Monitoring and Assessing the effects of Environmental Flows: the VEFMAP approach

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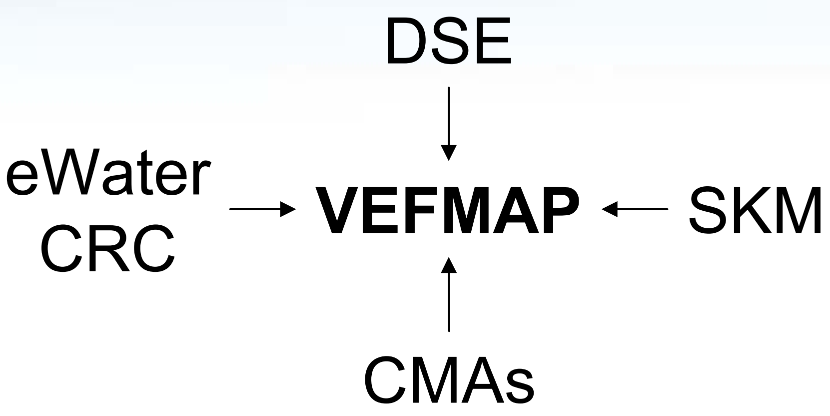
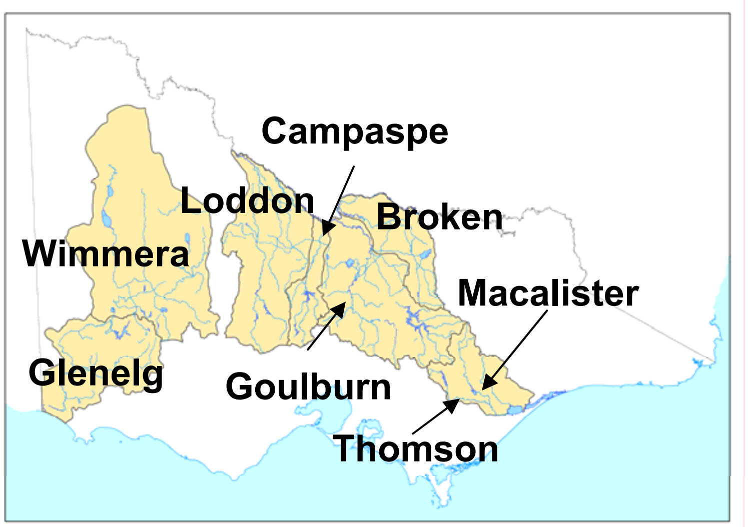
Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP)

- 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





The Approach

- Development of compatible monitoring programs across the state
  - Hypothesis based (conceptual models)
  - Prioritise monitoring effort based on
    - Conceptual understanding
    - Expected ability to detect a response

- Statewide analyses using Bayesian hierarchical models, and where possible combining data from different rivers

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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 frequentist analyses

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

- This has caused some unease
  - Trialling framework in 2007

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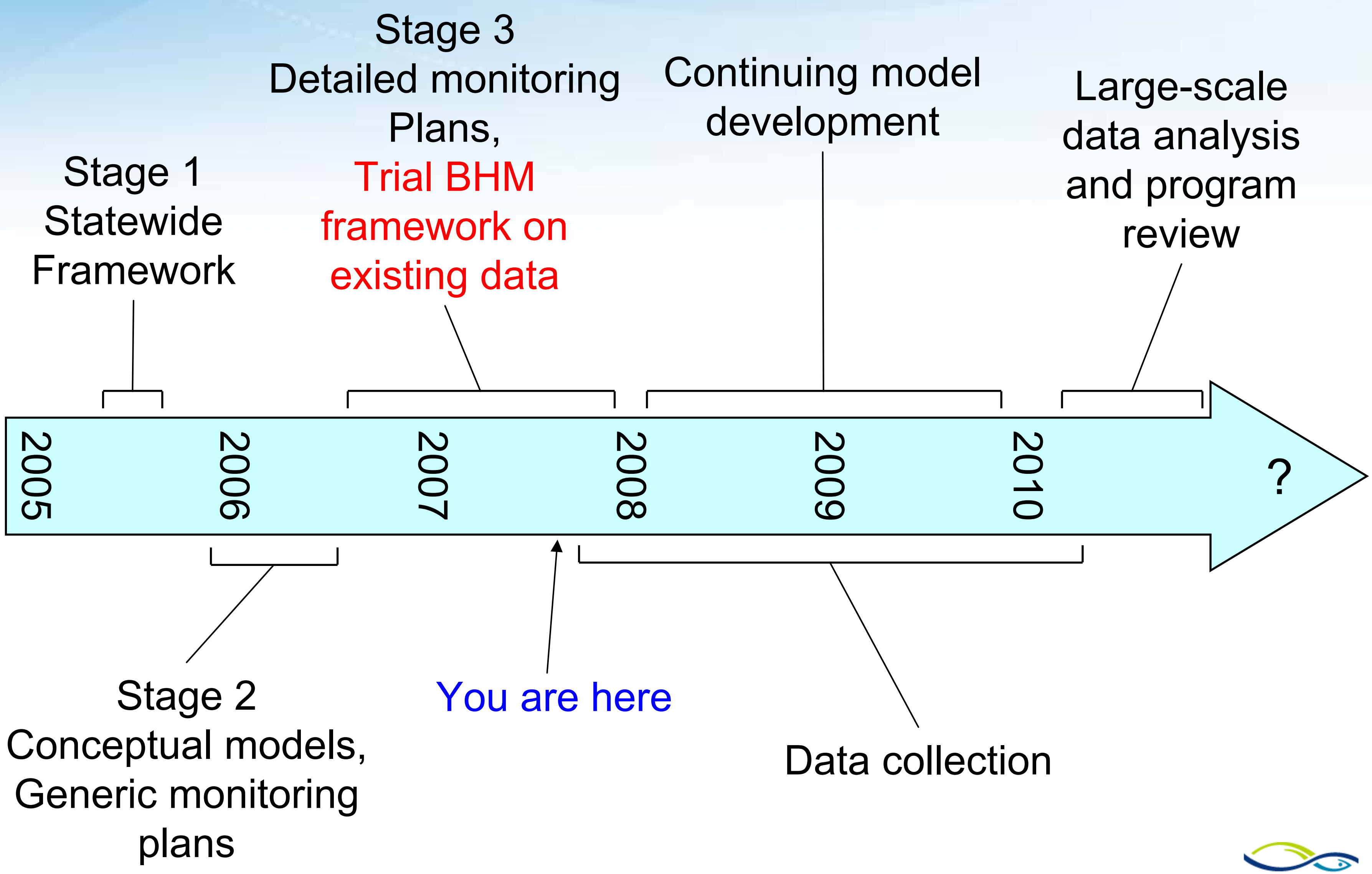
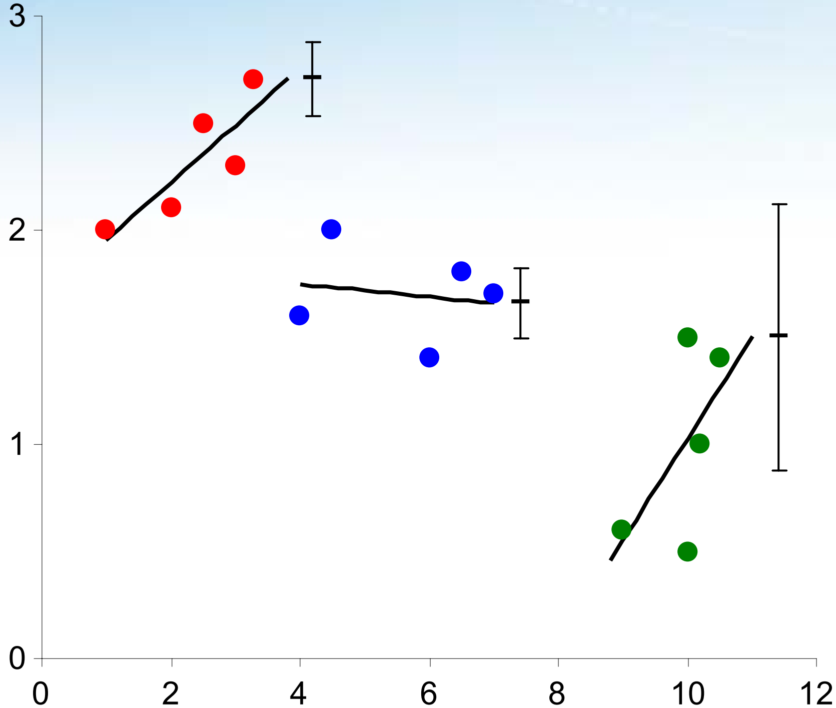
Implementation



Why BHM?



Site 1: β = 0.27 ± 0.17
Site 2: β = -0.03 ± 0.17
Site 3: β = 0.48 ± 0.62

- Interested in regression slope (β) at the site level, which should be similar
  - But few data and much unexplained variability at each site
  - Site-level estimates vary widely and can be very uncertain

Bayesian Statistics – Bayes' Formula

Likelihood function: driven by data

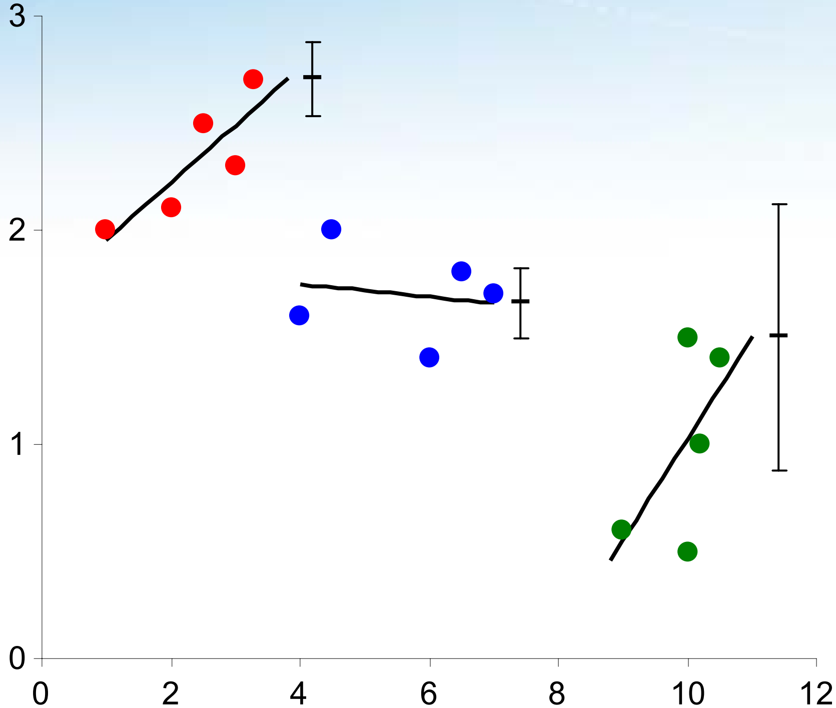
Prior Probability: Level of belief in the model before data collection

Posterior Probability: Probability of model, given the data

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

Total probability of the data occurring

Non-informative prior distribution



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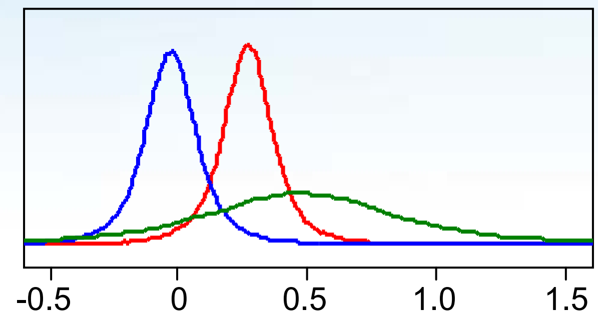
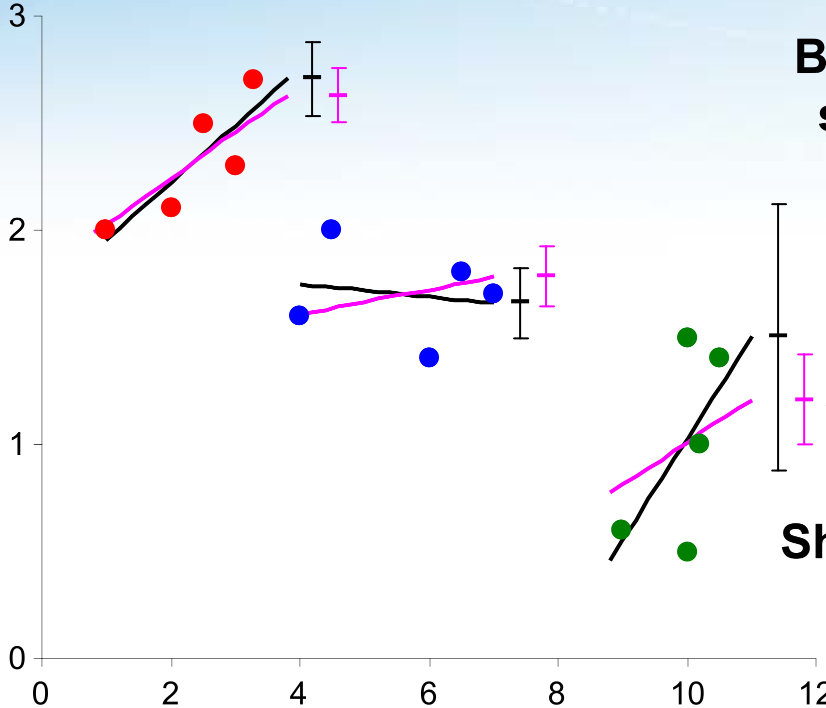
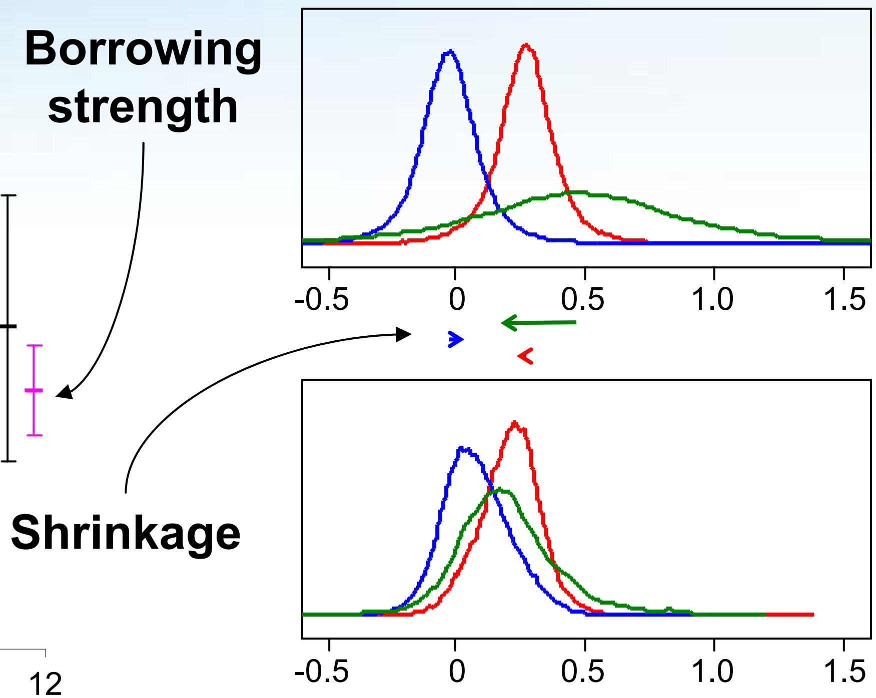


Non-informative prior distribution vs. hierarchical priors





Site 1: β = 0.27 ± 0.17 ⟶ 0.21 ± 0.12

Site 2: β = -0.03 ± 0.17 ⟶ 0.08 ± 0.14

Site 3: β = 0.48 ± 0.62 ⟶ 0.20 ± 0.21

No prior data used, just the expectation that the sites are related

- Sites with less data / greater uncertainty more affected
- Results for data-rich sites will be practically unaffected

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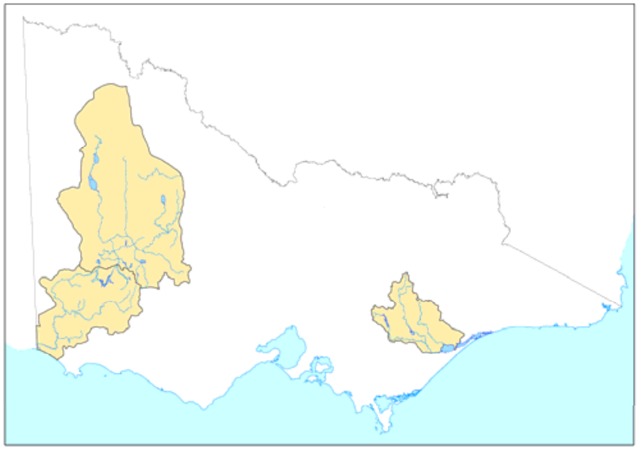
Testing the analytical framework

- Need to demonstrate efficacy of BHM before large scale analysis of data in 2010
  - Possible analyses driven by data availability
  - Not answering eflows questions of primary interest
- Models applied to existing data
  - Salinity (EC) in Glenelg and Wimmera rivers
  - Fish (Australian Smelt) in the Thomson River



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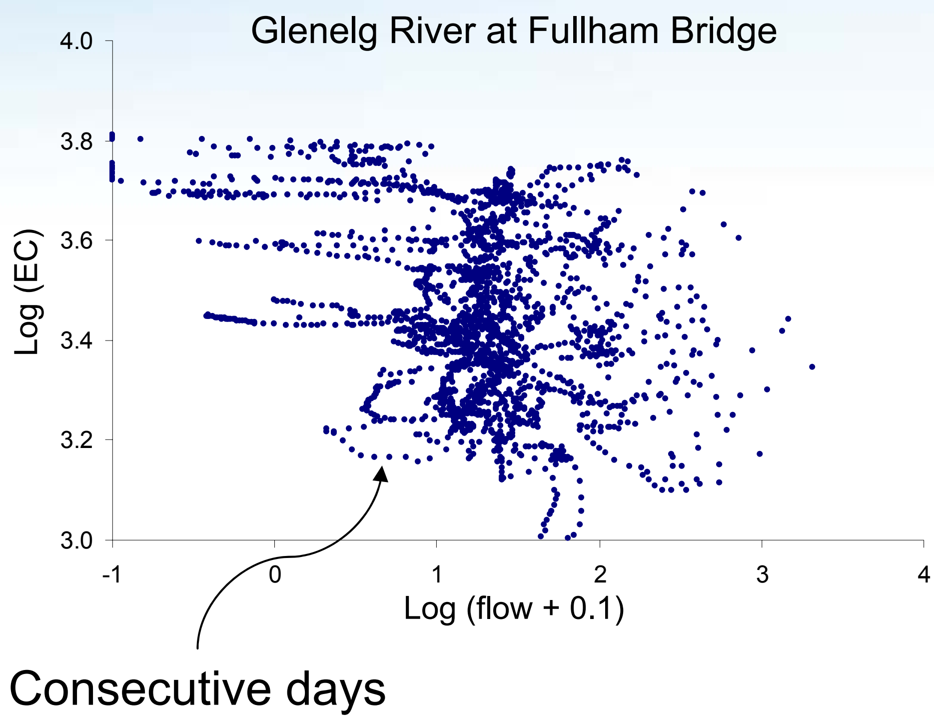
Effect of Flow on Salinity

- What is the relationship between flow and EC?
  - Pretty poor!
- Lots of data, but highly autocorrelated
  - Model needs to take advantage of this



salinity = previous salinity + flow effects + non-flow effects

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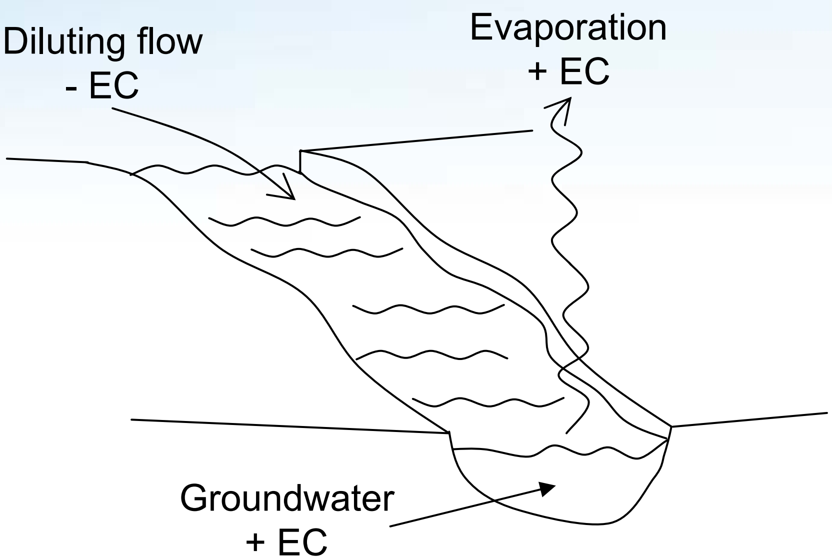
Conceptual model → statistical model

- Hypothesise
  - 'Background' rate of salinity increase
  - Rate of salinity decrease proportional to flow
    - Scale according to summer low flow recommendation, which often aim to 'maintain' or 'improve' water quality



$$EC_i = EC_{i-1} - k_1 \frac{Q_i}{Q_R} + k_2$$

- Parameter of main interest
  - $p(k_1 > 0)$ "flow reduces EC"

Implementation and Results

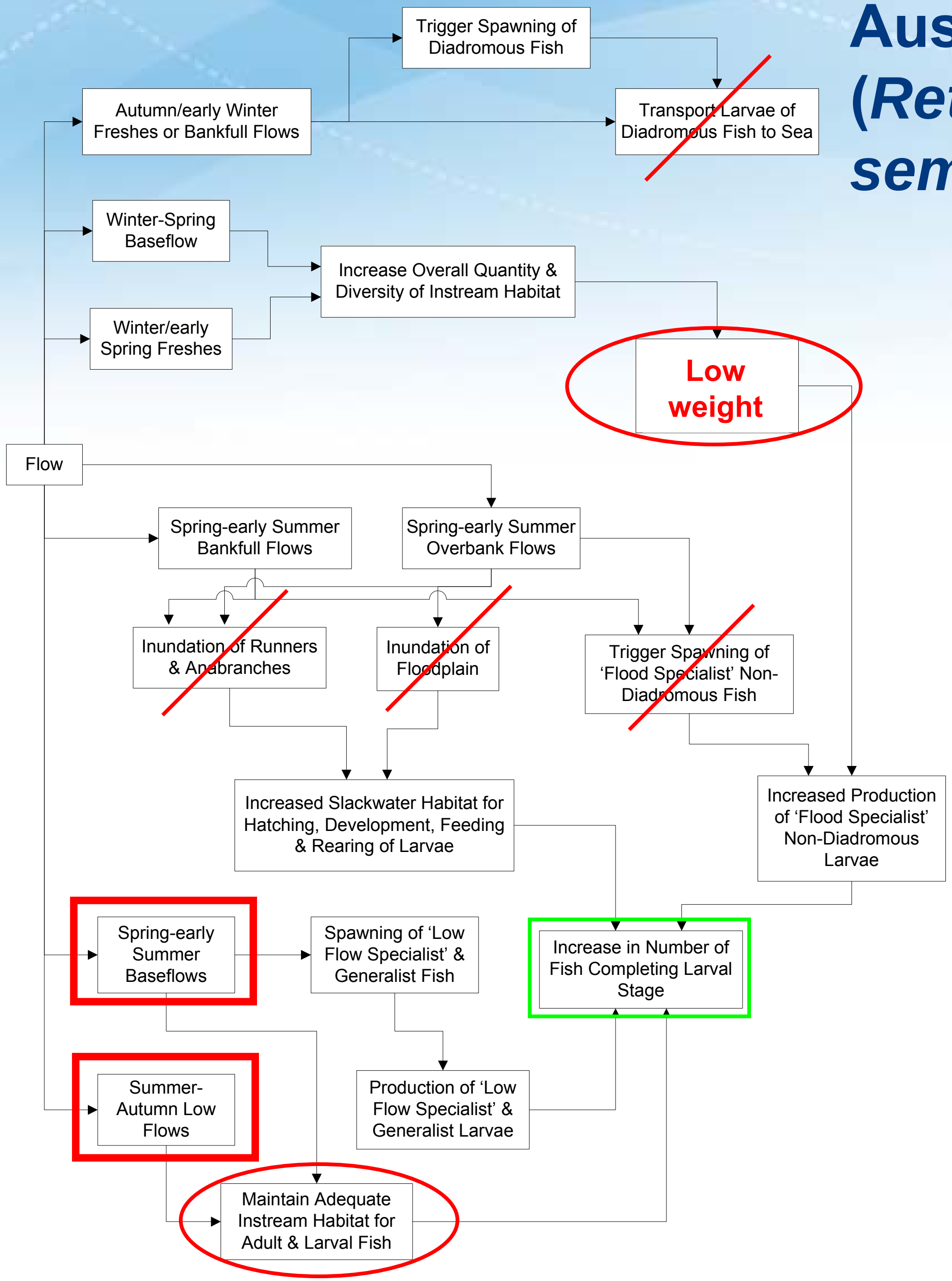
- 8938 ‘summer’ EC measures, 10 sites, 2 rivers
- Modelled at site, river and multi-river hierarchies

More hierarchical →

River	Site Name	Sites $p(k_1 > 0)$	Sites(Rivers) $p(k_1 > 0)$	Sites(Rivers(State)) $p(k_1 > 0)$
Glenelg	Fulham Bridge	**1.00**	**1.00**	**1.00**
	Harrow	**0.82**	**0.82**	**0.82**
	Burkes Bridge	**0.99**	**0.98**	**0.98**
	Dergholm	0.67	0.64	0.64
	Sandford	0.58	0.57	0.57
	Dartmoor	**0.00**	**0.00**	**0.00**
Wimmera	Walmer	**0.10**	**0.10**	**0.11**
	U/S Dimboola	**0.20**	0.24	0.24
	Lochiel Railway Br.	**1.00**	**1.00**	**1.00**
	Tarranyurk	**1.00**	**1.00**	**1.00**

- Sensible results for Glenelg (except Dartmoor)
- Wimmera results harder to interpret
- Possibility of model inadequacies (e.g. saline fronts increasing EC)

Australian Smelt (*Retropinna semoni*)



- Non-diadromous
- Non 'flood-specialist'
- Little floodplain, runner or anabranch habitat in the Thomson
- Pre-spawning condition of adults probably has little effect

- Concentrate on summer low flows and the slow-flow habitat for young fish

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Characterising flow for habitat

- VEFMAP monitoring will measure slow flow habitat
  - But we don't have that yet
- Summer flows in the Thomson generally exceed recommendations
  - Highest: Reach 4a (2005-2006)
    - 149 ML d^{-1} (Q_R = 20 ML d^{-1})
- May expect this to negatively affect fish that need slow flow habitat for larvae and juveniles
- Characterise summer flow in terms of average proportion of recommendation

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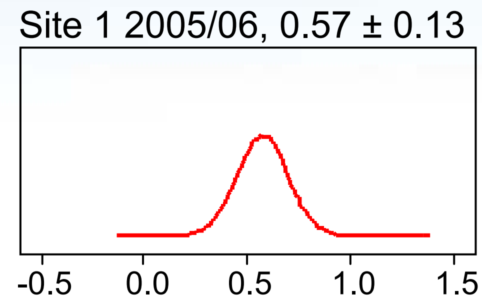
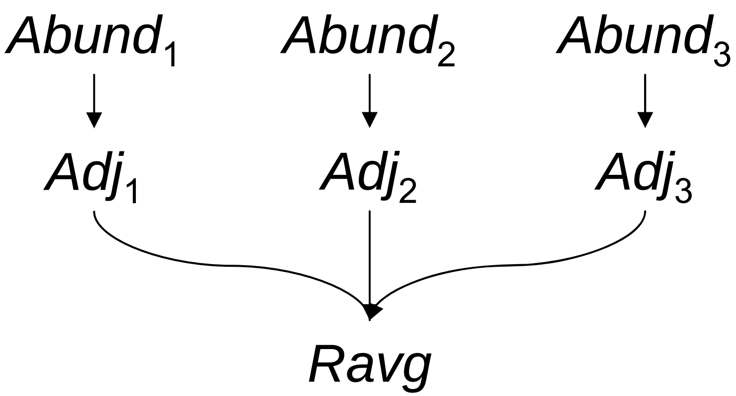
Analysis

- Worries over fish data
  - Turbidity and flow on day of sampling reduce sampling efficiency
    - Include these effects in the model as covariates
    - Leads to uncertain 'data'



- Analyses conducted at reach scale
  - Flow data availability
  - Fish expected to respond at this scale
- Parameters of main interest
  - β at reach level
  - $p(\beta < 0)$ – negative effect of high flow



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

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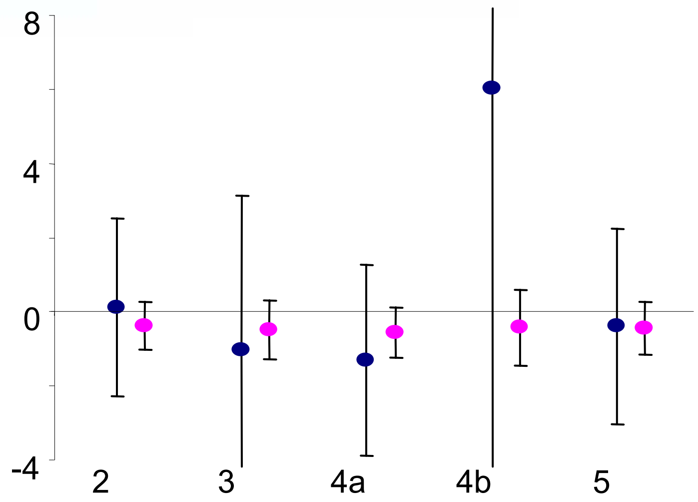
Implementation and Results

- 44 site-level estimates (5 reaches, 3 years)
- Modelled at reach and river levels

More hierarchical →

Reach	Location	Reach $p\ (\beta < 0)$	River $p\ (\beta < 0)$
2	Thomson Dam - Aberfeldy R.	0.44	0.73
3	Aberfeldy R. - Cowwarr Weir	0.67	0.77
4a	Old Thomson River	**0.88**	**0.82**
4b	Rainbow Creek	0.21	0.74
5	Rainbow Creek - Macalister R.	0.60	0.76



- Largest effect in most flow-affected reach (4a)
- Weak positive effect in reach 4b (where $Q < Q_R$)
  - HM obscures this effect – model inadequacy (we should regress against habitat rather than flow
- HM shows weak evidence of river-scale effects of high summer flows on abundance of Australian Smelt.

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Synthesis

- Bayesian framework allows analyses not possible with frequentist techniques
  - Autocorrelation model for EC
  - Within analysis adjustment for Tu and dFlow for Smelt
- Different effects of hierarchical modelling
  - Driven by data availability
  - Very helpful for data-poor analyses
- Results highlight possible inadequacies in model structure
  - Continue development
  - But a very promising start

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Where to now?

- Publish
- Complete implementation of monitoring programs
- Pray for rain
- Undertake further development work on model structures during 2008-09
- Major analysis of data 2010
- Review of program
  - Implementing changes based on lessons learned
    - Flow recommendations
    - Monitoring programs

Conclusions

- VEFMAP’s cooperative approach is helping to establish compatible monitoring programs

- Bayesian Hierarchical Modelling shows promise in identifying the effects of flow on ecosystem response

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