"3D" Analysis of Uncertainty in Groundwater Sustainable Yield – Deconstructing, Describing and Dealing

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Uncertainty in Sustainable Yield Estimates

- Why bother about uncertainty?
- *Deconstructing* uncertainty
- *Describing* uncertainty
- *Dealing* with uncertainty

Why bother about uncertainty in Sustainable Yields?

- For assessing risk that water availability will change
- Part of the National Water Initiative

"Clear identification and assignment of risks between governments and water users over possible future reductions in water availability"

(COAG, 2003)

Assigning risk of reduced or less reliable water allocation

Water Users

bear risks associated with natural events (climate change, drought, bush fires)

Government

bear risks of change to entitlements not previously provided for and arising from policy changes (such as new environmental objectives)

Water Users + Government

After 2014, share risks associated with bona fide improvements in knowledge about water system’s capacity to sustain extraction levels. Before 2014, users bear the risk.

Also opportunity for voluntary development of risk sharing formula

Intergovernmental Agreement on National Water Initiative

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Deconstructing Uncertainties in Sustainable Yield

Community Values

Conceptual Understanding

Quantification

1. Uncertainty in Community Values

Sustainable Yield is...

> "The groundwater extraction regime, measured over a specific planning timeframe that allows acceptable levels of stress and protects dependent economic, social and environmental values"
>
> *NGC, 2003*

...a social construct

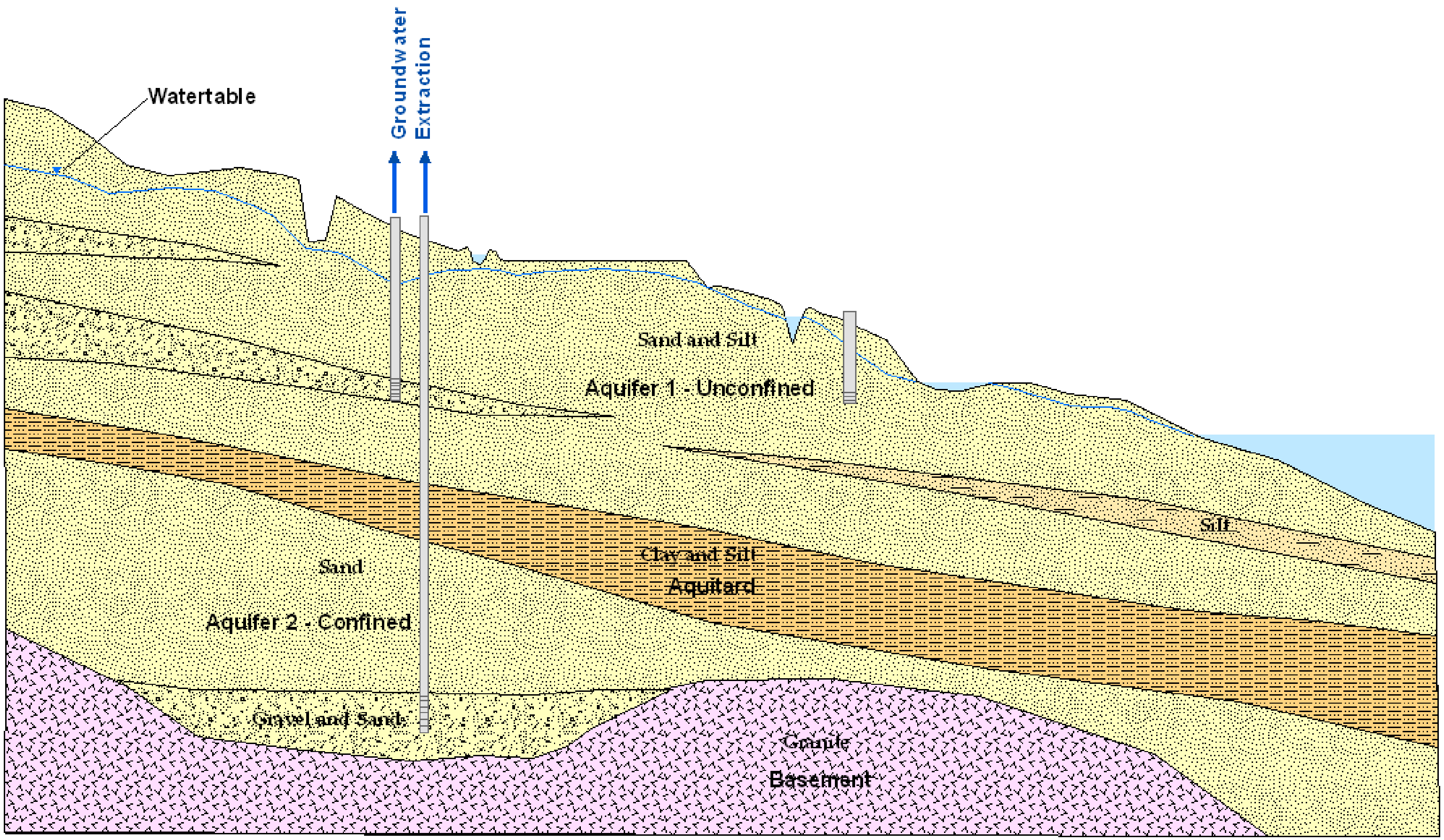
Q1: What are the impacts of groundwater pumping?

Land subsidence in California
www.uwsp.edu

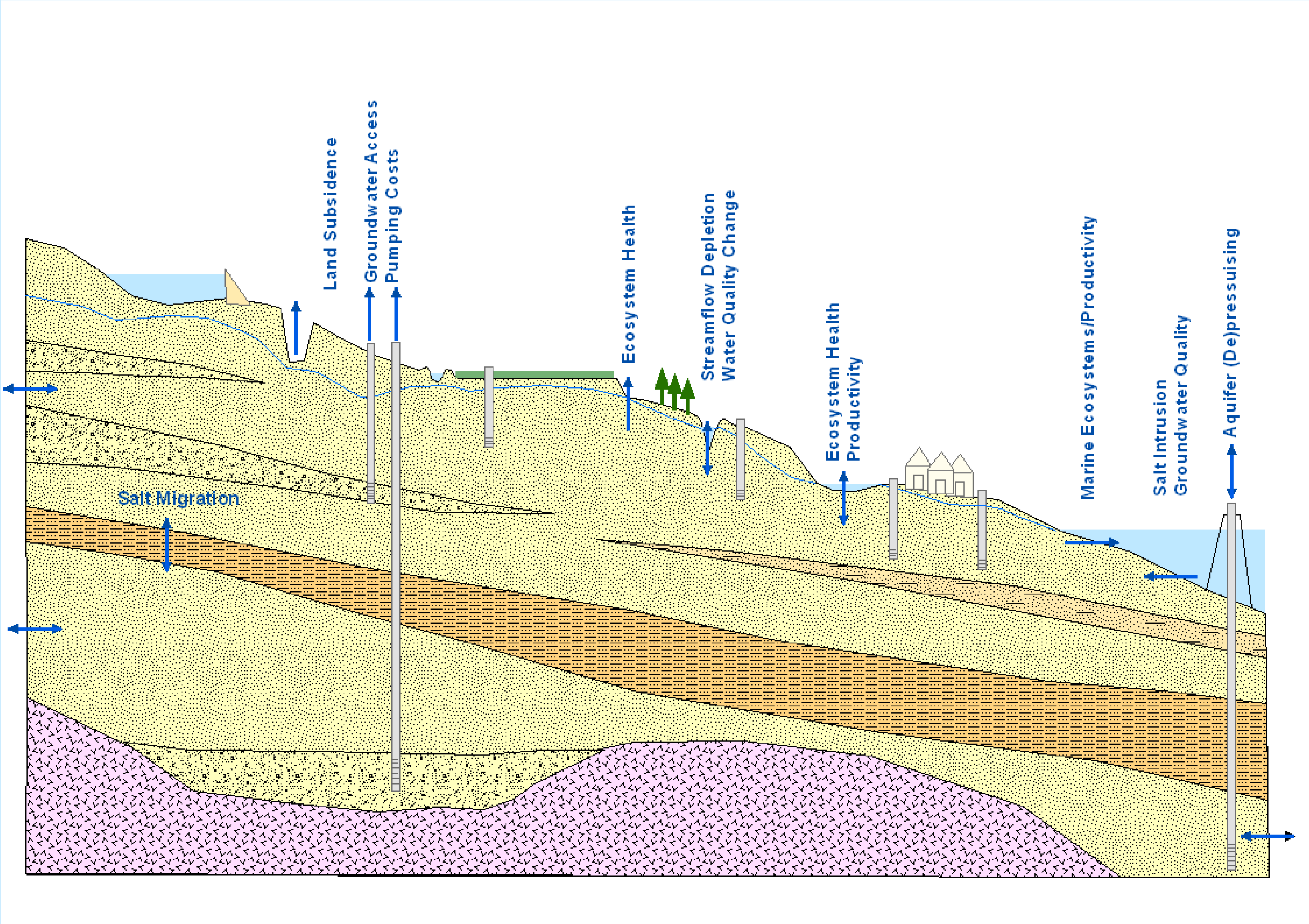
- Multi-faceted
  - Many consequences of reduced groundwater levels/pressure
- Spatial context
  - Function of bore distribution and density
- Time context
  - Lags between pumping and impacts

Groundwater management is all about managing impacts

Example Aquifer



Impacts of groundwater extraction

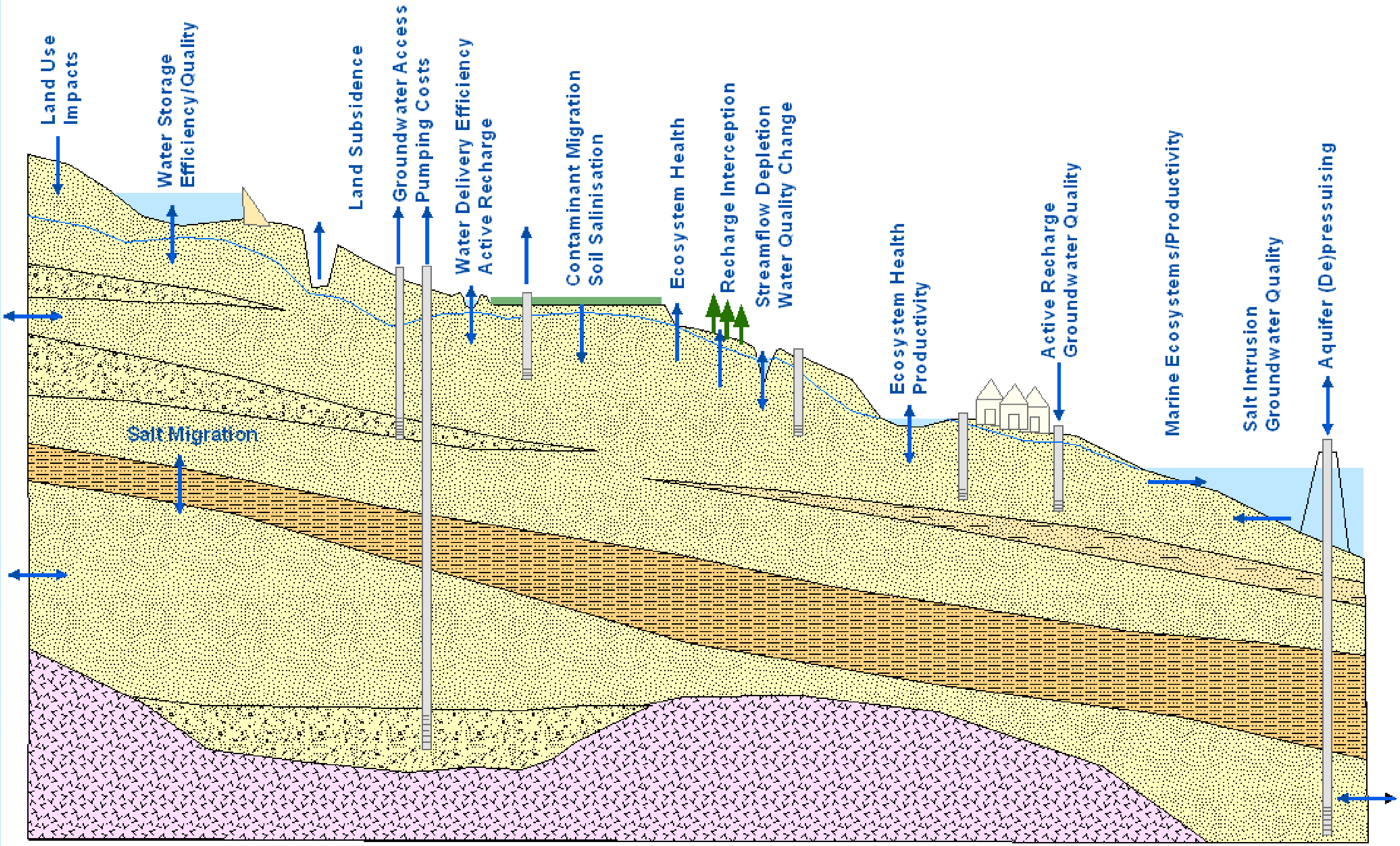


Q2: Are these impacts acceptable?

- Strategic importance of dependent economic, social and environmental values
- Tradeoffs between impacts are inevitable
- Nature of impacts – timing, dynamics, reversibility, thresholds
- Availability of alternative water supplies
- (Future) technological solutions and intergenerational equity

Blanche Cup mound spring, GAB
www.gabcc.org.au

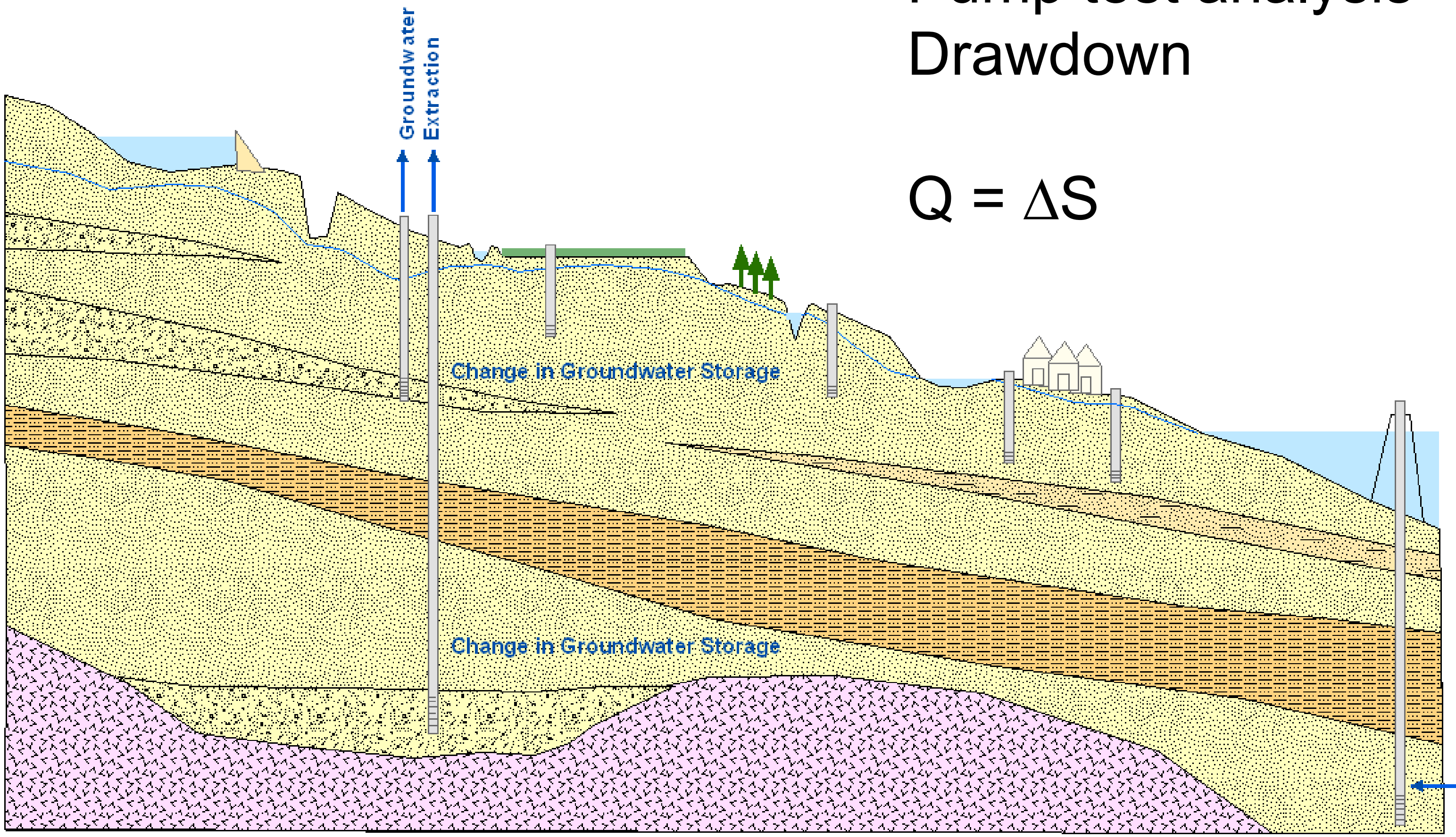
Impacts of groundwater extraction
+
Impacts on the groundwater resource



2. Uncertainty in Conceptualisation

- Evolution in general conceptual basis of groundwater management
- Evolution of conceptual models at the aquifer level

The Aquifer Hydraulics Paradigm



Aquifer Yield Focus
Pump test analysis
Drawdown

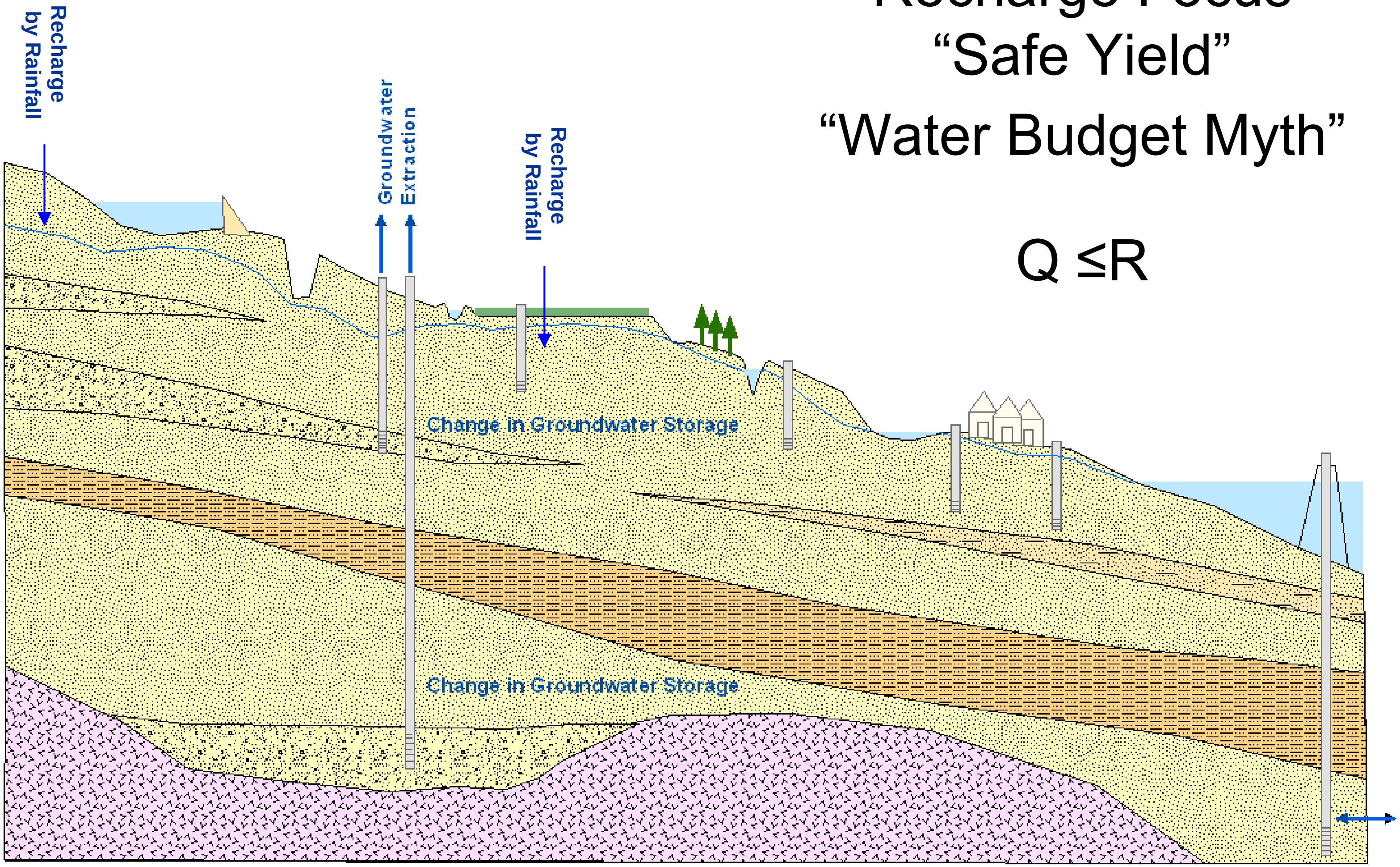
$Q = \Delta S$

"The amount of water extracted was based on the hydraulic characteristics of the aquifer itself" (Maimone, 2004)

The Recharge Paradigm

Recharge Focus
"Safe Yield"
"Water Budget Myth"

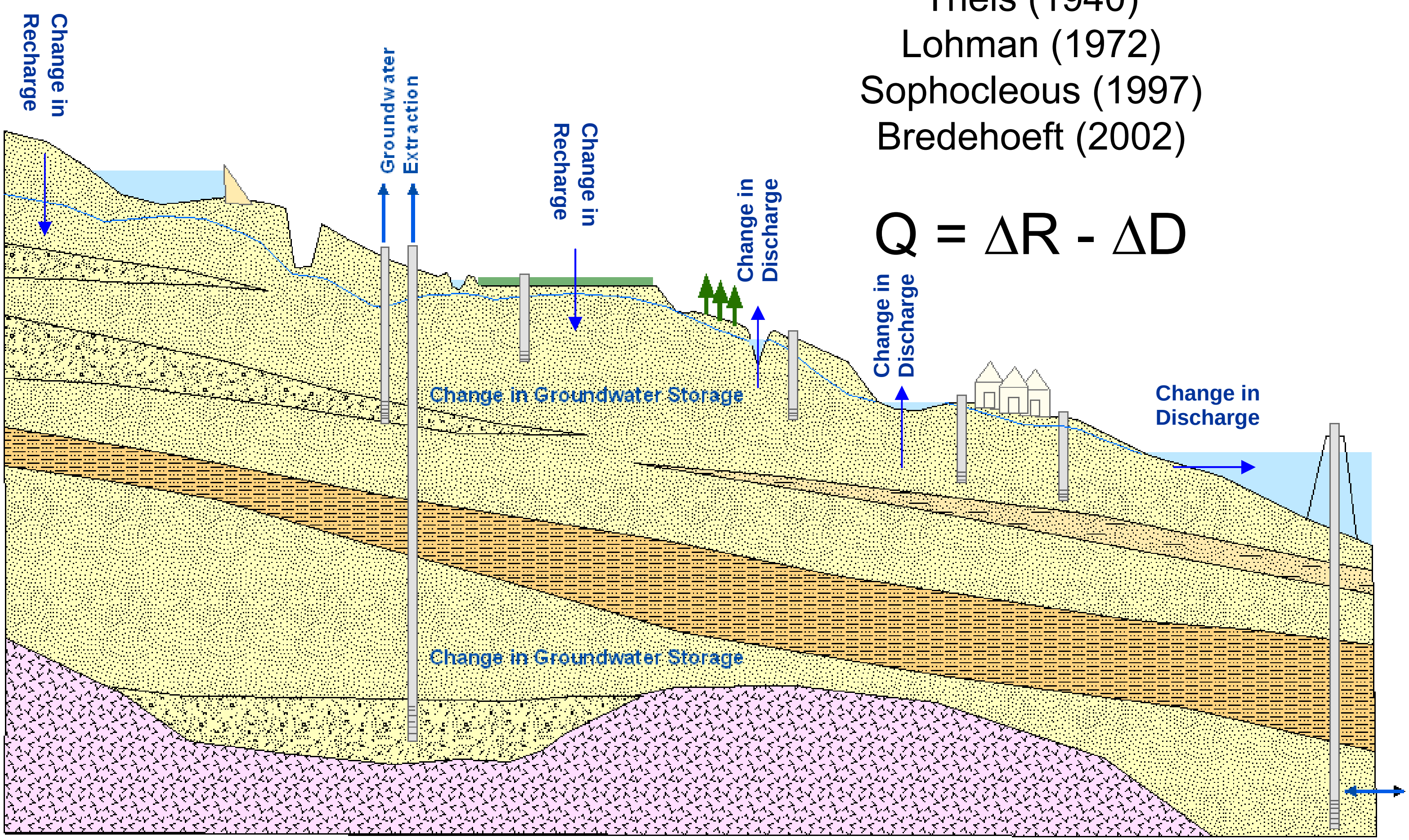
$Q \leq R$



"The idea.. in which the size of a [groundwater] development if is less than or equal to recharge is considered to be "safe" is fallacious"

(Bredehoeft, 1997)

The Capture Paradigm



Recharge/discharge capture

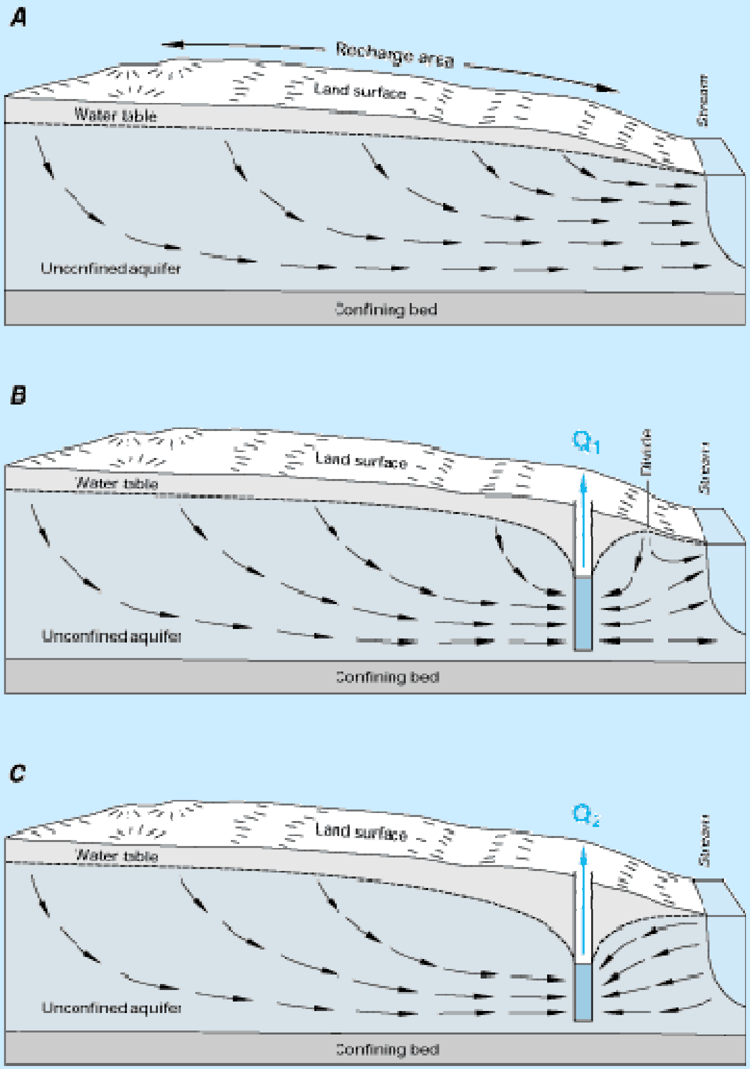
Theis (1940)
Lohman (1972)
Sophocleous (1997)
Bredehoeft (2002)

$$Q = \Delta R - \Delta D$$

"It is the natural pattern of discharges, as well as the changes that occur to recharge and discharge caused by groundwater pumping, that matter"

(Maimone, 2004)

Example of Capture



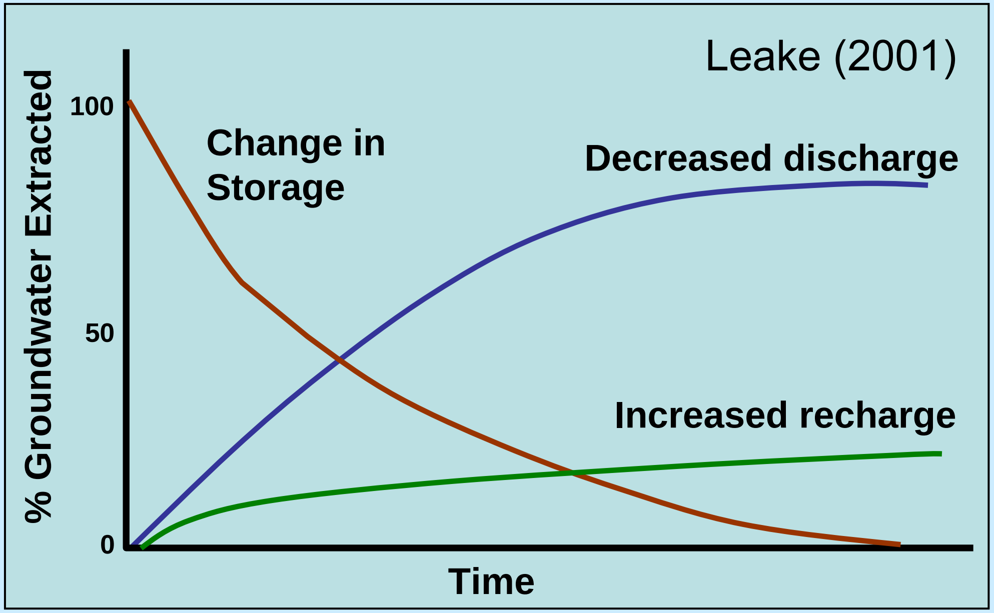
Winter et al. (1998)

Natural conditions

Discharge Interception

Induced Recharge

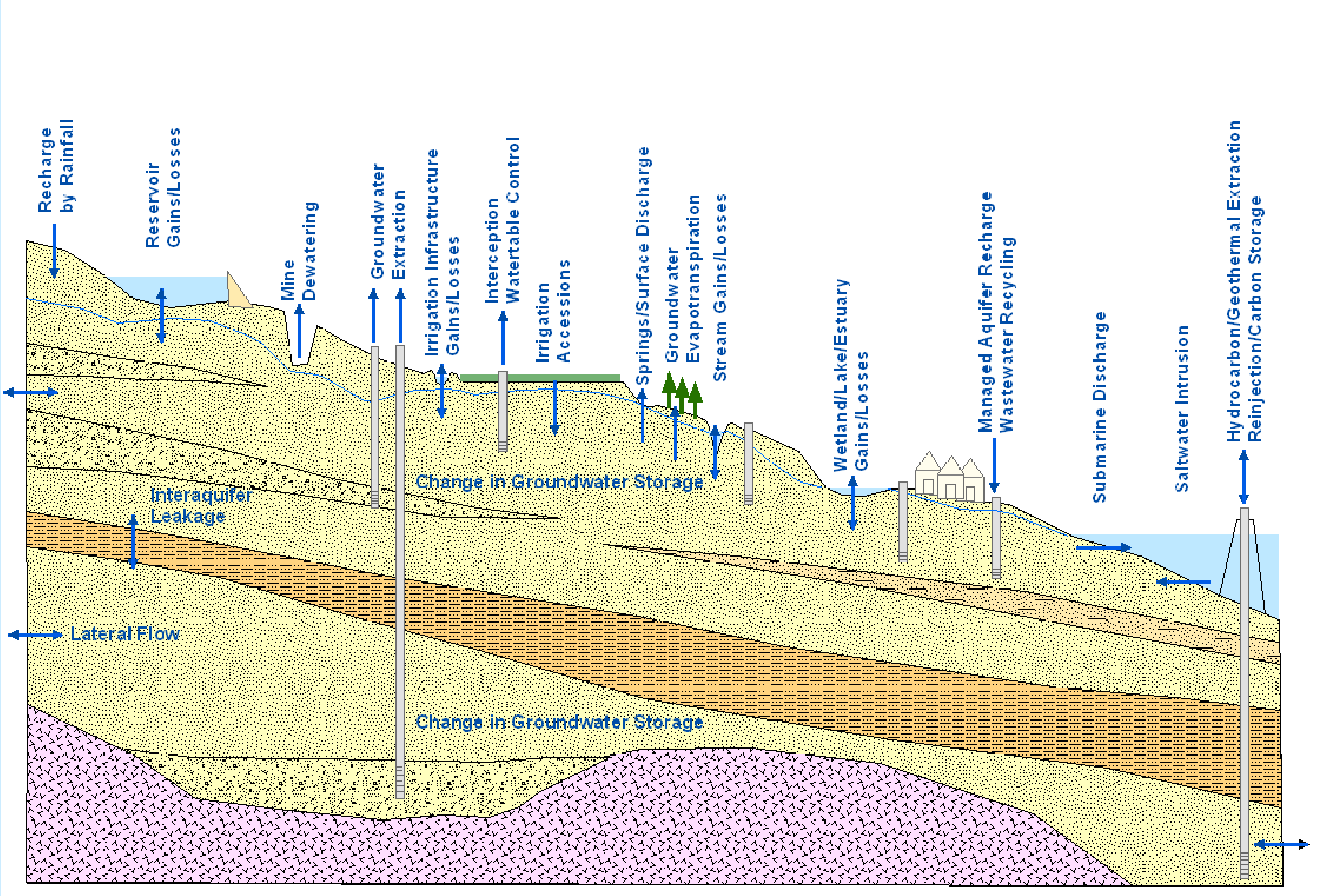
Important Implications of Capture conceptual model



- Requires post-development conditions
  - Based on **change** in recharge/discharge
  - Need to develop/stress aquifer to understand it (or make predictions)
- Depends on how aquifer has been developed
  - Infrastructure/operations
  - Borehole distribution (relative to discharge features)
- Discharge is the focus

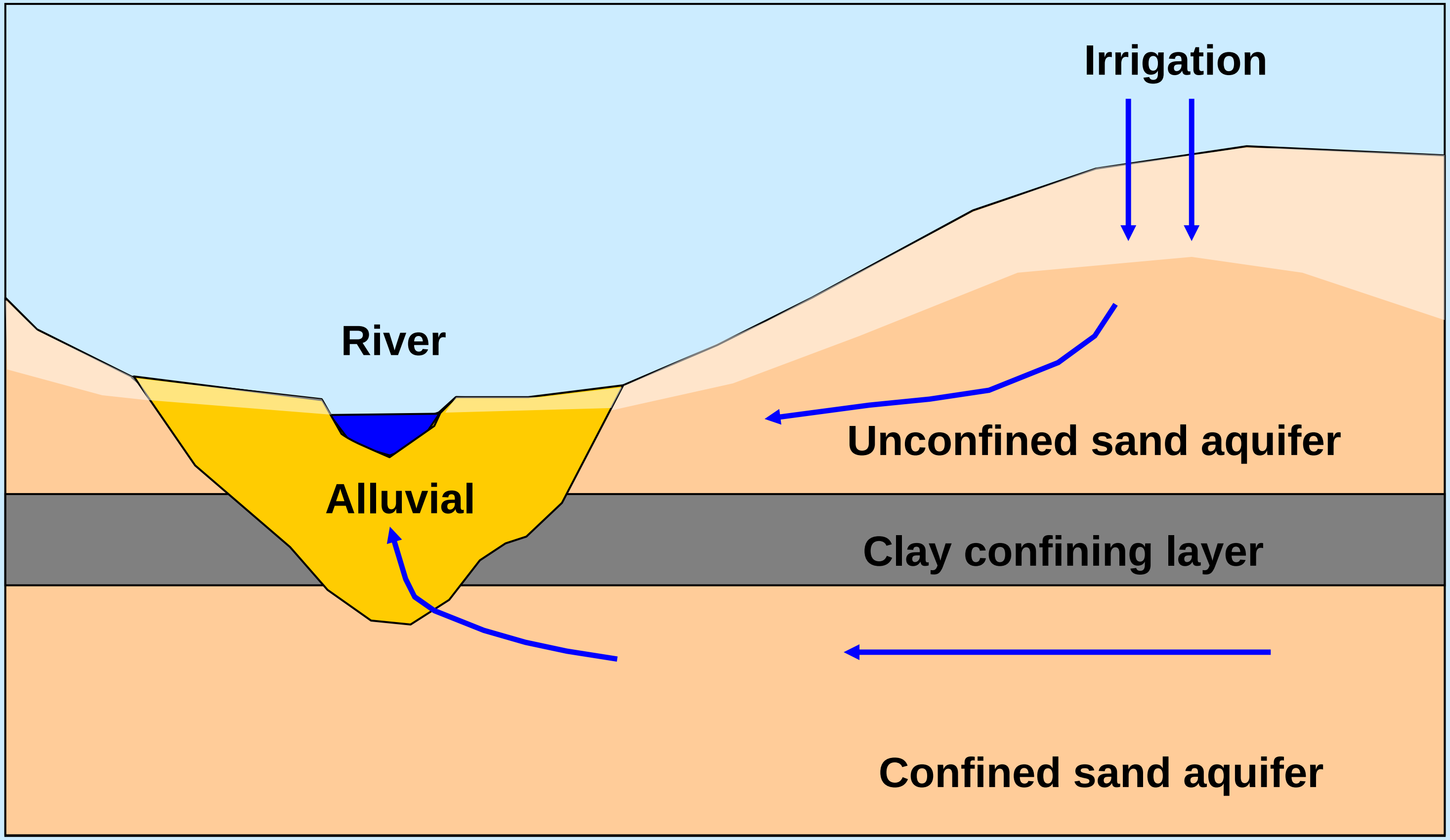
“The conceptual basis for [groundwater] management should be understanding of system behaviour rather than a budgetary approach” (Bidwell, 2003)

Post development Water Budget



“The [ground]water budget includes man’s intervention in the water cycle”
(Maimone 2004)

Conceptual Understanding at the Aquifer Level



3. Uncertainty in Quantification

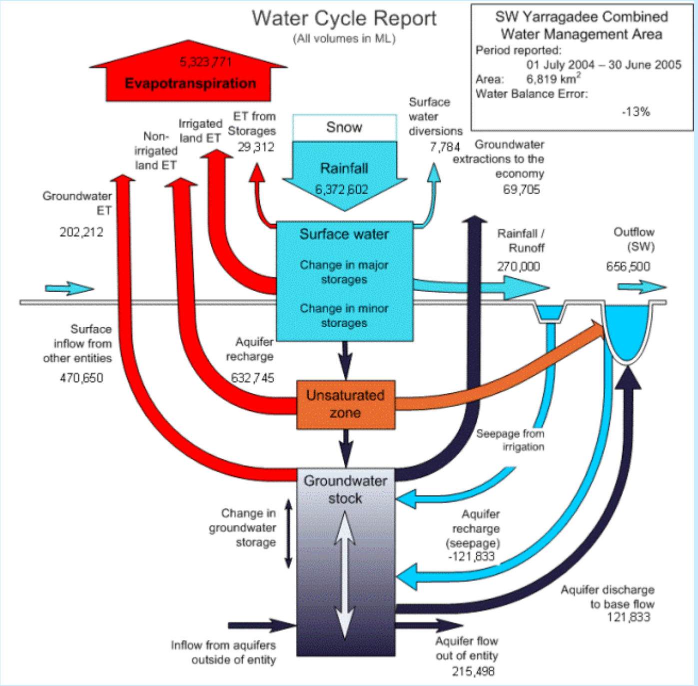
Need to Quantify:

- Aquifer properties
- Water balance components and dynamics
- Social, economic and environmental impacts
- Management response

Uncertainty in Quantification

We need to:

- Simplify complex natural systems by making key assumptions
- Interpolate between sparse data points
- Integrate processes that operate at different scales (in space and time)
- Assess dynamics that are highly variable
- Deal with parameters that vary over orders of magnitude
- Use models with non-unique solutions



www.water.gov.au

Uncertainty in Sustainable Yield Estimates

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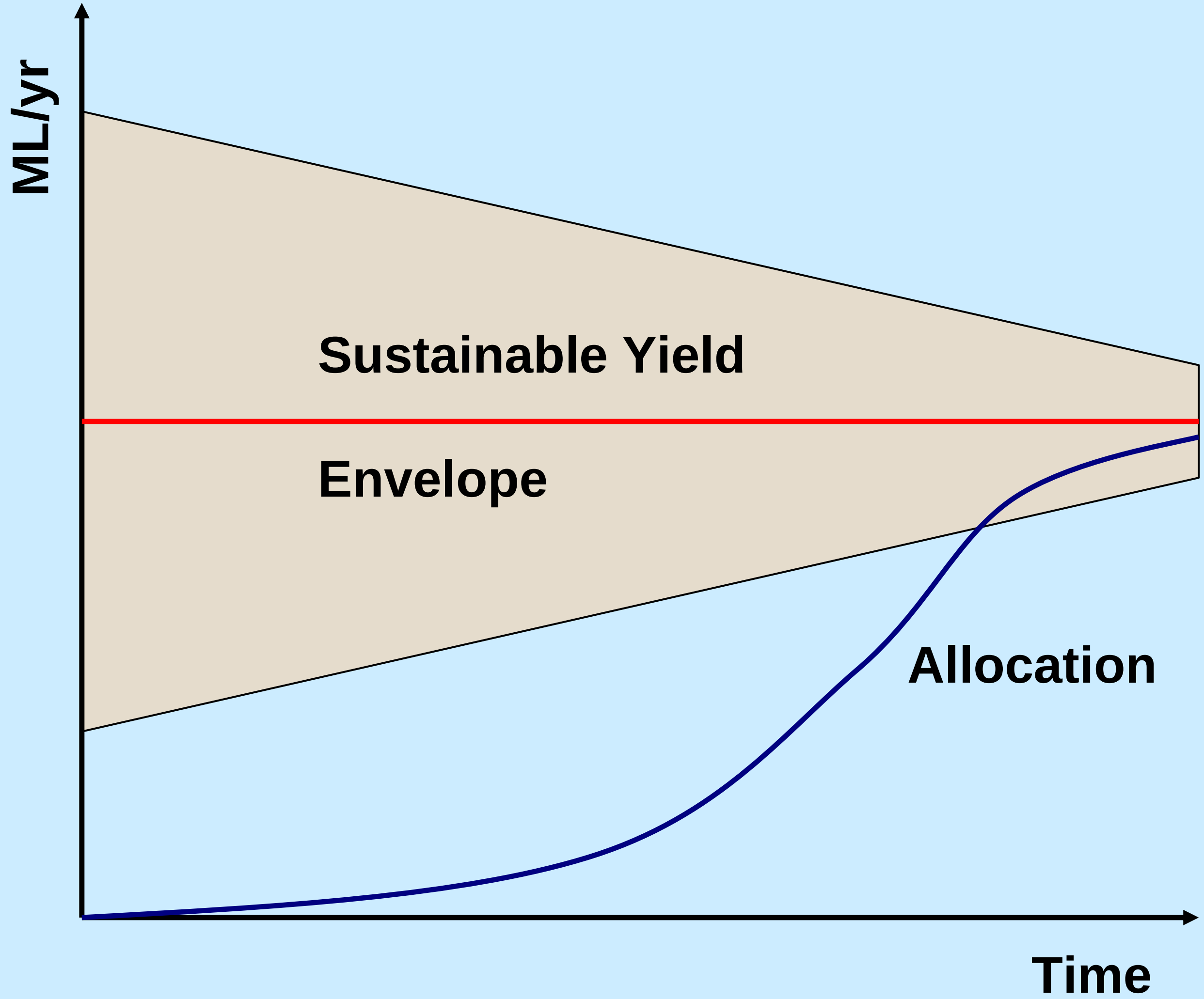
Idealised Groundwater Allocation History



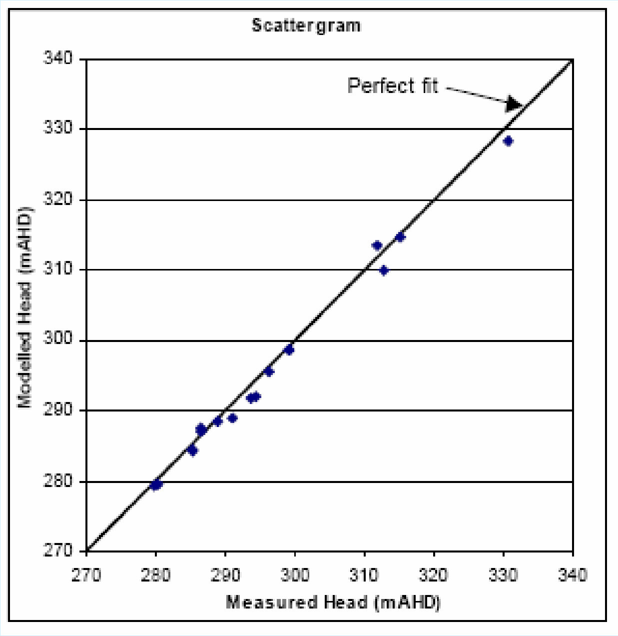
The purpose of sustainable yield is to define an upper threshold for allocation

Existing Approaches – National Assessments

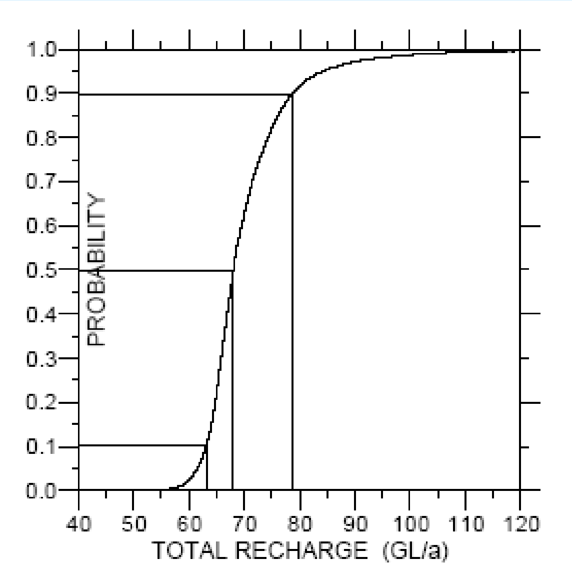
Class	Groundwater Quantity Assessment	Estimated Accuracy
A	Based on reliable recorded and surveyed data that have required little or no extrapolation or interpolation	±10%
B	Based on approximate analysis and limited surveys. Some measured data and some interpolation/extrapolation to derive the dataset	±10-25%
C	Little measured data, based on reconnaissance data	±25-50%
D	Derived without investigation data. Figures estimated from data in nearby catchments, or extarpolated/interpolated from any available data	±50-100%
E	No data	

NLWRA 2001; AWR2005

Existing Approaches – Modelling Guidelines



Indicators of calibration performance



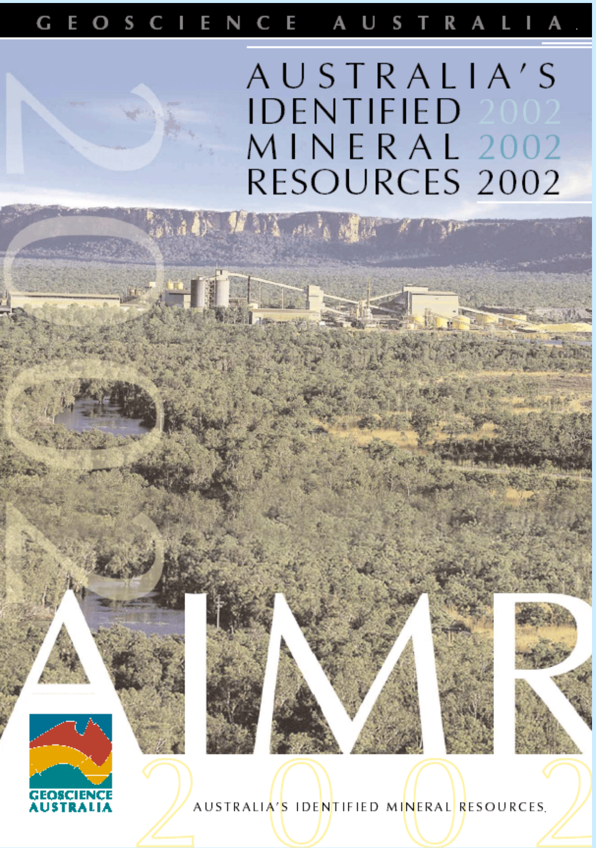
Stochastic approaches
Outputs as probability distributions

Middlemis et al. (2001)

Mining Industry Comparison

- Clear differences between groundwater and mineral resources
- Similar uncertainty issues – community values, conceptual understanding, quantification
- Expectation that uncertainty is communicated
- Mandatory standards for reporting on the ASX – the **‘JORC Code’**

The "JORC" Code



- Standard terms to communicate different levels of confidence
- Checklists of criteria used for assessing and reporting
- Governing principles of transparency, materiality and competence

JORC Principles

- **Transparency**
  - Sufficient information that is clearly and unambiguously presented, is provided showing how the resource assessment was made
- **Materiality**
  - Relevant information is presented that enables a reasoned and balanced judgement regarding the resource assessment
- **Competence**
  - Requirement that the resource assessment is based on work that is the responsibility of a suitably qualified and experienced person who is subject to an enforceable professional code of ethics

JORC Reporting Categories

Increasing level of geological knowledge and confidence

Geological assessment

Exploration Results

Mineral Resources

Ore Reserves

Inferred

Indicated ↔ Probable

Measured ↔ Proved

the "modifying factors"

Consideration of mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors

Proposed Groundwater Reporting Categories

Hydrogeological assessment

Increasing level of hydrogeological knowledge and confidence

Groundwater Source?

Groundwater Resources

Groundwater Reserves?

Inferred

Indicated ↔ Probable

Measured ↔ Proved

the "modifying factors" – impact assessment

Consideration of economic, legal, environmental, social and governmental factors

JORC-Based Categories for Mineral Resources

Decreasing degree of geological assurance →

Decreasing degree of economic feasibility ↓

		IDENTIFIED		
		DEMONSTRATED		INFERRED
		MEASURED	INDICATED	
ECONOMIC		10 Mt @ 30 g/t Au		10 Mt @ 30 g/t Au
SUB-ECONOMIC	PARA-MARGINAL			
	SUB-MARGINAL			

Proposed Uncertainty Categories for Sustainable Yields

Decreasing degree of hydrogeological assurance →

Decreasing feasibility for beneficial uses ↓

Increasing groundwater salinity, mg/L ↓

	Measured	Indicated	Inferred	
Fresh	10,000 ML/yr Fresh		10,000 ML/yr Fresh	1,500
Marginal				3,500
Brackish				14,000
Saline			10,000 ML/yr Saline	

Increasing levels of uncertainty →

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Important Implications of Capture conceptual model

Sustainable yield based on:

- Changes in water balance due to groundwater extraction
- Assessment of impacts including acceptability
- Post-development conditions
- How aquifer has been developed

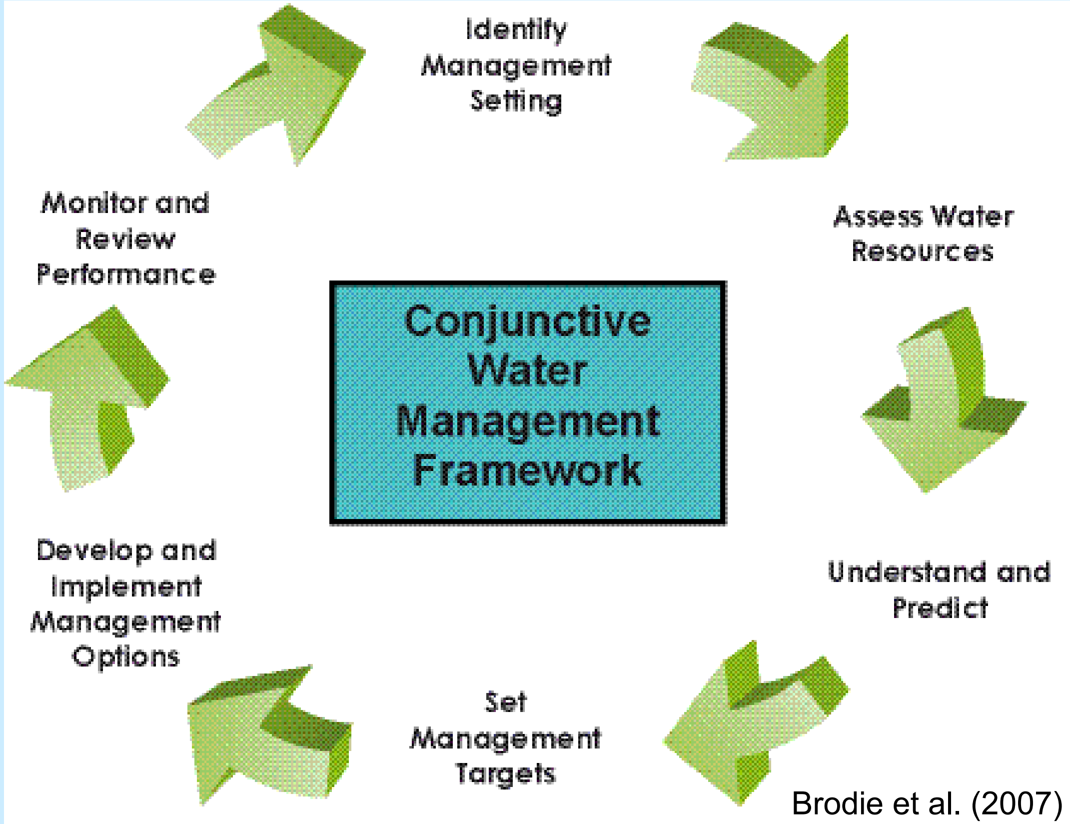
This requires two approaches:

- **Adaptive Management**
- **Precautionary Principle**

Sophocleous (2000); Maimone (2004); Seward et al. (2006)

Adaptive Management Framework

- The "suck it and see" approach
- Tension with providing long-term water security
- Management timeframes
- Cycle of review of water sharing plans



Brodie et al. (2007)

"The concept of adaptive management appears to be the only viable approach in dealing with the uncertainties" (Maimone 2004)

Precautionary Principle

The **Precautionary Principle** is applied..

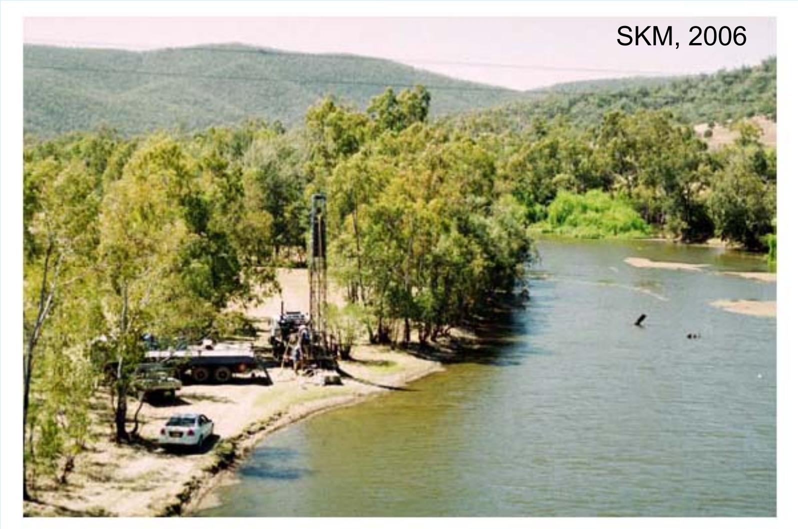
..where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

1992 Rio Declaration on Environment and Development

Precautionary Principle..translated

The **Precautionary Principle** is applied..

..where there are threats of *unacceptable impacts from groundwater extraction*, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to *deal with these impacts*



Conclusions

Sustainable yield…

- combines biophysics, economics, society and environment
- is based on impacts and their acceptability
- is based on the post-development water budget
- assessment framed by risk, probability and uncertainty
- where using the capture paradigm means that we have to be adaptive
- we can learn from other disciplines