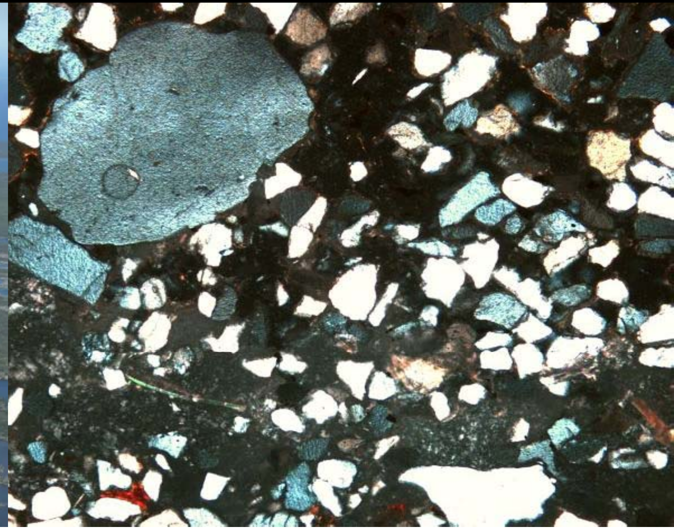




DEC TEC Course 4th November 2009

Groundwater dependant ecosystems and ecological water requirements

Outline

- Groundwater dependence
- Ecological water requirements and environmental flows
- Vegetation ecological water requirements
- Aqueous fauna ecological water requirements
  - Macroinvertebrates
  - Water bird Ecological Water Requirements
- Other flora/fauna
- TBL accounting and gaps

Groundwater dependent ecosystems (GDE)

- GDE includes ecosystems that use groundwater as all or only as part of their water supply. The groundwater dependence of ecosystems will range from complete reliance to those that partially rely on groundwater.
- The degree and nature of dependency will influence the extent to which ecosystems are affected by changes to the groundwater system, both in quality and quantity.

http://www.connectedwater.gov.au/framework/ground_dependant_ecosystems.html

Groundwater Dependence: Principles of Reliance

(Hatton and Evans 1998)

- Ecosystems evolve to exploit all physical resources.
- Most of Australia is either semi-arid or has seasonal drought.
- Thus, if groundwater exists within reach, ecosystems will develop that are to some extent dependent upon it.

Principles of Reliance: Corollaries
(modified after Froend)

- Reducing the availability of groundwater to ecosystems can result in;
  - a proportional reduction in health or areal extent,
  - or cross a threshold where the entire system collapses.
- The superabundance of (ground)water can be directly harmful (waterlogging) or indirectly (increased salinity via evaporation)
- ***The degree of dependence is proportional to the fraction of the annual water budget that ecosystem derives from groundwater*.** But this cannot be based on a mean annual understanding only, the seasonality of water sources is crucial. Groundwater is the only water resource many ecosystems have access to by the end of summer but also may be required for some part of a life cycle (breeding).
- Therefore you need to understand water balance and individual species water requirements in some detail (i.e. how they vary through the range of water regimes) before you can properly understand dependence.

The 4 attributes of groundwater dependence

The dependency of ecosystems on groundwater is based on one or more of these four basic groundwater attributes:

1. flow or flux - the rate and volume of supply of groundwater;
2. level - for unconfined aquifers, the depth below surface of the water table;
3. pressure - for confined aquifers, the potentiometric head of the aquifer and its expression in groundwater discharge areas; and
4. quality - the chemical quality of groundwater expressed in terms of upper and lower levels of pH, acidity, salinity and/or other potential constituents, including nutrients and contaminants.

Modified after SKM, 2001. Environmental Water Requirements of Groundwater Dependent Ecosystems. Technical Report Number 2, Sinclair Knight Mertz for Environment Australia

Wetland Water Budget/Balance - Revisited

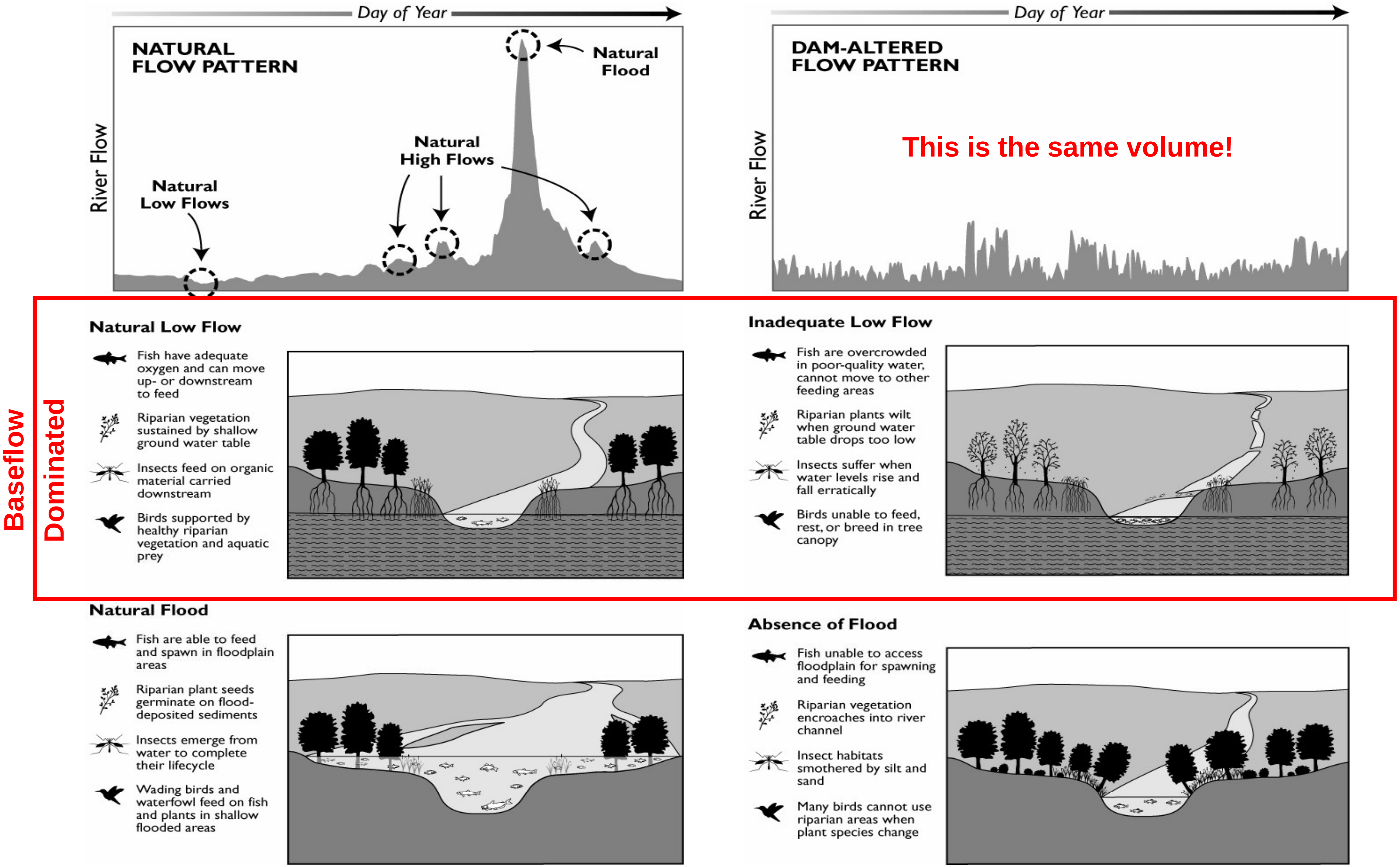
- A water balance is essentially the balance of the inflows and outflows of water for a given system
- This balance of inflows and outflows is one the most significant factors affecting the type, functions, and species composition of wetlands
- If the values can be quantified, simple balances can be used for managerial decision, future forecasting, etc.
- Useful in generation of models. Simple water balance models are one of the first types of models used in an impact assessment

Patterns of Water Usage of GDEs

- *Threshold values* – values within which the four key groundwater parameters must remain for the ecosystem to be maintained.
- *Rates of use -* that indicate the consumptive use and/or requirements of dependent ecosystems.
- *Temporal distribution of use -* timing, frequency, duration, episodicity – as previously stated must be described to determine EWR
- Can be highly site specific so can be risky to make assumptions regarding dependency

(modified after Froend)

Seasonality is important, It's not just a matter of mean annual water volume, level or chemistry, reduced baseflow can create inadequate low flows



<u>From</u>: Rivers for Life: Managing Water for People and Nature, Postel and Richter

Forms of Dependency
(Hatton and Evans 1998)

Entirely dependent - tolerate only small changes in groundwater regime before ecosystem collapse

Highly dependent - tolerate moderate change in groundwater regime before ecosystem collapse

Proportional dependence - decline in ecological processes proportional to change in water regime

Limited or opportunistic dependence - ecological processes irregularly dependent on groundwater

No apparent dependence - ecosystems appear to be entirely rain/surface water fed

Questions on Dependency

Given the presence of groundwater source dependency, several additional questions follow, including:

Question 1

Timing of dependency?

- All year, part of year, part of life cycle of the ecosystem? Wet years/decades *versus* dry years /decades, episodic dependence only?

Question 2

Degree of dependency?

- Is it total, partial, a mixture of both, facultative?
- Does dependency change with time/age of plant/species?
- Are we concerned with managing individual species (rare/endangered) ecosystem dependency threatened ecological communities?

(modified after Froend)

Categories of Groundwater Dependent Ecosystems

- Terrestrial vegetation
- River base flow systems
- Aquifer and cave ecosystems
- Wetlands
- Terrestrial fauna
- Estuarine and near-shore marine ecosystems

Categories of groundwater dependent ecosystems - **Terrestrial vegetation**

- Terrestrial vegetation may depend to varying degrees on;
  - the diffuse discharge of shallow groundwater or
  - a shallow depth to groundwater which is less than the maximum rooting depth,
- either to sustain transpiration and growth through a dry season or for the maintenance of perennially lush ecosystems in otherwise arid environments.
  - Banksia Woodlands of Gnangara mound with DTW < 8m
  - Tuarts and Karri in the SW Yarragadee outcrop areas

Modified from http://www.connectedwater.gov.au/framework/ground_dependant_ecosystems.html

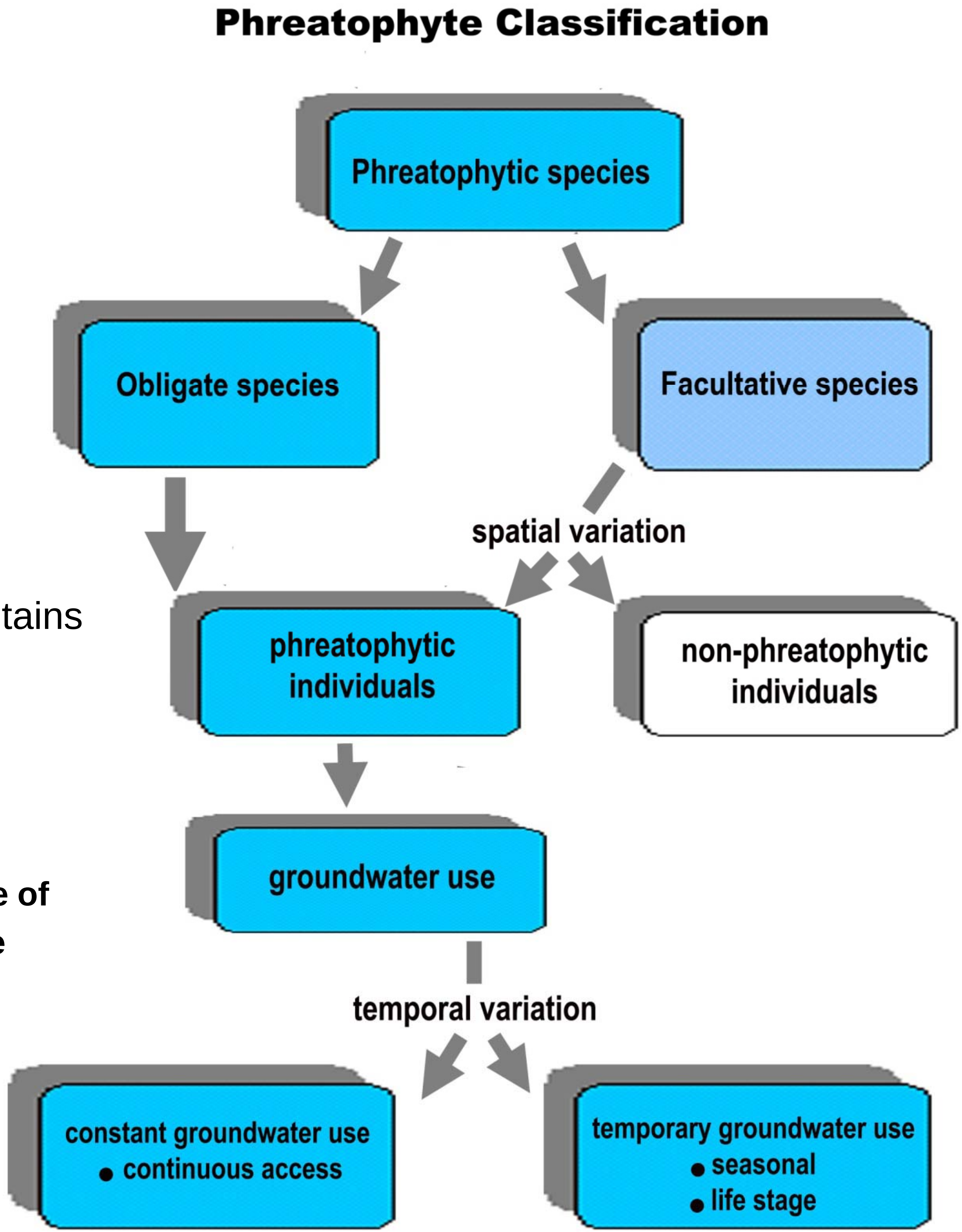
Variability in dependency

Obligate vs. Facultative Phreatophytes

Phreatophyte - A deep-rooted plant that obtains water from a permanent ground supply or from the water table.

Obligate - without an alternative system or pathway.

Facultative - Not obligatory but rather capable of adapting to different conditions. The opposite of facultative is obligate.



(modified after Froend)

Categories of groundwater dependent ecosystems - **Wetlands**

- Groundwater dependent wetland ecosystems are those that are at least seasonally waterlogged or flooded. Hatton and Evans (1998) considered that wetlands provide the most extensive and diverse set of potentially dependent ecosystems in Australia.
- Examples of groundwater dependant wetland ecosystems include; paperbark swamp forests and woodlands, swamp-forests and woodlands, swamp scrubs and heaths, swamp shrublands, sedgelands and mound springs ecosystems.
- The diversity of groundwater dependent wetland ecosystems means that each of the four key groundwater attributes can play some role in their dependency.

http://www.connectedwater.gov.au/framework/ground_dependant_ecosystems.html

Categories of groundwater dependent ecosystems - **River base flow systems**

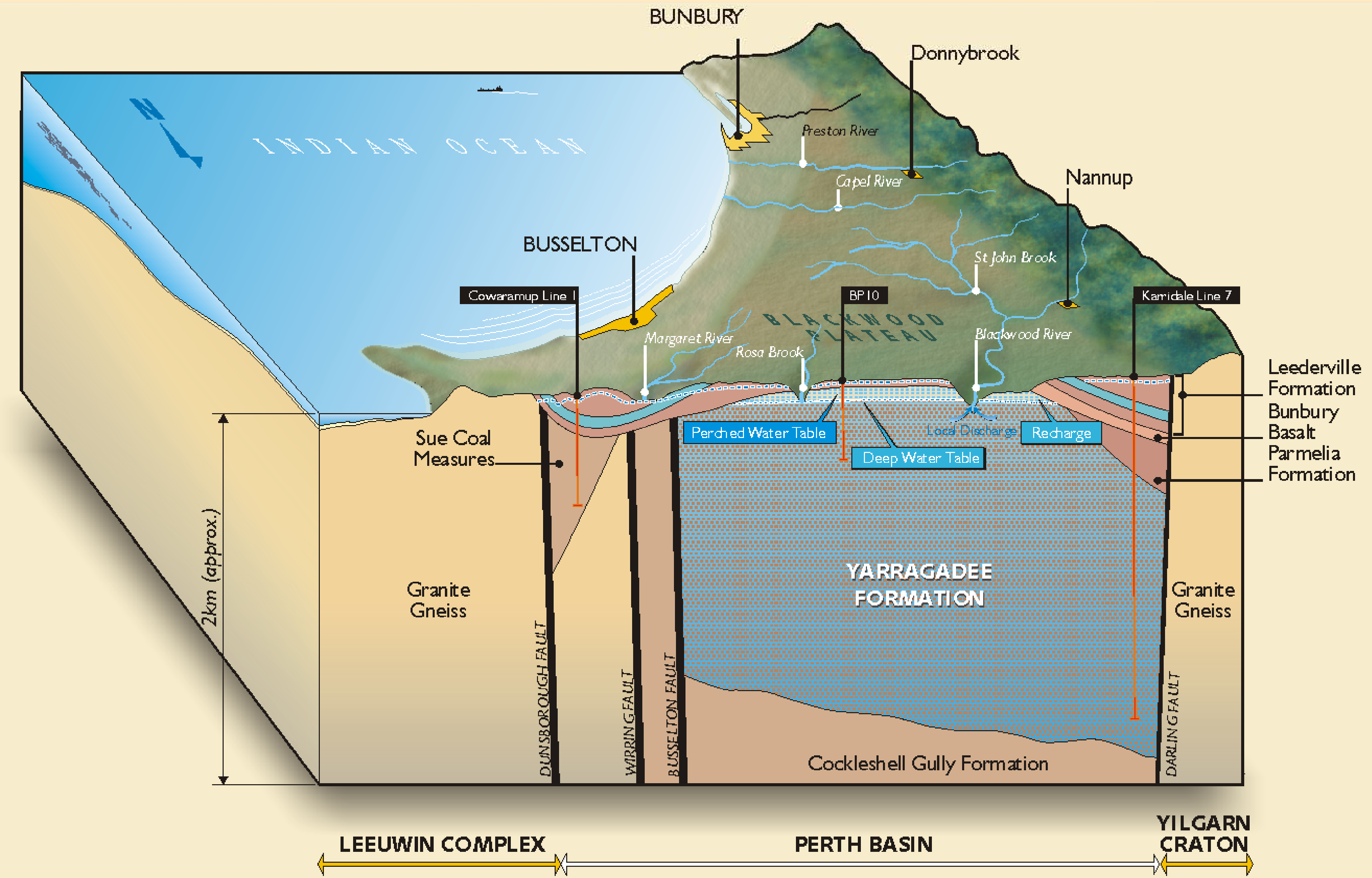
Stream flows may have a groundwater discharge as a baseflow component in many river reaches in Australia. This groundwater baseflow component may be vital to the character and composition of in-stream and near-stream ecosystems.

- Blackwood River downstream of Yarragadee outcrop areas.
- Gingin Brook

Modified from http://www.connectedwater.gov.au/framework/ground_dependant_ecosystems.html

SW Yarragadee

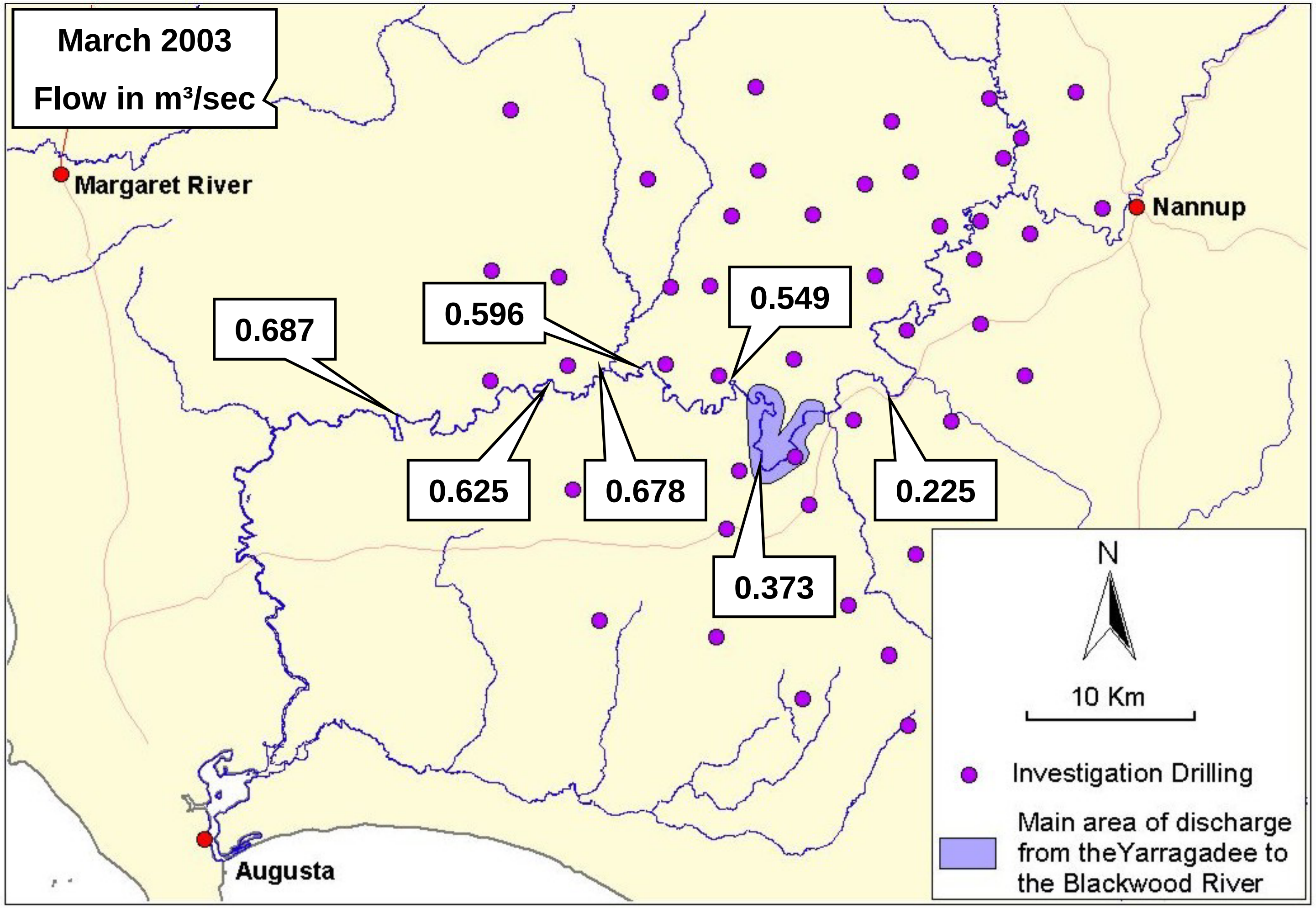
Compliments Department of Water




Compliments Department of Water
Yarragadee outcrop
March 2003

Compliments Department of Water

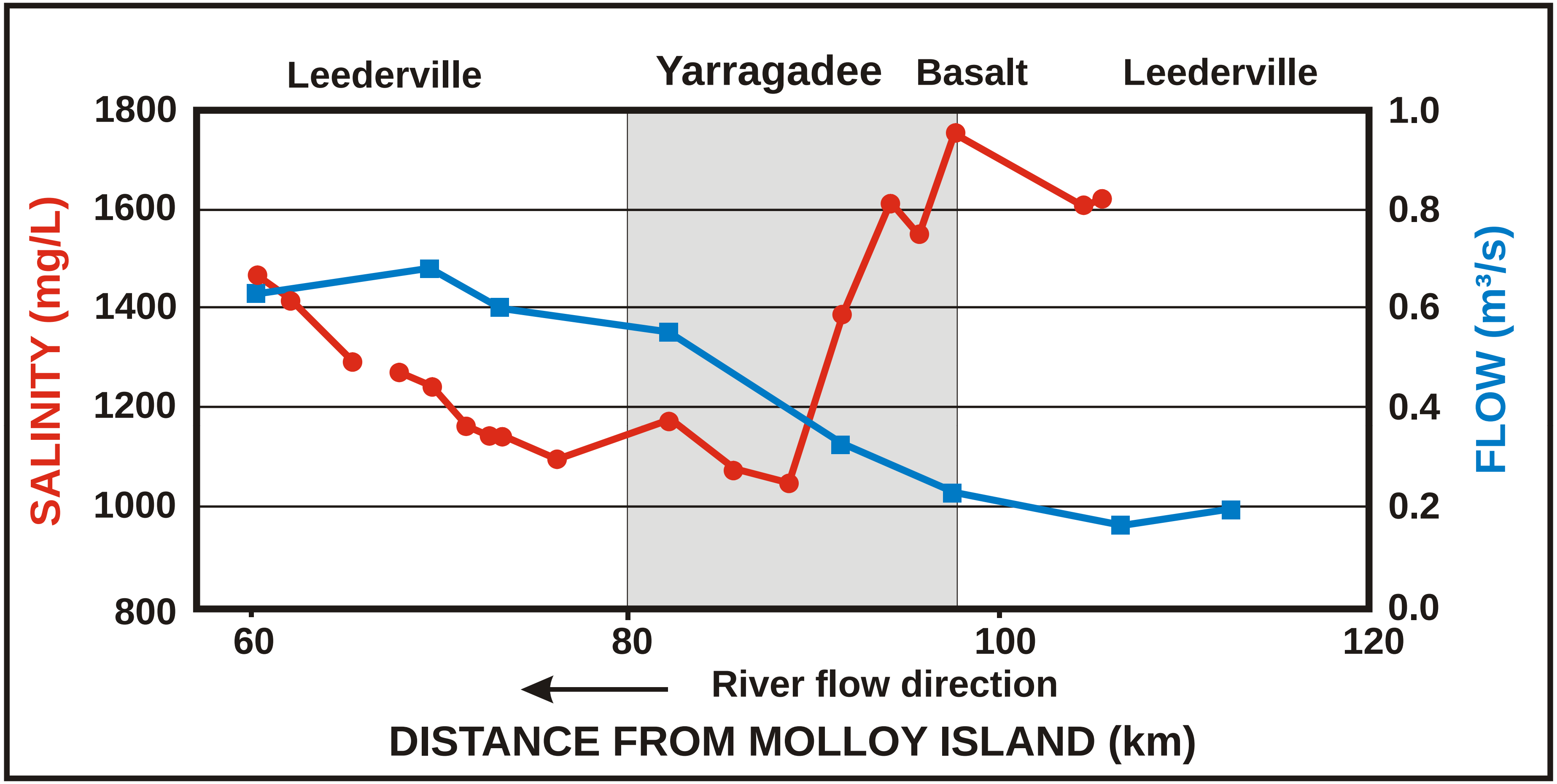
Blackwood River flow



South West Yarragadee Blackwood Groundwater Area

Compliments Department of Water

Blackwood River flow and salinity



South West Yarragadee Blackwood Groundwater Area

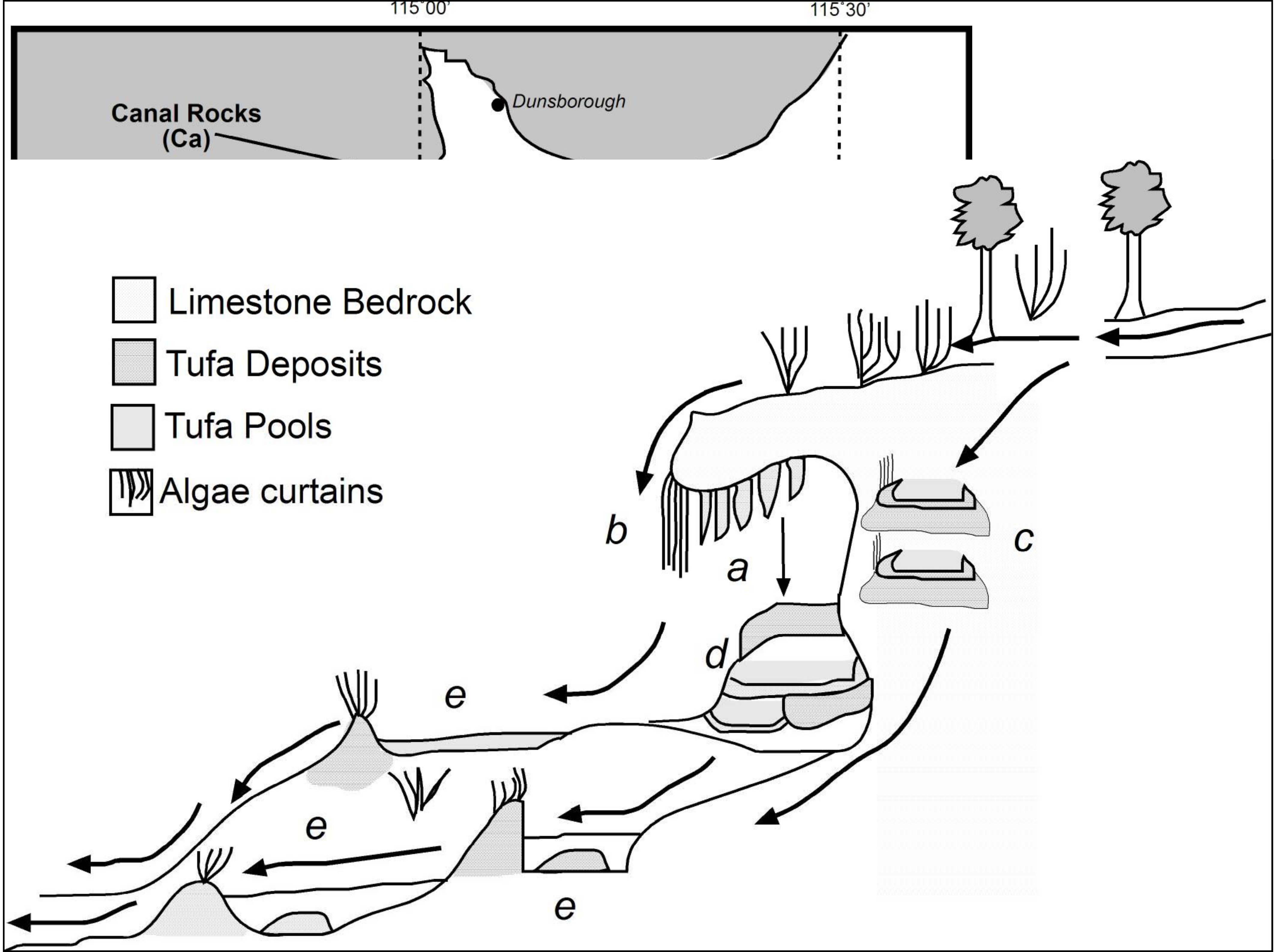
Categories of groundwater dependent ecosystems - **Aquifer and cave ecosystems**

- Hypogean (located beneath the earths surface) life exists in a continuum through different types of karstic, cave, porous and fissured aquifers.
  - Tufa communites, Cape to Cape
  - Stygofauna in the Cape Range

Modified from http://www.connectedwater.gov.au/framework/ground_dependant_ecosystems.html

Example of Entirely Groundwater Dependant River Baseflow/Cave/Karst Ecosystem - Tufas

- Microbalites which need to be wet all year round which form in rimstone pools and vertical sheets. Pools may also contain macroinvertabrates.
- Occurs in areas of carbonate rich groundwater discharge, typically from karst systems in the SW of WA, Turkey and China etc.
- Threats
  - Highly sensitive to changes in acidity/pH
  - nutrient increases from agricultural landuse practises (algal competition and eutrophication)
  - Climate change, not enough rainfall causing declines in groundwater flux
- EWR based on continuous flux and water quality
- Example – Ellensbrook near Margaret River …


115˚00'
115˚30'
Canal Rocks
(Ca)
Dunsborough
Limestone Bedrock
Tufa Deposits
Tufa Pools
Algae curtains
b
a
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e


Types of groundwater dependent ecosystems - **Terrestrial fauna**

- Groundwater dependent terrestrial fauna have a reliance on groundwater that is not based on the direct provision of habitat, but as a source of drinking water. Groundwater, as river baseflow or discharge into a spring or pool, is an important source of water across much of the country, particularly in northern and inland Australia and other areas with semi-arid climate.
- Its significance is greater for larger mammals and birds, as many smaller animals can obtain most of their water requirements from respiration.
- Pastoralists in inland Australia have made extensive use of groundwater to supply drinking water to grazing stock. In addition to watering stock.
- Don’t forget about humans!

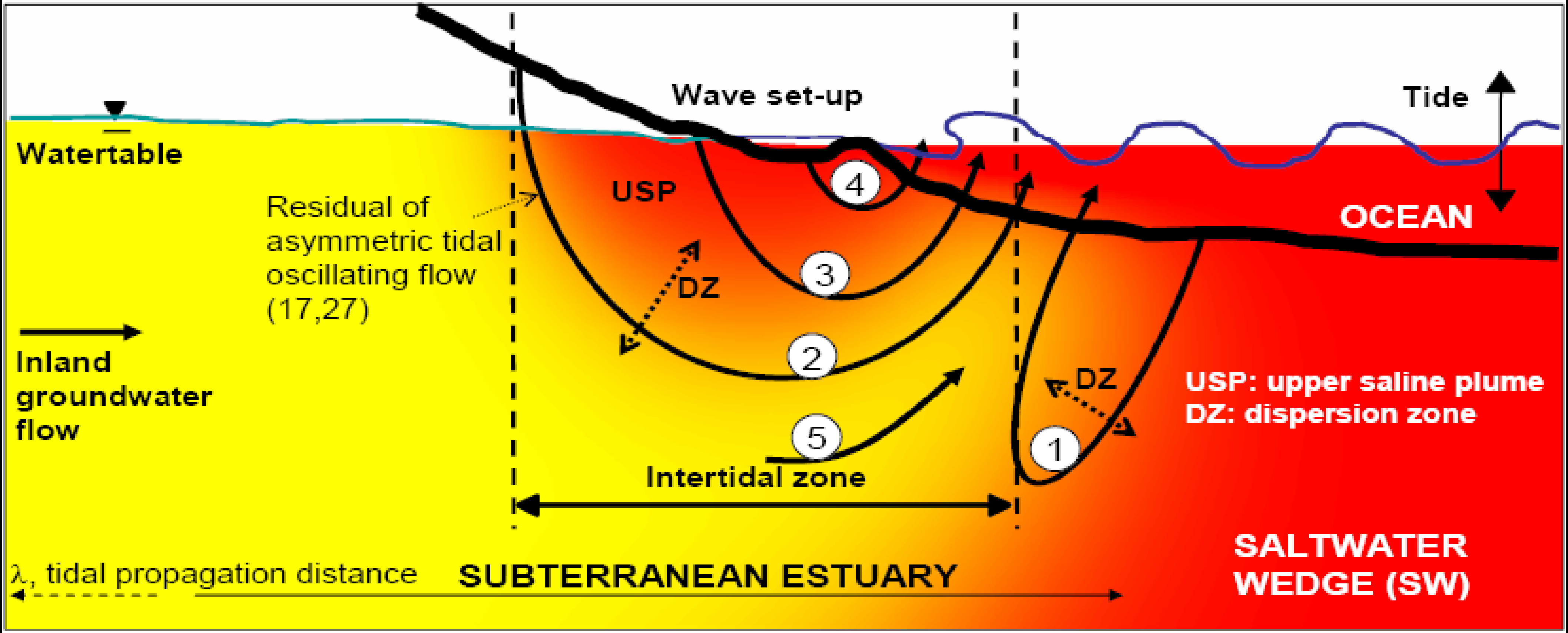
Modified from http://www.connectedwater.gov.au/framework/ground_dependant_ecosystems.html

Types of groundwater dependent ecosystems - **Estuarine and near shore marine systems**

- These types of ecosystems are the marine counterparts of the terrestrial ecosystems and can include coastal mangroves and salt marshes, coastal lakes, sea grass beds and marine animals.
- Some marine and estuarine animals depend on groundwater discharge to provide a suitable habitat or an appropriate environment in which species of plants and/or animals they eat will prosper.
- Groundwater discharge may be in the form of direct off-shore discharge or baseflow into streams that discharge to the ocean. (Hatton and Evans 1998).

http://www.connectedwater.gov.au/framework/ground_dependant_ecosystems.html

Effect of Tidal Range



1. Density-driven convection
2. Tidally driven circulation
3. Wave set-up driven circulation
4. Morphology driven circulation
5. Fresh groundwater discharge

Taken From Robinson et al. (2006), Driving mechanisms for flow and salt transport in a subterranean estuary. Geophysical Research Letters

Tidal Creek Hydr

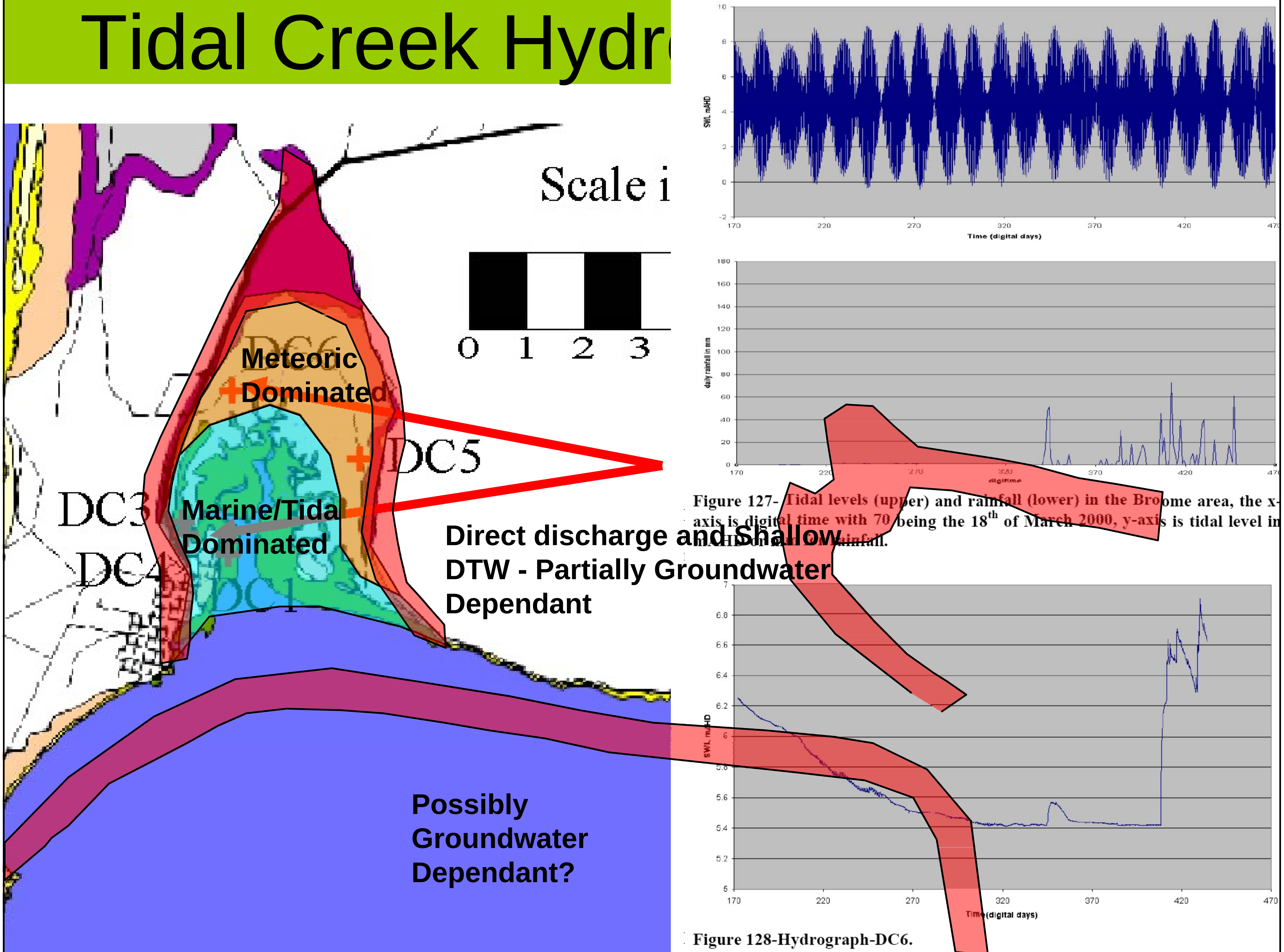


Figure 127- Tidal levels (upper) and rainfall (lower) in the Broome area, the x-axis is digital time with 70 being the 18th of March 2000, y-axis is tidal level in mAHD or mm of rainfall.

Figure 128-Hydrograph-DC6.

Toxic Cyanobacteria (blue-green algae) associated with groundwater conduits in the Bahamas

Received: 11 April 2005 / Accepted: 4 May 2005 / Published online: 18 February 2006

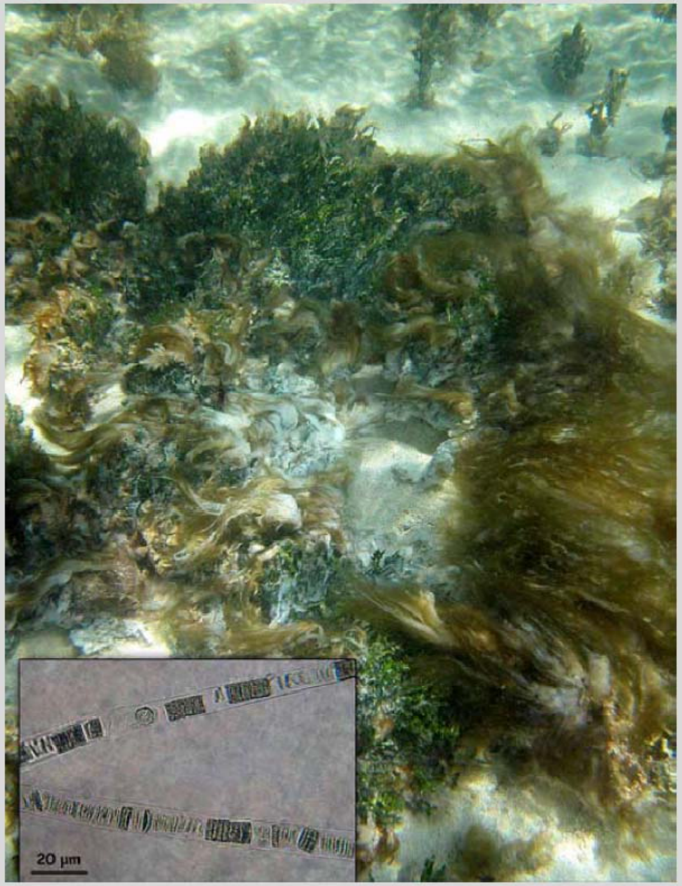


Fig. 1 Typical Bahamian groundwater conduit (*white sandy patch*) surrounded by the olive-colored toxic cyanobacterium *Nodularia* cf. *spumigena* and white strands of the sulfur-fixing bacteria *Beggiatoa*. *Inset* shows the anatomical characters (cells, trichomes, heterocysts, akinetes) characteristic of *Nodularia spumigena*

During a marine algal pilot study in the Abacos Islands, Bahamas (July 2004), we noted many spring-like submarine pockets of outflowing low-salinity groundwater. Interestingly, the mouths of these conduits were consistently encircled by conspicuous populations of the blue-green alga *Nodularia* cf. *spumigena* Mertens (Fig. 1), in association with filmy strands of white sulfur-fixing bacteria (*Beggiatoa*) smelling strongly of hydrogen sulfide.

Cyanobacteria of the nitrogen-fixing genus *Nodularia* are well known to form harmful algal blooms (HABs) worldwide. *Nodularia* spp. blooms occur in both planktonic and benthic habitats and are frequently toxic, due to their contribution of organic matter that fuels broad scale outbreaks of hypoxia and anoxia, with concomitant high levels of hydrogen sulfide. *Nodularia spumigena* produces the cyclic pentapeptide hepatoxin called nodularin (Rinehart et al. 1988), which, when ingested, can cause death (by liver hemorrhaging) in domestic and wild animals. Affected animals include cattle, horses, sheep, pigs, fowl, dogs, rodents, wild birds and fish. The olive-colored blue-green alga depicted (Fig. 1) is morphologically and anatomically consistent with *N. spumigena* (inset), although this species is holoplanktonic elsewhere.

Such *Nodularia* blooms are a further matter of economic importance because of significant human health hazards. Detrimental effects include bioaccumulation leading to toxic fish and shellfish poisoning (Falconer et al. 1992), as well as human ingestion of seawater contaminated by nodularin, which causes diarrhea, vomiting, weakness, anorexia and coldness of extremities (Carmichael 1997). Consequently, HABs of *Nodularia* have had serious impacts on tourism and recreational usages of waterways. Because *Nodularia* cf. *spumigena* (1) commonly forms groundwater-associated blooms producing hydrogen sulfide, (2) fixes atmospheric nitrogen and (3) ranks among the world's most toxic plants, further study of its ecological/environmental ramifications in Bahamian waters should receive high priority.

Acknowledgments We thank Vintage Props and Jets for round-trip air transportation to the Bahamas. We are grateful to Linton Beach and Harbor Cottages, Green Turtle Cay for lodging and boat facilities. Contr. Nos. 637 of Smithsonian Marine Station, Fort Pierce and 1626 of Harbor Branch Oceanographic Institution.

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Rinehart KL, Harada K, Namikoshi M, Chen C, Harvis CA, Munro MHG, Blunt JW, Mulligan PE, Beasley VR, Dahlem AM, Carmichael WW (1988) Nodularin, microcystin, and the configuration of Adda. J Am Chem Soc 110:8557–8558

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Inferred Groundwater Dependency

- Its not always possible to be 100% positive of an ecosystems groundwater dependence.
- To prove it complex physiological measurements must be correlated with hydrogeological/hydrological measurements.
- However in some situations you may want or have to infer groundwater dependence.

Inferred Groundwater Dependence

Ecosystem traits that imply groundwater dependency	Yes	No
Is the ecosystem identical or similar to another that is known to be groundwater dependent?	a	a
Is the distribution of the ecosystem associated with surface water bodies that are or are likely to be groundwater dependent? (e.g. permanent wetlands, streams with consistent or increasing flow along the flow path during extended dry periods)	a	a
Is the distribution of the ecosystem consistently associated with known areas of groundwater discharge? (e.g. springs or groundwater seeps in terrestrial and/or near shore marine environments)	a	a
Is the distribution of the ecosystem typically confined to locations where groundwater is known or expected to be shallow? (e.g. topographically low areas, major breaks of topographic slope)	a	a
Does the ecosystem withstand prolonged dry conditions without obvious signs of water stress?	a	a
Is the vegetation community known to function as a refuge for more mobile fauna during times of drought?	a	a
Does the vegetation in a particular community support greater leaf area index and more diverse structure than that in nearby areas in somewhat different positions in the landscape?	a	a
Does expert opinion indicate that the ecosystem is groundwater dependent?	a	a

Sinclair Knight Merz, *Environmental Water Requirements of Groundwater Dependent Ecosystems* (2001), Environmental Flows Initiative Technical Report Number 2, Commonwealth of Australia, Canberra.

Threats to Groundwater Dependant Ecosystems

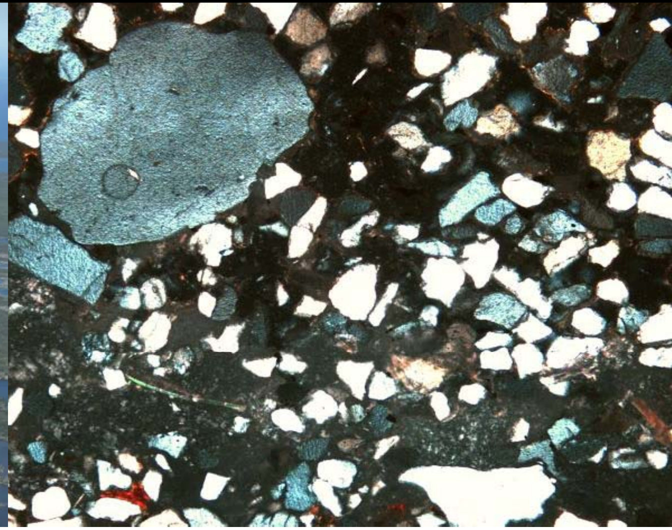
- Mankind's activities often threaten the condition and survival of groundwater dependant ecosystems. Our activities through;
  - Pumping groundwater
  - Changing landuse and modifying habitat
  - Damning and pumping from rivers
  - Climate change altering recharge and rainfall/surface water inflow
  - Etc
- Can all cause a change in the water balance of a groundwater dependant ecosystem which leads to hydrological response and threatens ecosystem function

Sinclair Knight Merz, *Environmental Water Requirements of Groundwater Dependent Ecosystems* (2001), Environmental Flows Initiative Technical Report Number 2, Commonwealth of Australia, Canberra.

	Threat to ecosystem		Vulnerability	Risk	Value
Ecosystem	**Process**	**Groundwater attribute**	***Impact if threat realised***	***Likelihood of threat being realised***	**Conservation value of ecosystem**
Entirely dependent on groundwater					
• Mound spring ecosystems	Water resource	Pressure	High	High	High
• Karstic groundwater ecosystems	Water resource, agriculture, mining	Level, quality	High	High	High
• Permanent lakes and wetlands of Swan Coastal Plain	Urban & commercial, water resources	Level, quality	High	High	Moderate
• Pilbara spring ecosystems	Mining, water resource, agriculture	Level, quality	High	Moderate	High
• Inland mangrove near 80 Mile Beach in Western Australia	No major current threat	Level	High	Low	High
• Arid zone groundwater calcrete ecosystems	Water resource, mining	Level, quality	High	Moderate	High
• Riverine aquifer ecosystems	Water resource, agriculture, urban & commercial development	Level, quality	High	High	Moderate
• Marine tide influenced cave (or anchialine) ecosystems	Water resource, mining	Level, quality	High	Moderate	High
Highly dependent on groundwater					
• Pilbara river pool ecosystems	Water resource, mining, agriculture	Level, quality	High	Moderate	Moderate
• Near shore stromatolites of coastal Western Australia	Urban & commercial, water resource	Level, quality	High	Moderate	High
• Groundwater dependent wetlands of basalt plains of Western Victoria	Water resource, agriculture, forestry	Level, quality	Moderate	High	Moderate
• Damplands of Swan Coastal Plain	Water resource, urban & commercial	Level, quality	High	High	Moderate

Ecosystem	Threat to ecosystem		Vulnerability	Risk	Value
	Process	Groundwater attribute	*Impact if threat realised*	*Likelihood of threat being realised*	Conservation value of ecosystem
Proportionally dependent ecosystems					
• Permanent coastal lake, dune and beachridge plain ecosystems of coastal NSW and coastal sand islands of NSW and Qld.	Urban & commercial, water resource, acid sulphate soils	Level, quality	High	High	Moderate
• Phragmites and Typha communities of permanently flooded swamps and lakes of inland areas of the south-eastern uplands,	Water resource, agriculture	Level, quality	High	High	Moderate
• Permanent base flow dependent swamps and river pools of Kangaroo Island	Water resource, agriculture	Level, quality, Flux	Moderate	High	Moderate
• Riparian swampland communities of Mount Lofty Ranges	Water resource, agriculture	Level, quality	Moderate	High	Moderate
• Swan Coastal Plain damplands and sumplands with paperbark and Banksia woodlands	Water resources, urban & commercial	Level, quality	High	High	Moderate
• Coastal swamp scrub sedgeland communities in the near-coastal dune systems of the Upper South East of South Australia	Agriculture	Level	High	Moderate	Moderate
Ecosystems with opportunistic groundwater dependence					
• Ecosystems of the Coorong	Agriculture, water resources	Level, quality	Moderate	High	High
• Ecosystems of permanent lakes and swamps at termini of inland rivers in the Central Lowlands and South Australian Ranges	Agriculture, water resource	Level	High	Moderate	Moderate
• Major ocean embayments such as Port Phillip Bay	Agriculture, urban & commercial, acid sulphate soils	Flux, level, quality	Moderate	High	Moderate

Sinclair Knight Merz, *Environmental Water Requirements of Groundwater Dependent Ecosystems* (2001), Environmental Flows Initiative Technical Report Number 2, Commonwealth of Australia, Canberra.

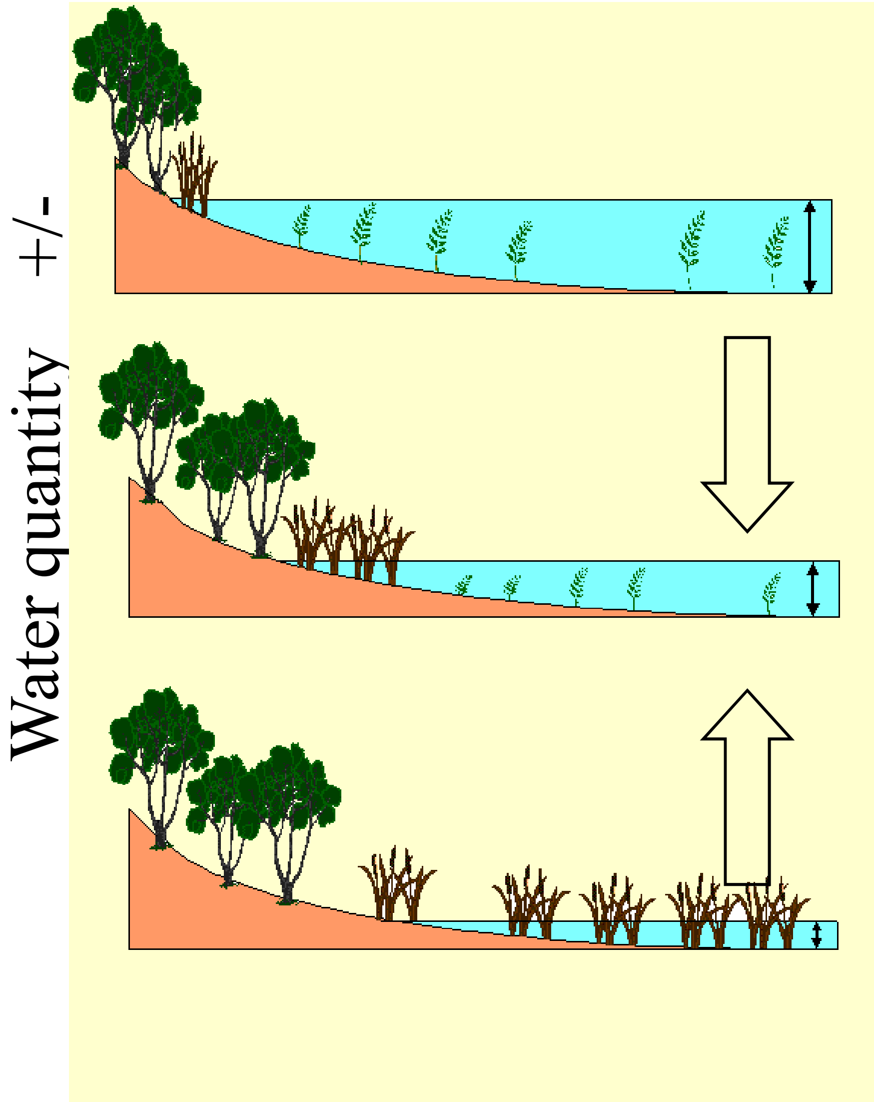




Response to Reduced Water Availability

Wetland and Terrestrial Vegetation Communities

Wetland vegetation response to change in water regime

Process of vegetation encroachment/ restriction similar in all wetland types

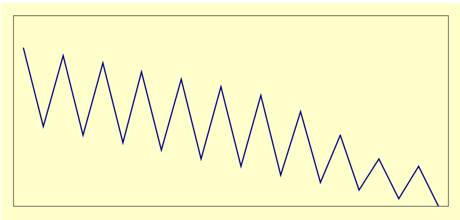


Factors which alter the character of vegetation encroachment/restriction:

- seasonality of inflow events
- episodicity of inflow events
- water quality (nutrients/salinity)
- composition of wetland vegetation
- proximity of source/resident populations of invasive species
- disturbance events (type, frequency)

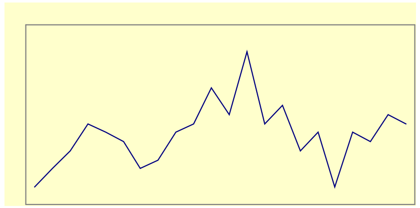
(complements Ray Froend)

Decreasing water regime



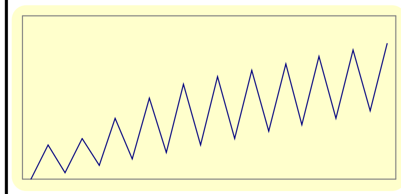
- Increase in exposed sediment
- Potential for acidification?
- increase in habitat for emergents
- increase in habitat for fringing woody species
- encroachment of vegetation (terrestrialisation)
- decrease in aquatic veg diversity

Fluctuating water regime



- Dynamic within predictable range in distribution and composition along water regime gradient
- highest species diversity
- absent or static populations of invasive species

Increasing water regime



- Reduction in habitat for emergent/fringing species
- Fringing vegetation death
- increase in habitat for submerged species (threshold depends on light climate and nutrients)
- decrease in diversity
- significant reduction in populations extent

(modified after Froend)

Vegetation EWR – Water Depth

The following represents the water depth ranges of the most common/dominant species at Gnangara wetlands;

- *M. rhaphiophylla* – mean 0.006 to -2.14 m, absolute 1.03 to -4.49 m.
- *M. preissiana* – mean -0.54 to -2.62 m; absolute 1.03 to -5.04 m.
- *E. rudis* – mean -0.7 to -3.26 m, absolute 1.03 to -6.44 m.
- *B. littoralis* – mean -0.39 to -1.92 m, absolute 0.43 to -3.09 m.
- *B. articulata* – mean 0.28 to -1.22 m, absolute 0.81 to -2.59 m.
- *T. orientalis* – mean 0.74 to -0.95 m, absolute 1.49 to -1.9 m.
- *A. fascicularis* – mean -0.35 to -2.26 m, absolute 1.03 to -4.6 m.

Dr. R. Froend, R. Loomes, Dr. P. Horwitz, M. Bertuch, Dr. A. Storey and M. Bamford, 2004, Study of Ecological Water Requirements on the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act - Task 2: Determination of Ecological Water Requirements. Centre for Ecosystem Management, ECU, Joondalup

Vegetation EWR – Inundation

- Duration of inundation (mean months/year) for the same set of species is as follows;
- *M. rhaphiophylla* – mean 2.15, absolute 9.4 (months/year).
- *M. preissiana*– mean 0.6, absolute 4.4 (months/year).
- *E. rudis* – mean 1.55, absolute 12 (months/year).
- *B. littoralis* – mean 0.3, absolute 2.8 (months/year).
- *B. articulata* – mean 3.26, absolute 12 (months/year).
- *T. orientalis* – mean 7.7, absolute 12 (months/year).
- *A. fascicularis* – mean 0.66, absolute 2.6 (months/year).

Dr. R. Froend, R. Loomes, Dr. P. Horwitz, M. Bertuch, Dr. A. Storey and M. Bamford, 2004, Study of Ecological Water Requirements on the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act - Task 2: Determination of Ecological Water Requirements. Centre for Ecosystem Management, ECU, Joondalup

Groundwater Depth and Results of Water Level Change

Table 2: Risk of impact level and magnitude of permissible change (m) for phreatophtyic vegetation.

Phreatophytic category	Low	Moderate	High	Severe
0-3m (wetland)	0-0.25	0.25-0.5	0.5-0.75	>0.75
0-3m (terrestrial)	0-0.75	0.75-1.25	1.25-1.75	>1.75
3-6m	0-1.0	1.0-1.5	1.5-2.25	>2.25
6-10m	0-1.25	1.25-2.0	2.0-2.75	>2.75

Table 3: Risk of impact level and rate of permissible change (m/year) for phreatophytic vegetation.

Phreatophytic category	Low	Moderate	High	Severe
0-3m (wetland)	0-0.1	0.1-0.2	0.2-0.3	>0.3
0-3m (terrestrial)	0-0.1	0.1-0.25	0.25-0.5	>0.5
3-6m	0-0.1	0.1-0.25	0.25-0.5	>0.5
6-10m	0-0.1	0.1-0.25	0.25-0.5	>0.5

Dr. R. Froend, R. Loomes, Dr. P. Horwitz, M. Bertuch, Dr. A. Storey and M. Bamford, 2004, Study of Ecological Water Requirements on the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act - Task 2: Determination of Ecological Water Requirements. Centre for Ecosystem Management, ECU, Joondalup

If Rooting Depth > DTW E=GDE

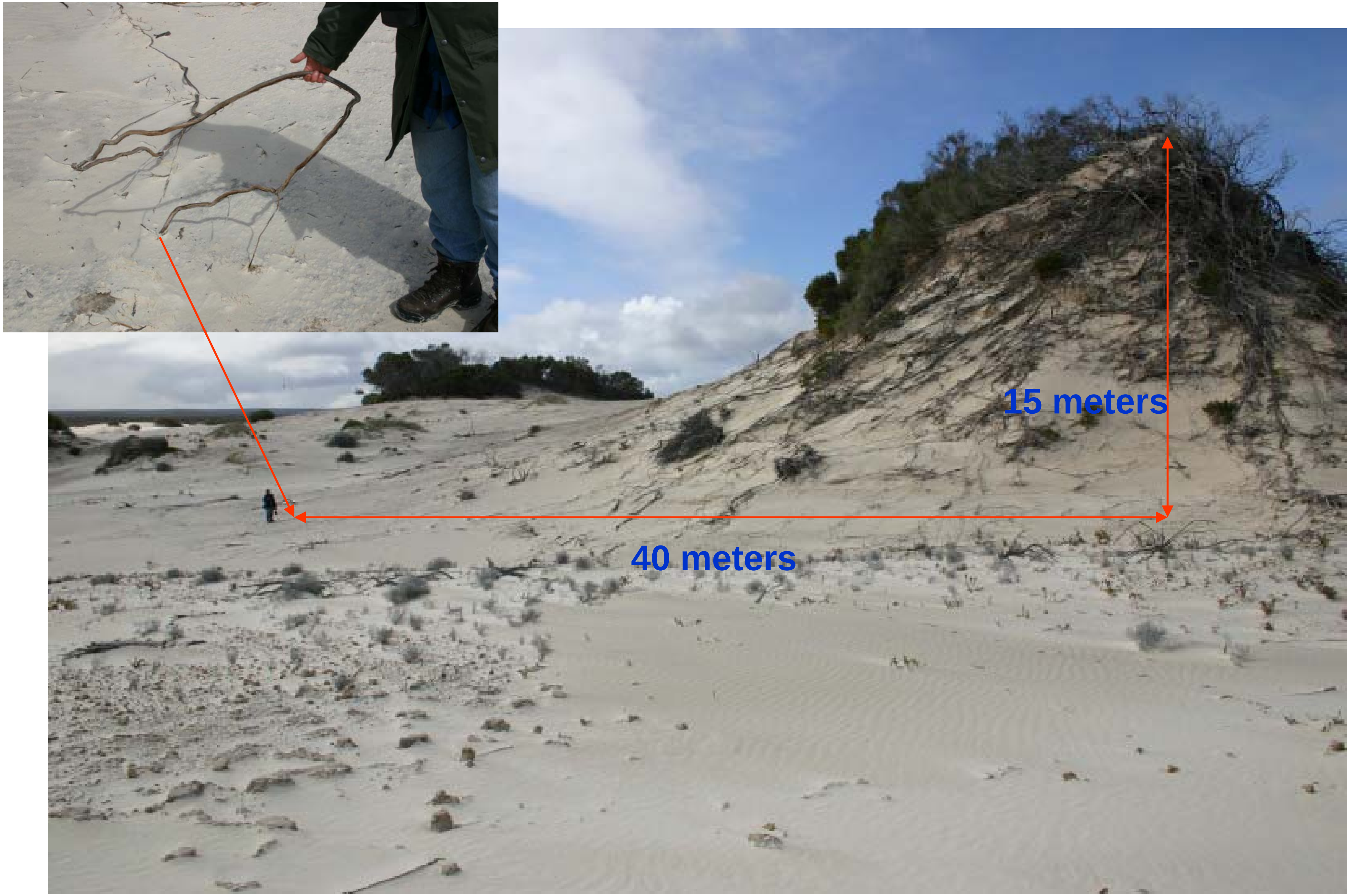
- The depth at which plants are able to grow roots has important implications for the whole ecosystem hydrological balance, as well as for carbon and nutrient cycling.
- Maximum rooting depth ranged from 0.3 m for some tundra species to 68 m for *Boscia albitrunca* in the central Kalahari;
- The average for the globe was 4.6±0.5 m.
- Maximum rooting depth by biome was
  - 2.0±0.3 m for boreal forest.
  - 2.1±0.2 m for cropland,
  - 9.5±2.4 m for desert,
  - 5.2±0.8 m for sclerophyllous shrubland and forest,
  - 3.9±0.4 m for temperate coniferous forest,
  - 2.9±0.2 m for temperate deciduous forest,
  - 2.6±0.2 m for temperate grassland,
  - 3.7±0.5 m for tropical deciduous forest,
  - 7.3±2.8 m for tropical evergreen forest,
  - 15.0±5.4 m for tropical grassland/savanna,
  - and 0.5±0.1 m for tundra.

Maximum rooting depth of vegetation types at the global scale
J. Canadell *et al, 1996, Oecologia Volume 108, Number 4 / December*

Rooting Depth Summary

- Grouping all the species across biomes (except croplands) by three basic functional groups: trees, shrubs, and herbaceous plants,
- the maximum rooting depth was
  - 7.0±1.2 m for trees,
  - 5.1±0.8 m for shrubs, and
  - 2.6±0.1 m for herbaceous plants.
- In WA Banksias ~8m (Gnangara Mound)
- Jarrah ~30m (Cave root mats)

Maximum rooting depth of vegetation types at the global scale
J. Canadell *et al, 1996, Oecologia Volume 108, Number 4 / December*



Extent of live roots of *Eucalyptus diversifolia* in eroded coastal dunes near Eyre WA

Vegetation communities in the Gairdner River area

Increased salinity and waterlogging is associated with a decline in community structure and diversity, and a failure to maintain existing recruitment strategies. This study should be seen as a precursor for similar studies to examine other salinity and waterlogging gradients related to applicable vegetation communities.

Classified vegetation into 3 communities:

1. SAMPHIRE FLATS – samphires represented 10-40% of species richness, trees <20% and emergents <30%.
2. SHRUBLAND – samphires 20-60%, trees 10-30%, emergents 10-50%.
3. WOODLAND – samphires<20%, trees 10-80%, emergents >20%.

Carey, M. 2003. The Effect of Hydrological Change on Plant Communities Associated with Flat-Topped Yate and the Implications for Management of Saline Landscapes. (Murdoch Uni.)

EWR's of Vegetation communities in the Gairdner River area

	Groundwater Depth	Groundwater Salinity	Best health indicators
SAMPHIRE FLAT	<0.5m most suitable. Depth never fell below 0.8m in this area. Health high when g/w <1m for 90% of time.	>80dS/m	G/w salinity in summer. Elevation above drainage line.
SHRUBLAND	0.5 – 1m. Depth should be <1m for >70% of time. Health declined when depth <0.5m for any given period of time.	60-80dS/m most suitable. However ranged from 30-110dS/m.	pH at 0.5m depth. Min. summer g/w depth.
WOODLAND	1.5 – 2.5m, most suitable. Not found in areas where g/w depth <1m. Health decreased as time g/w levels remained <1m from surface. Health best when g/w depth >1m for >93% of time.	<60dS/m most suitable. Never found in areas over 80dS/m.	G/w depth fluctuations during summer. Soil salinity at 5m.
GENERALLY		Health declined when g/w salinity exceeded 50dS/m. Only 20% of original veg'n remained when g/w salinity exceeded 110dS/m.	Time period g/w was less than 1m.

Carey, M. 2003. The Effect of Hydrological Change on Plant Communities Associated with Flat-Topped Yate and the Implications for Management of Saline Landscapes. (Murdoch Uni.)

Wetland Vegetation – Salinity and waterlogging tolerances by species

SPECIES	SALINITY	WATERLOGGING
M. cuticularis	ECe 800-1600mS/m (12) EM 38 >150mS/m (6[1]) Lake salinity >100 000mg/L (30[3])	High (27). 2 years inundated max. before growth effected. 6 years inundation leads to 50% deaths (5[2/3]). G/w depth of 0.5 – 2.5m (26[3])
M. brevifolia	ECe 400-800mS/m (12,27) Most sensitive to change (26[3])	Moderate (27) Most sensitive to change (26[3])
E. occidentalis	ECe 800-2500mS/m (24[2]). Good survival at ECe 1800 mS/m in 30-90cm soil depth (10[3]). Root zone soil salinity at max. ~10dS/m will cause negative effect (7[3]). EM 38 of <200mS/m (6[1]). <60dS/m for g/w salinity (26[3]). Lake salinity <50 000mg/L (30[3])	High (24[2]). G/w depth of 1 – 2.5m (26[3]). 2 years inundated max. before growth effected. 6 years inundation leads to 50% deaths (5[2/3]).
S. quinqueflora	ECe 1600+ mS/m (2[2]). Don't exceed g/w salinity of 100 dS/m (26[3]). ECe >16 dS/m (13[3]).	Found in littoral/supralittoral zone (15[3]) Ideal g/w depth of 0.3 – 0.5 m (26[3])
H. pergranulata	ECe >16 dS/m (13[3],1[1],17, 20, 23) Tolerate EC 1:5 400dS/m in summer (14[3]). Don't exceed g/w salinity of 100 dS/m (26[3]).	Found in littoral/supralittoral zone (15[3]) Will tolerate high waterlogging, not sure for how long (14[3]) Ideal g/w depth of 0.3 – 0.5 m (26[3])
H. lepidosperma	Found in brackish to hypersaline (15[3]). Don't exceed g/w salinity of 100 dS/m (26[3]). ECe >16 dS/m (1[1],17, 20, 23)	Found in littoral/supralittoral zone (15[3]) Ideal g/w depth of 0.3 – 0.5 m (26[3])

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Notes for previous

DEGREE OF RELIABILITY OF REFERENCES

1 A suggestion. No reasonable research demonstrated.

2 A number of measurements, but not over a range of areas. Or the author is of reputable Expertise with much experience.

3 Reasonably extensive research; numerous plots surveyed over a given district and numerous samples taken.

4 Conclusive results given through extensive research.

Plants, Macronutrients and Metals

- Plants are composed of water and complex organic molecules synthesised from water, nutrients, CO_2 from air and energy from the sun.
- Elements can be grouped as;
  - macronutrients - N, P, K, S, Ca and Mg (Note that C, O and H are required also but occur in excess)
  - essential micronutrients - Fe, Cu, Mn, Zn, Co, Mo, Ni, V, Na, Rb, B, Se
  - elements with beneficial or restricted essentiality - Al, Sn, Cr, Sr, As, Ag, Cd and Pb may be required at low levels but are toxic in higher concentrations
- However inadequate or excessive concentrations of the above may produce toxic reactions in plants (i.e. condition decline and/or mortality).
- The dynamics of this is dependant on the particular species and particular metal.
- Processes which create metal contamination (spills and acid sulphate oxidation for example) may therefore create metal excesses causing plant degradation.

Kraus H, 1994, Plants and the Chemical Elements: VCH Publishers

Essential Micronutrients

- Boron is believed to be involved in carbohydrate transport in plants; it also assists in metabolic regulation. Boron deficiency will often result in bud dieback.
- Chlorine is necessary for osmosis and ionic balance; it also plays a role in photosynthesis.
- Cobalt is essential to plant health. Cobalt is thought to be an important catalyst in nitrogen fixation. It may need to be added to some soils before seeding legumes.
- Copper is a component of some enzymes and of vitamin A. Symptoms of copper deficiency include browning of leaf tips and chlorosis.
- Iron is essential for chlorophyll synthesis, which is why an iron deficiency results in chlorosis.
- Manganese activates some important enzymes involved in chlorophyll formation. Manganese deficient plants will develop chlorosis between the veins of its leaves. The availability of manganese is partially dependent on soil pH.
- Molybdenum is essential to plant health. Molybdenum is used by plants to reduce nitrates into usable forms. Some plants use it for nitrogen fixation, thus it may need to be added to some soils before seeding legumes.
- Zinc participates in chlorophyll formation, and also activates many enzymes. Symptoms of zinc deficiency include chlorosis and stunted growth.

Kraus H, 1994, Plants and the Chemical Elements: VCH Publishers

Compounded Threats

- The ability of plants to survive water logging or increased water salinity is compounded by other deleterious environmental pressures.
- For example, the time most plants can survive waterlogging is decreased if the water is saline (next slide).
- Similar relationships exist for acidity/alkalinity and metal deficiencies/excesses.

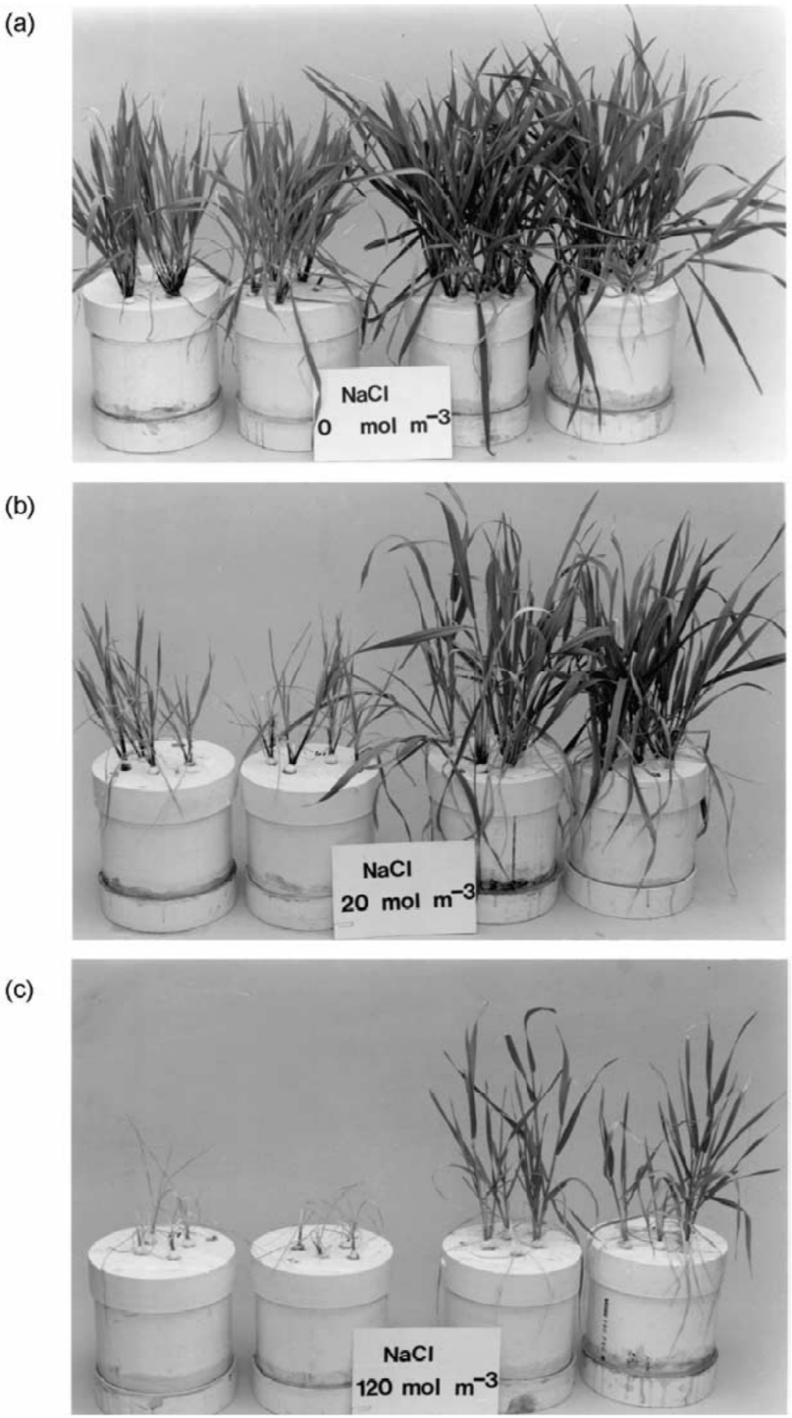


Figure 5. Hypoxia and salinity interact to decrease the growth of wheat plants (after Barrett-Lennard, 1986b). Pots on the left were hypoxic (N_2-bubbled for 33 days); pots on the right were aerated. (A) Zero salt in the solutions; (B) 20 mol m^{-3} NaCl in the solutions; (C) 120 mol m^{-3} NaCl in the solutions.

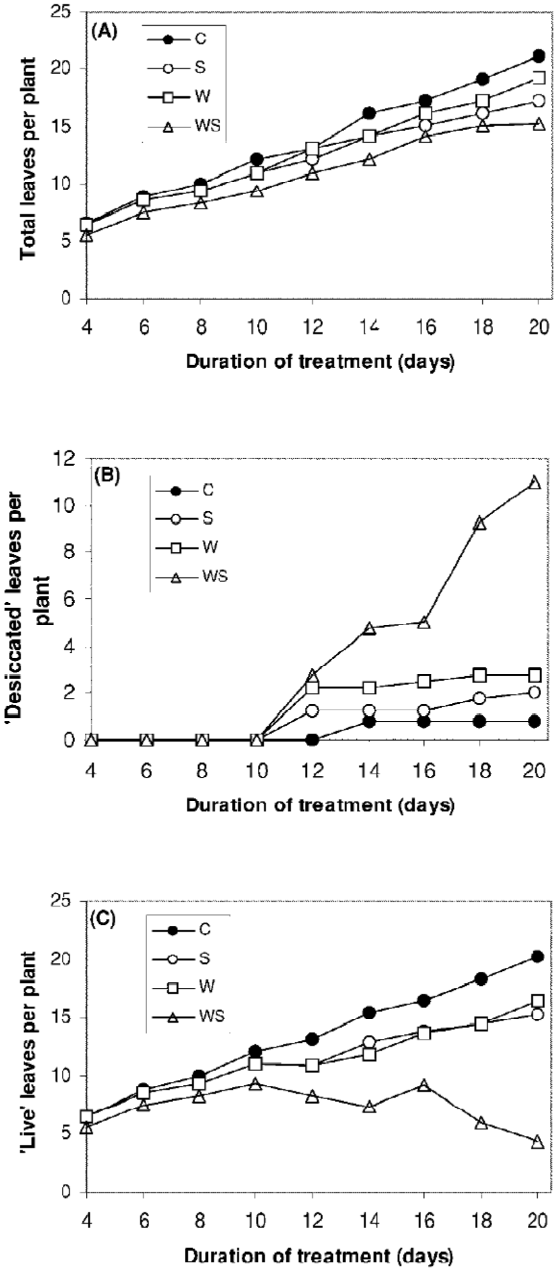
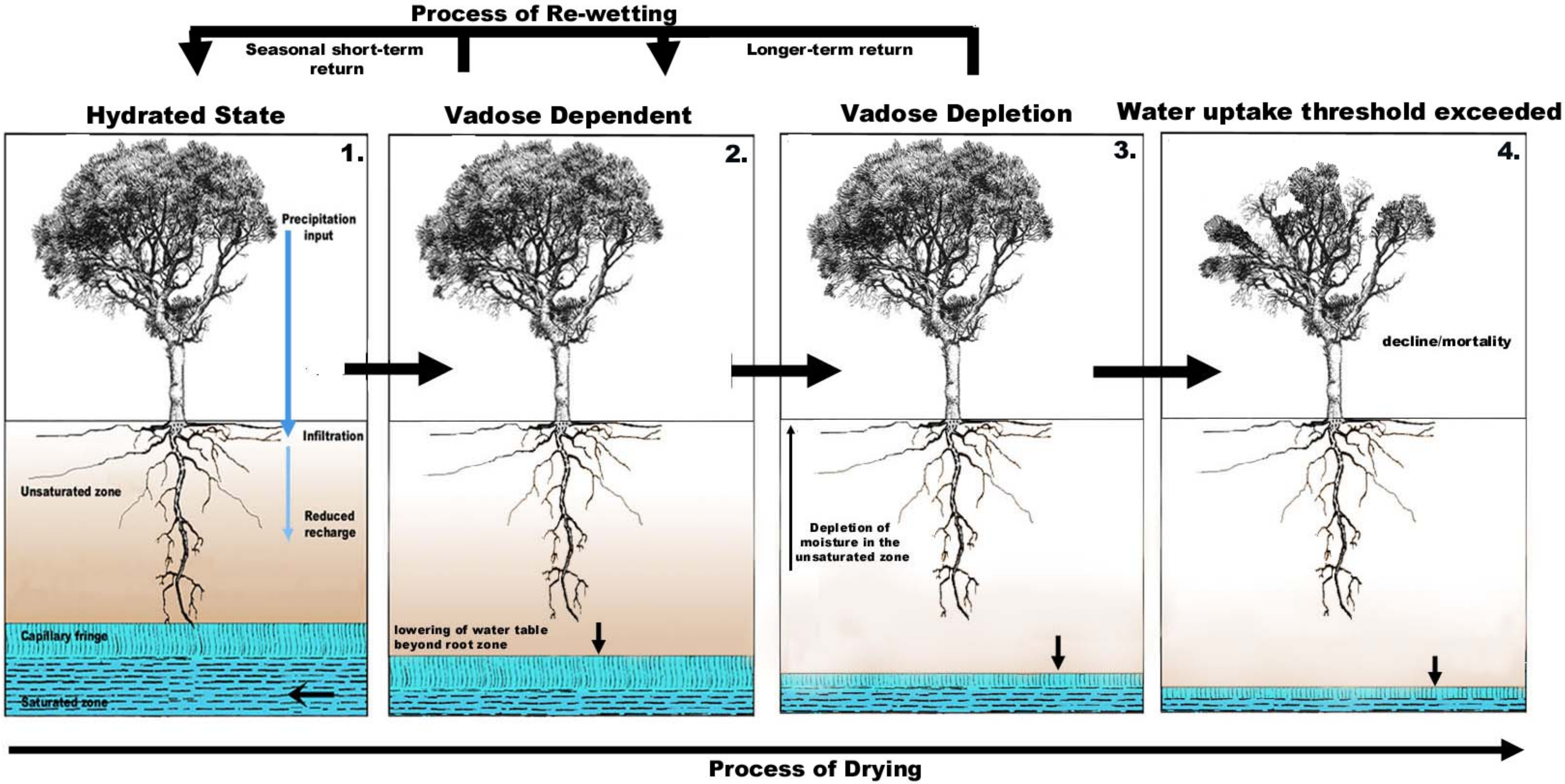


Figure 3. Impacts of waterlogging and salinity on *Cucurbita pepo*: (A) total leaf numbers, (B) numbers of 'desiccated' leaves, and (C) numbers of 'live' leaves (after Huang et al., 1995a,b). Plants were grown in irrigated sand cultures under glasshouse conditions. Waterlogging was applied on day 14 after emergence; the salinity treatment was gradually applied between days 14 and 16. Treatments are: C (drained, non-saline), S (drained, irrigated with 100 mol m^{-3} NaCl), W (waterlogged, non-saline), WS (waterlogged with 100 mol m^{-3} NaCl).

Drawdown Impacts on Water Availability and Phreatophyte Response

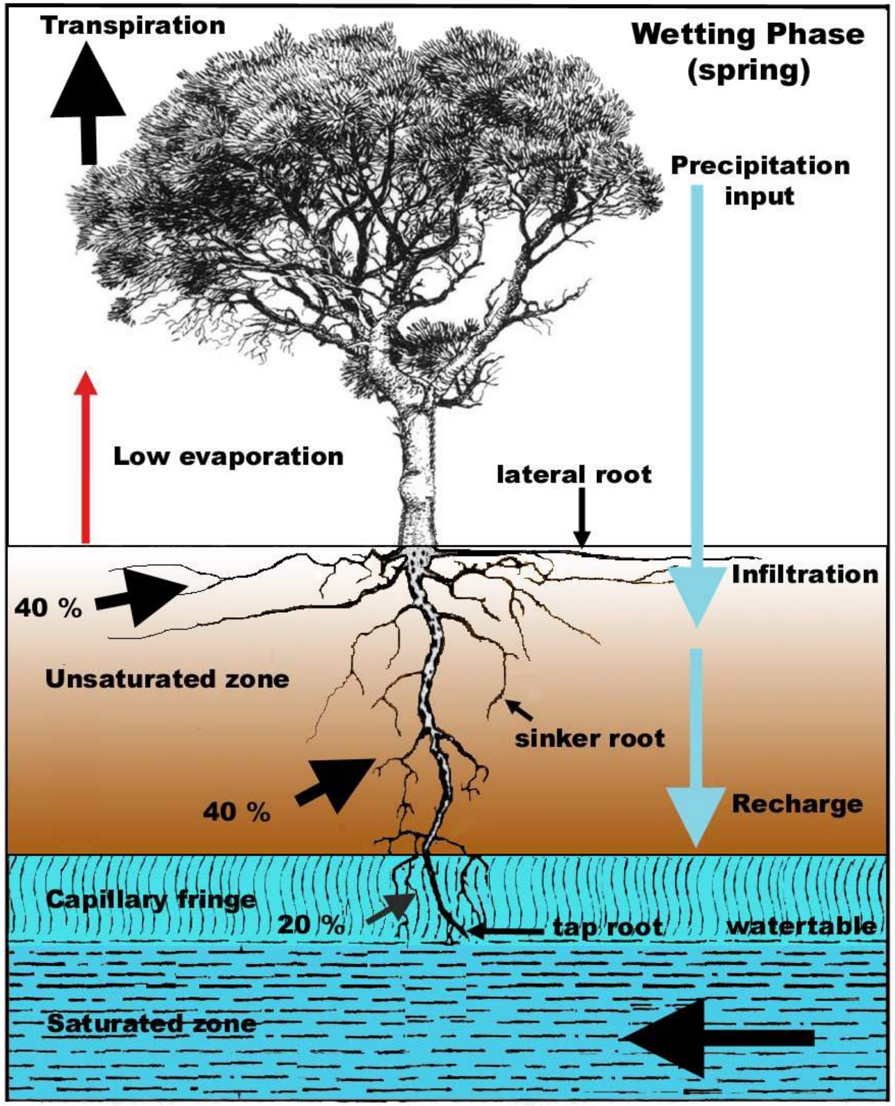


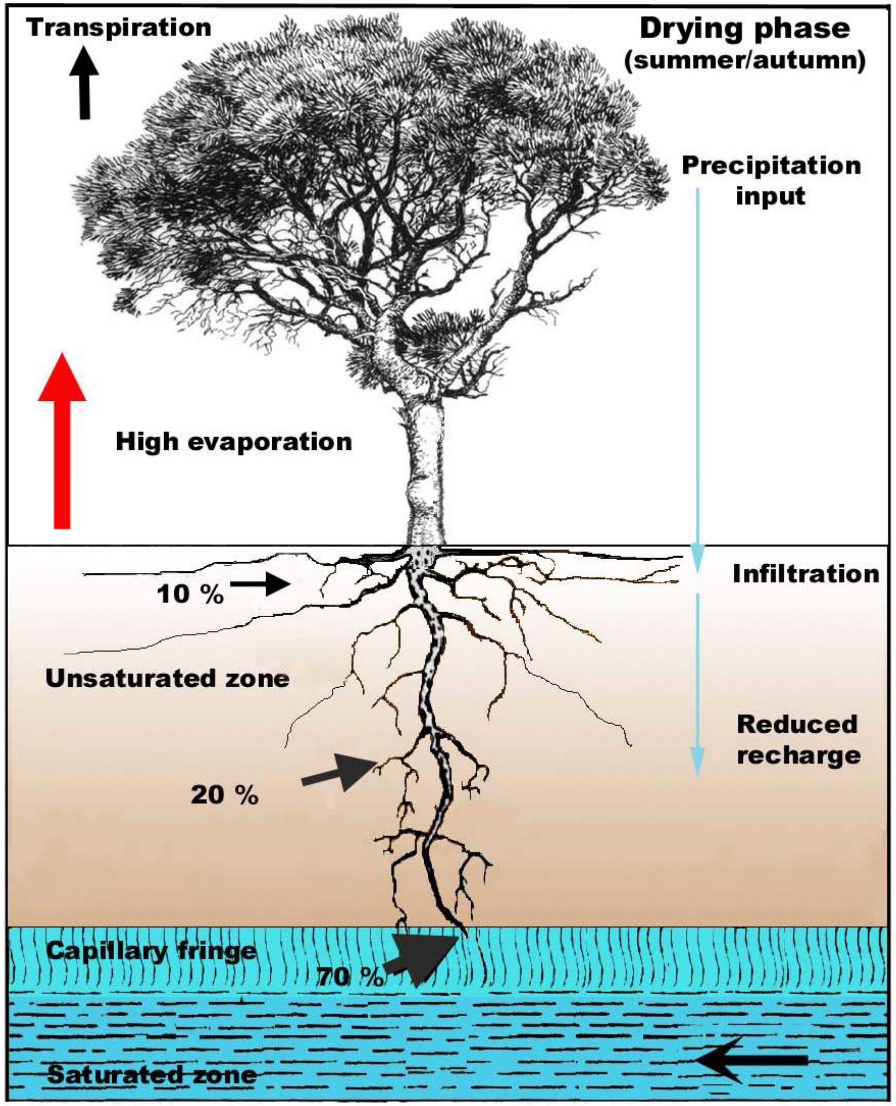
(complements Ray Froend)

Individual Scale

Seasonal variability in groundwater use

Heightened vulnerability during summer; strategic timing of abstraction



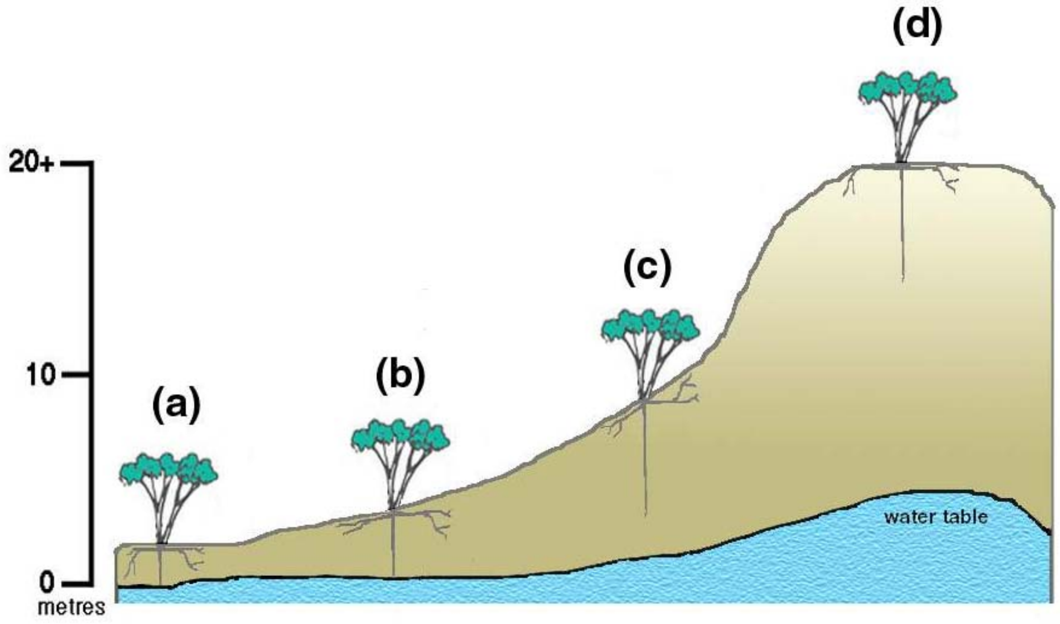


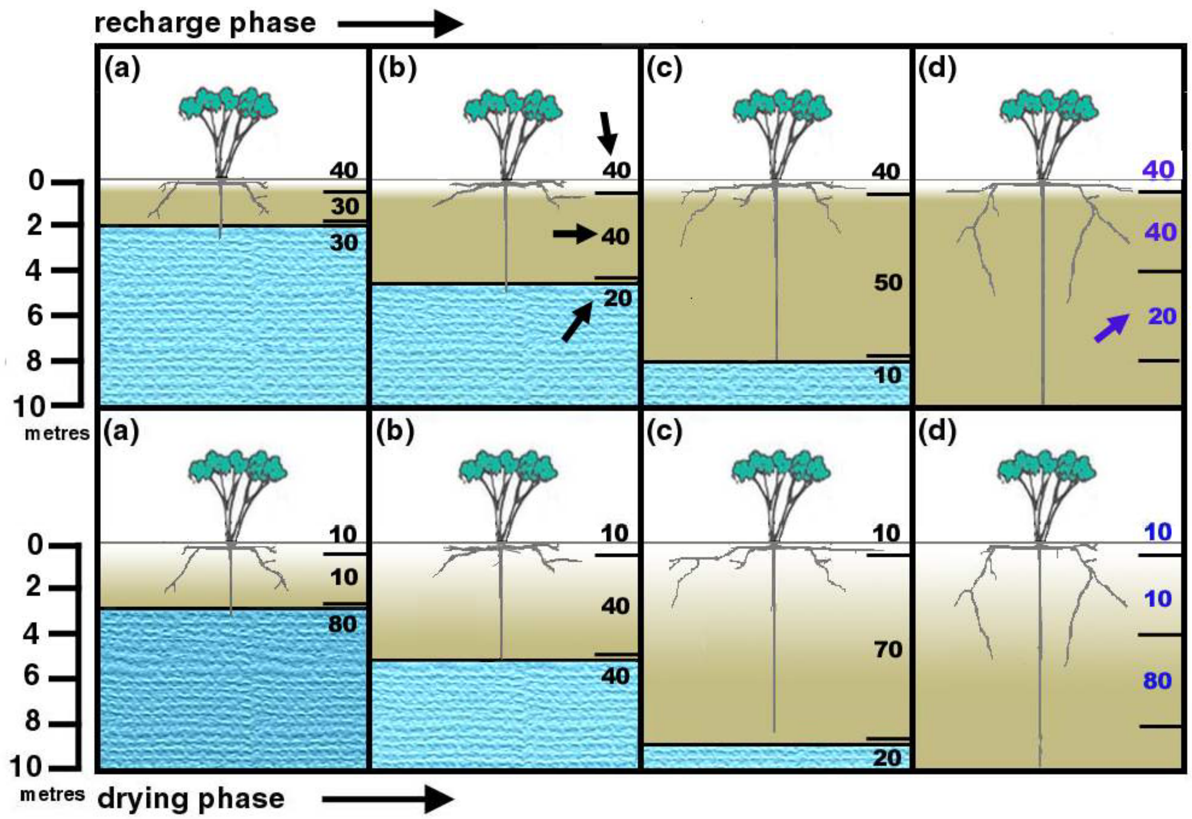
Population Scale

Spatial variability in groundwater use

Variation in vulnerability within population

Strategic placement of abstraction bores



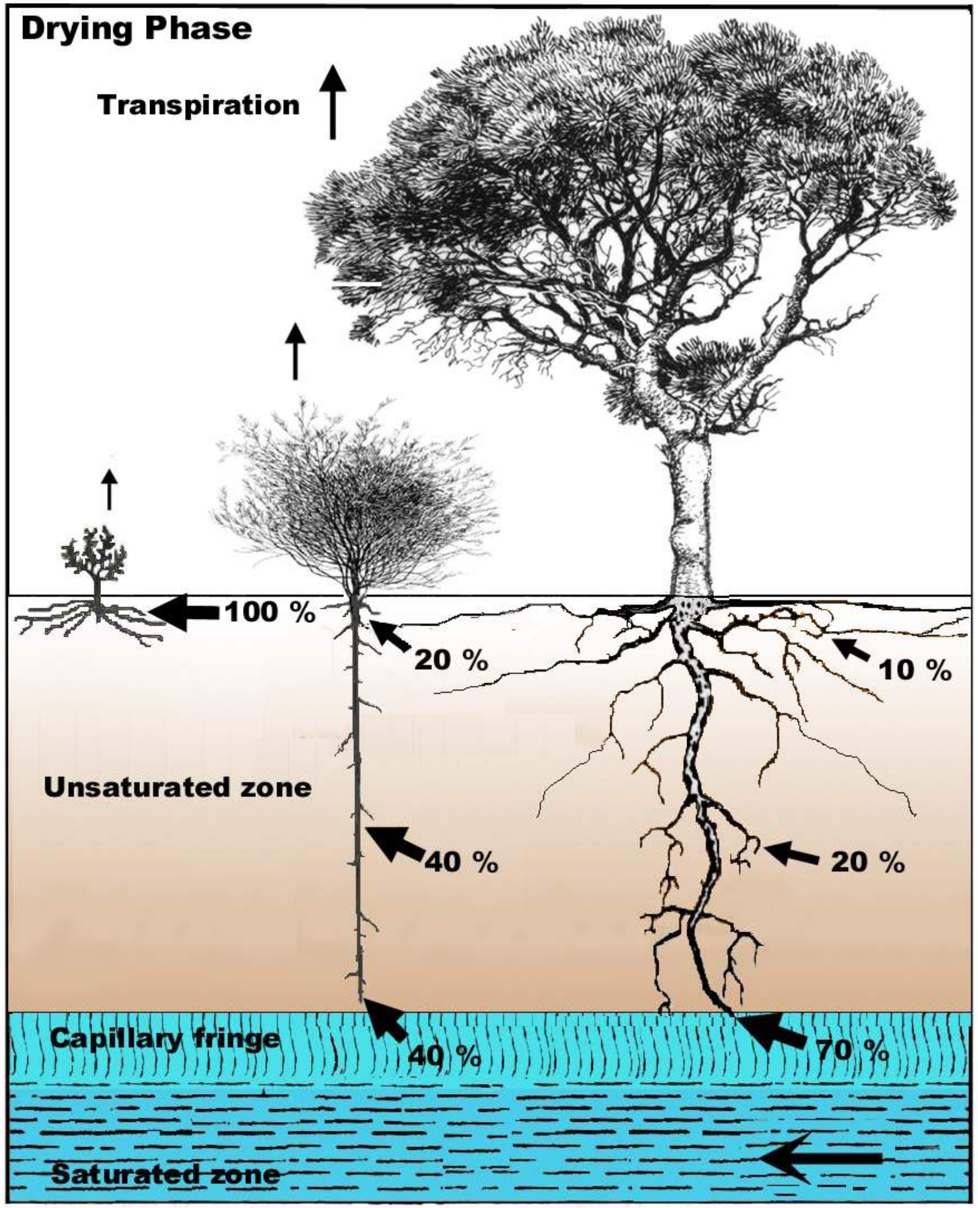


Community Scale

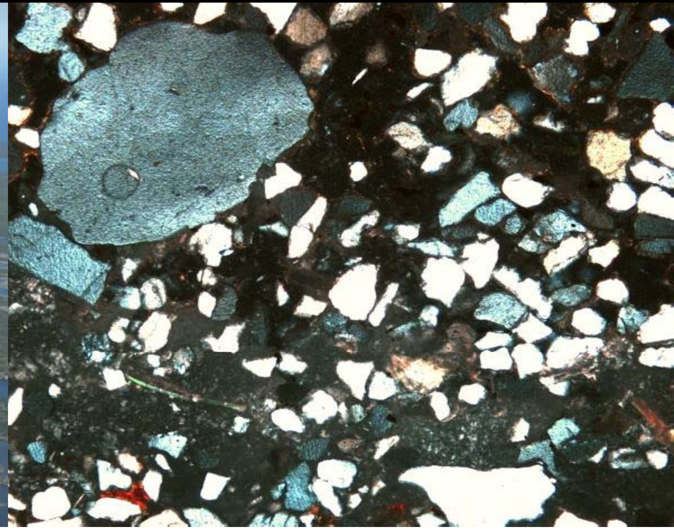
Interspecific differences in groundwater use

Variability in plant community response correlated with species composition

Strategic placement of abstraction bores



(complements Ray Froend)



Response to Reduced Water Availability and Reduced Water Quality

Macroinvertebrate Communities

What are Macroinvertebrates

- Macroinvertebrates are those invertebrates that can be seen without the aid of a microscope or magnifying glass.
- Aquatic macroinvertebrates are those that spend all or part of their life cycles in water. They include many insects, crustaceans, mites, molluscs and worms.
- The term ‘water bugs’ is often used as shorthand for aquatic macroinvertebrates. However, scientifically speaking the word ‘bug’ applies only to insects of the order Hemiptera (often called ‘true bugs’).
- Around the world, various groups of animals and plants are used in the assessment of aquatic ecosystem condition.

Chessman B, 2003, *SIGNAL 2 – A Scoring System for Macro-invertebrate (‘Water Bugs’) in Australian Rivers*, Monitoring River Heath Initiative Technical Report no 31, Commonwealth of Australia, Canberra.

Why Study Macroinvertebrates?

1. Macroinvertebrates are found in almost every water body, even rivers and ponds that dry from time to time.
2. Macroinvertebrates are easy to catch with simple hand nets and relatively easy to identify.
3. There are many different types of macroinvertebrates. Each type requires particular environmental conditions in order to survive, grow and reproduce. Some types are tolerant of water pollution whereas others are very sensitive. So biologists can tell a lot about the environmental conditions in a water body from the types of macroinvertebrates present and their abundances.
4. Some macroinvertebrates are mobile but many, such as mussels, are sedentary. A sedentary macroinvertebrate collected from a particular site on a river may have been living there for months or even years. For the sedentary macroinvertebrate to survive, conditions must have been suitable throughout this period. If a pulse of severe pollution flows through a site it many be many months before new animals colonise and the macroinvertebrate community recovers, even if water quality returns quickly to normal. So studying macroinvertebrates provides an indication of past conditions as well as present conditions. In contrast, a spot water quality measurement provides information only on conditions at the time of sampling.
5. Macroinvertebrates are a major component of biological diversity. About 99% of animal species are invertebrates. Understanding the effects of human activity on aquatic macroinvertebrates helps in finding ways to conserve them.
6. A healthy macroinvertebrate community is important to the normal functioning of a water body. Macroinvertebrates occupy a central position in the food webs of rivers and streams. Almost every type of organic matter is eaten by some macroinvertebrate or another; algae, water plants, dead leaves and wood are all food for some types of invertebrates. In turn, macroinvertebrates are eaten by one another and by most types of aquatic vertebrates including fish, frogs, turtles, birds, platypus and water rats.

Chessman B, 2003, *SIGNAL 2 – A Scoring System for Macro-invertebrate ('Water Bugs') in Australian Rivers*, Monitoring River Heath Initiative Technical Report no 31, Commonwealth of Australia, Canberra.

Effects of increased salinity

- Decreases in water quality (increased salinity or TDS) will impact on the species composition of macroinvertebrates
- pH and Acidity is more complex but some approximate relationships are possible
- Metals … ???

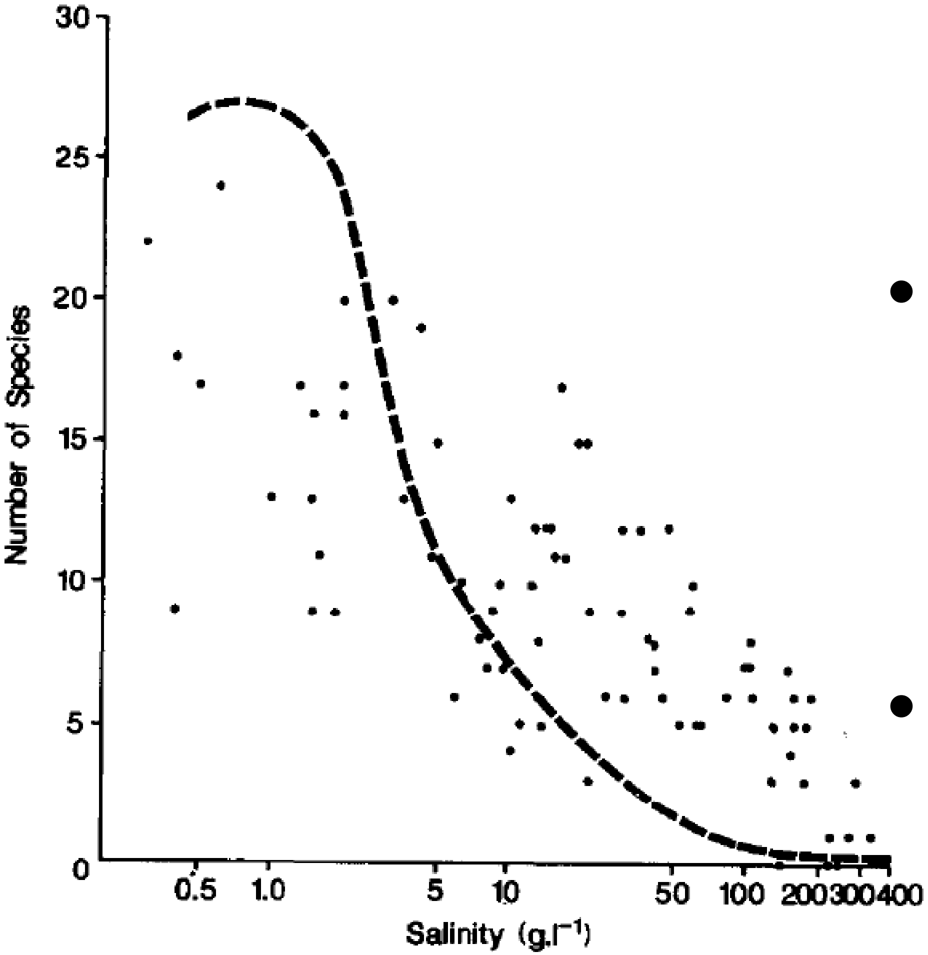


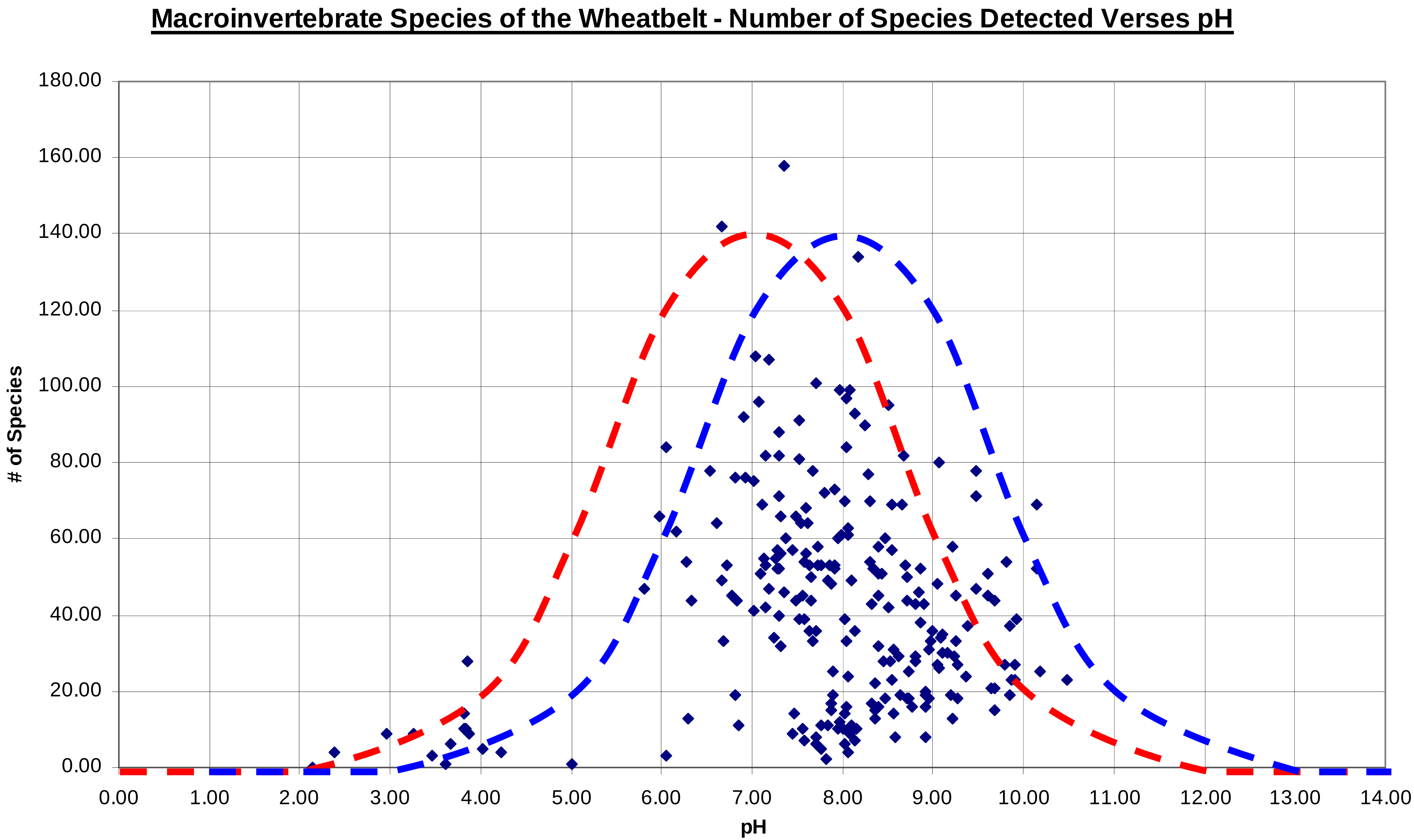
Fig. 2. Number of species : salinity in the 79 localities studied.

Hydrobiologia **197**: 257–266, 1990.
F. A. Comín and T. G. Northcote (eds), Saline Lakes.

Salinity as a determinant of salt lake fauna: a question of scale

W. D. Williams, A. J. Boulton & R. G. Taaffe
Department of Zoology, University of Adelaide, North Terrace, Adelaide, S.A. 5000, Australia

Macroinvertebrates verses pH



Macroinvertebrate EWR

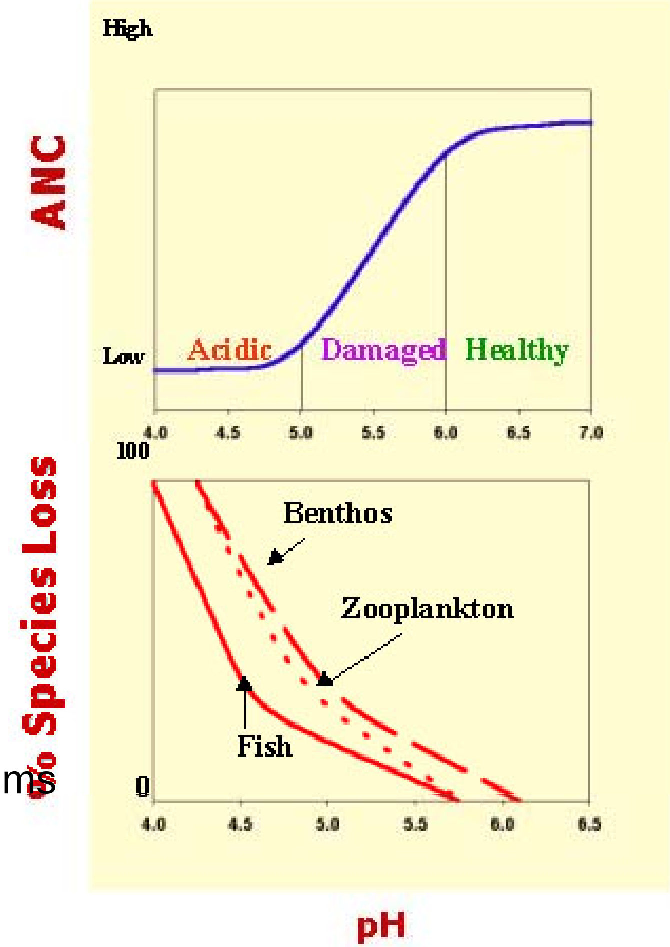
Tolerances for the following are required to determine the EWR;

- Hydroperiod requirements to maintain both ecological niche and breeding cycles (drought/flood)
- Unsuitable water quality based on upper and/or lower level tolerances of:
  - Salinity (or total dissolved solids)
  - Temperature
  - pH/Acidity/Alkalinity
  - Metal content
  - Nutrients
  - Dissolved Oxygen Levels
  - Herbicide / pesticide residues
  - and should include information applicable across the life cycle of the communities where possible, i.e. egg bank persistence requirements

Overall Salinity Thresholds for Aquatic Flora/Fauna

Salt risk thresholds followed by justification for threshold impacts considered in relation to change in number of days above each threshold and probable impacts.

- **2 000 mg/L**
  - Classified as High Brackish
  - Adverse effects to riparian and/or fringing vegetation
  - Sensitive freshwater plants limit
  - Limit of most freshwater micro invertebrates
- **4 000 mg/L**
  - Classified as Saline
  - Upper limit of most freshwater aquatic plants
  - Macro invertebrate species richness starts to decrease rapidly
- **10 000 mg/L**
  - Classified as Mid saline
  - Limit of majority of algae
  - Limit of most freshwater fish (reproduction)
  - Marron lethal at 17 000 mg/L
  - Limit of most macro invertebrate (substantial change)
  - The upper limit of many commonly occurring freshwater organisms
- **30 000 mg/L**
  - Classified as Highly Saline
  - Seawater 35 000 mg/L
  - Only 16/61 SW Water bird species prefer over 20 000 mg/L

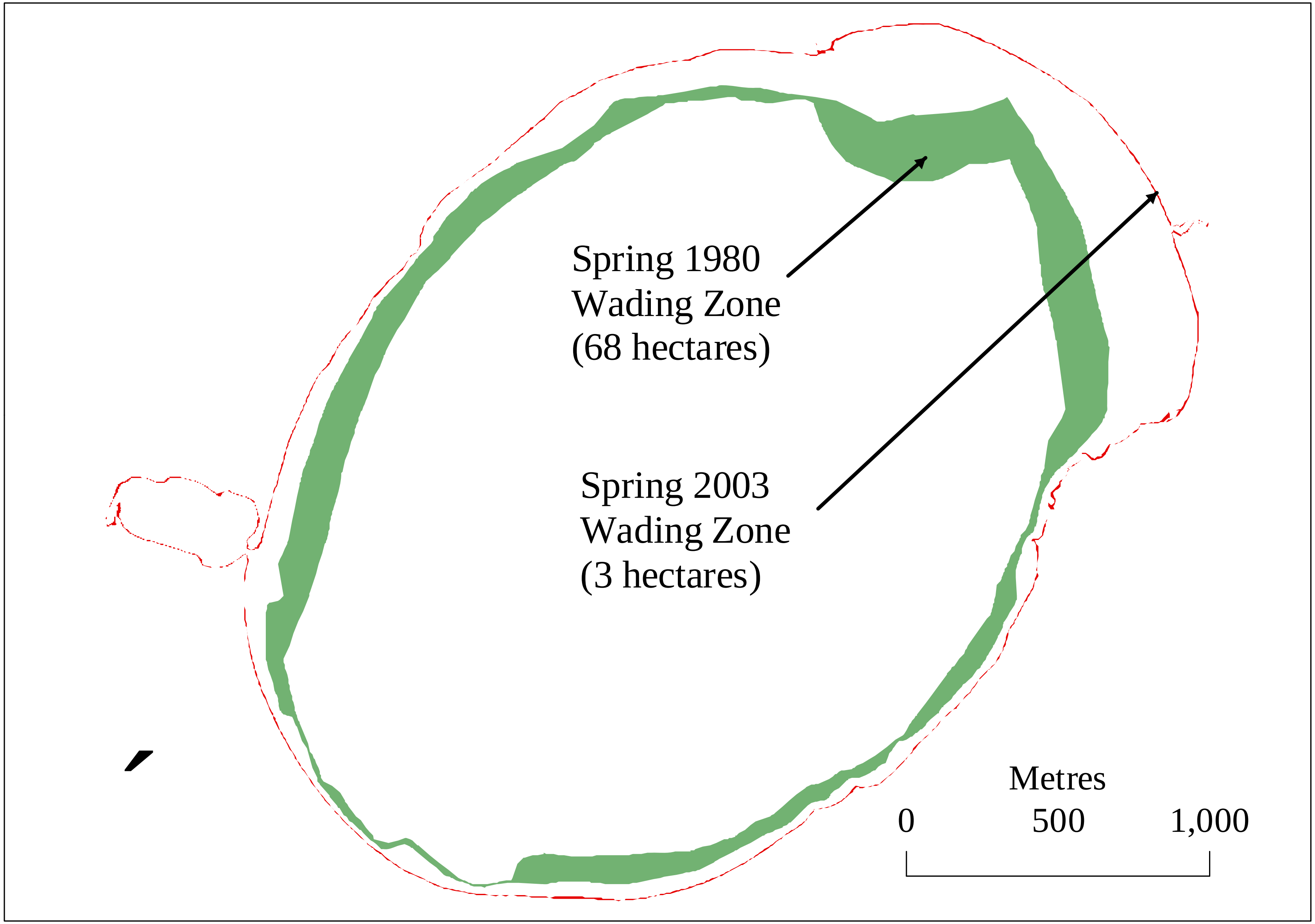


EWR's - Optimal Waterbird Habitat

- Lake Warden Wetland System
- Key Objective is to determine the water regime required to maintain water bird numbers.
- Water bird numbers have declined since land clearing has increased inflows and level of coast wetland suite.
- Determining Waterbird habitat from literature reviews (Massenbauer)
  - Exposed shore zone (Beach)
  - Wading zone (< 25 cm depth)
  - Shallow diving zone (25 – 50 cm depth)
  - Deep diving zone (> 50 cm depth)
- Projecting lake depth records onto the DEM, converting volumes and defining habitat areas.

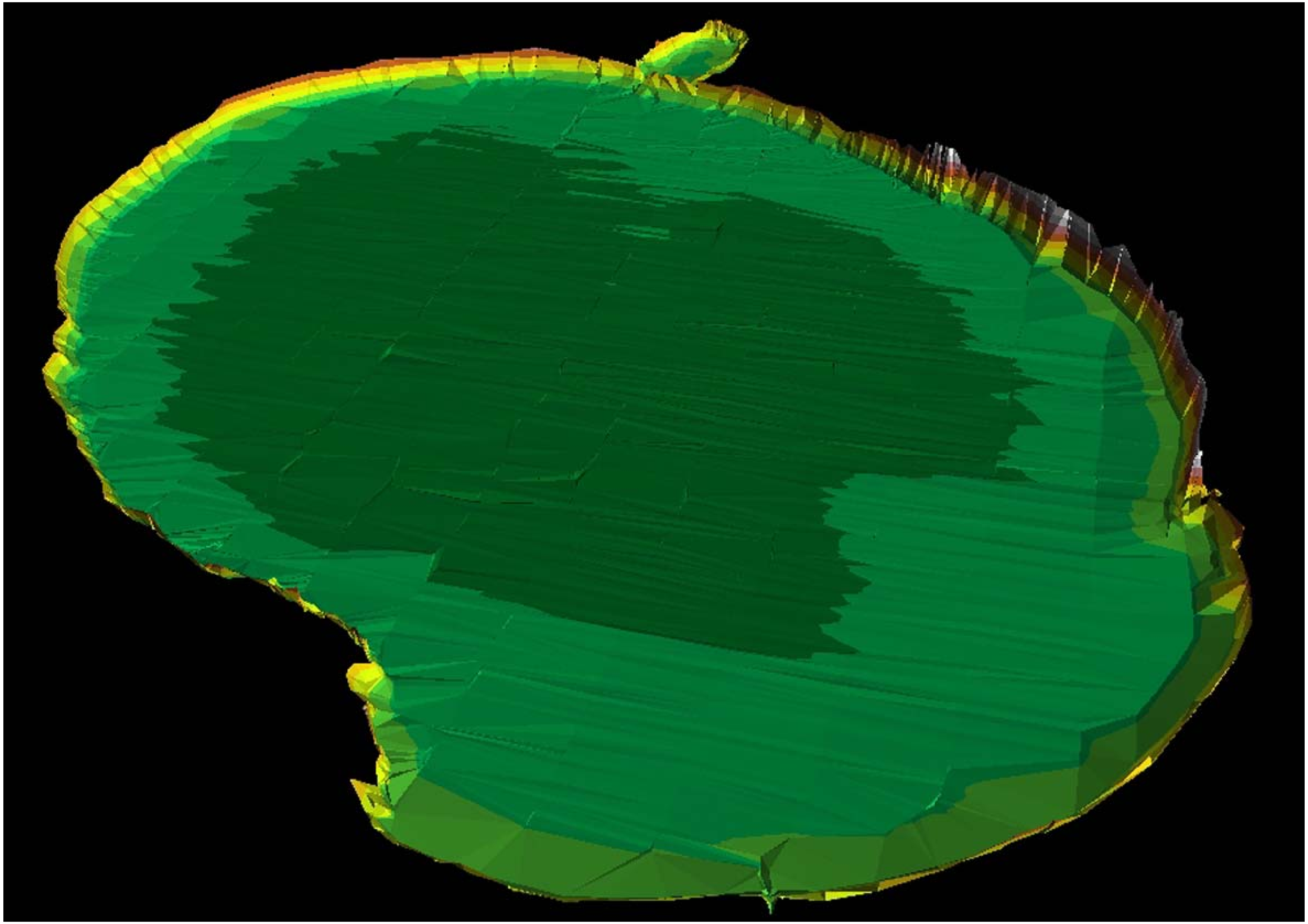
Lake Warden Waterbird Habitat Areas

Historic (early 1980's) Wading zones have decreased by 65 ha.



Compliments Tilo Massenbauer

3D Bathymetry Model – Lake Warden



Compliments Tilo Massenbauer

Quantitative Overall Wetlands EWR

Components	Attributes
Vegetation	Groundwater Depth
Waterbirds	Surface water depth
M/invertebrates	Duration of flooding
Other Fauna	Duration of drying
Sediment	Rate of drawdown
	Seasonality
	Long-team cycles
	Episodic events
	Landscape hydrology

Units:

Relative level

Weeks/months/years

Rates

- EWRs must be identified for each component
- Wetland vegetation: mean ecohydrological ranges for common species
- Macroinvertebrates: permanence and seasonal depth of surface water
- Waterbirds: permanence and seasonal depth of surface water
- Other vertebrates: qualitative categories of dependence.
- Sediment processes: possibly requires maintenance of moist organic sediments (<0.50) to prevent sulphate oxidation if substantial peat deposits or nutrient release
- Understand there is some degree of natural change

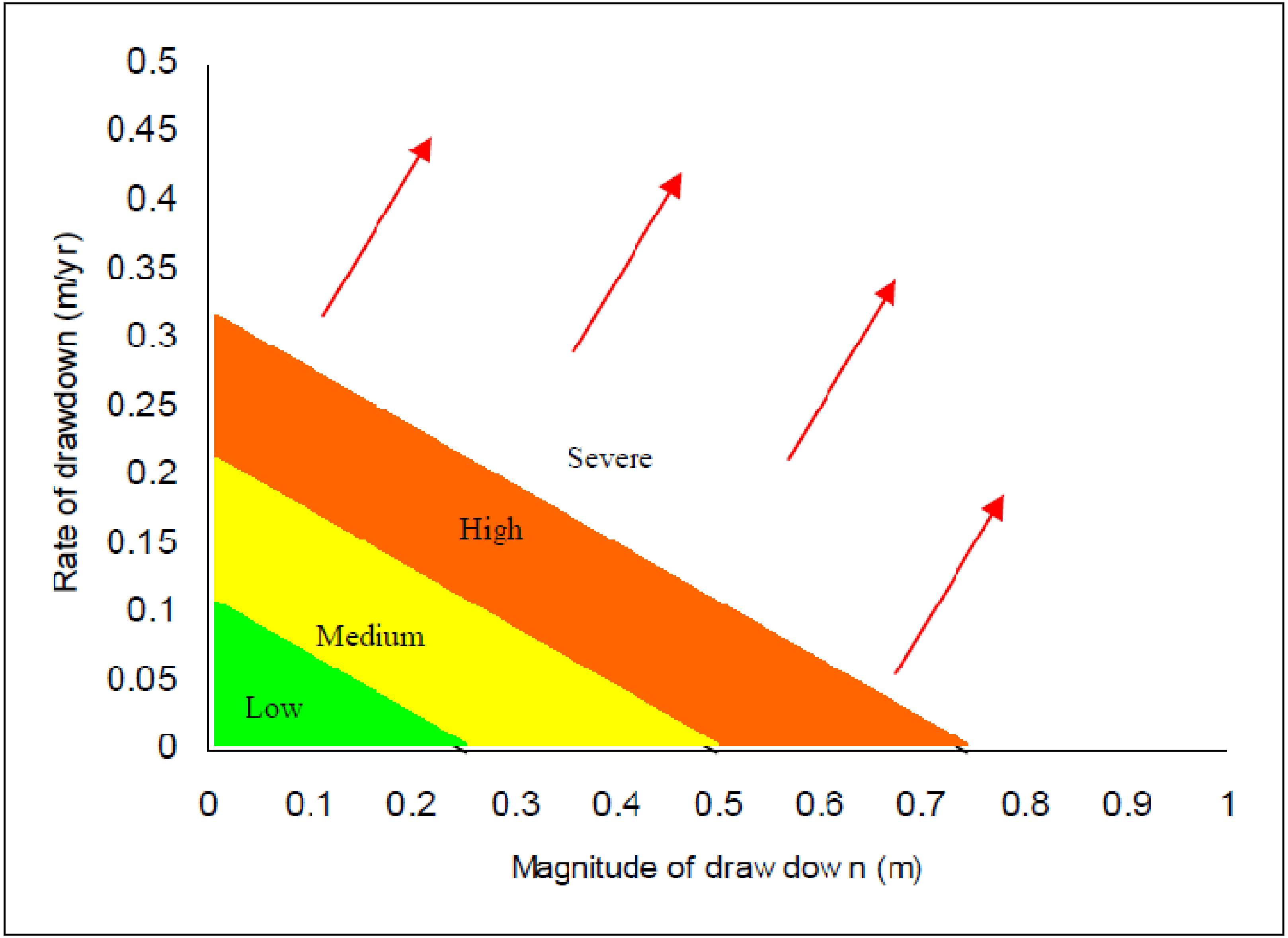


Figure 2: Risk of impact categories for wetland ecosystems based on rate and magnitude of groundwater drawdown.

Dr. R. Froend, R. Loomes, Dr. P. Horwitz, M. Bertuch, Dr. A. Storey and M. Bamford, 2004, Study of Ecological Water Requirements on the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act - Task 2: Determination of Ecological Water Requirements. Centre for Ecosystem Management, ECU, Joondalup

GDE's in the way of progress… why do we need them?

•***Intrinsic/spiritual/philosophical/amenity values.*** Biodiversity assets, such as GDE's contribute to our spiritual/philosophical beliefs that establish and explain the role of humans in the world/universe. The aesthetics of where we live is important too. Some of this fairly esoteric but go from living in Perth to East Los Angeles … then you might feel differently!

•***Opportunity values.*** The potential for future use of genetic resources. We don't know what's out there, we need to look before we lose it; new products, new medicines etc.

•***Knowledge and educational values.*** By striving to understand the environment we are striving to understand how our world works, this includes ourselves and our role in the ecology of the planet.

•***Leisure/recreational values.*** Recreational and tourism opportunities.

•***Productive use values.*** Plants and animals harvested for domestic use, but do not pass through a market and are not sold or purchased.

•***Consumptive use values.*** Plants and animals used commercially.

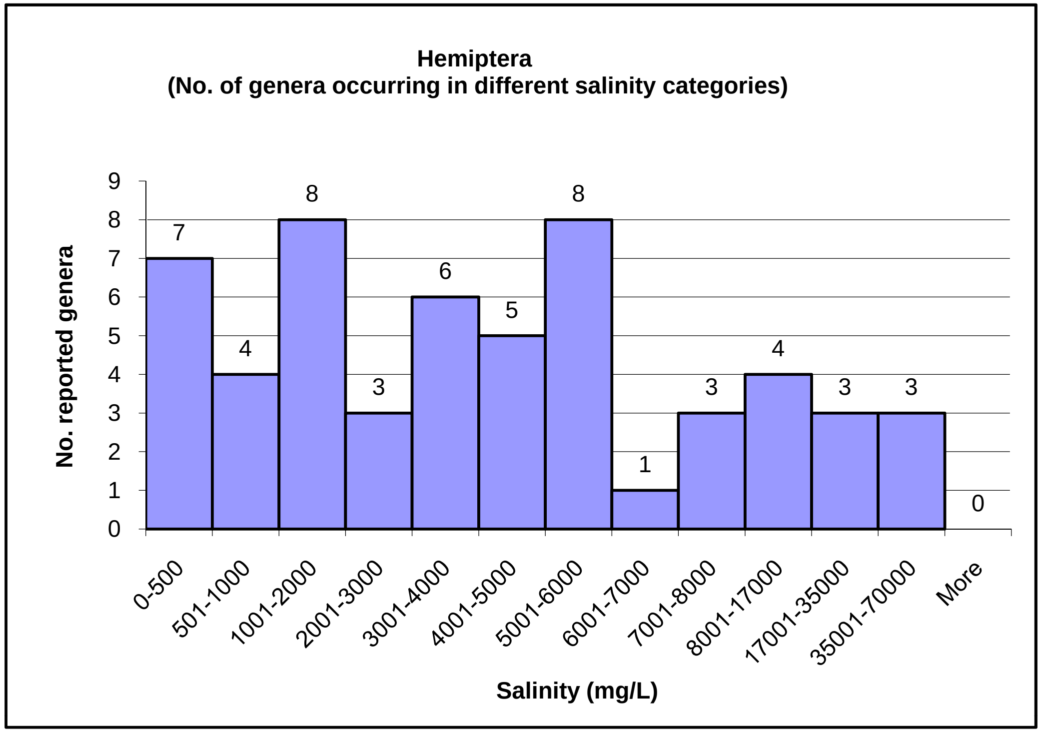
Wallace, (2003)

Limitations - Tolerances and Thresholds for the Biosphere … how much is too much!

- For both the deterministic and probabilistic methods we need to understand both biota tolerances and ecosystem changes (ecological regime shifts).
- We are starting to gather the sort of information required;
  - ECOtox (USA) tolerances.
  - Salt Sensitivity Database (MDB) tolerances.
  - CSIRO – Healthy Country Database (MDB) tolerances.
  - Resilience.org, ecological regime shifts.
  - WA specific data, some journal papers but large gaps.
- Ecosystem change. Collapse only occurs in the most severe of events, typically the ecology of an area switches to an alternative regime, eg Wheatbelt in areas of moderate secondary salinity, Gnangara Mound terrestrialisation of some wetlands, although this is usually slow under natural rates (climate variability etc).
- What you lose in rapid ecological regime shifts is diversity in the number of species and genetic diversity within species.

Salt Sensitivity Database

Salinity category (mg/L)	Genera
0-500	7
501-1000	4
1001-2000	8
2001-3000	3
3001-4000	6
4001-5000	5
5001-6000	8
6001-7000	1
7001-8000	3
8001-17000	4
17001-35000	3
35001-70000	3
More	0
Total	55



- Salt sensitivity database: User beware based on limited research and not comprehensive, Murray Darling focused.

- ANZEEC Water Quality Guidelines can also be helpful for getting VERY rough EWR’s from a water quality perspective.

Tolerances and Thresholds, Gaps and Requirements

There are gaps in our understanding of how WA biota and ecological regimes have/may shift because of our impacts. Some info is out there but we urgently need a detailed understanding of;

- Biota tolerances to water level and soil moisture changes.
- Biota tolerances to chemicals and compounds: salt, pH, metals, nutrients, petrochemicals etc.
- Thresholds (absolute and rate of change) for of ecological regimes to shift without causing catastrophic consequences (i.e. monocultures etc).
- Feedback mechanisms between altered hydrology and chemistry, acid sulphate soils, eutrophication, erosion, sedimentation etc.
- We also need site specific information about palaeoecology and palaeohydrology.
  - How has the environment changes prior to our influence? Rate and absolute levels of change are required.

Tolerances and Thresholds, Gaps and Requirements … Research Now! Continued.

- If that all wasn't complicated enough we need to understand; variations across age categories of a species, variations based on local evolution (endemism) which could also change the tolerances and thresholds. So generally even if we have an indication about a species, it needs to be refined with some site specific research for confirmation or refinement.
- Common, commercially relevant and iconic species have received most of this attention. Rare, endangered and priority species are more poorly represented.
- Development proponents will benefit from this as there will be less confusion and ambiguity, regarding large and lucrative projects. i.e. less risk. However big budget organisations need to fund more on and off site research as it will indirectly and possibly directly in the future benefit them.

Conclusions.

- Substantial amounts of additional research into the interaction between resource & development projects with the environment is required. Existing info also needs to be collated at a state level.
- Without this information adaptive management is nearly impossible and confusion will dominate during attempts. Artificial maintenance is a poor surrogate for good planning. Some examples of partial failure; Wanneroo wetlands, Yanchep caves, mining near TEC’s etc.
- During periods of confusion the economics of the situation tends to overrides the potential for environmental/ecological harm.
- Then all of society, present and future, lose out, due to the loss of biodiversity assets or a reduction in ecosystem services.