Modelling and Decision Support for Integrated Groundwater Management

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SIMULTECH 2012
July 30, Rome
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
POLICY SECTORS

WATER PURPOSES

(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

1. Problem description and goals definition

2. Conceptualisation (way of solution):
   (a) Identification of measures
   (b) Identification of criteria and indicators
   (c) Model set-up, calibration and validation

3. Scenario definition and identifications of management alternatives

4. Simulation and estimation of effects/impacts

5. Evaluation of the management alternatives

6. Comparison and negotiation

Decision making

Acceptable consensus?

Stakeholder participation needed
Model-support needed

Next iteration:
   mitigation, adaptation, compensation, new alternatives

Recommendation(s) for decision making

(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
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<tr>
<th>Step</th>
<th>Tasks involved</th>
<th>Tools</th>
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| 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:

**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

**Monitor & evaluate**
- Treating emerging concerns
- Identifying need for change

**Implement**
- Adoption
- Compliance

**Commitment to action**

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”

(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
  - (Prioritise)
  - (Reduce) At source
- Describe
- Propagate In analysis
- Communicate To decision makers
- Manage Remaining uncertainty

- Proper processes and protocols, good practice guidelines eg NUSAP
- Benchmark against standard, catalogue & rank uncertainties

- Significance for decision, risks incurred
- Sensitivity assessment
  → simplifying model/problem

- Inverse modelling
- Data acquisition planning

- Monte Carlo and related analyses inc Bayesian methods
- Scenario simulation
- Analysing model components then linkages

- Extended peer review & stakeholder involvement
- 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, and 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)
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
Spatial Scale

Hydrological model zones

Legend
- Streamflow gauge
- River
- Surface water zone
- Groundwater zone

Elevation (metres)
- High: 1494
- Low: 116
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
### Beliefs and Views

#### Dominant beliefs about the Namoi
- Egotistic: 11.1%
- Altruistic: 58.5%
- Biospheric: 12.9%
- Egotistic & Altruistic: 8.29%
- Egotistic & Biospheric: 5.53%
- All: 1.84%

#### 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 indiv: 4.82%
- High org, Low indiv: 23.6%
- Low org, High indiv: 3.03%
- Low org, Low indiv: 68.9%

#### Over allocation
- Problem: 39.2%
- Not a problem: 60.8%

#### 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%

#### Deepen 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%

#### Change to spray irrigation
- Yes: 33.3%
- No: 33.3%
- Not applicable: 33.3%

#### Groundwater management zone
- Lower Namoi: 25.0%
- Zone 1, 6, 7, 10: 10.0%
- Zone 2, 9: 10.0%
- Zone 3: 9.46%
- Zone 4: 18.0%
- Zone 5, 11: 11.7%
- Zone 8: 12.0%

#### Water theft compensation
- None: 25.0%
- 25% compensation: 25.0%
- 50% compensation: 25.0%
- 100% compensation: 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%

#### 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%

#### Compliance Scenario
- Decrease: 25.0%
- Small increase: 25.0%
- Large increase: 25.0%

#### Climate scenario
- No change: 25.0%
- Small change: 25.0%
- Moderate change: 25.0%
- Large change: 25.0%

#### Property scale
- Small: 36.4%
- Moderate: 11.9%
- Large: 38.0%
- Not likely: 13.0%

#### License_holder_type
- MCFB: 50.0%
- MCES: 50.0%

#### Personal norms
- None: 3.8%
- 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 & 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: 5.09%
- All: 28.8%

#### Personal values
- Biospheric: 63.5%
- Egotistic: 13.7%
- Biospheric & Egotistic: 22.7%

#### Over allocation
- Problem: 39.2%
- Not a problem: 60.8%

#### Trends in weather and climate
- No change: 25.0%
- Change cropping: 25.0%
- Enter water market: 25.0%
- Change technology and met...: 25.0%

#### 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%

#### Completed short course
- Yes: 33.9%
- No: 66.1%

#### Groundwater management zone
- Lower Namoi: 25.0%
- Zone 1, 6, 7, 10: 10.0%
- Zone 2, 9: 10.0%
- Zone 3: 9.46%
- Zone 4: 18.0%
- Zone 5, 11: 11.7%
- Zone 8: 12.0%

### Other model variables

#### Scenarios
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?
• 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
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

- **Temperature Rainfall**
  - CMD Module
  - Effective Rainfall

- **NON-LINEAR MODULE**
  - Quickflow Fraction
  - Slowflow Fraction
  - Surface Storage
  - Shallow Subsurface Storage
  - Shallow Groundwater Storage
  - Deep Groundwater Storage

- **Surface Water Extractions**
  - Streamflow
  - Surface Runoff
  - Shallow Sub-surface Runoff
  - Recharge

- **Groundwater Extractions**
  - Infiltration
  - Discharge

- **Natural Losses and Lateral Flow**
  - Groundwater Extractions

- **Surface Water**
  - Shallow Subsurface Storage
  - Deep Groundwater Storage

- **Shallow Groundwater**
  - Infiltration

- **Deep Groundwater**
  - Groundwater Extractions
  - Natural Losses and Lateral Flow
Spatial Scale

Hydrological model zones

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Lower Namoi
Maules Creek
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.

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Legend:

- A
- B
- C
- D
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
Hydrological indicators for channels:
- Median daily baseflow (ML/day)
- Cease-to-flow (days/yr)
- Total flow (ML/yr)

Hydrological indicators for benches and anabranches:
- Flood duration (days/yr)
- Flood frequency (events/yr)

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)
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
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<tr>
<th>Uncertainty Management Action</th>
<th>Audit by falsification of conclusions</th>
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| 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
“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.”
References


