UNIVERSITÉ MONTPELLIER 2
SCIENCES ET TECHNIQUES

Ecole Doctorale SIBAGHE
Systèmes Intégrés en Biologie, Agronomie, Géosciences, Hydrosciences et Environnement

Habilitation à Diriger des Recherches

L'étude de la variabilité des hydrosystèmes hétérogènes au moyen des traceurs environnementaux dans un contexte de changement global

Sarah Tweed

IRD Institut de recherche pour le développement

G-eau
Gestion de l'Eau, Acteurs, Usages

Éducation et emploi

Hydrogéologue, Hydrochimiste

Emplois

2013-actuel Chercheur - IRD, UMR G-eau, Montpellier
2010-2013 Lecturer (MCF) - Université de James Cook, Australie
2007-2010 Chercheur - Université de James Cook, Australie
2003-2006 Chercheur - Universités de Monash et de Melbourne, Australie

Formations

2003 Ph.D. (Doctorat) - Université de Melbourne, Australie
1998 Bachelor of Science (Honours) - Université de Melbourne, Australie

Recherche

Comment peut-on améliorer notre compréhension de la variabilité des hydrosystèmes hétérogènes à partir des traceurs environnementaux ?

Forçage intrinsèque

i. Hétérogénéités géologiques

Forçages externes

ii.Fluctuations climatiques

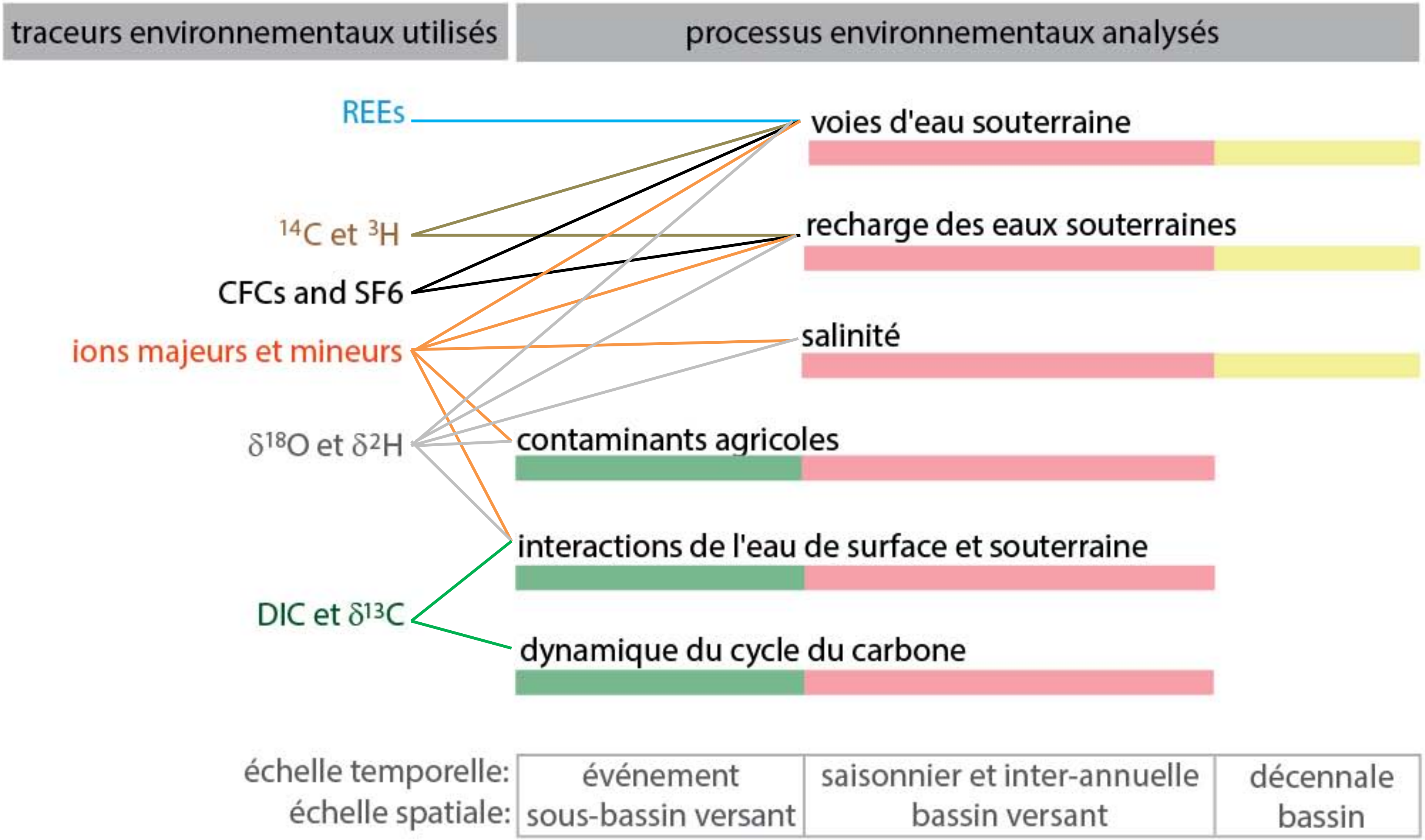
iii.Pressions anthropiques

Etudes de cas

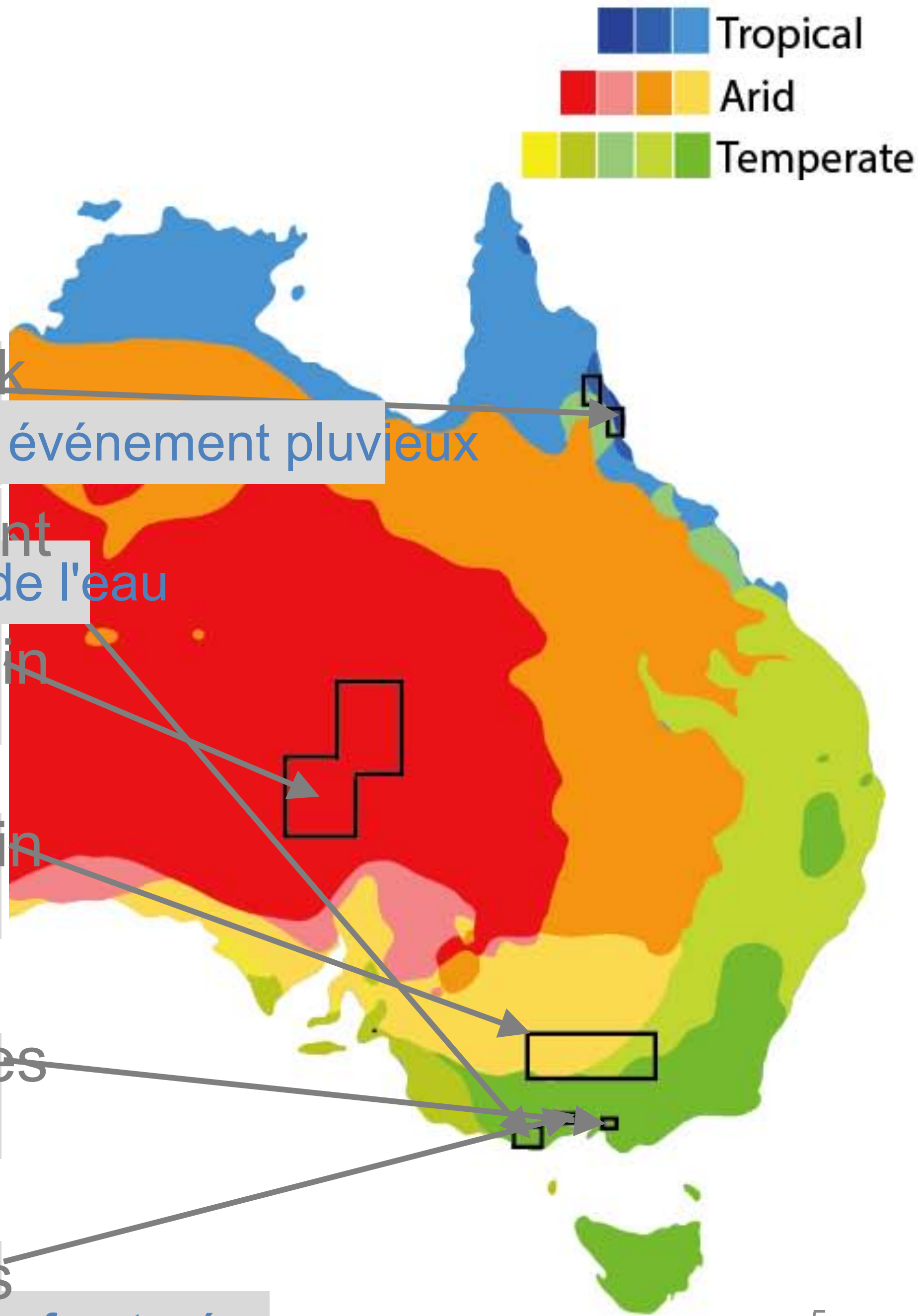
- Problématiques
- Conditions environnementales
- Echelles espace-temps

Quels sont les traceurs adaptés au site ?

Approche : Traceurs Environnementaux



Etudes de cas



Scheu Creek
Transport des contaminants pendant un événement pluvieux

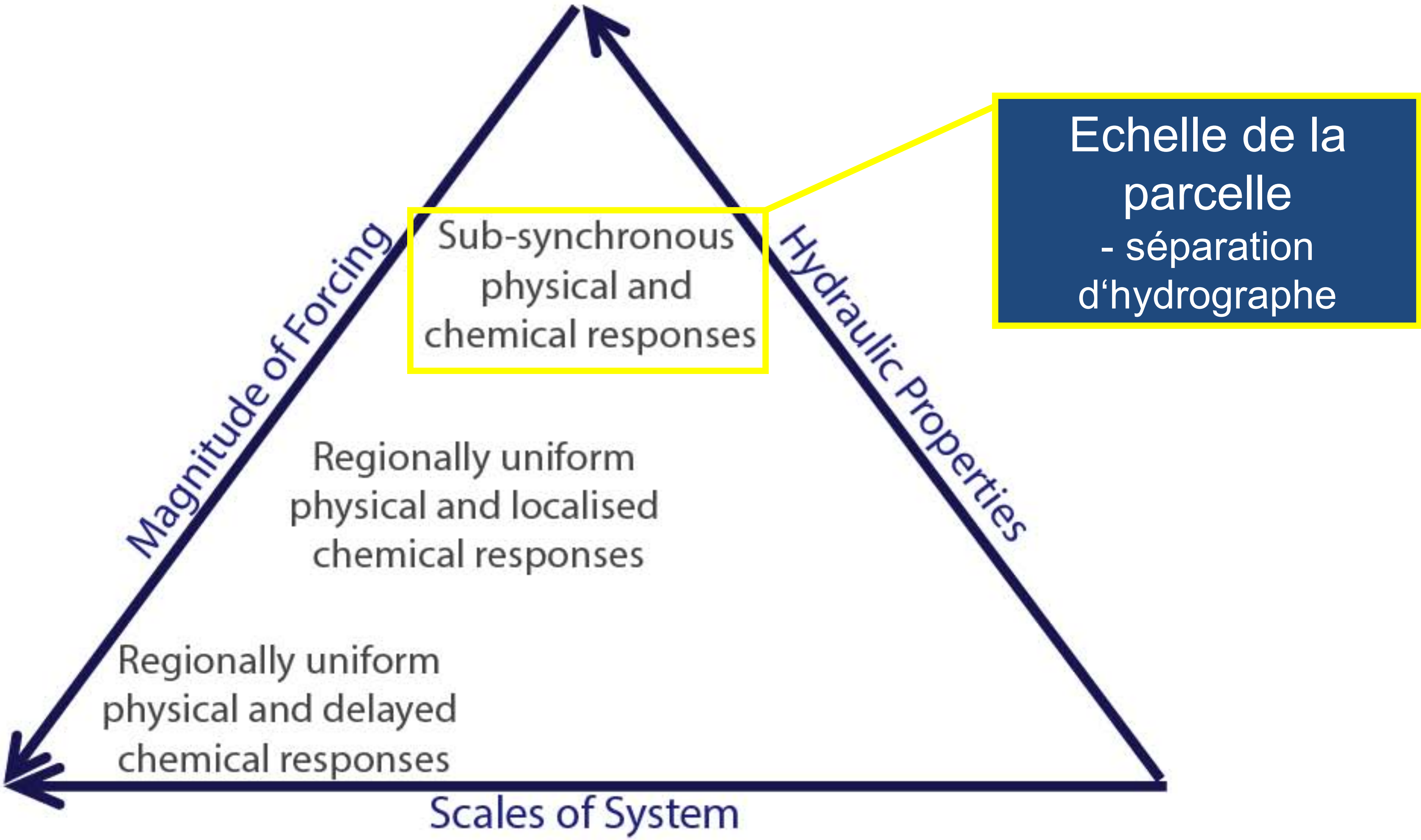
Corangamite Catchment
Impacts de la sécheresse sur la qualité de l'eau

Lake Eyre Basin
Recharge par les plaines d'inondation

Murray Groundwater Basin
Contrôles de salinité

Dandenong Ranges
Mélange dans des aquifères fracturés

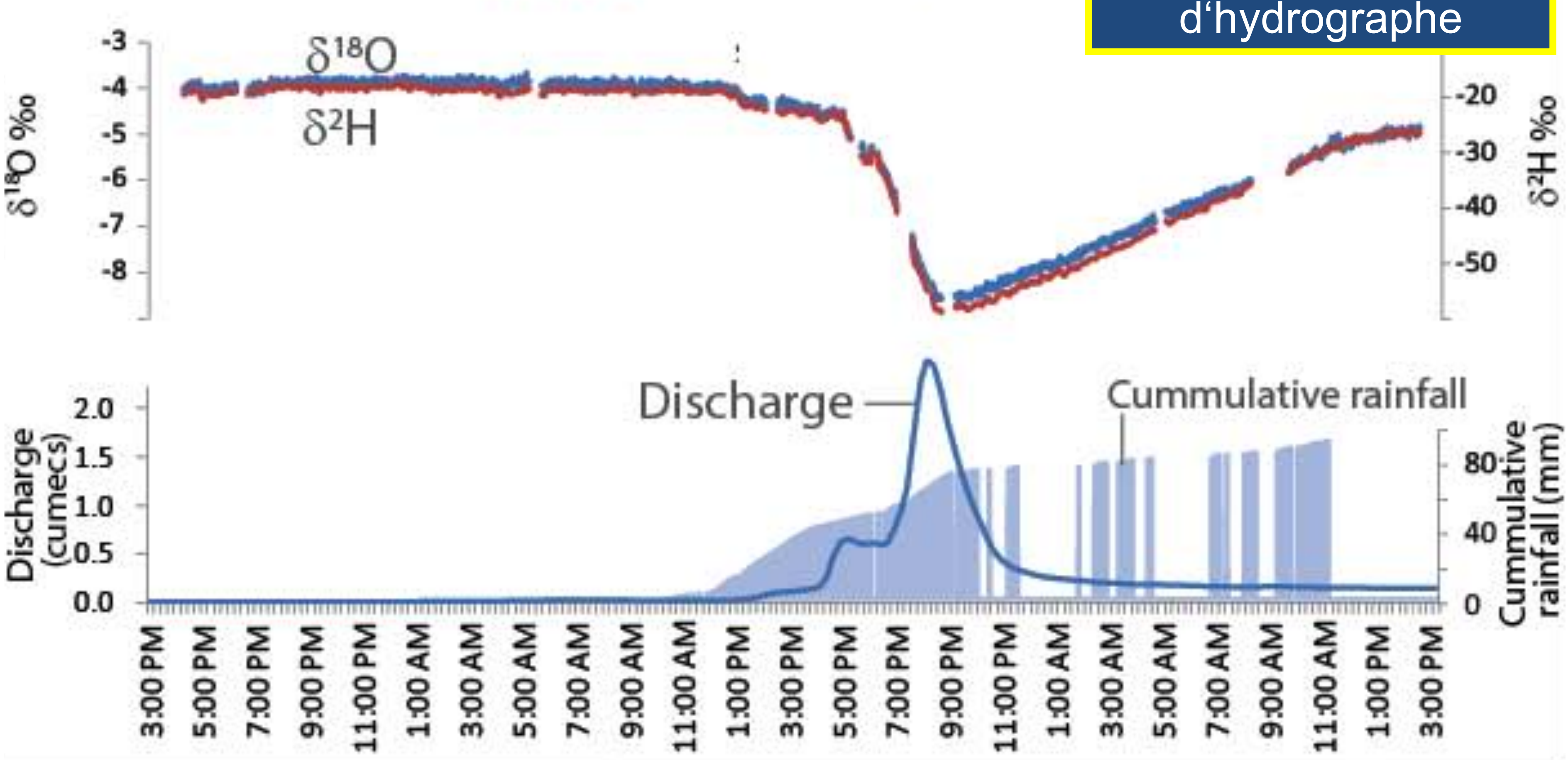
Mineral Springs
Ecoulements profonds dans les aquifères fracturés

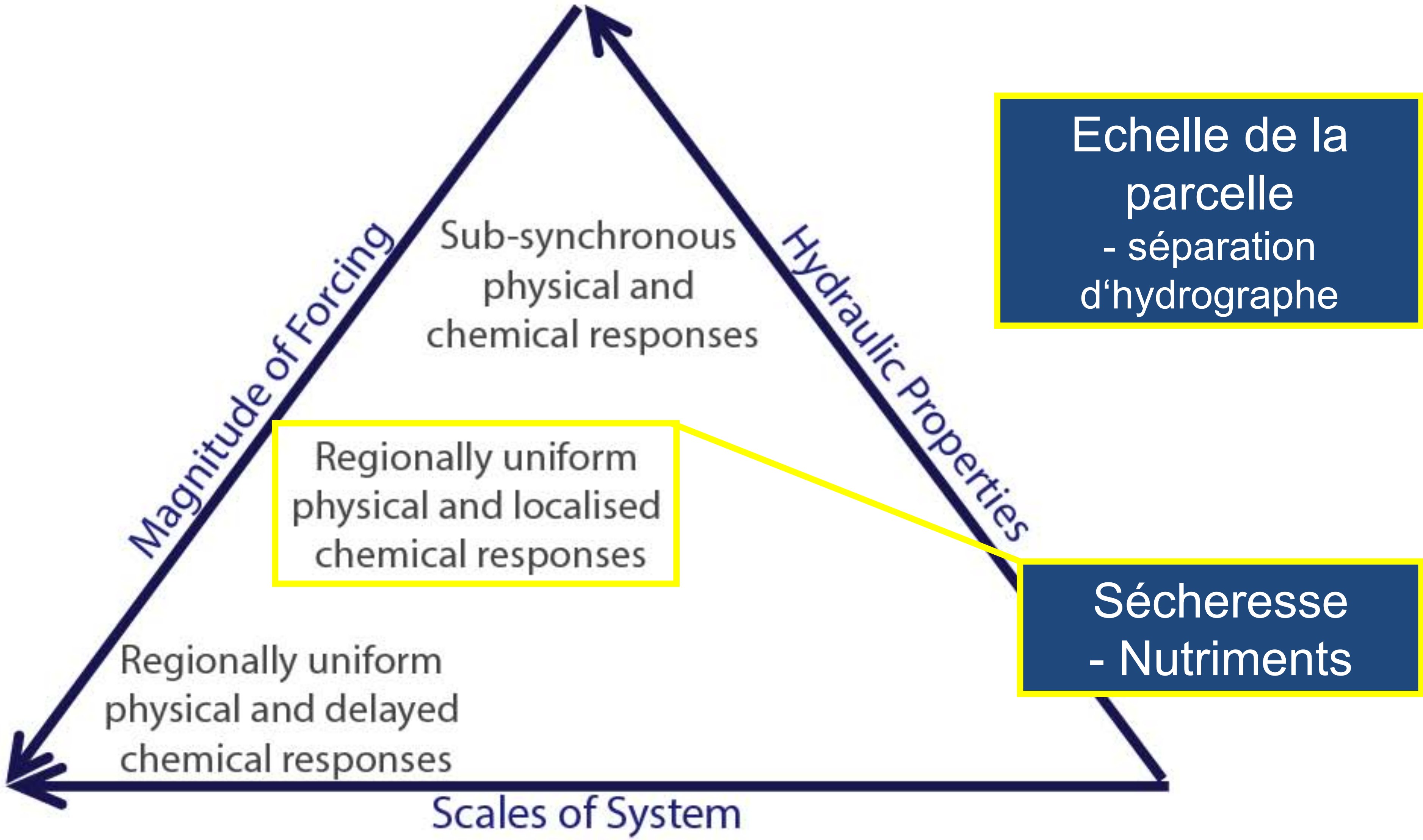


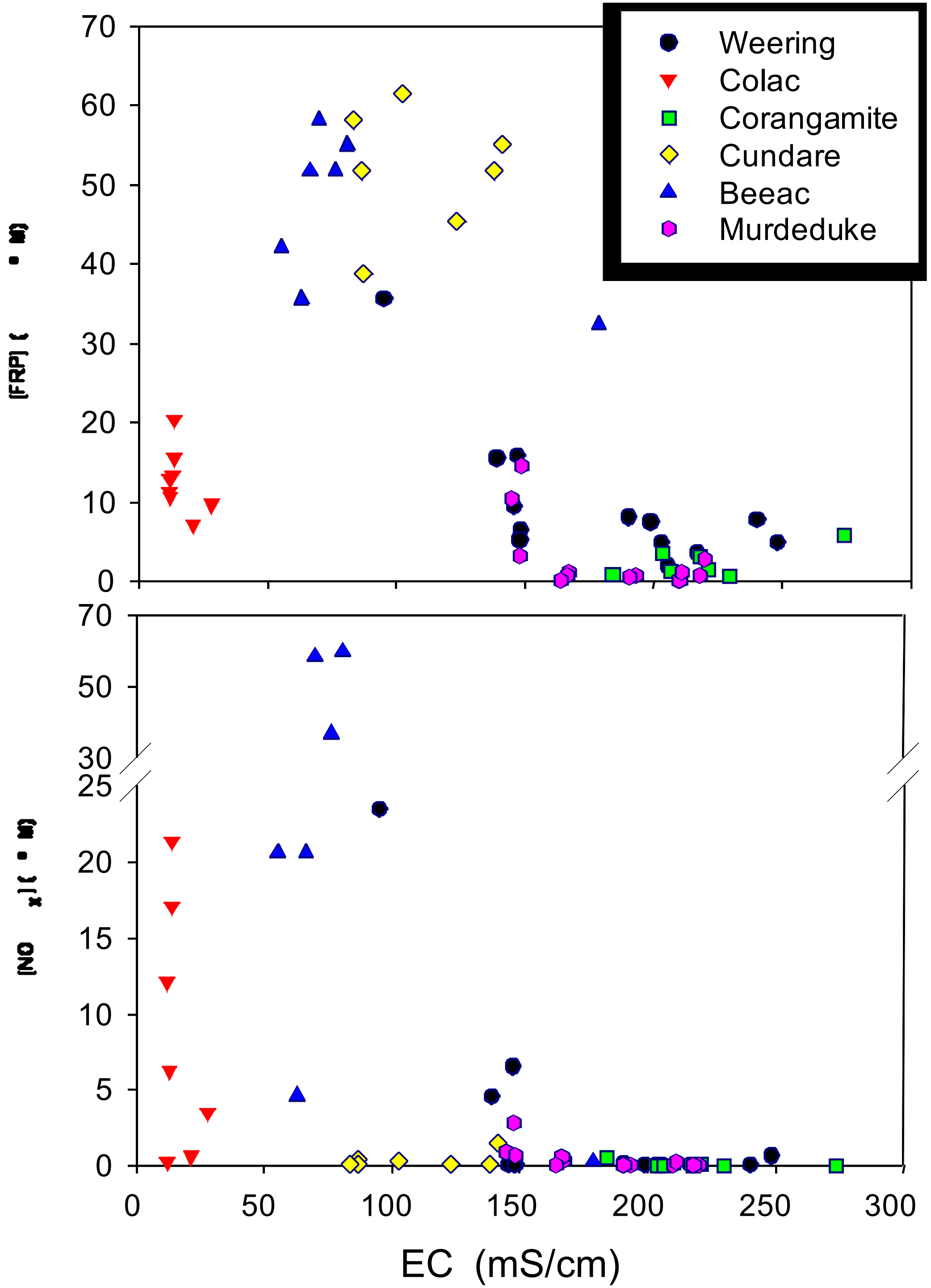
Synthèse des forçages externes

Echelle de la parcelle

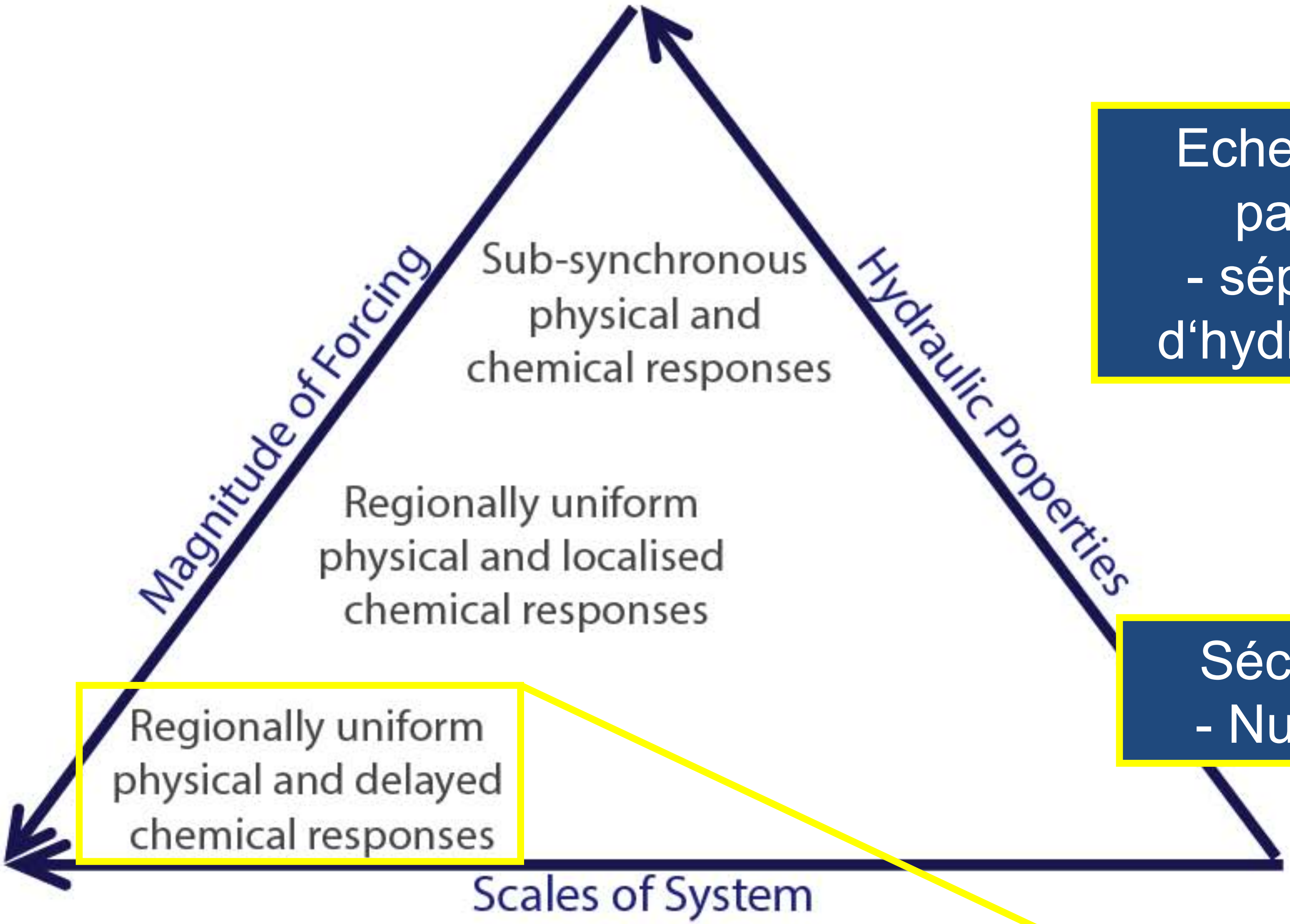
- séparation d'hydrographe




Sub-synchronous physical and chemical responses
Regionally uniform physical and localised chemical responses
Regionally uniform physical and delayed chemical responses
Magnitude of Forcing
Hydraulic Properties
Scales of System
Echelle de la parcelle
- séparation d'hydrographe
Sécheresse
- Nutriments



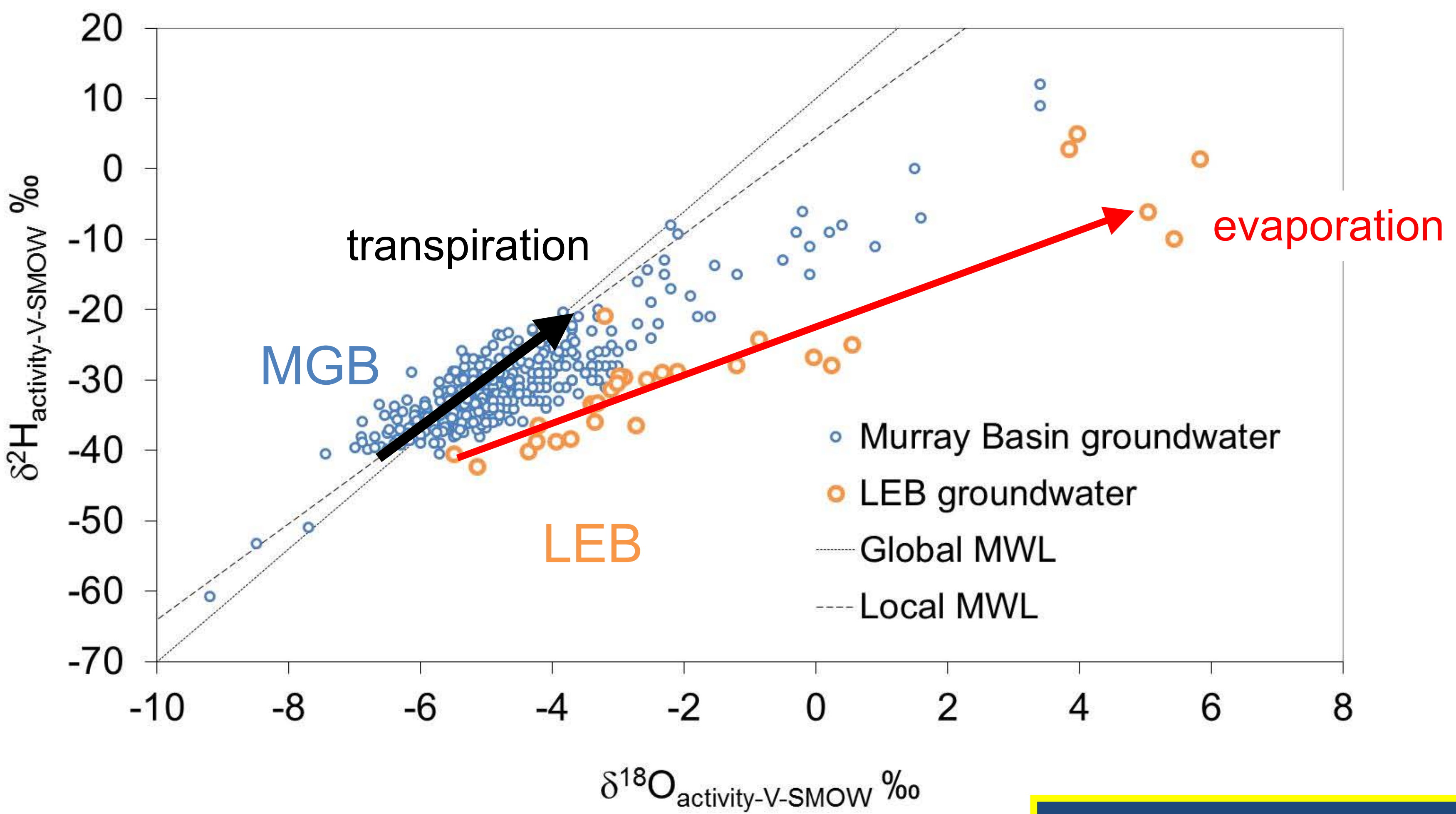
Sécheresse
- Nutriments



Echelle de la parcelle
- séparation d'hydrographe

Sécheresse
- Nutriments

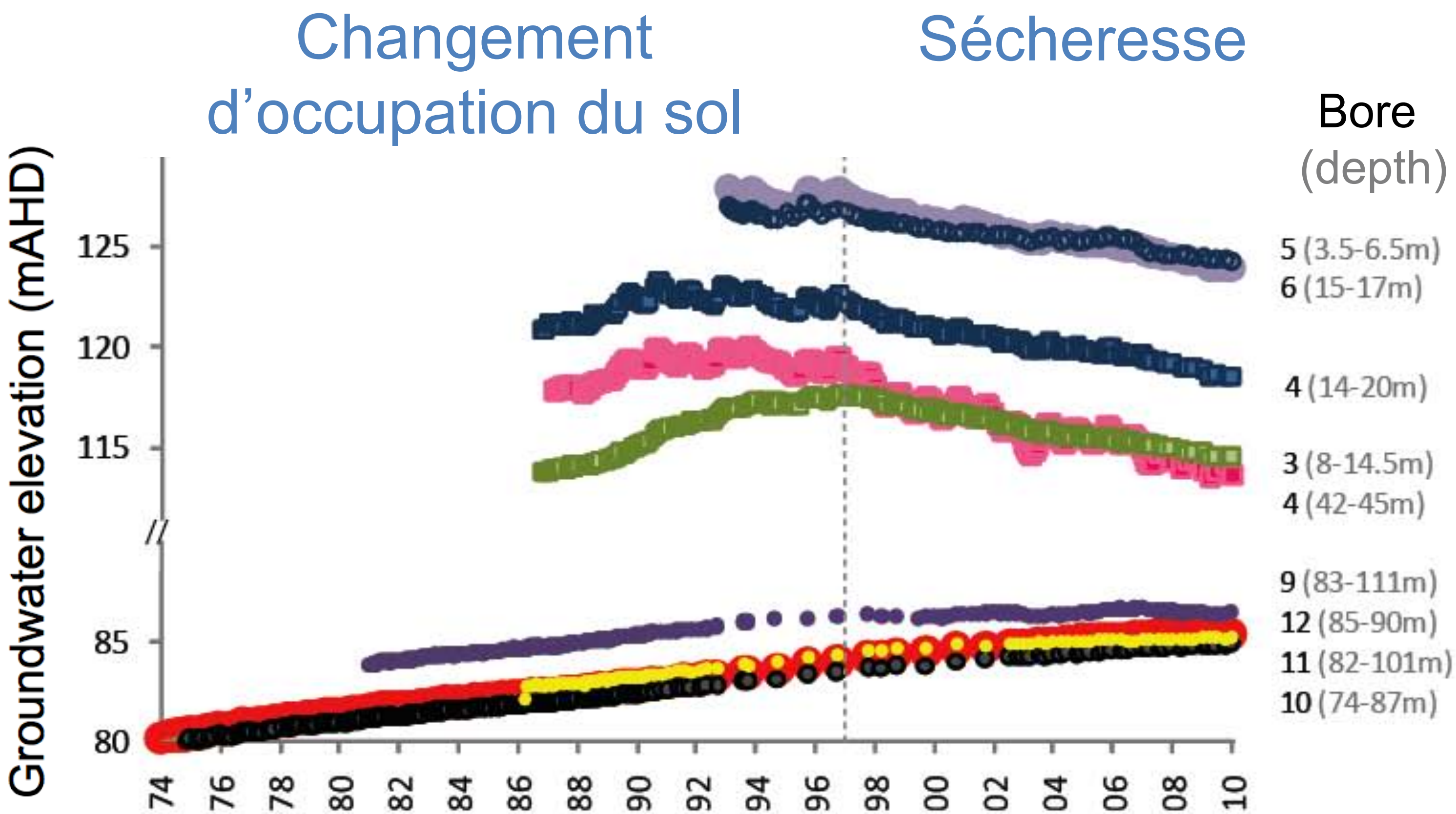
Changement d'occupation du sol
- Salinité



- Transpiration des eaux souterraines dans le MGB (semi-aride)

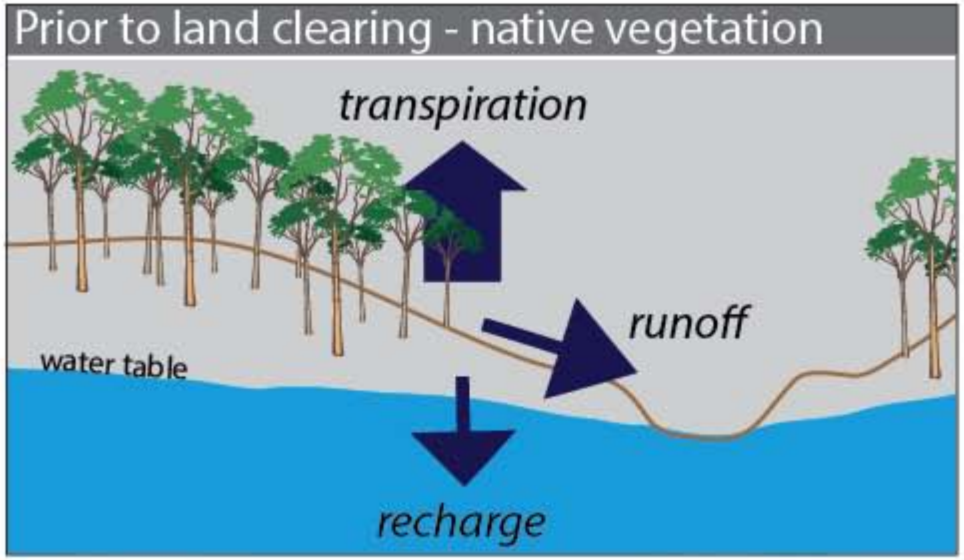
Changement d'occupation du sol

- Évaporation des eaux souterraines dans le LEB (aride)

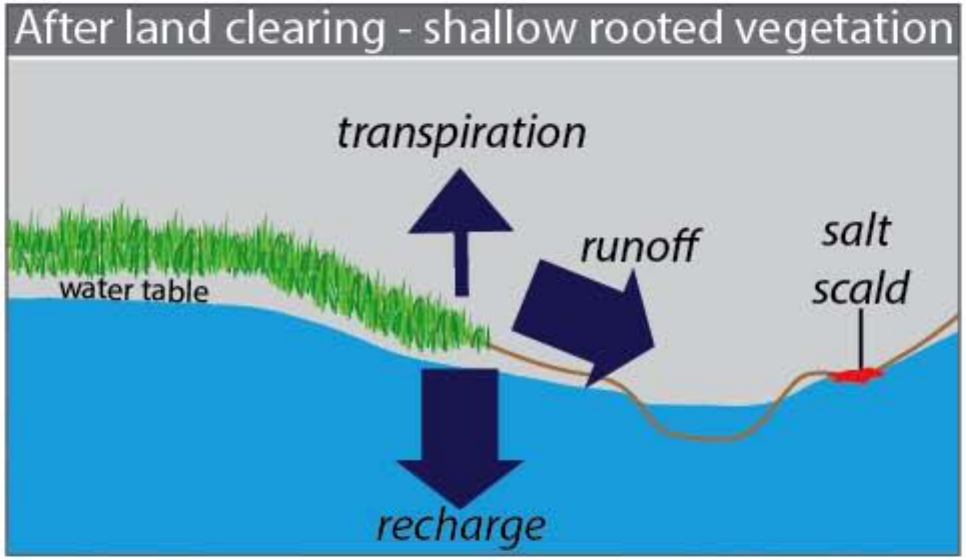


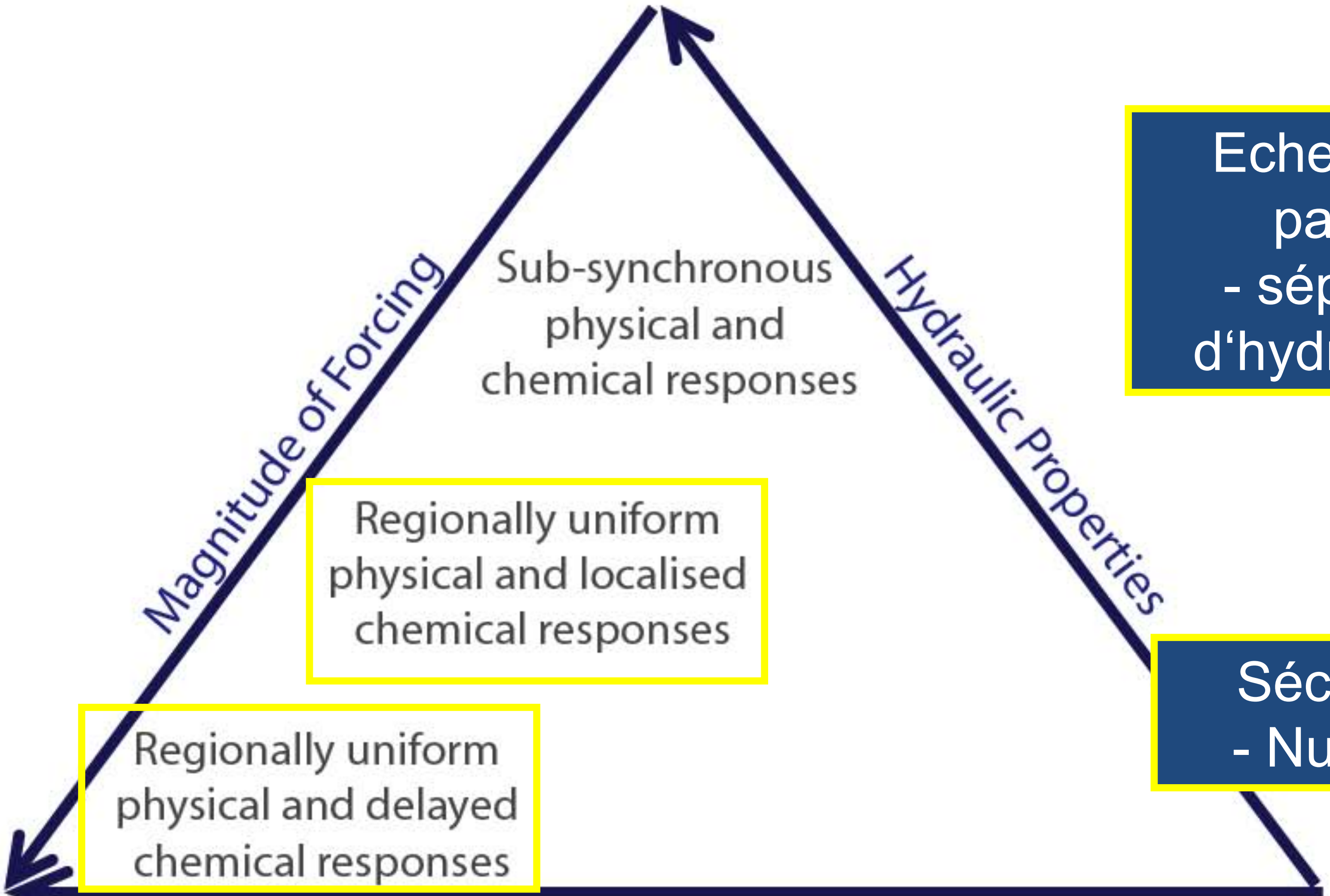
Changement d’occupation du sol
Sécheresse
Bore
(depth)
Groundwater elevation (mAHD)
125
120
115
85
80
74
76
78
80
82
84
86
88
90
92
94
96
98
00
02
04
06
08
10
5 (3.5-6.5m)
6 (15-17m)
4 (14-20m)
3 (8-14.5m)
4 (42-45m)
9 (83-111m)
12 (85-90m)
11 (82-101m)
10 (74-87m)

Transpiration :
système avant changement d'occupation du sol



Augmentation du niveau des nappes :
système après changement d'occupation du sol (pratiques agricoles européens)





Echelle de la parcelle
- séparation d'hydrographe

Sécheresse
- Nutriments

<u>Défis</u>

- Distinguer forçages actuels et historiques effet sur la qualité de l'eau
- Utilisation de traceurs environnementaux pour contraindre les processus physiques dans les hydrosystèmes

<u>Avantages</u>

Chimie peut mettre en évidence les processus historiques importants que le système physique actuel ne représente plus

Utilisez les leçons apprises dans ces hydrosystèmes

i. Échelles et forçages multiples
ii. Représentativité des données
iii. Traceurs multiples
iv. Les systèmes régionaux

Projets de recherche actuels et futurs

Datation des eaux souterraines

-> Fonctionnement hydrologique : Niger, Australie

Hydrosystèmes fortement modifiées

-> Irrigation : Senegal, Maroc

-> Transport de contaminants agricoles : Australie, France

-> Fonctionnement du continuum eau-sol-plante sous conditions climatiques extremes : France

Australian Research Council
Victorian Mineral Waters Commission
Corangamite Catchment Management Authority
National Groundwater Centre



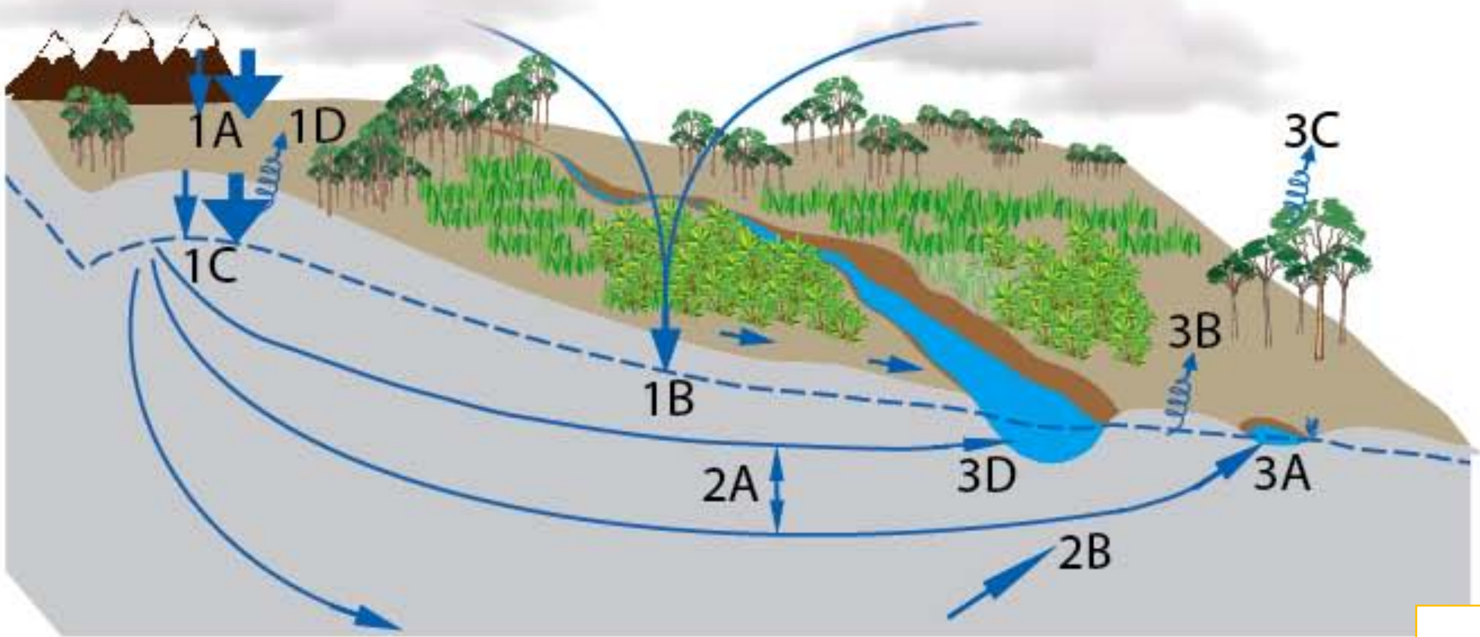

Thanks







1. Research Retrospective



physical

1. Recharge	2. Flow Pathways	3. Discharge
A. rainfall intensity and seasonal rainfall($\delta^{18}O$, $\delta^{2}H$) B. rainfall origin ($\delta^{18}O$, $\delta^{2}H$) C. via dual porosity (^{3}H, ^{14}C) D. evaporation during recharge ($\delta^{18}O$, $\delta^{2}H$)	A. mixing (majors, CFCs, ^{14}C) B. deep groundwater flow ($\delta^{18}O$, $\delta^{2}H$)	A. to lakes (Cl/Br, Cl) B. via evaporation ($\delta^{18}O$, $\delta^{2}H$) C. via transpiration ($\delta^{18}O$, $\delta^{2}H$) D. to rivers ($\delta^{18}O$, $\delta^{2}H$, Si)
- recent (CFCs, SF6) - paleo ($\delta^{18}O$, $\delta^{2}H$, ^{14}C)	- origin of solutes ($\delta^{13}C$, majors/trace) - controls on salinity ($\delta^{18}O$, $\delta^{2}H$, Cl/Br, majors)	- transfer of inorganic carbon (DIC, $\delta^{13}C$) and contaminants (nutrients, herbicides, pesticides)

chemical

Study area	Climate	Mean annual rainfall (mm)	Terrain	Dominant geology	Dominant land use	Hydrosystem process studied
Mineral Springs*	temperate oceanic	880	valleys and base of hillslope	basalt and sediments	grazing and dryland cropping	spring water origins and flow pathways
Dandenong Ranges*	temperate oceanic	600 - 1200	highlands	basalt and marine sediments	horticulture	recharge processes, groundwater flow in fractured aquifers
Corangamite Catchment*	temperate oceanic	730	plains	basalt, and alluvial sands and clays	grazing and dryland cropping	drought impacts on water quality
Glenelg Hopkins Catchment	temperate oceanic	550	plains	basalt, and alluvial sands and clays	grazing and dryland cropping	groundwater and lakes interactions
Murray Groundwater Basin*	cold semi-arid	400–600	plains	paleochannels, and alluvial sands and clays	grazing and dryland cropping	salinity processes and groundwater pathways
Lake Eyre Basin*	warm desert	140-260	plains	sand, clay and sandstone	grazing	salinity and recharge processes
South Johnstone (Scheu Creek)*	monsoon	3500	base of hillslope	basalt and sediments	sugar cane	groundwater and creek interactions, transport of contaminants and DIC
Atika Creek Catchment*	monsoon	1990	base of hillslope	mudstone siltstone	forested	transport of DIC
Mitchell River Basin*	monsoon and tropical savanna	1600	highlands and plains	sediments and igneous intrusive	forested and grazing	recharge origins, groundwater and river interactions, transport of [
Cape York Springs	tropical savanna	1900	valleys and base of hillslope	sandstones, bauxites, ferricrete, sand	forested and grazing	spring water origins

Environmental tracer sampling regime

Increasing study area	Number of sampling sites	Temporal resolution
Scheu Creek	6	hourly over 2 days; creek continuous (1 min)
Atika Creek	2	hourly over 2 days; creek continuous (15 min)
Dandenong Ranges	14	4 seasons (over 2 years)
Glenelg Hopkins Catchment	11	3 seasons (over 1 year)
Mitchell River Basin	13	weekly-monthly (over one year)
Mineral Springs	34	monthly (over 4 months)
Corangamite Catchment	6	monthly (over 2 years)
Cape York Springs	10	once
Murray Groundwater Basin	440	once
Lake Eyre Basin	36	3 seasons (over 1 year)

CFCs

Processes impacting CFCs

Recharge conditions

- CFC solubility is affected by recharge temperature
- Excess air effect; enrichment of CFC-12 relative to CFC-11 during dissolution of air bubbles that are trapped in the unsaturated zone

Aquifer and groundwater chemistry

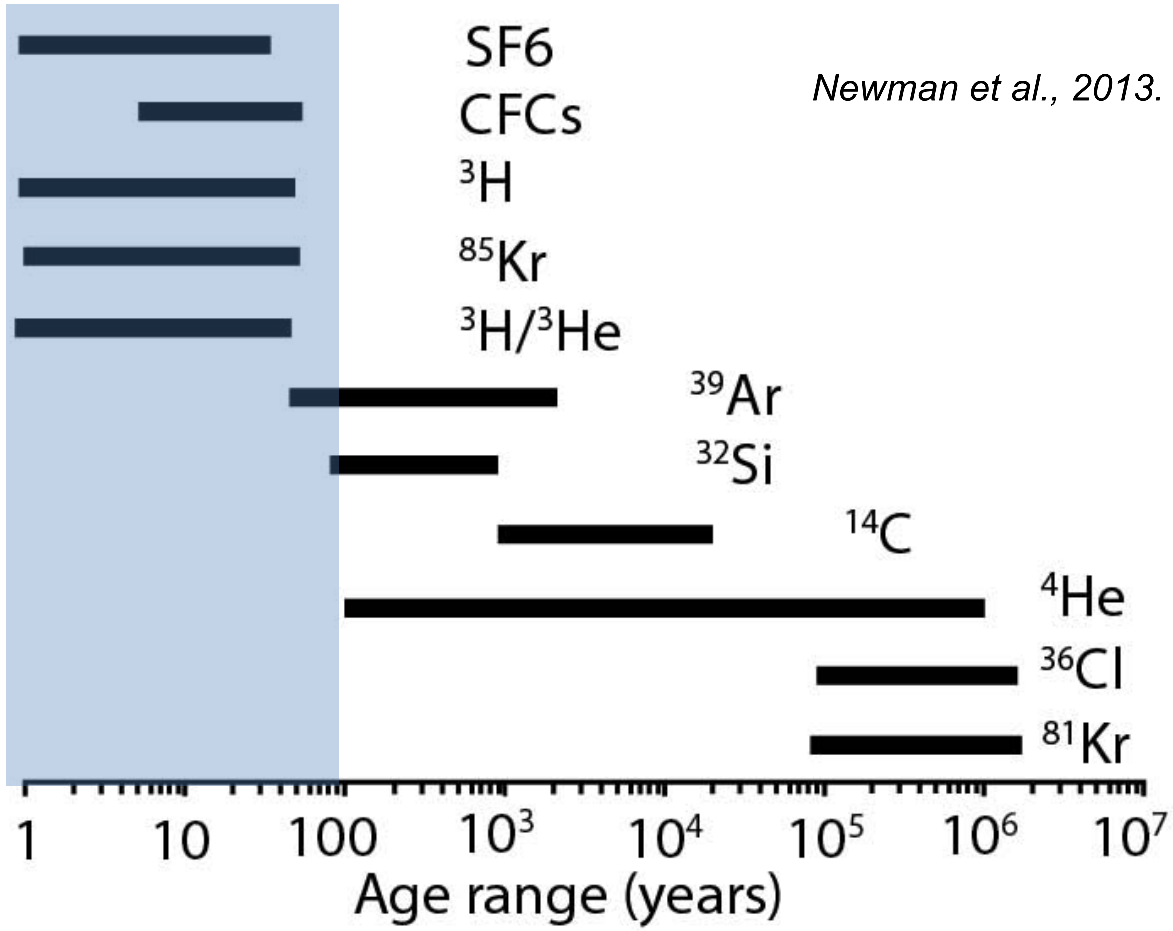
- In organic-rich aquifers sorbtion onto organic and mineral surfaces; increases in CFC-12 to CFC-11 and CFC-13
- Anaerobic microbial degradation; rapid loss of CFC-11 and CFC-13 compared with CFC-12
- In industrial and urban regions CFC contamination

During flow

- Vertical velocity and connectivity of fracture networks
- Mixing between fracture and matrix waters
- Solute diffusion effects

Improvements to CFC dating

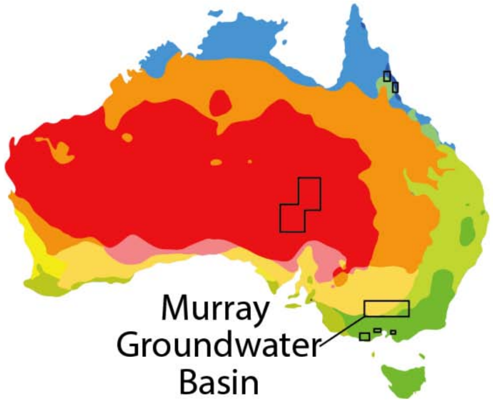
- Other dating tracers
- Noble gases to correct for excess air
- Environmental tracers to identify mixing effects
- Solute modelling to identify diffusive transport effects



Newman et al., 2013.

14C

Mixing in alluvial aquifers – Murray Groundwater Basin



Questions

Investigation of heterogeneous geological controls on inter-aquifer mixing

Approach

^{14}C

•Part of a greater research project which incorporates ^{14}C with $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ in MGB (~100 000 km^2)

Management Links

Water resource sustainability in a large agricultural basin

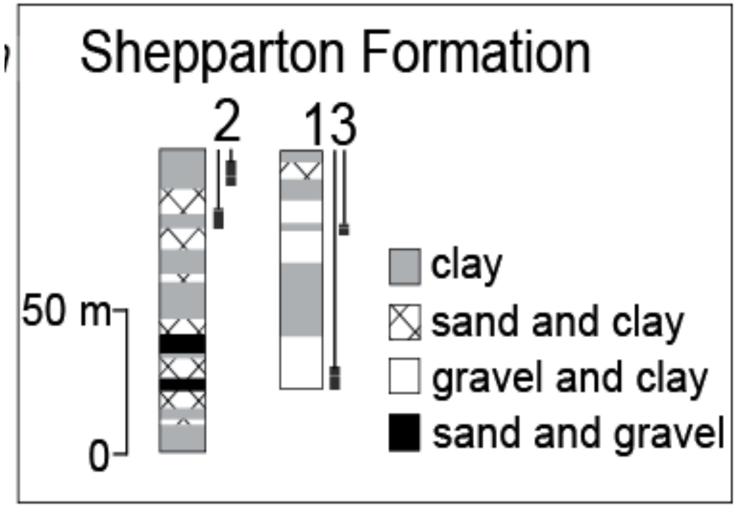
Funding

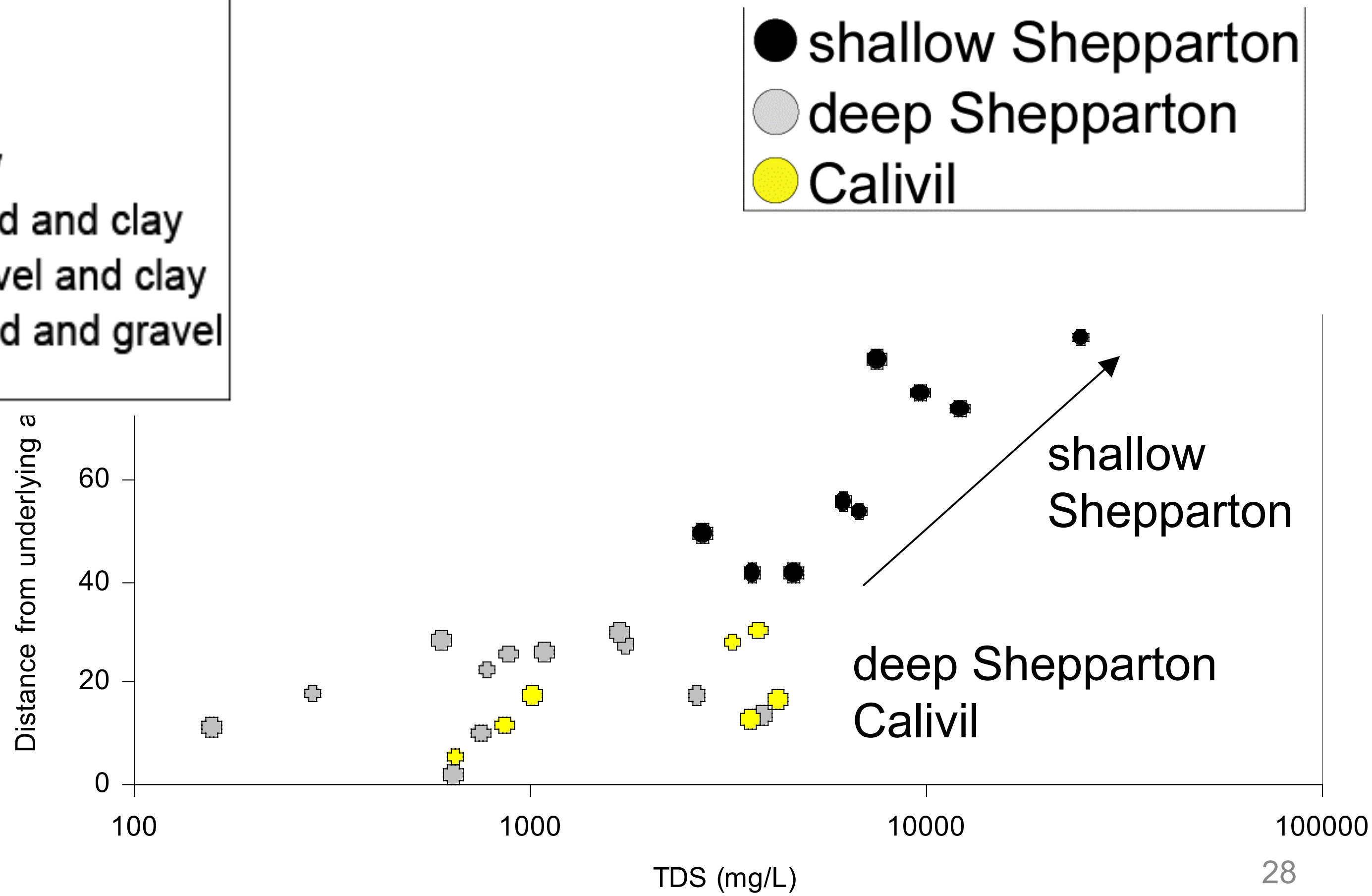
ARC

Cartwright, I., Weaver, T.R., Cendón, D.I., Fifielde, L.K., Tweed, S.O., Petrides B., Swane, I. 2012. Constraining groundwater flow, residence times, inter-aquifer mixing, and aquifer properties using environmental isotopes in the southeast Murray Basin, Australia. Applied Geochemistry, 27, 1698-1709.

Mixing in alluvial aquifers - Murray Groundwater Basin

- Deeper aquifers: fresher (TDS: 160 - 4,250 mg/L)
- Shallower aquifers: more saline (TDS: 2,180 - 24,700 mg/L)

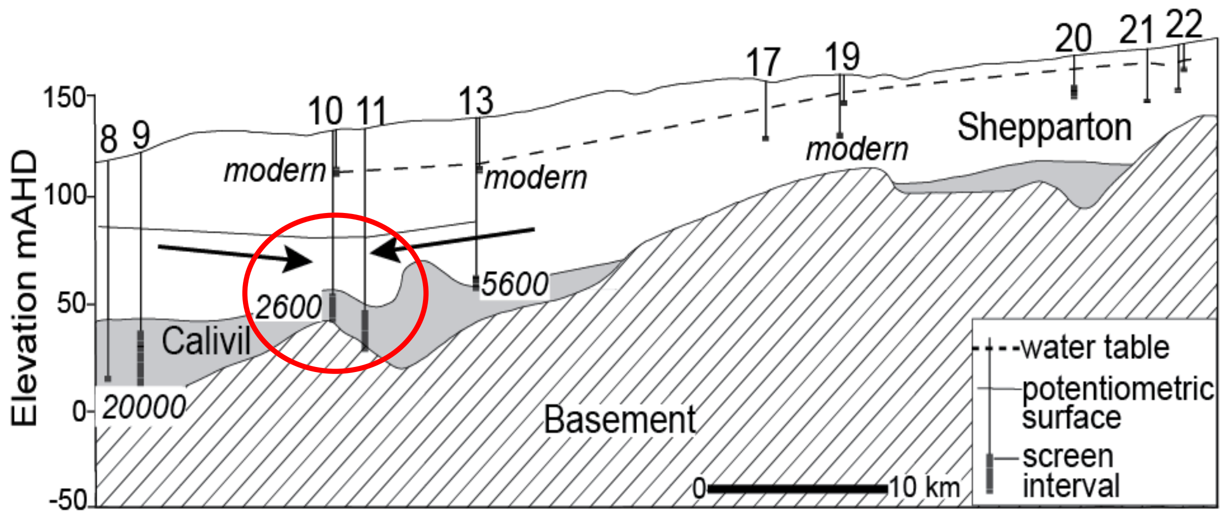




Mixing in alluvial aquifers - Murray Groundwater Basin

^{14}C

- 7 to 101 pmC
- Groundwater < 30m depth: modern recharge
- Groundwater 66-109 m: 2600-20000 years
- ^{14}C - areas of infiltration from the shallower system



Mixing in alluvial aquifers - Murray Groundwater Basin

$\delta^{18}O$ and $\delta^{2}H$

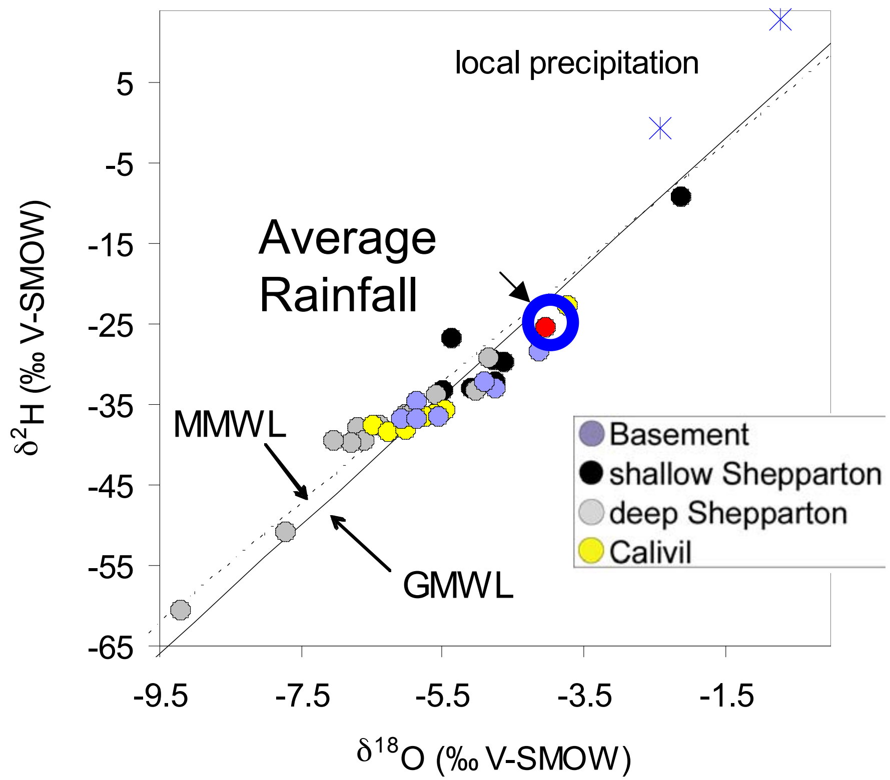
No correlation with ^{14}C age

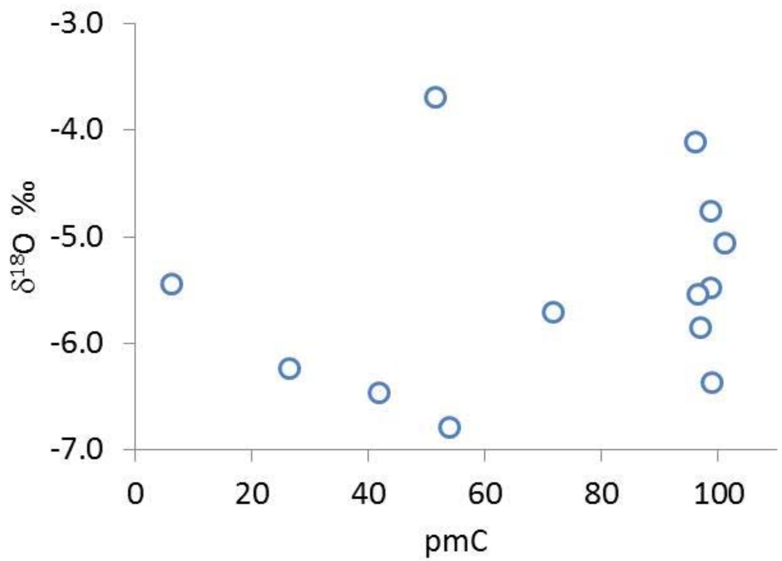
-> Older and younger groundwater recharged under similar conditions

or

-> Other factors effecting ^{14}C age

- Errors in ^{14}C correction
- Mixing
- Diffusion





Mixing in alluvial aquifers - Murray Groundwater Basin

^{14}C

Qualitatively infer groundwater mixing between two aquifers of complex alluvial deposits

•across MGB: significant inter-aquifer mixing

Mixing in alluvial aquifers - Murray Groundwater Basin

Challenges in calculating the residence time of water using ^{14}C

•Determination of the initial ^{14}C content, A_o; infiltrating water is isolated from unsaturated zone ^{14}C reservoir

•Mixing between waters

•Diffusive transport

•Heterogeneous geochemical reactions in aquifer

- Dissolution of carbonate minerals or organic material from the aquifer matrix;
- Deep-seated CO_2 from volcanic activity;
- CH_4 generated via the breakdown of organic material in the aquifer matrix

Mixing in alluvial aquifers - Murray Groundwater Basin

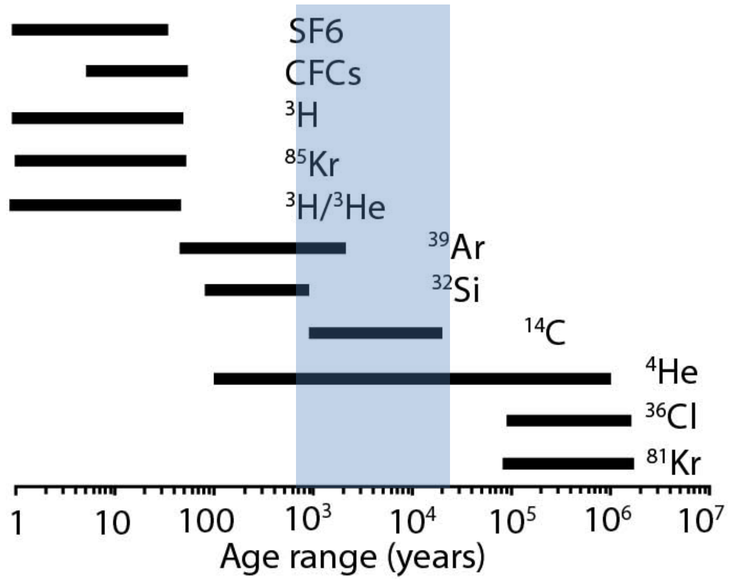
To overcome these challenges

•Multiple tracers of similar timeframes

•Environmental tracers to explore mixing

•Solute models to explore diffusion affect

•Correct for geochemical reactions;



- Dissolution of carbonates corrected using dilution factor (*q*)
  - Measured $\delta^{13}C$ of groundwater -16.6 to -8.8 ‰ V-PDB
  - Estimate of $\delta^{13}C$ of calcite dissolved 0‰ V-PDB
  - Estimate of $\delta^{13}C$ of soil -23‰ V-PDB
  - Estimate of recharge pH

^{14}C correction

Heterogeneous dissolution of carbonates corrected using dilution factor (*q*)

$$t = -8267 \times \ln\left(\frac{a_t\,{}^{14}C}{q \times a_o\,{}^{14}C}\right)$$

-8267 is the decay constant, a_t is the activity after some time, and a_o is the initial activity

$$q_{\delta^{13}C} = \frac{\delta^{13}C_{DIC} - \delta^{13}C_{carb}}{\delta^{13}C_{rech} - \delta^{13}C_{carb}}$$

$\delta^{13}C_{DIC}$ is groundwater -16.6 to -8.8 ‰ V-PDB, $\delta^{13}C_{carb}$ is calcite dissolved ~ 0‰ V-PDB

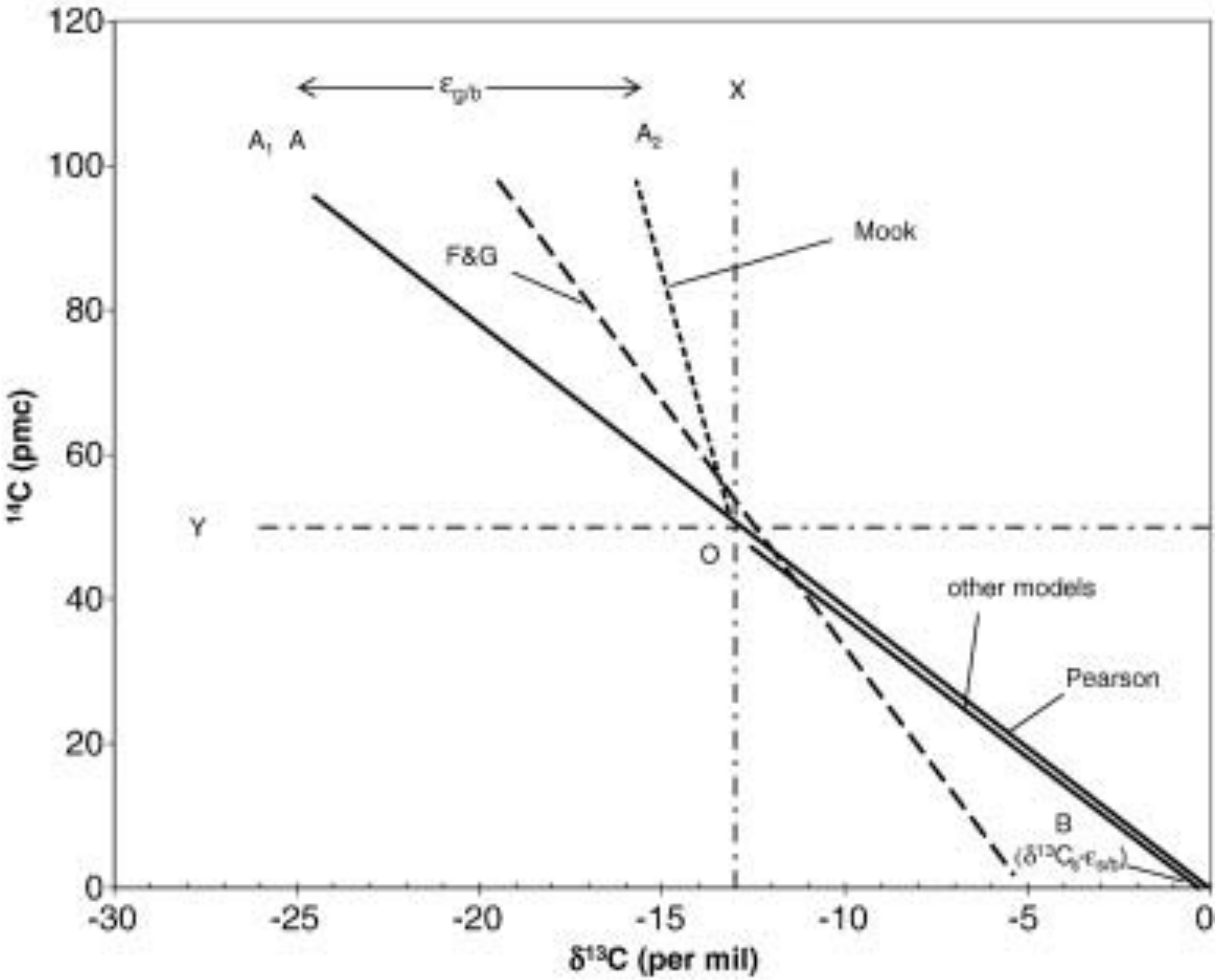
$$\delta^{13}C_{rech} = \delta^{13}C_{soil} + \varepsilon^{13}C_{DIC-CO_{2(soil)}}$$

δ^{13}C of soil ~ -23‰ V-PDB

enrichment between soil CO_2 and aqueous carbon ~ 2.4-8.5 ‰ V-PDB

- Recharge pH assumed
- Estimates of soil and calcite δ^{13}C values

Han and Plummer, 2013.

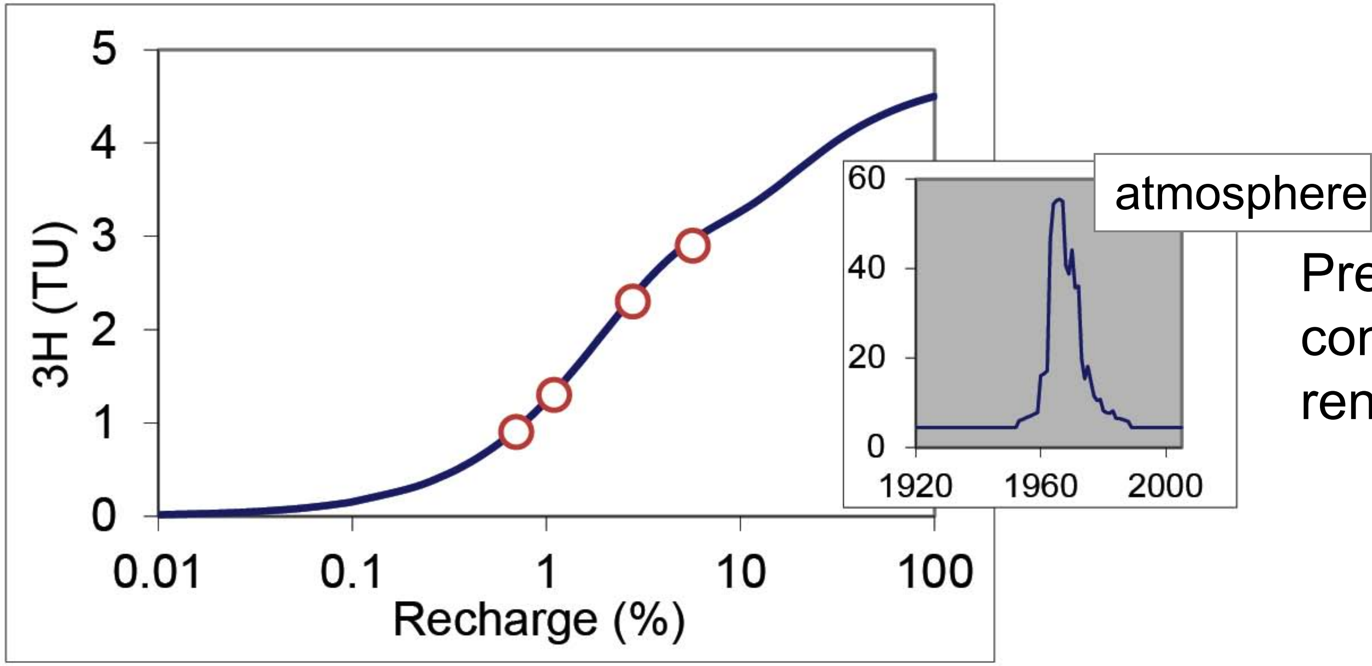


Models represented in the relationship of 14C vs. δ13C. Points A, A1 and A2 represent isotopic composition of gaseous soil CO2 , dissolved CO2 in water and HCO3−. Line O–B represents simulated values from the models of Wigley (1976), Evans et al. (1979), and Eichinger (1983). Pearson's model is shown by the line that connects the origin and A (or A_1). X and Y represent

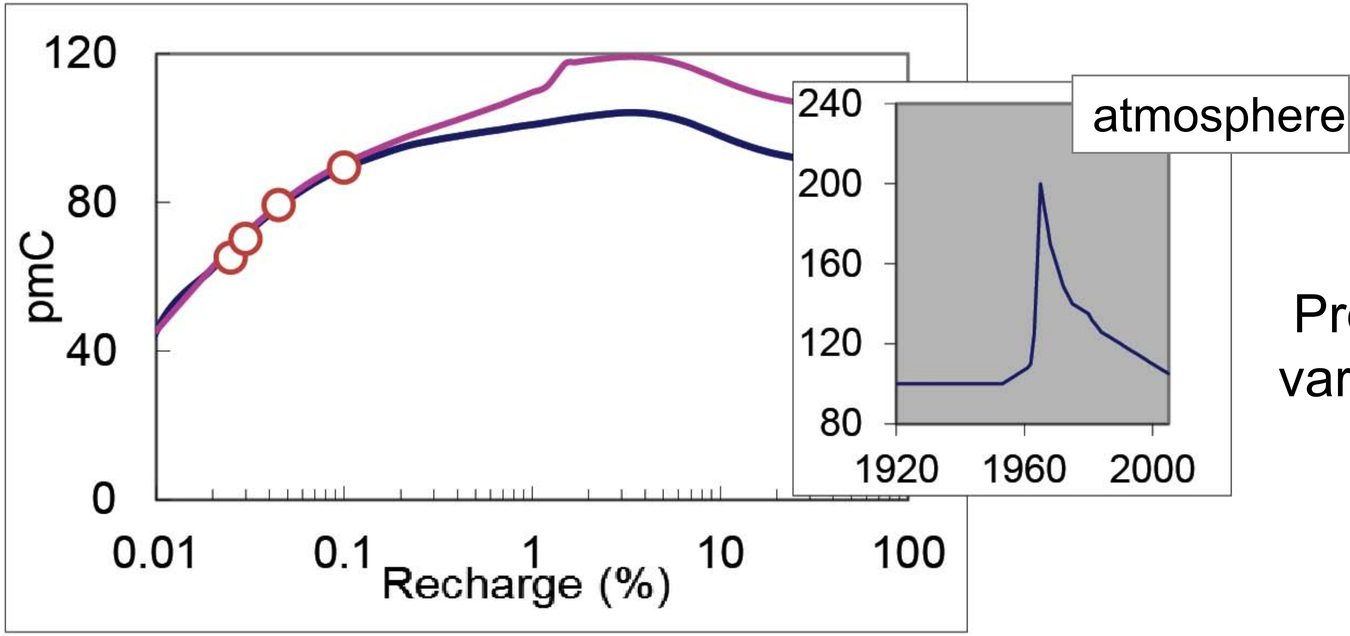
^3H and ^{14}C covariance curve

- Co-variance of ^3H contents and ^{14}C activities for expected values in recharge areas
- Renewal rate (Rn); percentage of aquifer replenished each year by recharge
- Recharge rates relate to renewal rates via the aquifer thickness (b) and porosity (n):

  $R = Rn\ b\ n$
- Calculations assume that pre-atmospheric nuclear test precipitation had the same ^3H concentration as modern precipitation in Melbourne (~4.5 TU)
- Use of ^{14}C to define renewal rates is complicated by the dissolution of old carbon from the aquifer matrix.
  - Simple assumption that 15% of carbon was derived from the aquifer

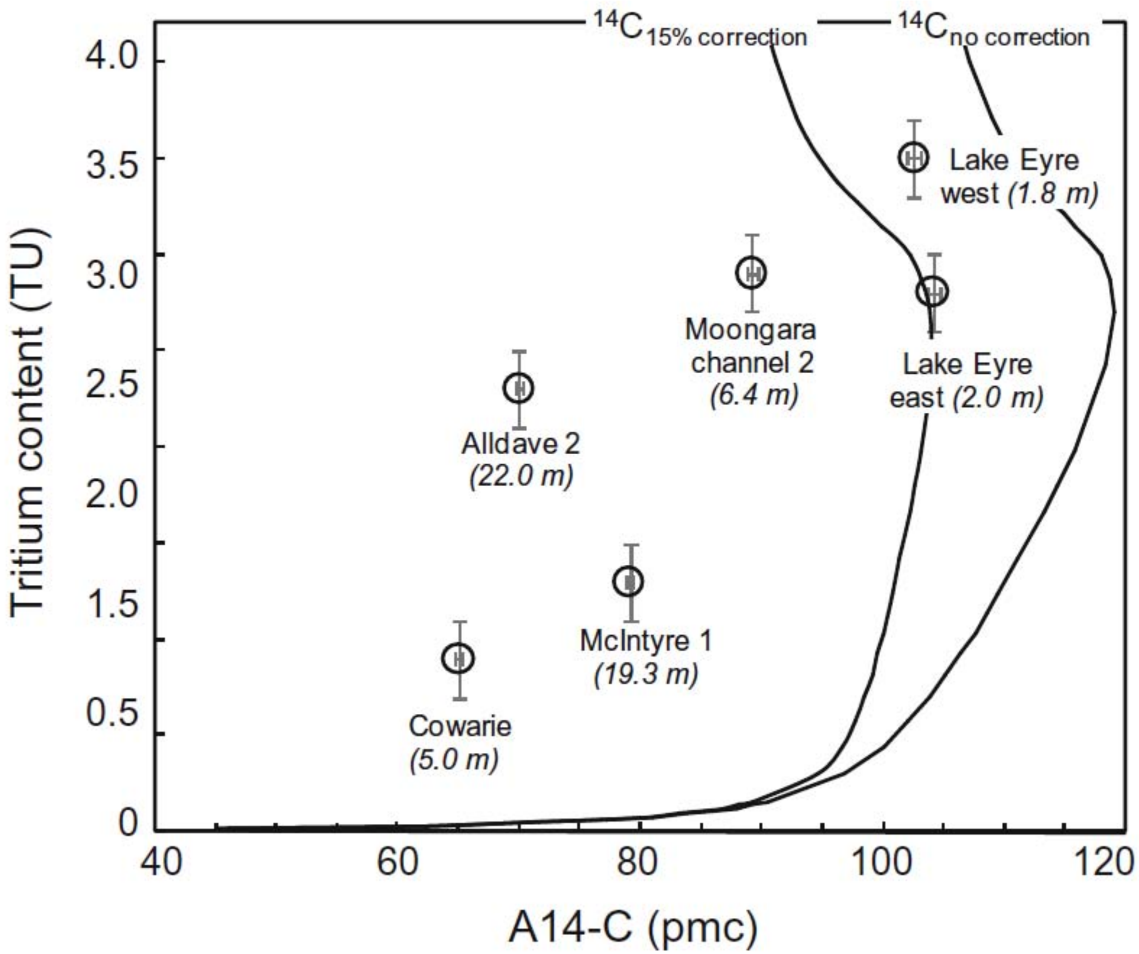


Predicted ^3H concentration for various renewal rates



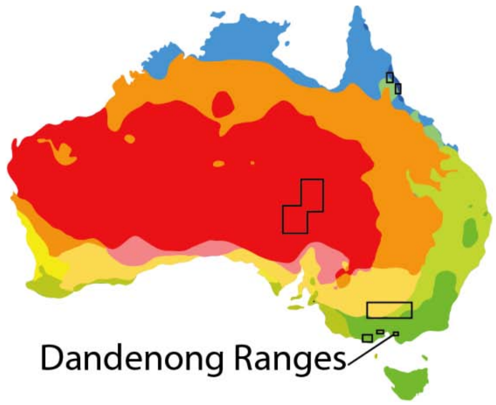
Predicted ^{14}C activity for various renewal rates

^3H and ^{14}C covariance curve



REEs

Mixing in fractured rock aquifers
- Dandenong Ranges



Question
In fractured rock aquifers extent of inter-aquifer mixing?

Approach
Major ions, CFC-11, CFC-12, and REEs

Management link
Aquifer vulnerability to intensive farming

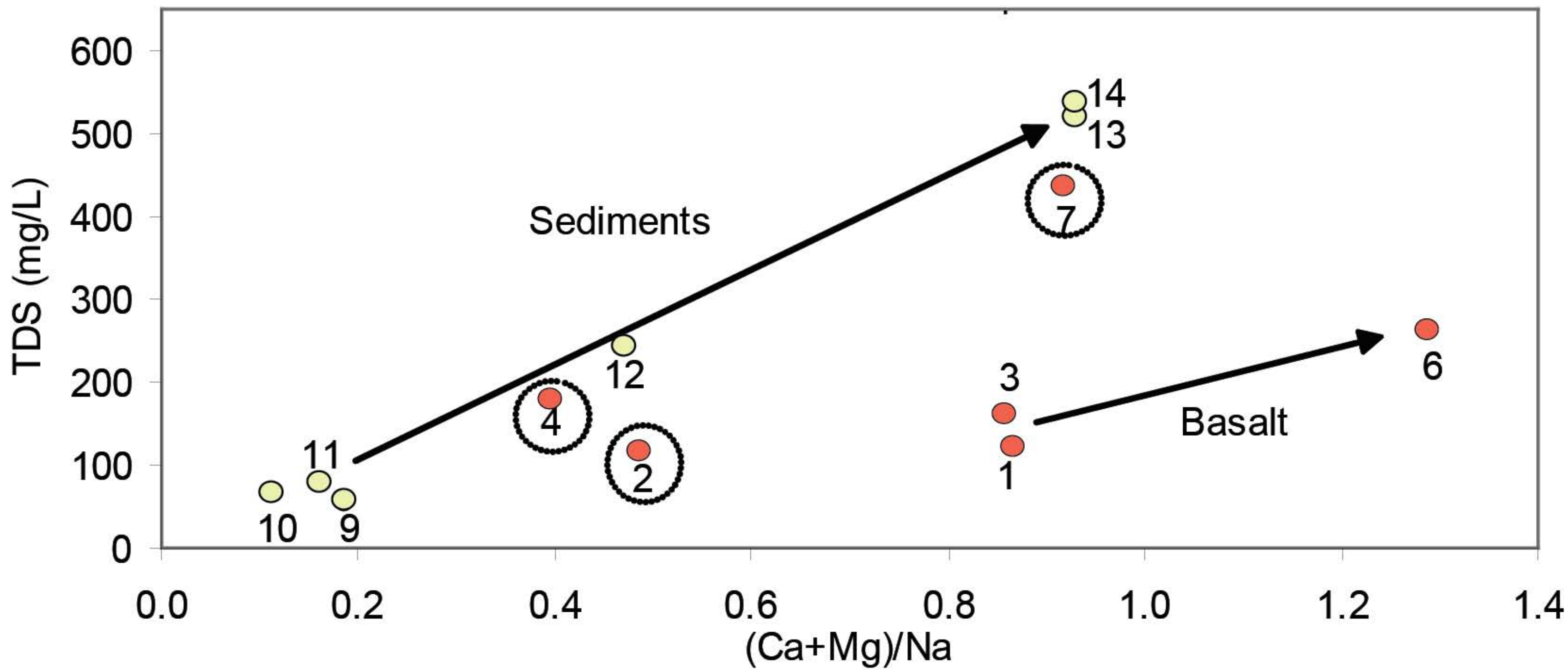
Tweed S.O., Weaver T.R., Cartwright I., 2005. Distinguishing groundwater flow paths in different fractured-rock aquifers using groundwater chemistry: Dandenong Ranges, southeast Australia. Hydrogeology Journal 13(5-6); 771-786

Tweed S.O., Weaver T.R., Cartwright I., Schaefer, B., 2006. Behaviour of rare earth elements in groundwater during flow and mixing in fractured rock aquifers. An example from the Dandenong Ranges, southeast Australia. Chemical Geology 234

Mixing in fractured rock aquifers - Dandenong Ranges

Major ion concentrations increase along groundwater flow paths

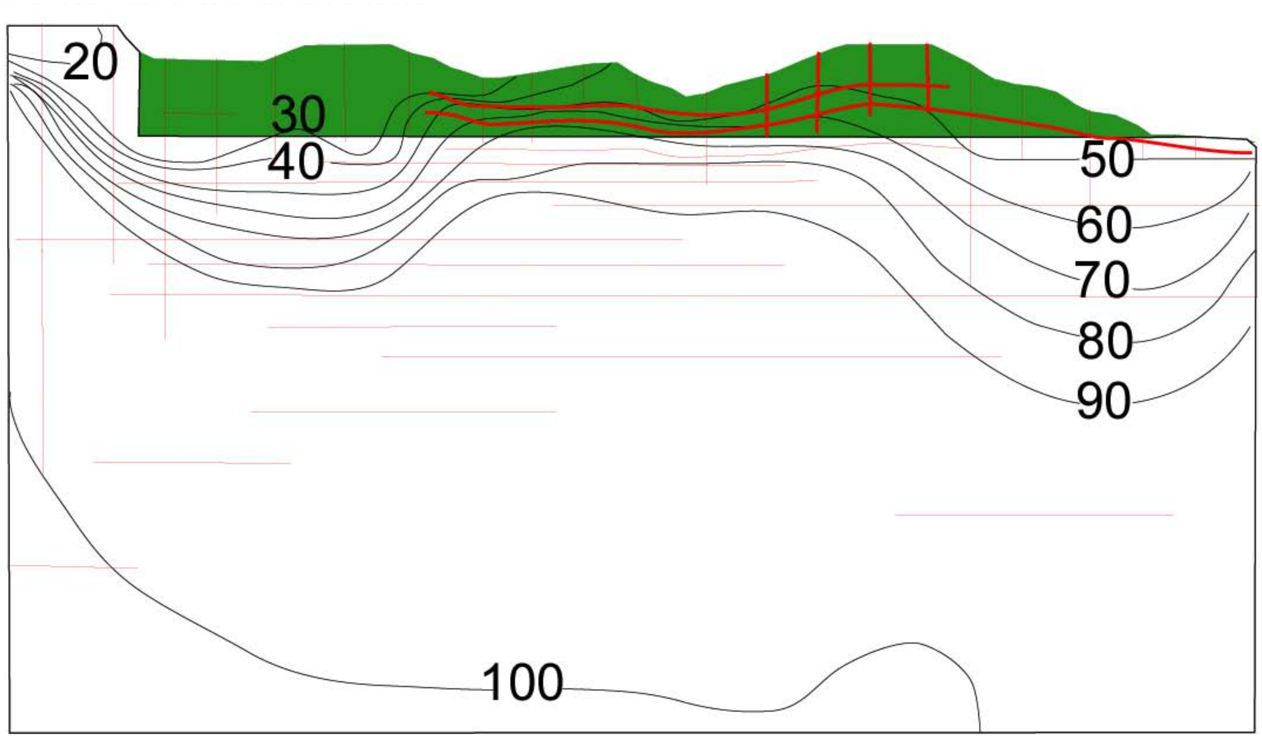
- Olivine and plagioclase dissolution
- Basalt aquifer - increases in Mg, Si and Ca to Na concentrations
- Mixing between groundwater from the basalt and sedimentary aquifers



Mixing in fractured rock aquifers - Dandenong Ranges

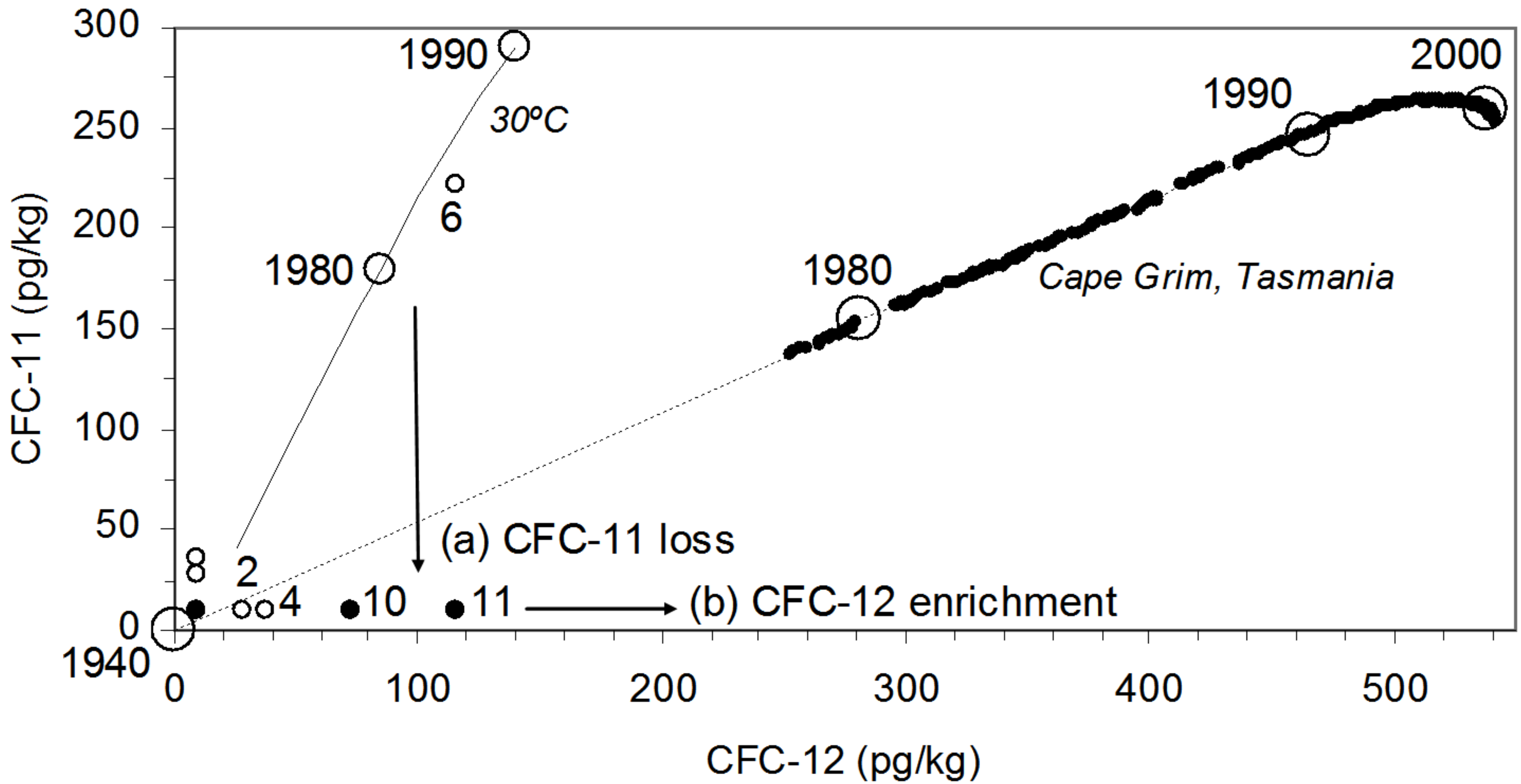
Physically based model (FRAC3DVS)

•Construct conceptual model for fracture flow pathways and mixing



Mixing in fractured rock aquifers - Dandenong Ranges

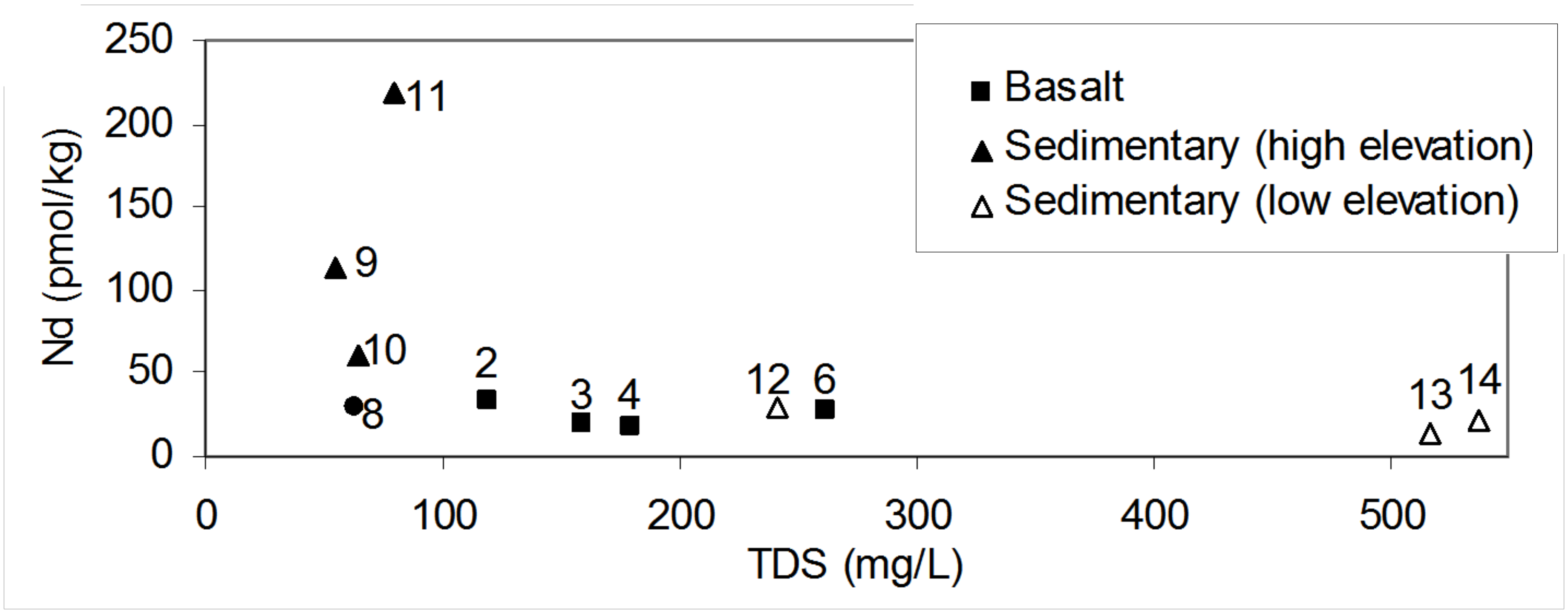
CFCs less successful indicators of groundwater processes



Mixing in fractured rock aquifers - Dandenong Ranges

REEs less successful indicators of groundwater processes

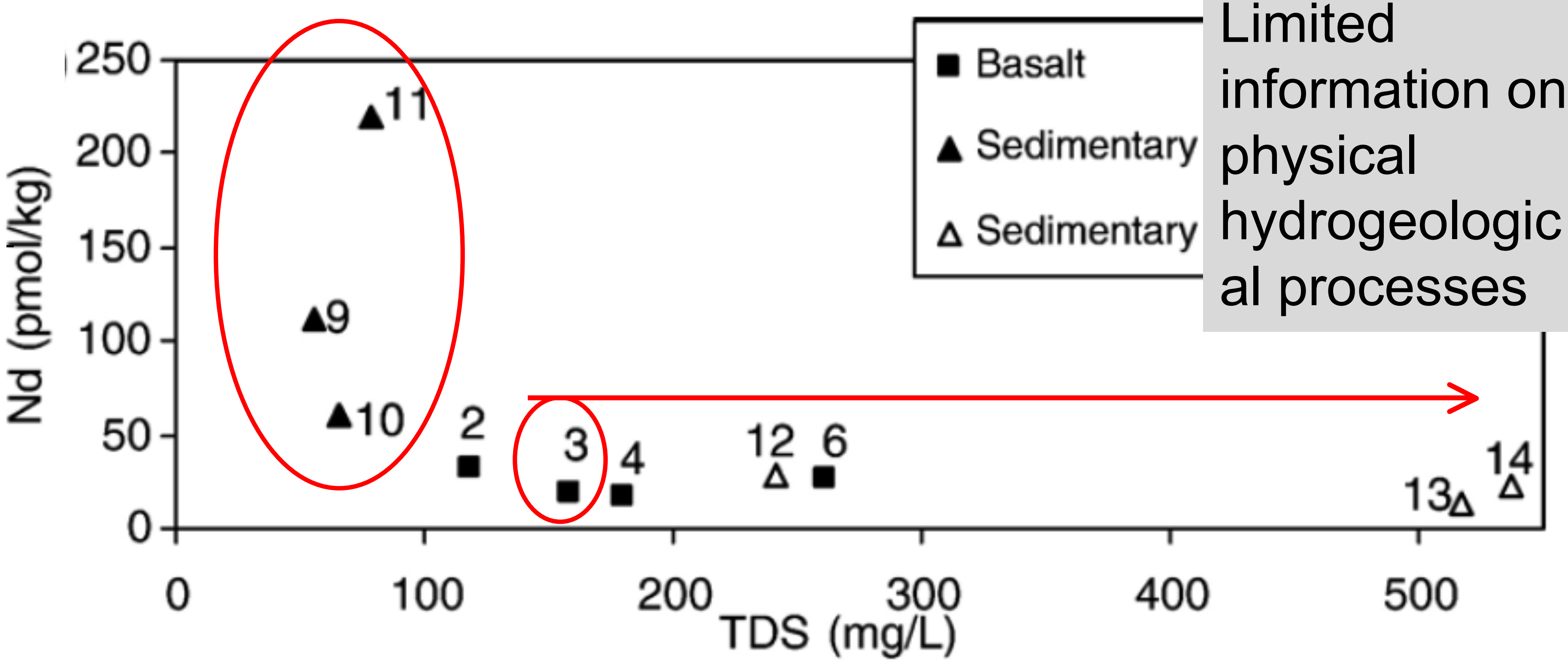
- Did not accumulate with increased flow
- Did not reflect mixing between basalt and sedimentary aquifers



Mixing in fractured rock aquifers - Dandenong Ranges

REEs

•Early-stage REE mobilisation in sedimentary aquifer
•Lower concentrations in recharge areas of basalt aquifer
•REE concentrations remain relatively constant along groundwater flow paths in basalt and sedimentary aquifers

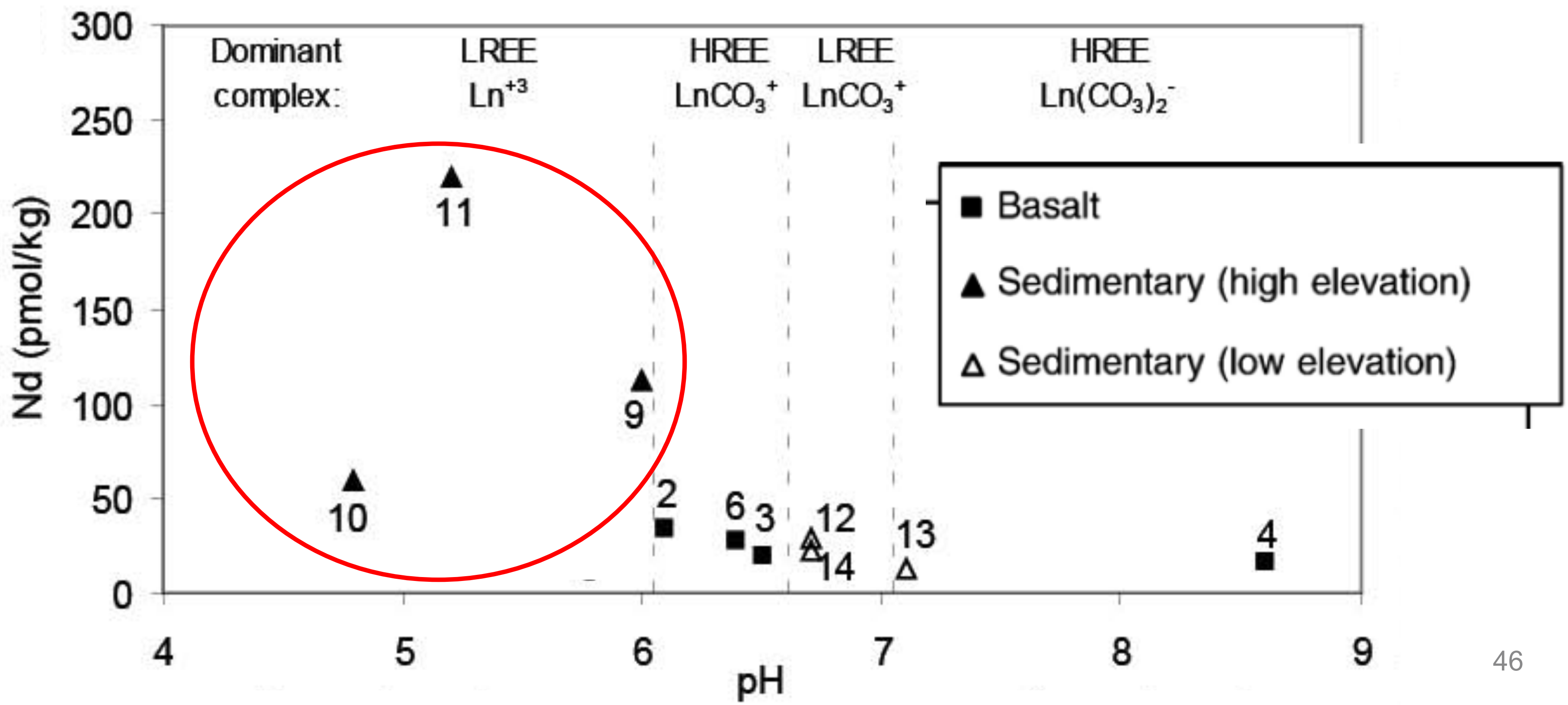


Limited information on physical hydrogeologic al processes

Mixing in fractured rock aquifers - Dandenong Ranges

REEs

Early-stage REE mobilisation in sedimentary aquifer with low pH values (pH < 6)



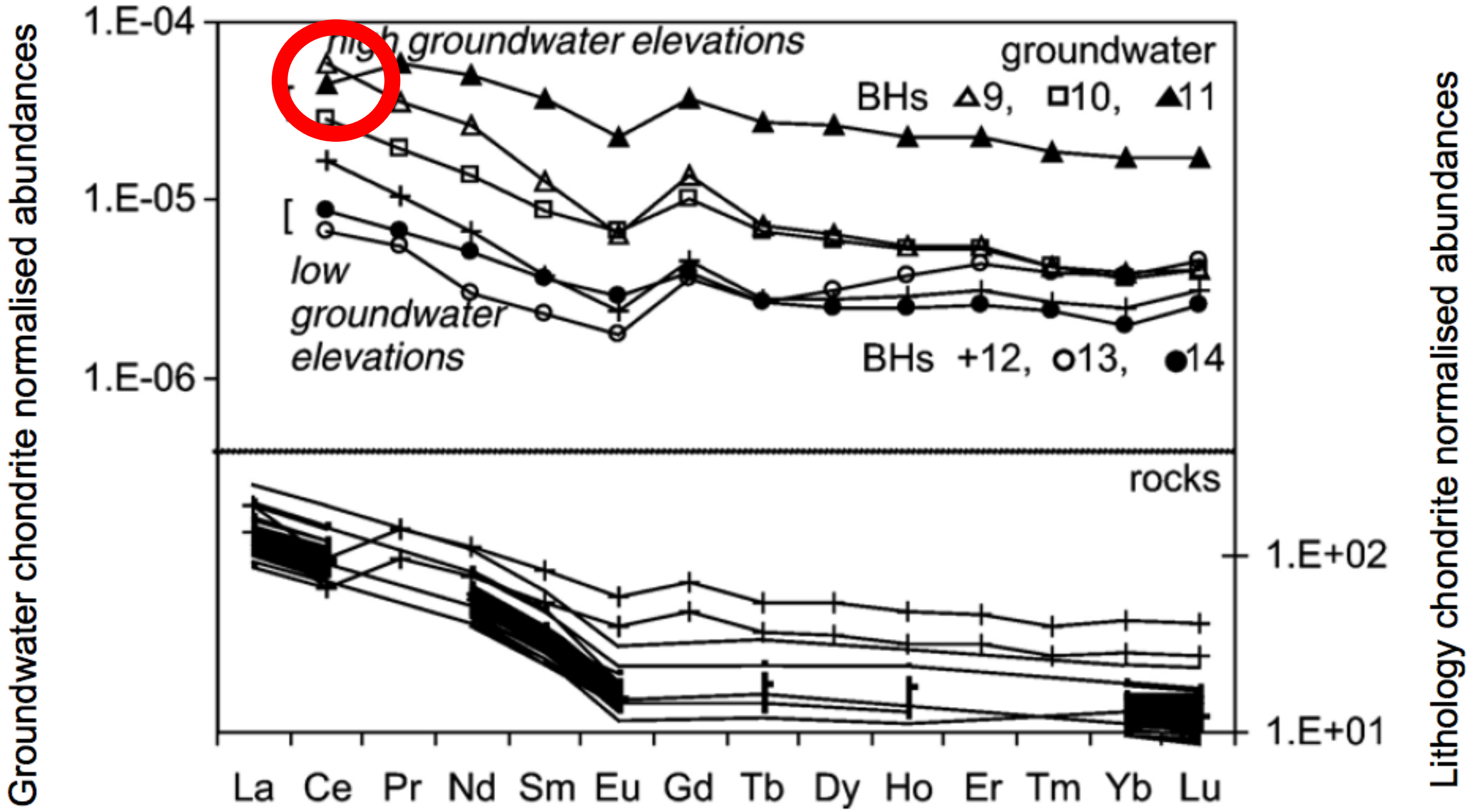
Mixing in fractured rock aquifers - Dandenong Ranges

REEs

Recharge sedimentary:

•localised source heterogeneity affected REE patterns and concentrations

-

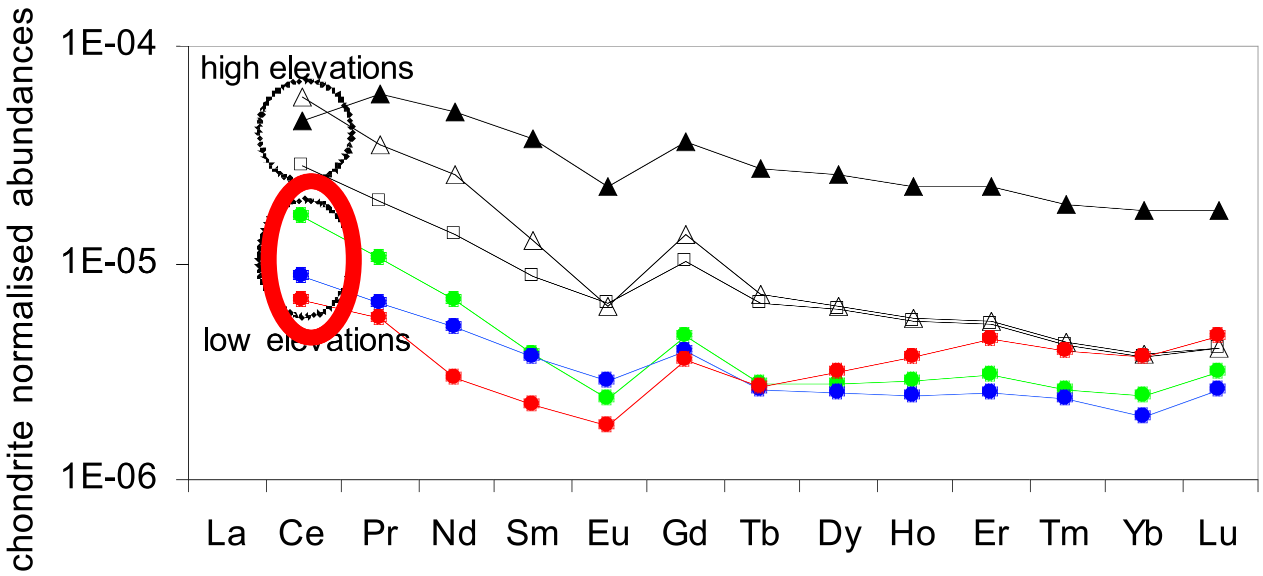


Mixing in fractured rock aquifers - Dandenong Ranges

REEs

Increased flow via sediments

•lower REE concentrations and variation in patterns due to sorption or co-precipitation



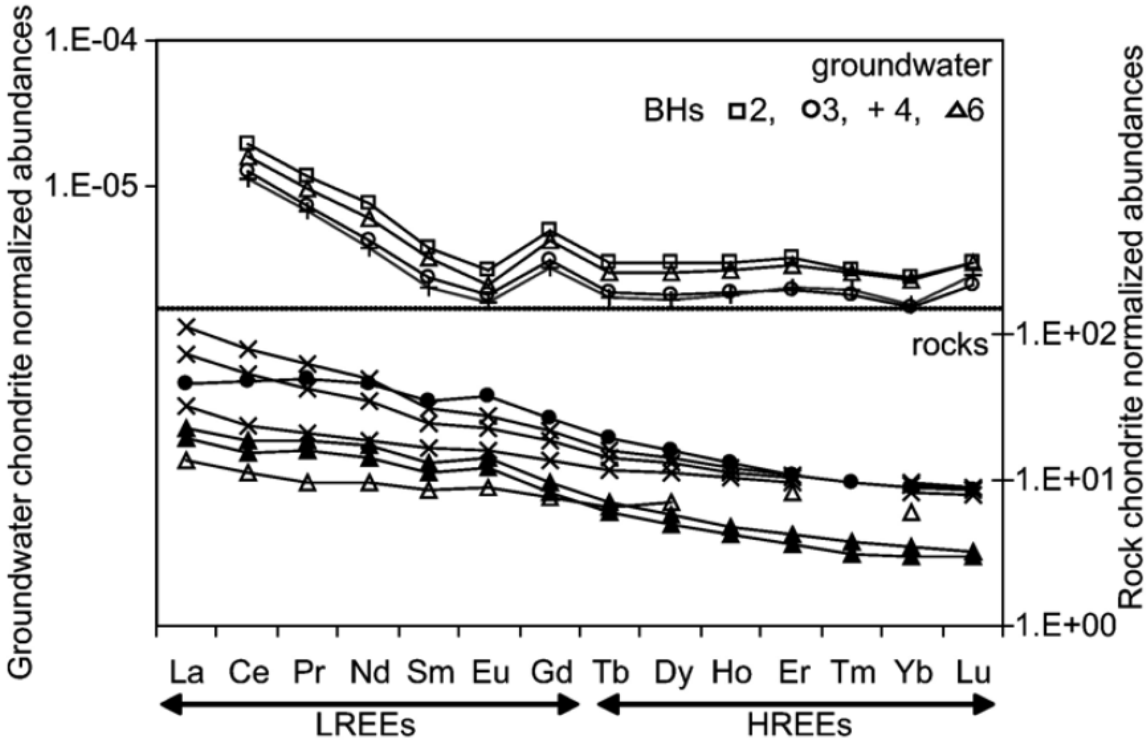
Mixing in fractured rock aquifers - Dandenong Ranges

REEs

Flow via basalt aquifer

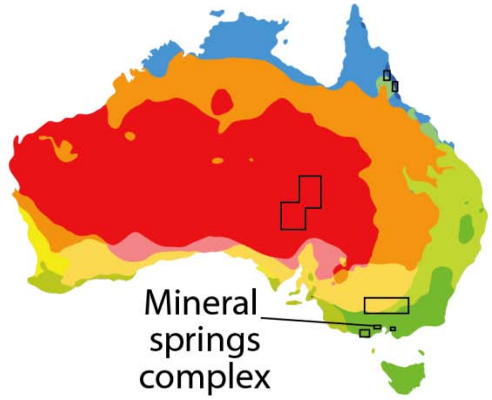
Low REEs concentrations (pH values 6.1 - 8.6)

•Almost identical REE patterns and concentrations in basalt aquifer groundwater do not reflect mixing with groundwater from the sedimentary aquifer, or REE removal via sorption or co-precipitation



Mineral springs

Deep flow in fractured rock aquifers – Mineral Springs



Question

Origins of waters and gas (CO_2) in naturally effervescent mineral spring waters?

Approach

$\delta^{13}C_{CO2}$ values of gas emissions, and $\delta^{18}O$, $\delta^{2}H$ and $\delta^{13}C_{DIC}$ of the spring waters

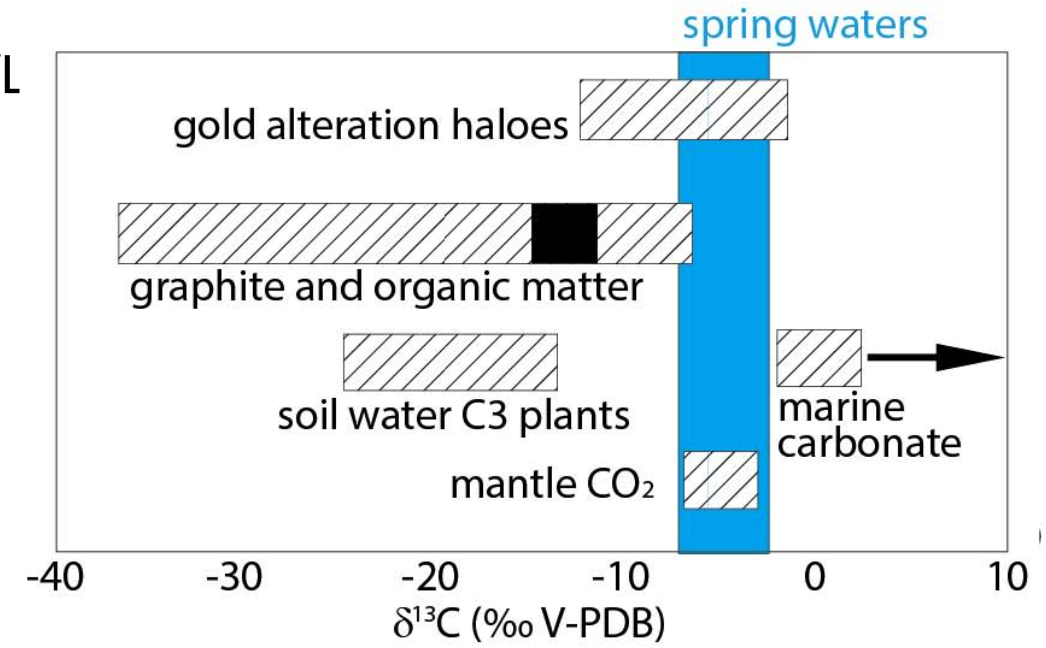
Management link

Protection of this popular tourist destination

Cartwright I., Weaver T., Tweed S., Ahearne D., Cooper M., Czapnik K., Tranter J., 2002. Stable isotope geochemistry of cold CO2-bearing mineral spring waters, Daylesford, Victoria, Australia: sources of gas and water and links with waning volcanism.

Circulation of deep groundwater flow – Mineral Springs

Up to 2500 mg/L CO_2 and 2650 mg/L HCO_3



$\delta^{13}C$ - DIC sources

- Spring water $\delta^{13}C$
  -5.9 to -0.1 ‰

•Gold veins
-13 to -2 ‰ – minor presence

•Magmatic CO_2
-6 to -3 ‰

➢ Correlation between spring abundance and eruption points

Other major ions

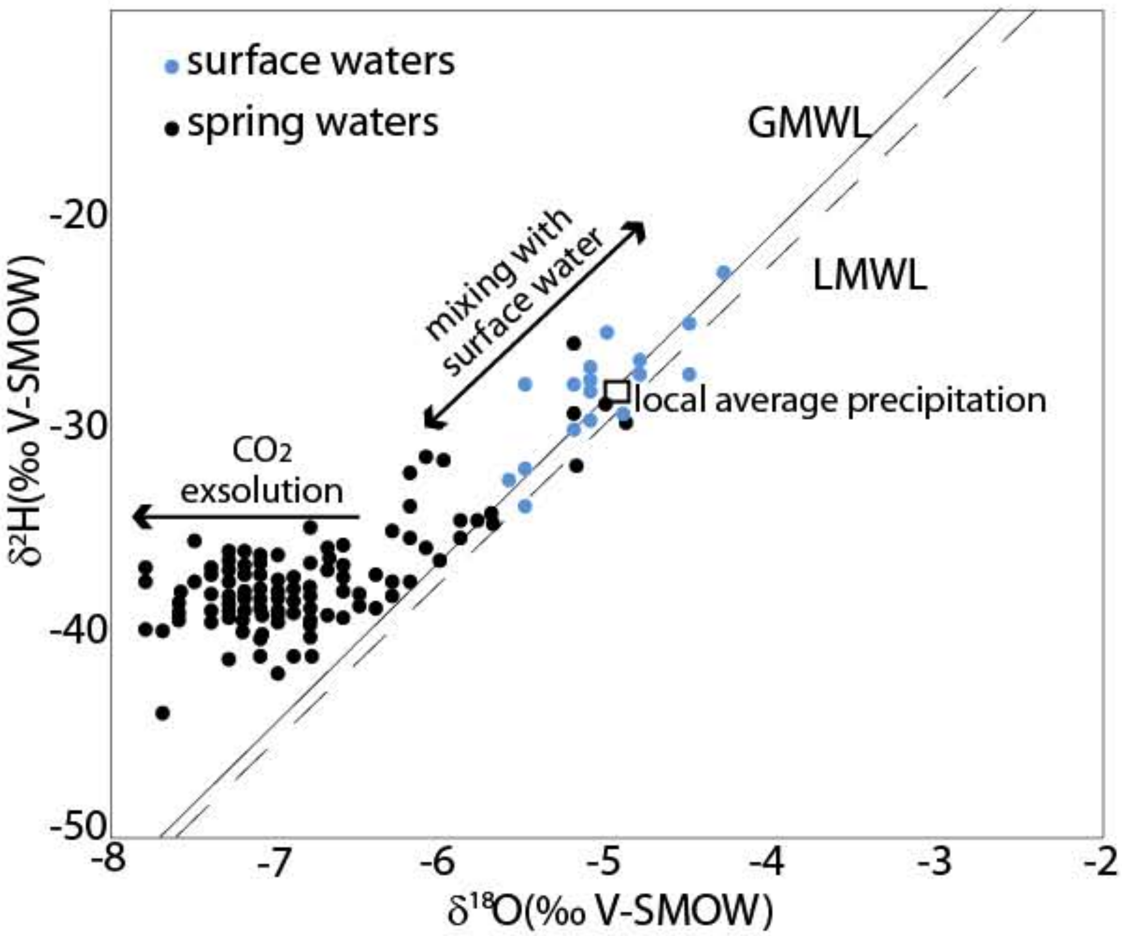
•Controlled by water–rock interactions in different fracture flow paths

Circulation of deep groundwater flow – Mineral Springs

$\delta^{18}O$ and $\delta^{2}H$

- Low $\delta^{2}H$ values not explained by modern rainfall recharge
- Springs recharged under colder climatic conditions (~3.5 to 3.0 ka BP)

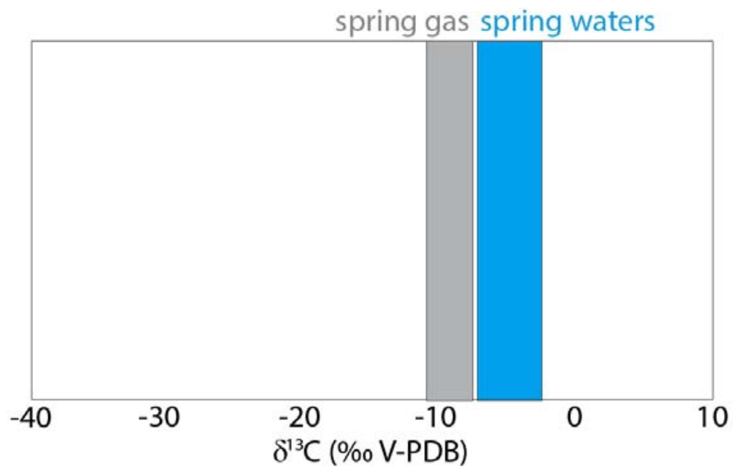
-



Circulation of deep groundwater flow – Mineral Springs

- Up to 2516 mg/L CO_2 and 2648 mg/L HCO_3
- $\delta^{13}C_{CO2}$ of gas emissions : -10.6 to -7.0 ‰
- $\delta^{13}C_{DIC}$ of spring waters: -5.9 to -0.1 ‰

- Difference in $\delta^{13}C_{CO2}$ of gas and $\delta^{13}C_{DIC}$ of the spring waters ($\delta^{13}C_{(DIC-co2)}$): 3–8%
- Predicted difference: 1 – 7% (at 10–50ºC and pH 5.8–6.9)
    - CO_2 is in approximate isotopic equilibrium with the DIC; part of a single mineral water–gas system

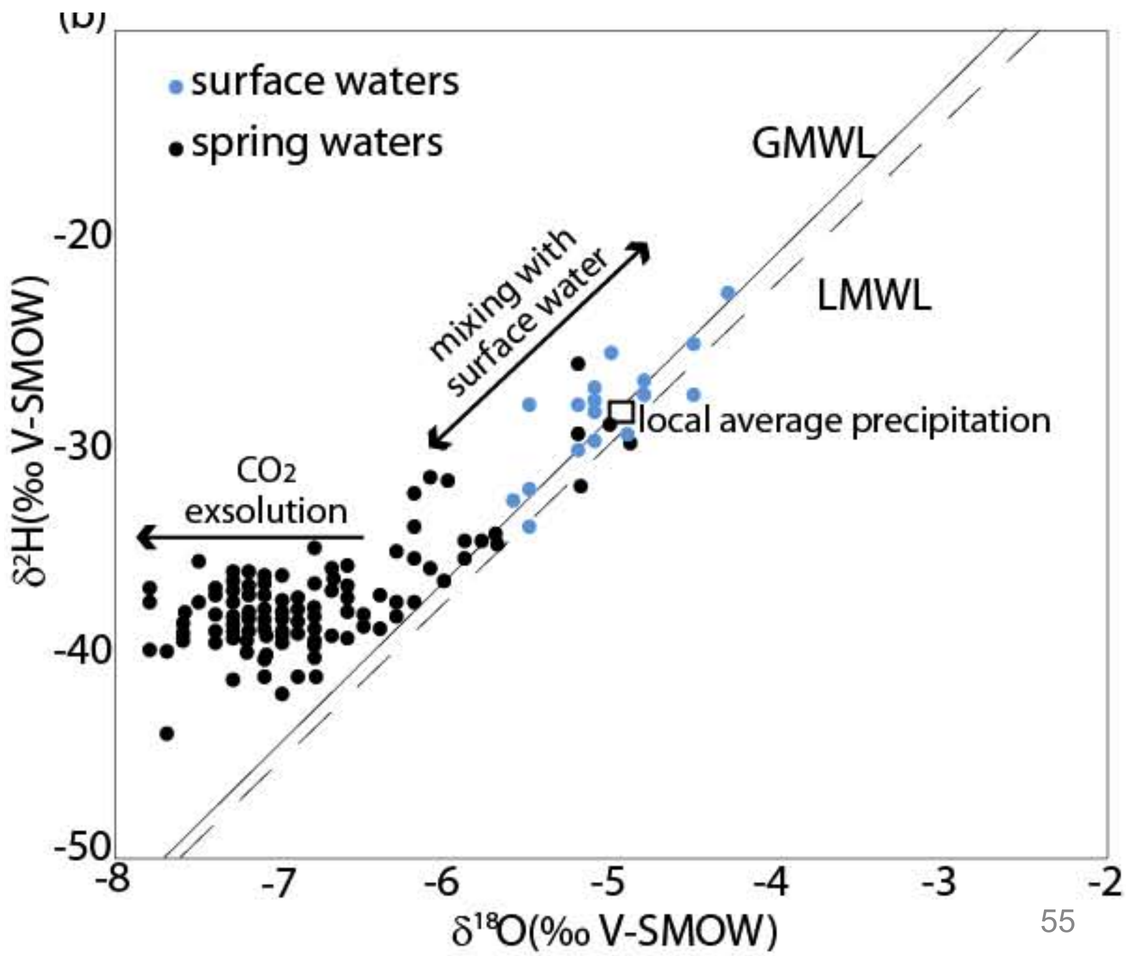


- Spring water $\delta^{13}C$ values function of
    - relative amount of CO_2 and DIC
    - $\delta^{13}C$ values of each of these components
    - not possible to measure the proportions of these two components

Circulation of deep groundwater flow – Mineral Springs

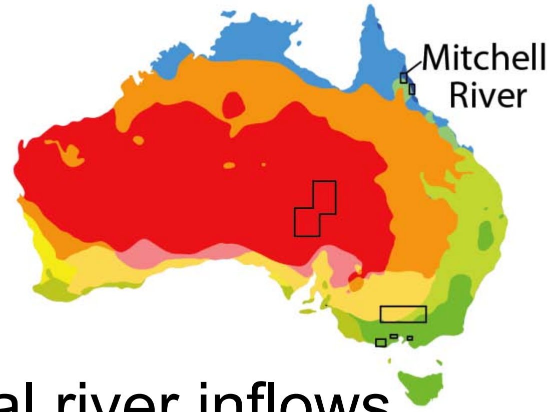
- Mineral springs $\delta^{18}O$ and $\delta^{2}H$ values lie to the left of meteoric water lines
  - As spring waters are transported to the surface the CO_2 exsolves which lowers $\delta^{18}O$

-



Mitchell 18O and DIC

Seasonal inflows from wet versus dry tropics – Mitchell River



Questions

Seasonal variations in the provenance of tropical river inflows

Approach

$\delta^{18}O$ as a tracer of rainfall provenance

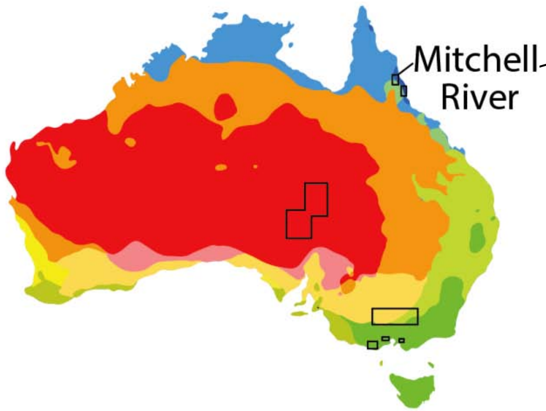
Funding

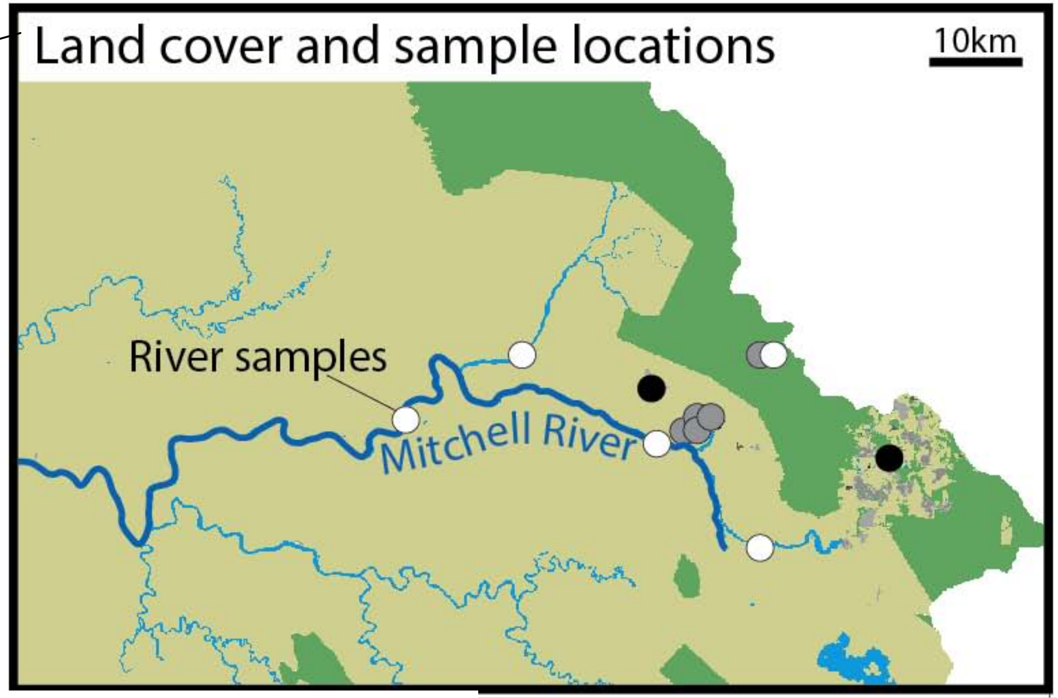
ARC and National Centre for Groundwater Research and Training (NCGRT)

Management links

Protection of tropical river ecosystems and water resources

Tweed, S., Leblanc, M., Bass, A., Harrington, G., Munksgaard, A. *In prep*. The origin and seasonal evolution of riverine DIC in a tropical river, northern Australia.

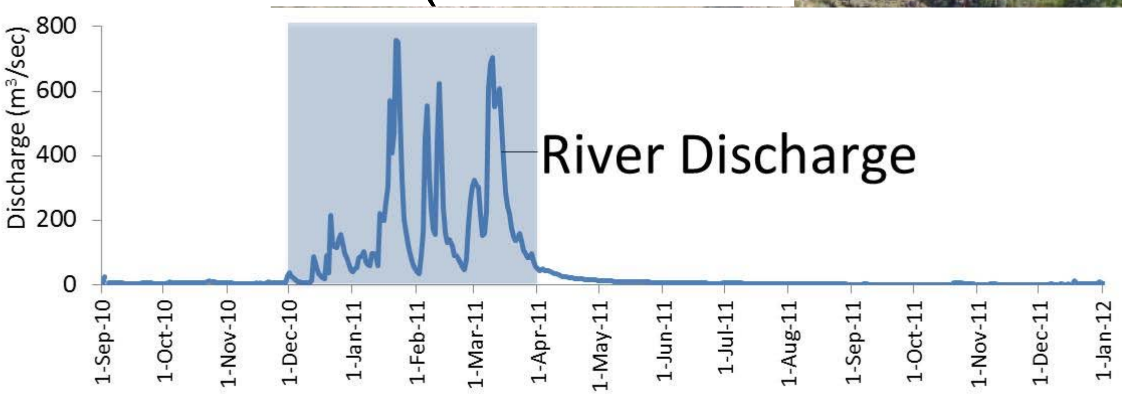


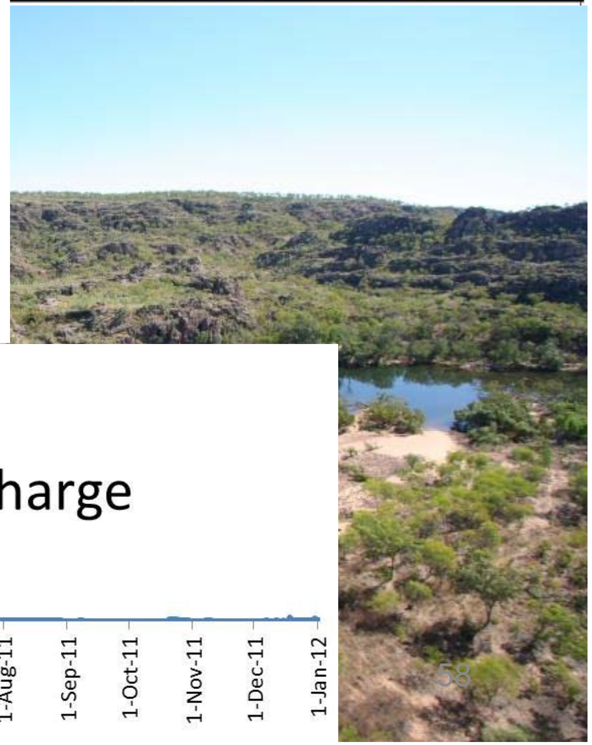


Wet tropics
- rainforest
- annual rainfall ~ 1600 mm/yr
- mountains

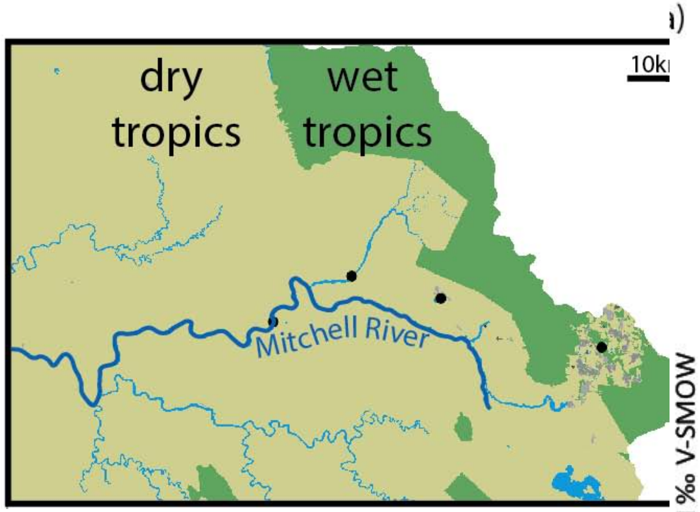
Dry tropics
- savanna vegetation
- annual rainfall ~ 900 mm/yr

Rivers
- high wet season flow
- low dry season flow; limited rainfall (<5% of

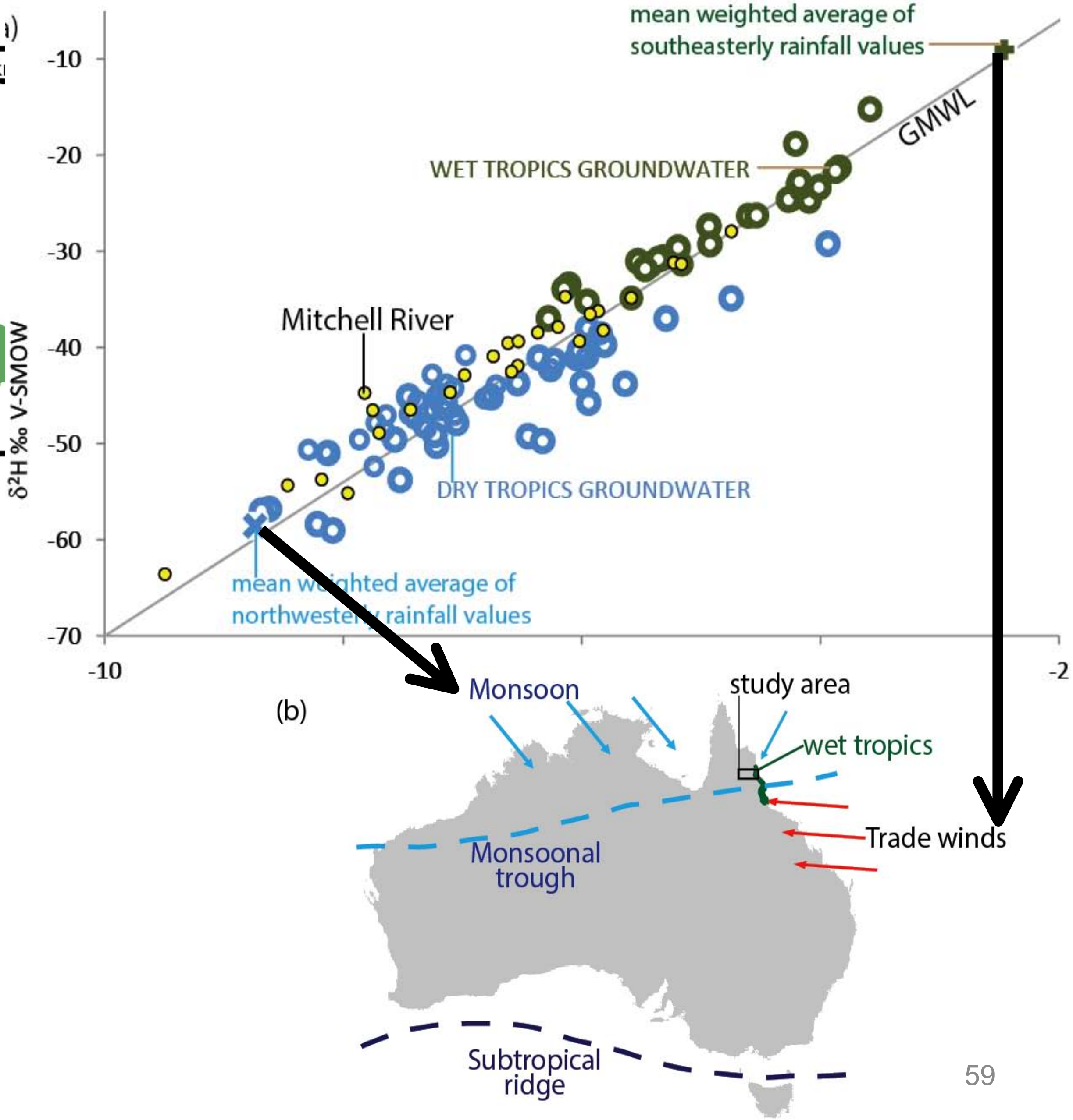




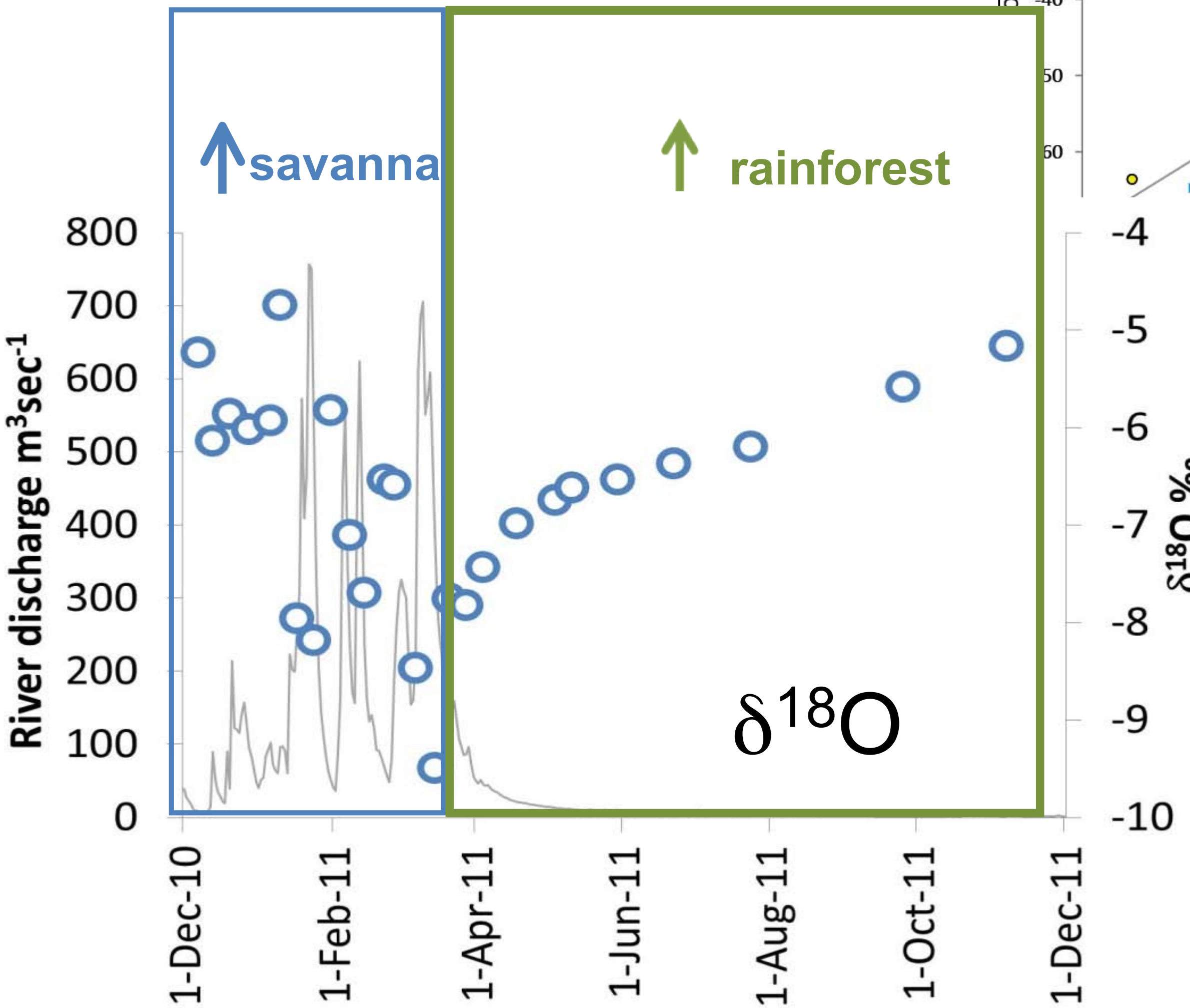
Seasonal inflows from wet versus dry tropics – Mitchell River

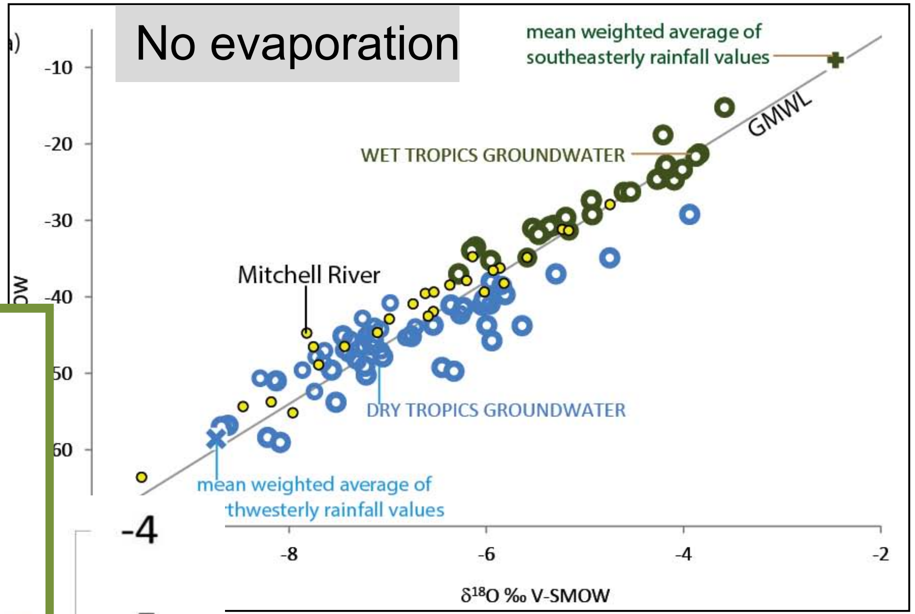


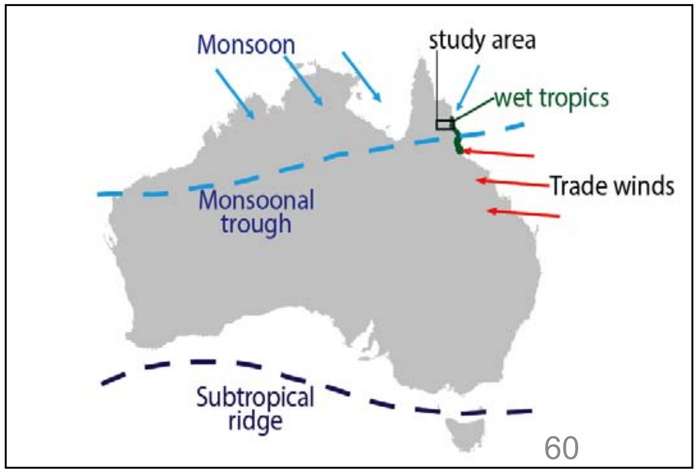
Rainfall provenance



Seasonal inflows from wet versus dry tropics – Mitchell River







Seasonal inflows from wet versus dry tropics – Mitchell River

$\delta^{18}O$

Information on a river - remote and logistically difficult to sample during the tropical wet seasons

Wet season

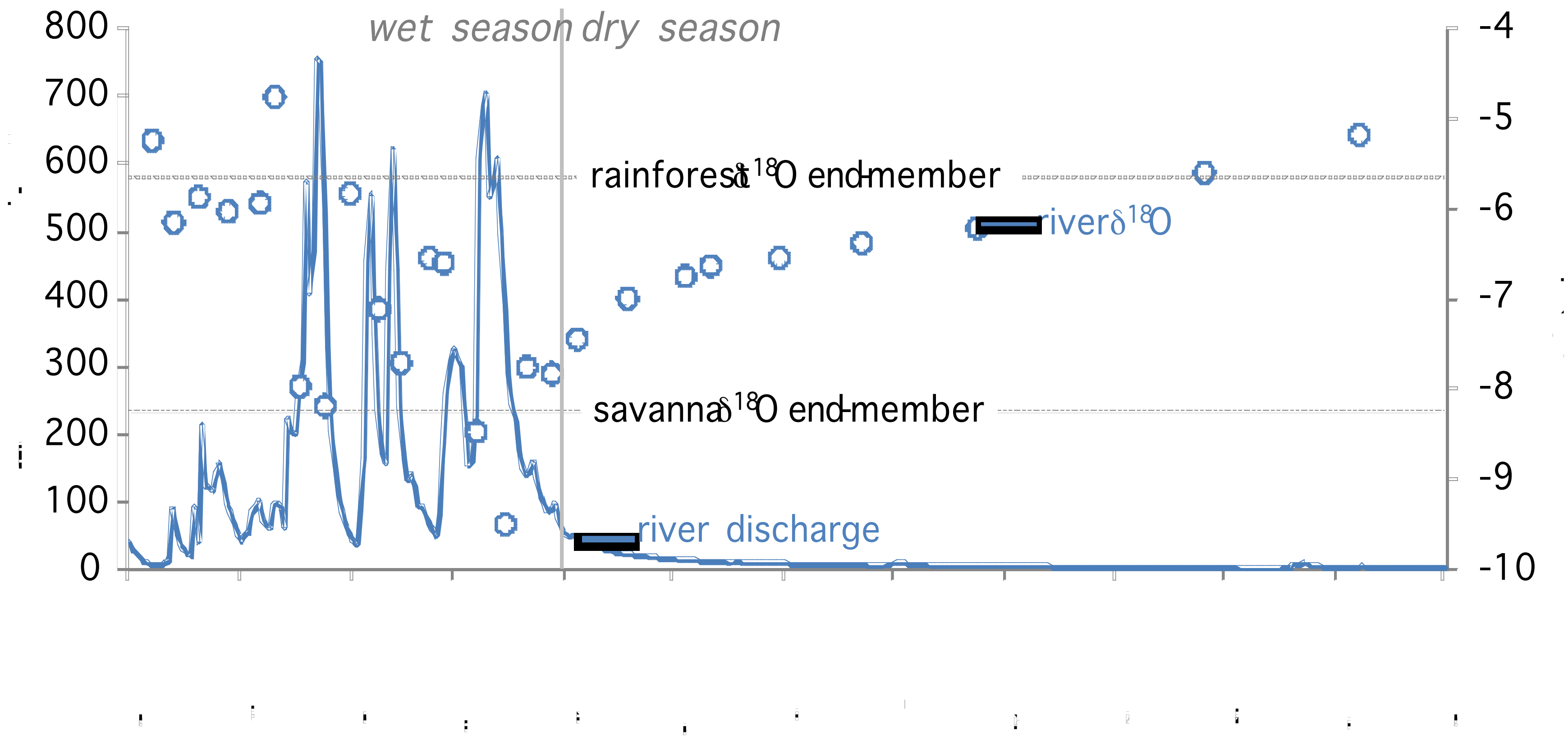
- Relative increase in inflows from savanna

Dry season

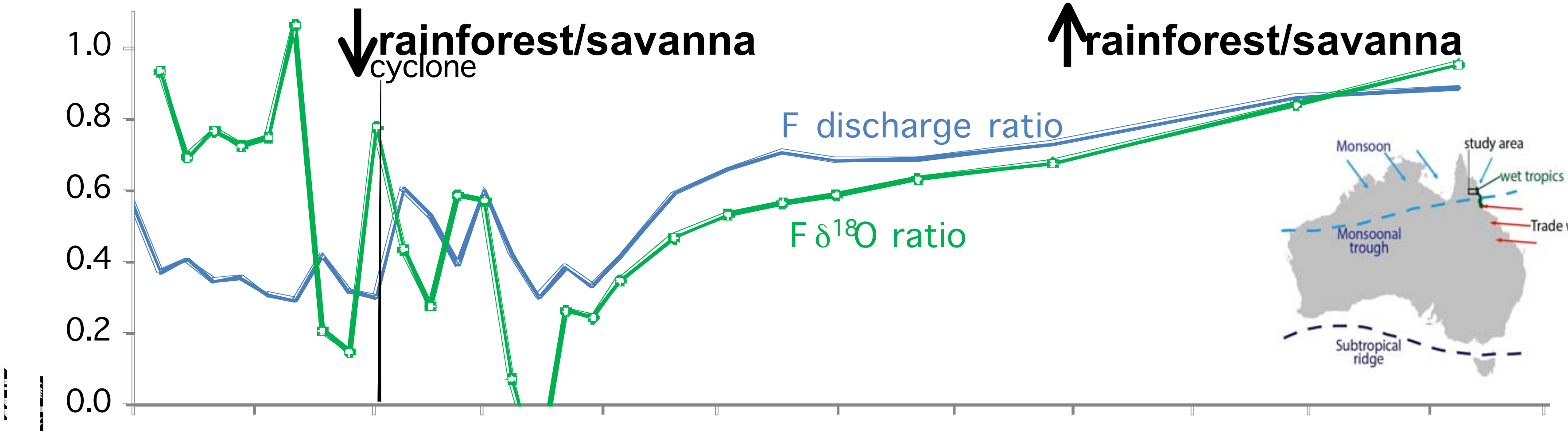
- Relative increase in inflows from rainforest

Improvements to component models

Use of constant end-members; dynamic end-members more likely; large variations in tropical rainfall



Seasonal inflows from wet versus dry tropics – Mitchell River



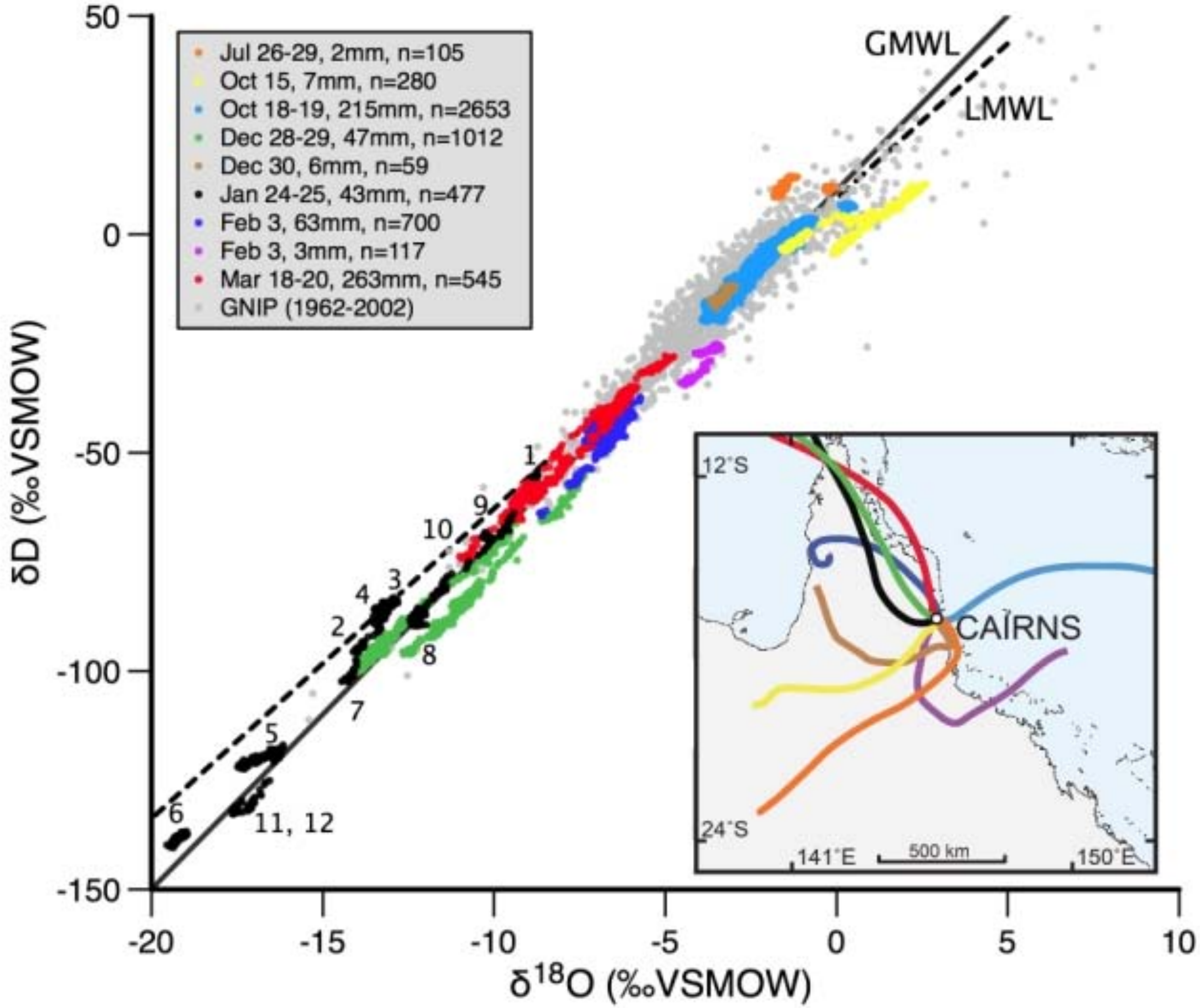
Fraction (F) of inputs from the rainforest to total river discharge is solved using $\delta^{18}O$ end-member for the savanna ($\delta^{18}O_{(SAV)}$), rainforested highlands ($\delta^{18}O_{(RF)}$), and the measured river $\delta^{18}O$ values ($\delta^{18}O_R$).

$$F = \frac{\delta^{18}O_R - \delta^{18}O_{(SAV)}}{\delta^{18}O_{(RF)} - \delta^{18}O_{(SAV)}}$$

Compared with a mixing fraction of river discharge (F_Q), calculated using the gauged discharge data from Rifle Creek (Q_{RIF} – increased rainforest), McLeod River (Q_{MCL}- increased rainforest) and Mitchell River (Q_{MIT} – mix savanna and rainforest):

$$F_Q = \frac{Q_{RIF} + Q_{MCL}}{Q_{MIT}}$$

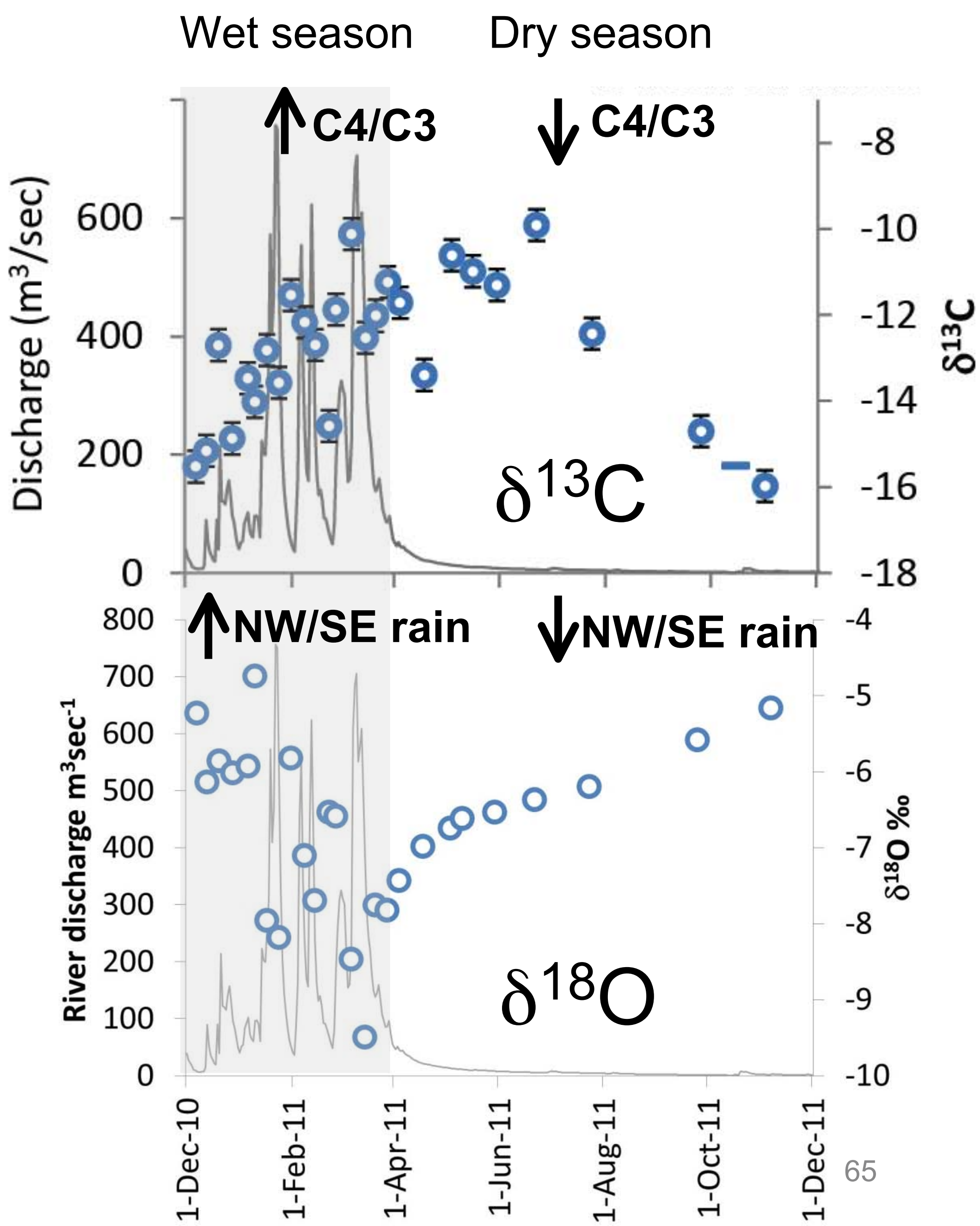
Tropical rainfall



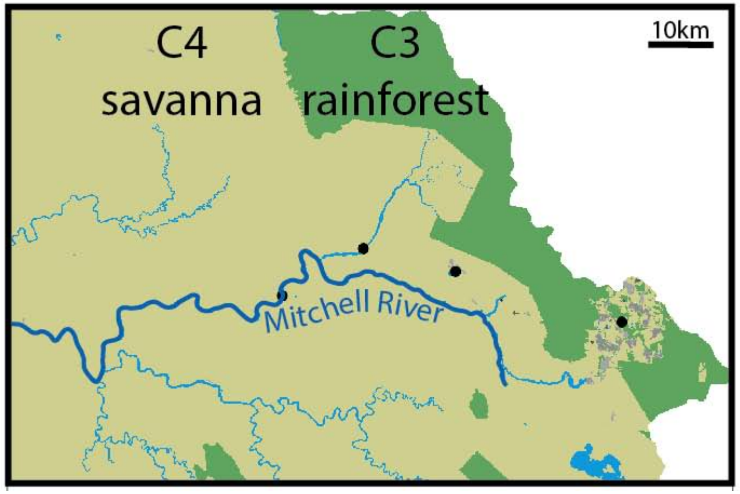
Results – $\delta^{18}O$

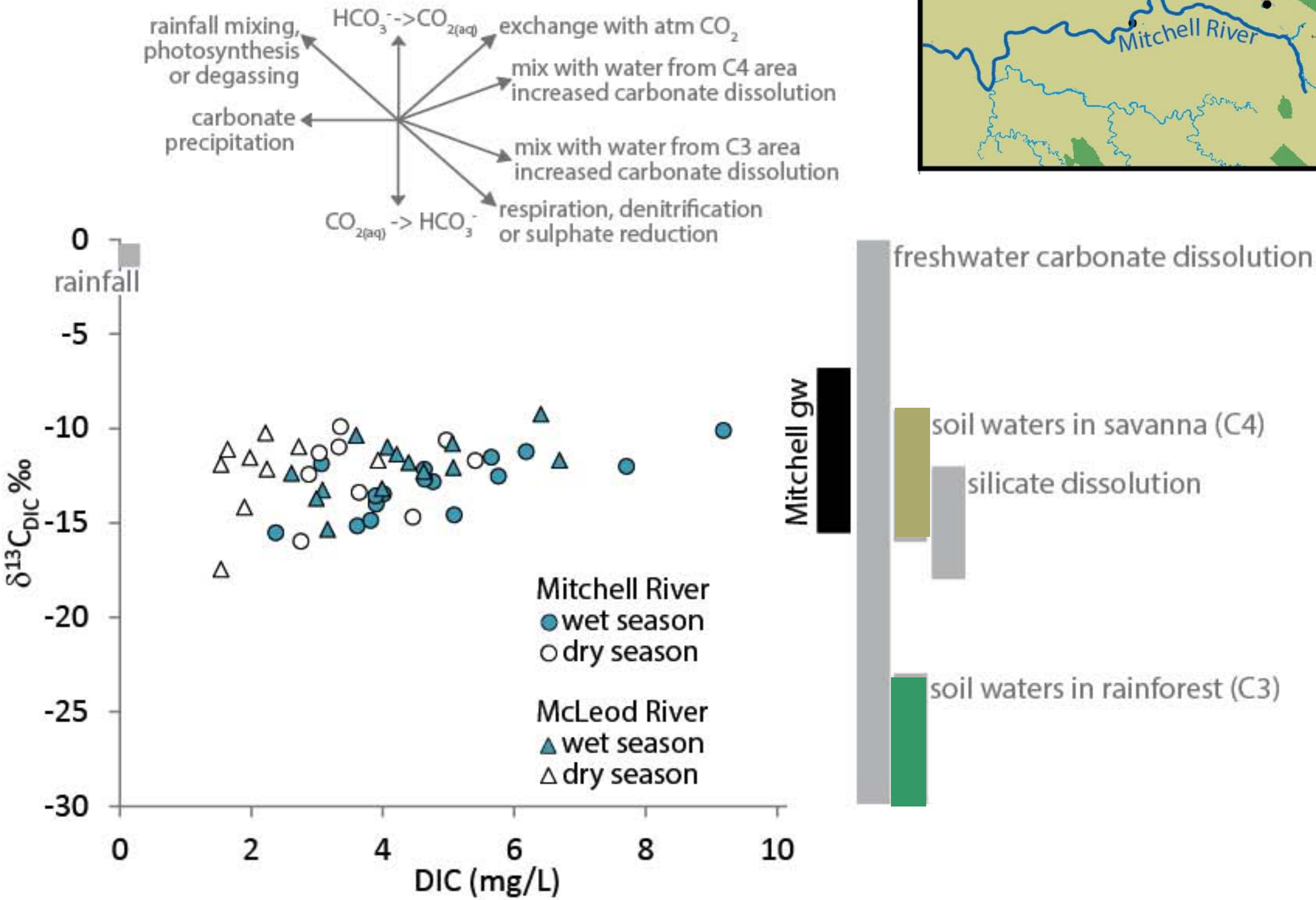
- Wet season
  - Relative increase in inflows from savanna

- Dry season
  - Relative increase in inflows from rainforest



δ13C – vegetation provenance





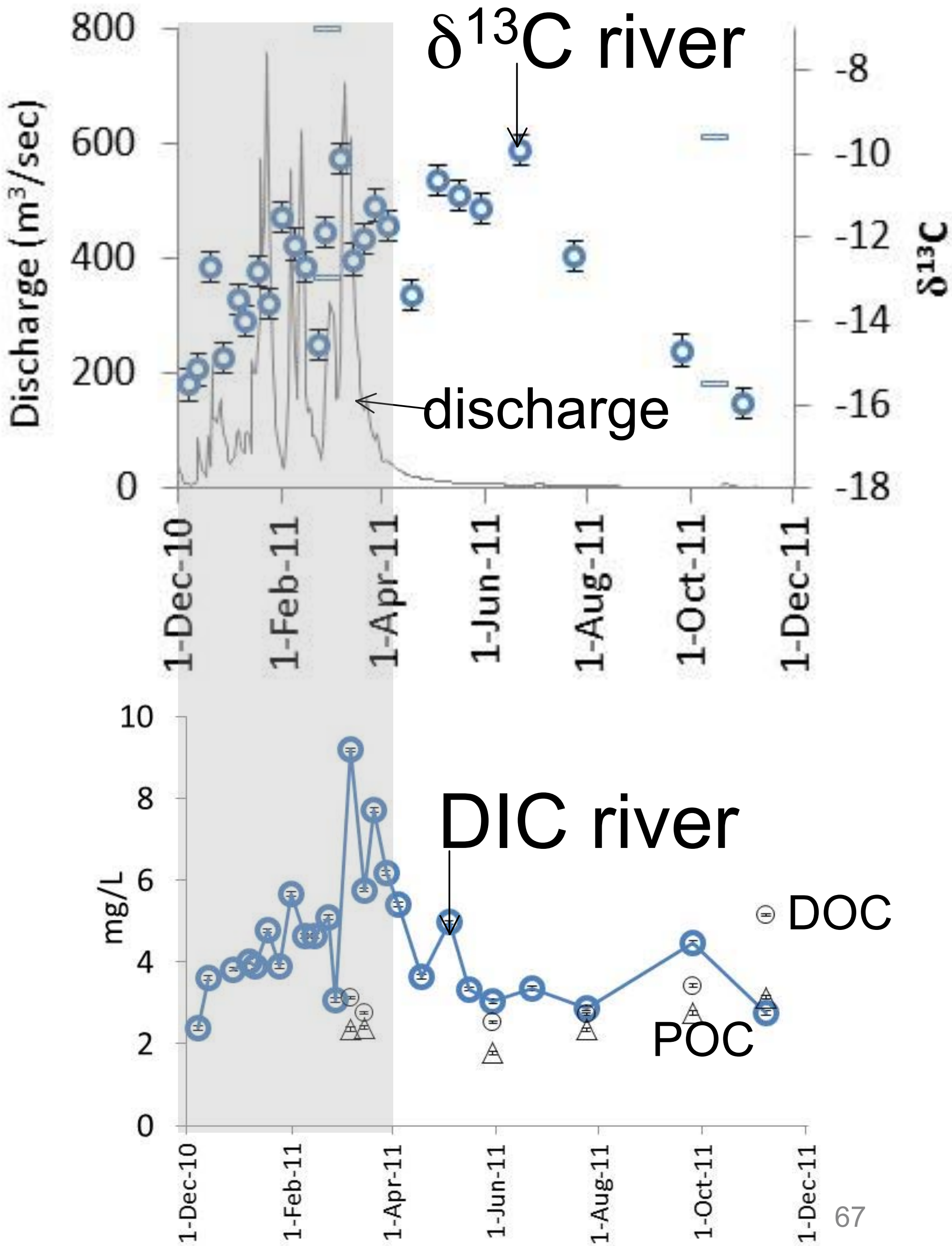
Results - DIC

- Wet season – increase in $\delta^{13}C$
- Dry season – decrease in $\delta^{13}C$

- Wet season – increase in DIC;

  -> groundwater
- Dry season – decrease in DIC

-> high wet season DIC export



Results - diurnal DIC

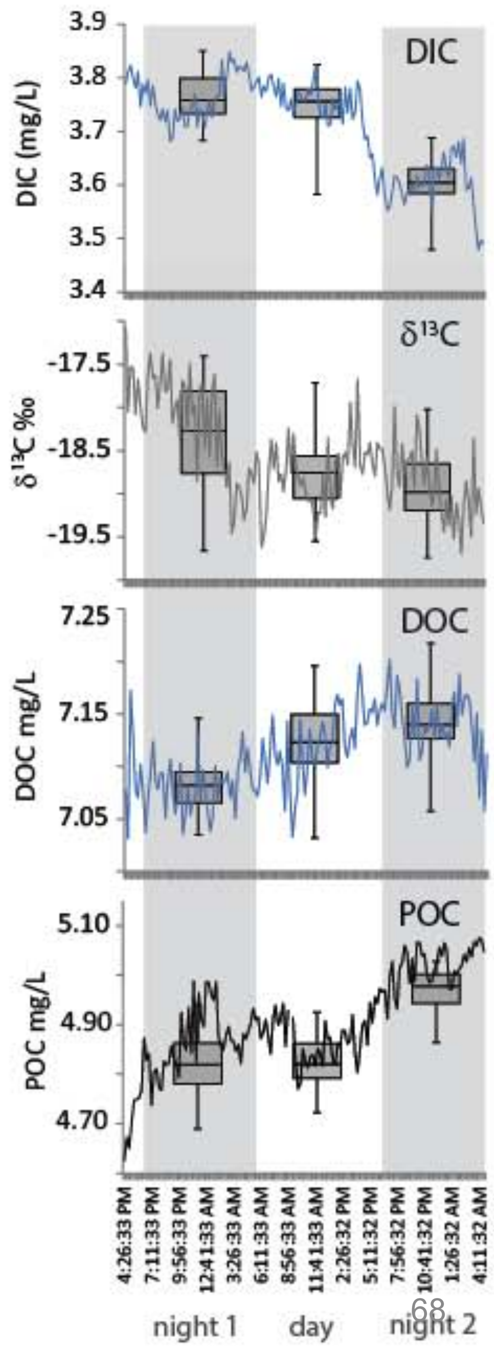
- inverse trends between DO and DIC values
- inverse trends between $\delta^{13}C$ and DIC values

Daylight:
- photosynthesis

Night:
- Respiration

-> Compared with seasonal changes the diurnal variations are relatively minor

max DIC change – diel: 0.27 mg/L
– seasonal: 6.81 mg/L

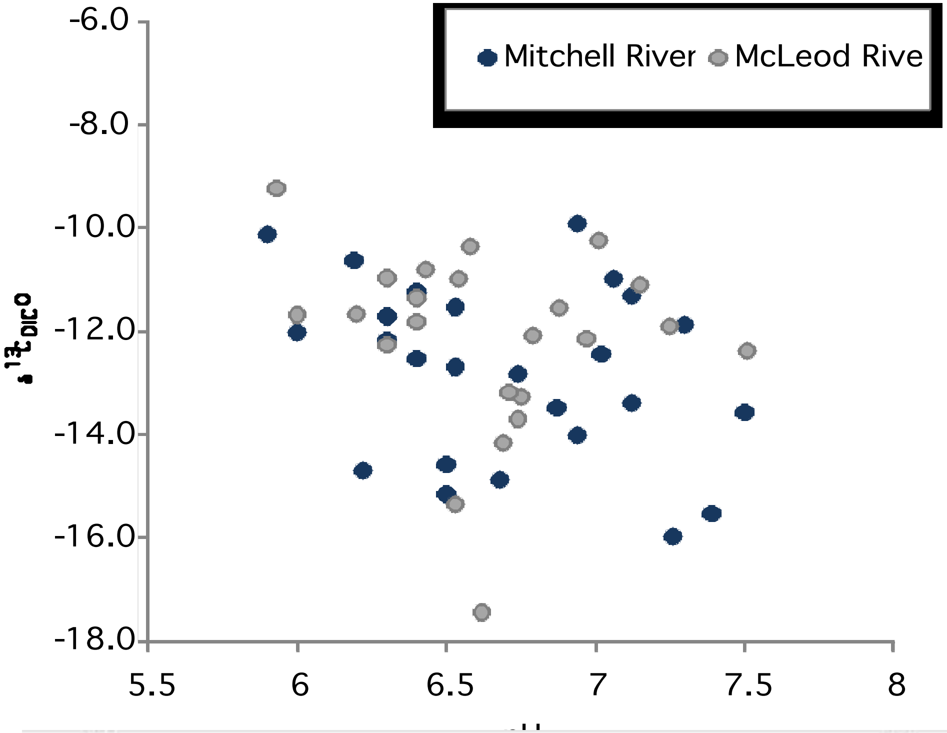


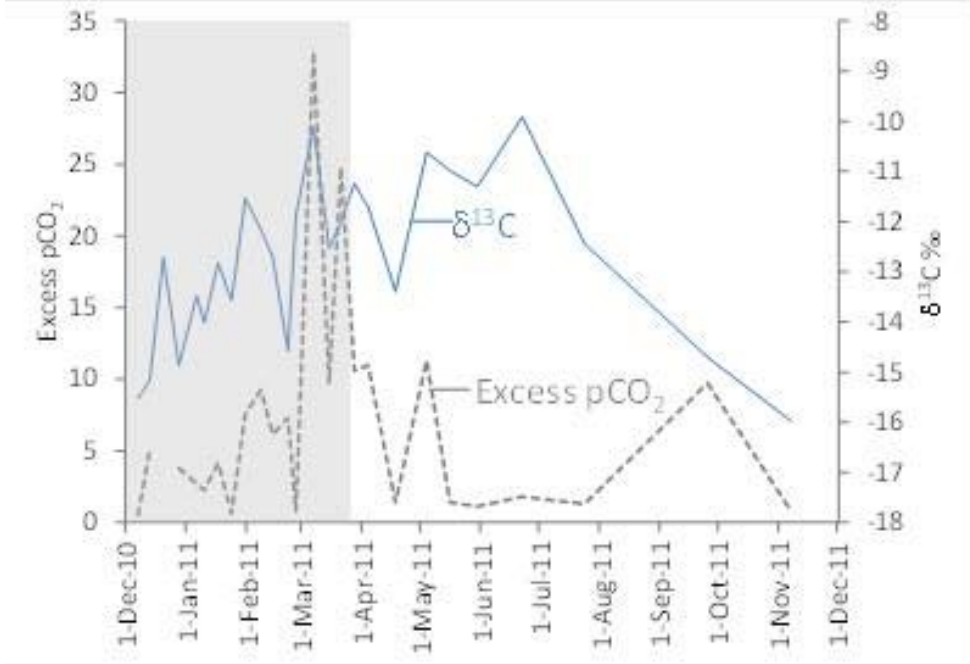
Seasonal DIC

Respiration ≠ corresponding increases in DIC and $\delta^{13}C$

Photosynthesis ~ no increase in pH with declines in DIC or increases in $\delta^{13}C$ (potential dry season affects)

Degassing ~ increase in excess pCO_2 and $\delta^{13}C$ during wet season; but SI show water is undersaturated with respect to CO_{2g} and DIC data do not show corresponding declines in concentrations



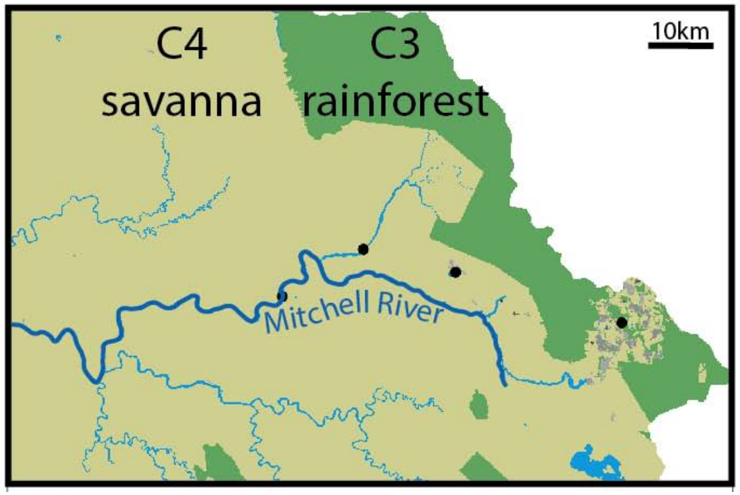


Seasonal DIC

Speciation ~ pH values
-5.90 to 7.50 wet season
-6.19 to 7.26 dry season
-speciation between $CO_{2(aq)}$ and $HCO_{3;}$
-trends in pH and $\delta^{13}C$ values indicate a weak inverse relationship

Geochemical reactions ~ SIs indicate that the rivers are undersaturated with respect to calcite, a
dolomite; potentially increase DIC conce

Mixing with waters from C3 and C4 area



Where there are

•distinct river discharge changes from the wet to the dry season

•distinct spatial variations in C3 and C4 vegetation

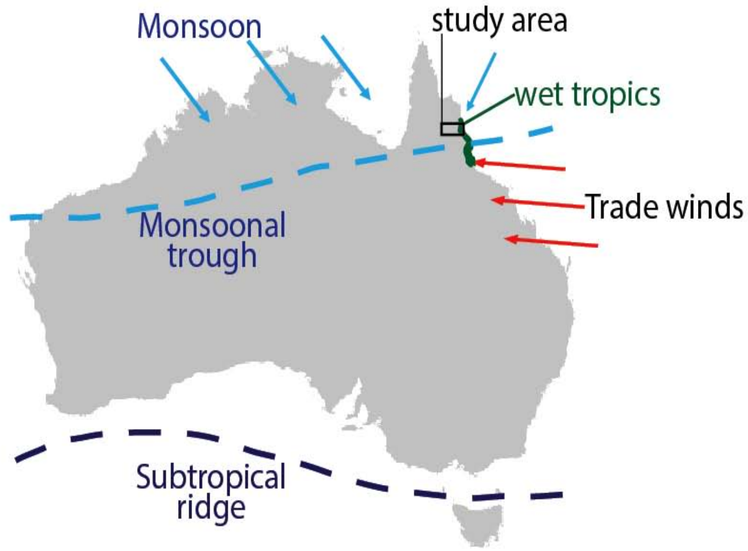
DIC and δ^{13}C are indicators of river inflows

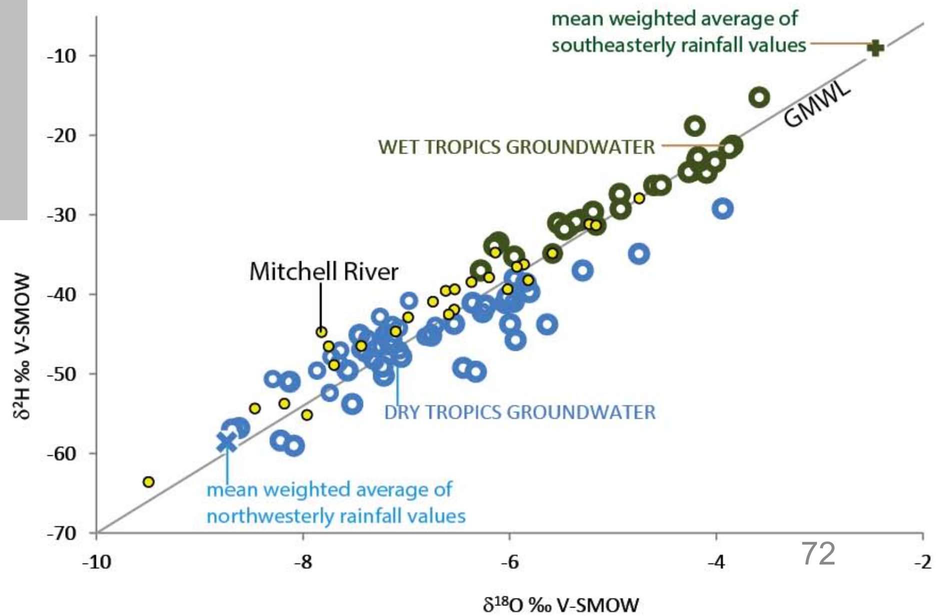
Improvements to component models

To improve :

Explore origin of isotopic differences in rainfall systems; just due to continental fall out or due to weather system differences?

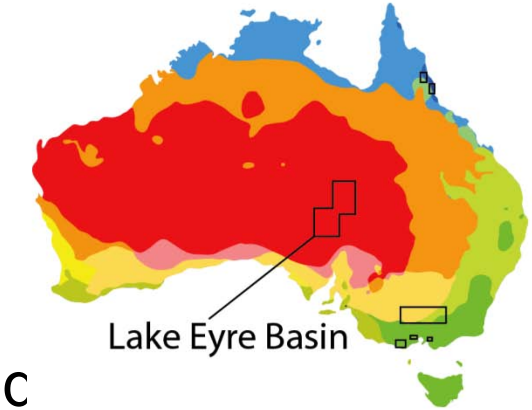
e.g. atmospheric moisture residence time (e.g. Aggarwal et ., 2012)





LEB

Floodwater recharge – Lake Eyre Basin



Question

Groundwater recharge from the intermittent flooc

(average annual rainfall 150 mm/yr)

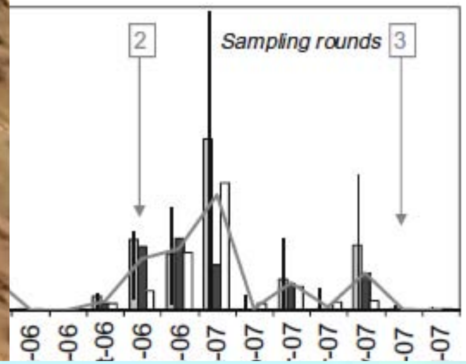
Approach

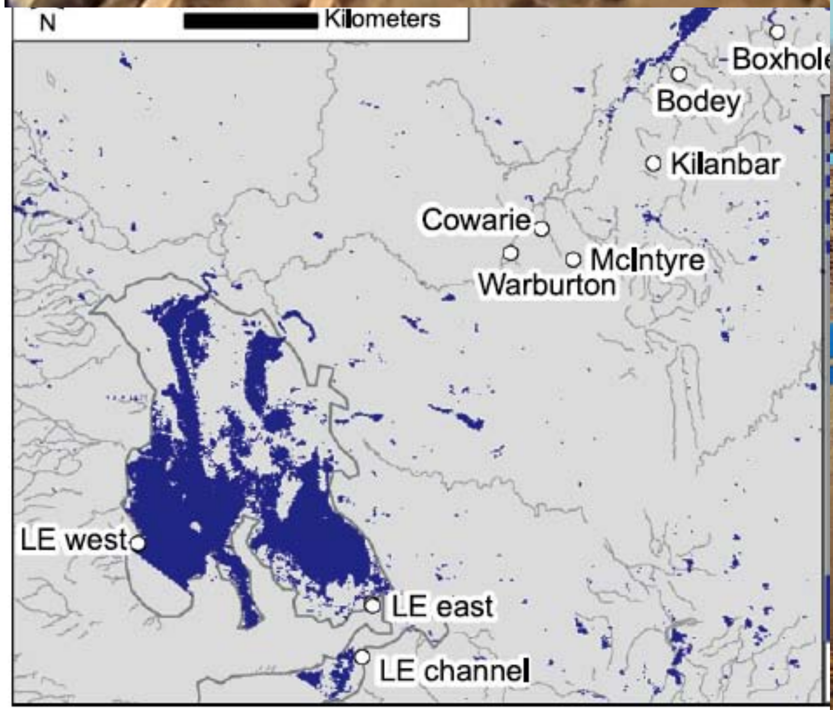
$\delta^{18}O$, $\delta^{2}H$, ^{14}C and ^{3}H - groundwater recharge processes

Management link

Arid system hydrogeological processes

Tweed, S., Leblanc, M., Cartwright, I., Favreau, G., Leduc, C., 2011. Arid zone groundwater recharge and salinisation processes; an example from the Lake Eyre Basin, Australia, Journal of Hydrology, 408, 257-275 asin


2
Sampling rounds
3


N
Kilometers
Boxhole
Bodey
Kilanbar
Cowarie
McIntyre
Warburton
LE west
LE east
LE channel

Floodwater recharge – Lake Eyre Basin

Groundwater chemistry before and after flood

- Groundwater TDS contents
  - before: 6,800-140,000 mg/L
  - after: 8,100-100,000 mg/L

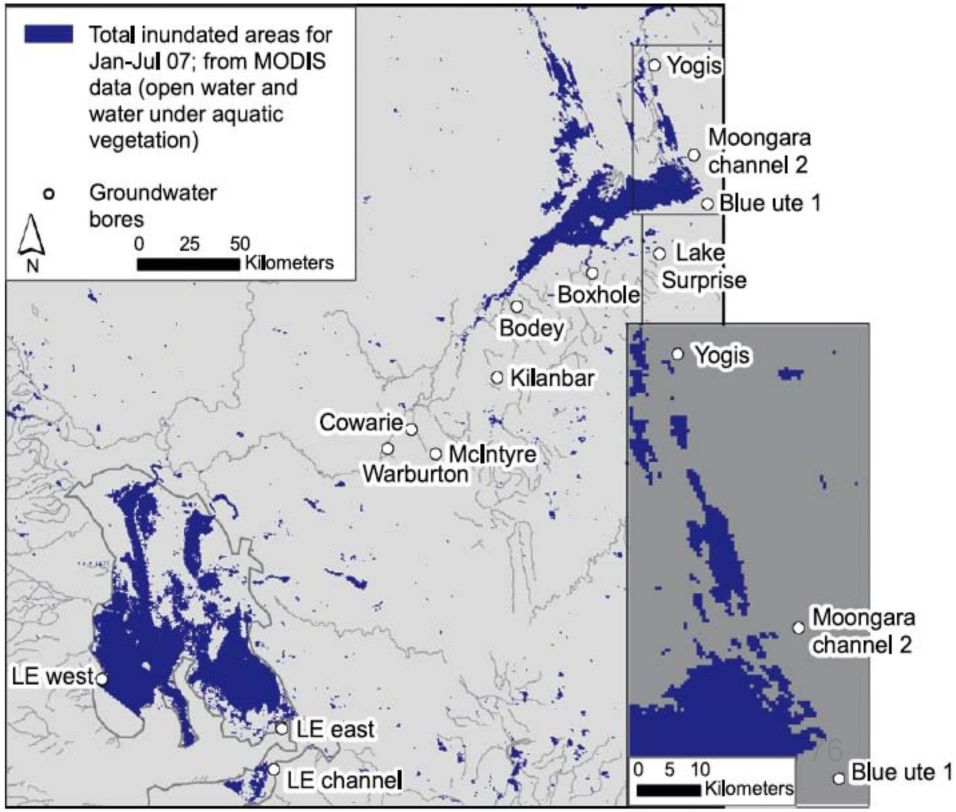
- Groundwater $\delta^2H_{activity}$
  - before: -41 to 3 ‰
  - after: -42 to 5 ‰

No evidence of a significant recharge event from floodwaters

Either

(1)Transit times are slow
- 6 months between flood and sampling;

(2)Volume of infiltrating water is low
- change in chemistry is minimal

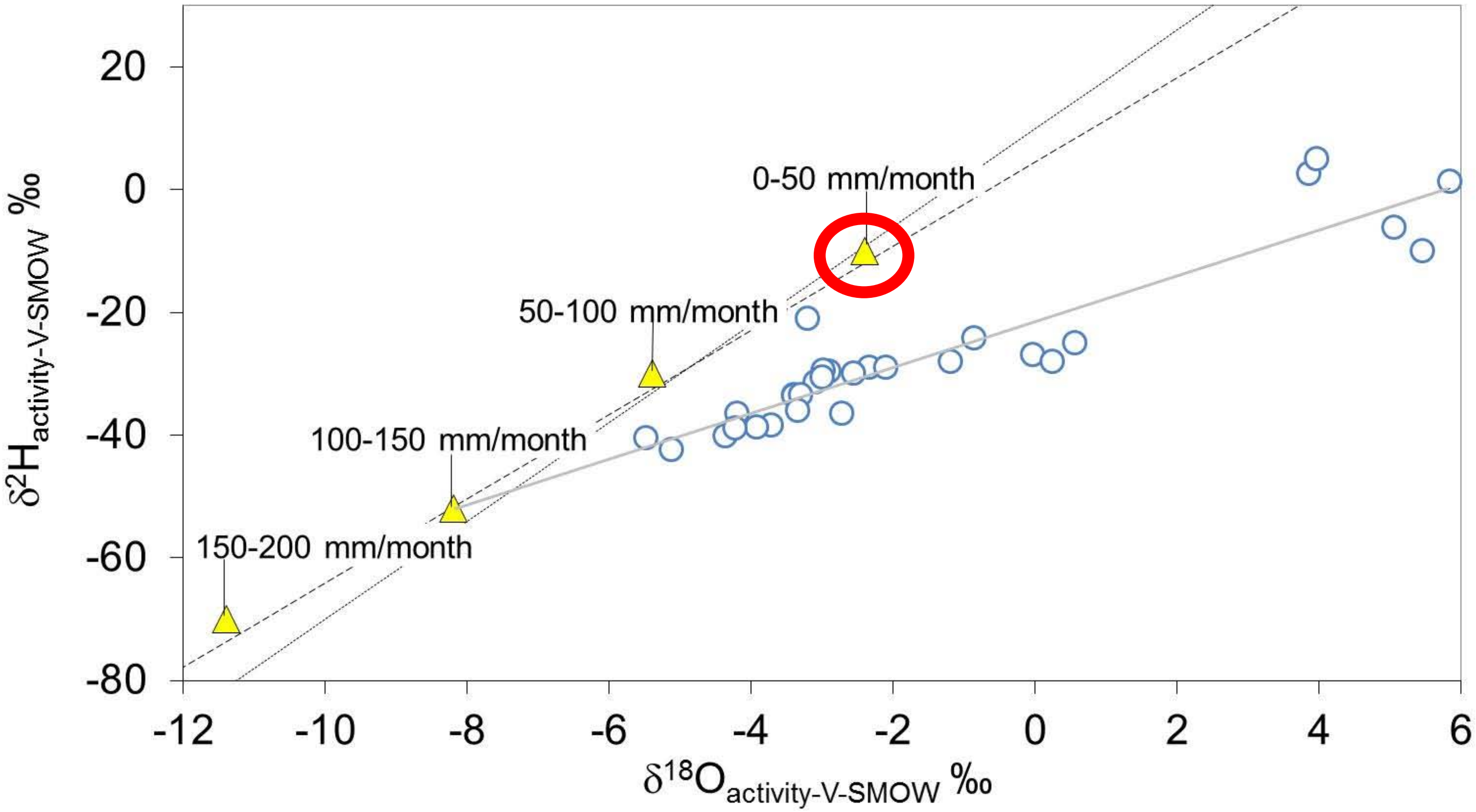


Floodwater recharge – Lake Eyre Basin

$\delta^{18}O$, $\delta^{2}H$ - long-term recharge processes

•Linearly interpolated isotope values for groundwater
•Corresponding rainfall levels are ~ 100-150 mm/month

•Highest average monthly rainfall is 33 mm (Jan)
•Groundwater recharge from local rainfall is not a regular occurrence



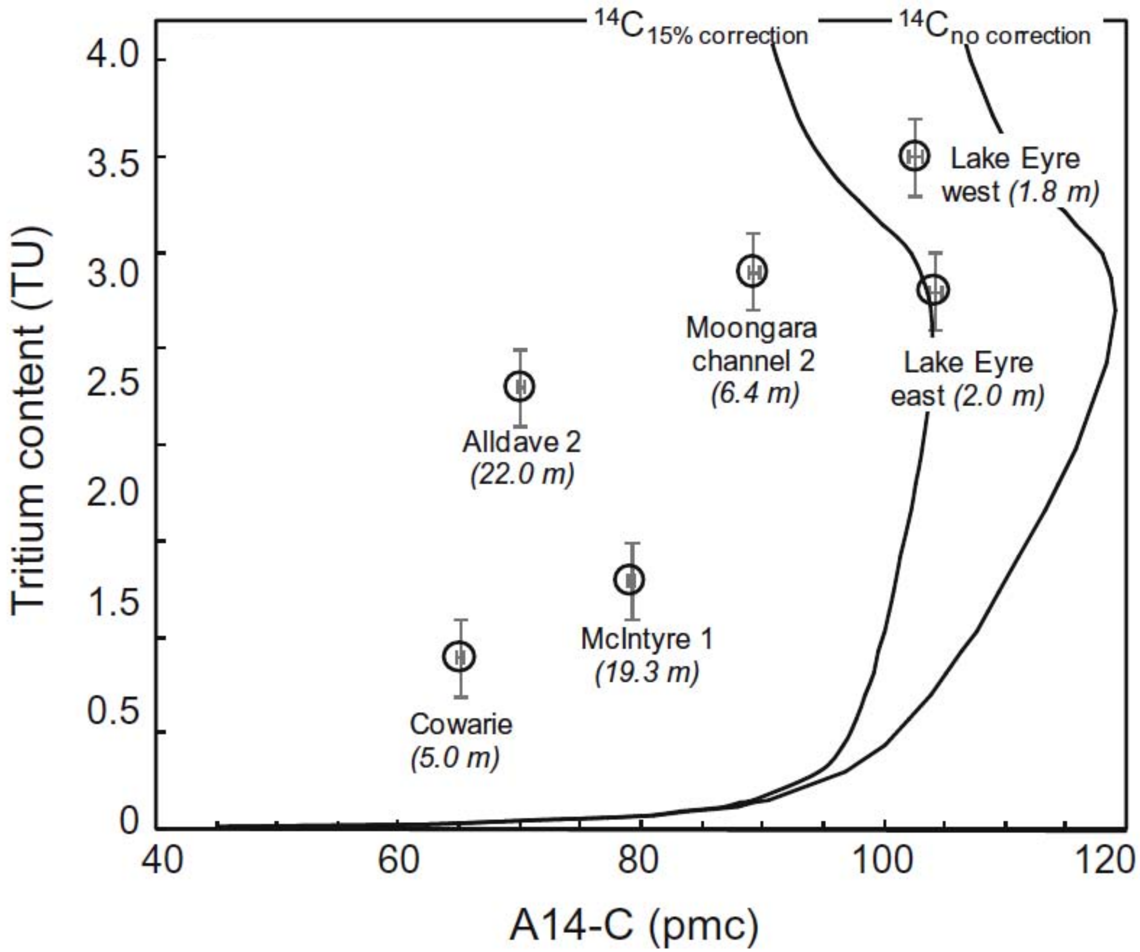
Floodwater recharge – Lake Eyre Basin

^{14}C and ^{3}H

- ^{14}C (65.1–104.2 pmC) and ^{3}H (0.9–3.5 TU)
- mixing between younger water and older water

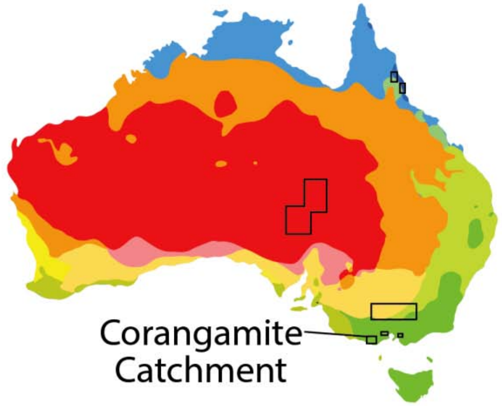
Dual porosity recharge

- cracking clays
- Fractured sandstone and shale aquifers



Corangamite drought

Drought impacts on water quality – Corangamite Lakes



Question

Impacts of drought on nutrient concentrations in groundwater through-flow lakes?

Approach

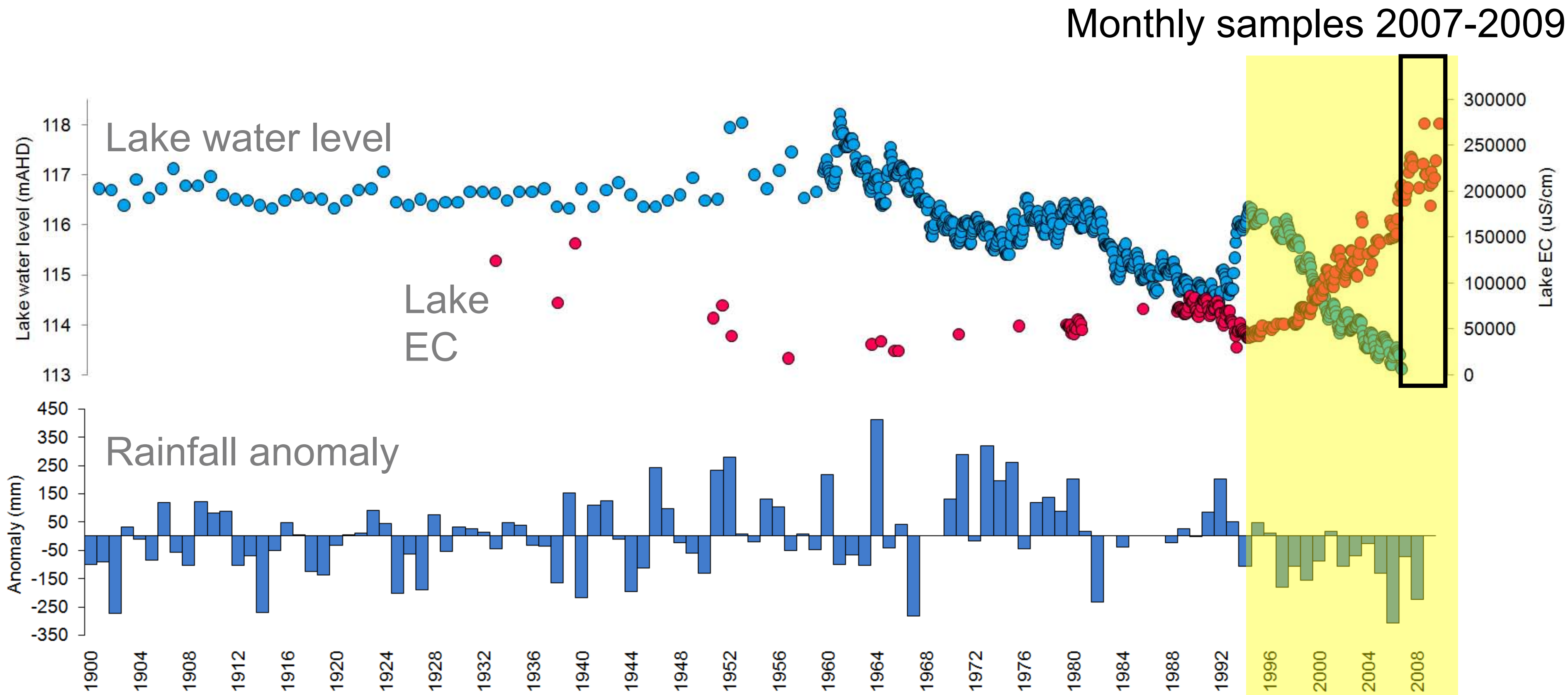
Major ions and nutrient concentrations

Management link

Ecologically important (Ramsar sites) lakes

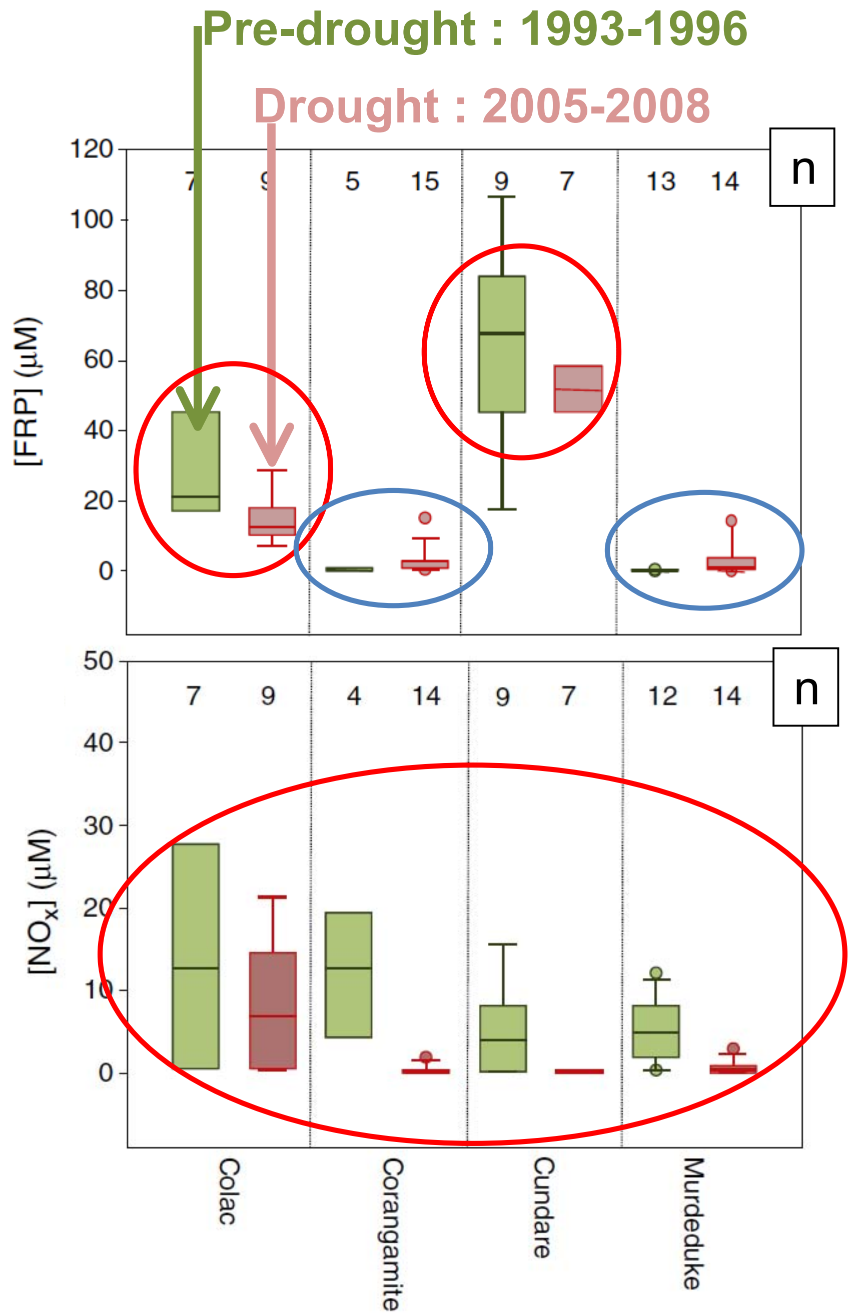
Tweed, S., Grace, M., Leblanc, M., Cartwright, I., Smithyman, D. 2011. The individual response of saline lakes to a severe drought. *Science of the Total Environment* 409, 3919-3933.

Drought: 1997 - 2011



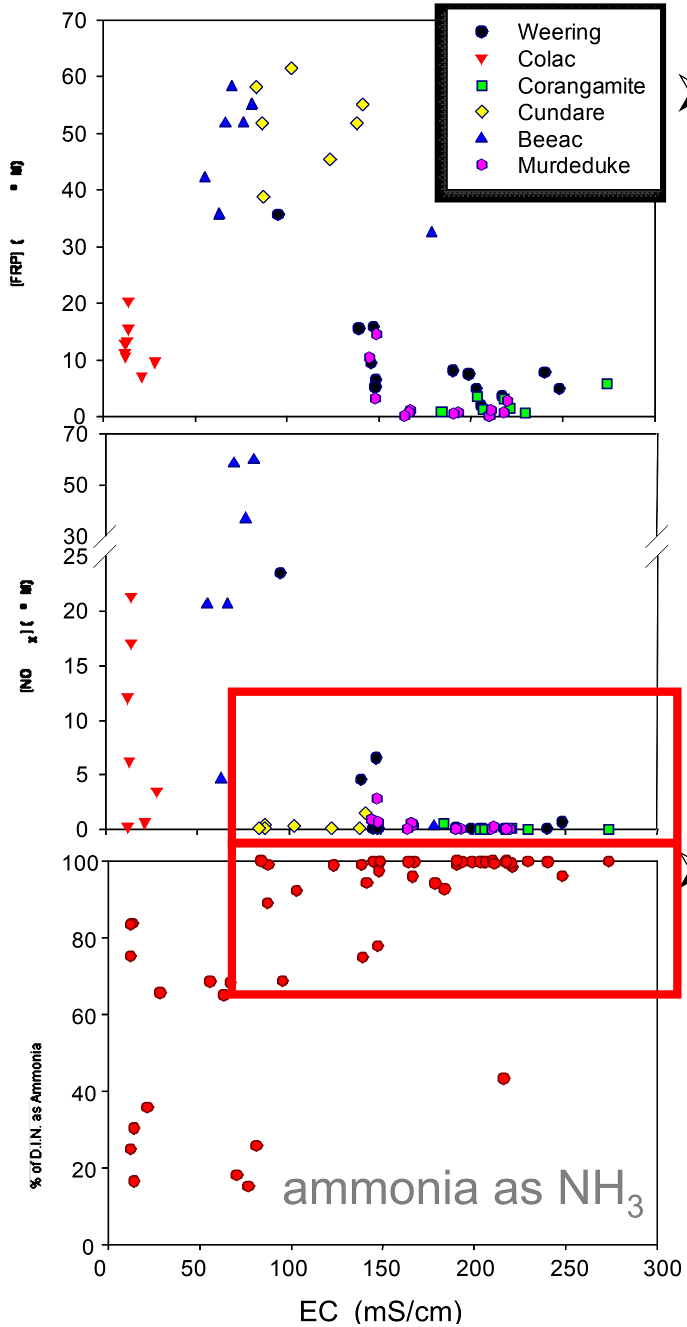
	1900-1937	1939-1959	1960-1993	1994-2009
Max change in water level (m)	↓ 0.7	↑ 1.7	↓ 3.6	↓ 3.2
Max change in EC (mS/cm)		↓ 120	↑ 53	↑ 230

Trends in changes in nutrients from pre-drought to drought?

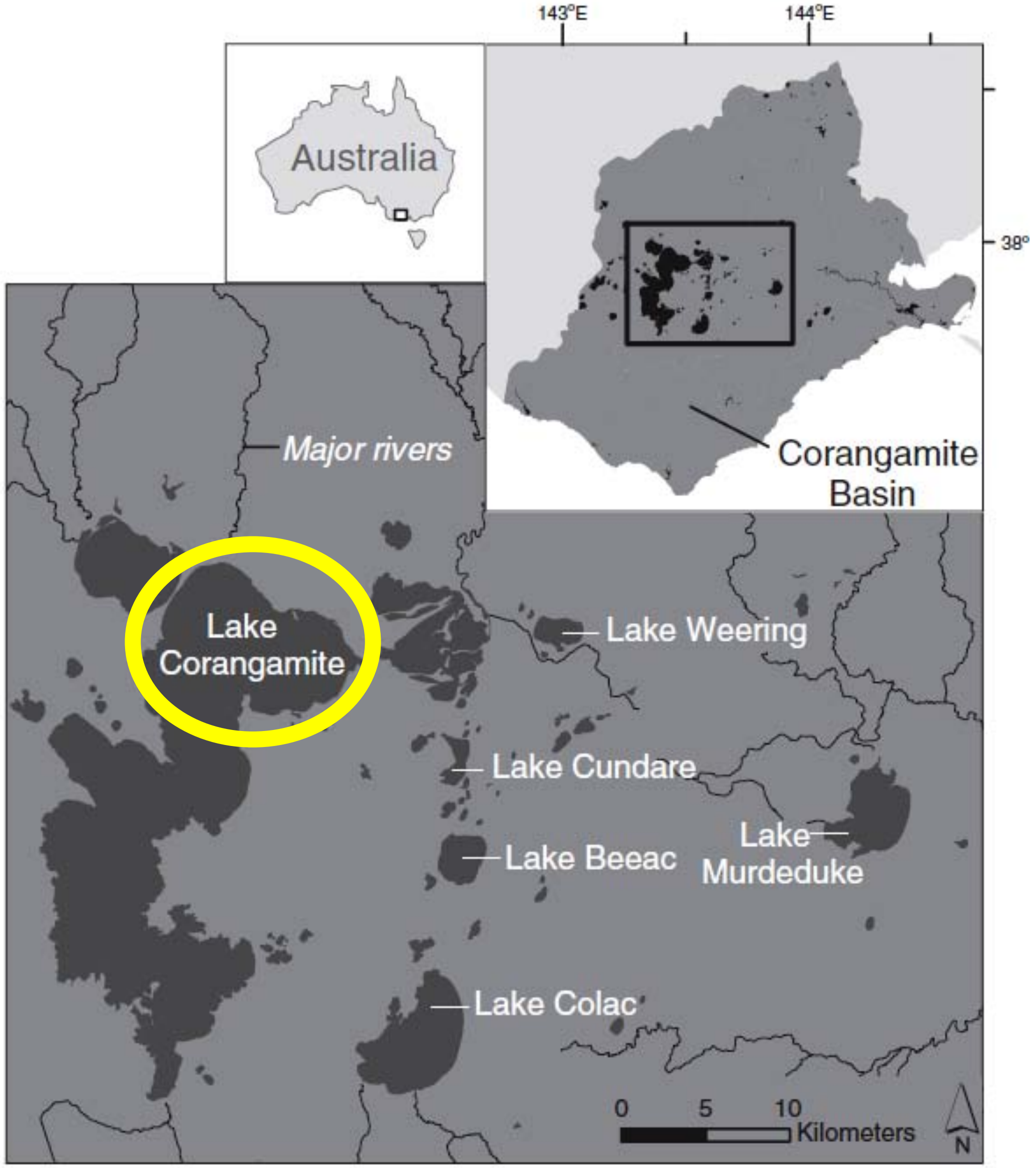


- Decrease in phosphate
- Minor increase in phosphate
- Decrease in NOx

Trends in changes in nutrients with lake salinity?



- FRP is largely determined by the individual lake (and sources) rather than the salinity
- EC < 100 mS/cm, greater NOx variability
- EC > 100 mS/cm, NOx concentrations low
- EC > 100 mS/cm, almost all of the D.I.N. is NH_3



Drought in context
e.g. Lake Corangamite

6 Lakes

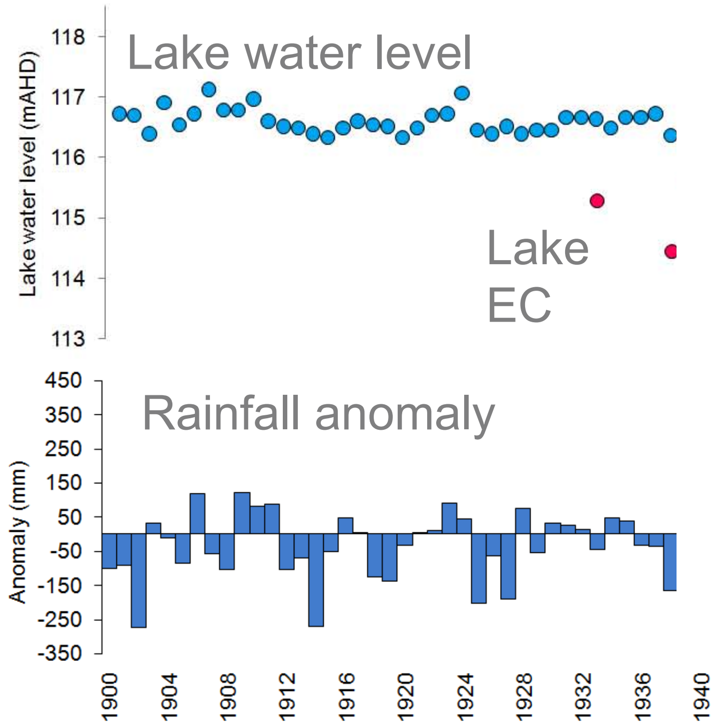
•mostly shallow (< 6 m)

•Range in sizes
- 0.13 to 241 km^2

•Mostly saline
- up to > 400 mS/cm

1900-1938: low rainfall

European settlement expansion 1830s - early 1900s



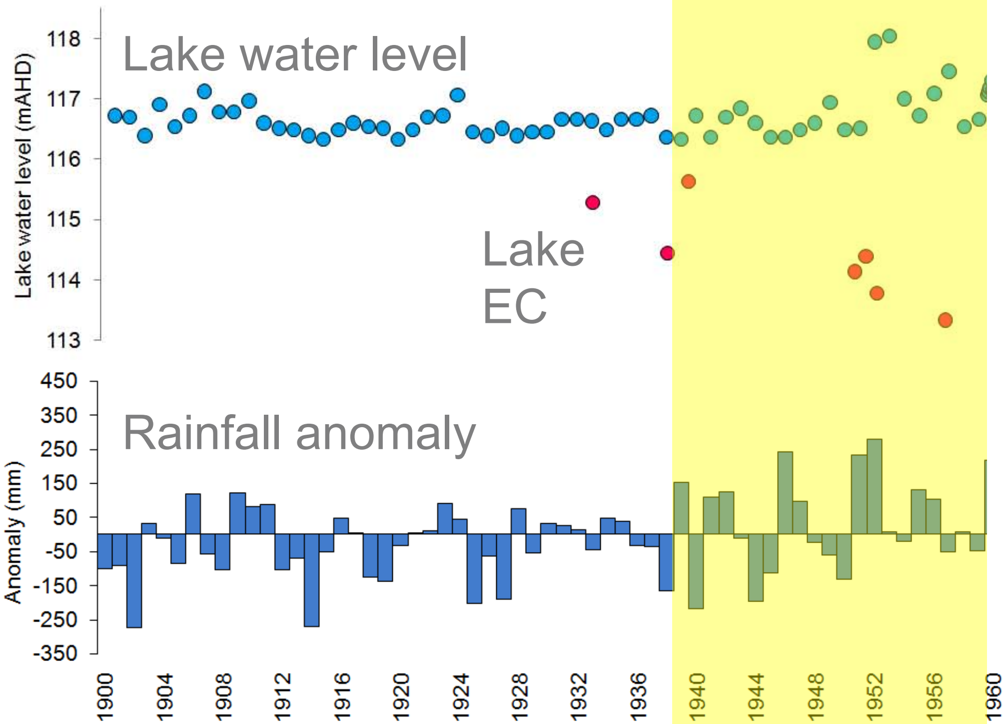
Lake Corangamite takes its name from the Colijon tribe word koraiyn, meaning bitter or salty

EC: 78 -124 mS/cm (1933-38)

Salt beside Lake Corangamite, c. 1920
(La Trobe Picture Collection, State Library of Victoria).

	1900-1937
Max change in water level (m)	↓ 0.7
Max change in EC (mS/cm)	

1939-1959: increased rainfall



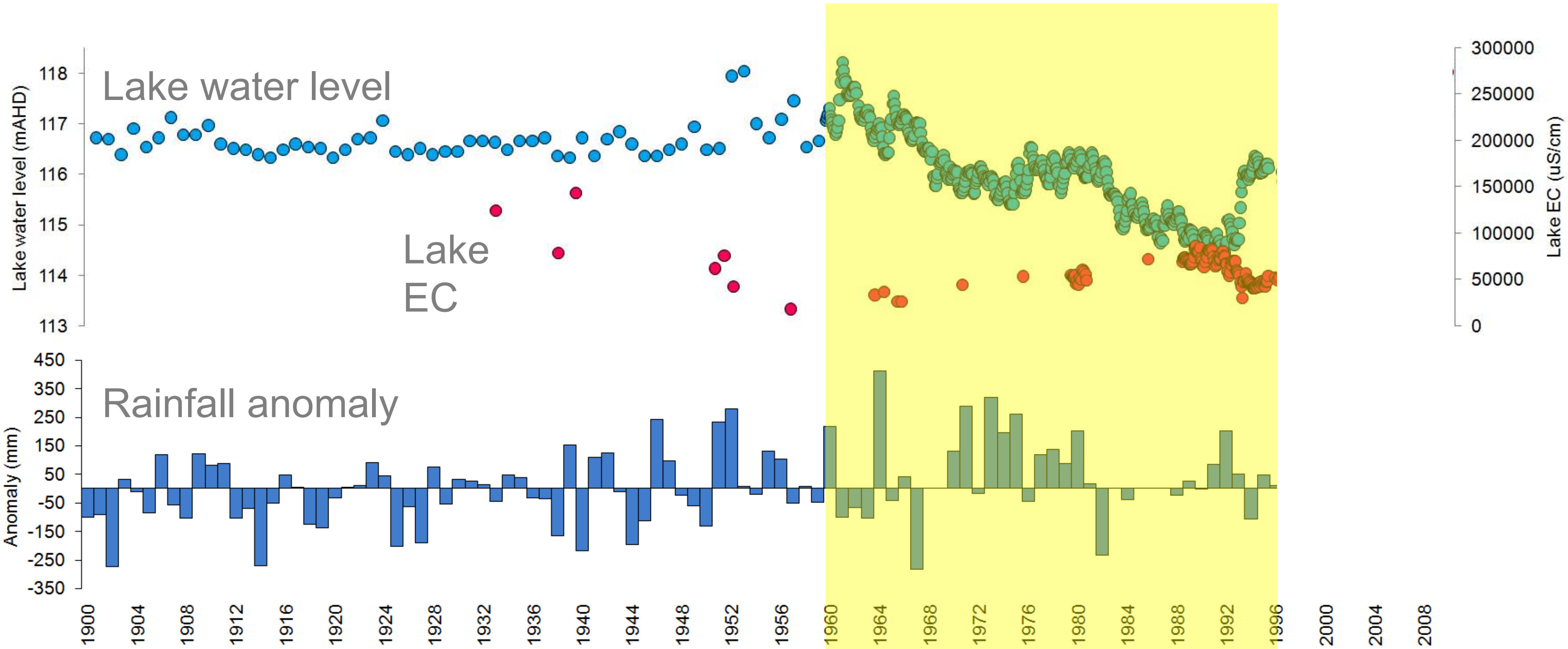
floods

A flooded farmhouse beside Lake Corangamite 1958
(La Trobe Picture Collection, State Library of Victoria).

	1900-1937	1939-1959		
Max change in water level (m)	↓ 0.7	↑ 1.7		
Max change in EC (mS/cm)		↓ 120	↑ 50.9	↑ 219

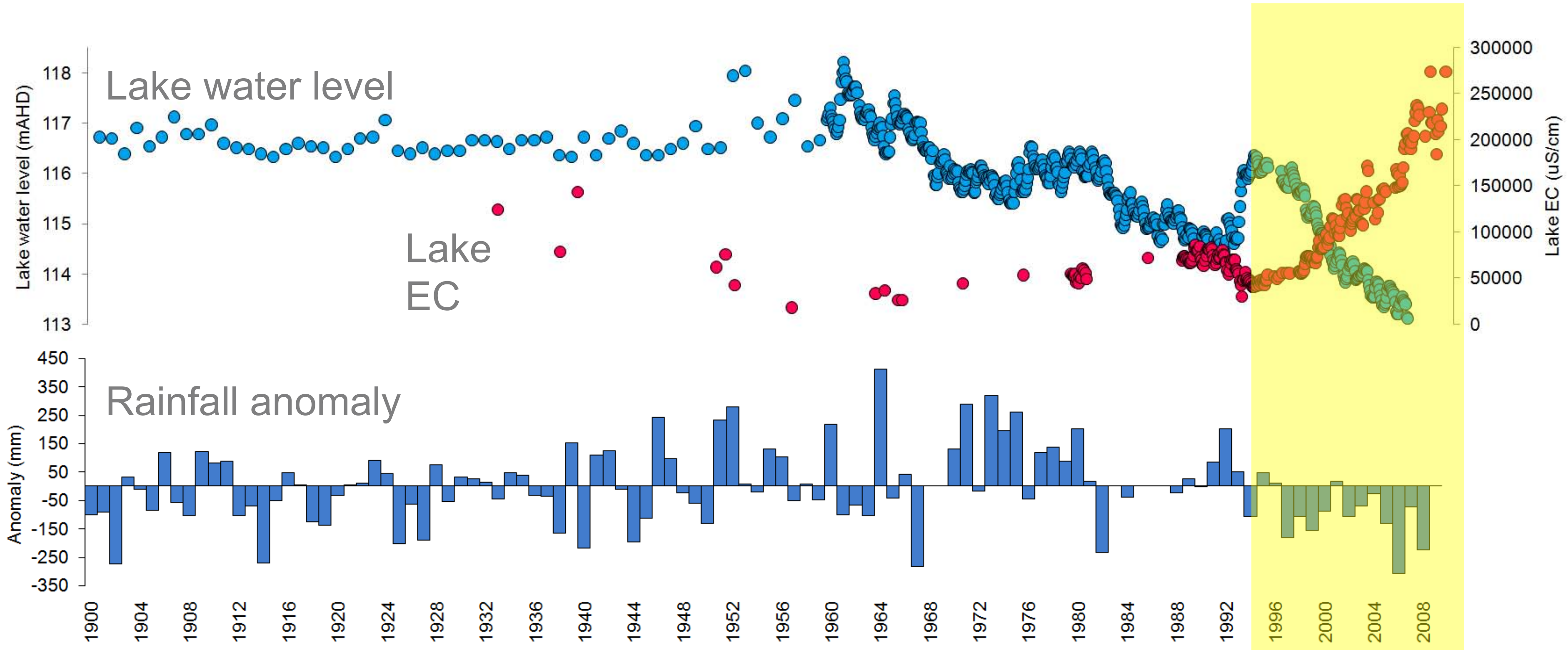
1960-1996: water diversion

Changes in lake biota; affected bird species



	1900-1937	1939-1959	1960-1993
Max change in water level (m)	↓ 0.7	↑ 1.7	↓ 3.6
Max change in EC (mS/cm)		↓ 120	↑ 53

1994 - present: drought

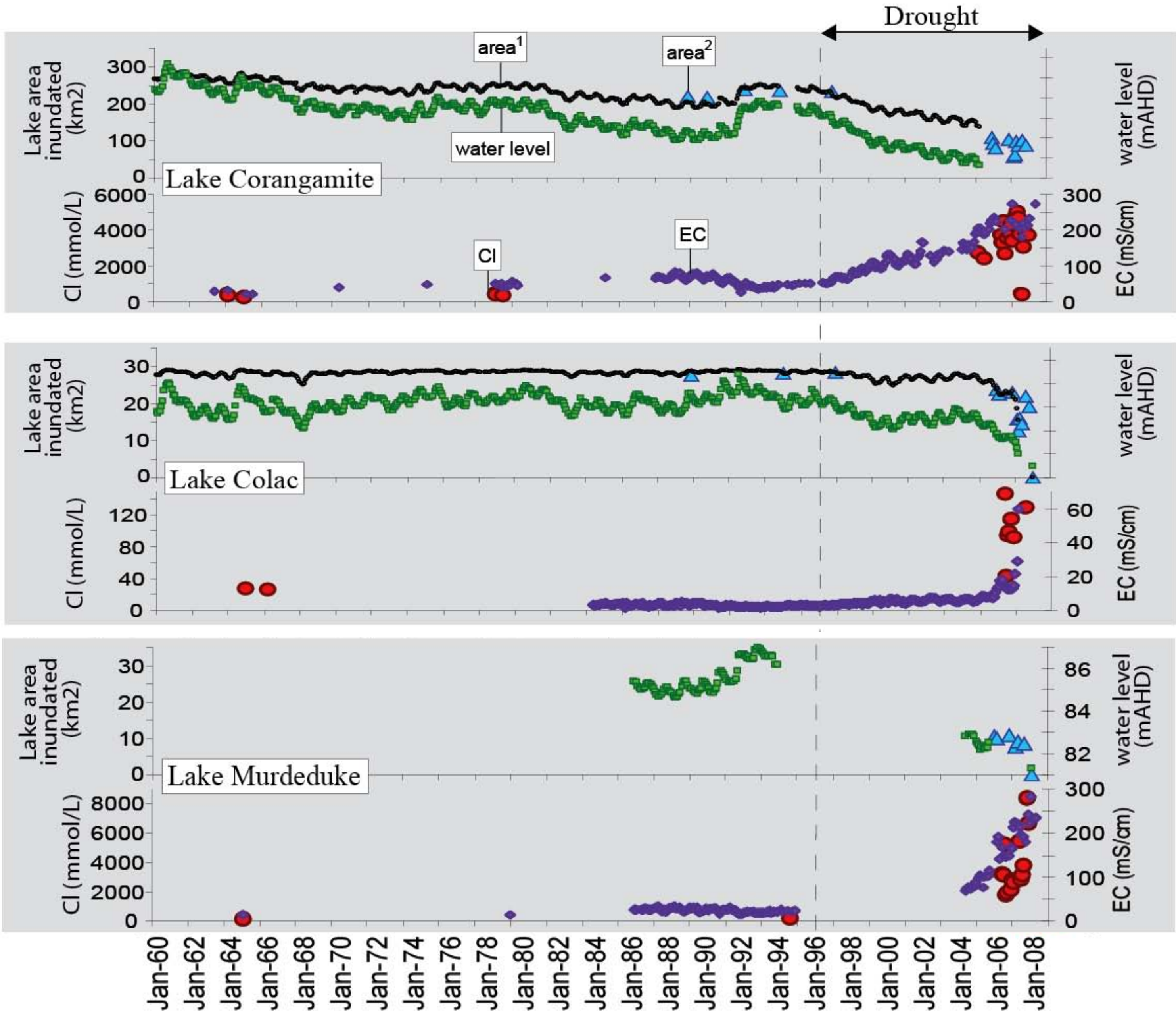


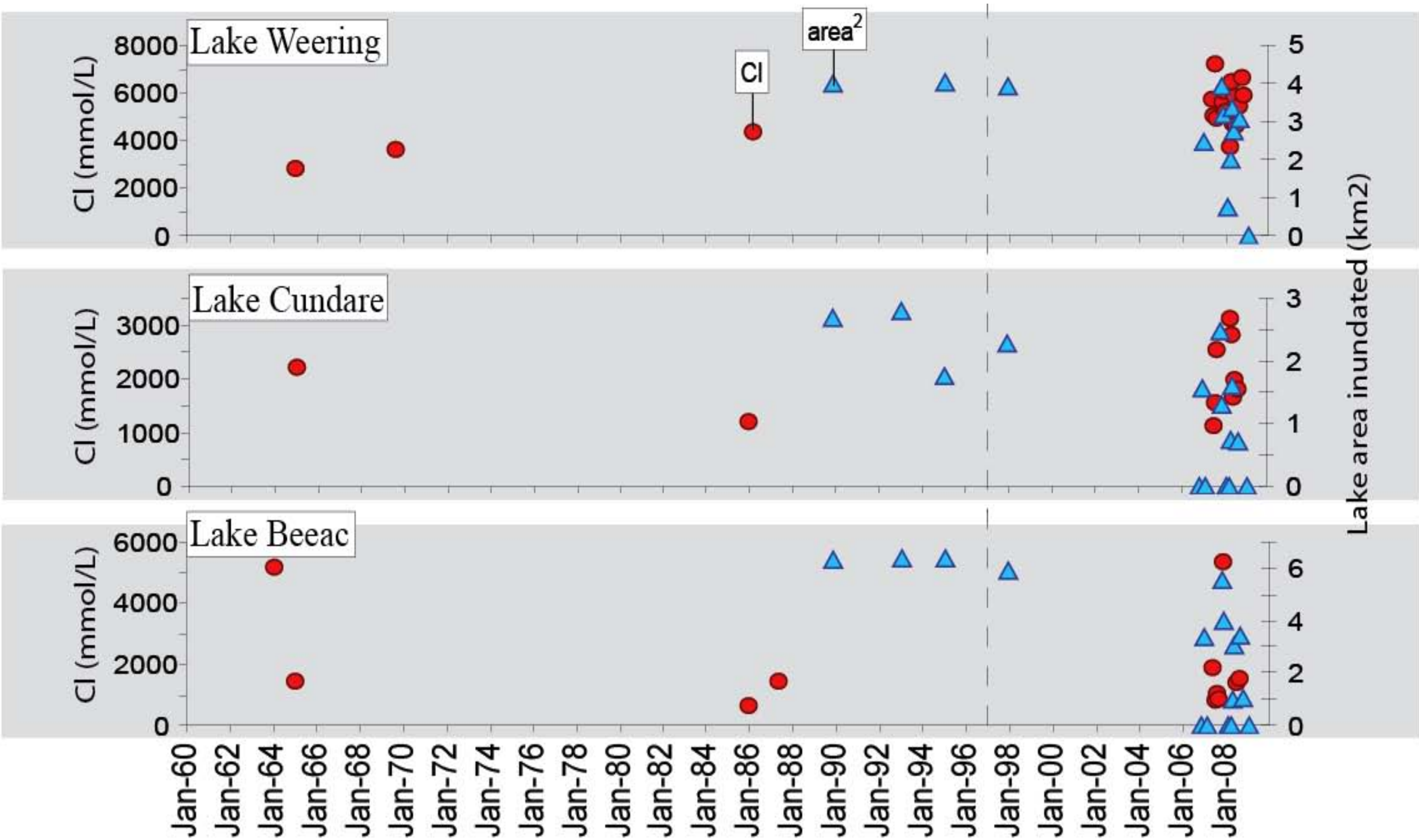
	1900-1937	1939-1959	1960-1993	1994-2009
Max change in water level (m)	↓ 0.7	↑ 1.7	↓ 3.6	↓ 3.2
Max change in EC (mS/cm)		↓ 120	↑ 53	↑ 230

Agriculture surrounding lakes

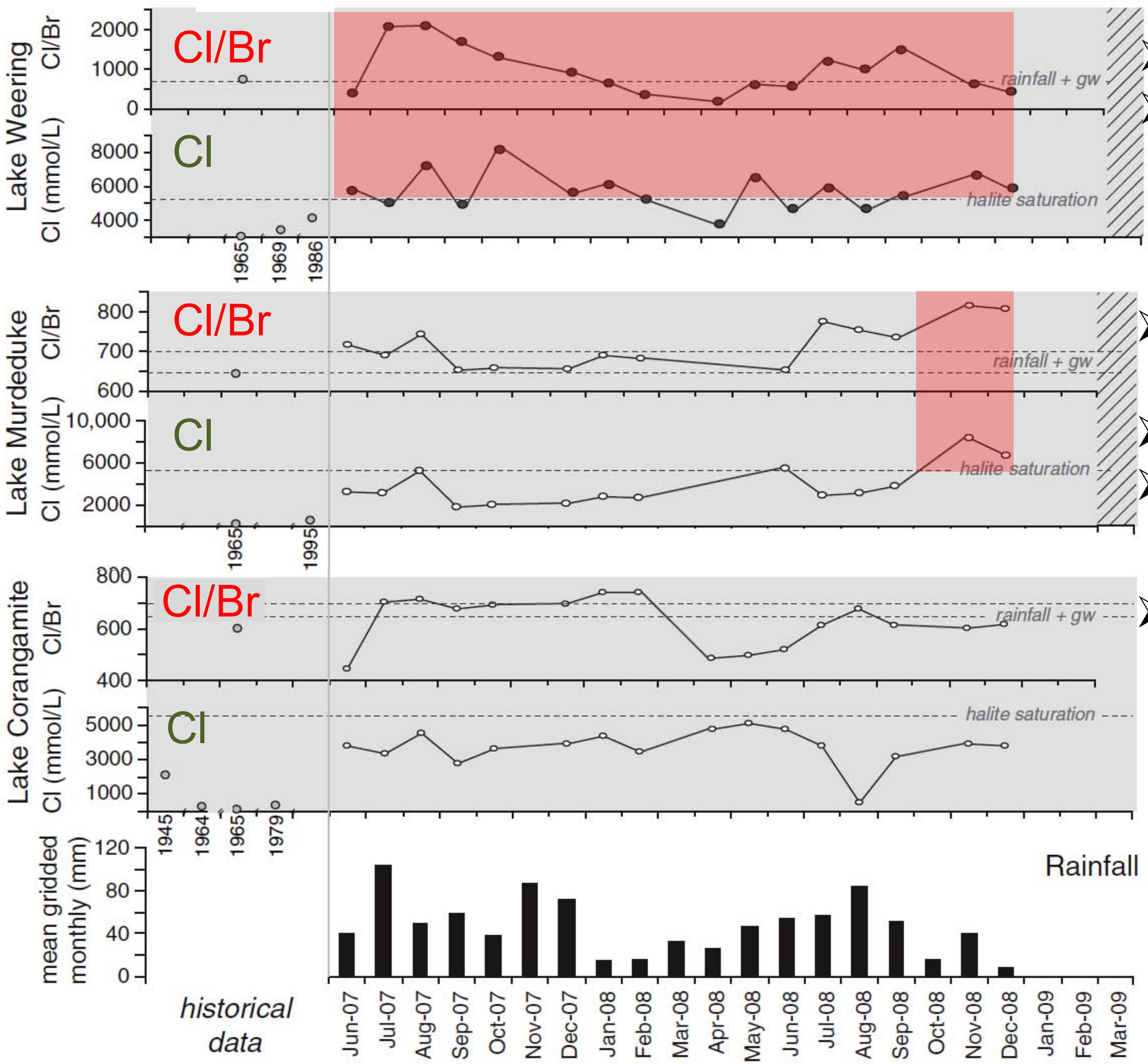
Sensitive to climatic variability…

Drought – increased EC


Drought
area1
area2
water level
Lake Corangamite
Lake area inundated (km2)
water level (mAHD)
Cl
EC
Cl (mmol/L)
EC (mS/cm)
Lake Colac
Lake area inundated (km2)
water level (mAHD)
Cl (mmol/L)
EC (mS/cm)
Lake Murdeduke
Lake area inundated (km2)
water level (mAHD)
Cl (mmol/L)
EC (mS/cm)
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08


Lake Weering
Lake Cundare
Lake Beeac
Cl
area2
Cl (mmol/L)
Lake area inundated (km2)
Jan-60 Jan-62 Jan-64 Jan-66 Jan-68 Jan-70 Jan-72 Jan-74 Jan-76 Jan-78 Jan-80 Jan-82 Jan-84 Jan-86 Jan-88 Jan-90 Jan-92 Jan-94 Jan-96 Jan-98 Jan-00 Jan-02 Jan-04 Jan-06 Jan-08

Multi-year drought impacts on water quality – Corangamite Lakes



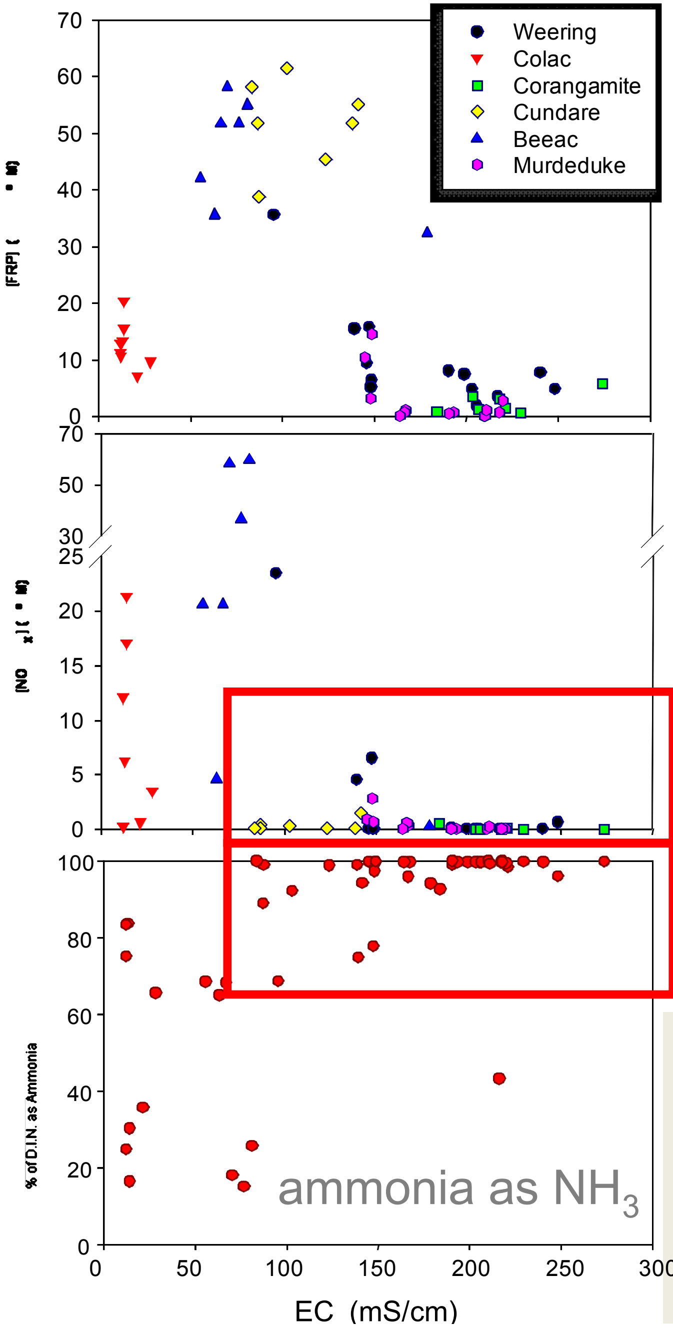
Varied responses in salinity processes to drought

- Pre-drought: evaporation
- Drought: Halite precipitation and dissolution

- Saturated with respect to halite
- Increase in Cl/Br ratios
- Increase influence of halite precipitation and dissolution

- No change

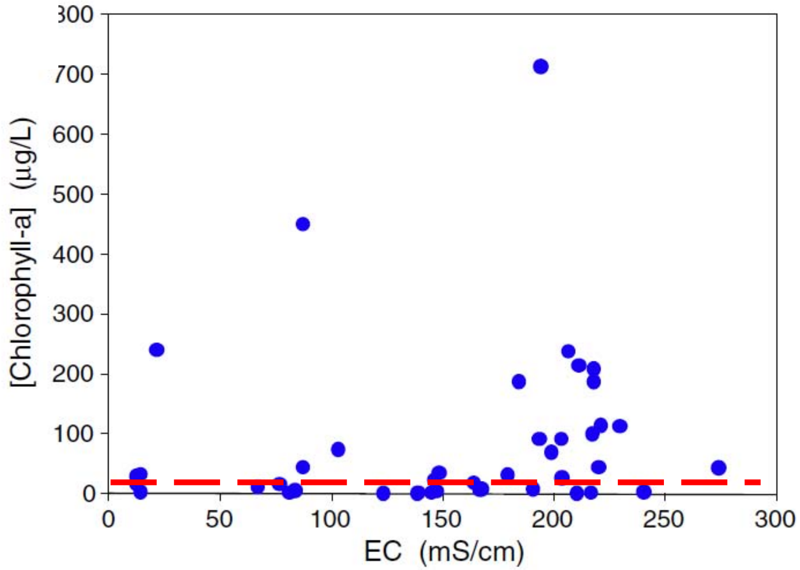
Trends in changes in nutrients with lake salinity?



- NO_x variations are driven not by salinity increases but by other biogeochemical processes
- EC > 100 mS/cm, almost all of the D.I.N. is NH_3 (pH 7.5 - 9.6)
- NH_3 can be toxic to a wide range of organisms at high concentrations

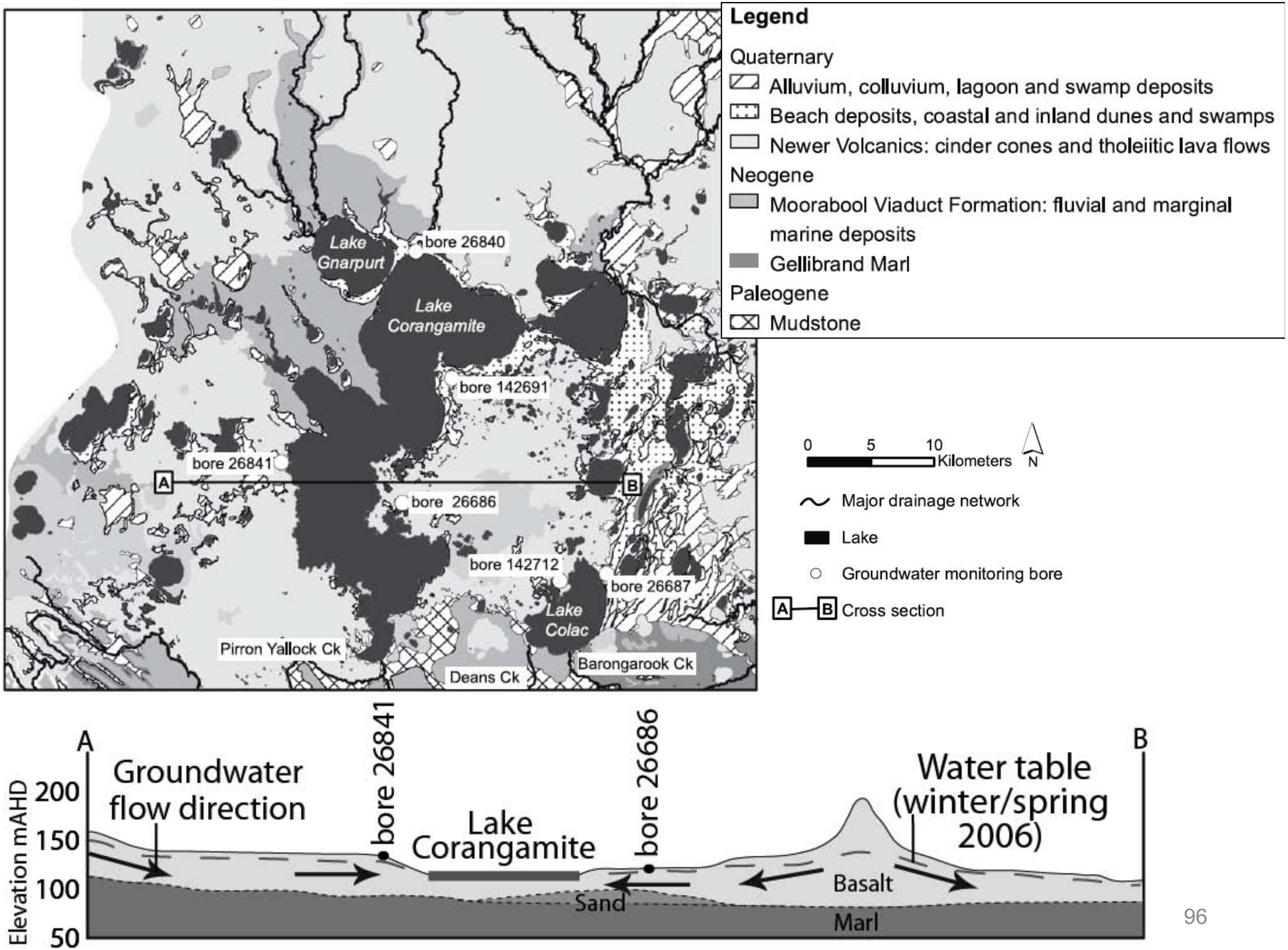
i) high concentrations of Na^+ can displace NH_4^+ bound to negatively charged suspended particles
ii) nitrification (of NH_4^+ to NO_3^-) is suppressed due to the inability of ammonia oxidizing bacteria to function under hypersaline conditions

Trends in changes in nutrients with lake salinity?

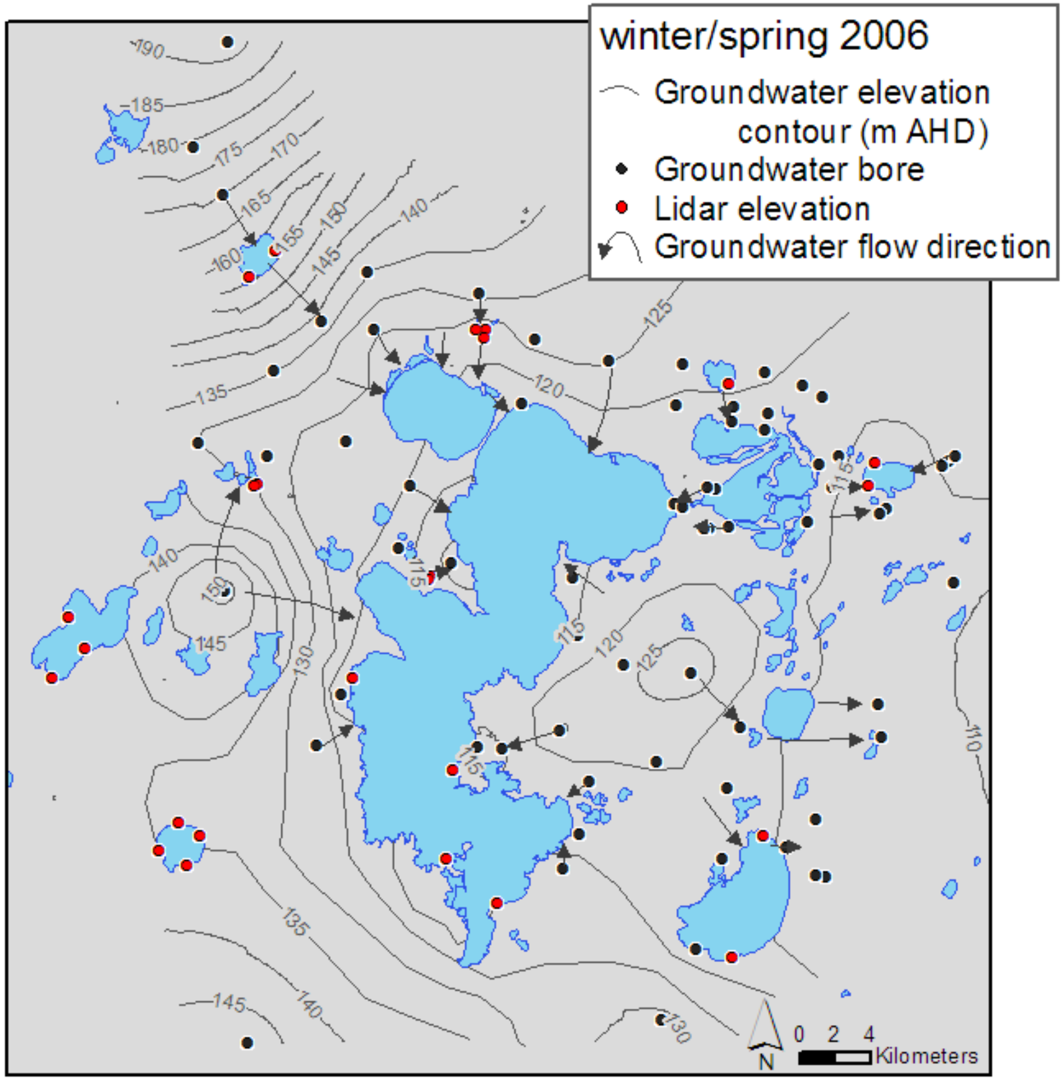


- At various times during the drought, each lake exceeds the 8 µg/L government trigger level

- EC ~ 200 mS/cm: high chlorophyll-a concentrations
- High salinities not constraining algal growth


Legend
Quaternary
Alluvium, colluvium, lagoon and swamp deposits
Beach deposits, coastal and inland dunes and swamps
Newer Volcanics: cinder cones and tholeiitic lava flows
Neogene
Moorabool Viaduct Formation: fluvial and marginal marine deposits
Gellibrand Marl
Paleogene
Mudstone
Lake Gnarpurt
bore 26840
Lake Corangamite
bore 142691
bore 26841
A
B
bore 26686
bore 142712
bore 26687
Lake Colac
Pirron Yallock Ck
Deans Ck
Barongarook Ck
0 5 10 Kilometers
N
Major drainage network
Lake
Groundwater monitoring bore
Cross section
Elevation mAHD
200
150
100
50
Groundwater flow direction
bore 26841
Lake Corangamite
bore 26686
Water table (winter/spring 2006)
Basalt
Sand
Marl

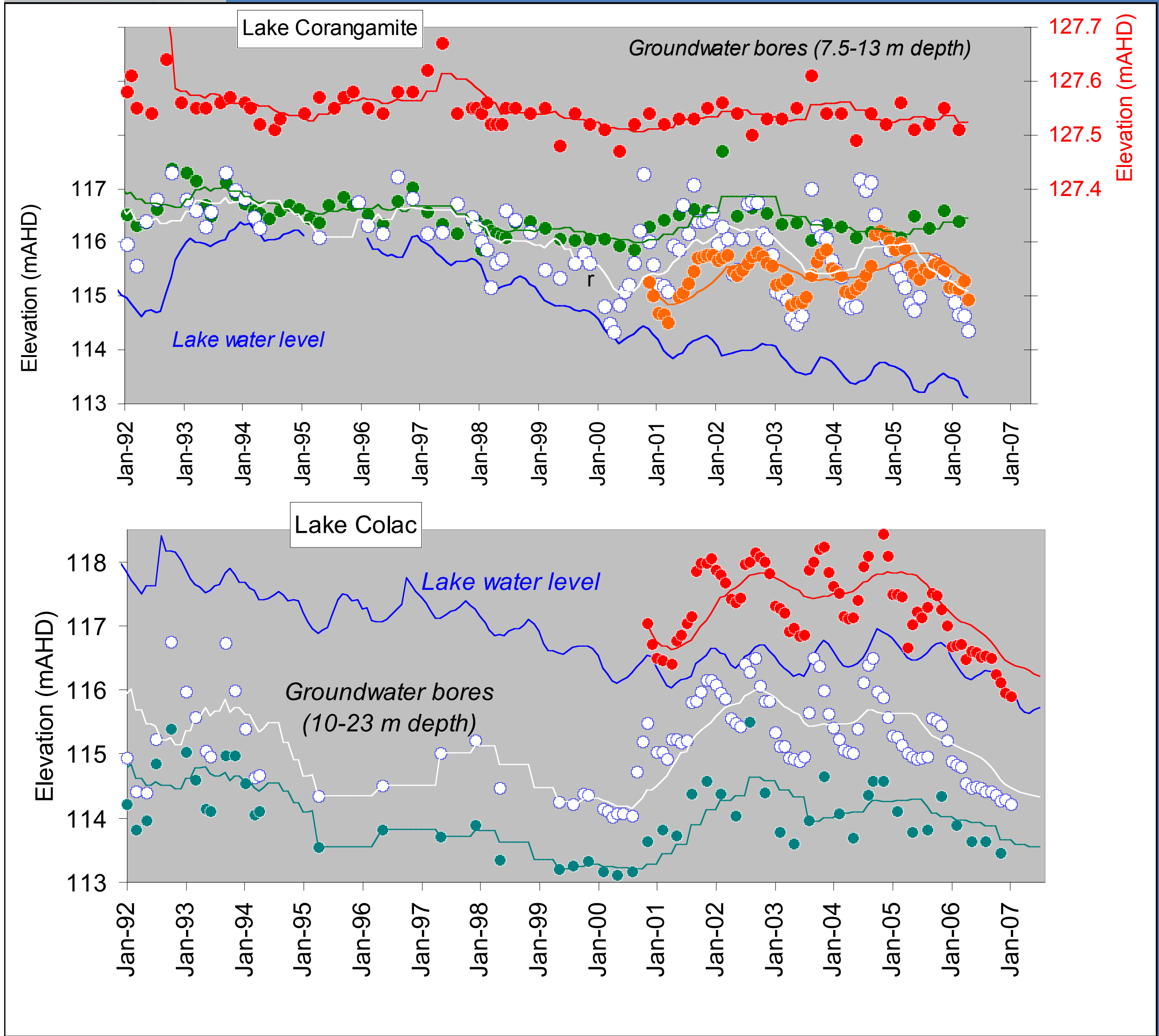
Temporal variation
groundwater and lakes



Pre-drought (1992) vs. Drought (2006)

- Regional groundwater flow to the east
- Water table during drought is lower on average by
  - 0.73 m in summer/autumn
  - 1.24 m in winter/spring

Temporal variation groundwater and lakes



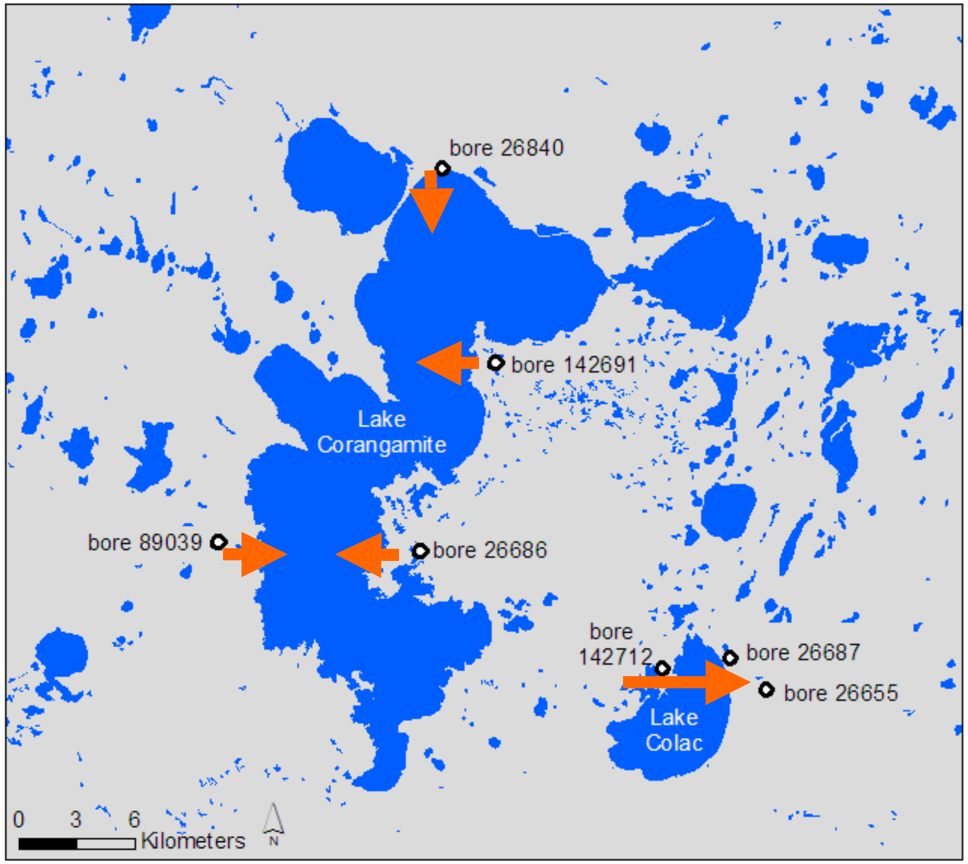
Lake levels decrease at a more rapid rate than the groundwater levels

- hydraulic gradients between groundwater and lakes have changed
- No reversals
  - Lake Corangamite remains a discharge lake
  - Lake Colac remains a throughflow lake

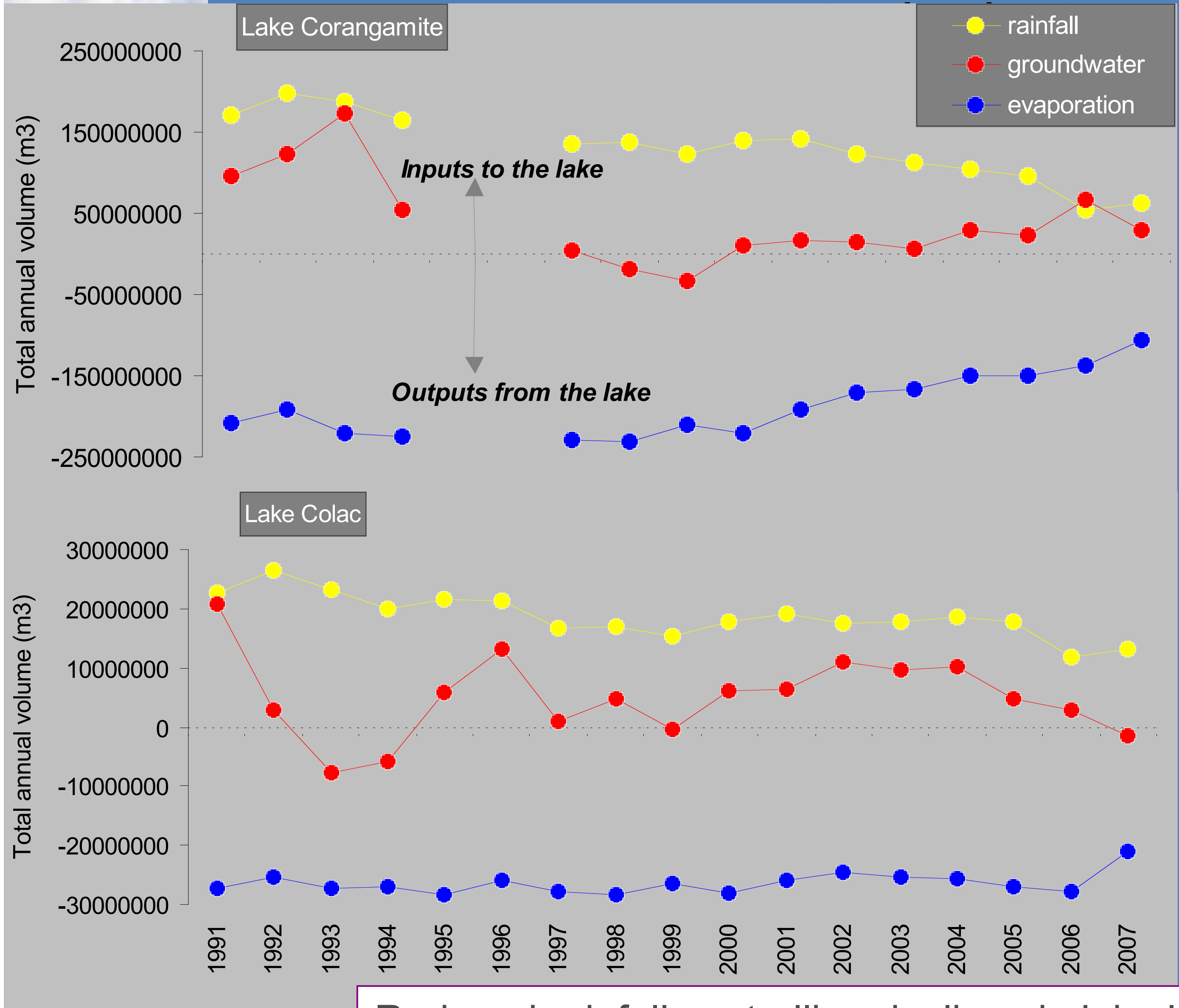
Temporal variation
groundwater and lakes

Limitation
– Point data: insufficient distribution of monitored groundwater bores surrounding lakes

..water budget



Temporal variation



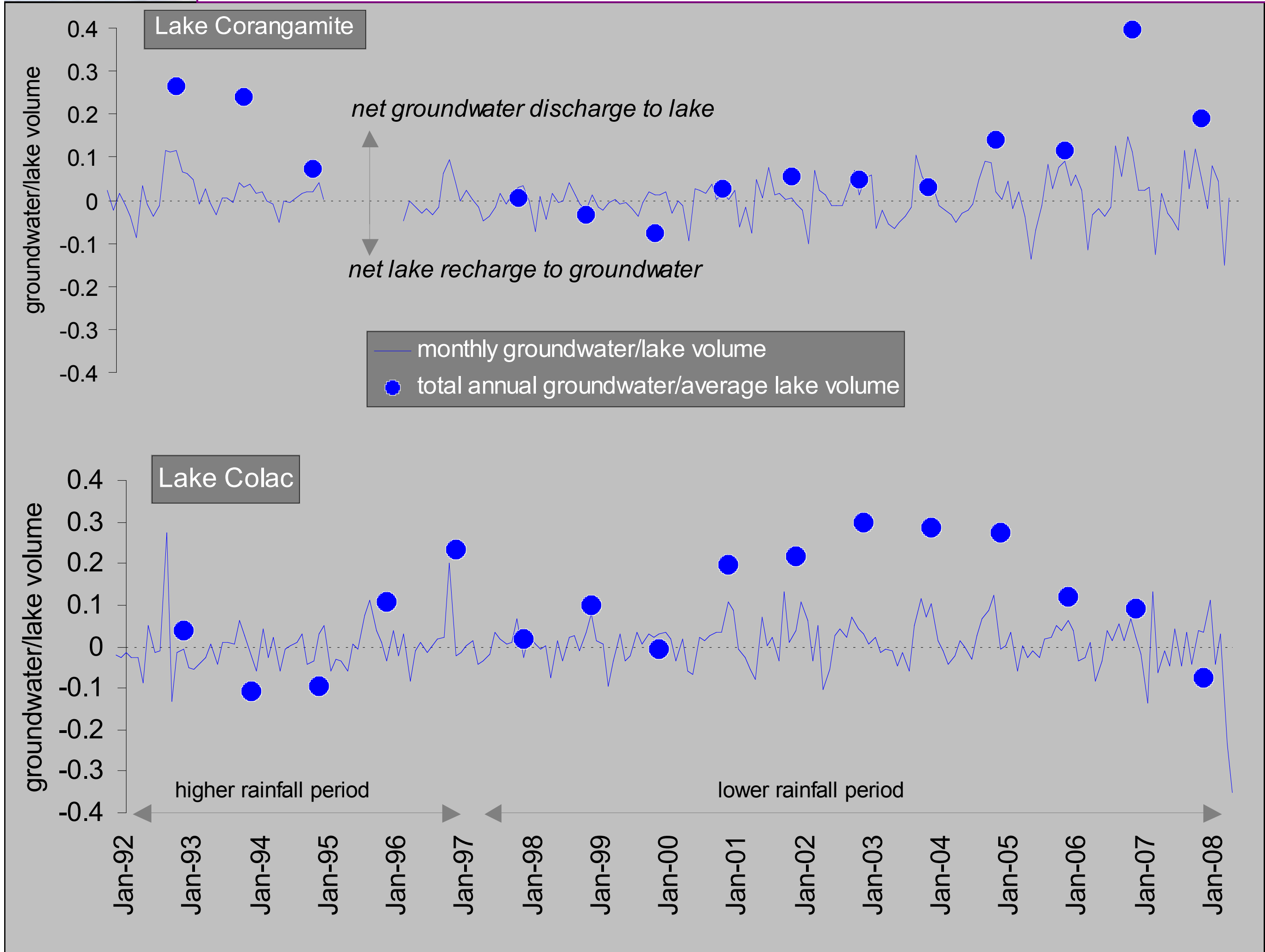
- Water in lakes from rainfall
- Reduced rainfall
- No decrease in groundwater discharge
- No increase in evaporation

Reduced rainfall controlling declines in lake levels

Temporal variation

water budget

varying responses in groundwater-lakes interaction to drought stress



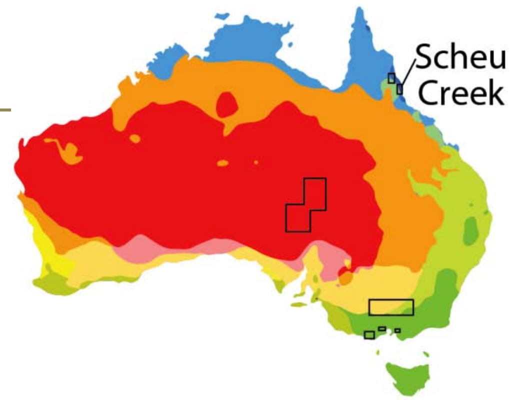
- Seasonal fluctuations
- Discharge decrease during wetter period
- Discharge increase during drought

- Seasonal fluctuations
- Discharge increase and then decrease during drought

Tweed, S., Leblanc, M., Cartwright, I. 2009. Groundwater-surface water interaction and the impact of a multi-year drought on lakes condition in south-east Australia. Journal of Hydrology, 379(1-2): 41-53.

High resolution $\delta^{18}O$ and $\delta^{2}H$

Contaminant transport during rainfall events – Scheu Creek



Question

High temporal resolution analysis of hydrological processes in a wet tropics?
(average annual rainfall 3000 mm/yr)

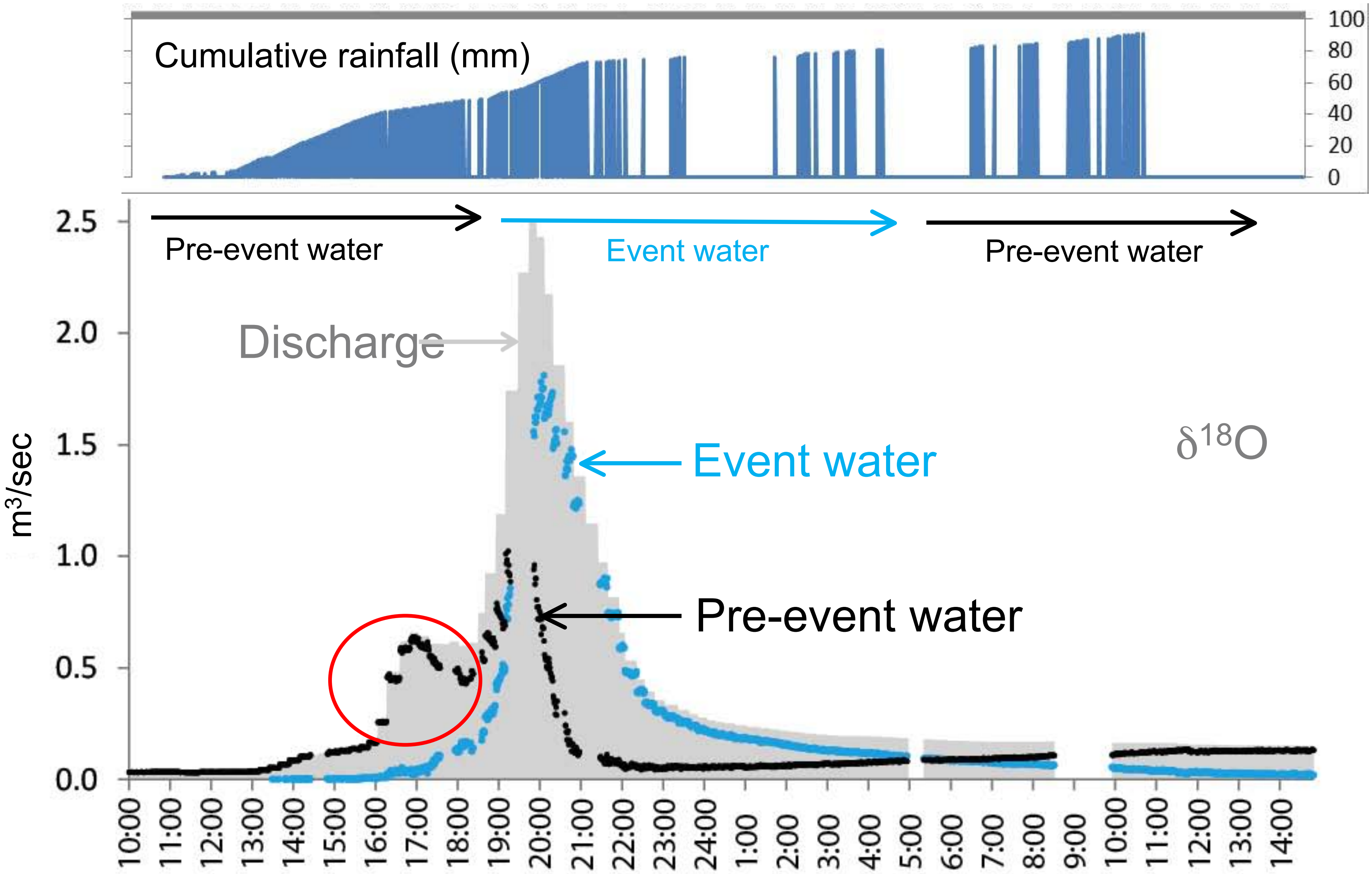
Approach

•$\delta^{18}O$, $\delta^{2}H$ and major ions to study river inflows
•Contaminant concentrations

Management Link

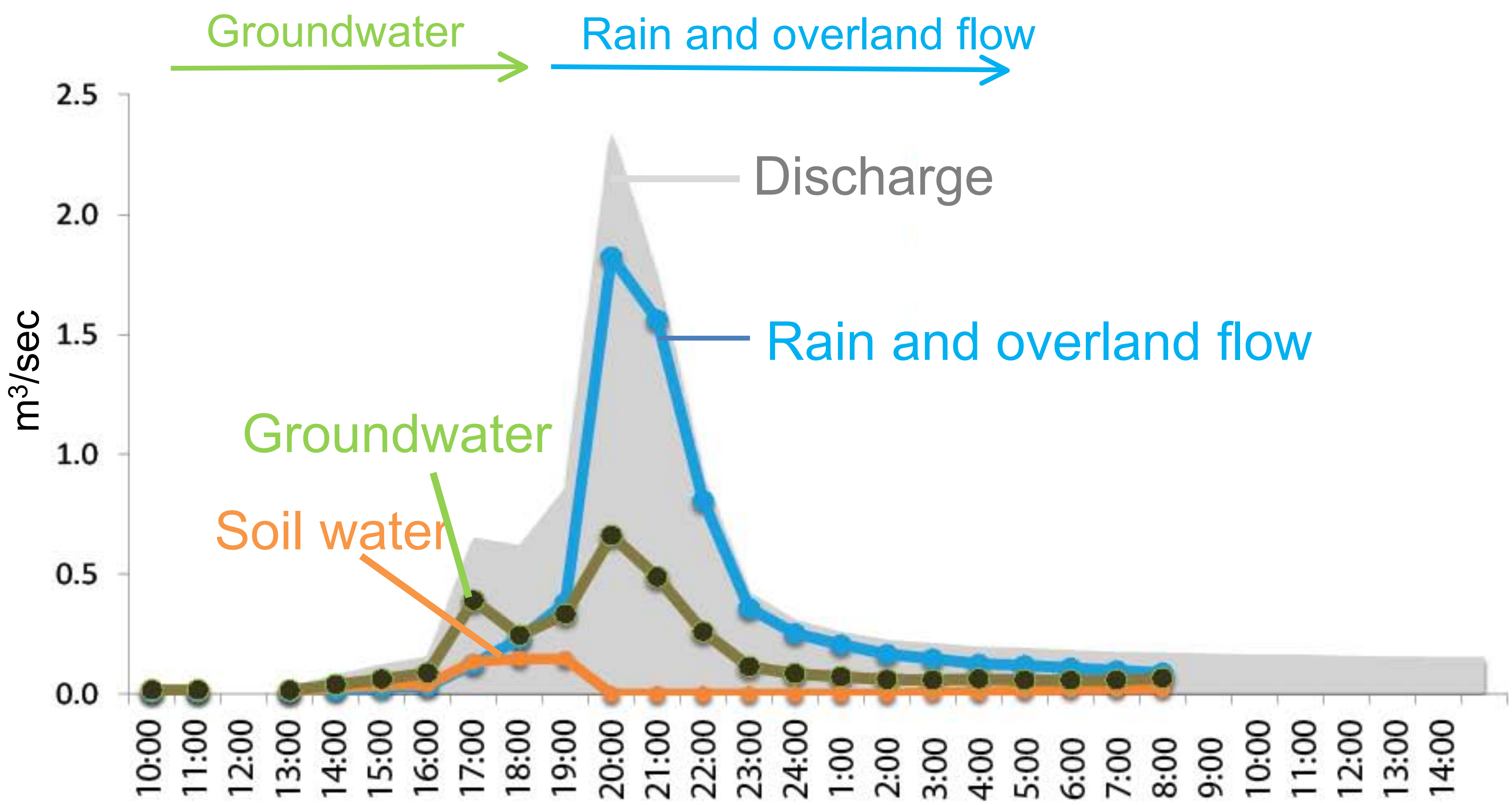
Protection of the Great Barrier Reef from the transfer of contaminants

Tweed, S., Leblanc, M., Rockett, N., Munksgaard, N., Harrington, G. *in prep.* Contaminant transfers in the wet tropics of northeastern Australia



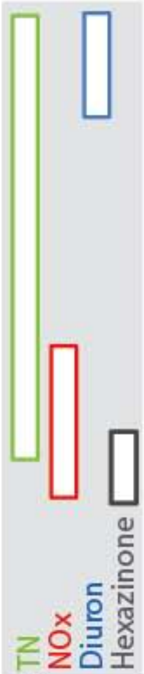
Subsurface system rapidly responds to changes

$\delta^{18}O$ and Si/Cl

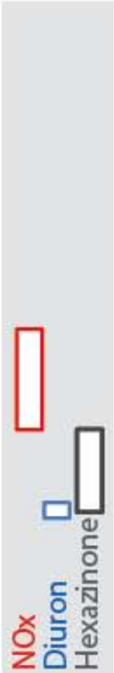


- Pre-event water: groundwater inflows
- Peak creek discharge: rain and overland flow

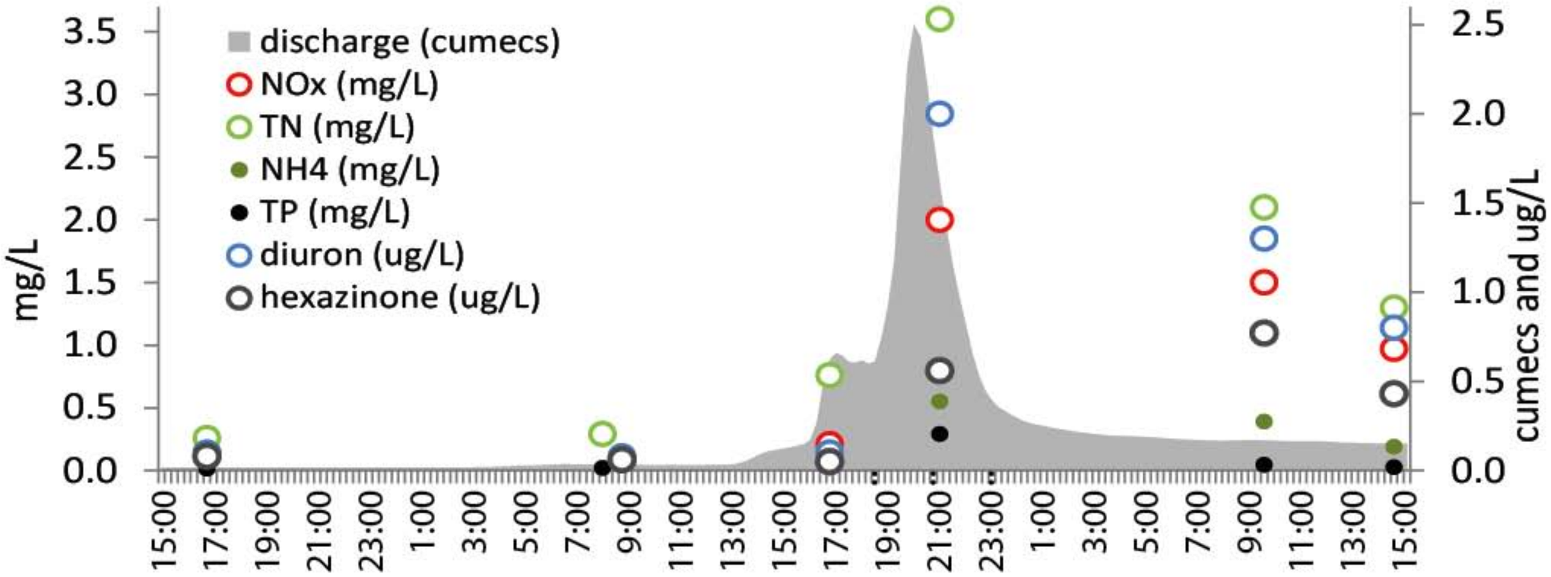
Contaminant transport during rainfall events – Scheu Creek



Overland flow



Ground-water



- Higher contaminant concentrations in overland flow
- Dominant flow pathway for contaminants via overland flow

Diffusion Sampling-CRDS (DS-CRDS)

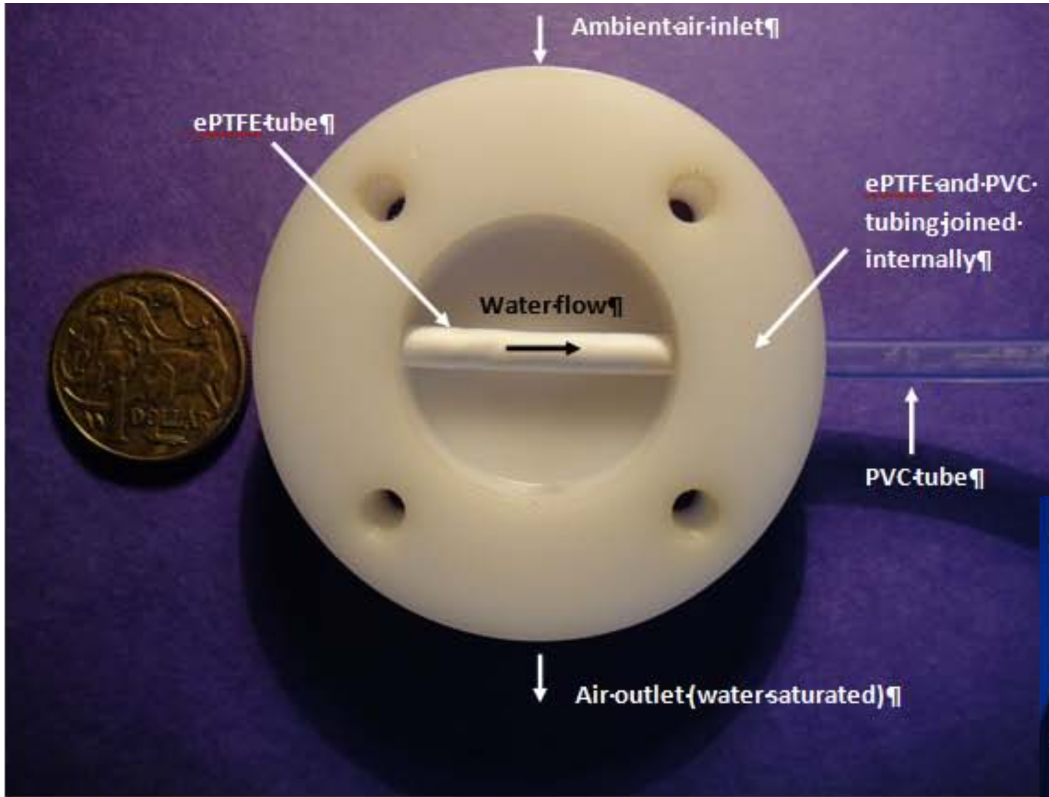
- Analysis of $\delta^{18}O$ and δD values by Cavity Ring-Down Spectrometry (CRDS)

- Diffusion sampling device utilises expanded PolyTetraFluoroEthylene (ePTFE) tubing developed for medical applications

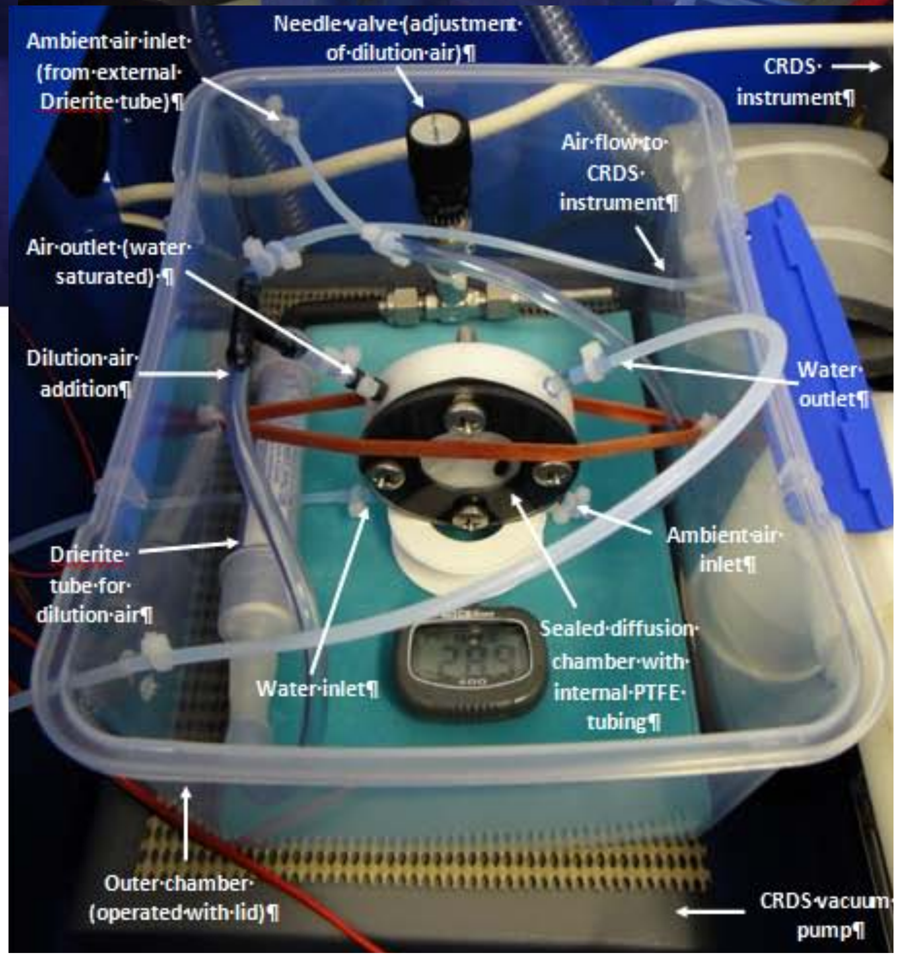
- Diffusion through porous ePTFE tubing delivers water vapour continuously from a liquid water source

- Precision for an integration period of 3 min
  SD = 0.1 % for $\delta^{18}O$
  SD = 0.3 % for δD

Munksgaard et al., Rapid Commun. Mass Spectrom. 2011, 25, 3706–3

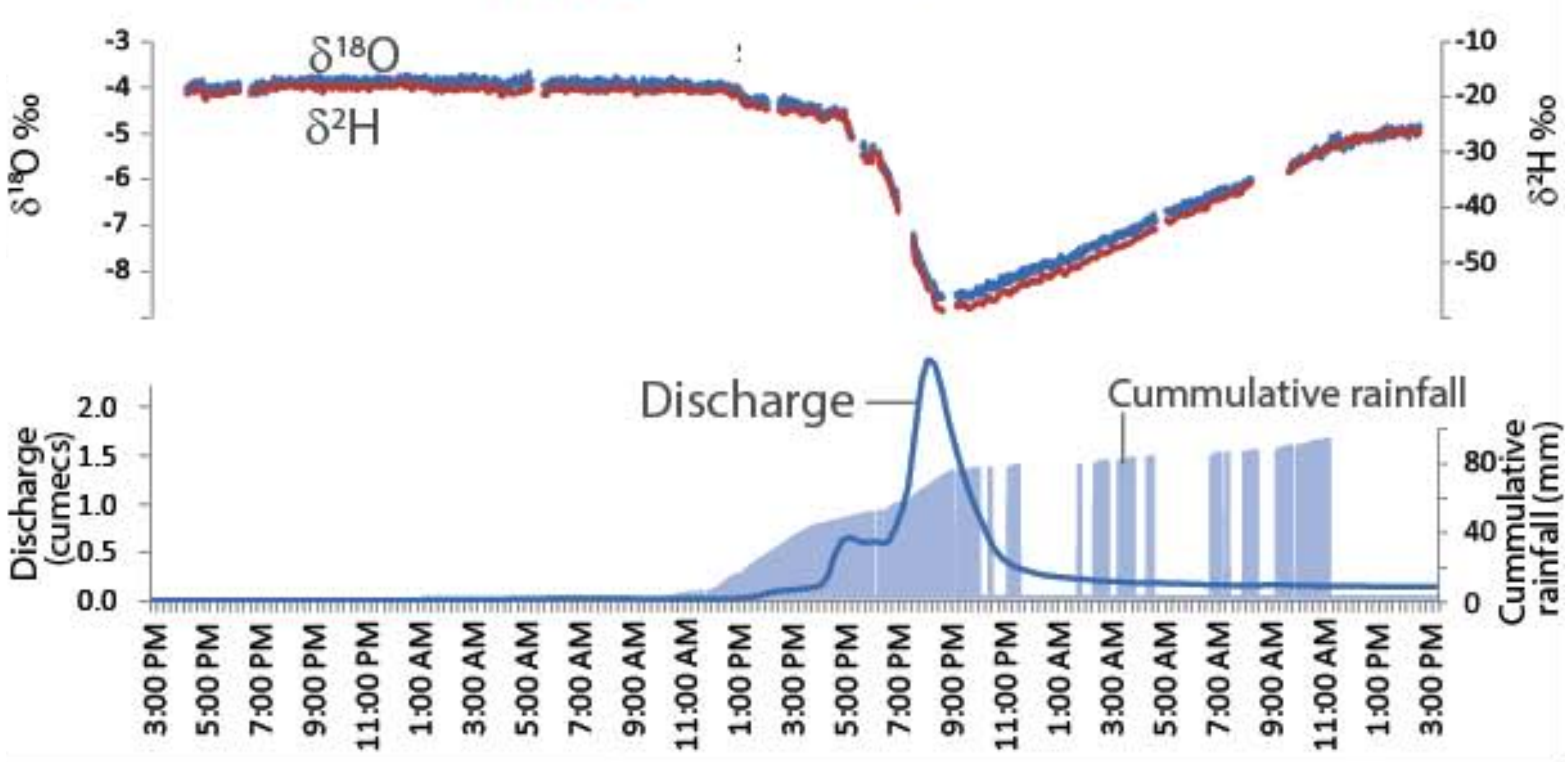


Inner diffusion chamber disassembled (seal and front plate removed)



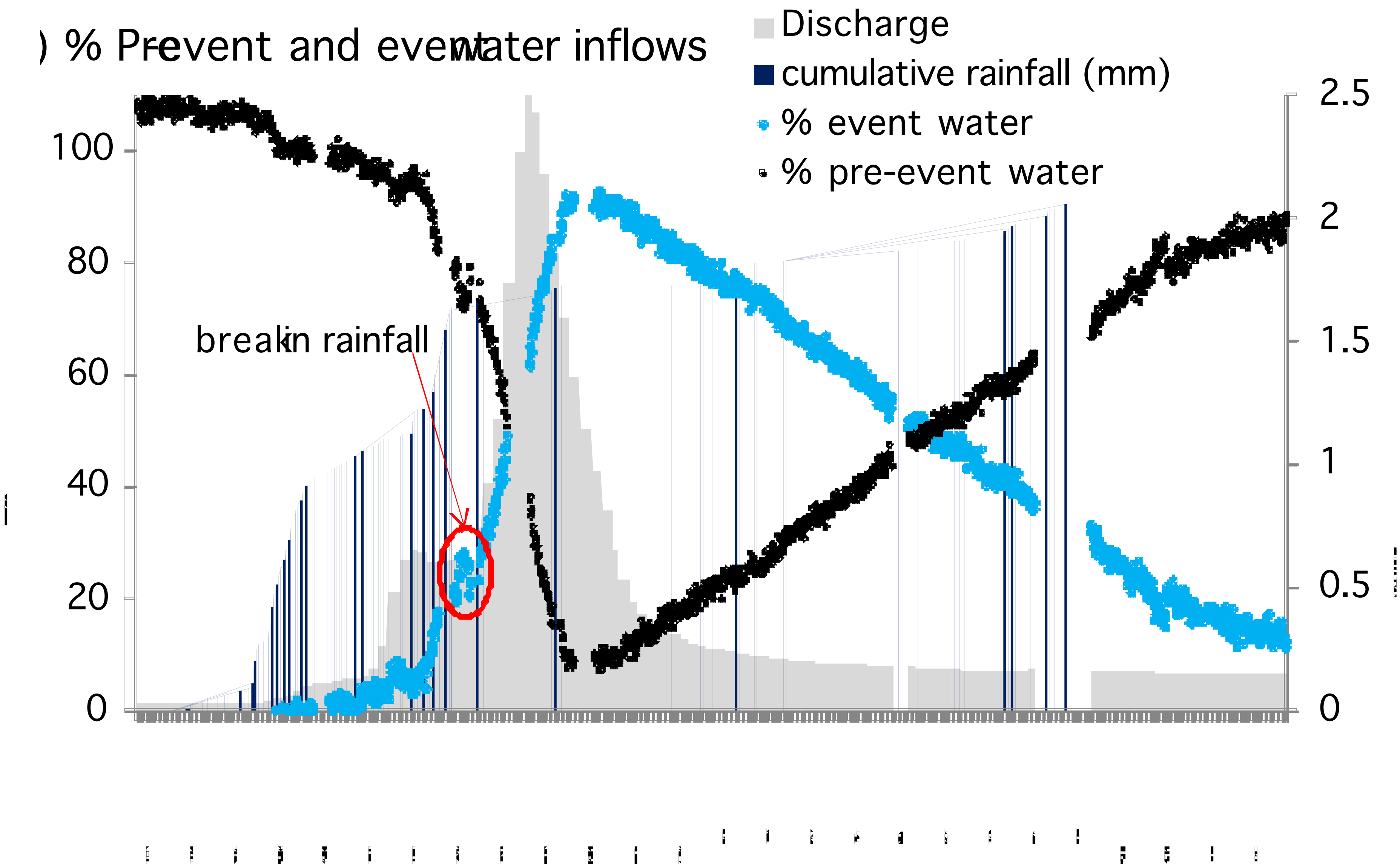
Munksgaard et al., Rapid Commun. Mass Spectrom. 2011, 25, 3706–3712

Contaminant transport during rainfall events – Scheu Creek



- $\delta^{18}O$ and $\delta^{2}H$: rapid changes in processes, one minute intervals

- Maximum time difference between the peak discharge and $\delta^{18}O$ and $\delta^{2}H$ values of 10 minutes



Rainfall stopped; decline in inflows from event water compared with pre-event water of 7% over 7 minutes

High resolution $\delta^{13}C$ and DIC

High resolution $\delta^{13}C$ and DIC

- Isotopic Continuous Dissolved Inorganic Carbon Analyser (ISO-CADICA)

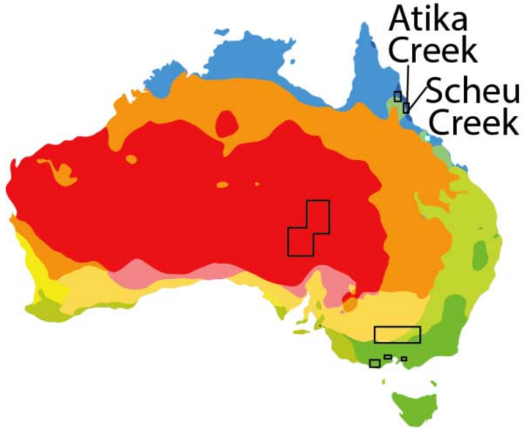
- Acidifies water and utilises ePTFE tubing to measure DIC concentrations and $\delta^{13}C_{DIC}$ values

- Accuracy approaching that of IRMS analysis

- Bass et al. (2012) ISO-CADICA: Isotopic – continuous, automated dissolved inorganic carbon analyser. Rapid Communications in Mass Spectrometry, Vol. 26(6), 639–644.

Atika and Scheu Creek

Carbon transport during rainfall events – Scheu Creek and Atika Creek



Question

Links between C transfers and land cover

Approach

High temporal resolution DIC concentrations and $\delta^{13}C$ values during a storm event - pristine rainforest and cultivated sub-catchments

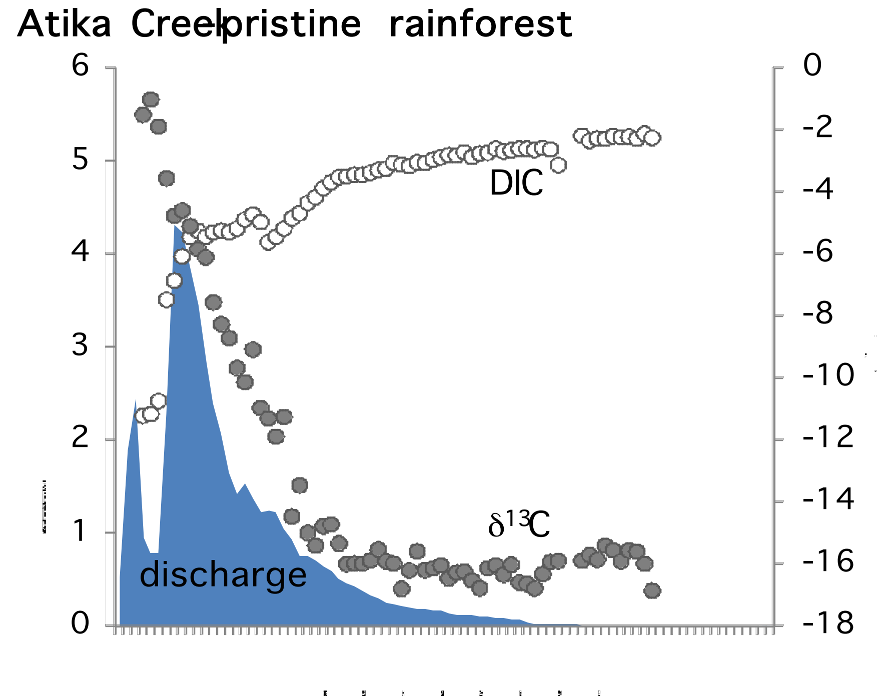
Funding

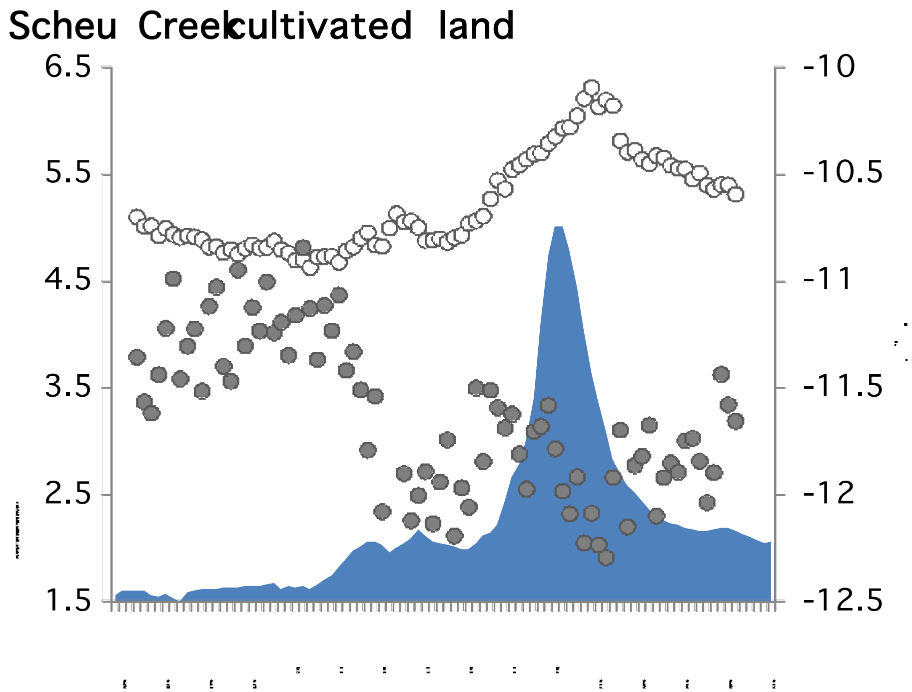
ARC and NCGRT

Management Links

Ecologically important in first-order streams

Bass, A., Munksgaard, N., Leblanc, M., Tweed, S., and Bird, M. 2014. Contrasting carbon export dynamics of human impacted and pristine tropical catchments in response to a short-lived discharge event. *Hydrological*





Rainforest

•$\delta^{13}C$ values with high variation (16‰)

•$\delta^{13}C$ - high component of rainwater input at the start of the storm, with increases in C3-derived DIC

•DIC values that increased after storm event

Cultivated

•$\delta^{13}C$ values with less variation (<2‰)

•$\delta^{13}C$ - dominate source of DIC is from C4 sources

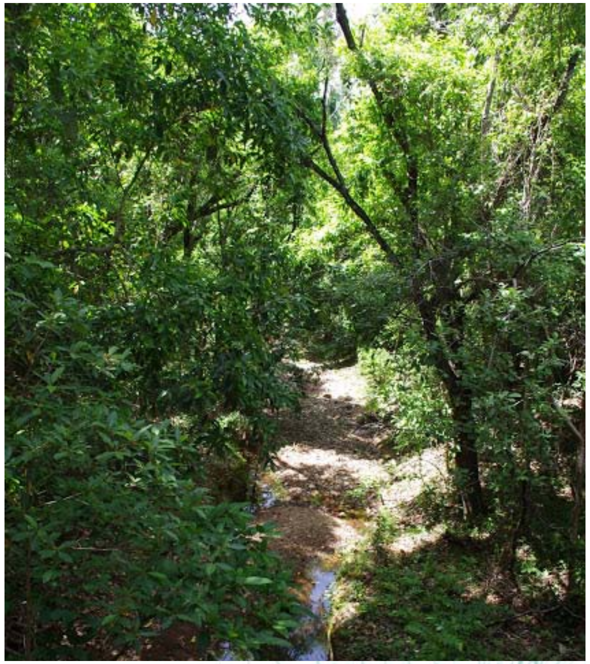
•DIC values that decreased after storm event

Carbon transport during rainfall events – Scheu Creek and Atika Creek

- Deployment of newly developed field equipment;

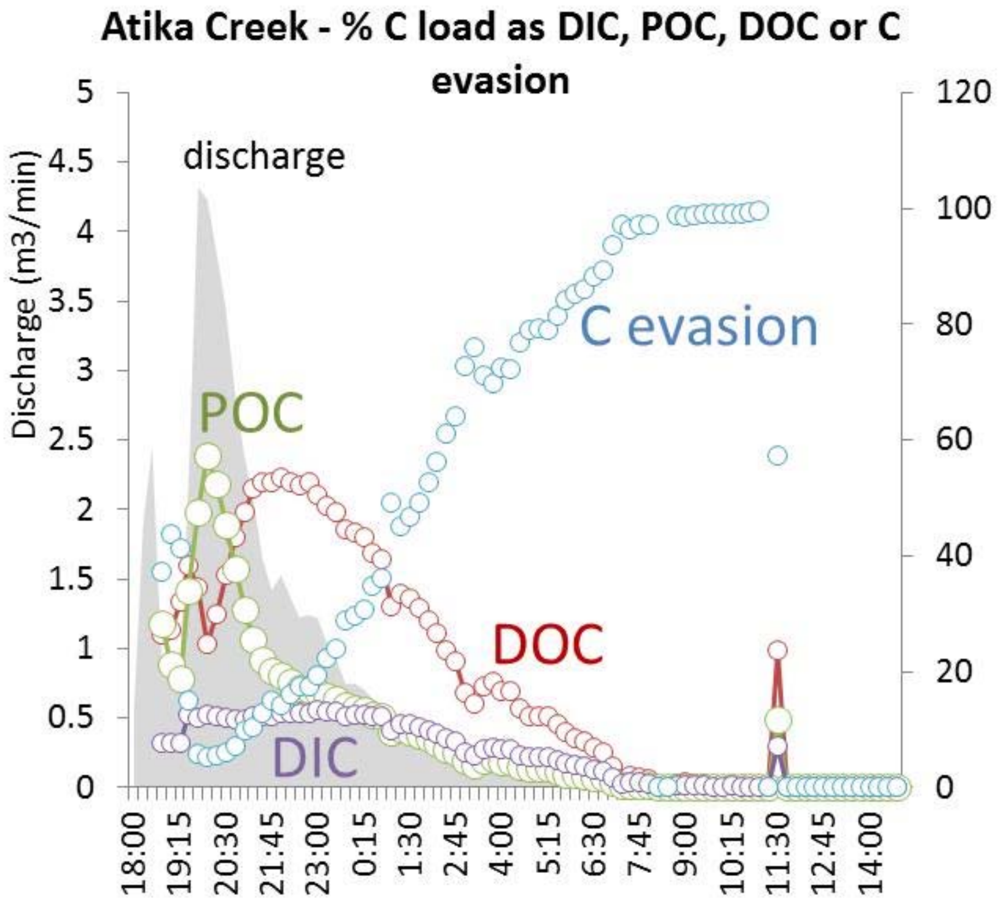
Isotopic Continuous Dissolved Inorganic Carbon Analyser (ISO-CADICA; Bass et al., 2012)

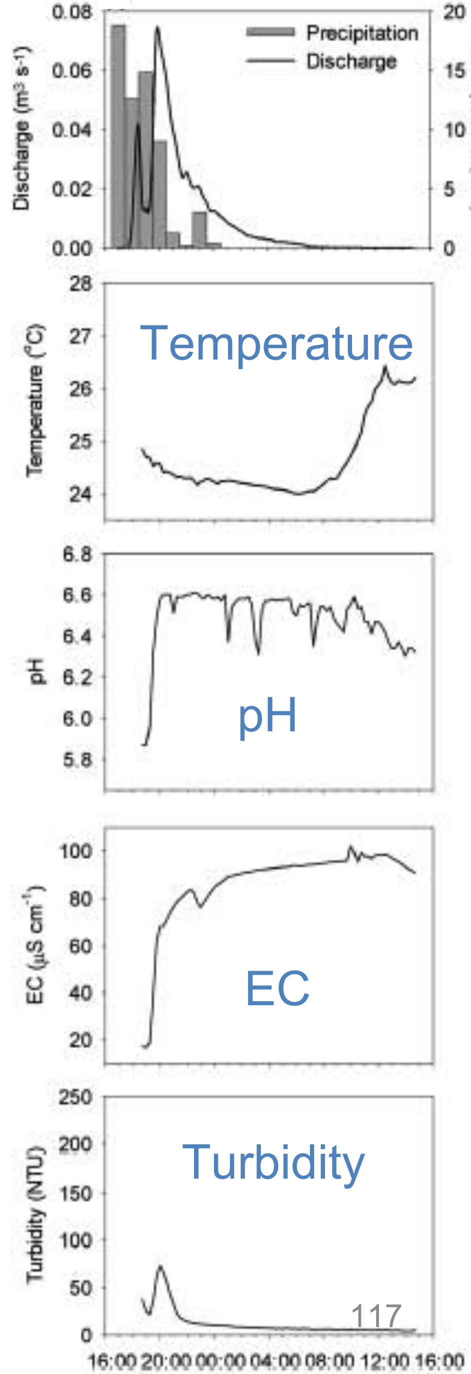
- Measure $\delta^{13}C$ and DIC values at high temporal resolution



Atika Creek

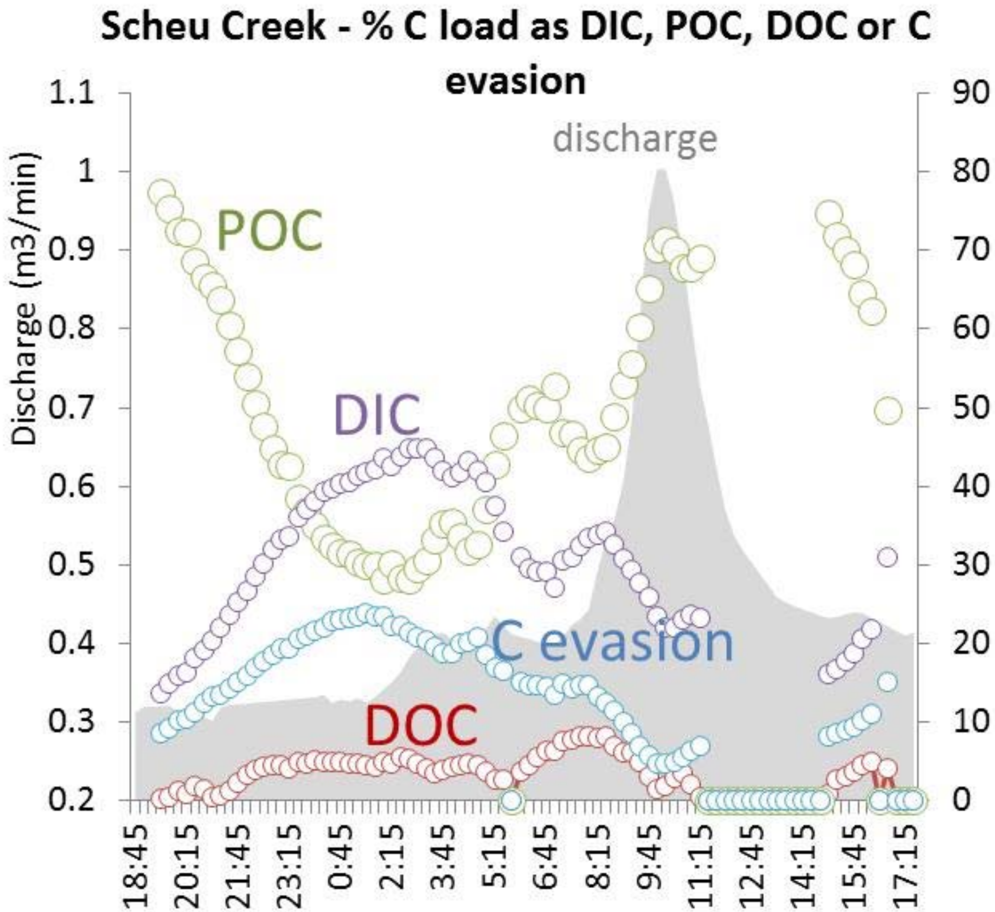
- Large initial variation
- DOC and POC concentrations higher than other rainforest studies - prolonged dry period preceding the study
- over 85% of C exported during baseflow is through vertical evasion to the atmosphere

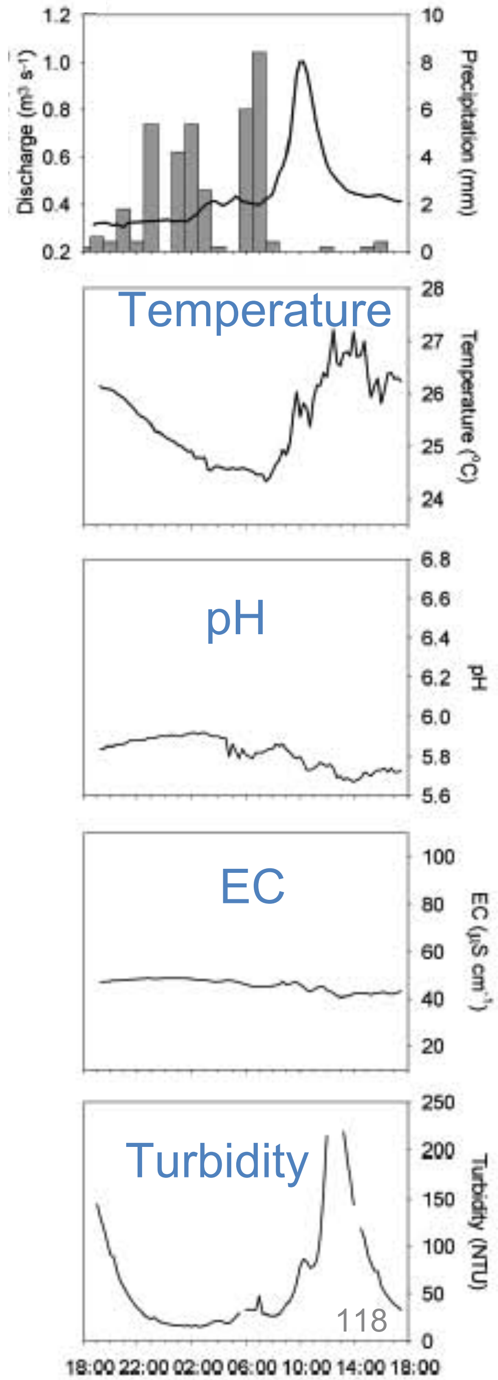


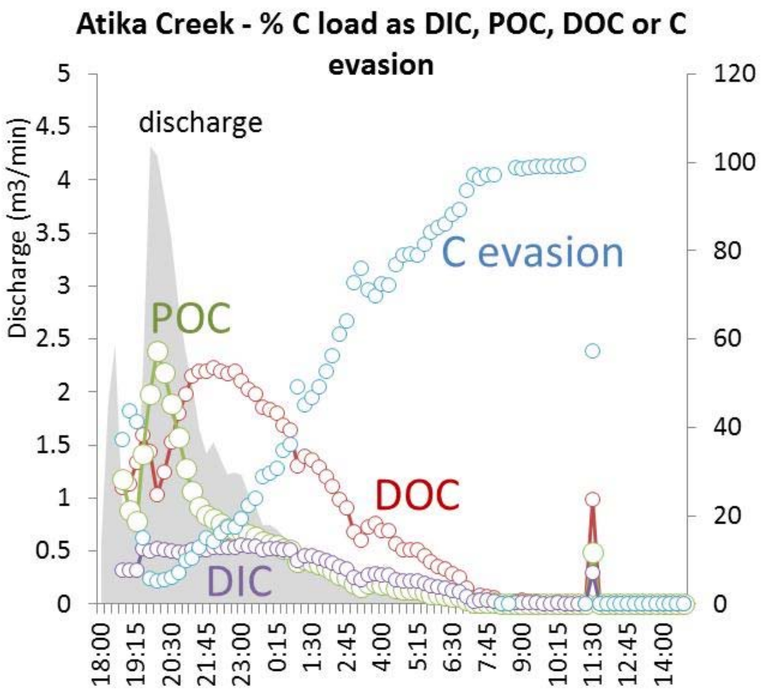


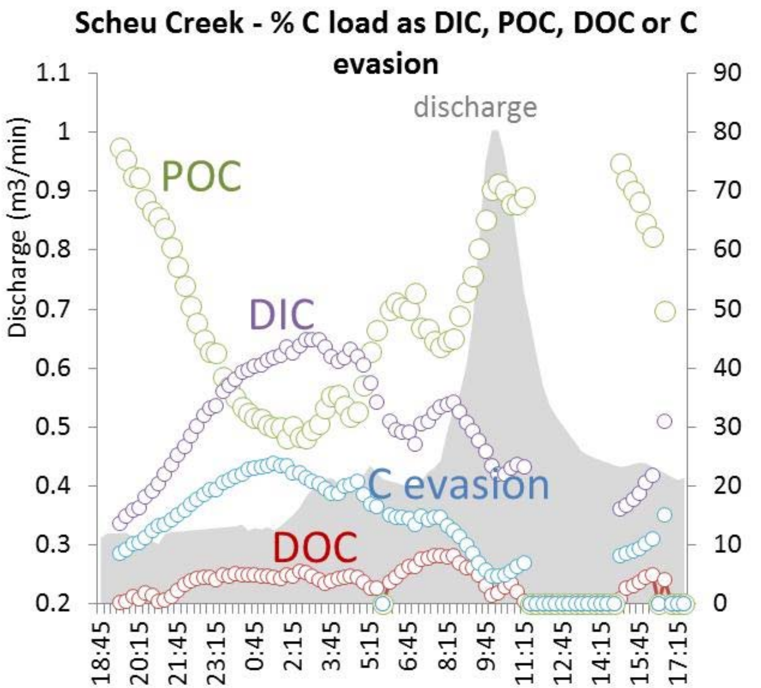
Scheu Creek

- Stable chemistry
- High POC and DIC concentrations
- Low C evasion to the atmosphere









Differences

Initial conditions

- SC: flow prior to event
- AC: initially dry; explanation for initially extreme variations in hydrochemical parameters

Influence of land cover

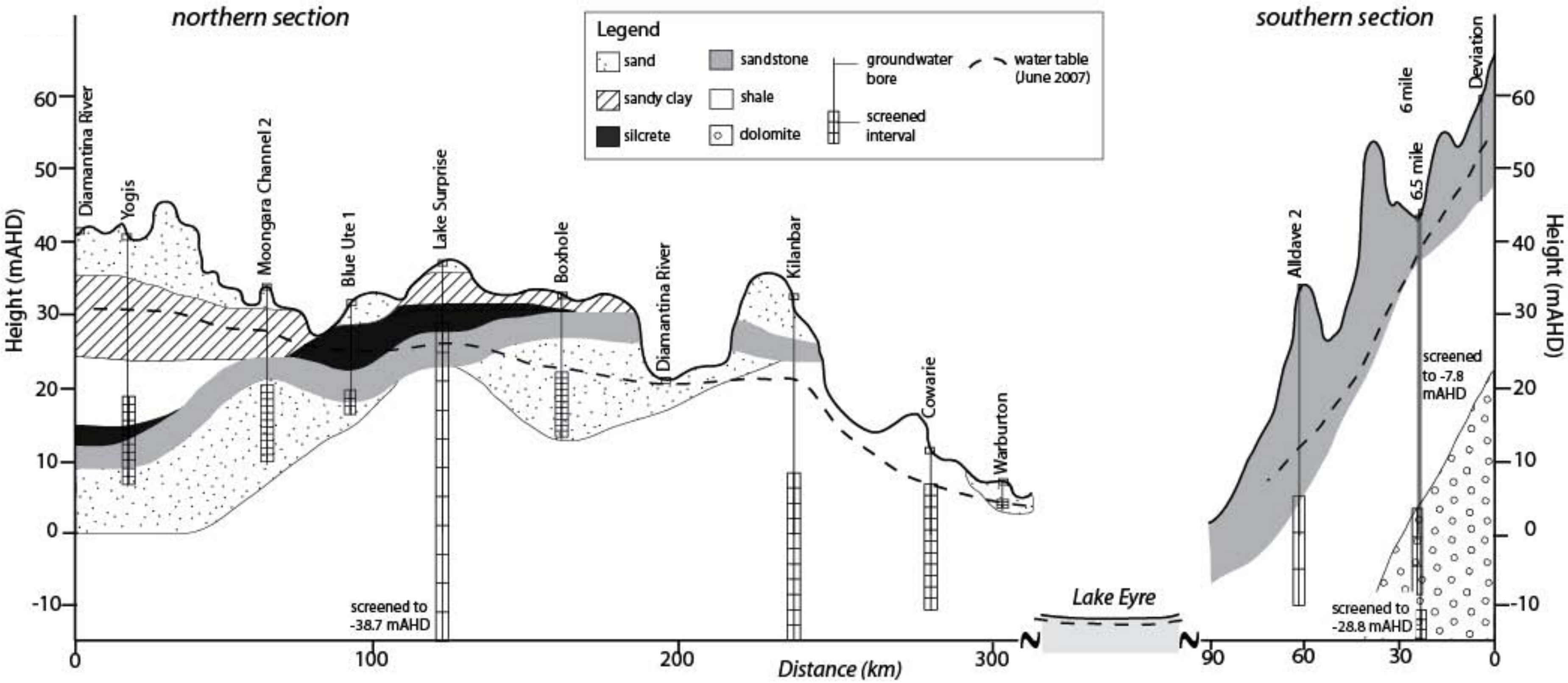
- POC concentration higher in SC
- DOC showed little significant change with increasing discharge in SC due to high clay content; adsorption

Interaction with groundwater

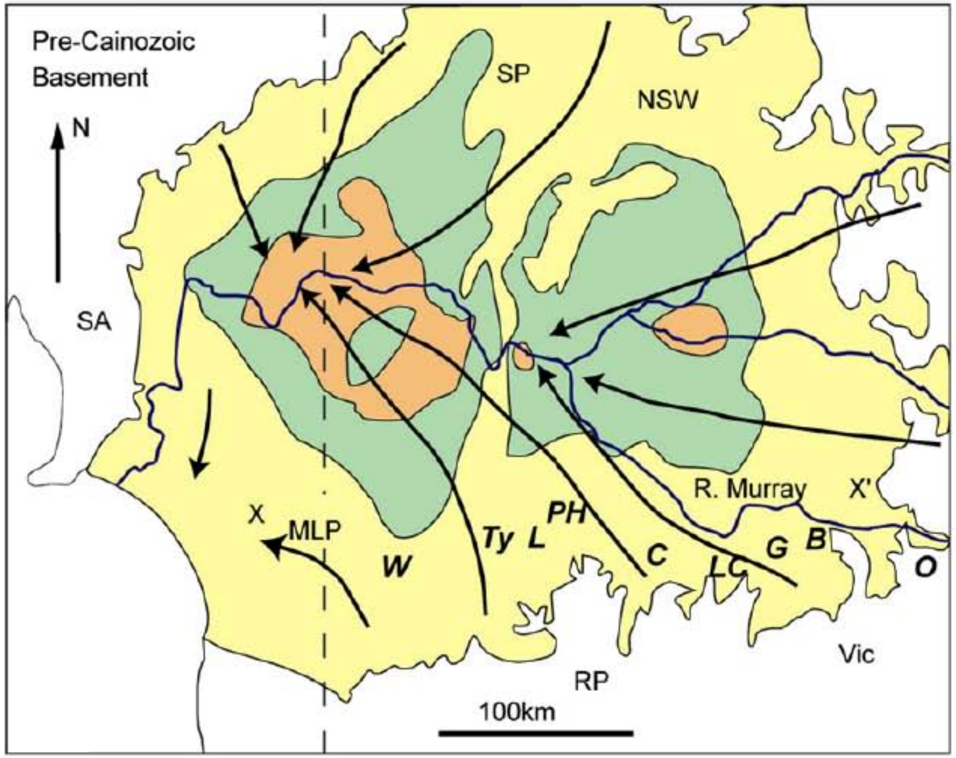
- SC increase in DIC concentration correlates to period of increased groundwater or soil water

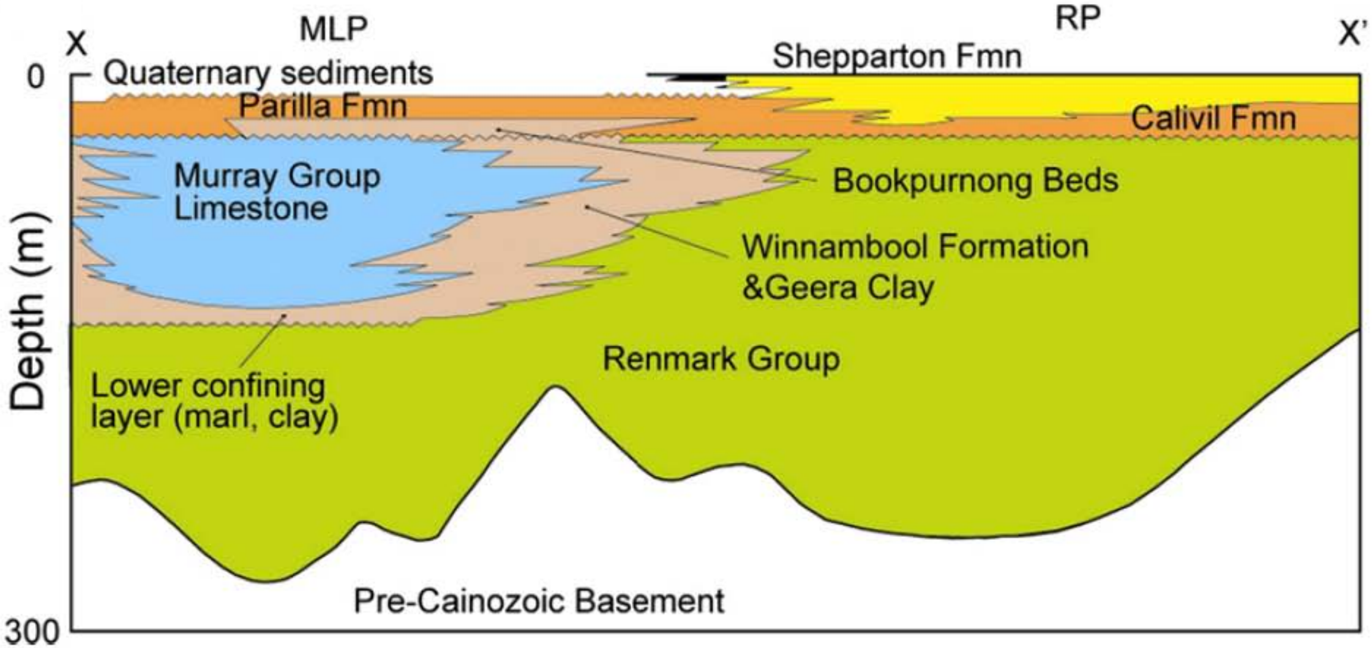
MGB and LEB

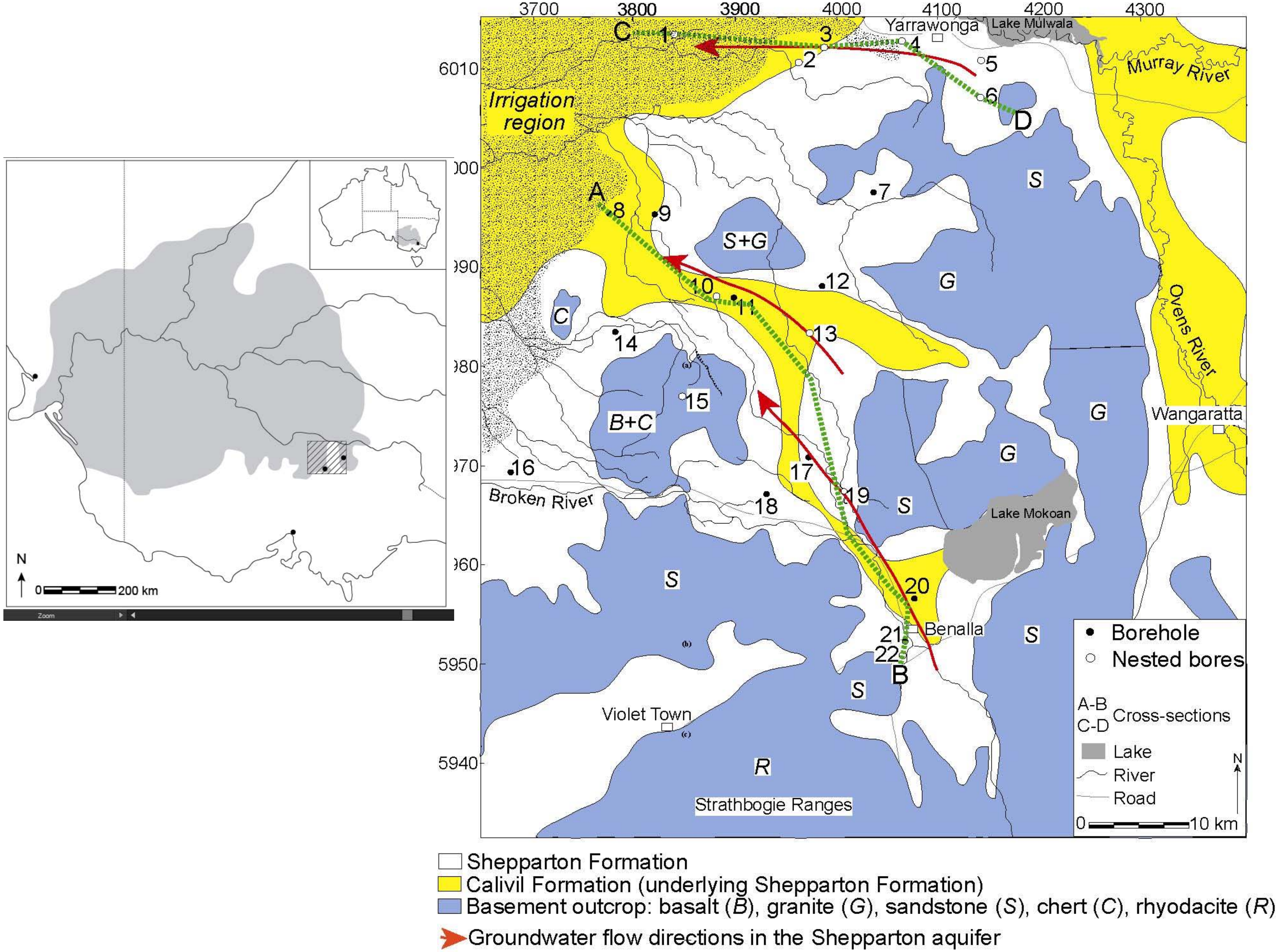
LEB geological cross-section



MGB


Pre-Cainozoic
Basement
N
SP
NSW
SA
R. Murray
X'
X
MLP
W
Ty
L
PH
C
LC
G
B
O
RP
Vic
100km
Depth to basement (m)
<200
200-400
>400


X
MLP
RP
X'
0
300
Depth (m)
Quaternary sediments
Shepparton Fmn
Parilla Fmn
Calivil Fmn
Murray Group
Limestone
Bookpurnong Beds
Winnambool Formation
&Geera Clay
Renmark Group
Lower confining
layer (marl, clay)
Pre-Cainozoic Basement

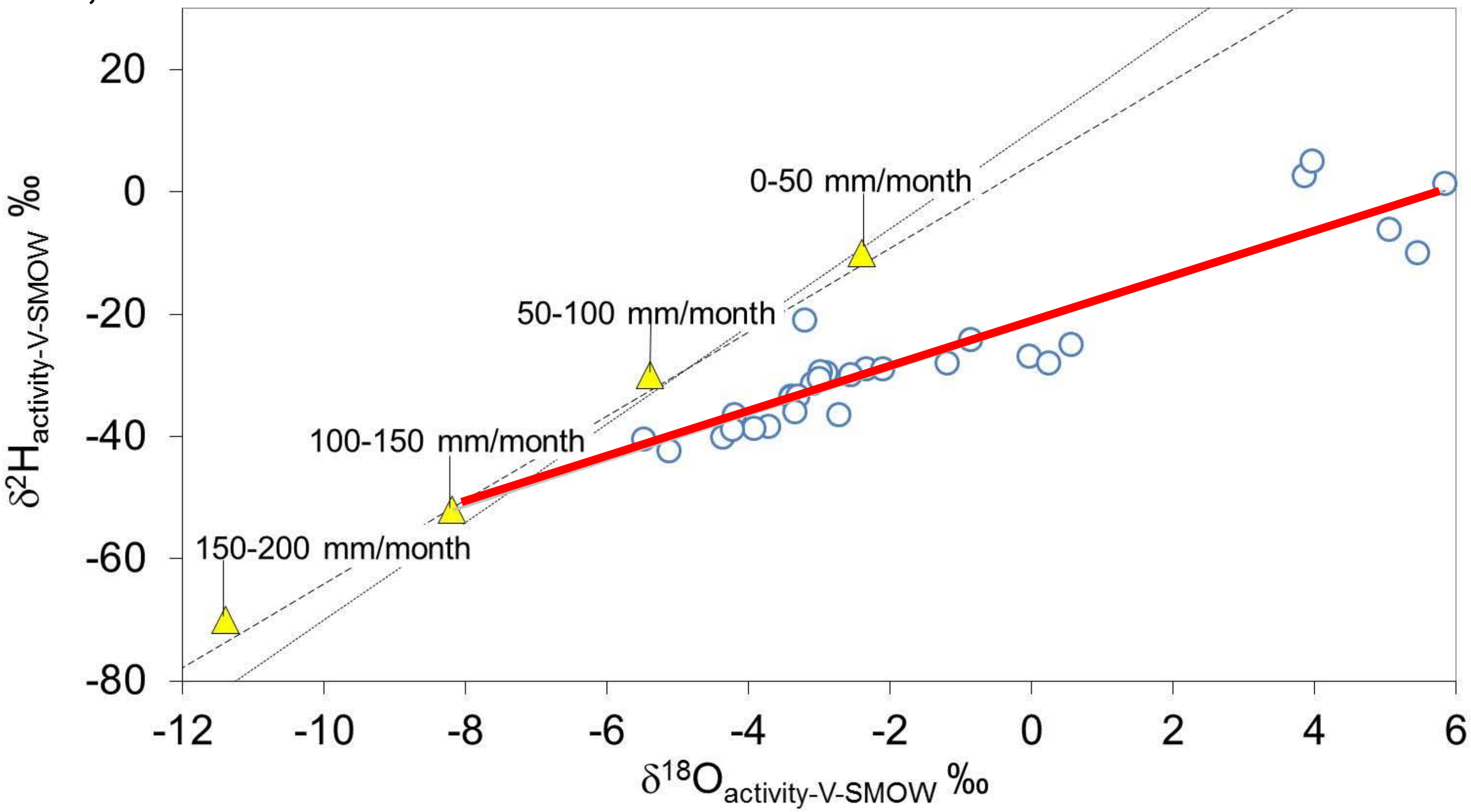


N
0 200 km
Zoom
3700
3800
3900
4000
4100
4200
4300
6010
5950
5940
Yarrawonga
Lake Mulwala
Murray River
Irrigation region
Ovens River
Wangaratta
Lake Mokoan
Broken River
Benalla
Violet Town
Strathbogie Ranges
A
B
C
D
S
G
S+G
C
B+C
R
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Borehole
Nested bores
A-B
C-D
Cross-sections
Lake
River
Road
0
10 km
Shepparton Formation
Calivil Formation (underlying Shepparton Formation)
Basement outcrop: basalt (B), granite (G), sandstone (S), chert (C), rhyodacite (R)
Groundwater flow directions in the Shepparton aquifer

$\delta^{18}O$ and $\delta^{2}H$ – long-term recharge processes

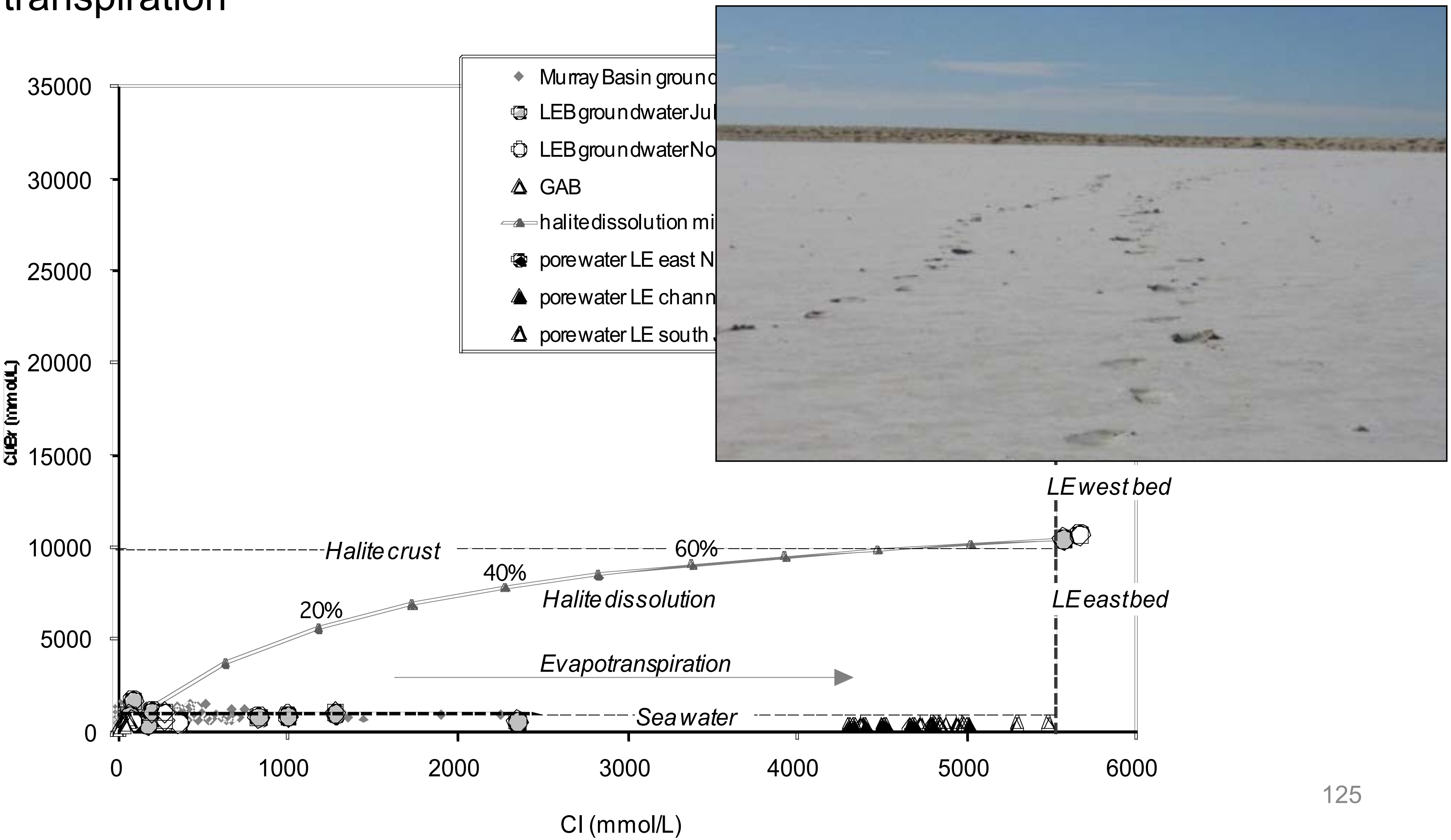
- Evaporation slope low (2.97)
- Evaporation from surface water or water table (4-6)

-> Water evaporated in the dry unsaturated zone – not from floodwaters;

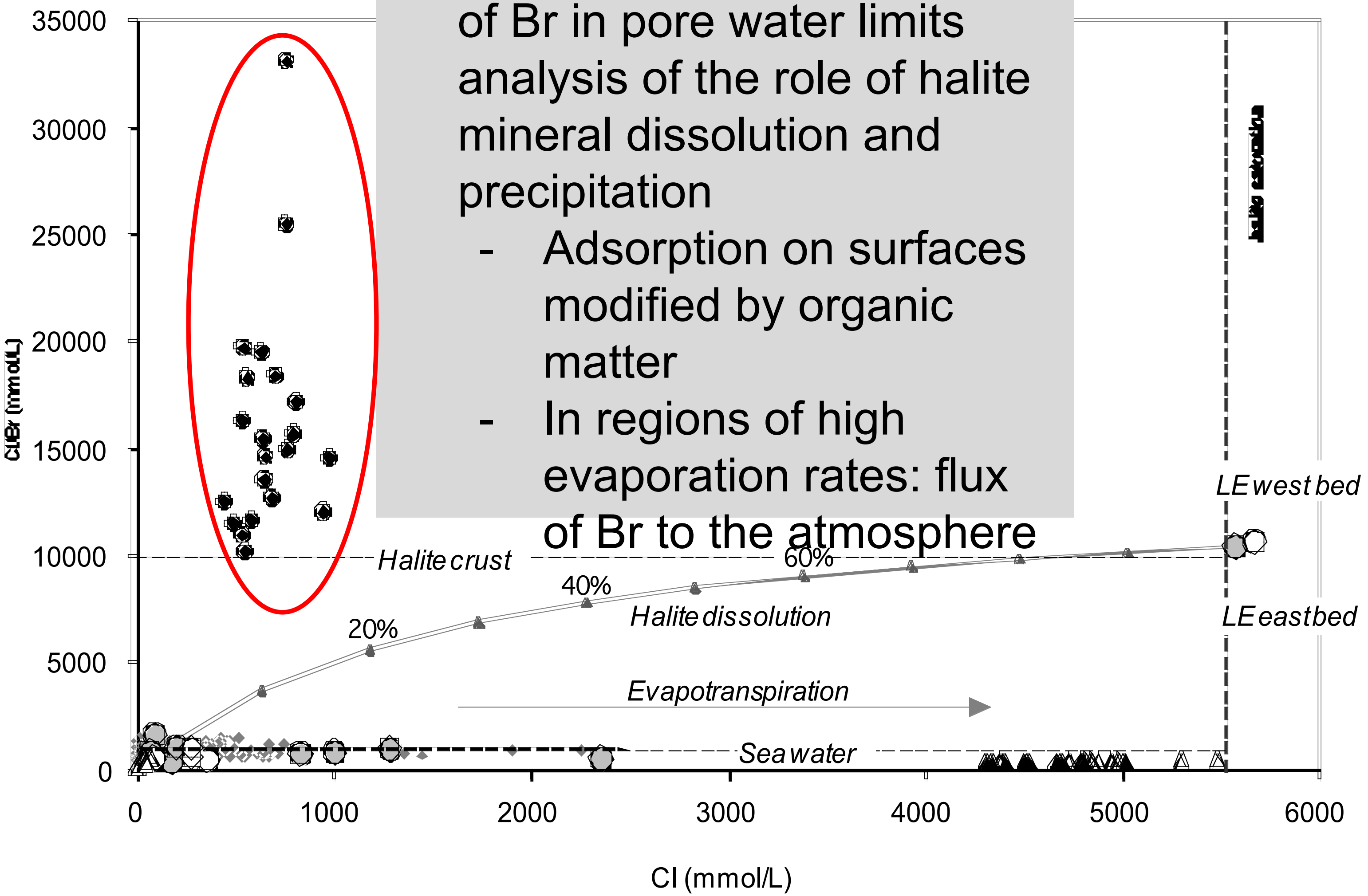


Salinity Controls – Murray Groundwater Basin and Lake Eyre Basin

Cl/Br ratios constant with increasing Cl concentrations: evaporation and/or transpiration



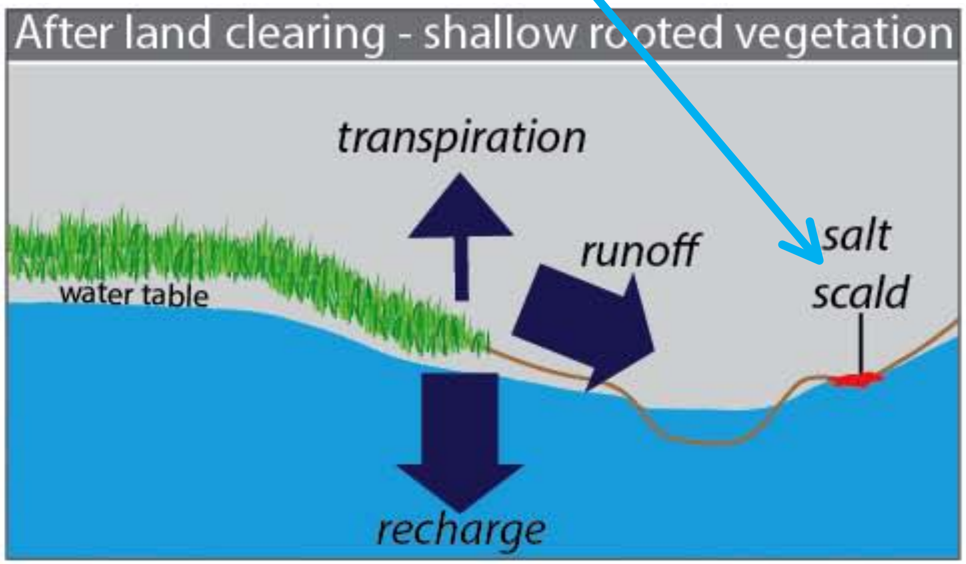
Salinity Controls –
Murray Groundwater Basin and Lake Eyre Basin

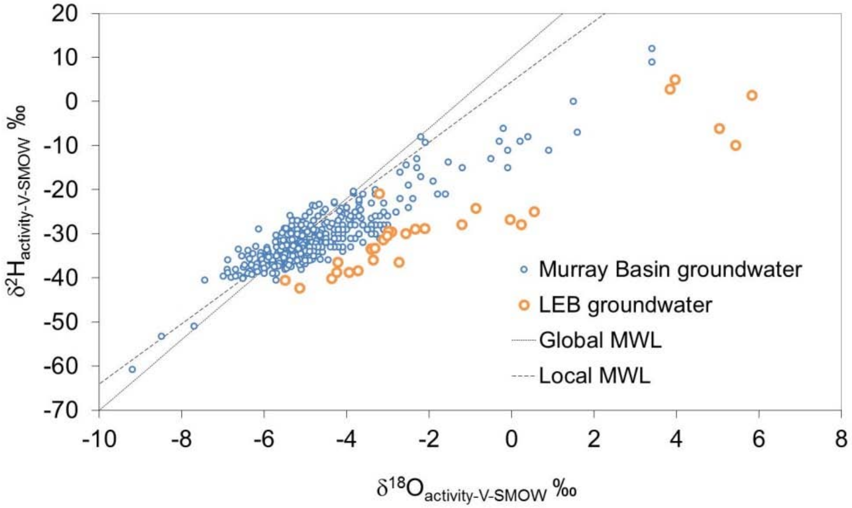


- Non-conservative behavior of Br in pore water limits analysis of the role of halite mineral dissolution and precipitation
  - Adsorption on surfaces modified by organic matter
  - In regions of high evaporation rates: flux of Br to the atmosphere

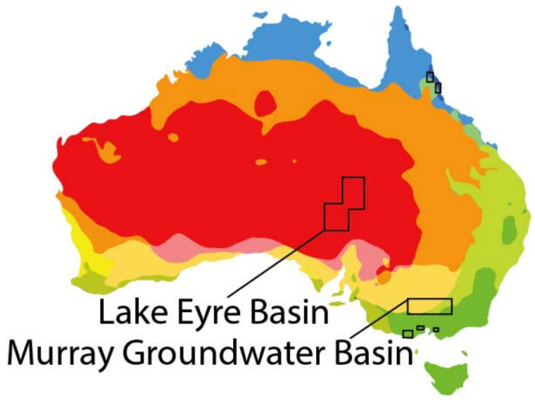
Salinity Controls – MGB

Localised secondary salinity – evaporation and cyclic evaporite dissolution





Salinity controls –
Murray Groundwater Basin (MGB) and Lake Eyre Basin (LEB)



Question

Salinity processes in two basins; LEB and MGB?

Approach:

Groundwater Cl/Br ratios, $\delta^{18}O$ and $\delta^{2}H$ data

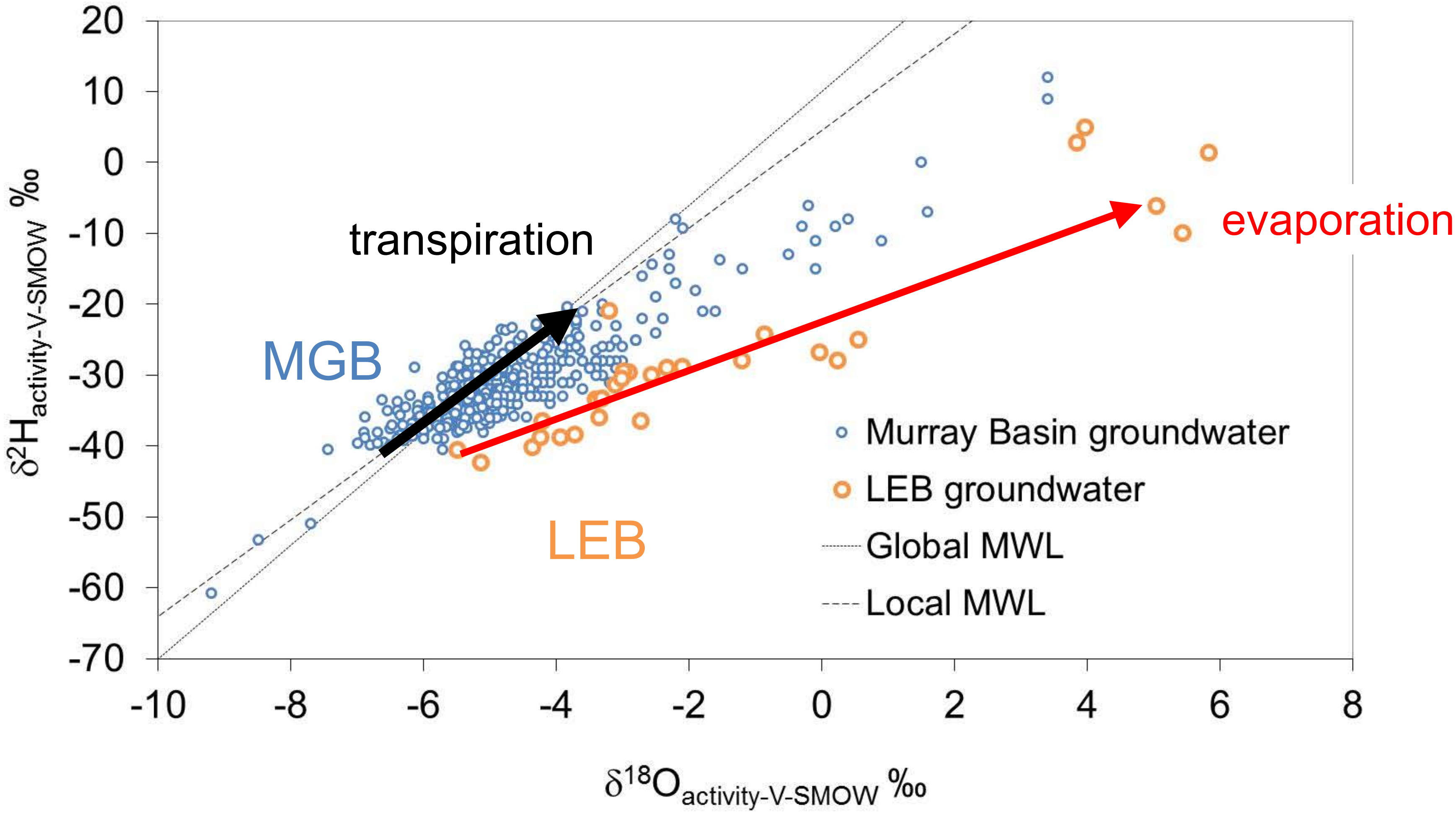
Management Link

Controls on salinity in more intensively cultivated MGB

Tweed, S., Leblanc, M., Cartwright, I., Favreau, G., Leduc, C., 2011. Arid zone groundwater recharge and salinisation processes; an example from the Lake Eyre Basin, Australia, Journal of Hydrology, 408, 257-275

Cartwright, I., Weaver, T.R., Cendón, D.I., Fifielde, L.K., Tweed, S.O., Petrides B., Swane, I. 2012. Constraining groundwater flow, residence times, inter-aquifer mixing, and aquifer properties using environmental isotopes in the southeast Murray Basin, Australia. Applied Geochemistry, 27, 1698-1709.

Salinity Controls – MGB and LEB



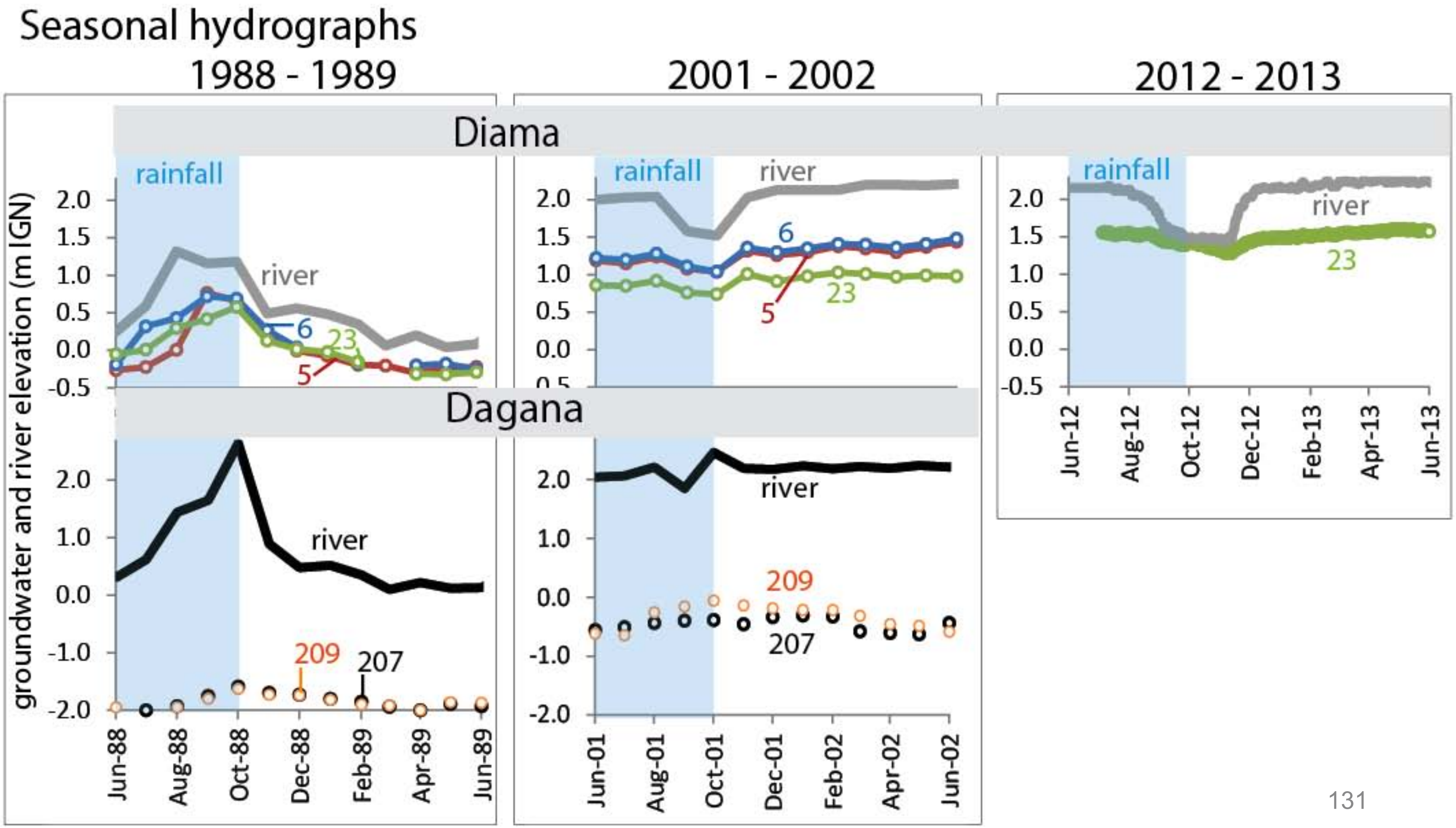
- Transpiration of groundwater in semi-arid MGB
- Evaporation of groundwater in arid LEB

Senegal example

Example : Senegal Delta

Non-uniform physical hydrosystem response to multiple changes

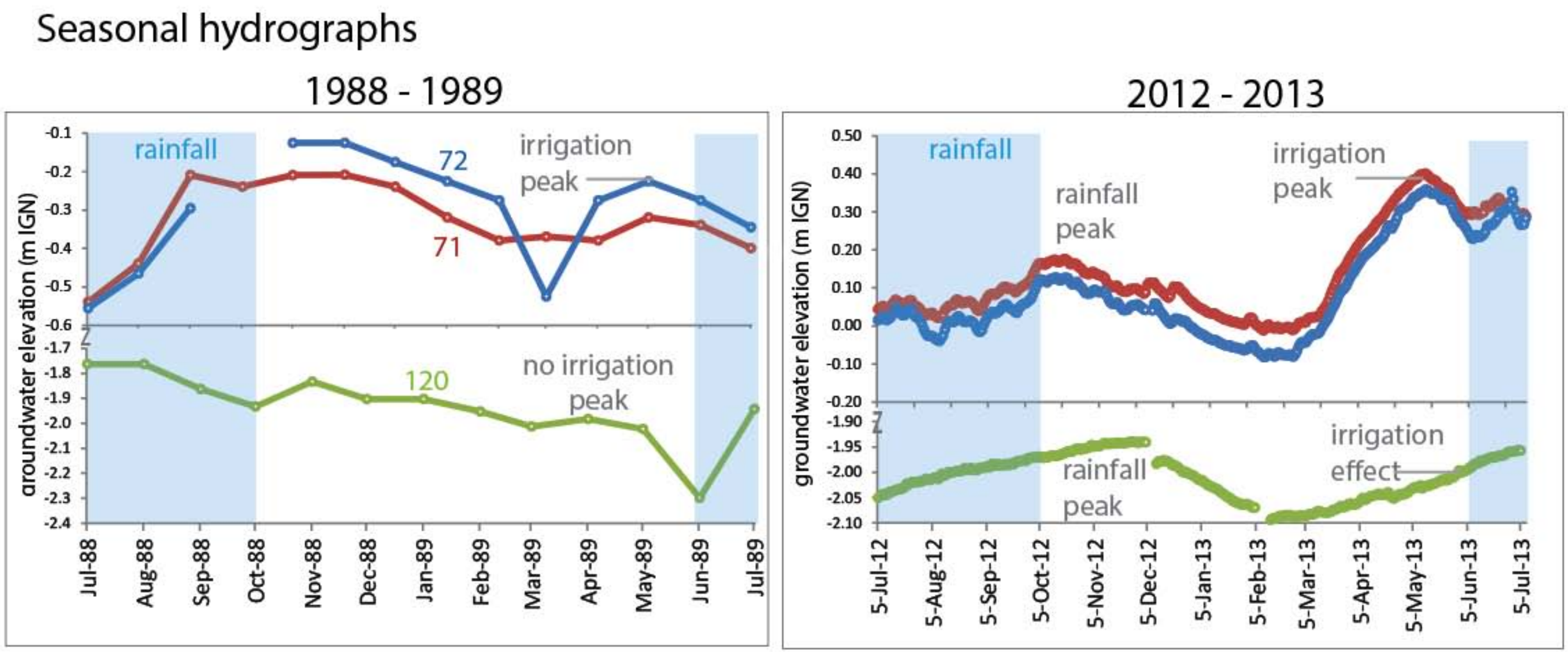
Groundwater close to rive



Example : Senegal Delta

Non-uniform physical hydrosystem response to multiple changes

Groundwater in irrigated area



Multiple controls on salinity in irrigated systems

Multiple environmental tracers

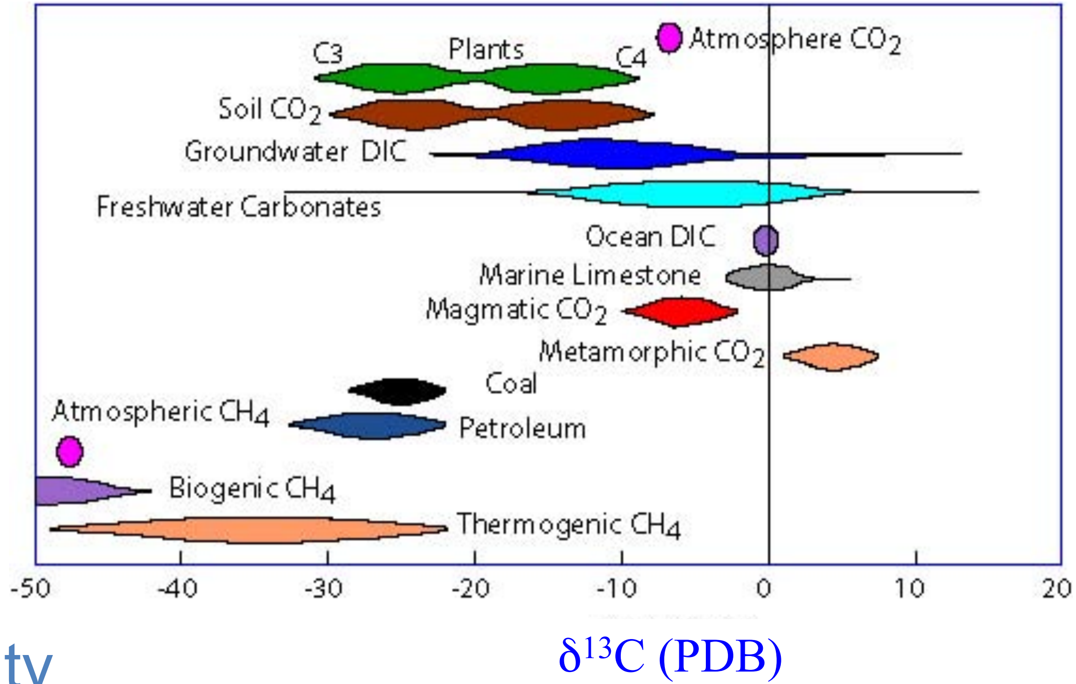
- Age of groundwater

  dating tracers

- Origin of water

  $\delta^{18}O$, $\delta^{2}H$ semi-arid / tropical rainfall

  $\delta^{13}C$ – marine



- Dominant control on salinity

  Na/Cl and Cl/Br ratios, $\delta^{18}O$, $\delta^{2}H$

Project approaches

Groundwater ages:
Interpretation within the hydrogeochemical system

1. Environmental tracers:
identify mixing processes

↓

2. Dating tracers:
selective analysis of multiple dating tracers

↓

3. Dating tracers:
sorption, degradation, contamination, terrigenic sources, excess air

↓

4. Matrix diffusion model:
affects of diffusion on dating tracer concentrations
parallel-plate (Sudicky and Frind, 1981), circular sectioned (Harrington et al., 2007)

↓

5. Quantify dynamics of local and regional groundwater systems:
dating and environmental tracer data, with physical data in numerical models
HydroGeoSphere (Therrien and Sudicky, 1996), KARST (Jourde et al., 2013)

↓

Projects 2 and 3

Groundwater C transfers

Stores of C?

•Spatial variations in groundwater C stores and contributions to rivers

Transfers of C?

•Comparison between seasonal and event scale processes

High temporal resolution $\delta^{13}C_{DIC}$, $\delta^{18}O$ and $\delta^{2}H$;
•ISO-CADICA
•DS-CRDS

•Variations in ages of groundwater transferring DIC to rivers

Groundwater ages

Impacts of land cover change on C transfers?

•Timeframes for anthropogenic forcings to impact on DIC transfers

Groundwater ages

Can we differentiate impacts from multiple forcings on water quality?

1. Potential impacts of different forcings

Transects of shallow zone/local processes over multiple land uses

Origins of solutes

- Environmental tracers coupled with land cover/use history

Fluxes of solutes

- Renewal rates long-term (dating tracers)
- Renewal rates event-scale (environmental tracers)

Groundwater ages

High temporal resolution $\delta^{18}O$ and $\delta^{2}H$; DS-CRDS

2. Propagation of forcings through regional system

Time lag between forcing and impact on chemistry

Groundwater ages

3. Evolution of solute through local and regional system

Mixing (environmental tracers)

Biogeochemical controls (environmental tracers)

Groundwater ages

Challenges in using environmental tracers to investigate variabilities

i. Multiple scales and forcings

ii. Data representivity

iii. Multiple tracers

iv. Regional systems

Challenges in using environmental tracers to investigate variabilities

i. Multiple scales and forcings

Retrospective

Most studies conducted at different sites

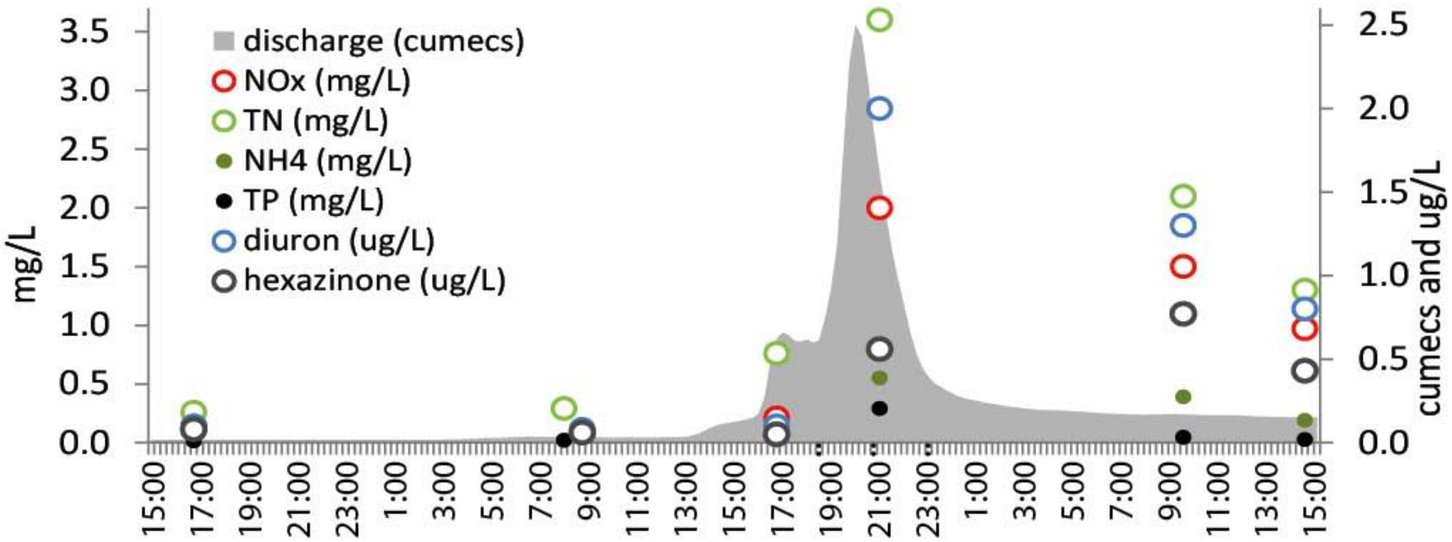
Scales

Contaminant transfers

- Event
- Seasonal?

Challenges in using environmental tracers to investigate variabilities

Scheu creek event scale

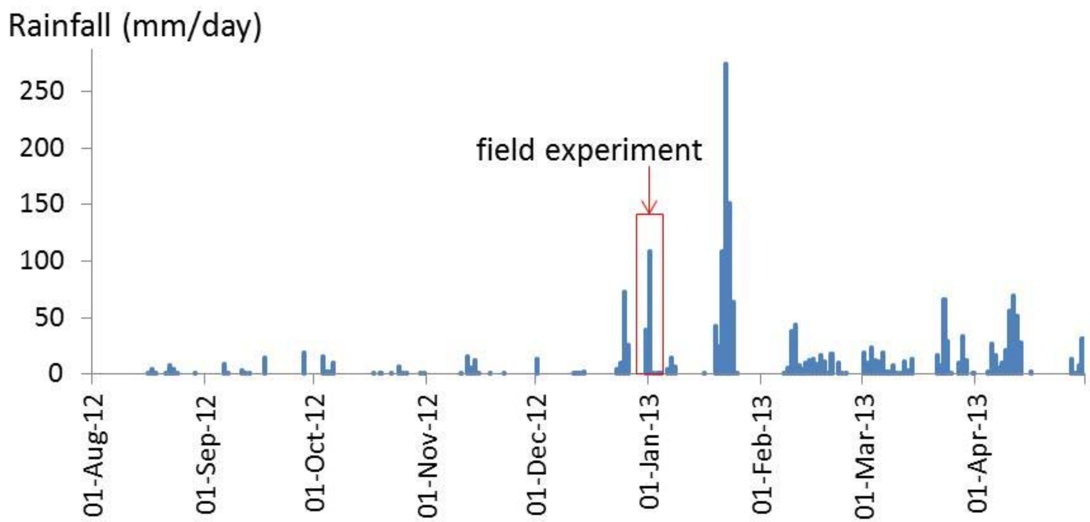


<u>Scales</u>

Contaminant transfers

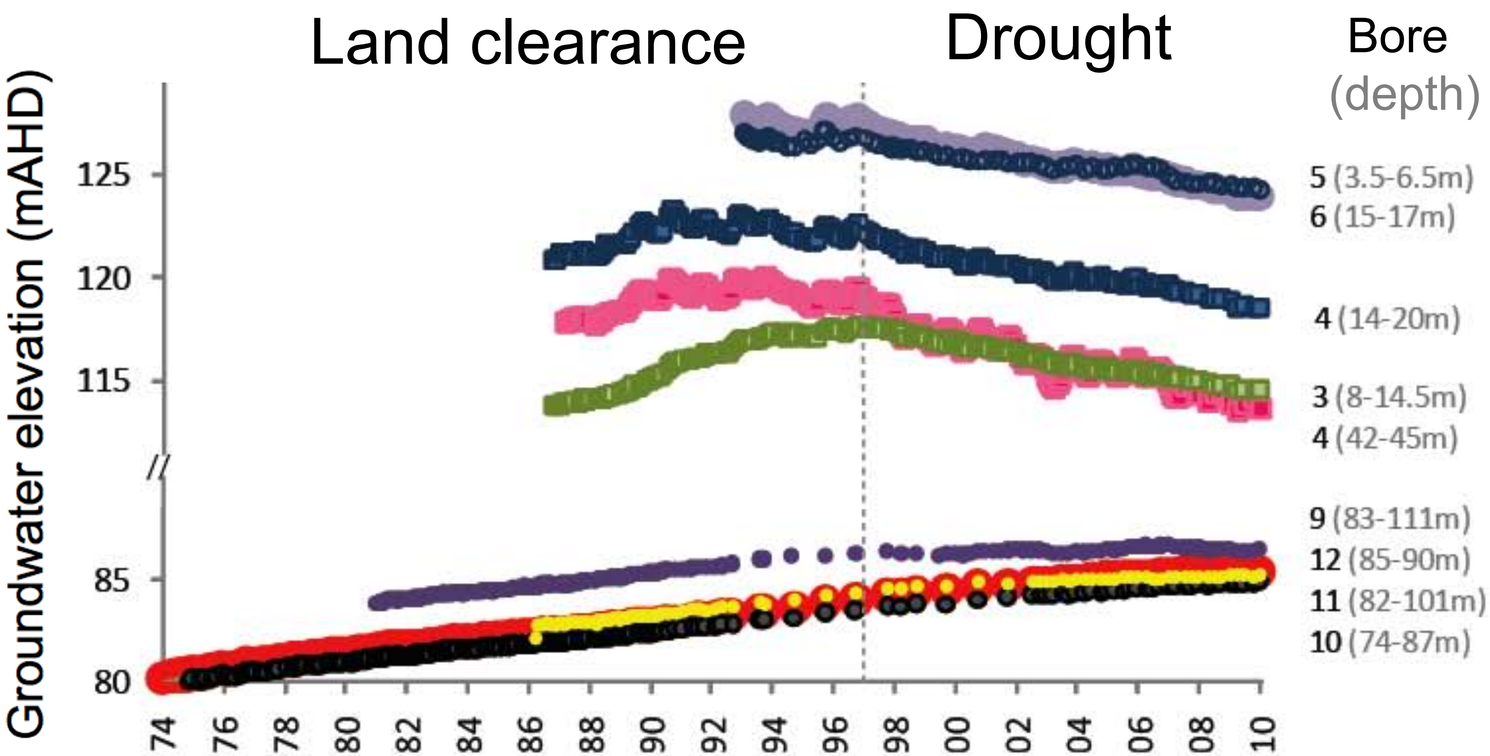
•Event

•Seasonal?



Challenges in using environmental tracers to investigate variabilities

Murray Groundwater Basi



<u>Forcings</u>

Effects on salinity

- Land clearance
- Drought ?

Challenges in using environmental tracers to investigate variabilities

i. Multiple scales and forcings

Retrospective

Most studies conducted at different sites

Scales
Contaminant transfers
•Event
•Seasonal

Forcings
Effects on salinity
•Land clearance
•Drought

Prospective

One site

- Multiple scales
- Multiple forcings

Impacts of forcing propagating through the hydrosystem

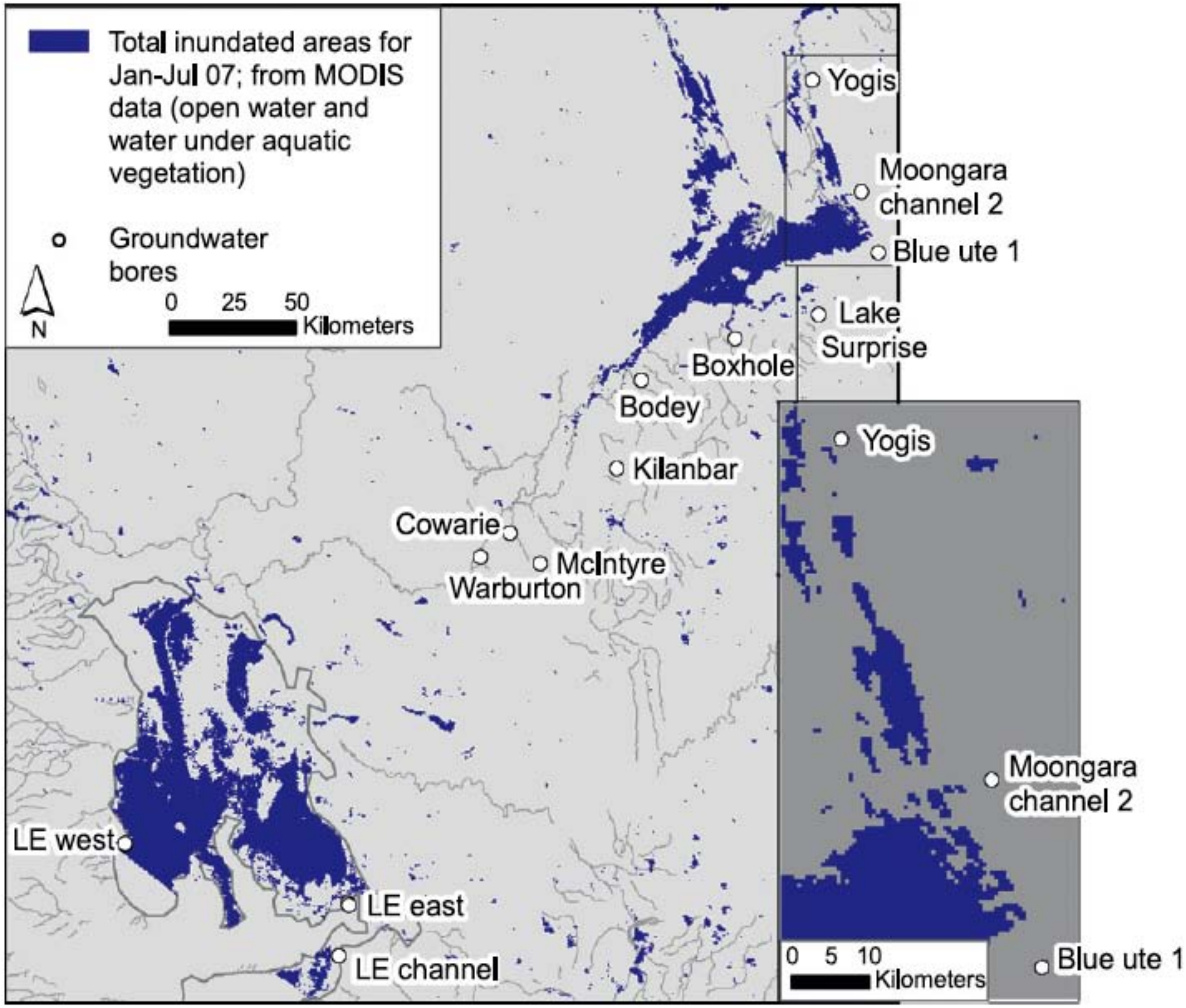
Challenges in using environmental tracers to investigate variabilities

ii. Data representivity

Lake Eyre Basi

Retrospective

Space
Insufficient data to represent floodwater recharge



Challenges in using environmental tracers to investigate variabilities

ii. Data representivity

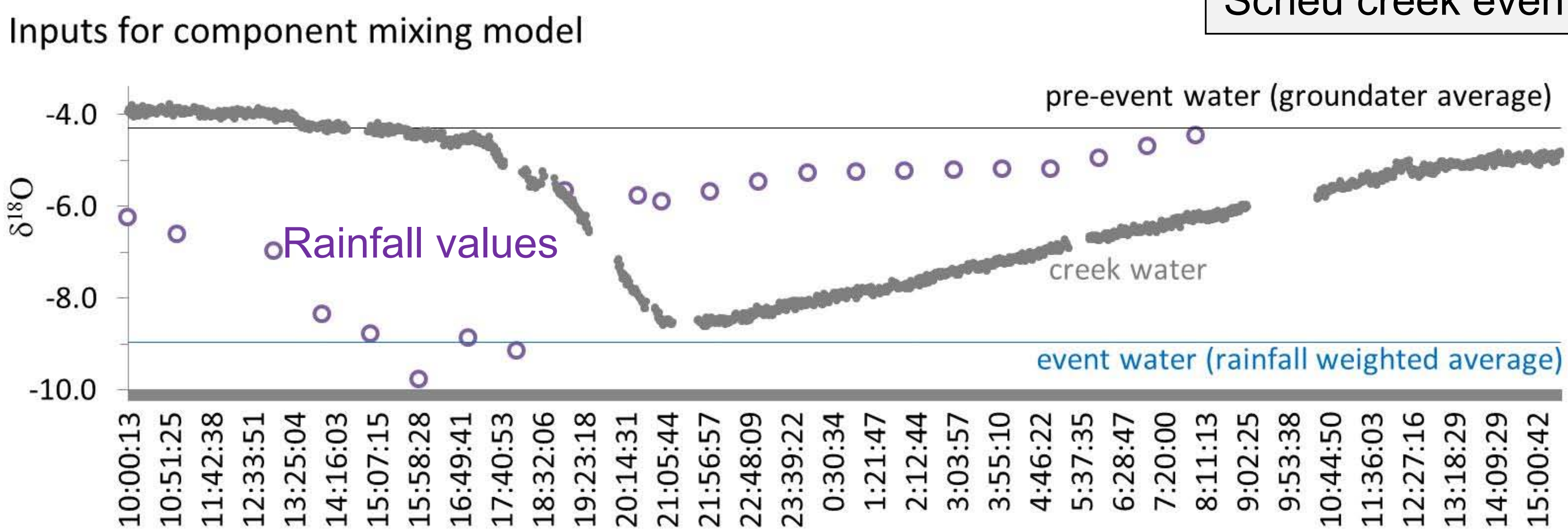
Retrospective

Space
Insufficient data to represent floodwater recharge

Time
Component mixing models: constant end-members

Challenges in using environmental tracers to investigate variabilities

Scheu creek event scale



Time

Component mixing models: constant end-members

Challenges in using environmental tracers to investigate variabilities

ii. Data representivity

Retrospective

Space

Insufficient data to represent floodwater recharge

Time

Component mixing models: constant end-members

Prospective

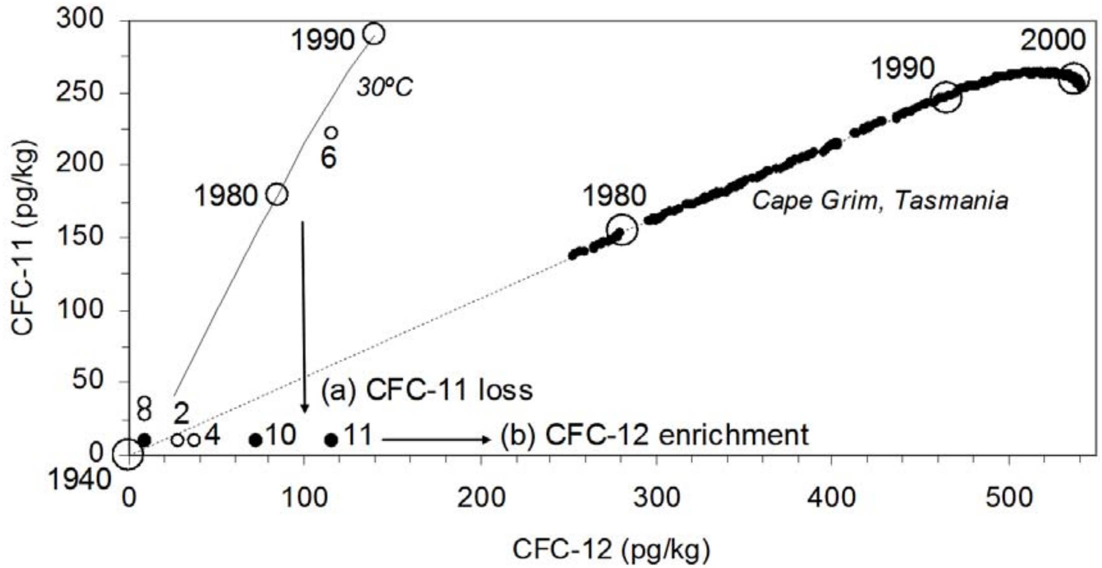
- Optimum sample frequency and density
- Dynamic end-members in models

Challenges in using environmental tracers to investigate variabilities

iii. Multiple tracers

Dandenong Range

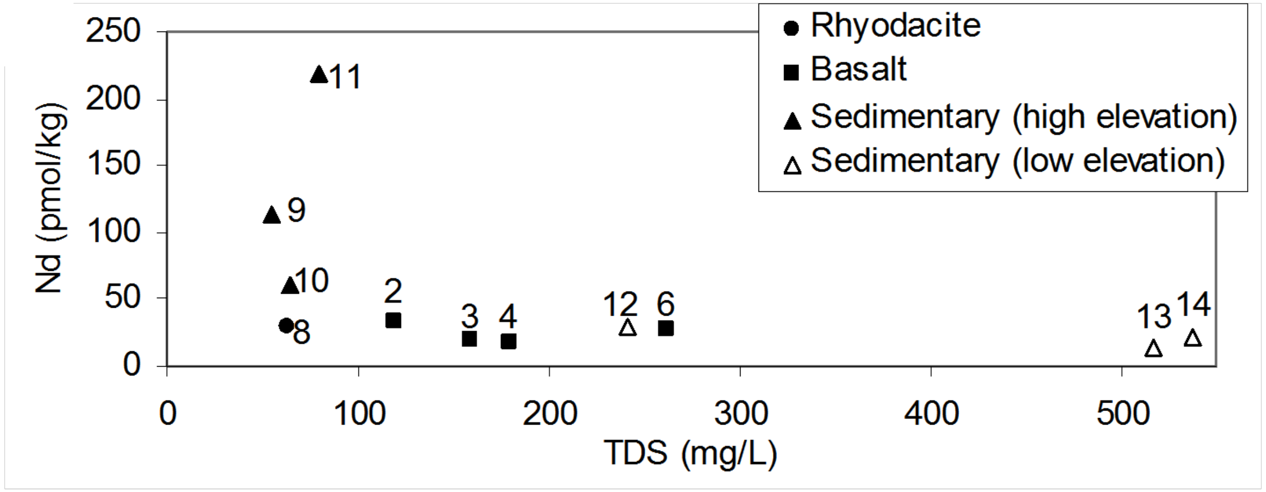
Retrospective



Suite of tracers

(1) Suitability to process

(2) Known mechanisms controlling solutes



Challenges in using environmental tracers to investigate variabilities

iii. Multiple tracers

Retrospective

Suite of tracers

(1) Suitability to process

(2) Known mechanisms controlling solutes

Prospective

Selective Analysis
Less expensive tracers to understand geological controls on mixing in system

Targeted tracers

-> Dating tracers

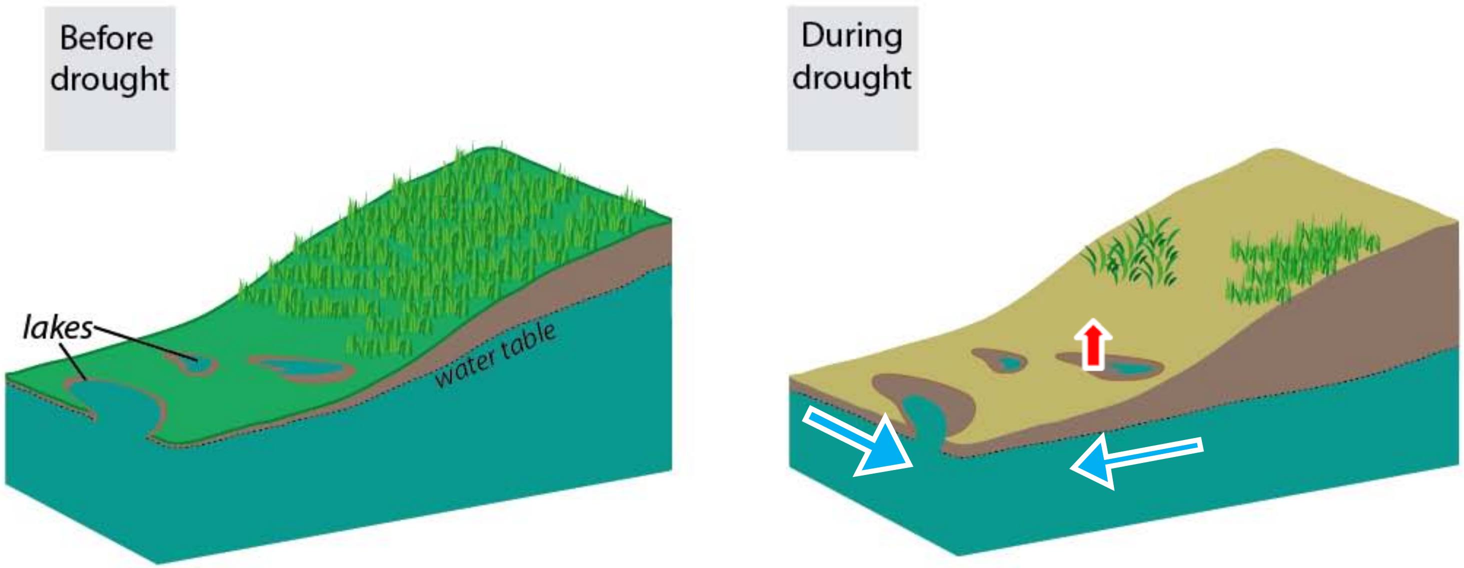
-> Contaminants

iv. Regional systems

Retrospective

<u>Impacts on chemical system</u>

•Localised - Drought (Corangamite: 13,000 km^2)



Challenges in using environmental tracers to investigate variabilities

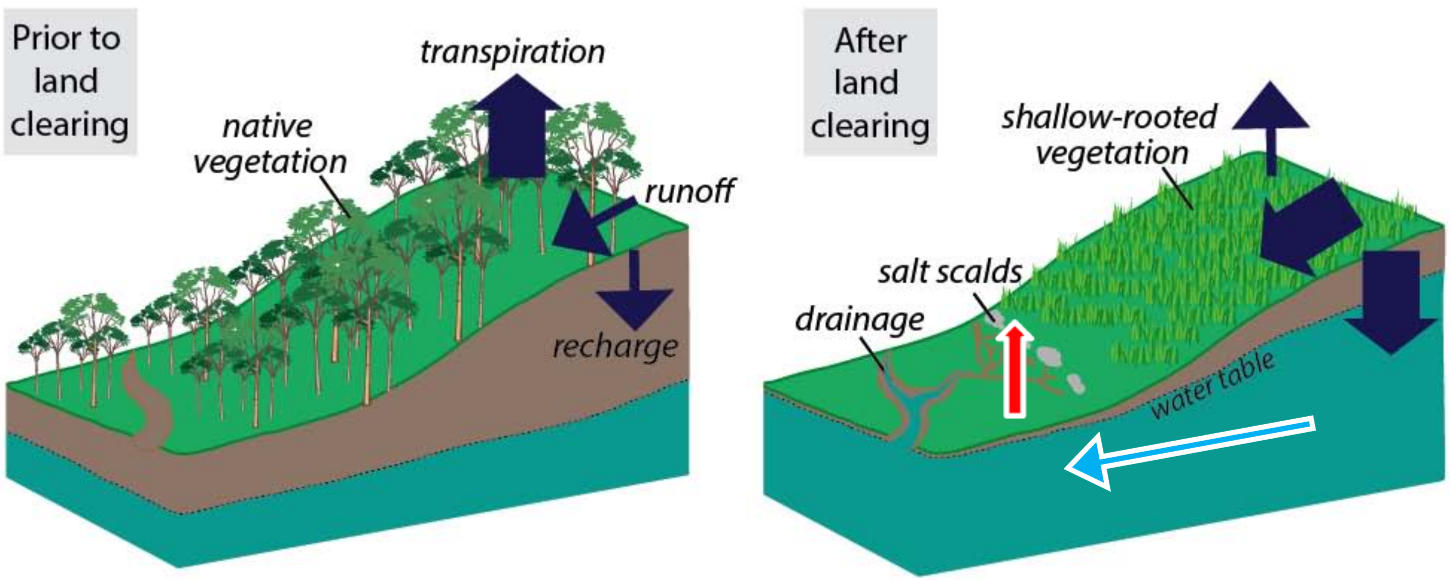
iv. Regional systems

Retrospective

<u>Impacts on chemical system</u>

•Localised - Drought (Corangamite: 13,000 km^2)

•Delayed - Land clearance (MGB: 300,000 km^2)



Challenges in using environmental tracers to investigate variabilities

iv. Regional systems

Retrospective

Impacts on chemical system
- Localised - Drought (Corangamite: 13,000 km^2)
- Delayed - Land clearance (MGB: 300,000 km^2)

Prospective

Challenges
- Distinguishing current versus historical forcings impacting water quality
- Using environmental tracers to constrain physical hydrosystem processes

Advantages
- Chemistry can highlight significant historical processes that the current physical system no longer represents

1. Groundwater ages

Builds on research in Australia and current research at IRD (Wankama catchment SW Niger)

Importance

- Water resources quantity assessments
  - ➢ Groundwater renewal rates and sustainable yield
- Water resources quality assessments
  - ➢ Fluxes and evolution of contaminants
- Impact of forcings assessments
  - ➢ Time lag for chemical system response

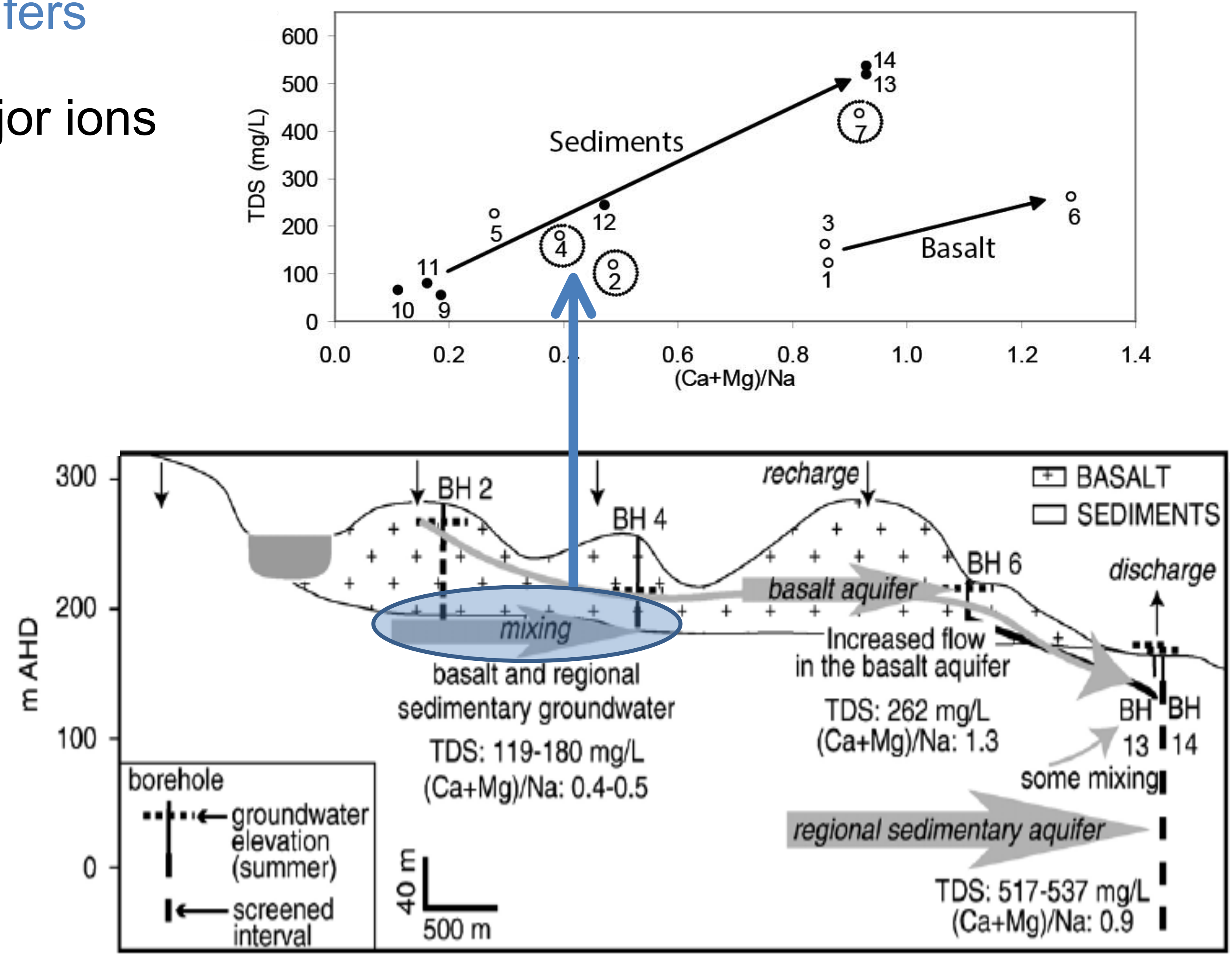
Challenges in measuring groundwater ages are amplified in heterogeneous systems (e.g. McCallum et al., 2013)

1. Tracer specific processes: sorption, degradation, terrigenic sources, contamination
2. Excess air effect
3. Mixing - average age of mixed waters
4. Solute diffusive transport – in dual porosity systems

Example 1.
Mixing between fracture rock aquifers

-major ions

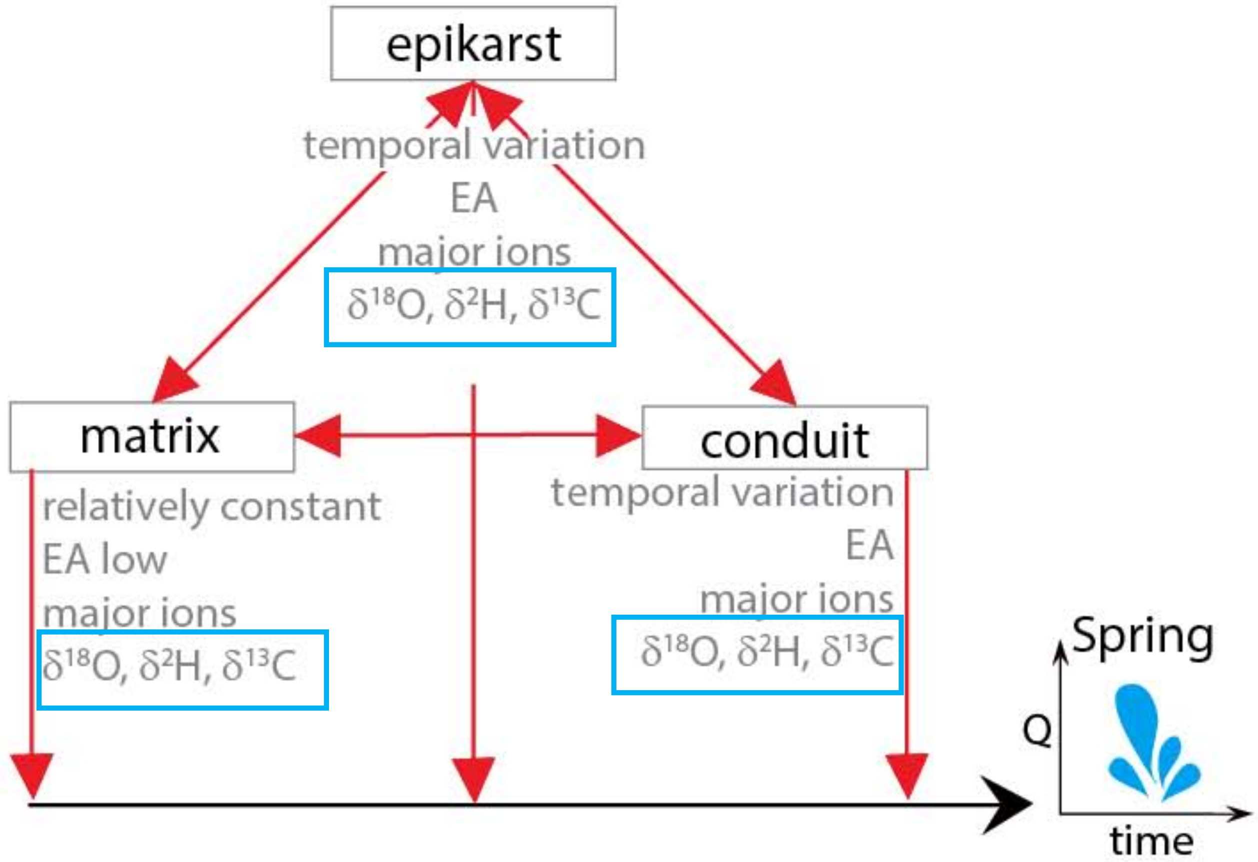
-



Example 2.
Sources of karst waters to springs – storm events (e.g. de Montety, 2013)

-> Mixing processes?

-> Impacts of diffusive transport?



Analysis of temporal variations in mixing between different flow pathways during storm events

2. Groundwater C transfers

Builds on previous research in Australia

Importance

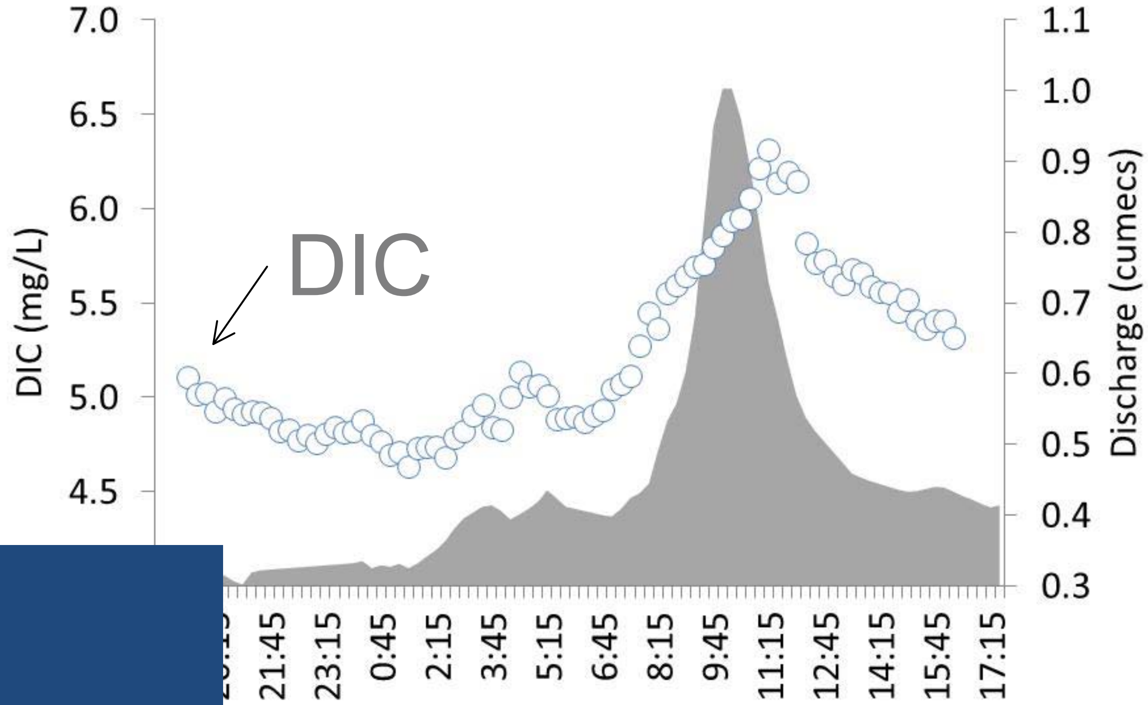
Linked water and carbon cycling

Knowledge gaps

Role of groundwater in the transfer of carbon from terrestrial catchments

- Stores of C
- Transfers of C
- Impacts of land cover change on C transfers

Groundwater C transfers

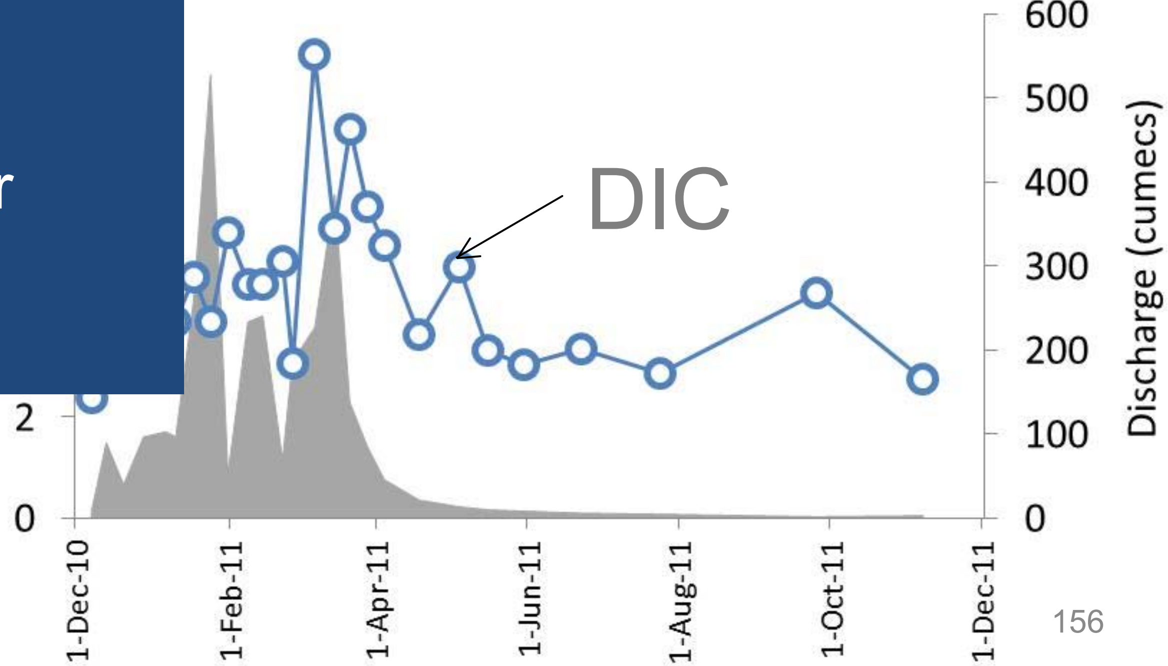


Event scale

-> Stores of C?

-> Transfers of C?

-> Impacts of land cover change on C transfers?



Seasonal scale

86% of the annual carbon load over a 4 month period

3. Heavily modified hydrosystems

Builds on current research at IRD (irrigated areas in lower Senegal Delta, Haouz Plain Morocco, and Crau Plain France)

Importance

Food and water security

Challenges

Chemical system can reflect current or prior conditions

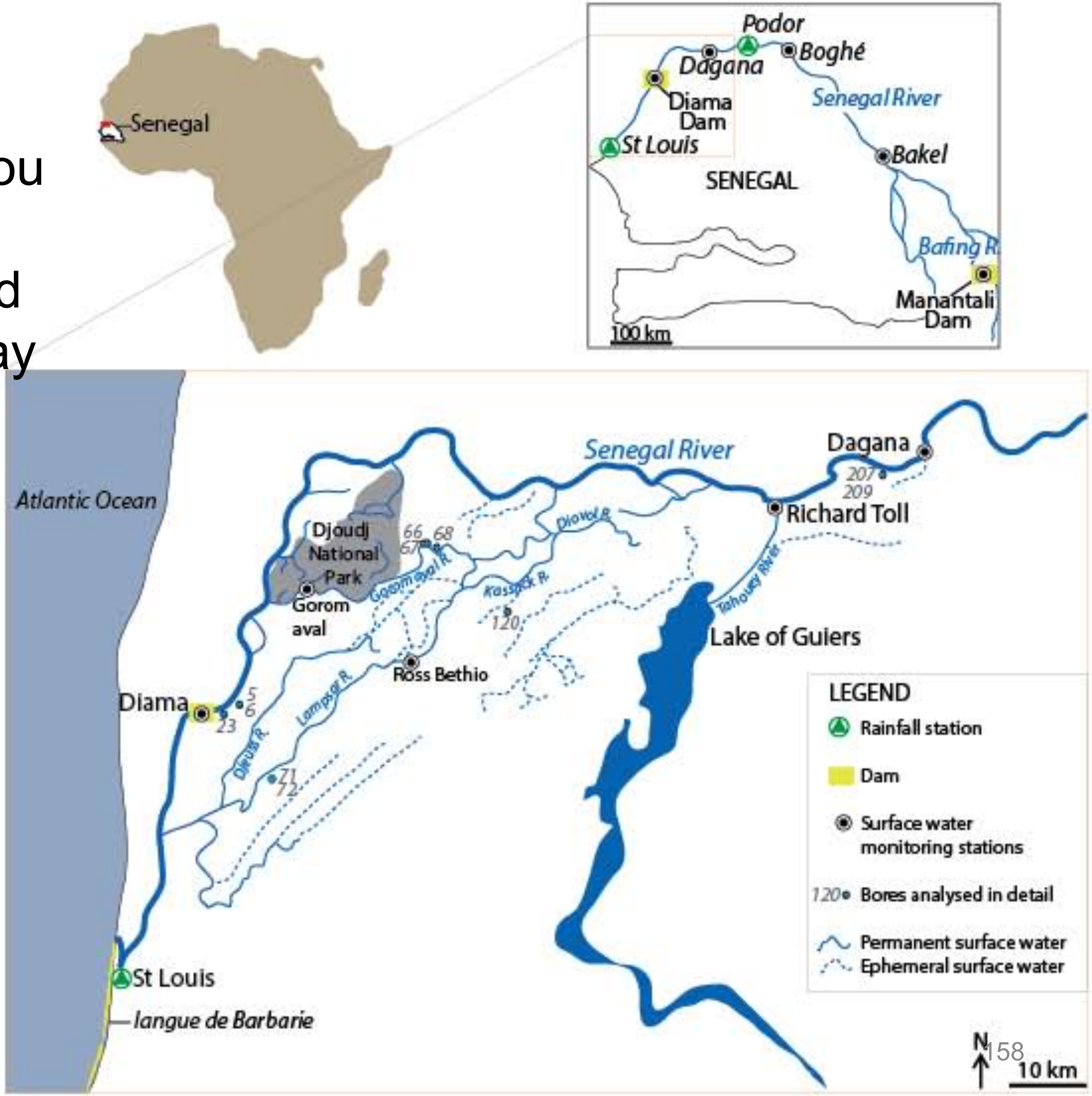
Question

Can we differentiate impacts from multiple forcings on water quantity and quality?

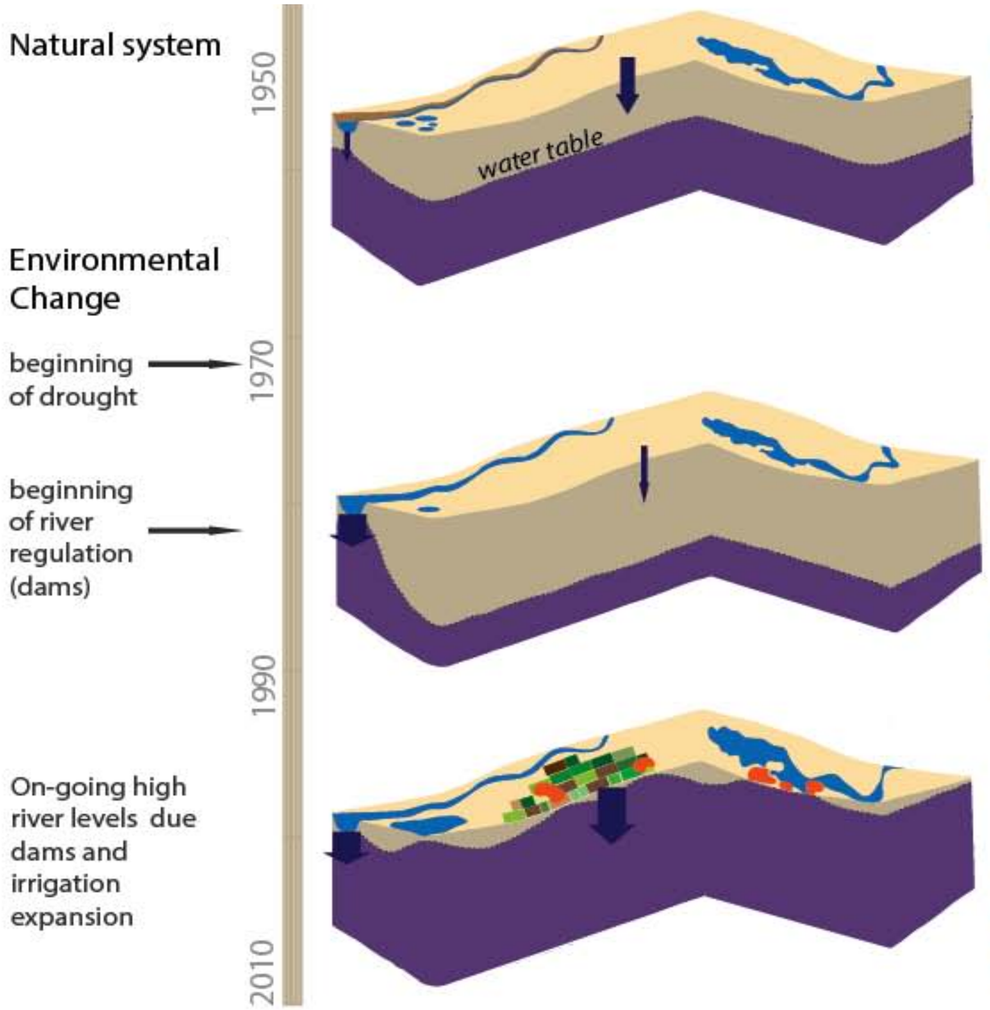
Example:
Senegal Delta

– Heterogeneous aquifer: disconnected sand and clay lenses

– Multiple forcings



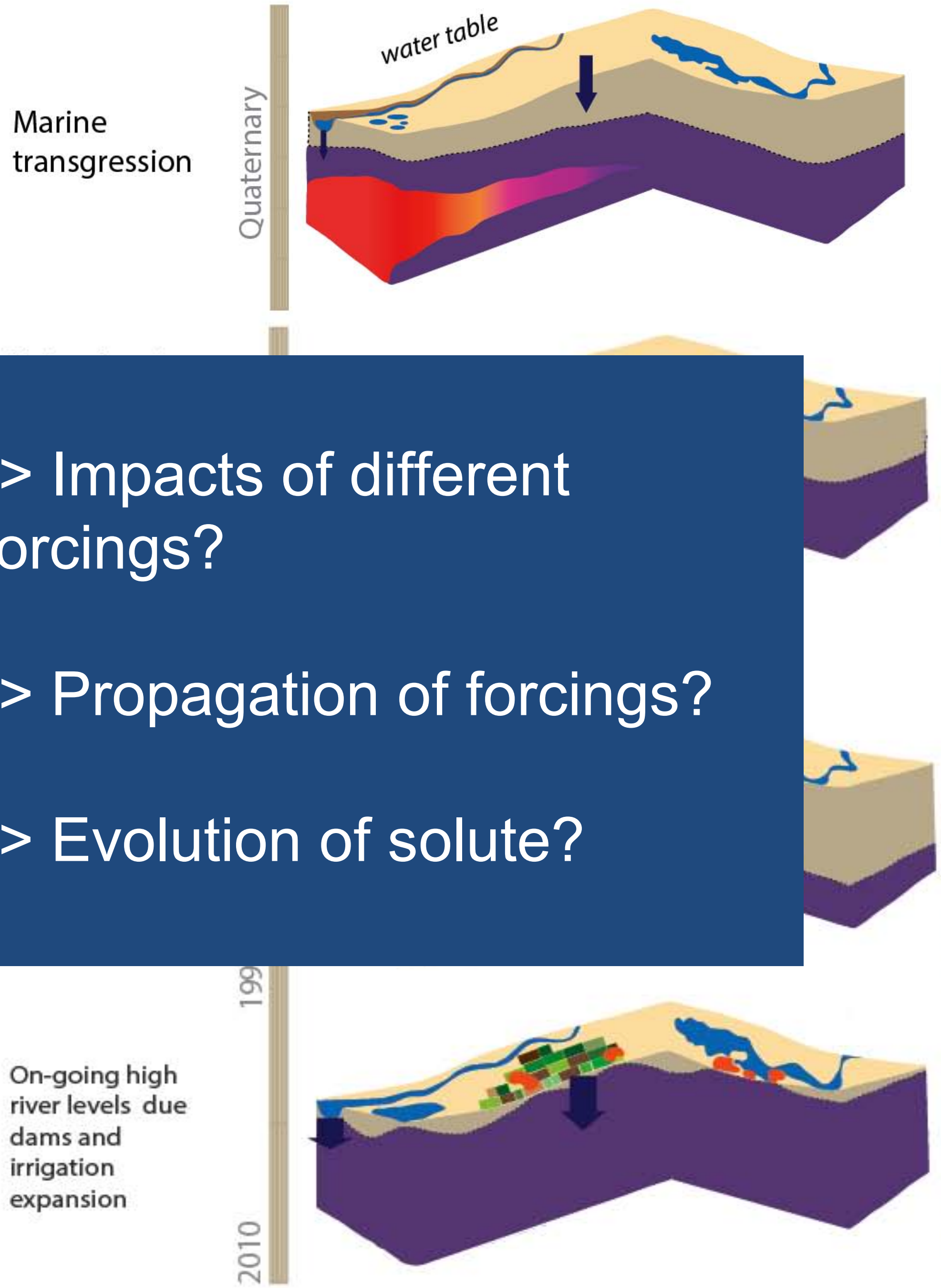
Physical hydrosystem changes



1970s

- Drought
- Start of dams regulating Senegal River
- Start of irrigation expansion

-> Non-uniform physical



-> Impacts of different forcings?

-> Propagation of forcings?

-> Evolution of solute?

- sea water transgressions

  ↑ salinity

- Drought

  Reduced recharge ↑ salinity

  Lower water tables ↓ salinity

- Dams regulating the River

  Increased river recharge ↓ salinity

- Irrigation

  Increased recharge ↓ salinity

  Water table close to the surface ↑ salinity