IAH 2011 Ineson Lecture

Integrating Land and Groundwater Management; Experiences in Australia and the Pacific

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Fenner School of Environment & Society
Australian National University

Dr Jack Ineson

"Fundamental contributions to investigation of groundwater resources…"

The success of the rapid progress in groundwater hydrology…must be attributed not only to Jack Ineson's unique knowledge but his ability to collaborate with a wide range of disciplines"

http://iahs.info/hsj/154/154015.pdf

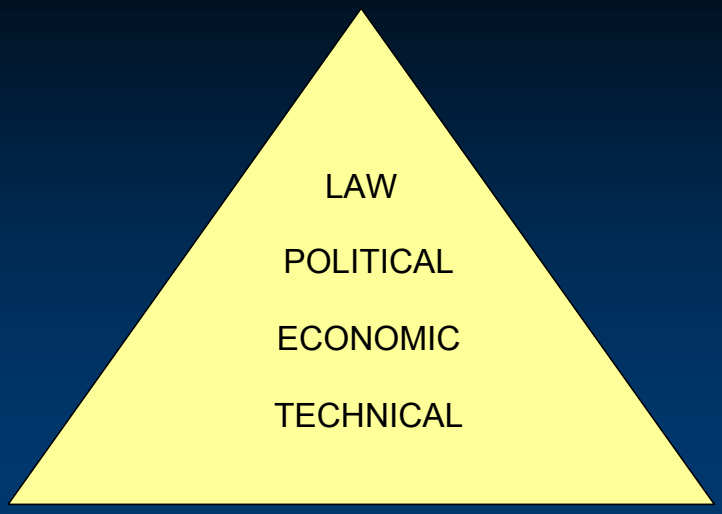
Outline

- Challenges in Water Resources & the Role of Science
- Water Reforms in Australia
  - The groundwater-surface water disconnect
- Salinity in the Murray Basin
  - Irrigation
  - Dryland
- Groundwater in Pacific Island Countries
- Conclusions

Challenges in Water Resources

- Increasing demand for freshwater
- Human impacts on water quality
- Coping with temporal variability
- Increasing complexity
- Challenges to Science

Bredehoeft (1997) Hierarchy of Factors Contributing to Decisions about Water



Reflections on Hydrology: Science and Practice. N. Burras (ed.) AGU 1997, pp 36-61.

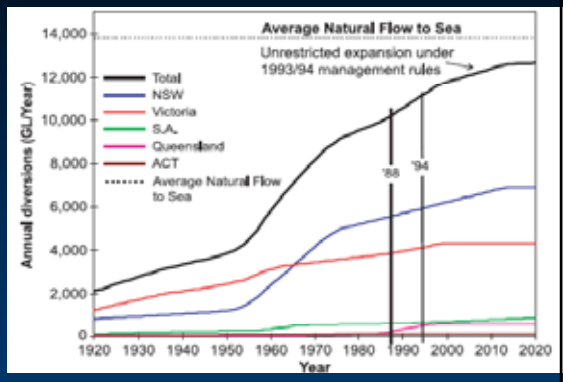
Water Reforms in Australia

Based on the 1992 Rio Declaration – sustainability

- National Strategy for ESD – 1992
- National competition policy - Hilmer report 1993
- Council of Australian Governments (COAG) water reforms 1995 – large economic incentives for reforms by States
- Cap on surface water abstraction from Murray-Darling 1995
- Australian Bureau of Statics Water Accounts 1996
- National Land & Water Audit 1999 & Salinity Audit 1999
- MDB Council Integrated Catchment Management Policy-2001
- National Water Initiative -2004
- Commonwealth Water Act 2007 (Amended 2008)

1995 Cap on Surface Water Abstraction in MDB

http://www2.mdbc.gov.au/__data/page/86/cap_brochure.pdf



Restricted SW abstraction to 1993/4 levels

Impact of the CAP on Groundwater Extraction

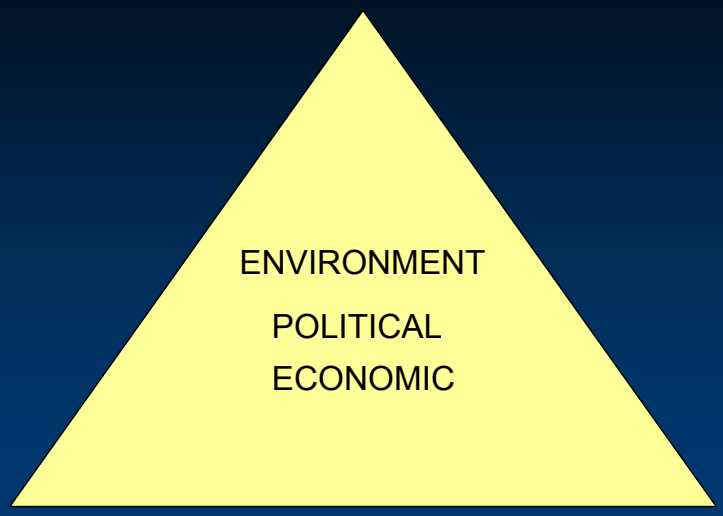
- Groundwater extraction from unconfined aquifers increased by 310 GL/year
- Stream flow decreased by over 180 GL/year
- Surface and groundwater audits conducted separately – some double accounting of water

Evans, R. (2007) The Effects of Groundwater Pumping on Stream Flow in Australia. Technical Report, Land & Water Australia, Canberra, 137 pp

Why wasn't Groundwater Included in the CAP?

- Surface and groundwater hydrology taught as quite separate subjects by generally different departments and tend to be managed by different agencies
- Capping groundwater use was considered too difficult
  - Number of wells and bores unknown
  - Generally unmetered pumping
  - Aquifers only partly understood
  - Limited temporal & spatial monitoring
  - Recharge poorly understood
  - Sustainable yield poorly characterised
- Jurisdictional tensions between States over water

Bredehoeft (1997) Hierarchy After the CAP



COAG National Water Initiative 2004

Australia's blueprint for how water will be managed into the future

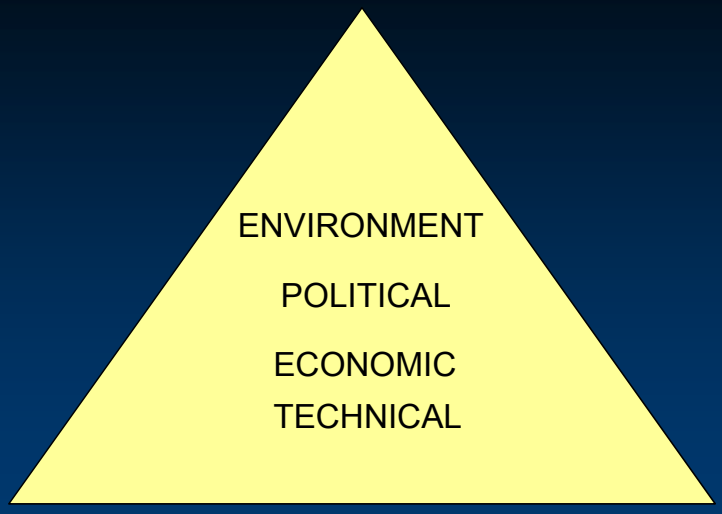
Objective 10

Recognition of the connectivity between surface and groundwater resources and connected systems managed as a single resource

Established the National Water Commission

Lead Australian Government agency for driving national water reform under the National Water Initiative

Bredehoeft (1997) Hierarchy Modified by NWI



Commonwealth Water Act 2007

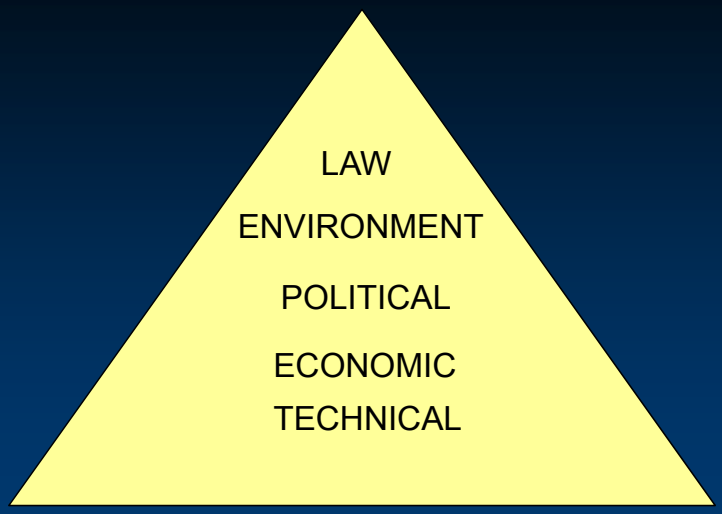
Purpose

To make provision for the management of the water resources of the Murray-Darling Basin, and other matters of national interest in relation to water and water information, and for related purposes

Commonwealth Water Act 2007

1. Defined *water resource to* mean:
   (a) surface water or ground water; or
   (b) a watercourse, lake, wetland or aquifer (whether or not it currently has water in it);
2. Gave additional powers to the Bureau of Meteorology: collecting, holding, managing, interpreting and disseminating Australia's water information - contextual information such as land use, geological and ecological information
3. Established the Murray-Darling Basin Authority :
   to measure, monitor and record the quality and quantity of Basin water resources & to develop the Basin Plan
4. Basin Plan - integrated management of the Basin water resources

Bredehoeft (1997) Hierarchy after 2007 Water Act



The Basin Plan

Integrated management of the Basin water resources ...by providing for:

(b) the establishment and enforcement of environmentally sustainable limits on the quantities of surface water and ground water that may be taken from the Basin

(c) Basin-wide environmental objectives for water-dependent ecosystems and water quality and salinity objectives;

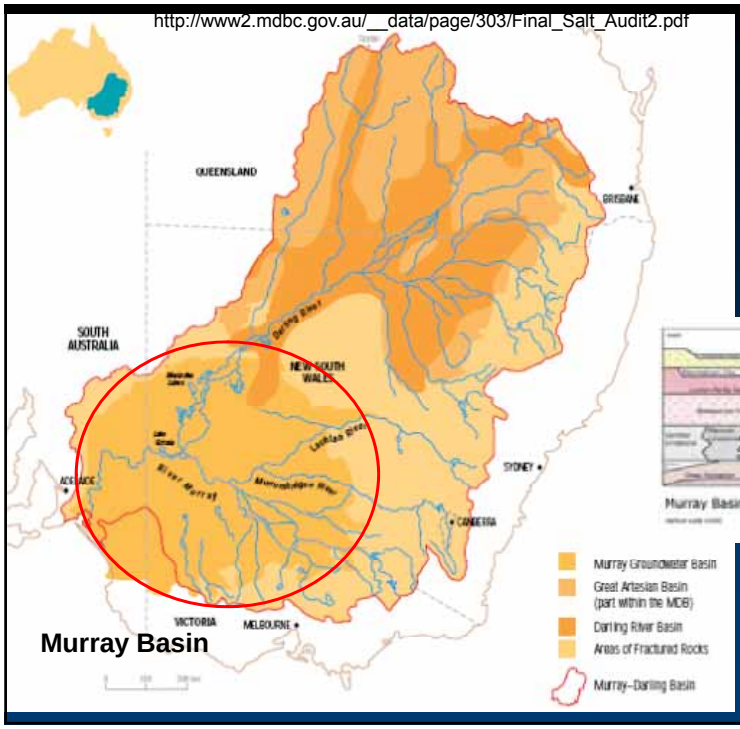
The Plan must include the size, extent, connectivity, variability and condition of the Basin water resources; and water quality and salinity

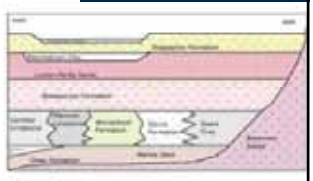
Bredehoeft (1997) Hierarchy and 2011 Basin Plan

LAW
POLITICAL
ENVIRONMENT
SOCIAL-CULTURAL
ECONOMIC
TECHNICAL

Ground-water Zones of the Murray Darling Basin

http://www2.mdbc.gov.au/__data/page/303/Final_Salt_Audit2.pdf





Murray Basin cross section

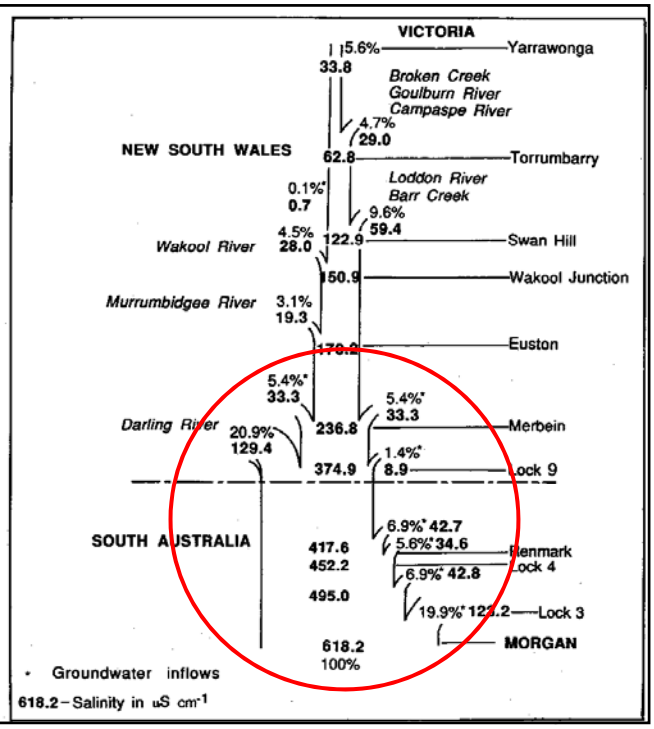
River Murray Salinity (EC)

Salinity

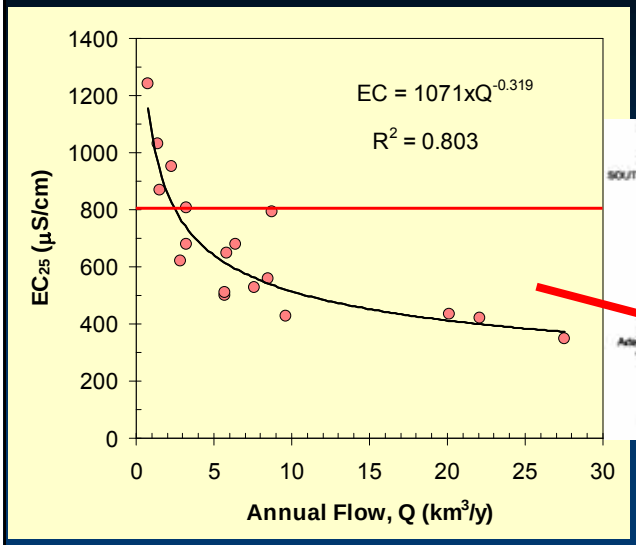
EC =µS/cm

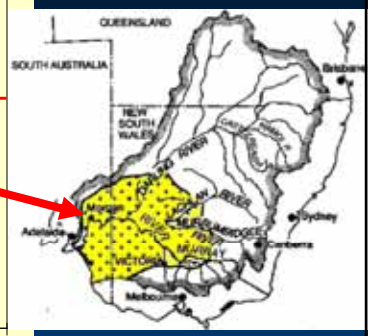
TDS (mg/L)

≈ 0.6xEC



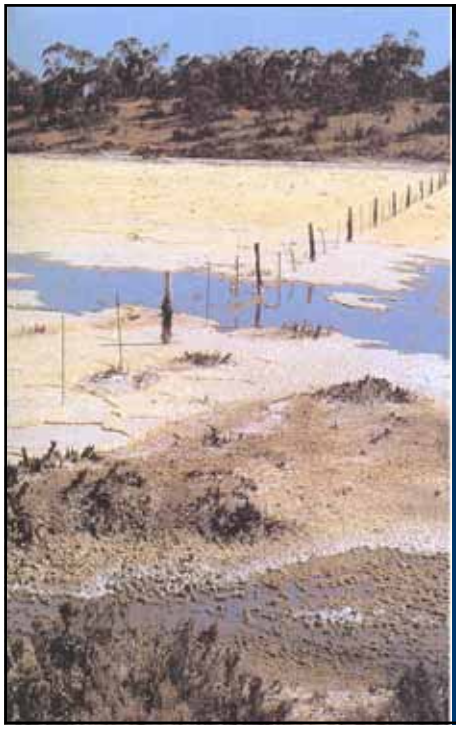
Annual Salinity & Flows in Murray River





Hydrol Processes (2009), **23**, 2485-95

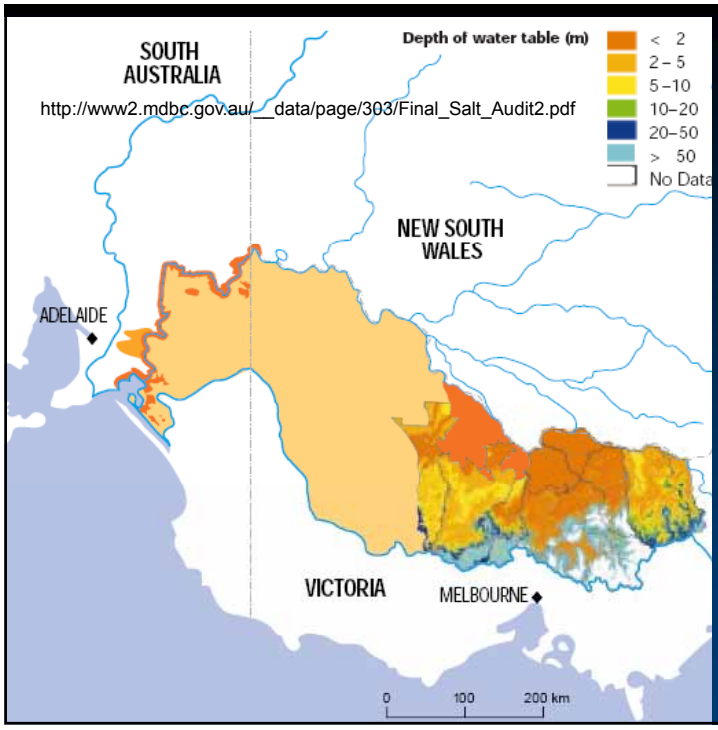
IAH London 20 Oct 2011



Salinity in the Murray Darling Basin

Two sources of increased salinity discharge:

1. Irrigation
2. Dryland Cropping

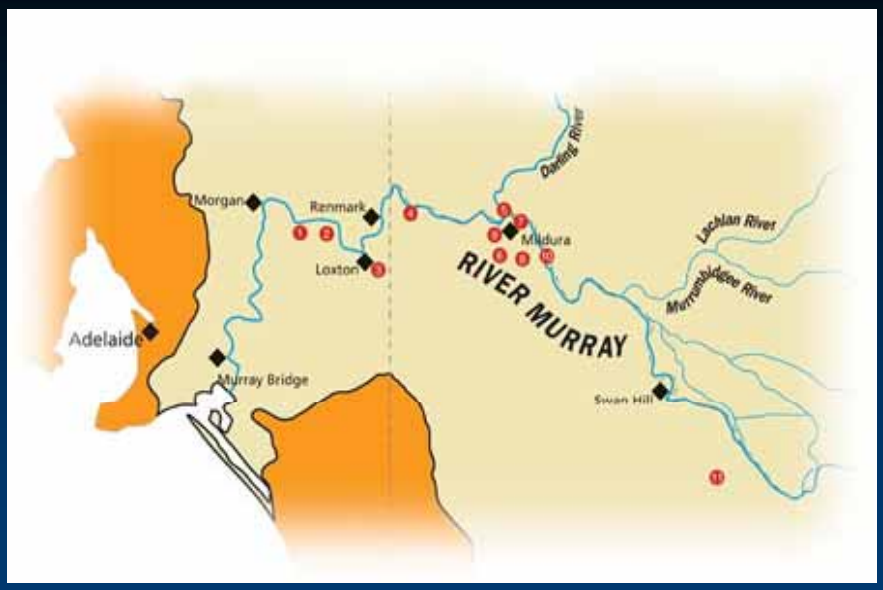


http://www2.mdbc.gov.au/__data/page/303/Final_Salt_Audit2.pdf

Depth to Water Table in Irrigation Areas

Irrigation, a key contributor to rising water tables & salinity discharge

Groundwater Salt Interception Schemes



http://www2.mdbc.gov.au/__data/page/303/Final_Salt_Audit2.pdf

Salinity Disposal Basins Wakool –Tullakool NSW

Disposal of Intercepted Salinity in Salt Lakes

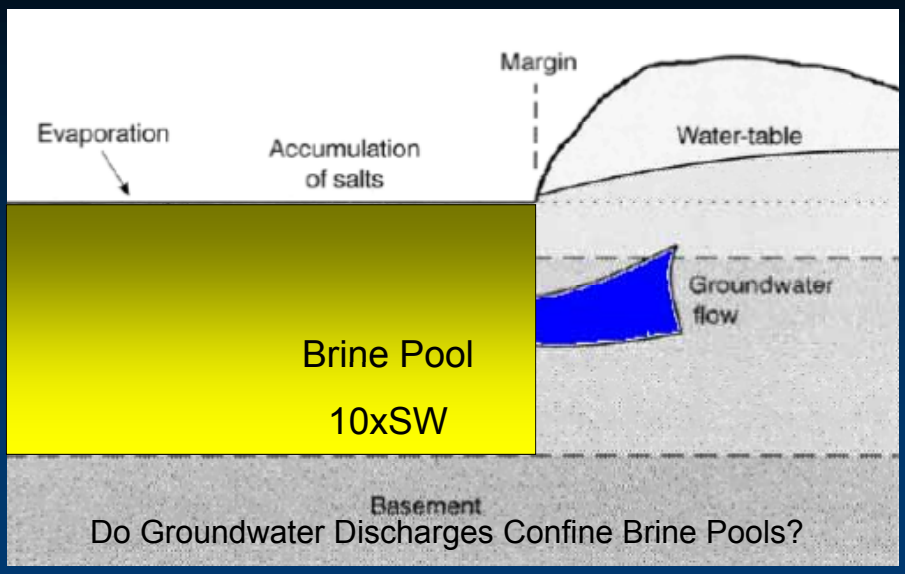
WRR (1995) **31,** 1343-53

Proposed Salt Lake Disposal

Engineered Disposal Basin

Will there be environmental consequences?

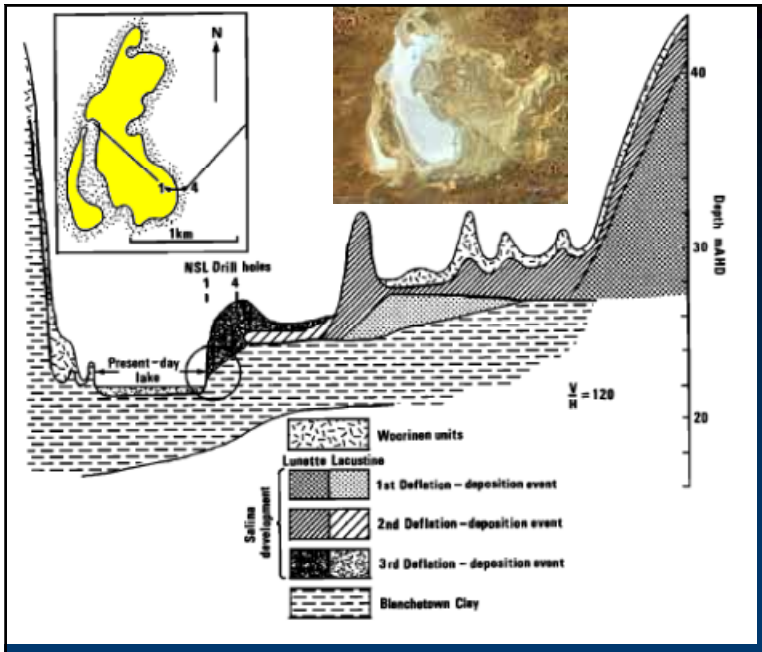
Salt Lake Model



Do Groundwater Discharges Confine Brine Pools?

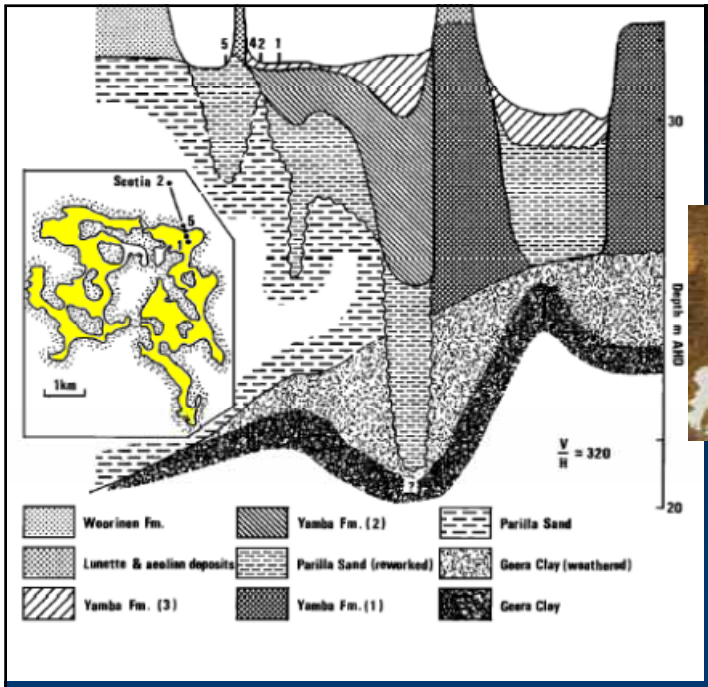
WRR (1997) **33**, 1199-1217

Nulla Spring Lake



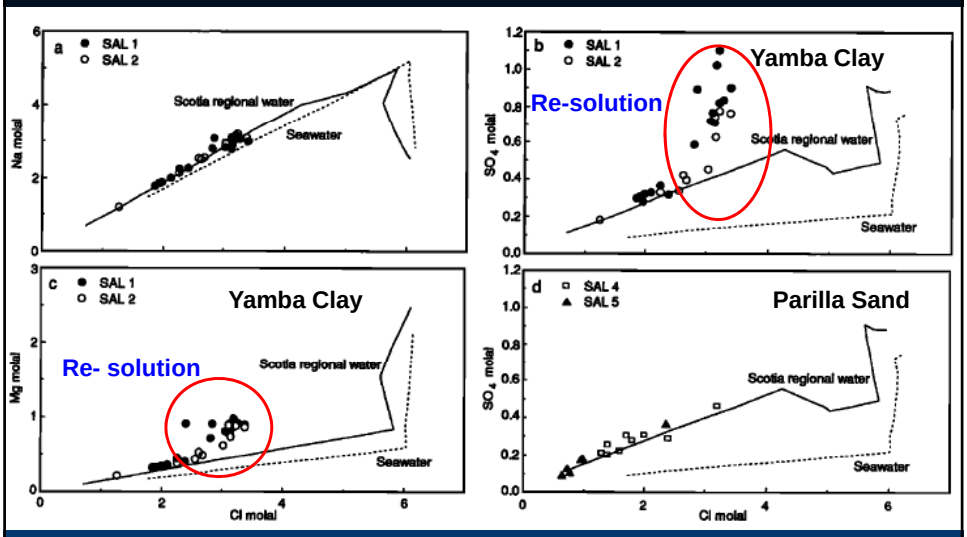
WRR (1995) **31,** 1343-53

Scotia Lake Complex



WRR (1995) **31,** 1343-53

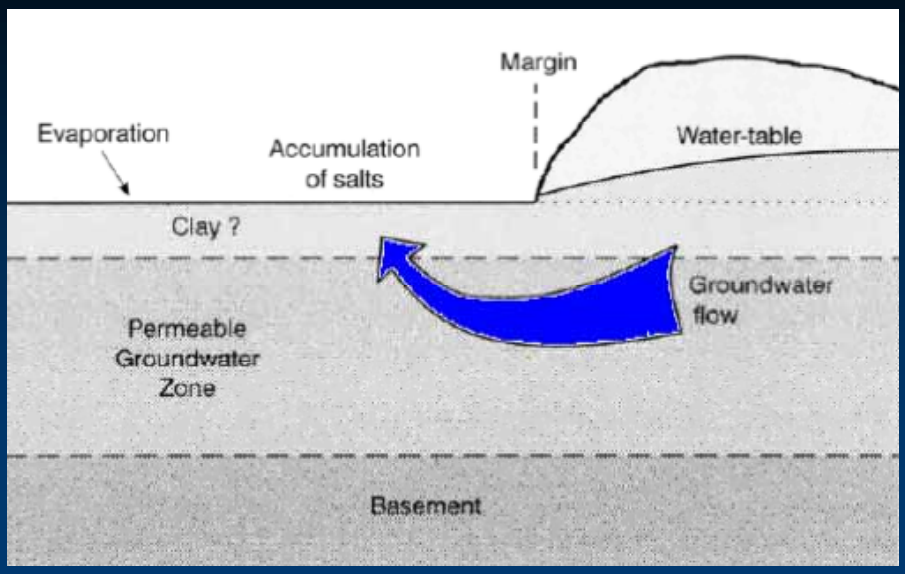
Groundwater Composition versus Modelled Evaporation



WRR (1995) **31,** 1343-53

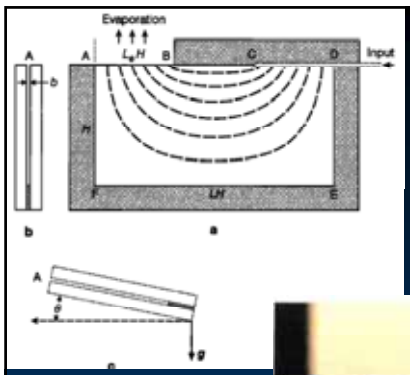
IAH London 20 Oct 2011

Model Salt Lake



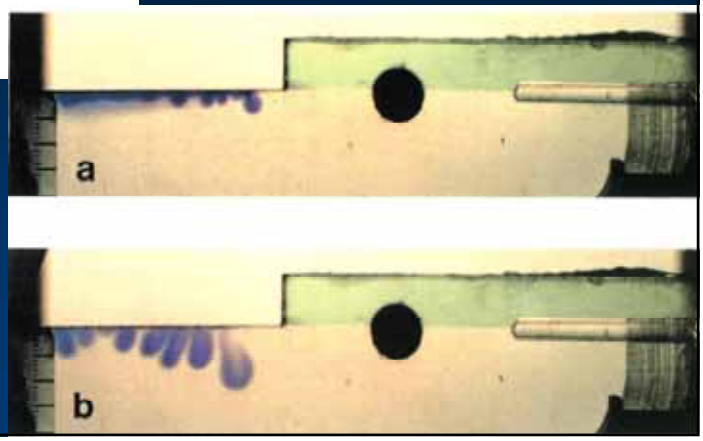
WRR (1997) **33**, 1199-1217, 1219-28

IAH London 20 Oct 2011



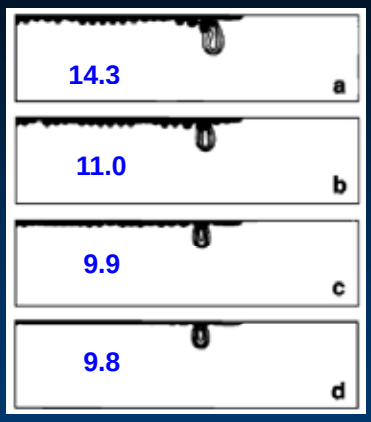
Hele-Shaw Model of Onset of Groundwater Instability beneath Evaporating Salt Lakes

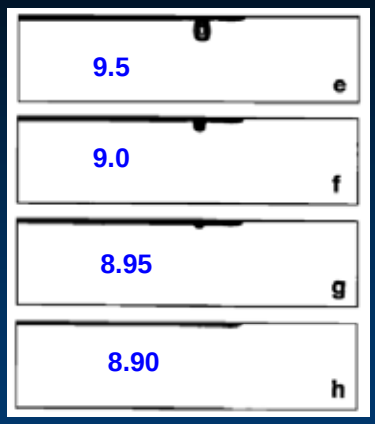
WRR (1997) **33**, 1199-1217, 1219-28



Numerical Model of Onset of Instability

WRR (1997) **33**, 1199-1217



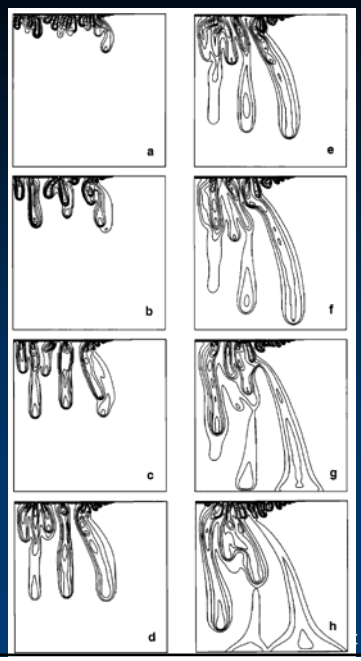


$$R_\delta = \frac{\Delta\rho}{\nu_r \varepsilon}\left[\frac{gk\sin\theta}{\rho_r} + \varepsilon\frac{d\nu}{d\rho}\right]$$

$$k_{min} \approx \frac{\nu_r R_\delta \varepsilon}{g\gamma}$$

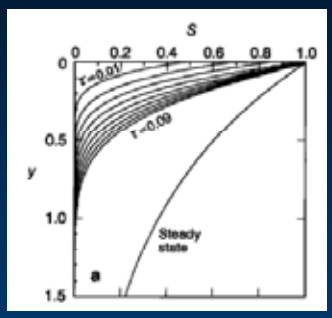
$k_{min} \geq 10^{-14} m^2$

Hele-Shaw & Numerical Models of Plume Development



WRR (1997) **33**, 1219-1228

Conclusions from GW Geochemistry, H-S & Numerical Models of Evolution of Salt Plumes beneath Salt Lakes



Salt lakes capped with significant thicknesses of clay

- suitable for use as disposal basins

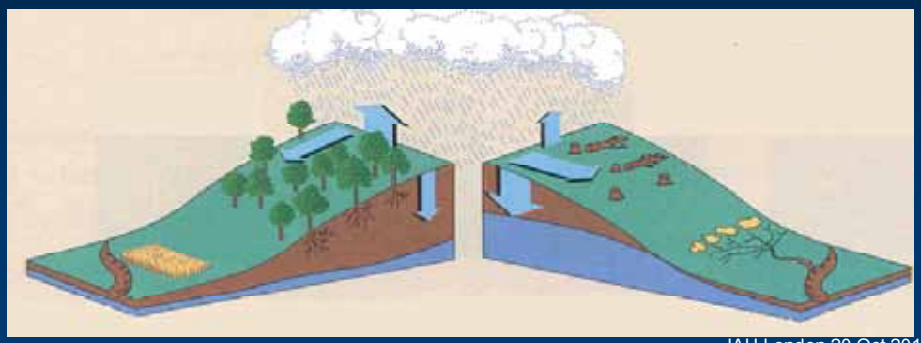
- evaporating boundary layer is stabilised by the groundwater evaporative discharge

WRR (1995) 31, 1343-53; WRR (1997) **33**, 1199-1217, WRR (1997); **33,** 1219-1228

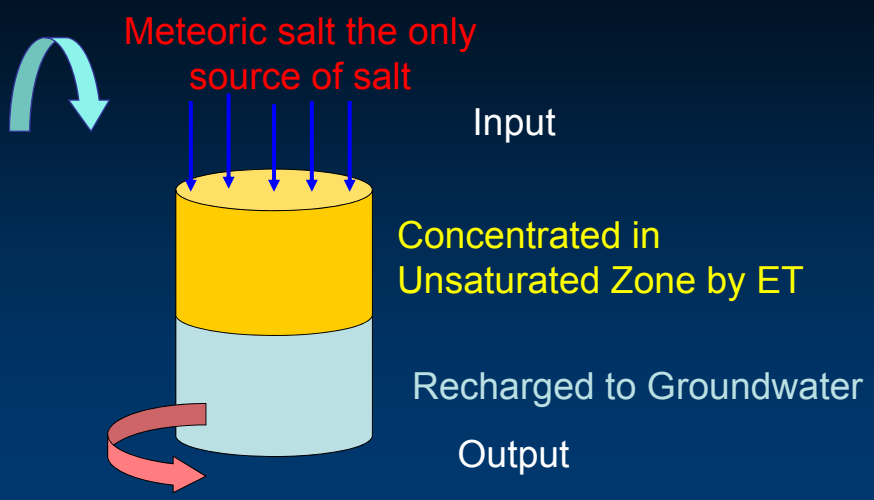
Dry-Land Cropping and Salinity

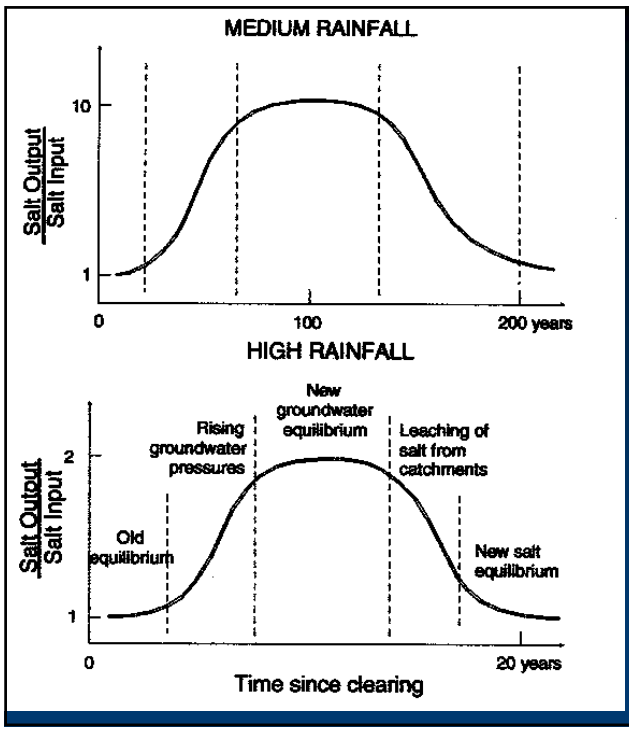
- **Clearing of native vegetation in recharge areas has increased groundwater recharge.**
- **Saline watertables rise - outbreaks of salinity**

http://www2.mdbc.gov.au/__data/page/303/Final_Salt_Audit2.pdf



Assumed Source of Groundwater Salinity

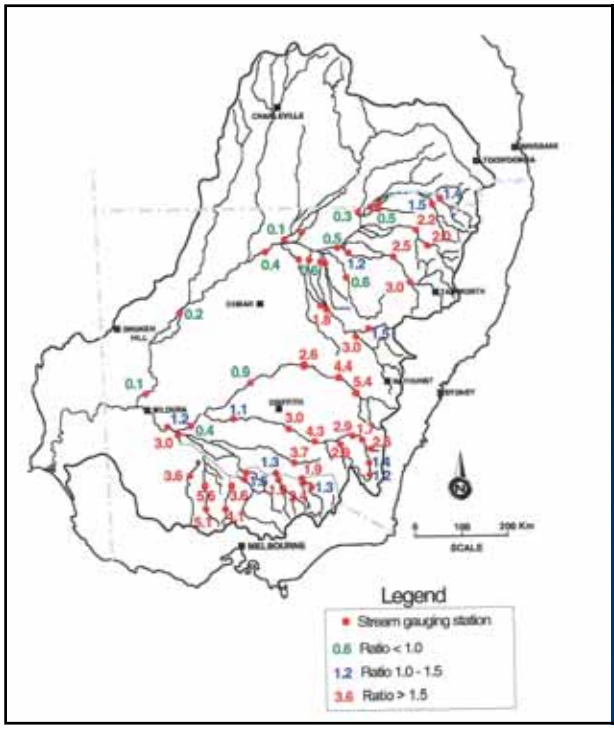




Land Clearing and Salt Output/Input Ratios

Salinity Input due to cyclic salt in rain

Salinity output caused by mobilisation of stored cyclic salt.



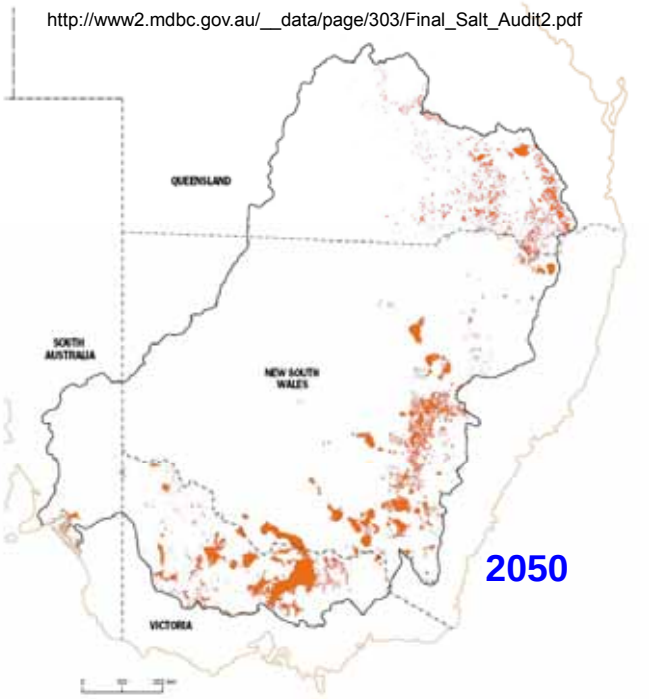
Salt O/I Ratios Catchments in the MDBC

Ratios > 1

Increased salinity discharge

Coupled with Estimated Trends in Watertable Rises predicted major future impacts on stream salinity

http://www2.mdbc.gov.au/__data/page/303/Final_Salt_Audit2.pdf



Future Areas of High Risk of Salinity – rising WT

3.4 million ha in the eastern and southern regions salt-affected within 50 years

Predicted Mobilisation of Salt

http://www2.mdbc.gov.au/__data/page/303/Final_Salt_Audit2.pdf

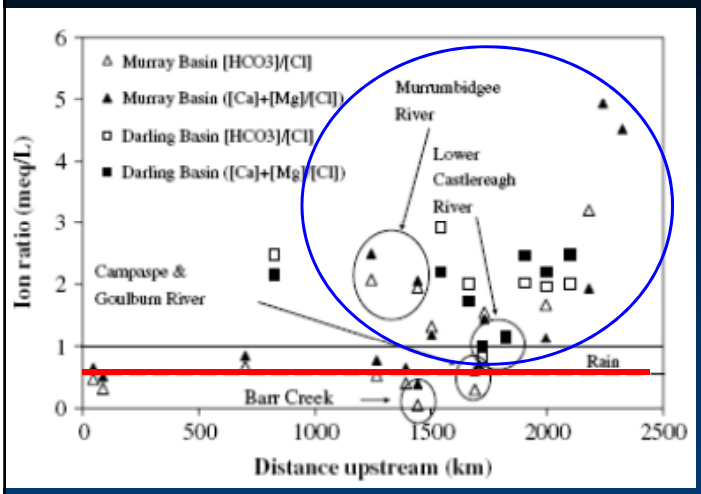
Dryland Salinity a National Priority

National Action Plan for Salinity & WQ $A1.3B

Basin Salinity Management Strategy 2001-15

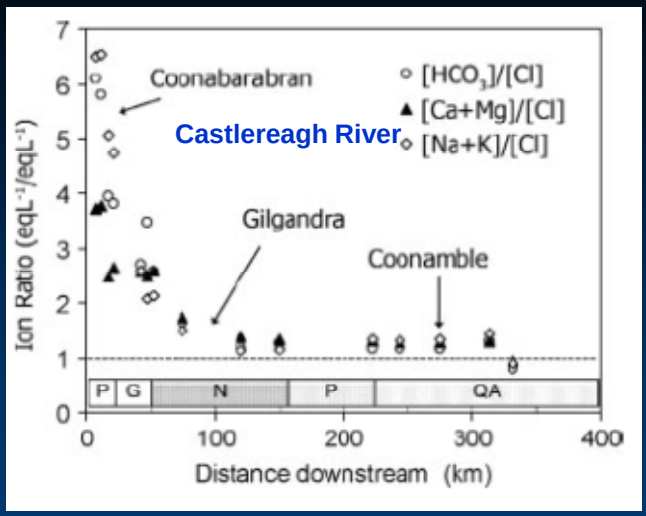
But is cyclic salt the source?

Stream Chemistry and the Cyclic Salt Model?



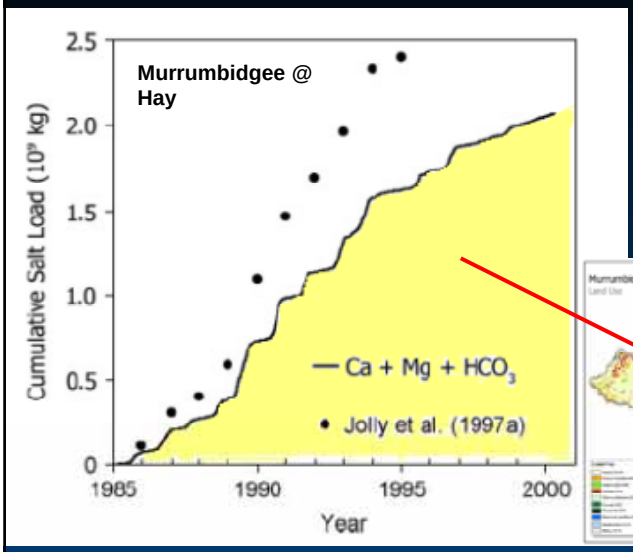
Hydrol Processes (2009), **23**, 2485-95

Mineral weathering source of salt in upper M-D basin



Mineral Weathering & Stream Chemistry in the upper MDB

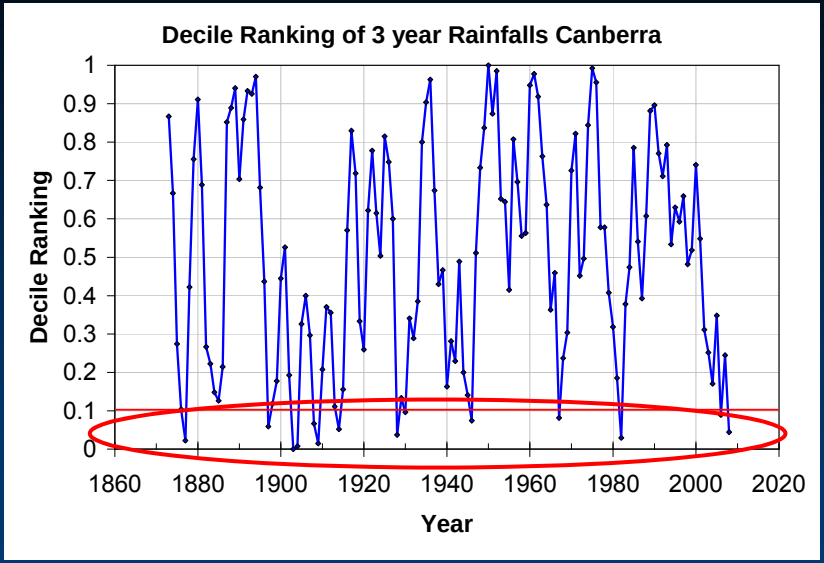
Hydrol Processes (2009), **23**, 2485-95



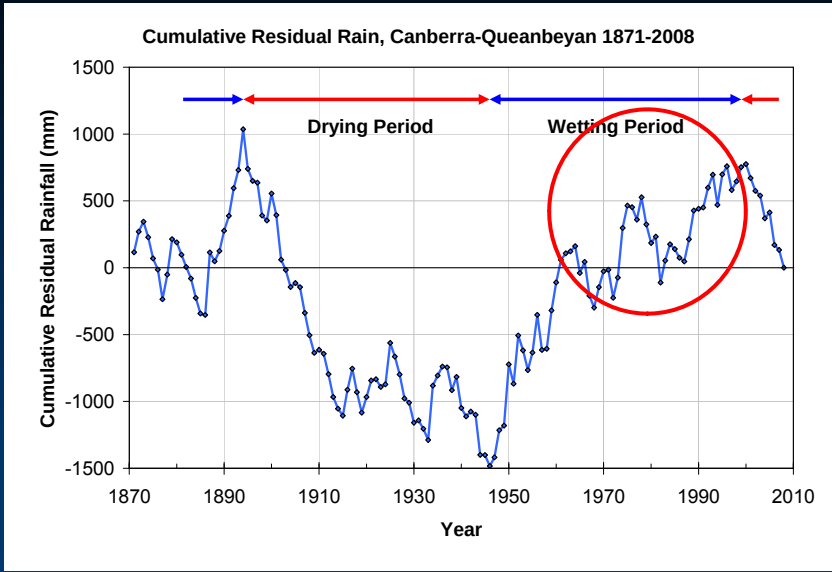
Contribution of Mineral Weathering to Stream Salt Load

Hydrol Processes (2009), **23**, 2485-95

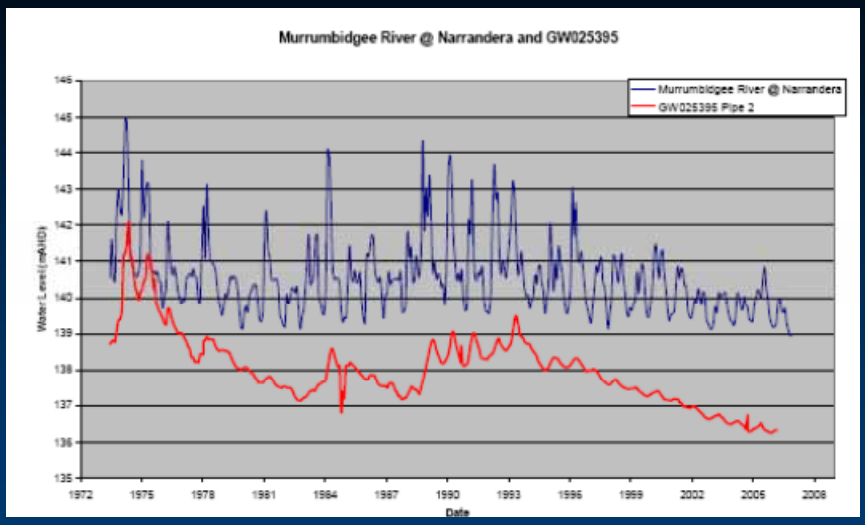
Rising Watertables & Shorter Period Rainfall Variation



Rising Watertables & Long Period Rainfall Variation



Groundwater & Stream Levels in Murrumbidgee



Mid Murrumbidgee Alluvium. Groundwater Management Area 013: Gundagai to Narrandera. Groundwater Resources Status Report – 2007

Predictions of the 1999 Salinity Audit

1. Ignored mineral weathering as a source of salt
2. Overestimated salt O/I ratios for cyclic salt
3. Ignored the impact of climate variability on groundwater levels & dryland salinity
4. Overestimated future salinity hazards
5. Brought about major policy & land use change

Water Resources in Pacific Carbonate Islands

Hydrogeology Journal (2010) 18: 227–246

Bredehoeft (1997) Hierarchy in Many PICs

POLITICAL

SOCIAL-CULTURAL

Vulnerability of Water Resources in Pacific ICs

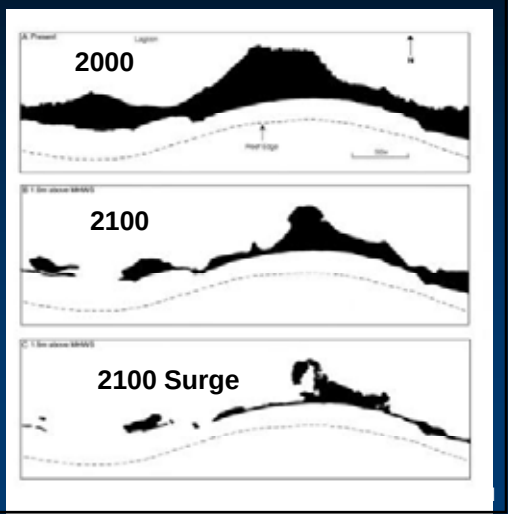
- Climate variability
- Impact of humans - urbanisation
- Hydrogeology
- Knowledge constraints
- Capacity/Resource Limitations
- Governance
- Cultural-social issues

Societies at the limit of sustainability

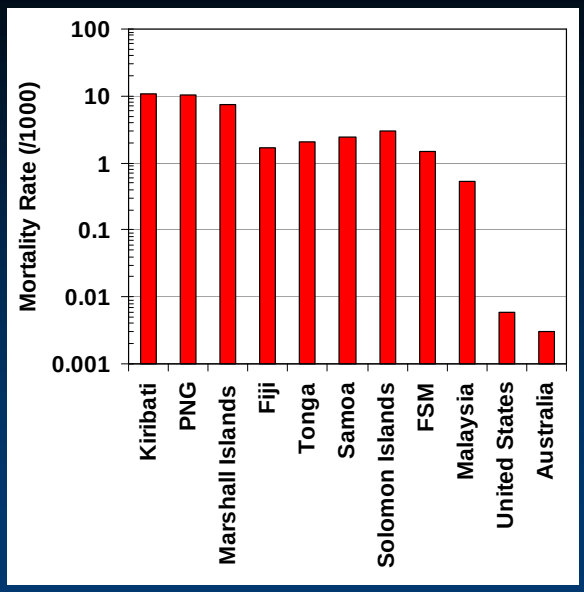
Lomi Tuvalu 29 Feb 2005

Climate Change & Sea Level Rise

Sea level rise and island area (WB, 2000)



Immediate Problems: Water-related Human Health

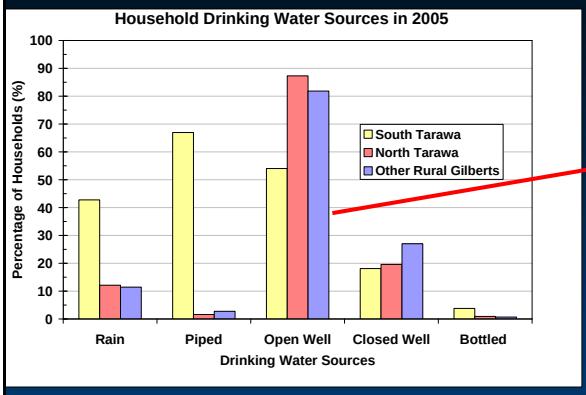


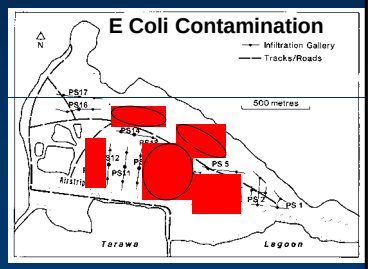
3,000x

Infant mortality - diarrhoeal diseases

Source: WHO CHIPS 2005

Health & Drinking Water Sources



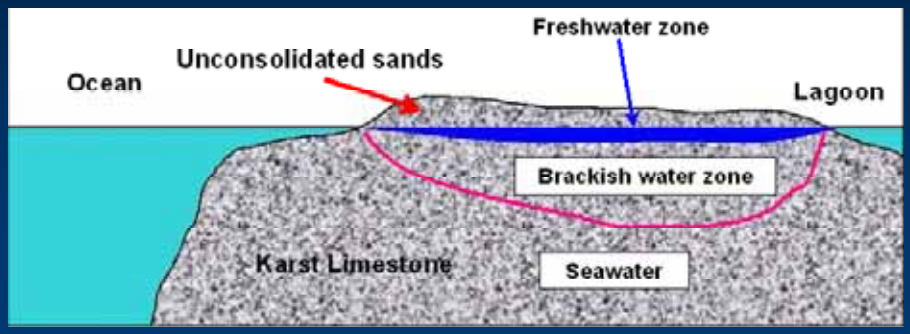


Vadose Zone J (2007) **6** 581-90

Hydrogeology

Groundwater Lens

Delicate balance between recharge , ET losses, discharge and mixing with seawater and groundwater abstraction



Critical Factors Controlling Fresh GW and Transition Zone

- Characteristic island width, W or area, A
- Groundwater recharge rate, R
- Characteristic aquifer hydraulic conductivity, K_0
- Pumping rate, Q
- Relative density contrast, $\alpha = (\rho_s - \rho_0)/\rho_0$
- Dispersion coefficient, D

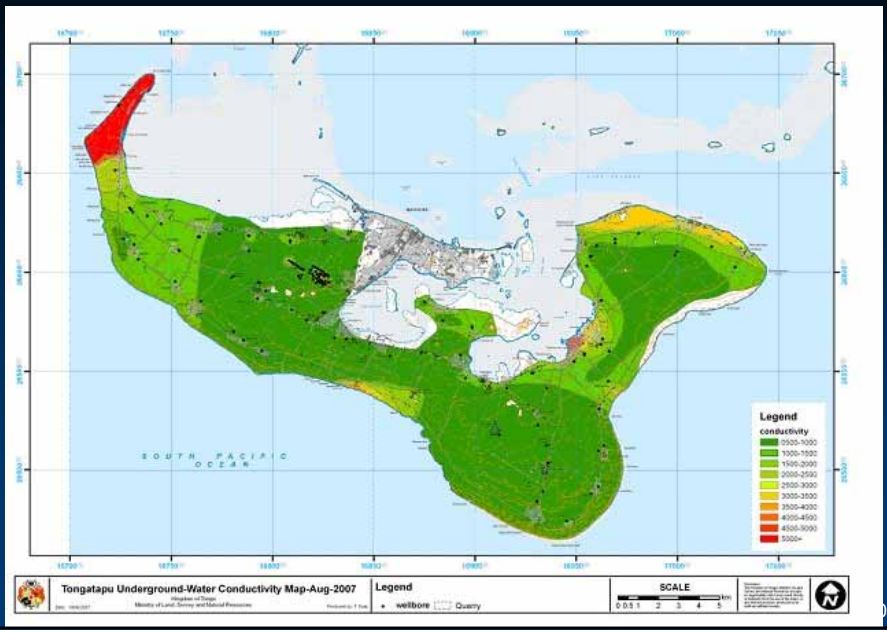
Dimensionless groups

R/K_0 $q = (Q/A)/R$ α $\alpha W K_0/D$ L/W

$$\frac{\delta_p}{H_p} = \frac{1}{1-q}\left(\frac{K_0}{R}\right)\left(\frac{D}{\alpha W K_0}\right)^{1/2}$$

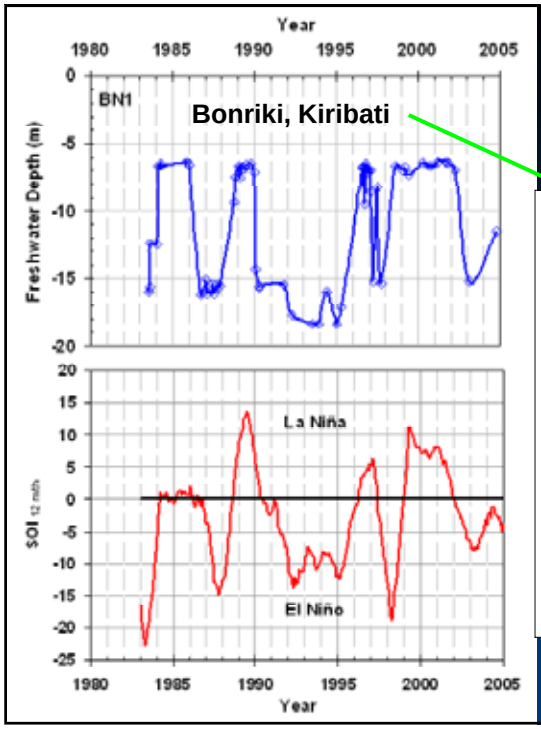
Vadose Zone J.(2007) **6**:581–590

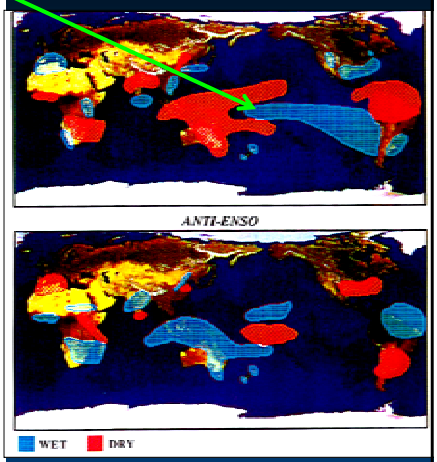
Groundwater Salinity Tongatapu



011

Freshwater depth & ENSO





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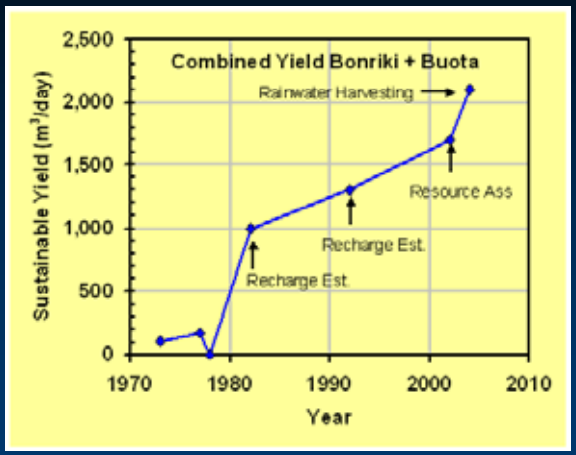
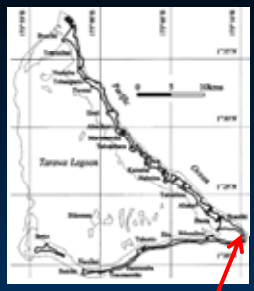
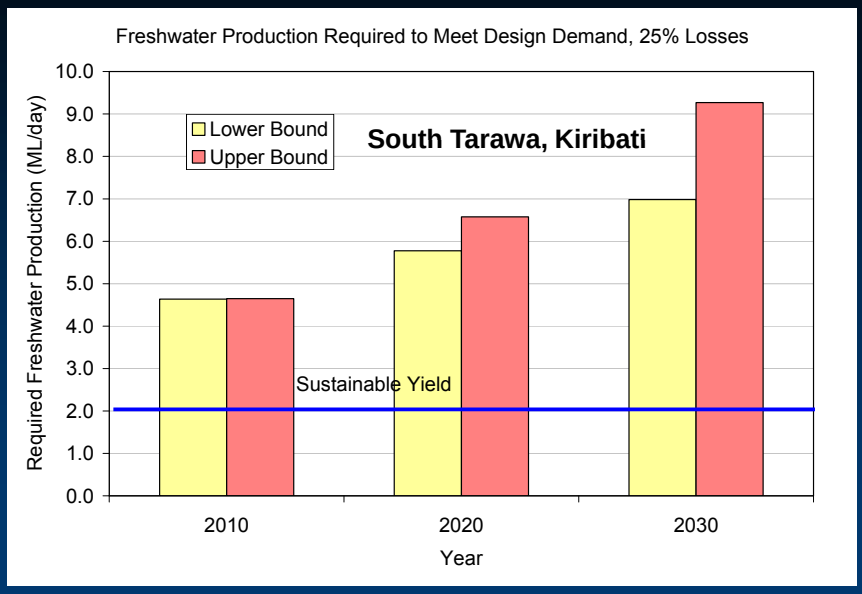
Assessment of Sustainable Groundwater Yield





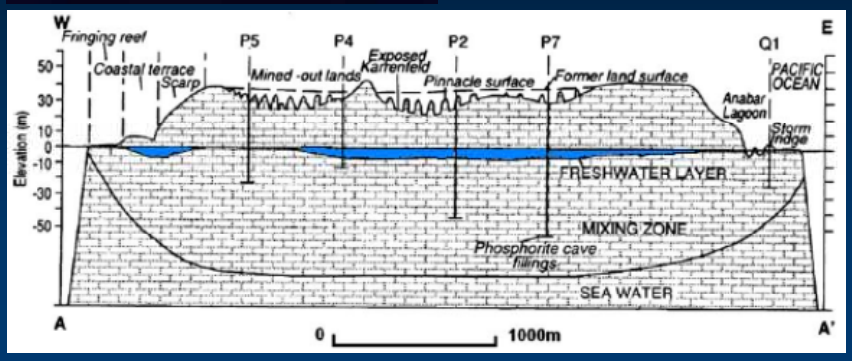
Bonriki, Tarawa, Kiribati

Sustainable Yield & Predicted Demand



Nauru-Groundwater Assessment

3 D numerical modelling based on 1987 drilling data



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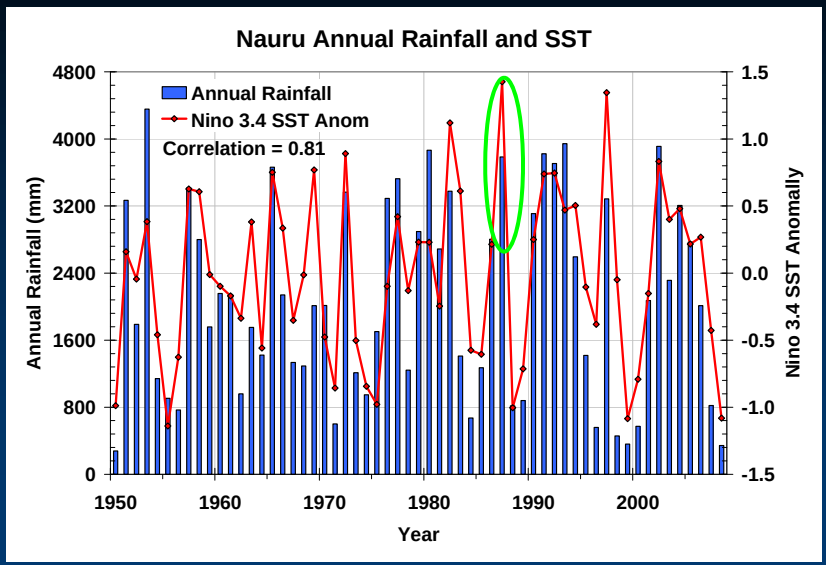
Nauru – Rainfall Variability



Recent Assessment of Nauru Groundwater

- Nauru has no major, sustained freshwater lens
- Discrepancy demonstrates:
  - Dynamic nature of freshwater lenses,
  - Their vulnerability to climate variability,
  - Fundamental importance of long-term monitoring , and
  - Sensitivity of groundwater models to calibration data
- Nauru has no water policy, plan, legislation or water agency nor any formal policy process.

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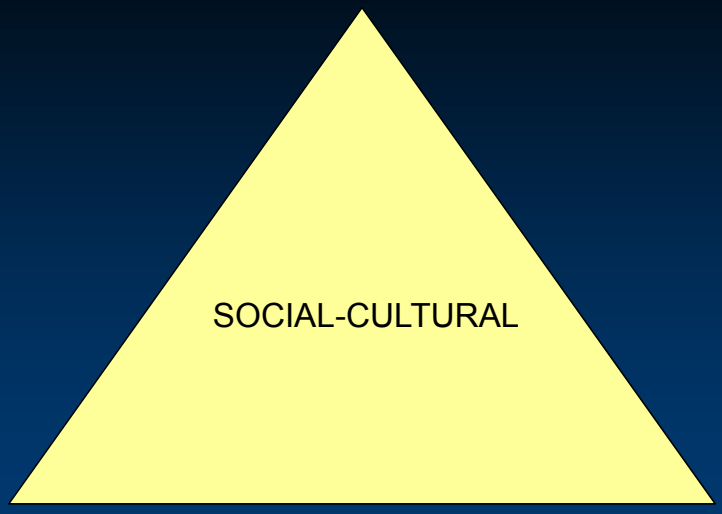
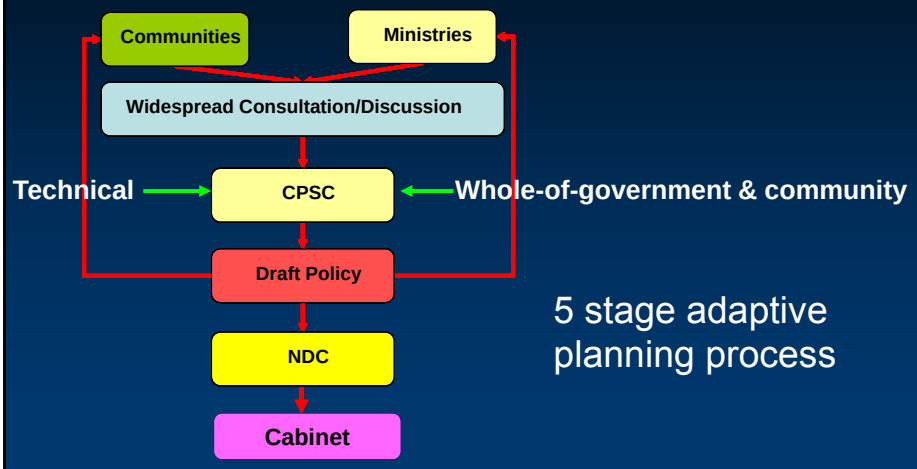
Bredehoeft (1997) Hierarchy in Nauru



Continuing Work in Nauru

Development of National Water Policy & Implementation Plans



5 stage adaptive planning process

Cultural Constraints

Conflict between the demands of an urbanised society and the traditions and practices of subsistence communities

- Land, principal wealth
- Access to land & common property resources essential for survival (urban areas)
- Land tenure has customary rights – ownership of groundwater
- Allegiance to extended family not society
- Reluctance to share knowledge

Bredehoeft (1997) Planned Hierarchy in PICs

Concluding Comments

- Incorporating climate variability in policy and plans remains a major challenge
- Soundly-based water science and engineering is fundamentally important to good water management
- Other factors contribute to decisions on water
- For hydrology to be incorporated effectively into policy, those factors must be recognised

Governance Issues

- Transition from subsistence culture to highly urbanised community
- Complexity of small, widely-dispersed communities & crowded urban centres
- Lack of equity – urban vs rural
- Knowledge gaps - sustainable yields
- No national water policy/legislation/plans
- No whole-of-government approach
- No engagement of the community
- Very limited capacity & resources

>15,000 pers/km^2