Environmental flow monitoring and evaluation: lessons learned from VEFMAP

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Summary: What have we learned?

- Monitoring and evaluation of environmental flows presents difficulties beyond those experienced by most river restoration projects
  - Technical difficulties
  - Logistic difficulties

- In VEFMAP researchers have implemented novel approaches to dealing with the technical difficulties

- But design and implementation of monitoring programs; and the collection, collation and interpretation of data rely completely on a strong partnership between the researchers and managers

Monitoring of Stream Restoration

- Historically very poor
  - 10% of US projects
  - 14% of Victorian projects

- No information on synthesis of the data that do exist

- Assessment of effects of flow enhancement dominated by case-studies

# River Basins	**Temporal Scale**	
	1-3 yr	**> 3 yrs**
Single	17	8
Multi	3	

Webb et al. (2010) *Marine and Freshwater Research.*

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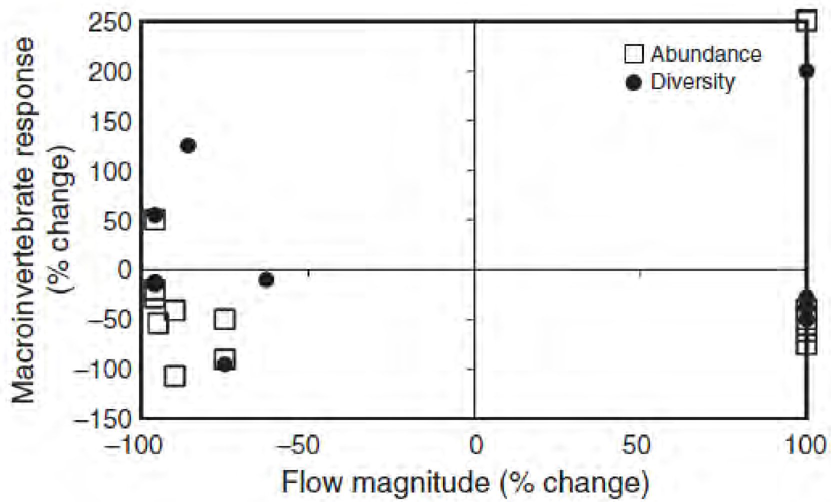
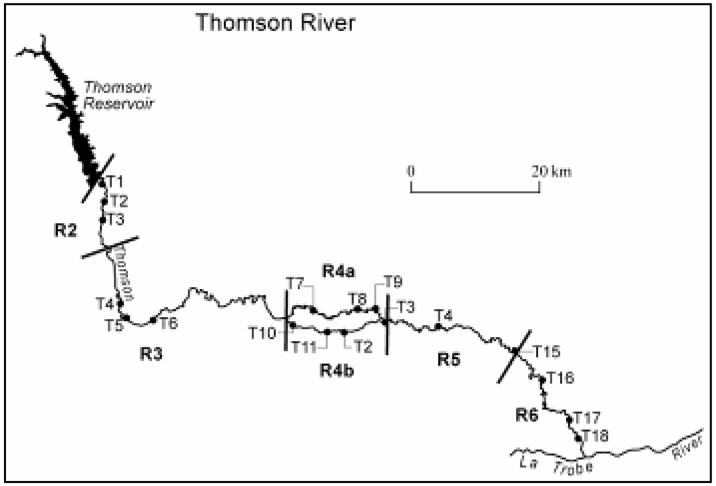
Assessing effects of flows presents scientific problems

- Ecosystem responses to flow not well characterised
  - Conceptual models are patchy and not well-founded
- Flow provision is patchy and uncertain
  - No Before – After boundaries
  - Different levels of attainment across space and time
- Finding controls difficult
  - Large, unique systems
- Re-imagining condition monitoring data
  - ‘Coordinated Intervention monitoring’



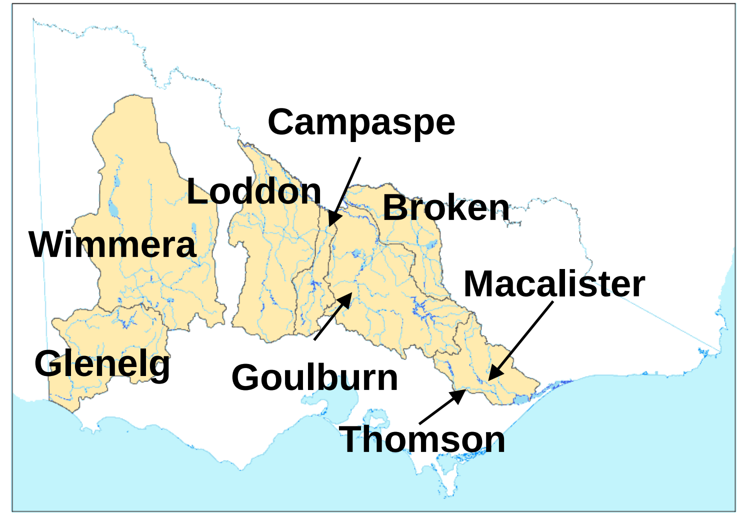
Poff & Zimmerman (2010) *Freshwater Biology*

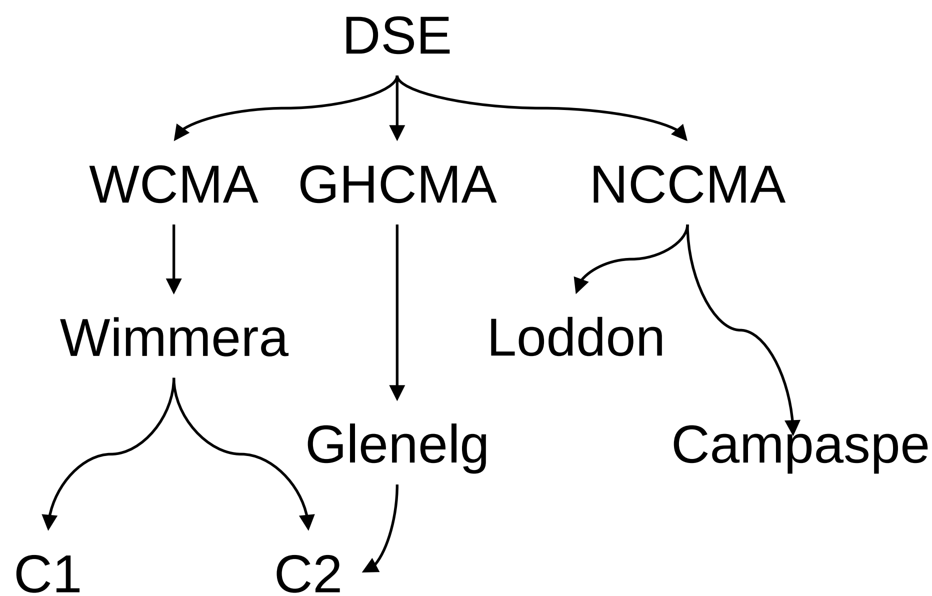


Webb et al. (2010) *Freshwater Biology*

Large-scale monitoring presents logistic problems

- Department of Sustainability and Environment (DSE): state level managers
- Different catchment management authorities (CMAs) responsible for the different rivers
  - Issues vary among rivers
    - Local specialisation of programs
  - CMAs contract work to consultants
    - Inconsistency in monitoring / assessment





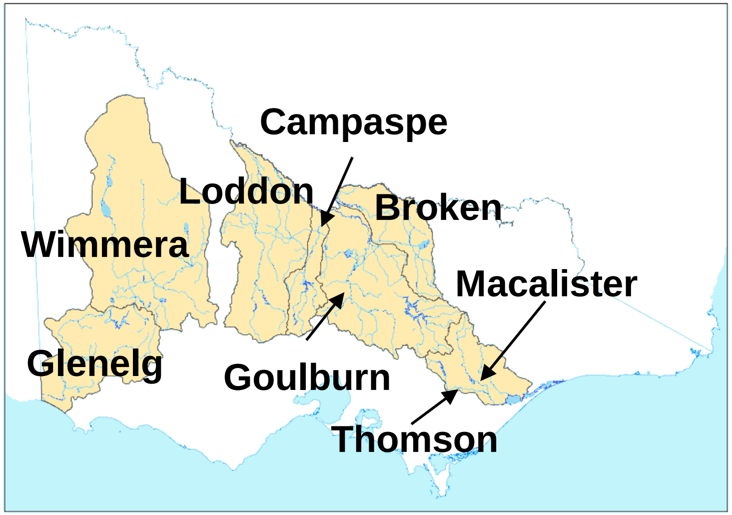
DSE

U. of Melb eWater → **VEFMAP** ← SKM

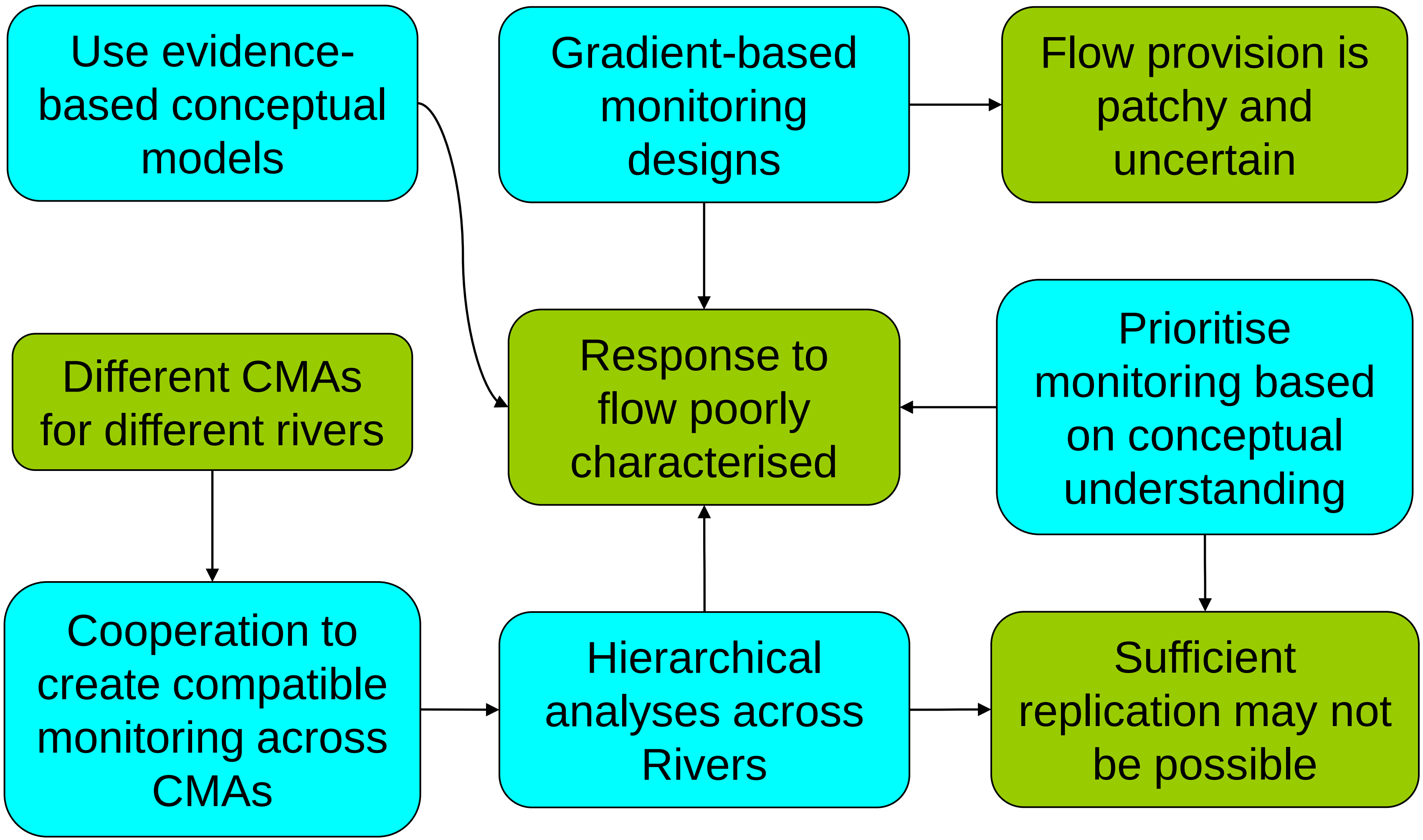
CMAs

- Partnership between managers and scientists

- Major Aims
  - Maximizing ability to detect ecosystem-level responses to environmental flows
    - Get creative
  - Doing so with the highest level of scientific integrity
    - Peer review
    - Publication

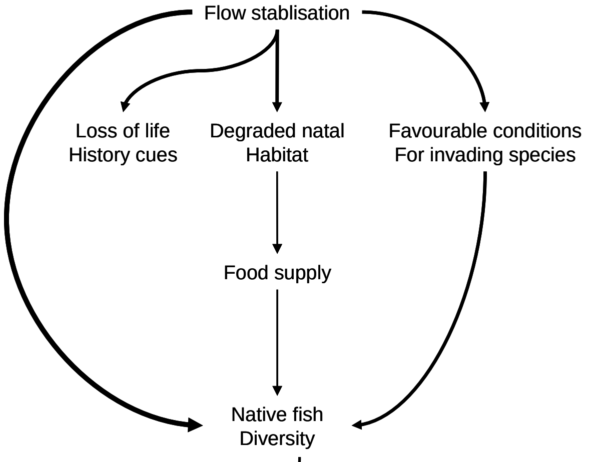


Confronting the difficulties



Use knowledge and data

Evidence-based conceptual model



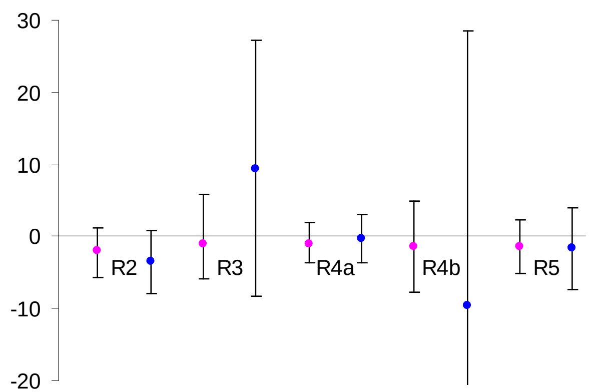
Process-based numerical model

$$Abund = Adj + \delta Tu + \gamma dQ$$

$$Adj \sim N\left(Ravg, Rsd\right)$$

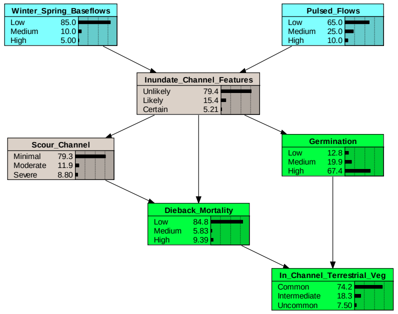
$$Ravg = \alpha + \beta \frac{\overline{Q}}{Q_R}$$

Hierarchical Bayesian analysis



Monitoring data

Expert elicitation of priors



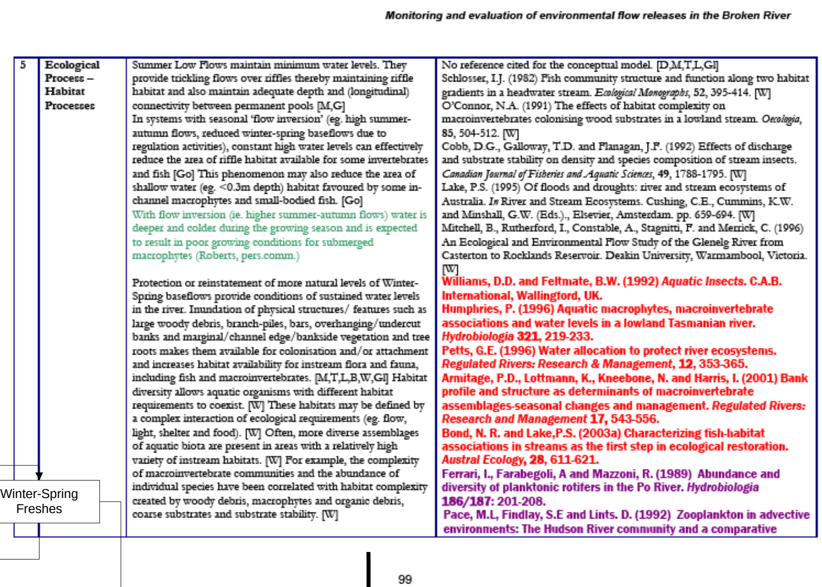
What to monitor?

- Conceptually linked to flow component/s or flow regime
  - Hypothesis-based monitoring
- Well-developed measurement techniques
- Measureable with sufficient precision to detect a response
- Expected to respond within a reasonable timeframe
- Considered valuable by stakeholders
- Economic to measure

- Groups of monitoring endpoints
  - Discharge
  - Channel form
  - Fish assemblages
  - Vegetation
  - *Water quality (salinity, nutrients)*
  - *Invertebrates*

Evidence for conceptual relationships

- For priority groups of endpoints there were many conceptual relationships available
  - How many of them had some support?



Monitoring and evaluation of environmental flow releases in the Broken River

5	**Ecological Process – Habitat Processes**	Summer Low Flows maintain minimum water levels. They provide trickling flows over riffles thereby maintaining riffle habitat and also maintain adequate depth and (longitudinal) connectivity between permanent pools [M,G] In systems with seasonal 'flow inversion' (eg. high summer-autumn flows, reduced winter-spring baseflows due to regulation activities), constant high water levels can effectively reduce the area of riffle habitat available for some invertebrates and fish [Go] This phenomenon may also reduce the area of shallow water (eg. <0.3m depth) habitat favoured by some in-channel macrophytes and small-bodied fish. [Go] With flow inversion (ie. higher summer-autumn flows) water is deeper and colder during the growing season and is expected to result in poor growing conditions for submerged macrophytes (Roberts, pers.comm.) Protection or reinstatement of more natural levels of Winter-Spring baseflows provide conditions of sustained water levels in the river. Inundation of physical structures/ features such as large woody debris, branch-piles, bars, overhanging/undercut banks and marginal/channel edge/bankside vegetation and tree roots makes them available for colonisation and/or attachment and increases habitat availability for instream flora and fauna, including fish and macroinvertebrates. [M,T,L,B,W,Gl] Habitat diversity allows aquatic organisms with different habitat requirements to coexist. [W] These habitats may be defined by a complex interaction of ecological requirements (eg. flow, light, shelter and food). [W] Often, more diverse assemblages of aquatic biota are present in areas with a relatively high variety of instream habitats. [W] For example, the complexity of macroinvertebrate communities and the abundance of individual species have been correlated with habitat complexity created by woody debris, macrophytes and organic debris, coarse substrates and substrate stability. [W]	No reference cited for the conceptual model. [D,M,T,L,Gl] Schlosser, I.J. (1982) Fish community structure and function along two habitat gradients in a headwater stream. *Ecological Monographs*, 52, 395-414. [W] O'Connor, N.A. (1991) The effects of habitat complexity on macroinvertebrates colonising wood substrates in a lowland stream. *Oecologia*, 85, 504-512. [W] Cobb, D.G., Galloway, T.D. and Flanagan, J.F. (1992) Effects of discharge and substrate stability on density and species composition of stream insects. *Canadian Journal of Fisheries and Aquatic Sciences*, **49**, 1788-1795. [W] Lake, P.S. (1995) Of floods and droughts: river and stream ecosystems of Australia. *In* River and Stream Ecosystems. Cushing, C.E., Cummins, K.W. and Minshall, G.W. (Eds.)., Elsevier, Amsterdam. pp. 659-694. [W] Mitchell, B., Rutherford, I., Constable, A., Stagnitti, F. and Merrick, C. (1996) An Ecological and Environmental Flow Study of the Glenelg River from Casterton to Rocklands Reservoir. Deakin University, Warrnambool, Victoria. [W] **Williams, D.D. and Feltmate, B.W. (1992) *Aquatic Insects*. C.A.B. International, Wallingford, UK.** **Humphries, P. (1996) Aquatic macrophytes, macroinvertebrate associations and water levels in a lowland Tasmanian river. *Hydrobiologia* 321, 219-233.** **Petts, G.E. (1996) Water allocation to protect river ecosystems. *Regulated Rivers: Research & Management*, 12, 353-365.** **Armitage, P.D., Lottmann, K., Kneebone, N. and Harris, I. (2001) Bank profile and structure as determinants of macroinvertebrate assemblages-seasonal changes and management. *Regulated Rivers: Research and Management* 17, 543-556.** **Bond, N. R. and Lake,P.S. (2003a) Characterizing fish-habitat associations in streams as the first step in ecological restoration. *Austral Ecology*, 28, 611-621.** **Ferrari, I., Farabegoli, A and Mazzoni, R. (1989) Abundance and diversity of planktonic rotifers in the Po River. *Hydrobiologia* 186/187: 201-208.** **Pace, M.L, Findlay, S.E and Lints. D. (1992) Zooplankton in advective environments: The Hudson River community and a comparative**

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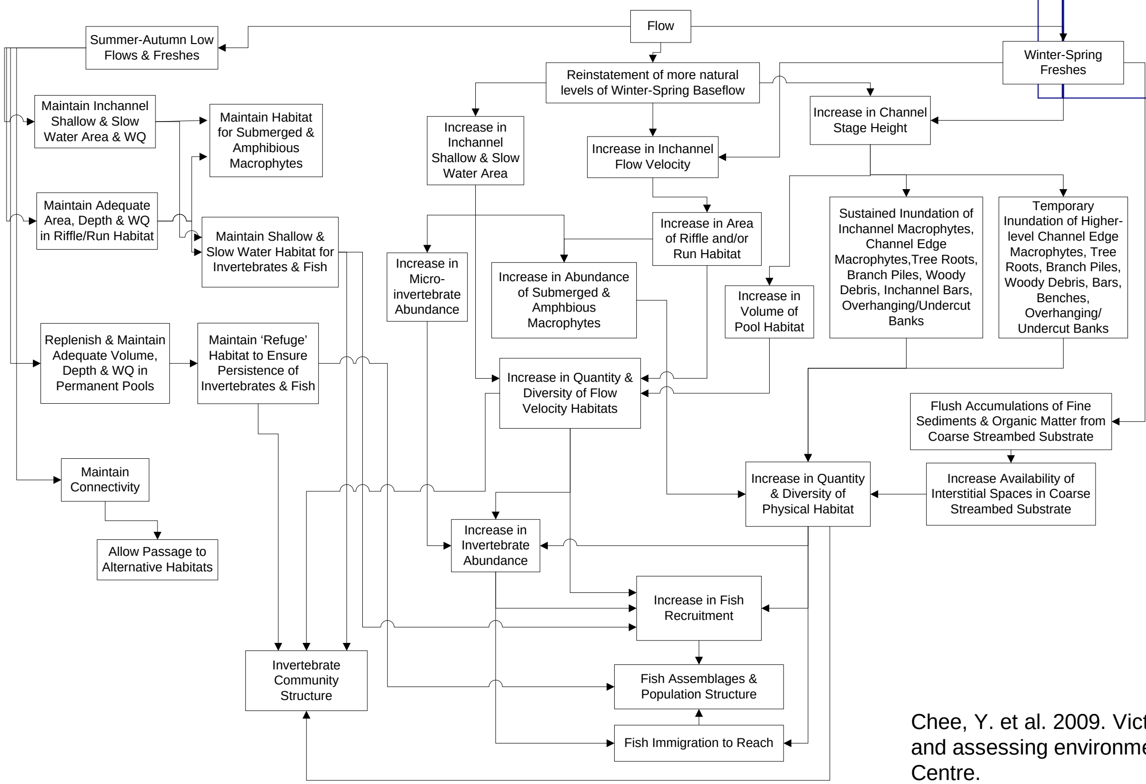
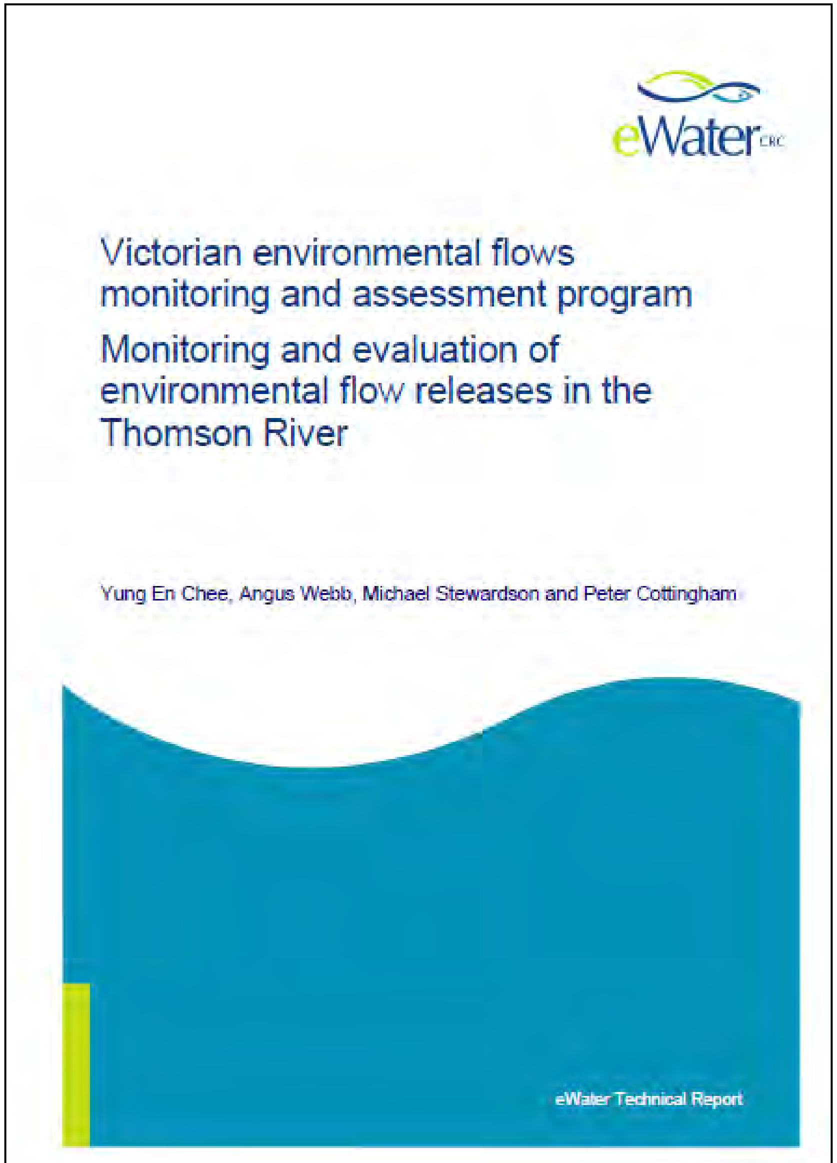


- Prioritise monitoring
- Select endpoints
- Inform analytical models

Chee, Y. et al. 2009. Victorian Environmental Flows Monitoring and Assessment Program: Monitoring and assessing environmental flow releases in the Thompson River. e-Water Cooperative Research Centre.

Stage 2a reports – first mistake



eWater CRC

Victorian environmental flows monitoring and assessment program

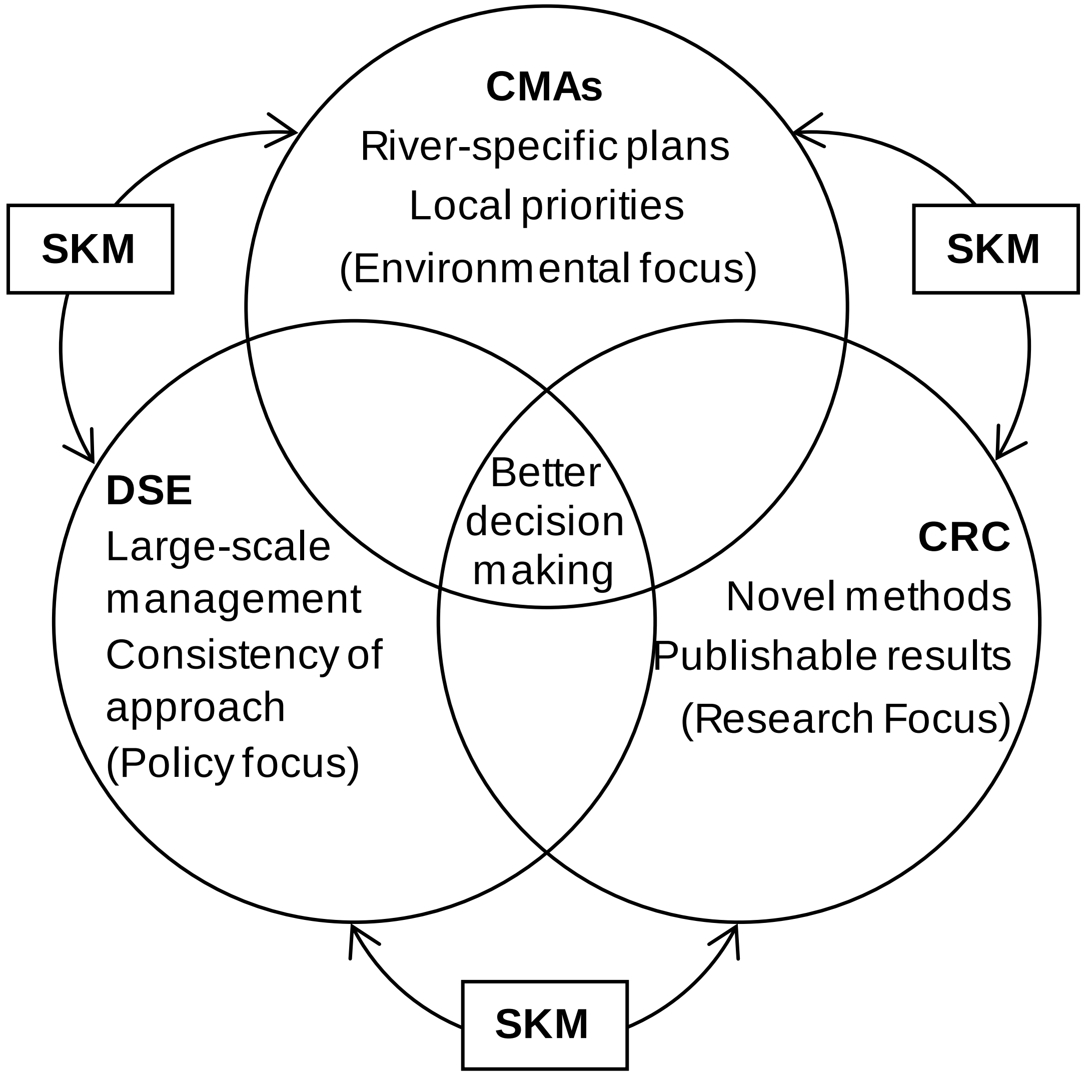
Monitoring and evaluation of environmental flow releases in the Thomson River

Yung En Chee, Angus Webb, Michael Stewardson and Peter Cottingham

eWater Technical Report

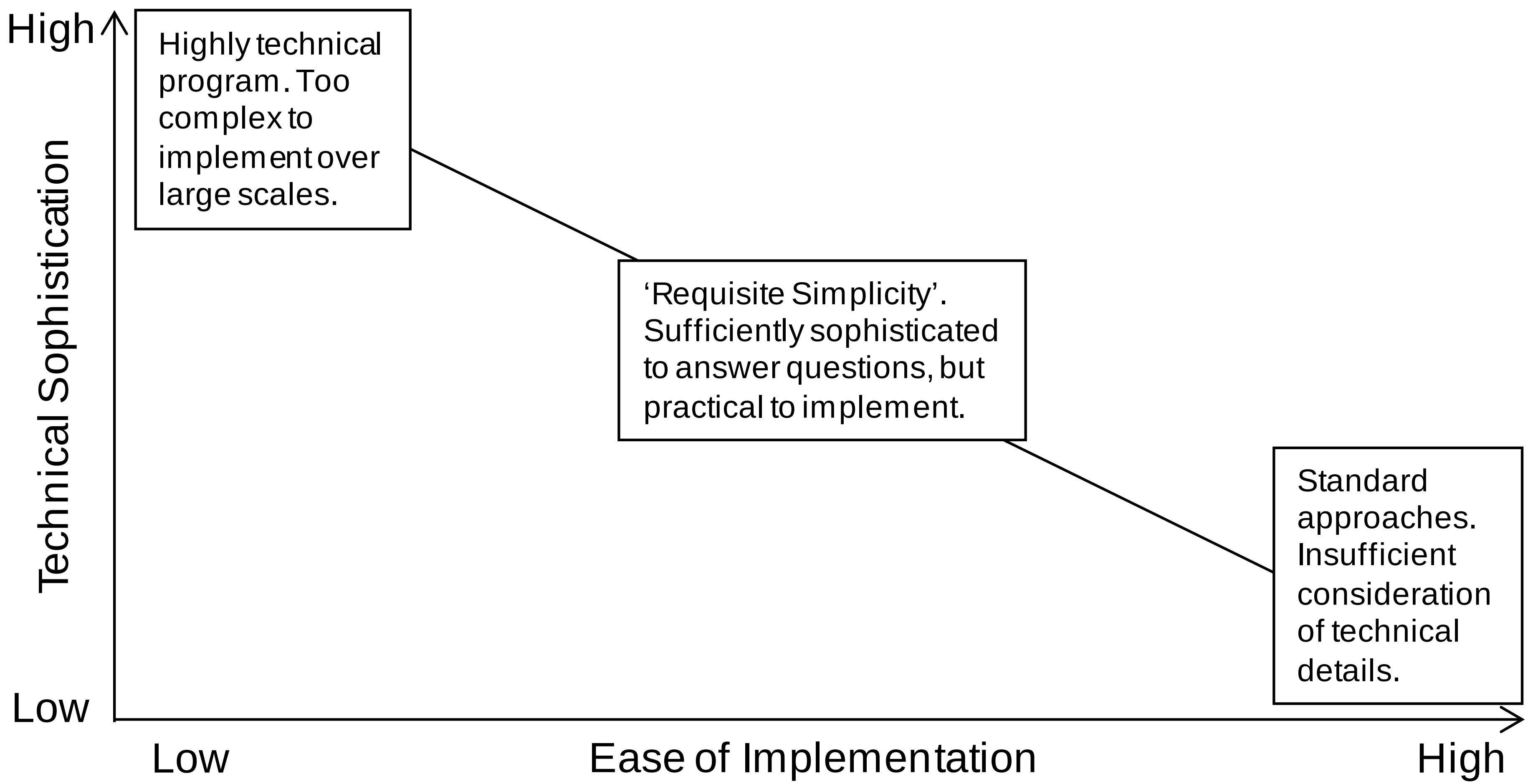
- Good conceptual models to underpin program design
- General advice on the types of monitoring techniques that should be used
- Could not actually be used to design a program on the ground

What's in it for me?



Webb et al. (2010) *Marine and Freshwater Research.*

Different priorities in monitoring



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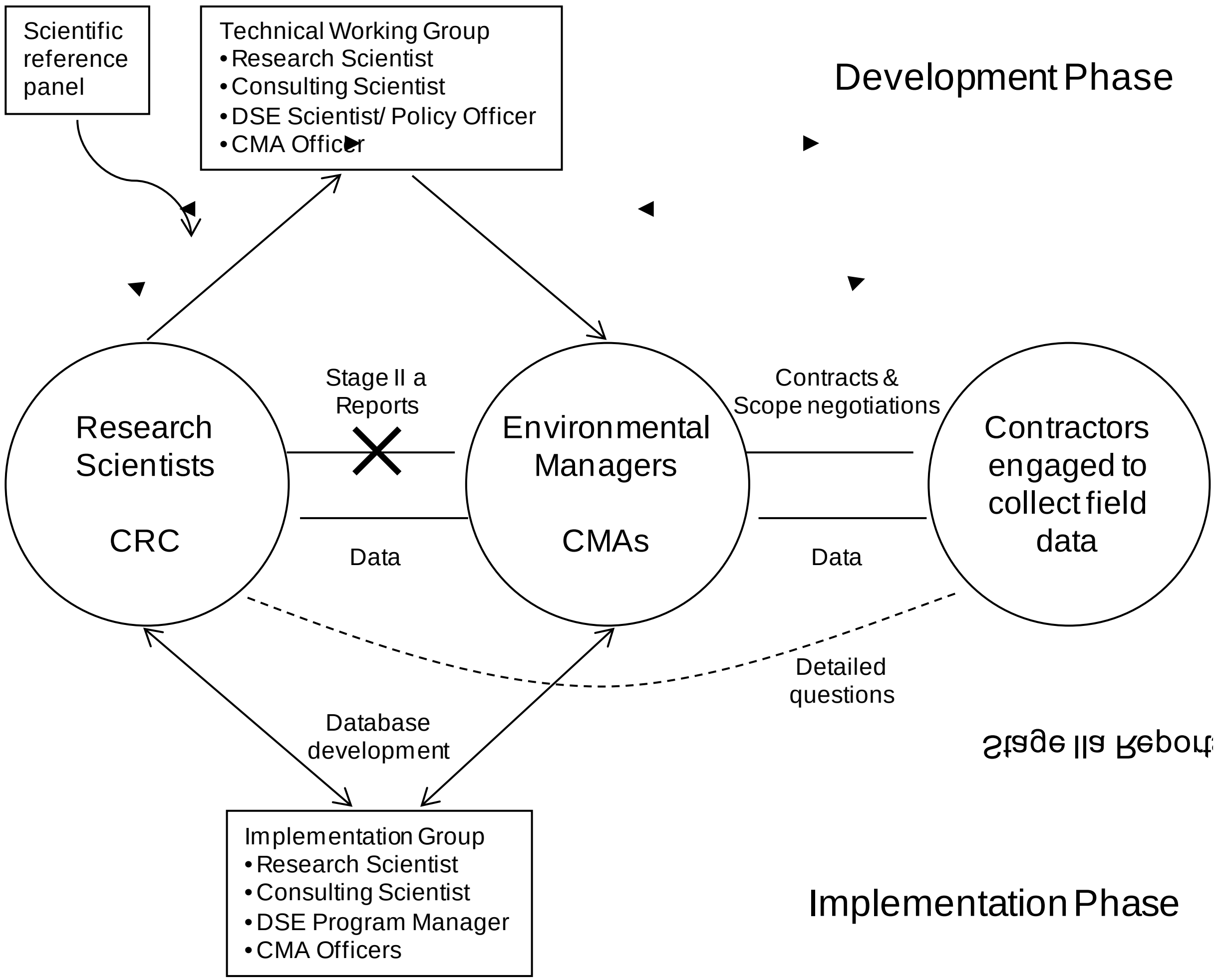
Collaborative framework

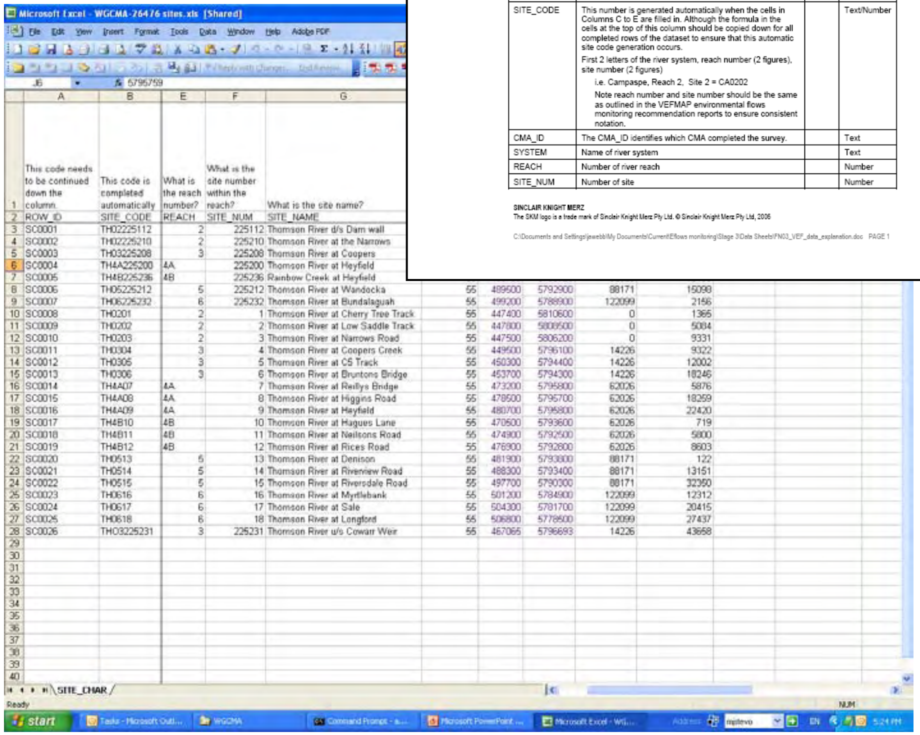


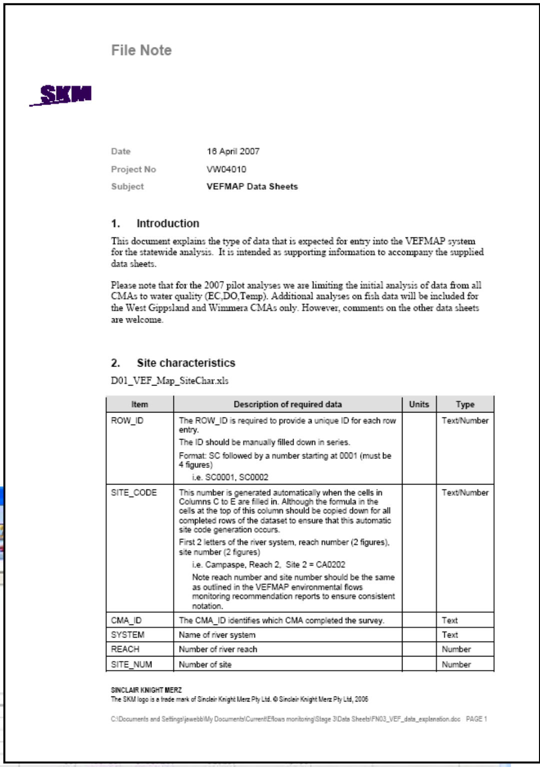
- Stage 2a design reports done by researchers
  - Stage 2b brought the parties together
  - Programs developed with input from all parties

Webb et al. (2010) *Marine and Freshwater Research.*

Implementation challenges

- Data format
  - Standardised data sheets
  - Central database
- Top-end failure
  - Easy to know what we want, harder to specify that to others
- Continuity of project team
  - EWR Officer turnover
- Contractor engagement
  - Cost overruns
  - Incorrect data collection
- Maintain communication





File Note

SKM

Date 16 April 2007
Project No VW04010
Subject **VEFMAP Data Sheets**

1. Introduction

This document explains the type of data that is expected for entry into the VEFMAP system for the statewide analysis. It is intended as supporting information to accompany the supplied data sheets.

Please note that for the 2007 pilot analyses we are limiting the initial analysis of data from all CMAs to water quality (EC,DO,Temp). Additional analyses on fish data will be included for the West Gippsland and Wimmera CMAs only. However, comments on the other data sheets are welcome.

2. Site characteristics

D01_VEF_Map_SiteChar.xls

Item	Description of required data	Units	Type
ROW_ID	The ROW_ID is required to provide a unique ID for each row entry. The ID should be manually filled down in series. Format: SC followed by a number starting at 0001 (must be 4 figures) i.e. SC0001, SC0002		Text/Number
SITE_CODE	This number is generated automatically when the cells in Columns C to E are filled in. Although the formula in the cells at the top of this column should be copied down for all completed rows of the dataset to ensure that this automatic site code generation occurs. First 2 letters of the river system, reach number (2 figures), site number (2 figures) i.e. Campaspe, Reach 2, Site 2 = CA0202 Note reach number and site number should be the same as outlined in the VEFMAP environmental flows monitoring recommendation reports to ensure consistent notation.		Text/Number
CMA_ID	The CMA_ID identifies which CMA completed the survey.		Text
SYSTEM	Name of river system		Text
REACH	Number of river reach		Number
SITE_NUM	Number of site		Number

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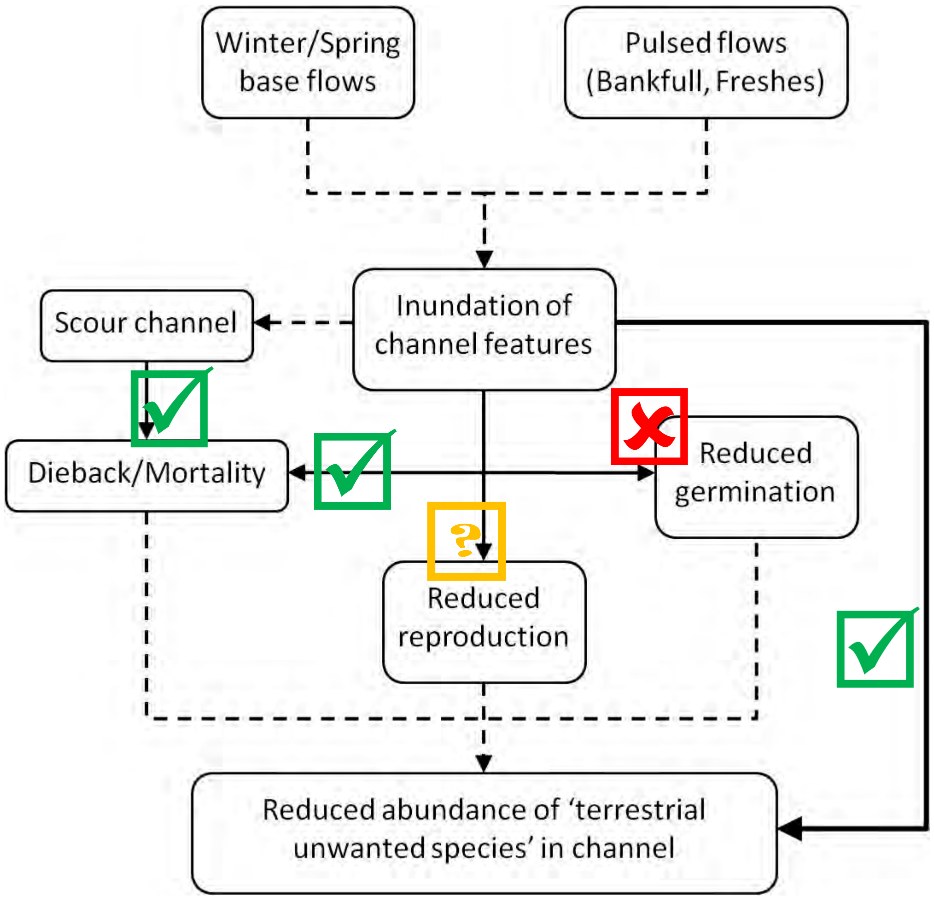
Priority for analysis: Removal of terrestrial vegetation from regulated river channels



- Priorities for analysis set by consulting with project partners
- Eco Evidence analysis of potential causal pathways

Miller et al. (in prep) *Restoration Ecology.*

Bayesian Statistics – Bayes' Formula

Likelihood function: driven by data

Prior Probability: Level of belief in the model before data collection

Posterior Probability: Probability of model, given the data

$$P(H|X) = \frac{P(X|H)P(H)}{P(X)}$$

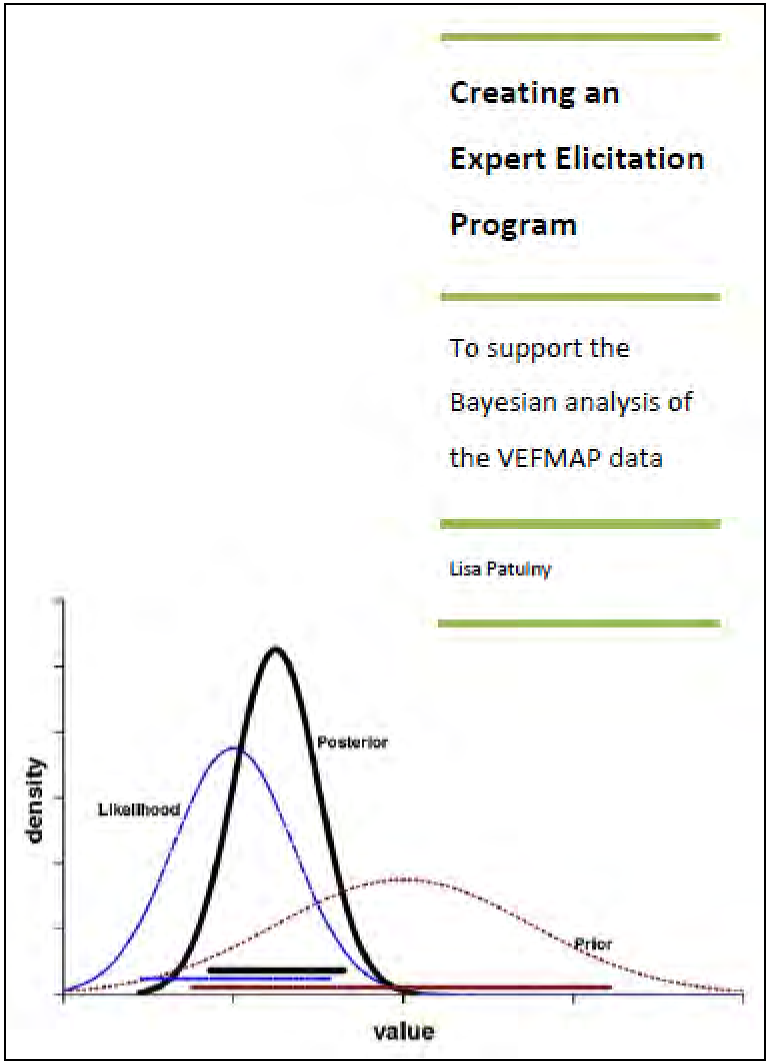
Expert elicitation for prior probabilities

Why use expert elicitation?

- uncertain data or not much data to accurately model complex system
- when hard data is lacking yet management decisions are required urgently

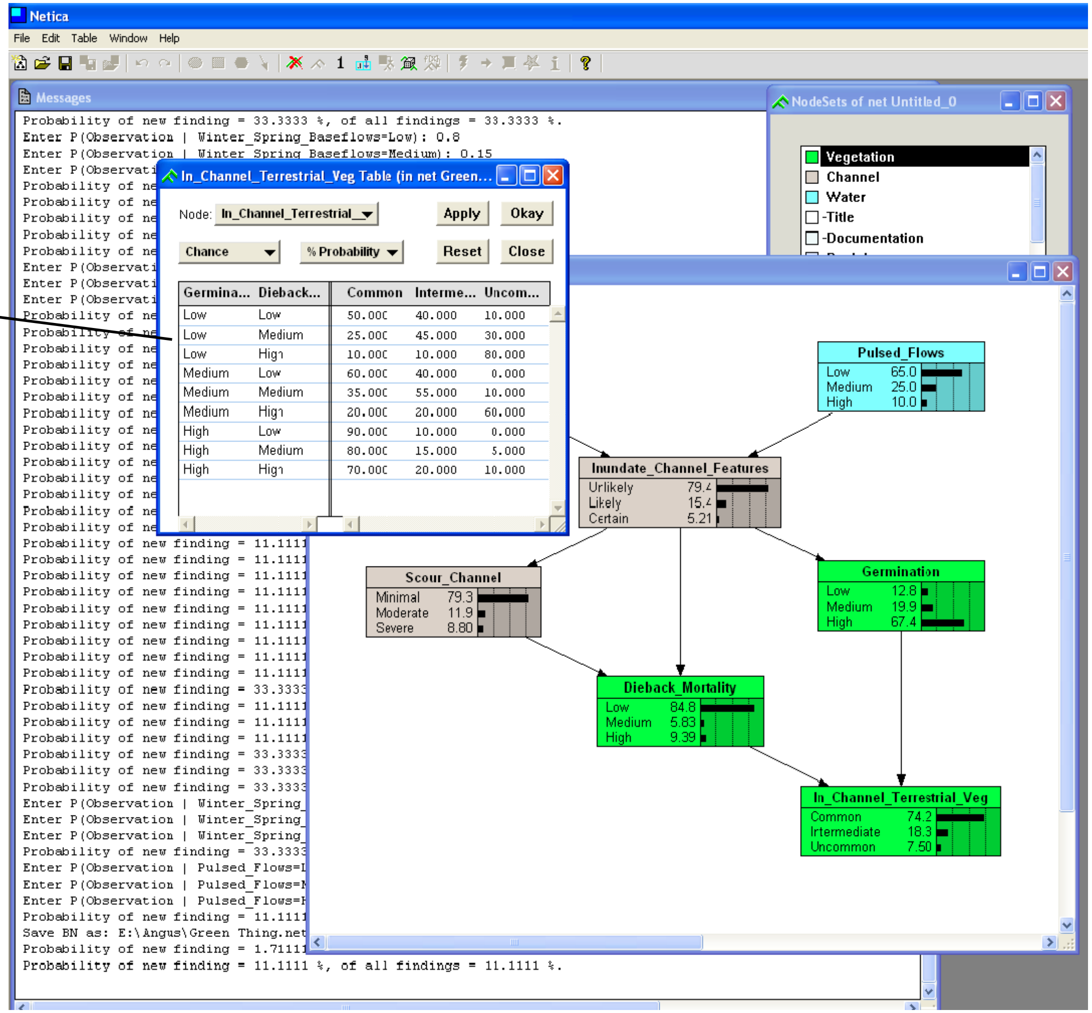
What questions would we ask:

"If we delivered this X flow, what is the probability that terrestrial vegetation cover in the channel will be 'high'?



Bayesian network model of expert elicitation results

Prior Probability Distribution

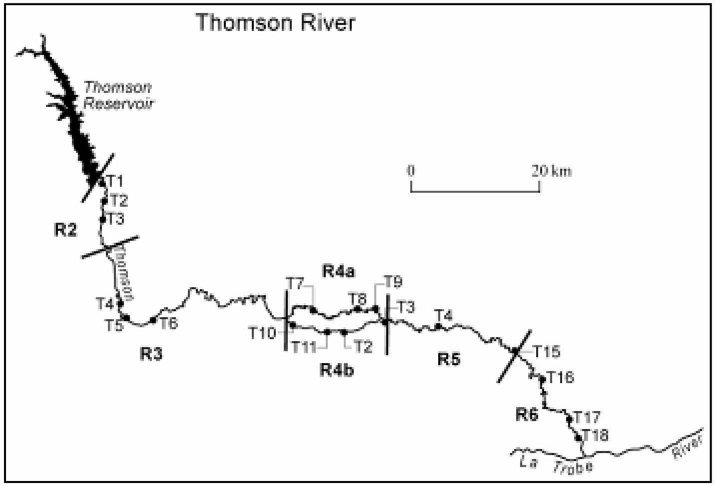


Why Bayesian Hierarchical Modelling?

- BACI methods generally not applicable
  - Shortage of Control and Reference Sites
  - eFlows do not have a Before/After boundary
- Data are messy
- Often sparse
- In general, don't conform to requirements of familiar analyses

- Bayesian Hierarchical Modelling (BHM)
  - More flexibility with models
  - Better ability to combine data in analyses, strengthening conclusions
  - Incorporate prior data to strengthen conclusions

Effects of flow regulation on Australian Smelt (*Retropinna semoni*) in the Thomson River



- Flow regulated for irrigation
- Smelt not considered to be overly sensitive to flow
  - But larvae / juveniles found in slow-flow habitats during summer
- Suspected sampling artefacts

Discharge / turbidity affects sampling efficiency →

$$Abund = Adj + \delta Tu + \gamma dQ$$

Response expected at reach scale →

$$Adj \sim N\left(Ravg, Rsd\right)$$

Abundance restricted by excess summer flow via loss of slow-flow areas →

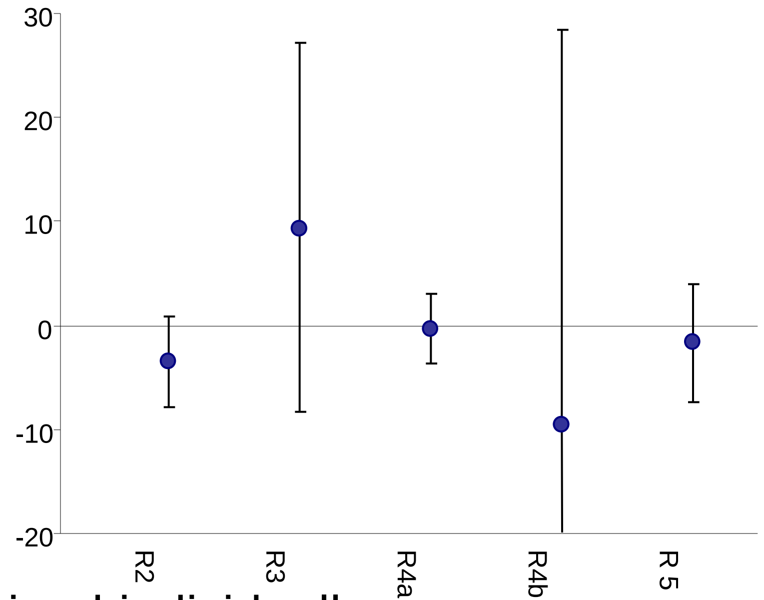
$$Ravg = \alpha + \beta \frac{\overline{Q}}{Q_R}$$

Webb et al. (2010) *Freshwater Biology.*

- 44 site-level estimates (5 reaches, 3 years)
- Effect of excess summer flows on smelt abundance

Reach	Location	Reach p ($\beta < 0$)
2	Thomson Dam - Aberfeldy R.	**0.05**
3	Aberfeldy R. - Cowwarr Weir	0.86
4a	Old Thomson River	0.42
4b	Rainbow Creek	0.30
5	Rainbow Creek - Macalister R.	0.28

Webb et al. (2010) *Freshwater Biology.*



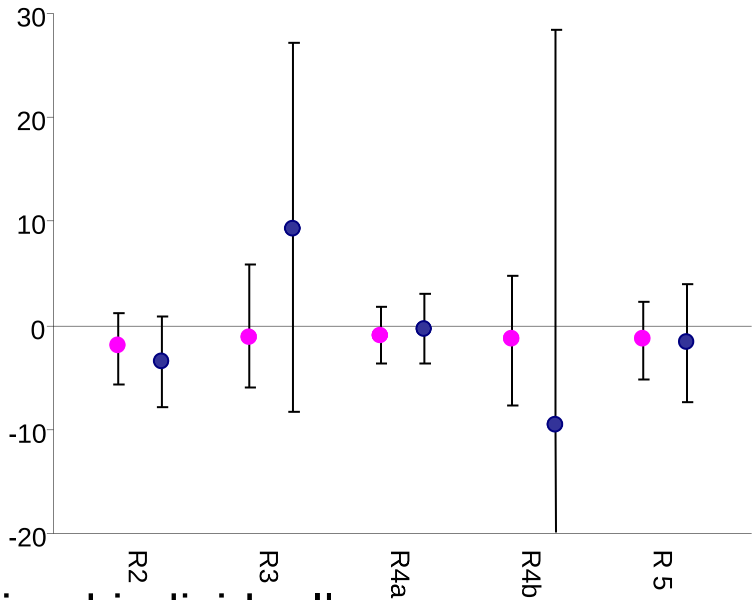
- Results inconclusive when reaches examined individually

- 44 site-level estimates (5 reaches, 3 years)
- Effect of excess summer flows on smelt abundance

More hierarchical →

Reach	Location	Reach p (β < 0)	River p (β < 0)
2	Thomson Dam - Aberfeldy R.	**0.05**	**0.11**
3	Aberfeldy R. - Cowwarr Weir	0.86	0.30
4a	Old Thomson River	0.42	0.25
4b	Rainbow Creek	0.30	0.26
5	Rainbow Creek - Macalister R.	0.28	0.21

Webb et al. (2010) *Freshwater Biology.*



- Results inconclusive when reaches examined individually
- Considerable effects of a hierarchical treatment
  - Shrinkage of means towards a grand mean
  - Borrowing strength to reduce standard deviations around reach means
- Some evidence of river-scale effects

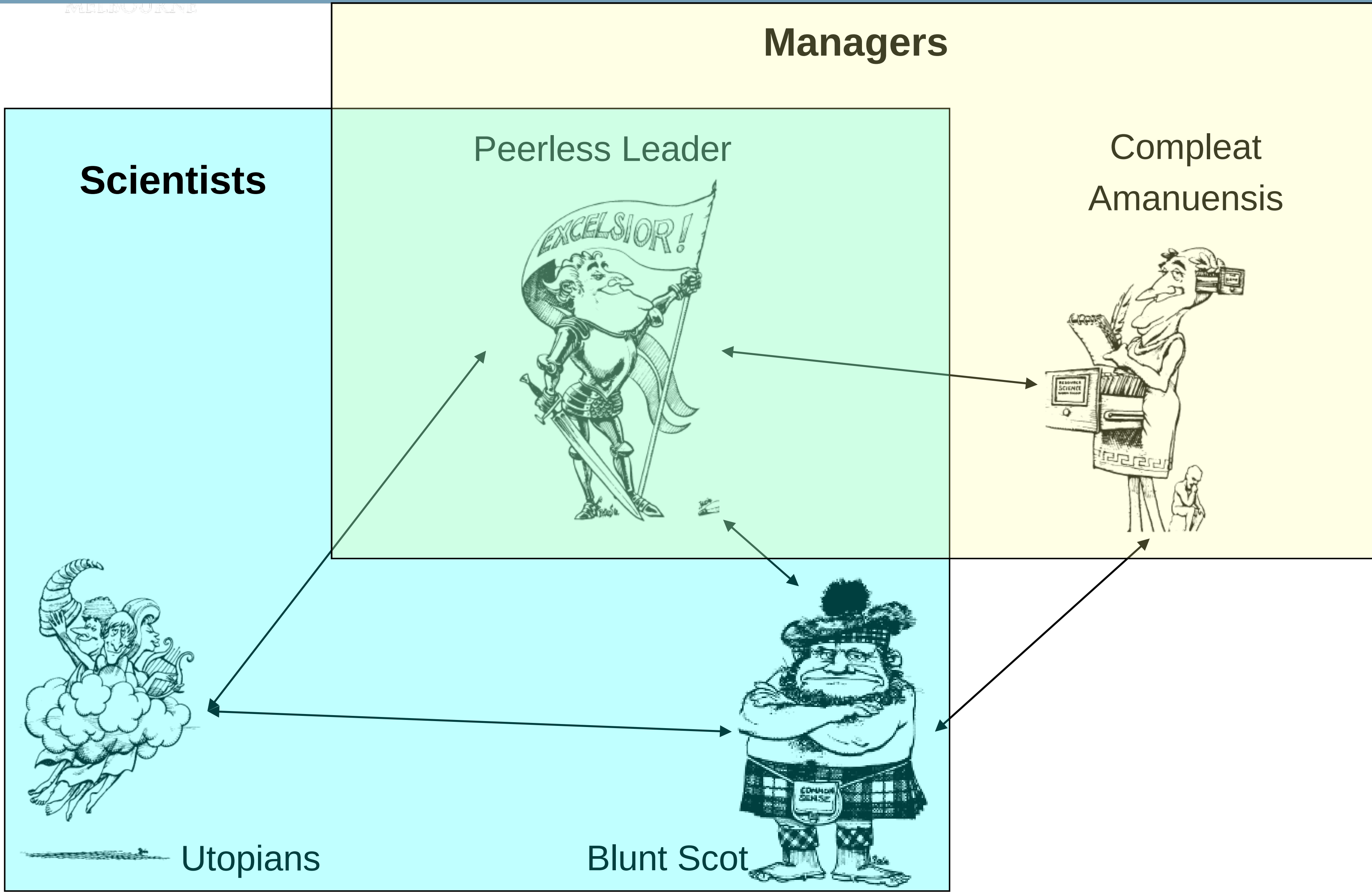
Conclusions

- Research benefits
  - Giant research project
    - Huge ‘field budget’
  - Wide spatial and temporal scales
    - General conclusions
  - ARC funding
  - Adaptive Management

- Management benefits
  - Accountability of eflows
  - Quality of program
  - Heavily scruitinized

- Partnership is vital for effective monitoring and assessment of eflows
  - Innovative Science
    - Evidence-based models
    - Bayesian analysis
  - Network of willing partners
    - Recognition of trade offs
    - Roles and individuals are important

Individuals and roles



Images and titles nicked from Holling and Chambers (1973) *Bioscience.*

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