconomic modelling (eg *Letcher et al., 2004, Water Res. Res.*); *and Newham presentation*

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Hybrid expert systems

- Component models of different mixed types
- Example types:
  - expert (eg linguistic, rule-based, decision trees)
  - Statistical/empirical eg regressions
  - BNs
  - complex computational models
  - metamodels
- Flexible but requires broad base of technical competence
- Limited availability of technical platforms

Integration Methods

Integration Methods		System Dynamics	Bayesian Networks	Coupled Complex Models	Agent Based Models	Hybrid Expert Systems
Model Purpose	Prediction		✓	✓		✓
	Decision Making	✓	✓✓	✓✓	✓	✓✓
	Social Learning	✓✓	✓✓	✓	✓✓	✓✓
Input Data Type	Qualitative and Quantitative		✓✓			✓✓
Focal Range of Issues, Models & Tradeoffs	Focused and In-depth	✓✓	✓✓	✓✓	✓✓	✓✓
	General and Broad	✓✓	✓✓		✓✓	✓✓
	Both	✓✓	✓✓		✓✓	✓✓
Spatiotemporal Capability	Spatial	✓	✓	✓✓	✓	✓
	Temporal	✓✓		✓✓	✓	✓✓
Express Uncertainty	Yes	✓	✓✓	✓	✓	✓✓

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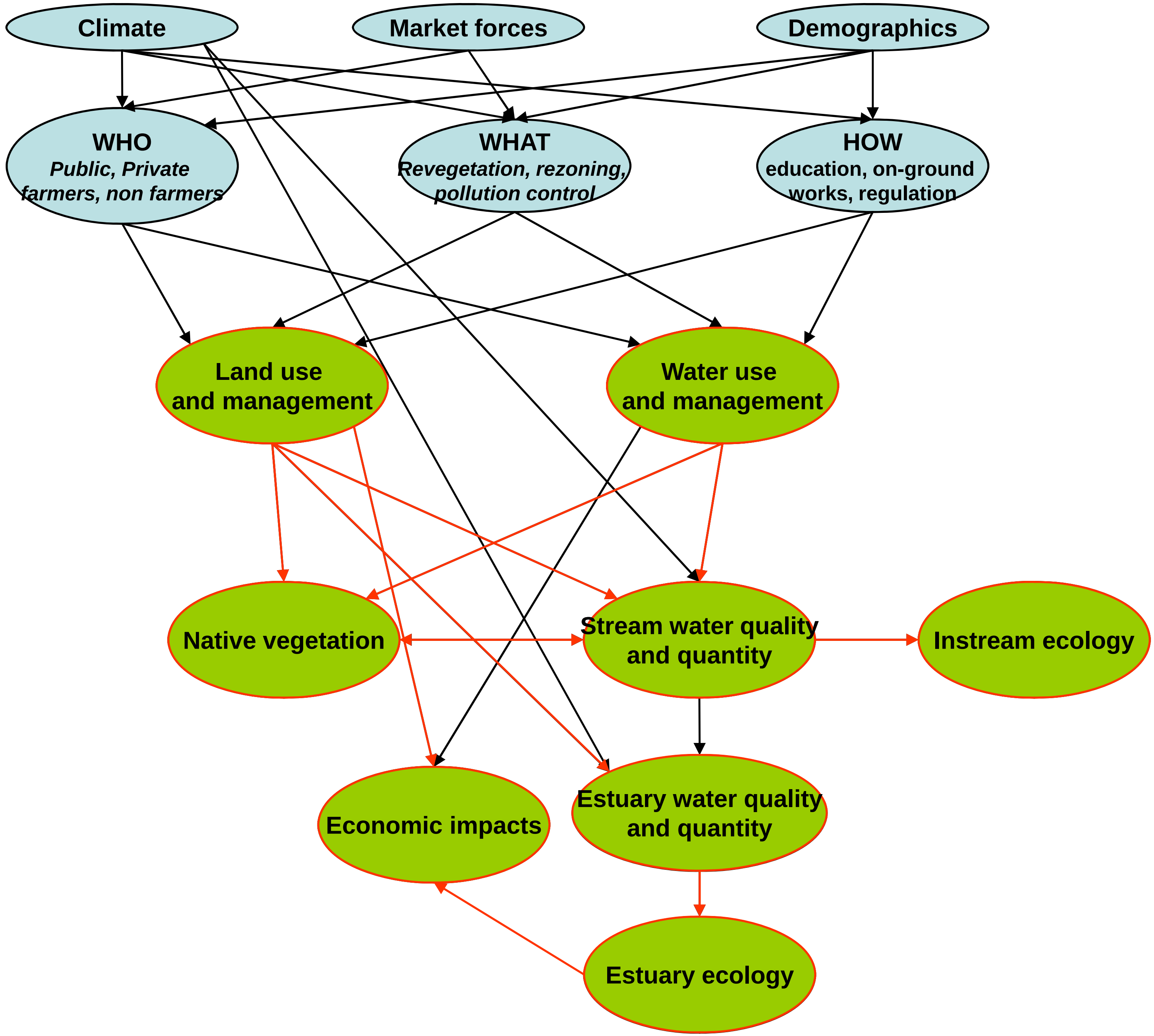
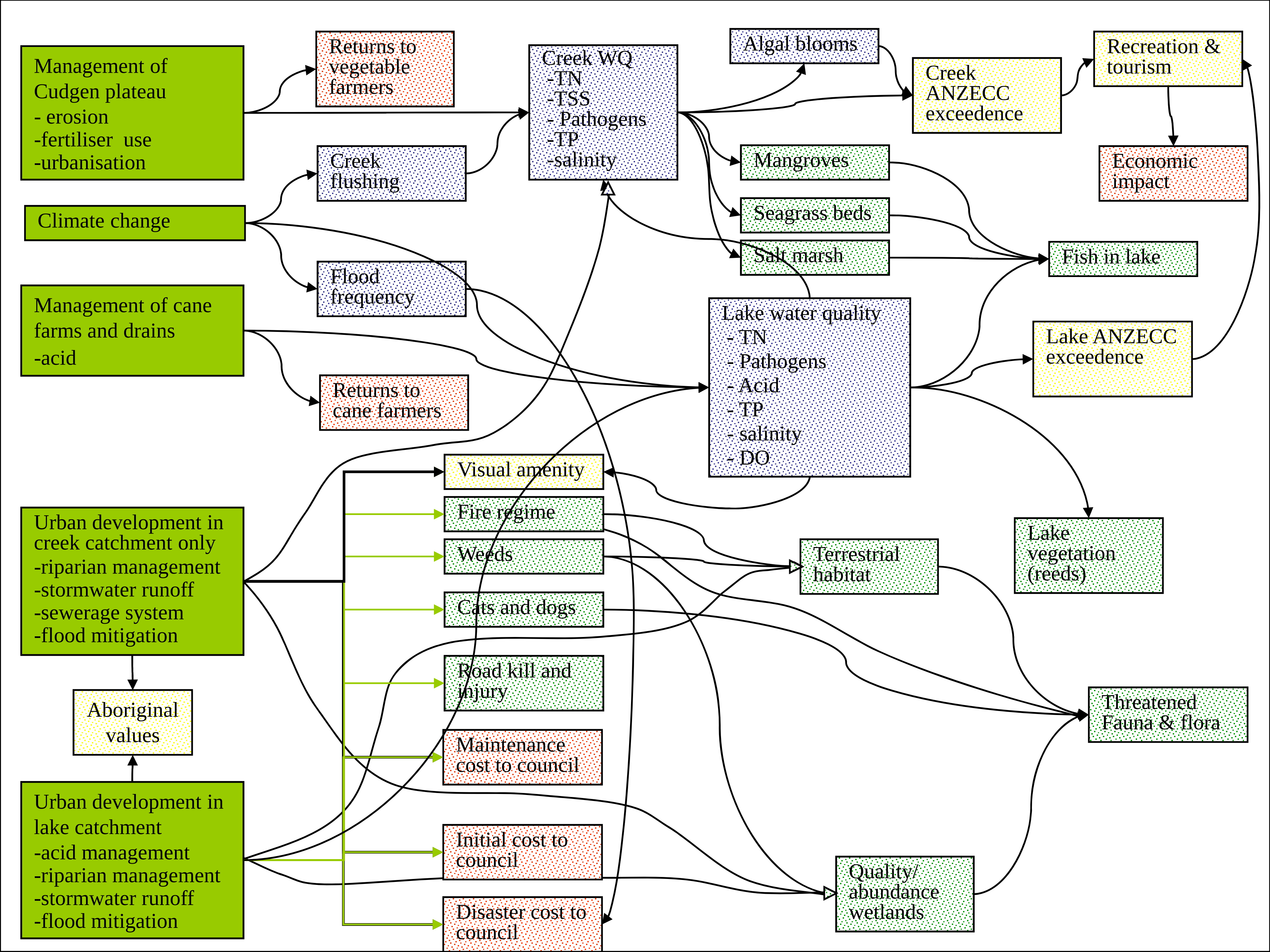
Integrated Modelling Examples

- Landscape Logic: investments to improve resource condition
  - Bayesian decision networks - Pollino talk to follow
  - Coupled complex models – previous Newham talk (CATCHMODS)
- Coastal Lakes Assessment & Management (CLAM)
  - Bayesian Networks for triple bottom line assessment
- Water Quality Improvement Planning
  - Hybrid expert system for Catchment Planning and Estuary Response (CAPER)
- Climate change and Catchment Planning: Central West CMA
  - Bayesian Network (EXCLAIM) for exploring impacts of climate change on aquatic resources
- Wetland Allocations: Gwydir and Narran (IBIS)
  - Hybrid expert system – integrated hydrology and hydrodynamics with BNs & other simple models for ecology

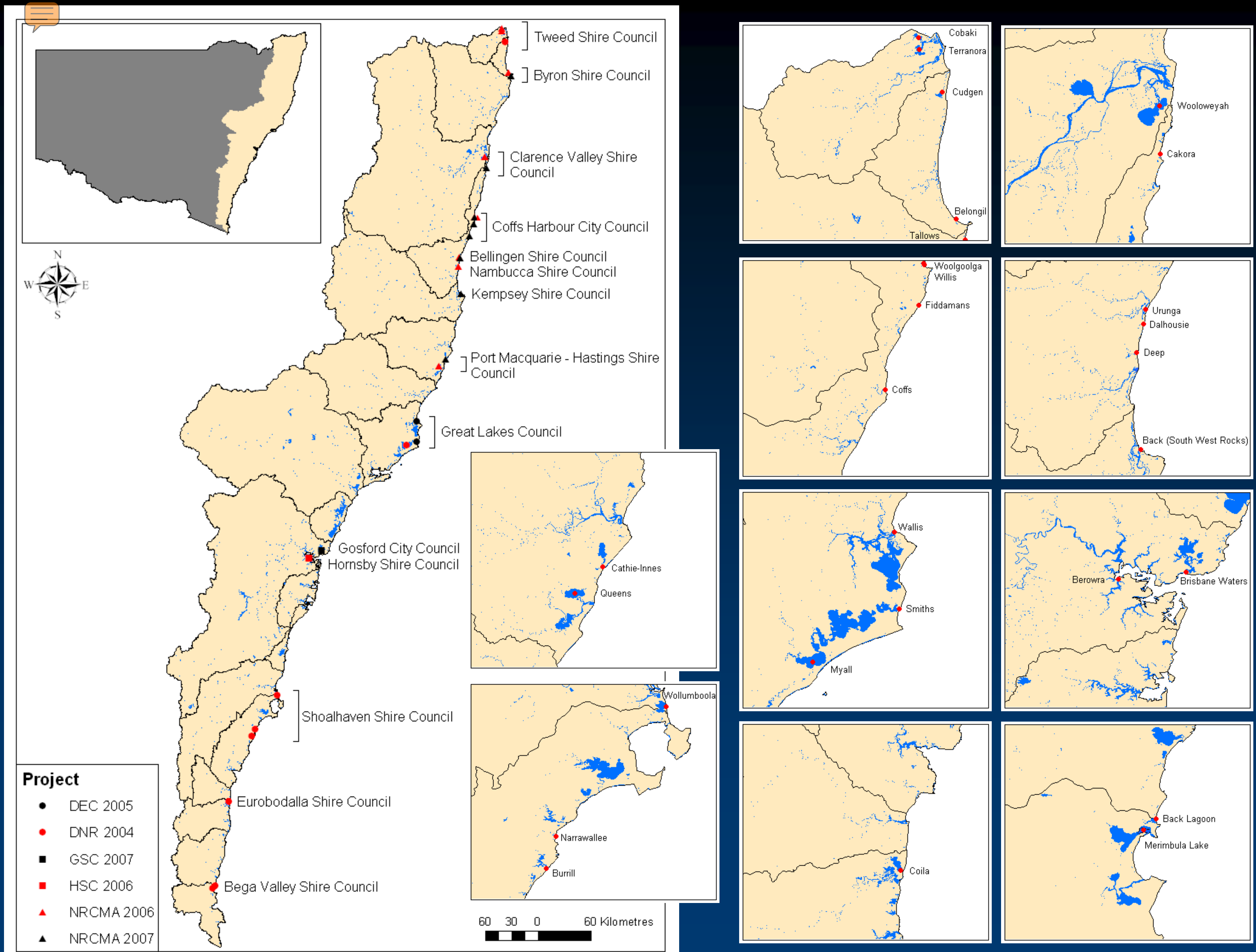

Climate
Market forces
Demographics
WHO
Public, Private farmers, non farmers
WHAT
Revegetation, rezoning, pollution control
HOW
education, on-ground works, regulation
Land use and management
Water use and management
Native vegetation
Stream water quality and quantity
Instream ecology
Economic impacts
Estuary water quality and quantity
Estuary ecology

Sustainability of Coastal Catchments

- CCI-related work
  - DSS Frameworks for economic-social-environmental assessments (CLAM dss)
  - DSS for identifying water quality and ecological improvement options (CAPER dss)



Management of Cudgen plateau
- erosion
-fertiliser use
-urbanisation
Returns to vegetable farmers
Creek WQ
-TN
-TSS
- Pathogens
-TP
-salinity
Algal blooms
Creek ANZECC exceedence
Recreation & tourism
Economic impact
Creek flushing
Climate change
Mangroves
Seagrass beds
Salt marsh
Fish in lake
Flood frequency
Management of cane farms and drains
-acid
Lake water quality
- TN
- Pathogens
- Acid
- TP
- salinity
- DO
Lake ANZECC exceedence
Returns to cane farmers
Visual amenity
Fire regime
Weeds
Cats and dogs
Road kill and injury
Maintenance cost to council
Initial cost to council
Disaster cost to council
Terrestrial habitat
Lake vegetation (reeds)
Threatened Fauna & flora
Quality/ abundance wetlands
Urban development in creek catchment only
-riparian management
-stormwater runoff
-sewerage system
-flood mitigation
Aboriginal values
Urban development in lake catchment
-acid management
-riparian management
-stormwater runoff
-flood mitigation



Tweed Shire Council
Byron Shire Council
Clarence Valley Shire Council
Coffs Harbour City Council
Bellingen Shire Council
Nambucca Shire Council
Kempsey Shire Council
Port Macquarie - Hastings Shire Council
Great Lakes Council
Gosford City Council
Hornsby Shire Council
Shoalhaven Shire Council
Eurobodalla Shire Council
Bega Valley Shire Council
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Queens
Wollumboola
Narrawallee
Burrill
Cobaki
Terranora
Cudgen
Belongil
Tallows
Wooloweyah
Cakora
Woolgoolga
Willis
Fiddamans
Coffs
Urunga
Dalhousie
Deep
Back (South West Rocks)
Wallis
Smiths
Myall
Berowra
Brisbane Waters
Coila
Back Lagoon
Merimbula Lake

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Northern Rivers CMA

- The NRCMA CLAM project
  - Assessed the sustainability of 16 coastal systems in the Northern Rivers CMA region
  - A *Coastal Lakes Assessment and Management (CLAM)* decision support tool was developed for each system
  - Aimed to assist decision-making that will maintain, and where possible enhance, the economic, social, cultural and ecological values of these systems
  - Capacity built with accredited local consultants

- Recognised by Environs - the Local Government Environment Network - with a 2007 Silver Environs Award in Outstanding Sustainability Partnerships; and the 2007 Gold Environs Award in Outstanding Sustainability Leadership.

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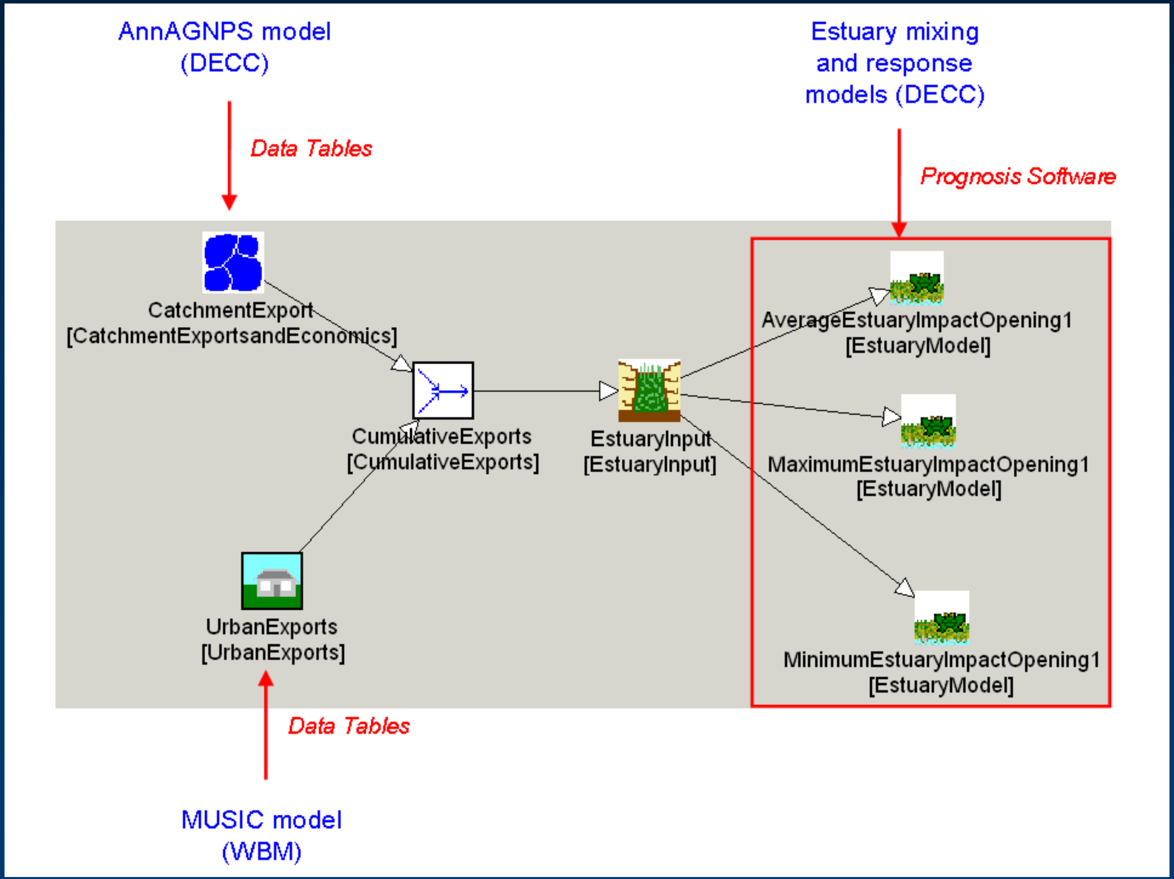
CAPER – the Great Lakes DSS

- Was used by iCAM and the Great Lakes Council to negotiate water quality improvement plans (WQIPs) for the Great Lakes region of NSW with Federal, State and Local Governments as well as community and environment groups
- Plans will guide future management of the catchments by identifying what action(s) are required to meet the required ecological condition of the lakes
- Plans provide a framework for the implementation of water quality improvement actions that are linked to statutory planning and other decision-making processes, and guide investment by all parties

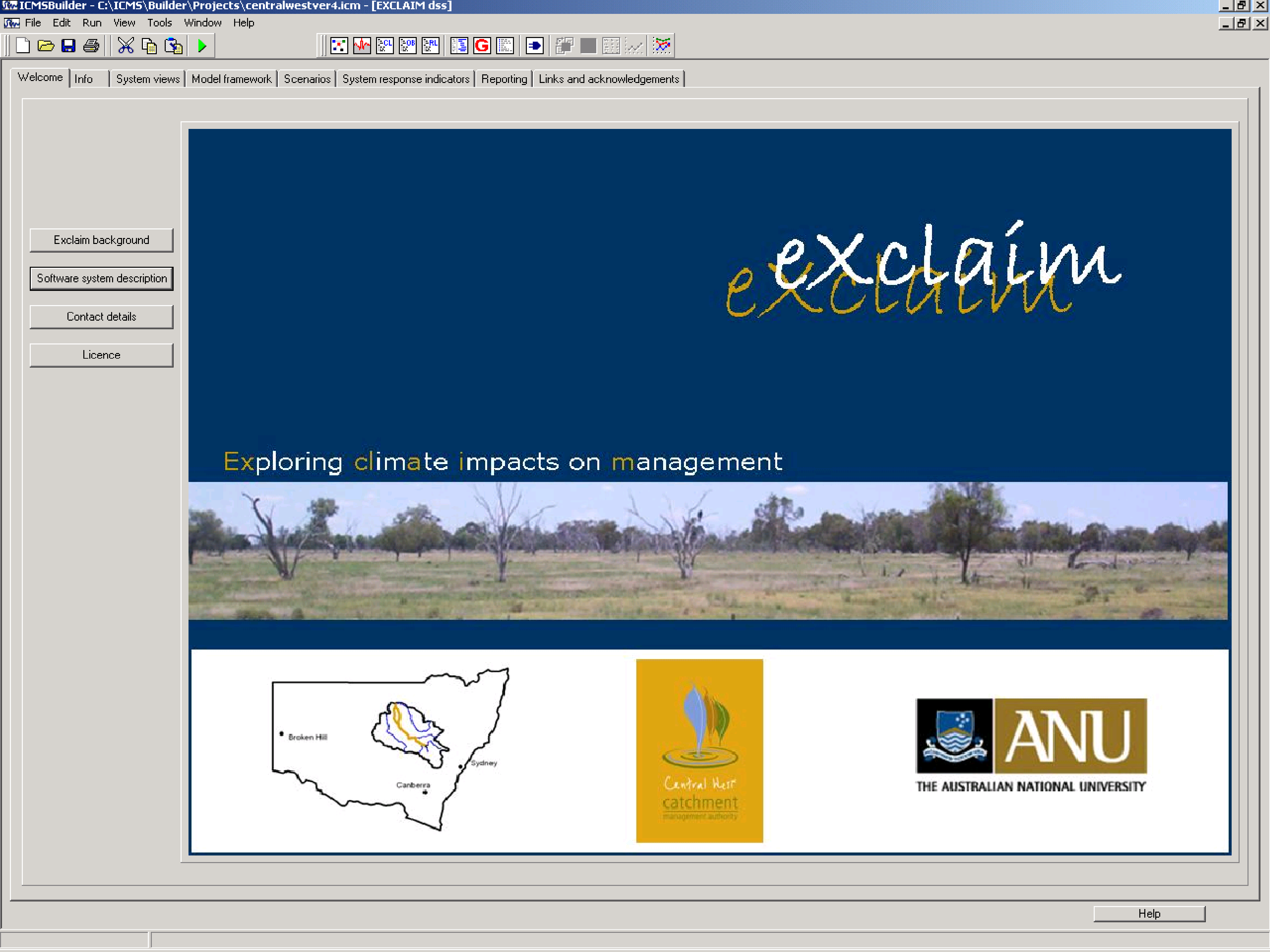
Great Lakes DSS (CAPER) for CCI

- Catchment Planning and Estuary Response (CAPER) tool
- Integrates outputs from the modelling and management research components of the CCI
  - Summaries of outputs from more complex models
  - Links models and management together to get the "catchment-to-estuary" story



CLAM and CAPER

- Coastal Lake Assessment and Management (CLAM) approach
  - Assess social, economic and environmental trade-offs associated with development, remediation and use options for coastal lakes and estuaries
  - Can be tailored to look at many types of issues
  - Provides a platform to share knowledge, discuss management options, understand the wide range of values within a coastal catchment and identify common goals
- Catchment Planning and Estuary Response (CAPER)
  - Relationship between catchment management to nutrient and sediment inputs to estuaries
  - Links estuary response to catchment inputs
  - Much tighter focus than CLAM
- Although a very different tool to CLAM, there are similarities in the philosophy of the approaches
  - consistent and transparent tool to aid management of coastal estuaries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Exploring climate impacts on management
Broken Hill
Sydney
Canberra
Central West catchment management authority
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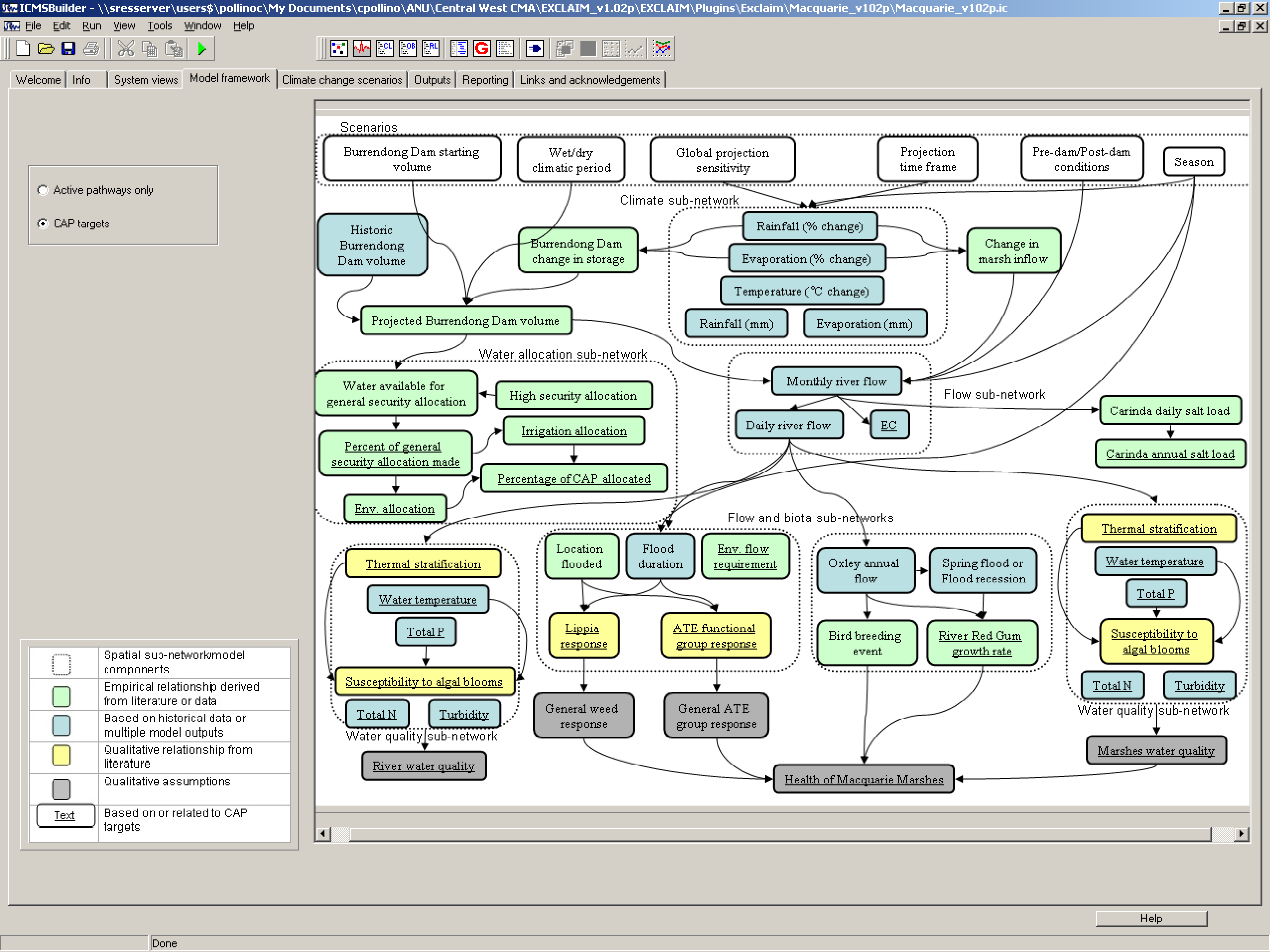
Help

Planning for Impacts of Climate Change on…

- **Water flows**
  - **Irrigation and environmental needs**
  - **‘High’ security requirements**
- **Water quality**
  - **Salinity**
  - **Nutrients**
- **River and wetland ‘health’**
  - **Ecological indicators**
    - **Algae, Vegetation, Birds, Fish**
- **Bayesian Network fed by flow scenarios**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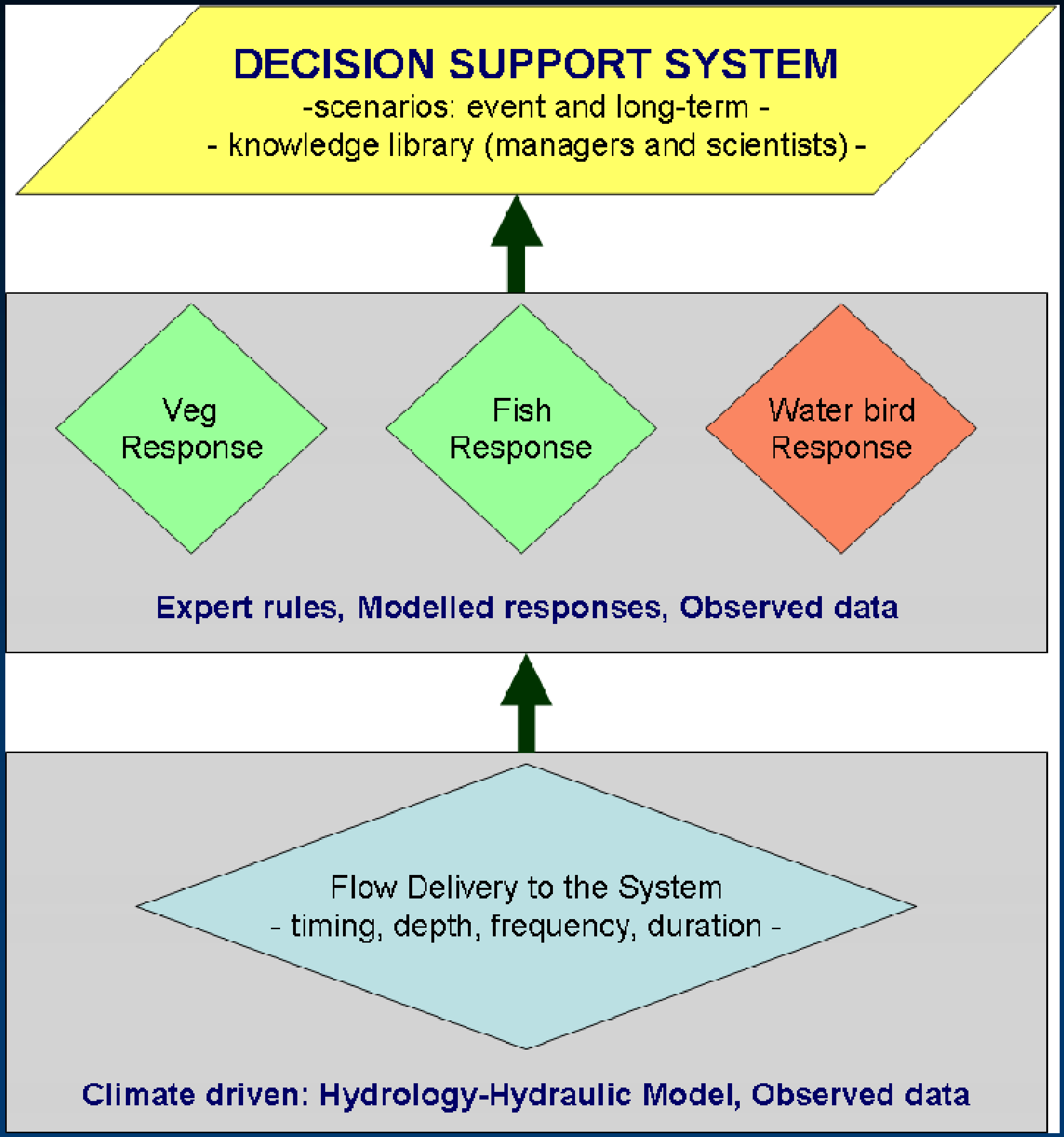
Active pathways only
CAP targets
Scenarios
Burrendong Dam starting volume
Wet/dry climatic period
Global projection sensitivity
Projection time frame
Pre-dam/Post-dam conditions
Season
Climate sub-network
Historic Burrendong Dam volume
Burrendong Dam change in storage
Rainfall (% change)
Evaporation (% change)
Temperature (°C change)
Rainfall (mm)
Evaporation (mm)
Change in marsh inflow
Projected Burrendong Dam volume
Water allocation sub-network
Water available for general security allocation
High security allocation
Percent of general security allocation made
Irrigation allocation
Percentage of CAP allocated
Env. allocation
Monthly river flow
Flow sub-network
Daily river flow
EC
Carinda daily salt load
Carinda annual salt load
Flow and biota sub-networks
Thermal stratification
Water temperature
Total P
Susceptibility to algal blooms
Total N
Turbidity
Water quality sub-network
River water quality
Location flooded
Flood duration
Env. flow requirement
Lippia response
ATE functional group response
General weed response
General ATE group response
Oxley annual flow
Spring flood or Flood recession
Bird breeding event
River Red Gum growth rate
Health of Macquarie Marshes
Thermal stratification
Water temperature
Total P
Susceptibility to algal blooms
Total N
Turbidity
Water quality sub-network
Marshes water quality
Spatial sub-network/model components
Empirical relationship derived from literature or data
Based on historical data or multiple model outputs
Qualitative relationship from literature
Qualitative assumptions
Text
Based on or related to CAP targets
Help
Done

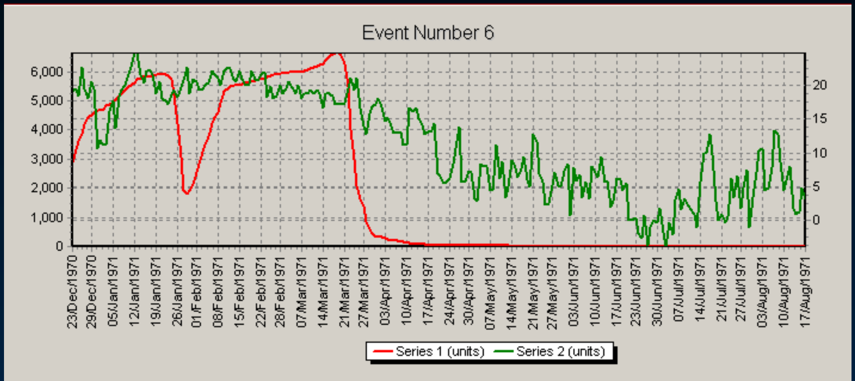
IBIS Wetlands DSS: Narran and Gwydir

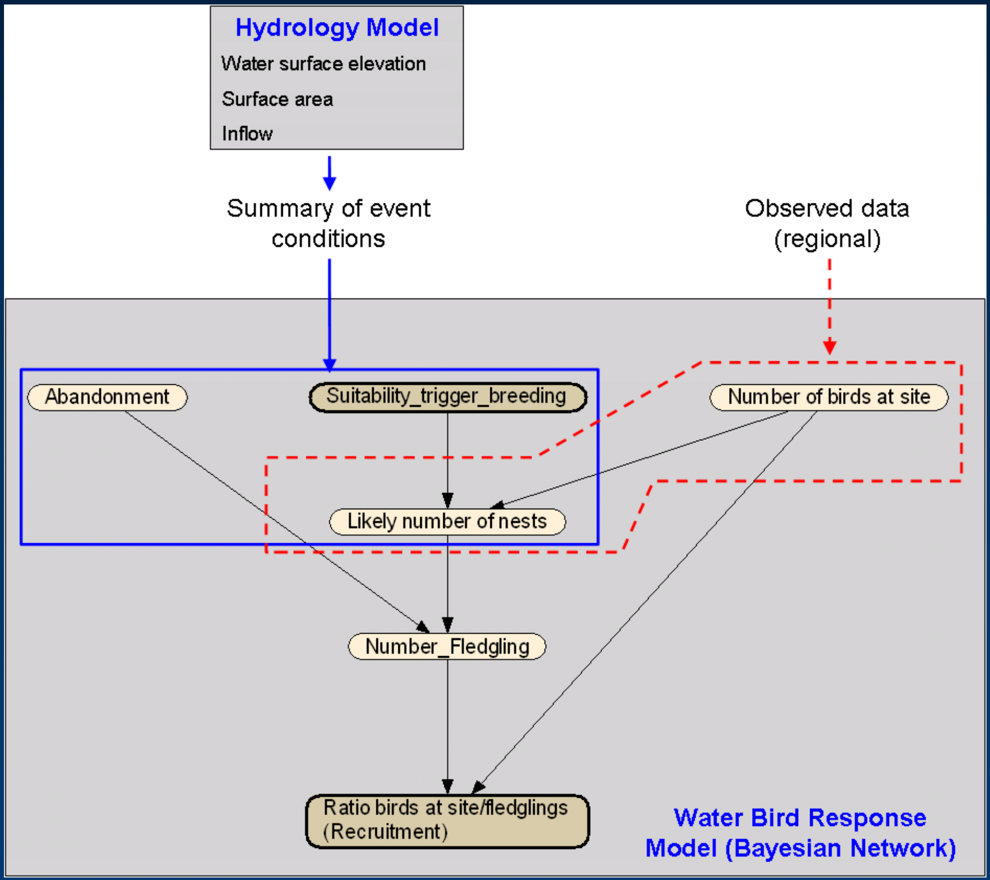


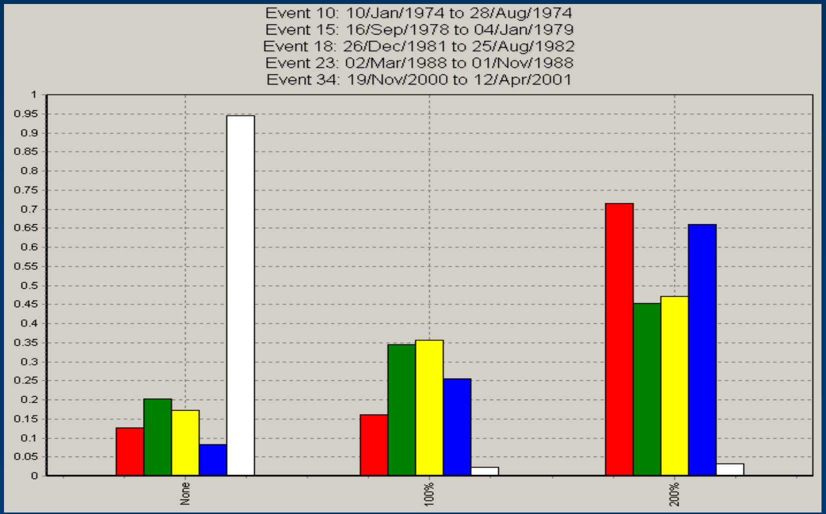
- User-friendly interface overlies the models and provides access to supporting information, model documentation and model results
- *Designed to support environmental flow decision-making (short and long term)*
- Integrated hydrology-hydrodynamics-BNs & other simple models for vegetation, fish & birds

Integration Model Structure: Bird model only

- Continuous daily hydrology model
- Characteristics of ‘event’ passed through discrete probabilistic response models
- *For each event*: the likely success of an outcome







Managing Uncertainty

- Uncertainty assessment and management methodologies
  - Benchmark against standard, catalogue & rank uncertainties
  - Significance for decision, risks incurred
  - Monte Carlo analysis
  - Extended peer review
  - Inverse modelling
  - Scenario simulation
  - Proper processes and protocols, good practice guidelines eg NUSAP

- Sensitivity assessment
  → simplifying model/problem
- Analysing model components then linkages
- Adaptive management

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However, uncertainties may be missed, or information on them too complicated to assimilate – decision-maker can weigh only a few things at a time.

Decision-maker’s conceptual model is crucial in selecting uncertainties to worry about and weighing them.

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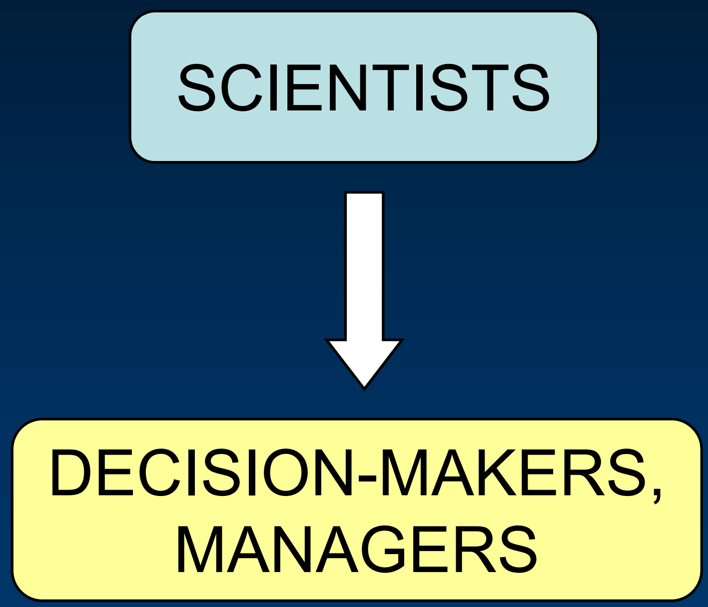
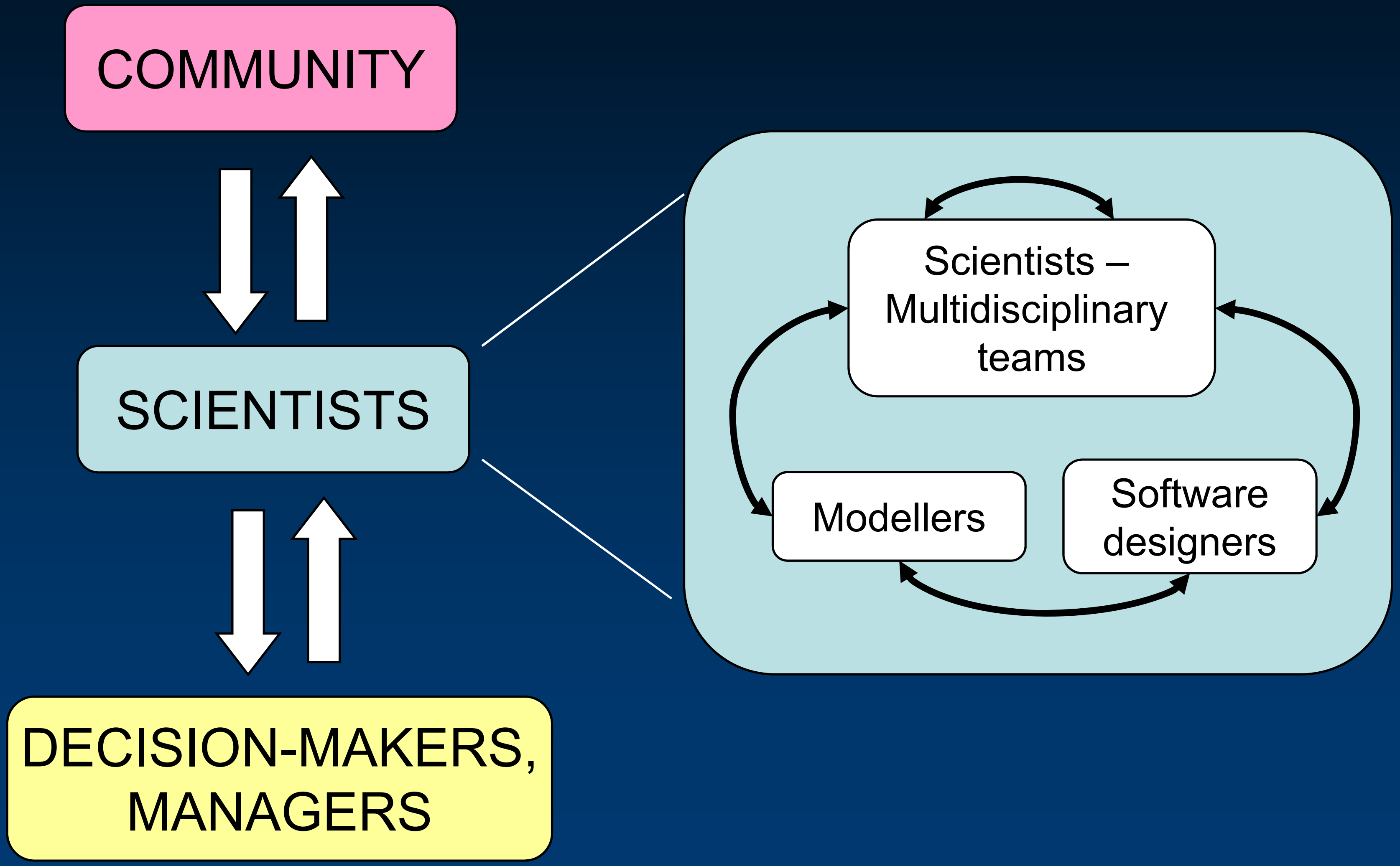
Communication

Traditionally…



Communication



What do we now know about IA

- Integrated modelling & DSS *can* build understanding & capacity, promote systems thinking, and clarify options – many examples now especially in planning and operational management
- Participation, engagement and deliverables need to incorporate *multiple* mechanisms and be a feature of the *entire* project cycle
- Time, resources and effort are required to build the essential trust between researchers and stakeholders
- Learning experience of researchers and stakeholder groups *may* be the most useful outcome – platform for the messy future
- We *can* integrate multiple issues, scales and disciplines into assessments – guidance for integrated modelling approaches
- Education and training is essential, and at many levels

“It is amazing what you can accomplish if you do not care who gets the credit.”

Harry S Truman

“The purpose of computing is insight, not numbers”

Richard W Hamming