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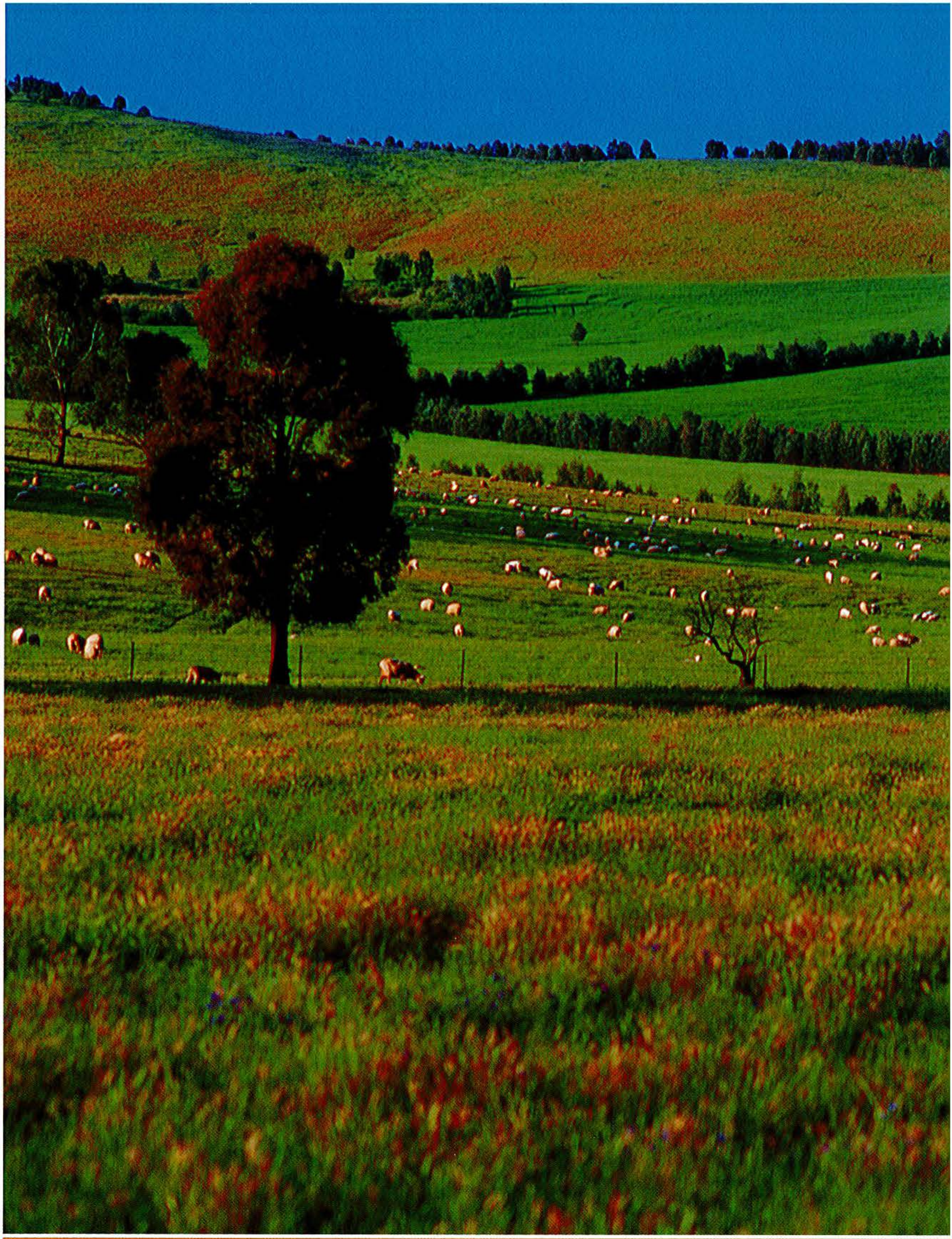

Groundwater Flow Systems Framework

ESSENTIAL TOOLS FOR PLANNING SALINITY MANAGEMENT

Glen Walker, Mat Gilfedder, Ray Evans, Phil Dyson & Mirko Stauffacher

MURRAY-DARLING BASIN COMMISSION

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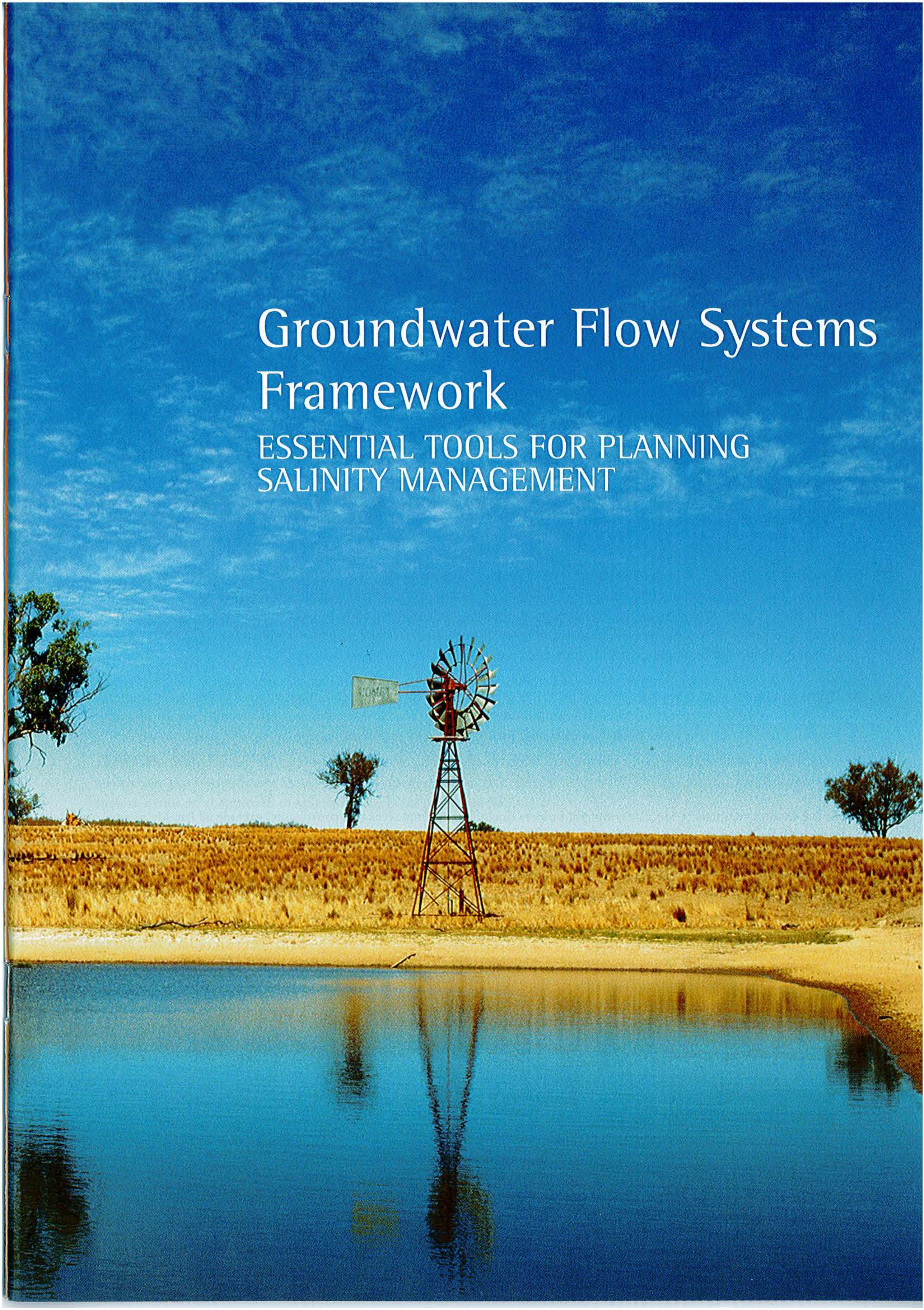

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Foreword

Australia is developing strategic approaches to protect land and water resources against the threat of salinity at National, State, Basin and regional levels. We recognise that salinity is essentially a groundwater problem, the movement of groundwater bringing salt to the land surface or moving it towards streams, rivers and lakes. A powerful decision support tool – Groundwater Flow Systems Framework – has been developed to guide investment decisions for salinity management

Understanding how groundwater responds to changes in recharge is the key to managing salinity. Focusing on groundwater, the Framework provides us with valuable insights into the causes of salinity, the risks it poses and the most appropriate planning and management options at different scales.

We have long known the general principles of groundwater recharge and its impact on saline discharge. But the Framework takes us much further forward in our understanding of how the processes vary across a large and diverse landscape. It is this that makes it so relevant to Basin communities and governments that are planning their own response to salinity, including prevention where this is still an option.

Case studies in different landscapes have now demonstrated the effectiveness of the Groundwater Flow Systems Framework across a range of scales. They have confirmed that the concepts can be applied across Australia and the results from well understood catchments can be extrapolated to other catchments where a similar groundwater flow system operates. These catchments make up salinity provinces, a useful template that will assist catchment communities in assessing the risk of salinity, its likely responsiveness to land use or land management change and the extent of change needed to meet end of valley targets.

There is still work to be done to map groundwater flow systems and identify significant salt stores at the catchment and sub-catchment scale where the detail of regional plans will be implemented. But the principles are now well established so that catchment communities have a basis for targeting their investment, choosing broad management options and measuring outcomes.

Natural resource management planning inevitably involves priority setting. This will be driven by the urgency and importance of the issue, the economic and social cost of intervention relative to the benefits to be gained within an acceptable time span, confidence in the outcome and the capacity of those involved to implement any necessary change.

The MDBC Basin Salinity Management Strategy recognises that effective management responses must be based on sound knowledge. The Groundwater Flow Systems Framework makes an important contribution to this knowledge base and enables a consistent approach to salinity management across the Basin.

W McDonald

Warwick McDonald
Director, Integrated Catchment Management Business

Glossary

aquifer	a layer of soil or rock that holds water and allows water to move through it
discharge	flow of groundwater to the earth's surface
discharge capacity	the rate at which the system can discharge without water tables rising above a level at which waterlogging or land salinity become a problem
drainability	the ability at any given point in the aquifer of the groundwater recharged up-gradient to drain laterally
geomorphic	related to landforms and the natural processes responsible for their formation
groundwater	all free water below the earth's surface
groundwater flow system (GFS)	a set of real aquifers that share similar characteristics and where processes leading to salinity are similar
hydraulic conductivity	physical property of an aquifer that determines the rate of movement of water through it
hydraulic gradient	the slope on a watertable that results in hydraulic pressure
hysteresis	a phenomenon in which a process or the value of a variable in a process is dependent upon the past history of the process. (e.g. response of a GFS to vegetation clearing is not a mirror image of the response following revegetation)
living with salt	increasing levels of salt in some areas is inevitable and hence there is a need to adapt to this more saline environment. In some areas, innovative approaches may turn the salinity problem into an economic opportunity
NCC	National Classification of Catchments
NLWRA	National Land & Water Resources Audit
permeability	Capacity of a substance (e.g.soil or rock) to allow water to pass through it
primary salinity	naturally occurring salinity
recharge	The component of rainfall that drains into the groundwater
regolith	weathered or sedimentary material over the bedrock
salinity province	region in the landscape where the physical processes contributing to dryland salinity are similar and where the salinity management options are also similar
secondary salinity	salinity that has been induced by human activity such as clearing of native vegetation
transmissivity	the product of hydraulic conductivity and aquifer thickness
water table	upper surface of the groundwater – soil profile is saturated below and unsaturated above the water table

Contents

Source: Mat Gilfedder

01 An issue as large as the landscape

Salinity in the Australian landscape is primarily a groundwater problem. Salts occur naturally in the groundwater and subsoil, and changes to land use are mobilising them.

The Groundwater Flow Systems (GFS) Framework interprets the vital relationships between landscapes and groundwater systems leading to dryland salinity, taking into account the different geologies and landforms found throughout the Murray-Darling Basin. This framework helps us assess the salinity risk faced by catchments, define how each GFS is likely to respond to interventions, and then design the most appropriate and cost effective salinity management options.

Where is the salt?

Salt is a natural feature of much of the Australian landscape, vast quantities of salt being the inheritance of an old, dry and relatively flat continent.

A proportion of this salt comes from the weathering of rocks, but most has drifted in with rain from the oceans. Small increments of salt have accumulated over millions of years in an environment where evaporation generally exceeded rainfall and where much of the drainage led only towards the centre of the continent. Over eons this salt in the landscape has moved around in response to changes in climate. For example, during the glacial retreat ending the most recent ice age, large volumes of salt were blown and re-deposited in the Murray-Darling Basin.

The natural environment has accommodated this salt, Australia having about 29 million hectares of primary salinity – land that is naturally saline. Some of it is characterised by salt lakes, and present long before the land was cleared for agriculture.

Much more land contains salt leached into the soil profile (above the water table), so that it can no longer be seen at the surface. Some salt has even leached into the groundwater system, gradually reappearing lower in the catchment as saline surface seeps or in baseflow to streams, rivers and lakes.

Thus much of the Australian landscape came to be influenced by salt, but generally in a state of dynamic equilibrium, the rate of groundwater recharge balanced by the rate of discharge.

Upsetting the balance

Dryland salinity (sometimes referred to as secondary salinity) in Australia is now a concern because it is spreading. It is appearing where it has not been seen before, and more salt is finding its way into water resources.

The National Land and Water Resources Audit (NLWRA, 2001) revealed that:

- Approximately 5.7 million hectares are affected by or are at risk from dryland salinity and this could increase three-fold to 17 million hectares by 2050.
- By 2050, up to 20,000 km of rivers and streams could be adversely affected by saline inputs.
- Approximately 630,000 ha of remnant native vegetation and associated ecosystems lie within dryland salinity risk areas. These areas may increase by up to 2 million ha over the next 50 years.
- Some 20,000 km of major roads and 1600 km of railways occur in regions that are mapped as high risk. By the year 2050, these figures could grow to 52,000 km and 3600 km, respectively.
- Over 200 rural towns could suffer damage to infrastructure and other community assets from dryland salinity in the next 50 years.

Source: Mirko Stauffacher

State	1998–2000	2050
New South Wales	181,000	1,300,000
Victoria	670,000	3,110,000
Queensland	not assessed	3,100,000
South Australia	390,000	600,000
Western Australia	4,363,000	8,800,000
Tasmania	54,000	90,000
Total	**5,658,000 ha**	**17,000,000 ha**

* The Northern Territory and the Australian Capital Territory are not included, since dryland salinity issues are considered relatively minor in these areas.

Table 1: *Predicted areas at high risk from shallow water tables or with high salinity hazard by 2050 (NLWRA, 2001)*

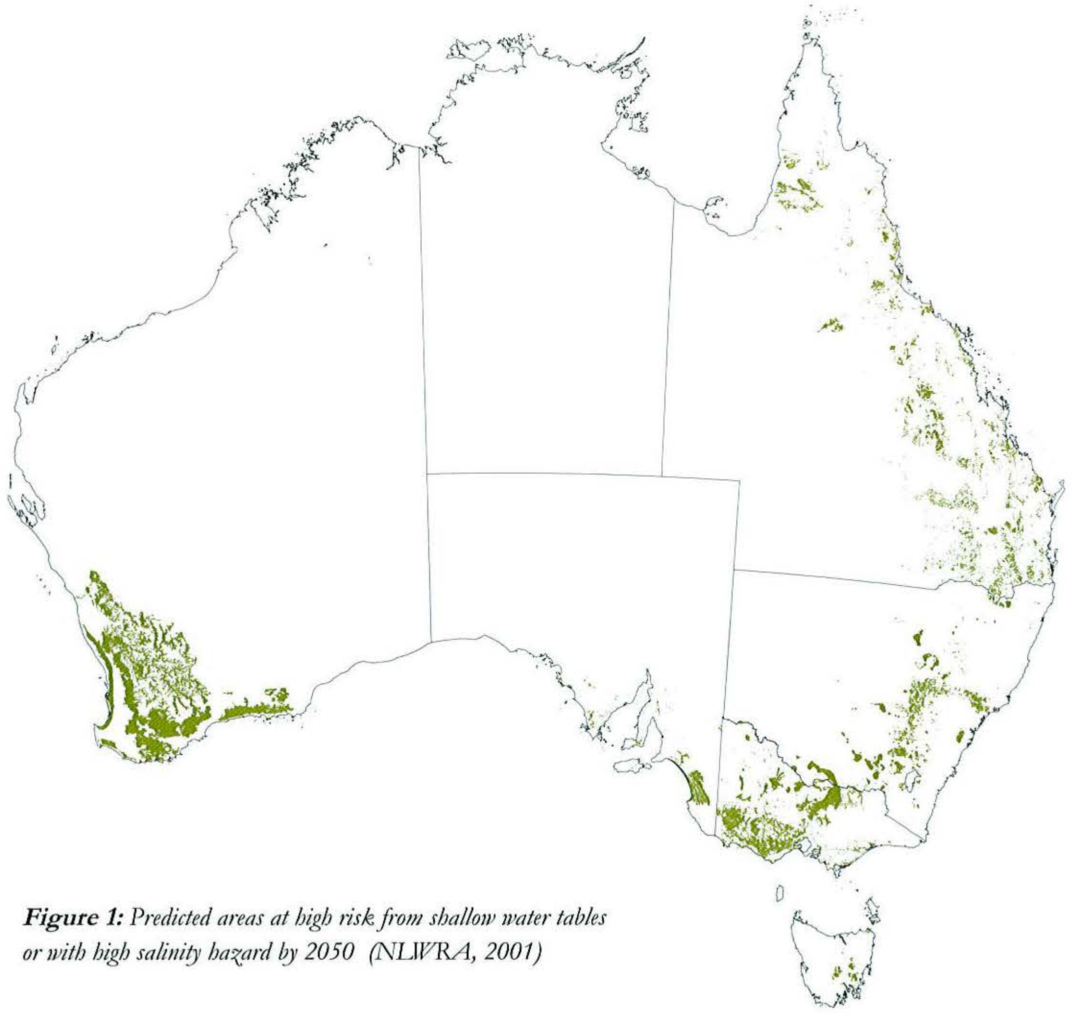


Figure 1: *Predicted areas at high risk from shallow water tables or with high salinity hazard by 2050 (NLWRA, 2001)*

This increase in salinity is driven by increasing groundwater flows that are mobilising the salt. This long-term trend will continue unless we take well informed steps to deal with it.

Principles for salinity management

Research has clearly shown an increase in groundwater recharge associated with current farming systems, resulting in increased groundwater flows. Even under best practice, farming systems based largely on shallow-rooted annual crops and pastures simply cannot control salinity (Walker *et al.*, 1999).

As groundwater recharges from rainfall (and from irrigation, leakage from surface water bodies including rivers, lakes and wetlands, and from sewers and septic systems) the groundwater system steadily fills. As it fills, stored salt in the soil profile is remobilised until it eventually discharges to the land surface or directly to rivers, streams or the ocean. The specific recharge and discharge behaviour is a characteristic of the particular groundwater flow system.

A steady state is only reached when the amount of water leaving the system is the same as that entering. Clearly, if land management practices permit more water to enter the system, more must also leave it, often bearing salt.

Despite the harm done by the discharge of saline water, the amount of salt discharged is really only a small fraction of the massive amounts stored in the landscape. In most systems we can do little to remove this salt within a reasonable time frame, so a more practical strategy is to keep it where it is, by limiting the movement of water through the soil profile. If this is not possible we must adapt to living with the increasingly saline environment, unless there are cost effective engineering strategies such as pumping or drainage.

Conceptual models allow us to simplify complex systems and predict their behaviour under various conditions. Before building a house, an architect will usually design a conceptual model. This will have, on paper, all the features and dimensions of the actual house (walls, floor slab, windows, etc) and be constructed of materials with known properties. From this the architect can run scenarios, testing the response of the model house to various perturbations (for example: wind, hot and cold, sound, soil movement).

Conceptual models are also useful in predicting changes in salinity. Recharge and discharge generally represent only a very small fraction of the water within a groundwater system, but it is these small perturbations that lead to land salinisation, waterlogging and saline baseflow to rivers and streams.

Groundwater movement is governed by the geological and geomorphic structure of the catchment, and the hydraulic properties of landscapes and aquifers. These are some of the physical attributes that hydrogeologists use to describe **Groundwater Flow Systems** – the conceptual groundwater models that they use to simulate natural processes of recharge and discharge. These groundwater flow systems will in turn respond to influences such as climate, land use and land management.


Source: NDSP

If our aim is to reduce land and stream salinity we must limit the discharge of saline groundwater from lower parts of a catchment. For this there are really only two broad options:

- reduce groundwater recharge, and/or
- remove groundwater before it can discharge.

A third option, living with salt, provides opportunities for minimising or even reversing the economic effects, but has limited impact on land and stream salinity.

This then leads us to five basic intervention tools:

- retain and conserve healthy native vegetation, taking advantage of its capacity to fully use soil moisture
- change land use and land management, making more and better use of perennial vegetation to further limit 'leakage' beyond the root zone
- change surface water management, using drainage to reduce recharge to groundwater
- dispose of groundwater by drainage or pumping, and
- develop productive and sustainable saltland agronomy.

Tackling salinity regionally

As with other natural resource issues, individuals acting alone will be unable to deal effectively with salinity. We have seen that salinity is an outcome of the behaviour of whole groundwater flow systems and any management plan that fails to address this will be unlikely to succeed. Governments have recognised this reality and indicated their willingness to invest in regional plans based on clear targets and appropriate monitoring to ensure the best outcomes.

So it is communities who now face the considerable challenge of developing regional plans to control salinity and improve water quality.

The general principles of groundwater recharge and discharge are quite well understood and we have various management options available (Stirzaker *et al.*, 2000). But choosing just the right management tools for a particular part of a catchment or river basin requires detailed understanding of:

- how the particular groundwater flow system functions
- how it will respond to intervention, and
- the implications for land and water users.

Clearly, the particular groundwater flow system holds the key to any regional strategy for managing salinity and water quality. The characteristics of each GFS will therefore guide our choice of appropriate interventions that must also have regard for the demands they make and the impact they have on land and water users. Critical questions for regional natural resource planners then become:

- What are the current impacts?
- What are the risks of doing nothing?
- What is the likely time interval between intervention in the GFS and a satisfactory salinity benefit?
- How much recharge reduction is needed to achieve a groundwater balance?
- What extent of land use change is required and how many landholders will be affected?
- What is the feasibility of removing groundwater by engineering means?

A matter of scale

The National Action Plan (NAP) for Salinity and Water Quality targets nine priority **regions** in the Basin for addressing salinity and water quality issues. We use the term 'region' to denote the scale of this planning unit, including those not targeted by the NAP.

Within a region there are generally several **catchments**, bounded by high points in the landscape so that all surface water is shed into a common river or major waterway.

Most catchments are made up of **sub-catchments** that shed their surface water into minor rivers or streams.

Catchment characteristics – vital clues to salinity management

Groundwater flow systems vary from catchment to catchment and within catchments according to their geology and geomorphology. Each system has key features that we must consider when assessing how that system will respond to management activities. This in turn helps regional and catchment planners address some of the questions that will underpin their investment decisions.

How long will repair take?

Just as salinity effects have lagged behind the land clearance that triggered them, so will recovery lag behind remedial activity. Groundwater flow systems are generally sluggish, so there will always be a delayed discharge response to a change in recharge.

The responsiveness of a GFS is closely related to the length of the flow path (how far the groundwater must travel between the points of recharge and discharge) as well as to hydrogeological properties of the aquifer (particularly its permeability and the hydraulic gradient).

Generally, larger groundwater flow systems that dominate the Murray-Darling Basin are slower to respond to changes in recharge.

Broadly, we can classify catchments as:

- Local flow systems - extend only a few kilometres along the flow path, the aquifers fill relatively quickly and land and river salinity might appear within a few years of land clearing.
- Intermediate flow systems - are about 5-50 km and may take 50-100 years to develop land salinity; but perhaps less for river salinity.
- Regional flow systems - are typically greater than 50 km along the flow path and might not show signs of land salinity for more than 100 years, although river salinity may increase sooner.

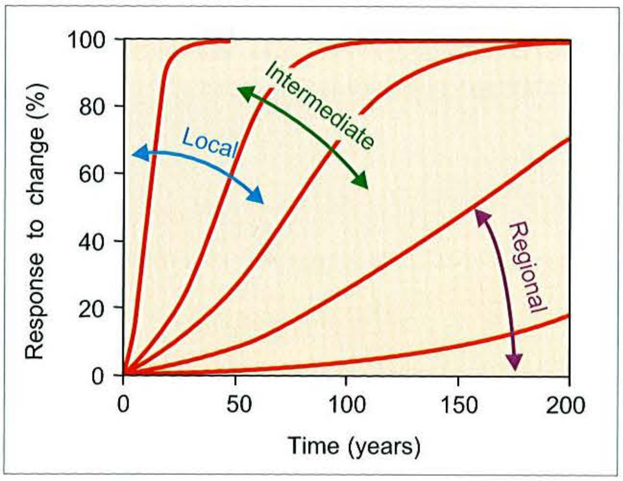


Figure 2: *Generalised groundwater response for local, intermediate and regional groundwater systems*

Regional systems that are already nearly 'full', and have a strong down-basin flow component in a highly *transmissive* aquifer, will also continue to discharge in the lower catchment, irrespective of recharge reduction.

> **Transmissivity**
> The rate at which groundwater moves laterally is governed partly by the permeability of the aquifer measured over its depth and the physical size of the aquifer (the cross-sectional area through which the groundwater can pass)

For some systems, regional aquifers may take hundreds of years to respond to changes in groundwater recharge. This has serious implications for priority planning based on land use change, including clearance or degradation of native vegetation. Whilst longer-term options might still be important, they should be undertaken in the context of:

- realistic stakeholder expectations
- a more immediate need to protect significant assets
- potential difficulty in justifying public investment and
- the inability of these options to help meet short-term targets.

The real issue for the catchment community is to assess how long they might have to wait for the desired discharge response to any reduction in recharge.

What if we do nothing?

Recharge is not constant but is affected by seasonal variations, floods, droughts and changes in land use that in turn lead to fluctuating groundwater levels. With these fluctuations, and often in the absence of local long term data, it is not always easy to determine the impact of previous land use change, let alone predict the likely impact of future changes.

Given a particular climate, the salinity risk will depend largely on the groundwater flow system and the factors that influence it, together with the salt stored in the landscape.

In landscapes that we have cleared to the point where increased volumes of saline groundwater are moving, the salinity risk is not so much *if* discharge will occur, but *when*.

In assessing risk we should also recognise that the response to recharge reduction is generally slower than the response to a comparable increase in recharge. This *hysteresis* effect underlines the difficulty of reversing the increased groundwater flow that will follow clearance or degradation of native vegetation or any other land use that results in an increase in recharge.

Hysteresis

Groundwater processes are not perfectly 'elastic' – they respond sluggishly to revegetation or changed land management, even more sluggishly than they responded to initial land clearance. Water tables therefore return relatively slowly, if at all, to their pre-clearance levels when recharge is arrested.

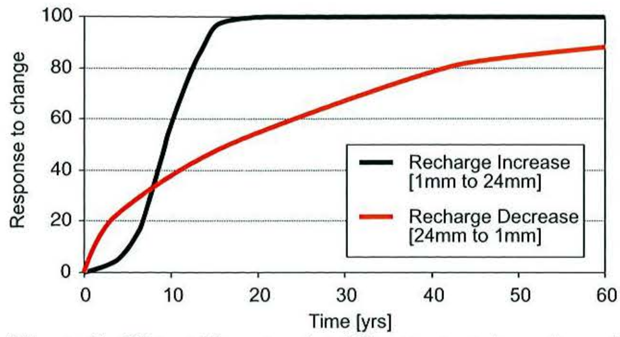


Figure 3: *Water tables respond at different rates to increasing and decreasing recharge*

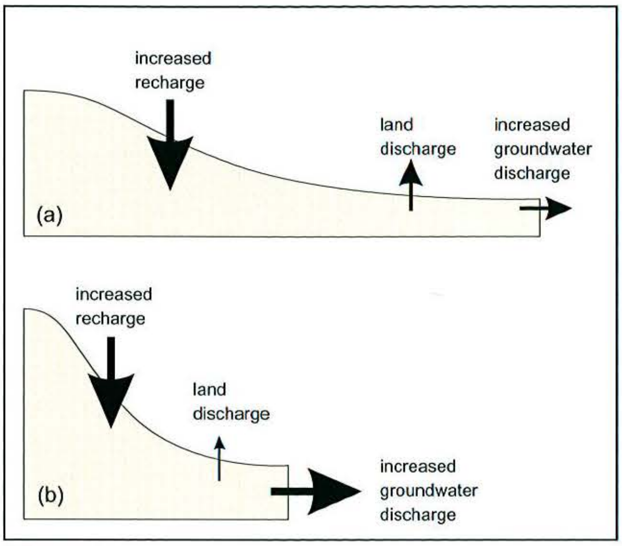


Figure 4:

(a) Slowly draining system

(b) Relatively freely draining system

How big is the task?

We can simplify complex groundwater movement by considering its two components:

- vertical filling where increased recharge causes water tables to rise
- lateral drainage where groundwater moves sideways in response to a pressure caused by a topographic gradient or increased recharge at some point along the aquifer.

Catchments that drain slowly (for example, those characterised by factors such as large size, relatively low relief, poorly transmissive aquifers or geological features that inhibit groundwater movement) will tend to respond to increased recharge by filling up the recharge zone. With little opportunity for groundwater to move away laterally, water tables rise to the land surface causing waterlogging, land salinisation and salt wash-off to streams.

In this case, we will avoid further land salinisation only if we can reduce recharge to a level where it is entirely balanced by the limited lateral drainage.

At the other extreme, increased recharge will create a pressure gradient sufficient to drive lateral movement in catchments that drain relatively rapidly (for example, smaller catchments with higher relief and/or more transmissive aquifers). In these catchments, where groundwater has the capacity to move laterally, we find increased groundwater (and hence salt) discharge further down the catchment, perhaps into streams, rather than rising water tables.

These two extremes will require quite different approaches to recharge control if we are to reverse groundwater trends. Depending on the groundwater flow system and the balance between vertical and lateral processes in the catchment, there will be large differences in the recharge reduction required to control salinity.

Clearly, the larger GFSs are likely to require a greater level of recharge reduction to reverse salinity trends. This implies more significant land use changes involving low recharge systems across the catchment - a further challenge for regional planning and for communities.

Over what area must we act?

The area of land use or management change required to achieve a target level of recharge reduction will increase with the size of the groundwater flow system. The costs and time for implementing these changes are then greater and the logistics of protecting affected assets more difficult.

On the other hand, the volume of water is less for smaller catchments and if we can identify high recharge zones we have a good opportunity for targeting recharge control.

What about water quality?

Stream salinity can be a significant issue even when there is little or no evidence of land salinisation. Recharge well below the threshold for land salinisation will still drive lateral drainage, eventually leading to discharge further down the catchment. However, recharge reduction along a river corridor as narrow as one kilometre can have a significant impact on groundwater drainage into the watercourse within a realistic planning time frame.

The critical issue for streams is the salt load, which is linked to catchment features including rainfall, soil properties, depth of weathering, and zones of evaporative concentration and alluvial volume. Many of the larger alluvial and sedimentary groundwater systems have very high groundwater salinities.

Can we pump or drain?

Pumping or draining groundwater is generally an expensive operation, difficult to justify unless to protect a high value asset or resource. The feasibility of engineering options depends strongly on the transmissivity of the aquifer, and hence the area over which the water table might fall, but also on other considerations such as the ability to safely dispose of saline groundwater.

Using the catchment clues

Groundwater flow characteristics, if we know them, point us towards the most appropriate broad salinity management options.

Source: Mat Gilfedder

We have seen that the larger groundwater flow systems generally have longer time delays and higher thresholds for reducing recharge to avoid land salinisation. Catchment communities will need to undertake huge areas of recharge reduction if they are to meet appropriate targets, and even then the impacts will occur over a long period of time. So, recharge reduction as a salinity management option, within our current planning horizon, is less likely for large groundwater flow systems than it is for smaller upland systems.

Clearing native vegetation or changing to high-recharge land use practices on regional groundwater flow systems would appear to be very risky, given the difficulty of reversing the changes.

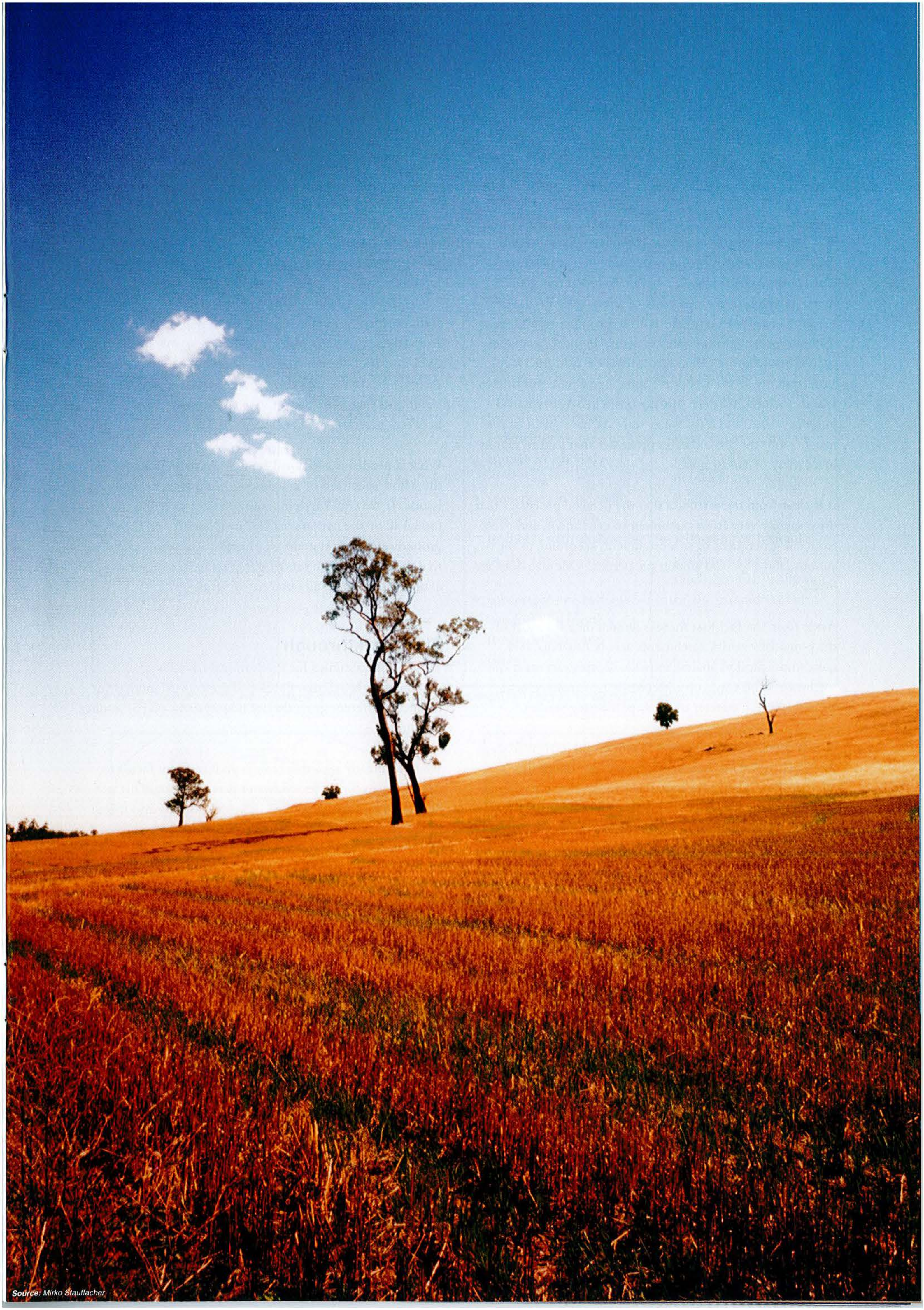
Whether engineering options can be applied will depend very much on groundwater characteristics, but as with other approaches it will be necessary to take account of agronomic, social and economic factors.

We already have a good understanding of how various groundwater flow systems can be expected to behave and respond to land use and land management change. However, two critical questions then emerge:

- just where in the landscape are these 'well understood' GFSs?
- how do real-world GFSs actually respond to these changes?

Since recharge rates increased following land clearing, some catchments have been monitored in sufficient detail to provide reliable answers to these questions. It is in those catchments that we can make confident predictions and guide sound investment in regional land management strategies.

These case studies, of catchments well-described over time, serve as pointers to the response of other similar catchments to land use and land management practices. As targeted monitoring programs establish long term spatial and temporal groundwater trends we can further improve our understanding of other catchments and make more confident assessment of risks and opportunities.



Source: Mirko Stauffacher

02 Moving forward with a Groundwater Flow Systems Framework

Understanding in a general sense how groundwater flow systems function is step one in learning how to manage dryland salinity. We have developed this general understanding through 30 years of investigations and research based on a number of well documented and now well-interpreted groundwater systems. Pioneering studies such as those in the Collie catchments of WA, the Deep Lead systems of the Loddon Plains, Axe Creek and Burkes Flat in Victoria, Western Murray Basin in SA, Brymaroo in Queensland and Yass Valley in NSW have given us the insights into the groundwater processes that lead to salinity in a variety of landscapes.

It is clear from these studies that the detailed processes that drive salinity vary from catchment to catchment, and even from sub-catchment to sub-catchment, according to the various landscape and aquifer properties. One size does *not* fit all.

Aside from the fact that there is limited data for most of the potentially at-risk catchments across Australia, it is quite impractical to analyse individually this vast array of catchments and come up with customised management scenarios in the manner of these pioneering studies.

Nonetheless, researchers have drawn useful lessons from those real-world catchments that were 'put under the microscope'. They have used these to develop conceptual models and applied them with some success to other catchments with similar geological and geomorphic characteristics, and where the groundwater flow systems lead to similar salinity issues. In turn, these similar groundwater processes should respond to similar interventions.

Extrapolating our understanding from one catchment to another provides a very useful tool, but only if we use a consistent way of describing these catchments and their GFSs. In the past this has not been the case, with significant variations between states, between regions and between government agencies.

What is needed is a national framework that embraces the whole spectrum of catchments types facing salinity issues. If we could systematically classify, describe and model all of the nation's 'classic' catchments and their groundwater flow systems we should then be in a position to design appropriate sets of generic management tools and extrapolate these to all other catchments.

The breakthrough

This was the stimulus for the National Classification of Catchments (NCC) that developed conceptual models for distinctly different groundwater flow systems (GFS) leading to salinity.

We have already seen that scale is an important factor to initially differentiate groundwater flow systems. This is illustrated in **Table 2** where GFSs are grouped into three broad classes.

Source: Mat Gilfedder

	Local GFS	Intermediate GFS	Regional GFS
Horizontal scale	• < 5 kilometres	• 5-50 kilometres	• 50 kilometres
Geomorphology	• subcatchments in higher-relief areas on edges of plateaus and ranges	• alluvial and, occasionally, glacial valley fill in foothills and valleys	• broad riverine plains on depositional basins
Geology	• fractured metamorphic and igneous rocks • colluvial sediments • aeolian sediments	• fractured metamorphic and igneous rocks • shallow (< 50 m deep) alluvial and colluvial sediments	• deep, interbedded marine, alluvial and aeolian sedimentary sequences (several hundreds of metres deep)
Structural features influencing groundwater flow	• subsurface low-hydraulic conductivity features such as bedrock highs and dykes • termination of aquifer at erosional surfaces	• reductions in hydraulic conductivity with distance from sedimentary source or aquifer weathering • reductions in hydraulic gradient or aquifer thickness with shallowing of the ground surface • subsurface low-hydraulic-conductivity features (bedrock highs and dykes)	• reductions in hydraulic conductivity with distance from sedimentary source or associated with structural deformation (faulting, folding) • reductions in hydraulic gradient or aquifer thickness with shallowing of the ground surface

Table 2: *Summary of the broad features of local, intermediate, and regional GFSs defined in the NCC (Coram, 1998).*

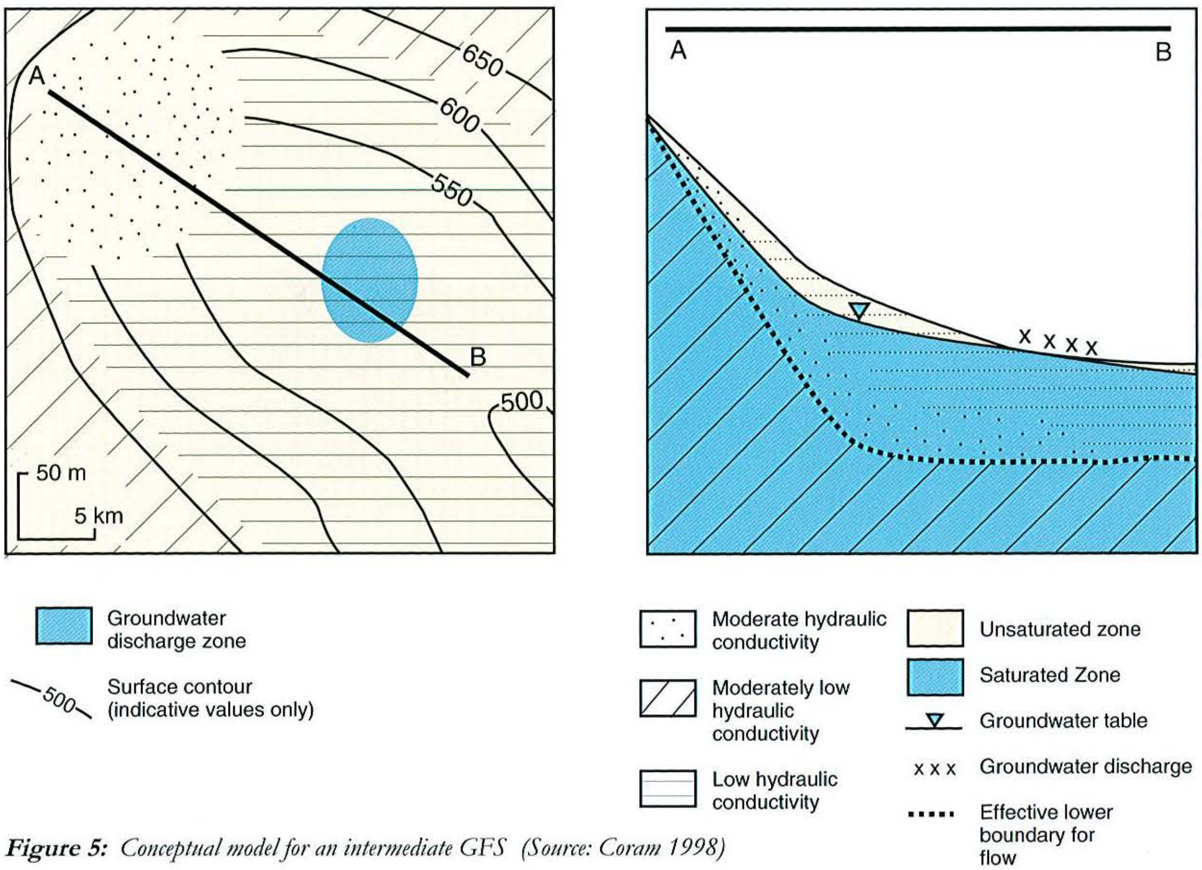


Figure 5: *Conceptual model for an intermediate GFS (Source: Coram 1998)*

While examples of each of the major systems have certain similarities, there are significant enough differences to warrant further classification into the fifteen sub-systems – eight local, four intermediate and three regional. Conceptual models have been developed to describe each of these fifteen GFSs and their distinctly different characteristics that influence the processes of recharge and discharge leading to salinity.

These conceptual models of groundwater flow systems are of great theoretical interest but little practical use unless we can actually relate them to real catchments in real landscapes. The models only reveal their value when we build them into an overall framework that locates them in the landscape where they can be 'fed' real data.

This was the challenge faced by the National Land and Water Resources Audit that sought to map *salinity provinces* - parts of the landscape where the physical processes contributing to dryland salinity are similar and where the salinity management options are also similar.

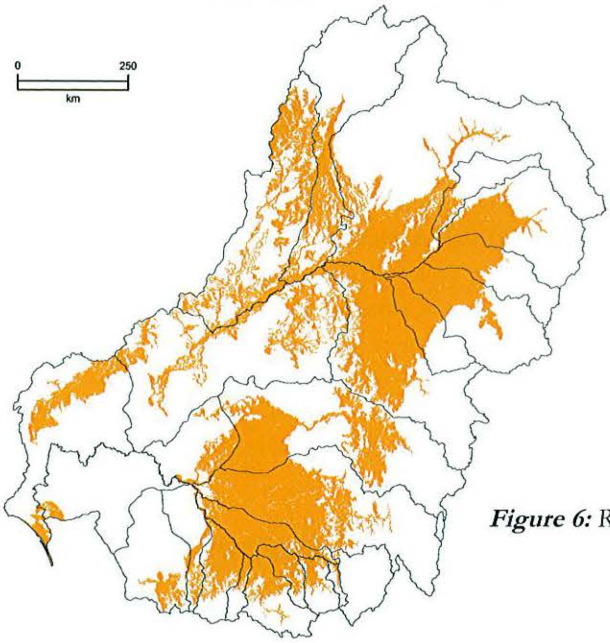
Source: Mat Gilfedder

That part of the landscape in which a particular GFS (or several GFSs of the same type) operates is referred to as a **salinity province**. Whilst the GFS is clearly influenced by catchment characteristics, the salinity province does not necessarily share a common boundary with the catchment. Surface flow systems do not necessarily match underground flow pathways.

Source: Bruce Munday

The basis for these salinity provinces draws upon the collective experience of hydrogeologists across Australia. By defining nationally consistent mapping rules based on measurable features such as landscape slope, elevation, and geological and geomorphological characteristics, it establishes principles for mapping all groundwater flow systems.

Source: Mirko Stauffacher



A **salinity province map** shows the distribution of zones where a particular GFS (or a set of similar GFSs) is likely to occur. As an example, **Figure 6** shows the location of a regional GFS in an alluvial aquifer.

Figure 6: *Regional GFS in an alluvial aquifer*

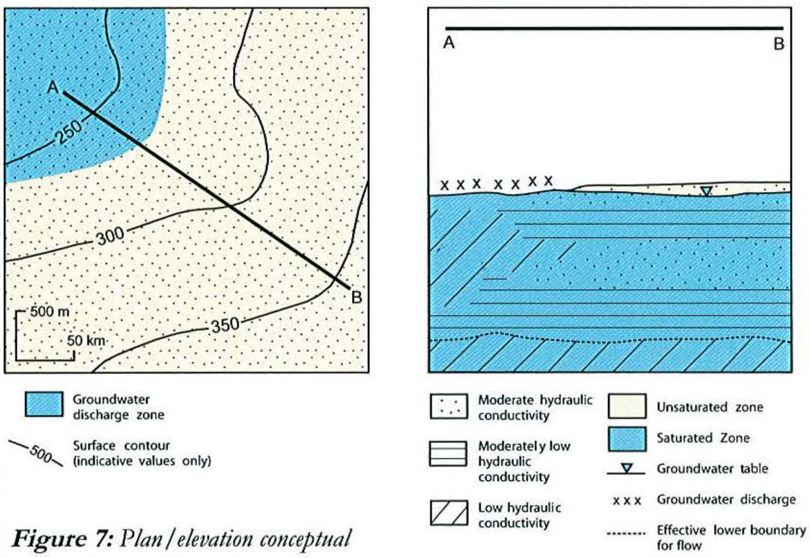


Figure 7: *Plan / elevation conceptual model (Source: Coram 1998)*

This type of aquifer system is commonly called a Deep Lead system, and occurs throughout the inland Riverine Plains of the Murray-Darling Basin. The NCC describes a conceptual model for this type of aquifer:

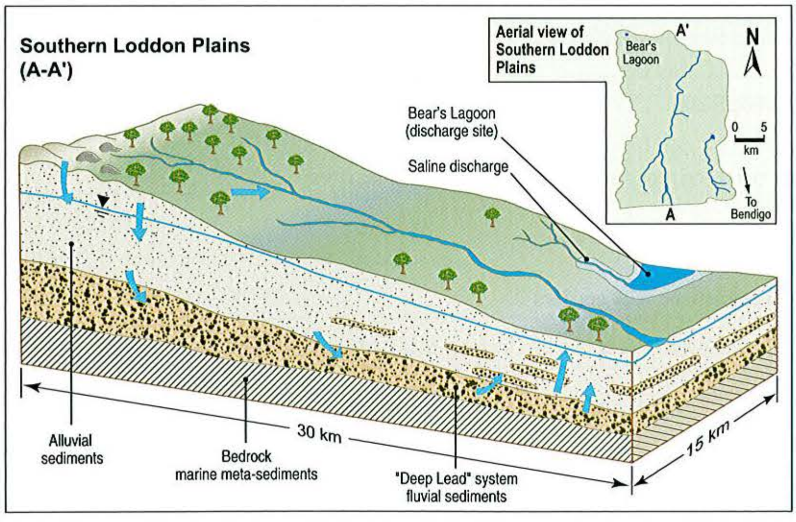


Figure 8: *3D diagram of Southern Loddon Plains case study*

The Southern Loddon Plains catchment in Victoria is a case study catchment which contains this type of aquifer.

While the hydrological processes are likely to be generally similar across these deep lead systems, the risk of salinity and the effectiveness of pumping as a management tool will vary with the precise nature of the alluvial material.

Putting GFSs to work

In the first instance, researchers have used these principles to develop a national map of salinity provinces characterised by particular groundwater flow systems. This national-scale map identifies local, intermediate and regional GFSs, helping us to determine broadly where salinity risk is greatest and where management activities are most likely to be rewarded. The map also locates hydrogeological and topographical features that characterise how dryland salinity progresses and how, in general terms, it might be managed.

We can map salinity provinces at any scale provided we have supporting data available at that scale. The relatively detailed GFS map for the Murray-Darling Basin (**Figure 9**) is derived from Basin-scale data. So we now have a framework within which to predict salinity risk, guide Basin policy decisions and identify broad management options at a Basin-wide scale.

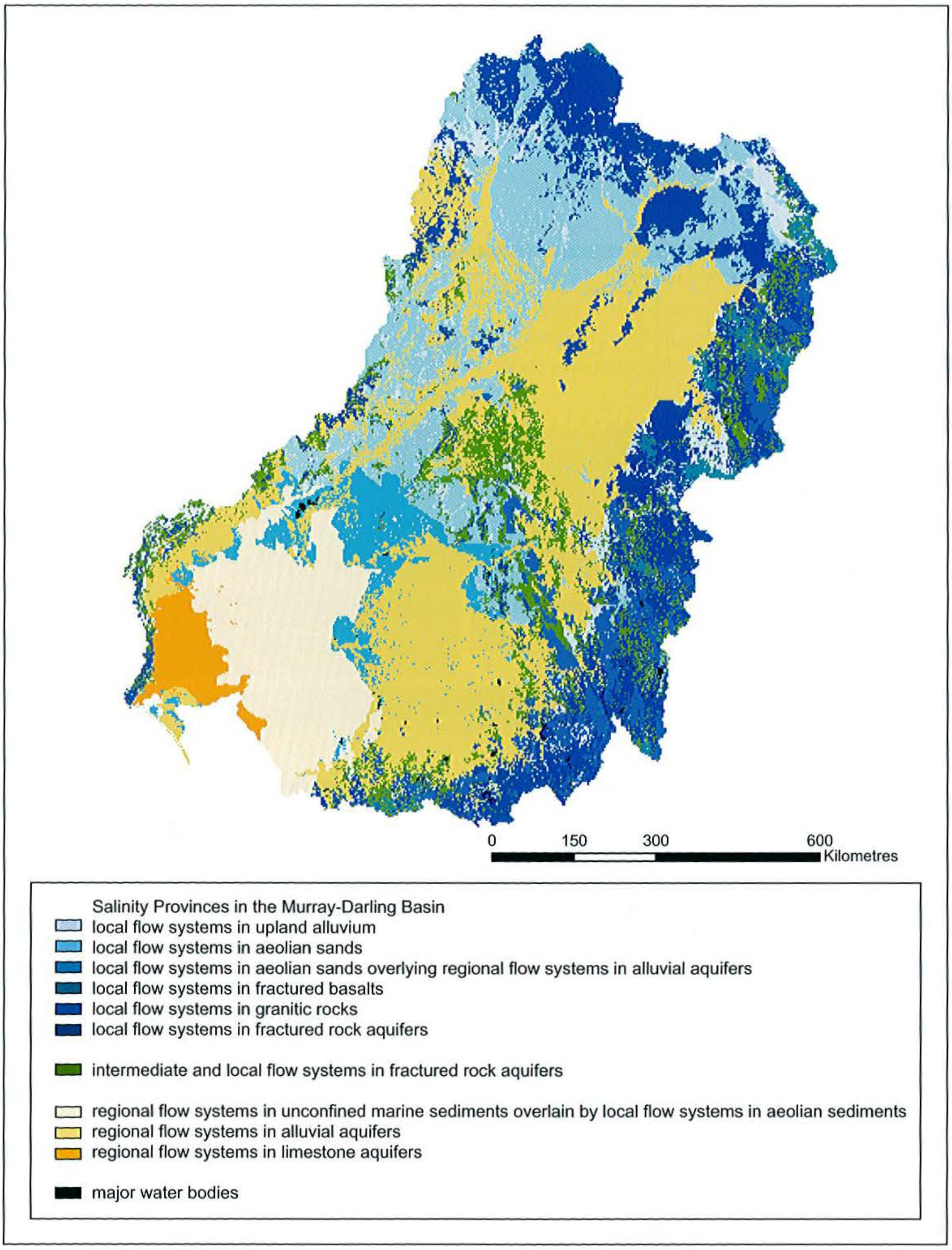


Figure 9: *Salinity provinces in the Murray-Darling Basin*

Useful as the Basin-scale map might be, it does not provide the site specific guidelines that would help catchment or sub-catchment groups assess their local conditions and management options. This challenge has been taken up by two other Murray-Darling Basin Commission projects:

- Tools for Improved Management of Dryland Salinity in the Murray-Darling Basin.
- Catchment Classification for Salinity Management.

Catchment communities working with these projects use the GFS methodology to produce their own relatively detailed salinity province maps. These maps are built up using data from regional and catchment plans along with local knowledge from hydrogeologists and salinity extension providers, and integrated with information from the Murray-Darling Basin Salinity Audit.

Figure 10 illustrates, as an example, the salinity provinces and their distribution for the Goulburn-Broken catchment in Victoria, whilst **Table 3** provides an assessment of the relative priority of each province for salinity management. Priorities are based upon the current understanding of the relative impact or potential impact on soils, stream water quality and stream salt loads.

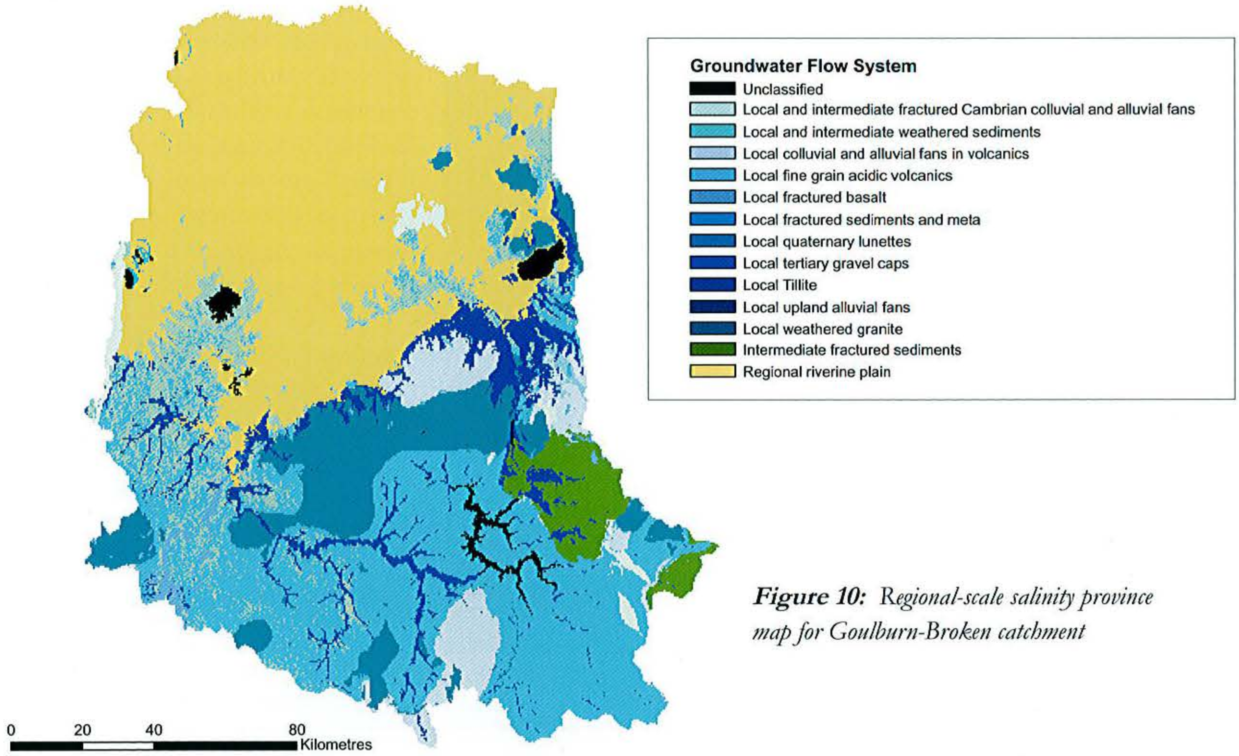
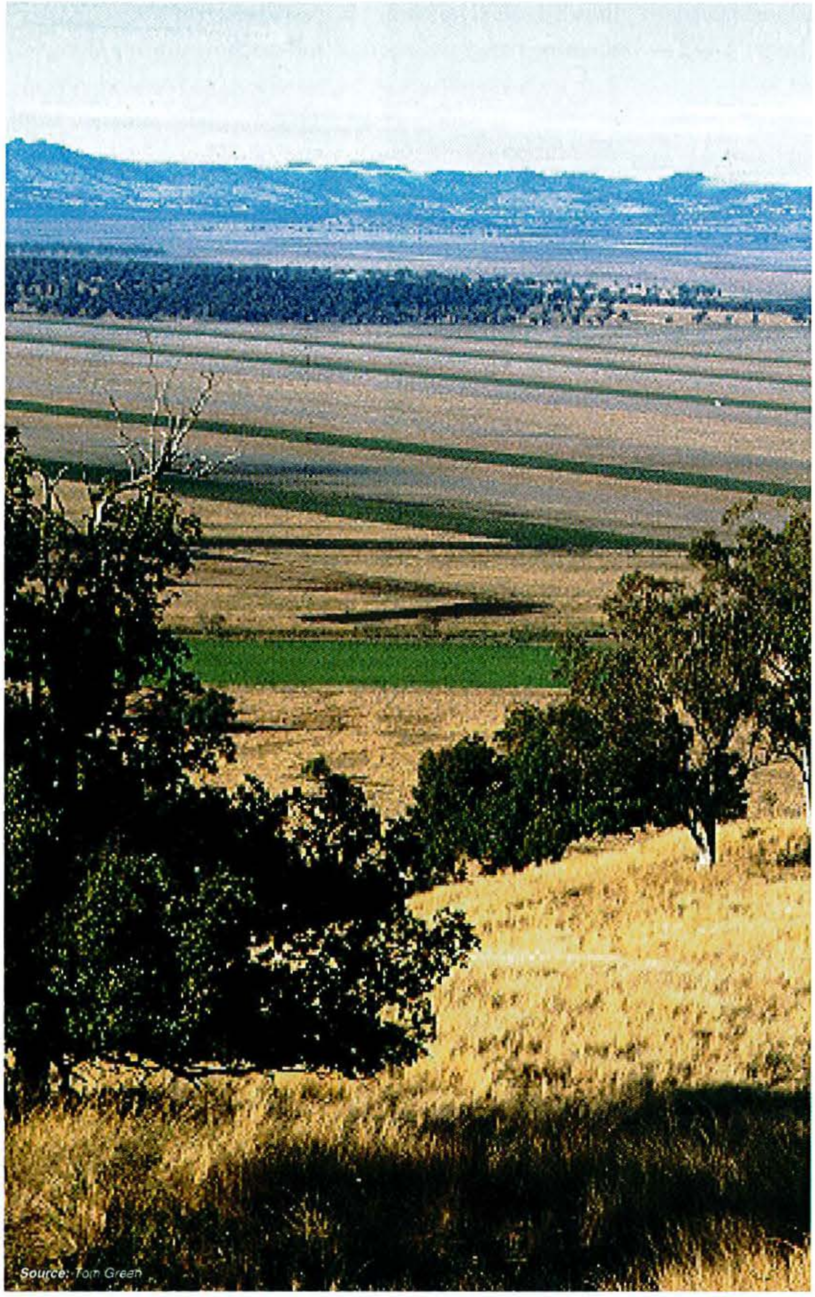


Figure 10: *Regional-scale salinity province map for Goulburn-Broken catchment*

Groundwater flow system	Salinity Risk (land)	Salinity Risk (water)	Salinity risk (salt load)
Alluvial plains (regional)	High	High	Medium
Fractured sedimentary rock (local & intermediate)	Medium - High	High	High
Fractured cambrium volcanic & sedimentary rock (local & intermediate)	Medium - High	Low - Medium	Low - Medium
Fractured rocks (local)	Low	Low	Medium
Granites & acid volcanic rock (local)	High	Low	Low
Alluvial plains (local)	Low	Low	Low

Table 3: *Characteristics of GFSs for Goulburn-Broken catchment (Tools for Improved Management of Dryland Salinity in the Murray-Darling Basin)*



The characteristics for each of these GFS types at this scale are now becoming more specific, allowing greater detail in the specification of suitable management options. Characteristics such as porosity and the depth of weathering help estimate total salt stores, while groundwater residence times and the fraction of the GFS connected to the surface help estimate the salt store which can be mobilised.

From this, the catchment community gains an overview of the relative risk associated with each system and the relative suitability of different management options for each salinity province. Moving to finer and finer resolution, towards the sub-catchment and paddock-scale, we require more detailed information to describe the variations between sub-catchments and determine the precise management options for salinity.

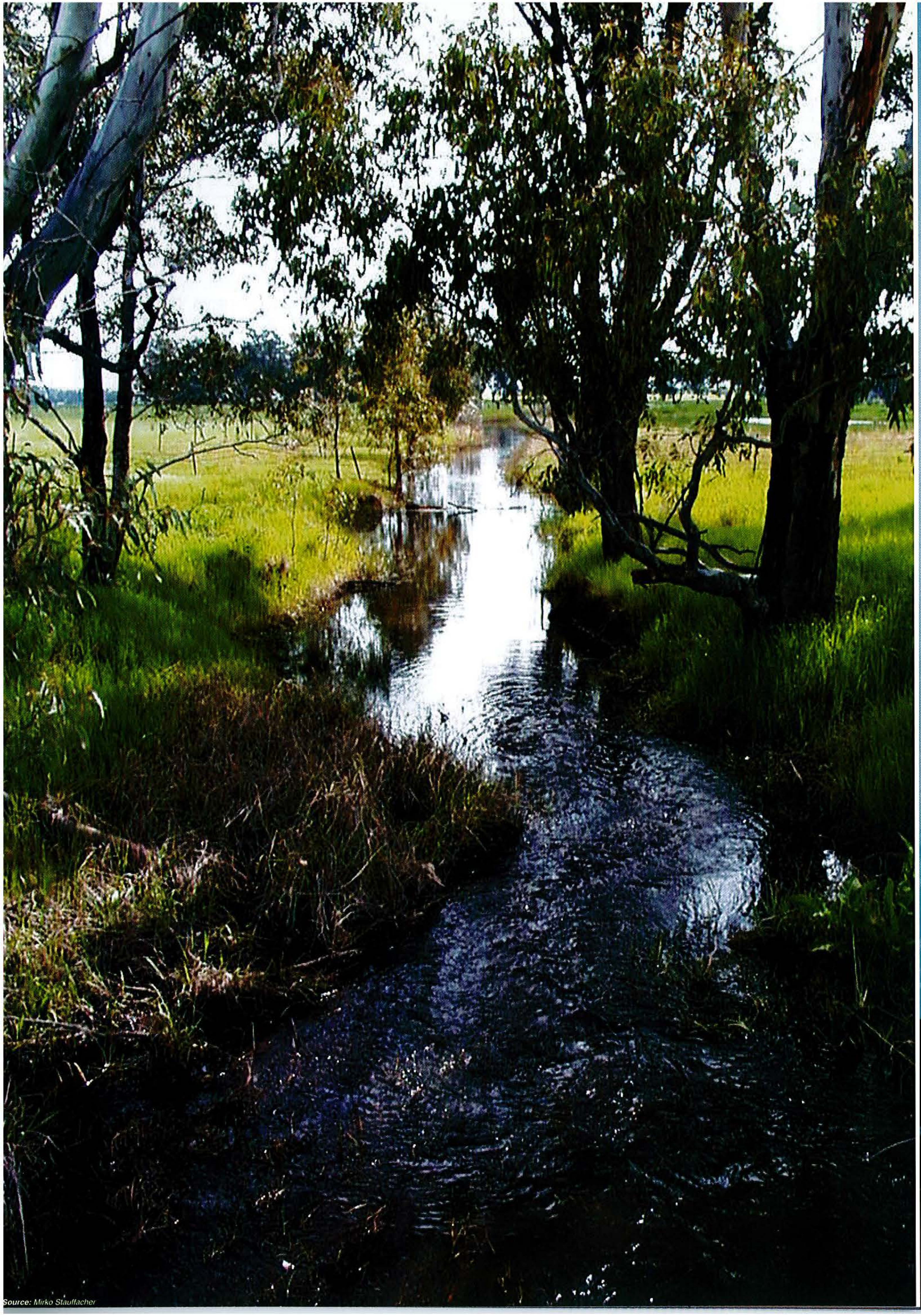
The National Classification of Catchments, the set of Groundwater Flow Systems and the map of salinity provinces together provide the framework in which effective salinity management planning can proceed. The utility of this framework draws on the similarities that exist between well described catchments and their 'look-alikes'. But no matter how strikingly similar, no two catchments are identical and it might be the one difference that is all important. The ultimate test of any model is: does it work?

Salinity provinces mapped at different scales serve different purposes. Mapping nationally provides very broadscale information that might assist general risk assessment and priority setting. However, to design specific management options (such as engineering works or recharge control) requires much finer scale mapping.

By analogy, a national map of native vegetation might indicate generally where we expect to find tropical rainforest, open savanna or grassy woodlands. However, local conditions might be quite different. Zooming in on say the 'grassy woodlands' we might well find that local conditions such as geological features, soil types or climatic variations have led to a distinctly different vegetation type, such as perhaps an open grassland or a temperate forest.

Similarly, regionally mapped salinity provinces indicate where a particular groundwater system is likely to be the dominant feature. However local variations in the geology and geomorphology might well lead to local groundwater flow systems with quite different properties to those on the national map. These local variations will be important considerations for detailed planning exercises and they highlight the risk of using an inappropriate scale when applying the GFS model to decision making.

At the national scale, it is also likely that more than one flow system might occur at a given point on the map; for instance local flow systems might overlay a regional flow system.



Source: Mirko Stauffacher

03 Groundwater Flow Systems - a reality check

Groundwater recharge, ultimately the driver of dryland salinisation, is a complex process influenced by many factors that are often difficult to quantify. Even dominant factors such as the recharge mechanism, rates of recharge and the location of key recharge areas require comprehensive data sets and expert knowledge of hydrological processes.

Current predictions of salinity trends are derived from models that allow us to simulate groundwater behaviour under existing landscape conditions. Researchers also use these models to paint other scenarios where the conditions are varied to reflect different land management practices.

Whilst understanding groundwater processes helps us assess management options, many questions remain requiring quantitative answers:

- What are the likely future impacts under different management scenarios, including doing nothing?
- Can we justify the costs of management options?
- Can regional targets be met?

We need confidence that there is data that actually supports our conceptual understanding and the use of GFSs as a classification. So we turn to case study catchments for an opportunity to test our understanding of groundwater processes against measured outcomes.

Models

There are actually two types of models involved hand-in-hand as these scenarios are developed. Firstly there is the conceptual model – the 'picture' or concept that captures the essential features of the catchment and the groundwater system, just as an architect might draw a **concept model** of a house. Then there is the **computer model** that assigns numerical values to many of the features of the model, inputs water as recharge then calculates the output (in time and space) as discharge. In our analogy, the architect would describe the properties and dimensions of the building materials (that is, *'parameterise'* the model) from which to then calculate say heat loss or sound penetration.

If the conceptual model is incorrect, the computer model will make spurious predictions. Should the conceptual model of our house neglect, say, the windows, we would incorrectly predict heat loss and sound penetration.

Similarly, no matter how precisely we might develop our concept model it will be of little value if we lack data to parameterise it or if that data is unreliable.

Very few catchments have been studied in such detail that we can confidently say that we understand exactly how their groundwater flow system will behave under different management scenarios. However, those that have make invaluable case studies from which we learn valuable principles and so we do understand in broad terms how similar catchments will behave.

Source: Mat Gilfedder

Case studies

Researchers use measured data and experience to develop an understanding of the way a particular catchment will behave. This data includes structural geology, geomorphology, aquifer properties and landscape topography, but we should never under-estimate the complexity of this task given the spatial and temporal variability of catchments.

The case studies are detailed enough to parameterise computer models such as FLOWTUBE, that then can be used assess how the catchment might respond to various management options.

These case studies give us confidence in our conceptual models which we can then use to help prioritise actions in other similar catchments.

> FLOWTUBE is a simple but powerful groundwater computer model developed by CSIRO Land and Water. By taking account of the cross sectional area (A) of the groundwater system, the regolith properties that influence groundwater flow rates (K), and the hydraulic pressure (P) driving it, FLOWTUBE can predict the discharge that will result from a particular recharge.
>
> First of all, FLOWTUBE must be 'parameterised' - A, K and P must be quantified for a small cell of the catchment and then statistically aggregated across the whole catchment.
>
> 'What if' scenarios can then be simulated by modelling the discharge that should result from recharge under various land uses and management practices.

To learn more, researchers have selected nine case study catchments representing a diverse range of groundwater flow systems for which there was sufficient existing data to parameterise:

- Brymaroo catchment - local flow system in fractured basalts
- Wanilla catchment - local and intermediate flow systems in deeply weathered sediments
- Kamarooka catchment - local flow systems in fractured rock
- Axe Creek and Kyeamba Creek catchments – intermediate and local flow systems in fractured rock
- Upper Billabong Creek, Southern Loddon Plains, Lake Warden and Liverpool Plains – regional flow systems in alluvial aquifers.

Figure 11: *Case study catchments*

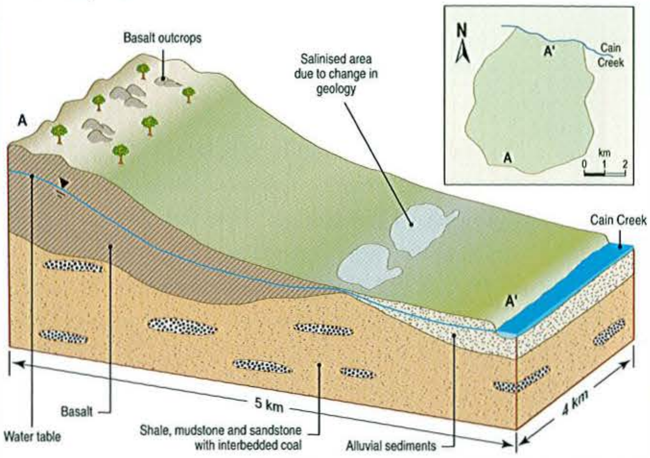
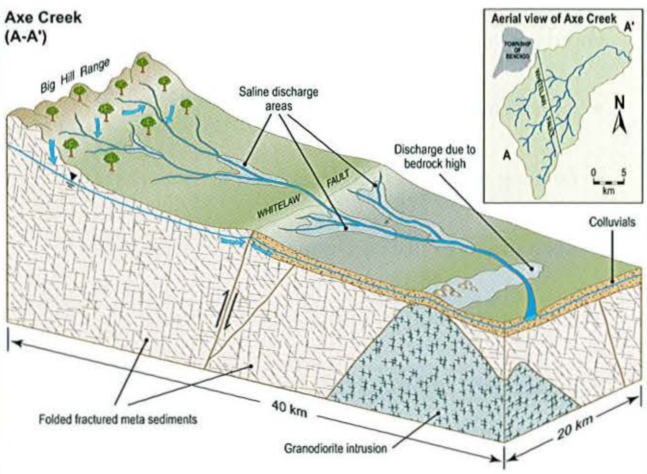
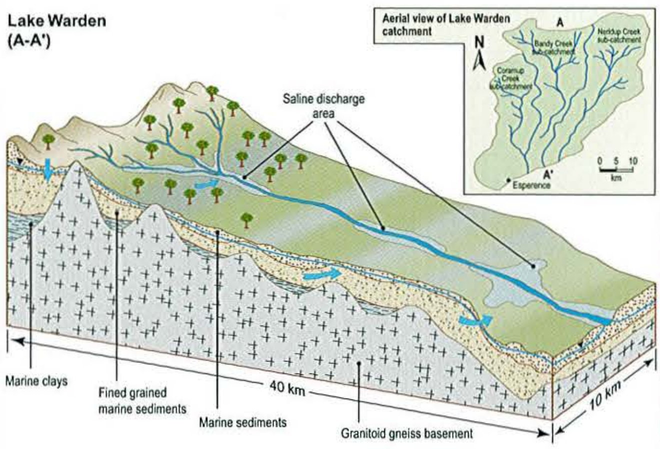
These are catchments with relatively well documented information on many of the factors that affect recharge and discharge:

- land clearing (when and where)
- farming practices (what has been grown where)
- deep drainage (leakage under various land uses)
- seasonal rainfall, run-off and evaporation
- piezometer and borehole data
- landscape elevation
- soil properties, and
- regional geology.

With this data, researchers parameterised the FLOWTUBE model to be consistent with the groundwater behaviour of the catchment under the current salinity conditions. Where there was sufficient data available, this provided a test of the conceptual models. The model was then used to predict likely behaviour under different land use and land management scenarios.

What do the case studies tell us?

The value of the case studies is much greater than just the light they shed on their particular catchments if the lessons can then be extended to other catchments of the same type. So the first test is to check that the case studies themselves are indeed representative of NCC conceptual models.

<table>
<tr><th>GFS</th><th>Predictions of NCC conceptual model</th><th>Case study modelling</th></tr>
<tr><td>Local systems

</td>
<td>
Farm-based solutions involving revegetation and perennial cropping in recharge areas and limited use of engineering solutions such as surface drains.</td>
<td>
50% recharge reduction should reduce salinity by 30% in 20 years (Brymaroo catchment).</td></tr>
<tr><td>Intermediate systems

</td>
<td>
Surface appearance of salinity may be very limited, but there may be extensive salt export to local streams.
Longer time lag between recharge reduction and impact on discharge.
Groundwater pumping from fractured rock systems can be difficult to establish.</td>
<td>
Discharge commenced 40-50 years after clearing, and the groundwater system has reached a new equilibrium.
The system will take much longer to drain than to fill, so while response to revegetation is likely to start within 20 yrs, it will take more than 100 years for much of the impact to be evident.
Groundwater pumping was not considered.</td></tr>
<tr><td>Regional systems

</td>
<td>
Amenable to groundwater pumping.
Farm-based and vegetation strategies precluded by magnitude of system.
'Living with salt' is an option.</td>
<td>
Responding positively to pumping.
Following a 50% recharge reduction (which will require revegetation of 75% of the area with perennials), groundwater levels are likely to stop rising within 100 years.
Living with salt is successful where discharge is not highly saline.</td></tr>
</table>

The detailed understanding of the case study catchments, across a range of different GFS types, shows promising agreement at the broadest level of the NCC. This agreement gives us confidence in the NCC, to which we can add the lessons learned about the effectiveness of various recharge reduction methods (e.g. Stirzaker *et al.,* 2002), although detailed management options will still need to consider site-specific conditions.

Using this knowledge ....

The case studies give us belief in the NCC and in our ability to map groundwater flow systems.

So, we now have a consistent method of mapping the landscape into distinct salinity provinces and associating these with conceptual GFS models. Importantly, we can describe in broad terms how groundwater functions in each part of the landscape. From this we can identify the typical processes leading to dryland salinity, prioritise catchments, propose options for managing them, and predict the most likely outcomes.

This will be important knowledge for regional and catchment planning groups. Knowing which flow systems respond best to revegetation or engineering measures will save time and money in on-ground investigations and fruitless effort. Knowing where salinisation has already stabilised supports planning for 'living with salt', with opportunities for profitable outcomes.

To determine whether land use changes will have a worthwhile effect, we need to determine whether proposals will push in the right direction, push far enough, and push quickly enough. Knowing the gross changes in a catchment's water and salt balance is an important first step before investing in more detailed work on how daily flow and salinity vary throughout the year.

...... with care

Groundwater Flow Systems are very complicated and it is still difficult to describe them accurately down to the paddock or sub-catchment scale. There are also very real limits to how reliably we can expect to transfer management principles from one well studied catchment to another that appears similar but is not well described.

This approach recognises that there is no one-size-fits-all solution to dryland salinity, and that land use and management strategies must be tailored to local conditions. This presents an obvious problem when we use averaged groundwater parameters for modelling catchment responses.

We should not be surprised to find, in such a vast and diverse landscape, that some catchments might not fit neatly into our catalogue of salinity provinces. But we now have a set of groundwater flow system models that help us interpret and describe groundwater behaviour at all scales.

In some instances we might find that the variability within a groundwater flow system is actually greater than the variability between different systems, providing a significant challenge to our classification scheme. Whilst we could remedy this by describing further catchment sub-systems, it comes at a price. The increasing detail and complexity negates the multiplier benefits of extrapolating knowledge from a few catchments to many that should be similar.

Source: Neil Hodge

A matter of scale

The current knowledge developed under the GFS banner is a starting point that introduces the concept and places an approach in front of those charged with management. The classification allows for broad policy development and regional prioritisation of management options. However we will require more complex tools as we focus in on key areas for more detailed assessment of options.

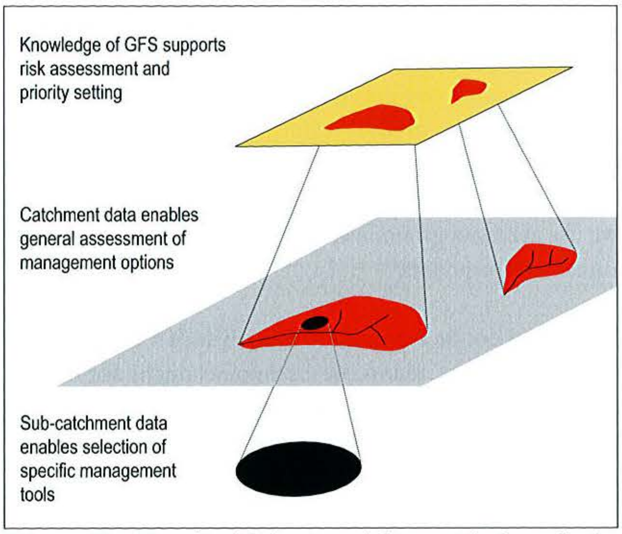


Figure 12: *More detailed data is needed to meet the demands of local decision makers*

At national and state scales the GFS Framework is guiding policy decisions by identifying local, intermediate and regional GFSs, helping to determine broadly where the salinity risk is greatest and where management activities are most likely to be rewarded.

In the Murray-Darling Basin, more detailed mapping allows regional predictions of salinity risk, guiding Basin policy decisions and identifying broad management options at this scale.

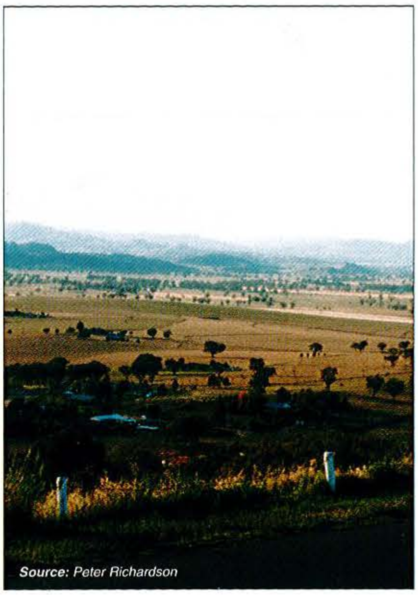
However, the real power of the GFS Framework is revealed when sub-catchment scale data is available, giving local communities site specific information for salinity management.

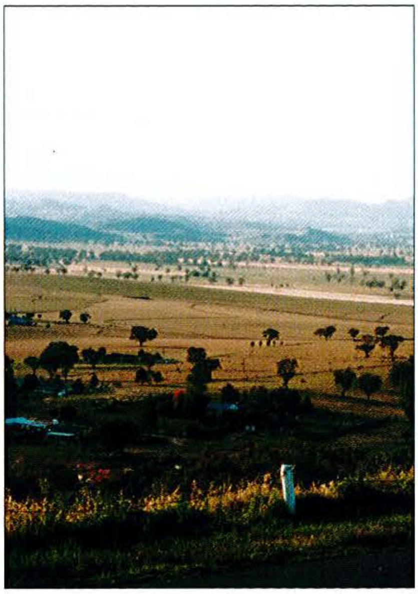
Inevitably, we will refine the Framework as GFSs are better classified with new spatial information/knowledge and where we improve our understanding of the governing process.

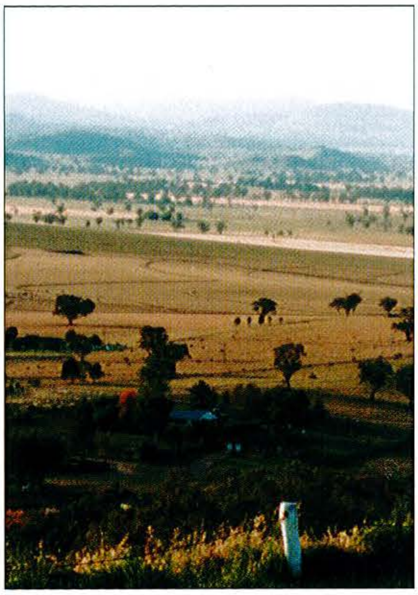
Recognising their strengths and limitations, we can now bring together the conceptual models, salinity province mapping, case study catchments, and an understanding of groundwater processes into this GFS Framework.

Returning to our analogy, a salinity province case study might be likened to a 'display home'. We will never live in the display home, but from its main features we can anticipate what it would be like to live there. Of course the physical model does not incorporate the socio-economic factors (such as employment opportunities, age distribution and so on) that might also affect the experience of living in such a house.

Case studies of salinity provinces are similarly limited. Even if we can predict the groundwater response to changed land use or management practices, there is no guarantee that the community will have the capacity or even the will to undertake these changes. Within a GFS Framework we can integrate socio-economic and other regional or catchment data with our understanding of the biophysical processes.







Source: *Mirko Stauffacher*

04 A framework for tough decisions

Salinity poses great and unique challenges, not only to resource managers but also to the researchers charged with providing explanations and answers. Secondary salinity has resulted from European-style agricultural systems that accelerated natural landscape processes - processes that may naturally occur in response to long-term climatic cycles over say 500,000 years.

Secondary salinity might never have emerged as such a huge problem had earlier generations understood what we now know. Whilst most land managers now appreciate at least the general relationship between land use and dryland salinity, we have so far made little impact on the areas affected and we face even greater future impacts on both land and water.

The intractability of the problem owes much to its uncertainty, that in turn relates to the inherently opaque characteristics of groundwater systems:

- the processes that drive salinity occur underground in an environment that we are still exploring
- the symptoms might take many years to emerge and we are yet to see their full manifestation
- the benefits are often realised long after the remedial action
- the symptoms are often revealed a considerable distance from the cause of the problem which might itself be very diffuse
- land managers who are affected by salinity are often not those whose practices contribute to the problem
- even when we have grasped the fundamental causes of salinity, there are many other factors (such as climate variability, changing land management practices and episodic events) that can mask underlying trends
- Australia is a vast continent across which we have documented very little quality data from which we might draw, and
- the task of managing the problem reverts to a small fraction of the population who work a large fraction of the land.

Taking up the challenge

The Groundwater Flow Systems Framework confronts these challenges by directly linking land use and management strategies to landscape-groundwater behaviour. Far more than just a theoretical description of hydrogeological processes, the Framework brings together all the key elements of a valuable and credible tool for salinity managers:

- an understanding of the causes of salinity, how groundwater recharges in response to changes in land use and management
- conceptual models that describe groundwater processes leading to discharge

Source: Mirko Stauffacher

- sound methodology for mapping the different groundwater flow systems

- case studies where groundwater processes have been closely studied and model predictions tested and validated, and

- groundwater and surface water data along with quantitative descriptions of hydrogeological features.

Understanding Australia's groundwater flow systems opens our eyes to the real magnitude of the problem. It is clear that nothing short of a well-informed national approach based on regional plans is needed. Catchment communities and individual land managers then have an essential role to play, but as part of regional initiatives. These will be strengthened by sharing information between well-studied catchments, supported by the skills and experience of a handful of expert hydrogeologists.

Within local groundwater systems individuals might even be able to manage salinity on their own property, but they will have to be joined by others to make an impact across their district. *An individual with a hose might protect the house but will not put out the bushfire.*

Working with the GFS Framework

The GFS Framework contributes in several ways to the task of salinity management.

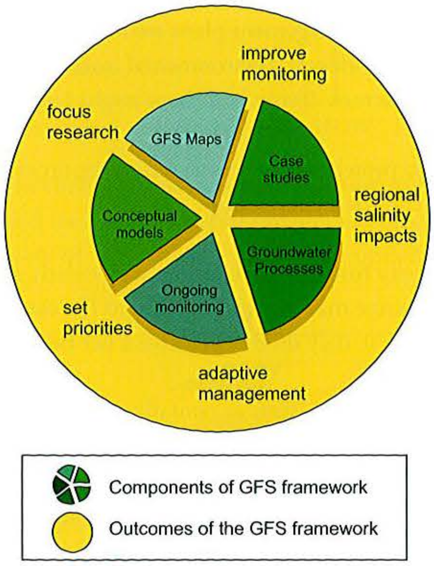


Figure 13: *Groundwater Flow Systems Framework*

Firstly, it **partitions the landscape into discrete areas,** salinity provinces, each characterised by a particular groundwater flow system. Regional planners can then prioritise catchments in terms of the risk they face and their likely responsiveness to salinity management. They can also assess the probable regional salinity response to various management options and help set reasonable expectations.

We can further support this process by **extrapolating our understanding** of well studied catchments to other catchments of the same type.

We can define GFSs at any scale, from regional through to national, but we must recognise that large scale classifications inevitably blur the actual detail. Whilst this might be adequate for regional risk assessment and priority planning, averaged GFS properties will be insufficient and misleading for site-specific recommendations for salinity management.

The GFS Framework reduces Australia's vast array of catchments down to fifteen representative classes. Some catchments will fit neatly into this classification, but inevitably there will be some that are 'borderline' – after all, they were not produced on an assembly line. So we must accept that there will be some variability within a particular class of GFS, reflecting a tension between the desire for accuracy (which leads to complexity) and the need for practicality (which demands simplicity).

The Framework also enables us to **aggregate information across the landscape.** Aggregating the impacts of changes made on different types of GFSs in different rainfall zones and for different land use changes, we can plan to meet targets for salinity, salt loads and base flow at downstream points of a river. In a similar way we can estimate the total area at risk of salinity, often in an environment where data is sparse and where the processes are not well understood.

The GFS Framework provides a structured approach to the groundwater aspects of these aggregations, however the accuracy of the outputs will depend on the availability of information. But we now have a platform from which to target groundwater and surface water monitoring networks to ensure that useful data is captured with least effort, and to focus further research on the region's most relevant issues.

Setting priorities

Regional planners are charged with setting priorities and time frames that involve ranking catchments and even sub-catchments for further investigations, for salinity-mitigation funding, and for implementing changes in land use and water management.

The MDBC Salinity Audit, the MDBC Salt Trends Report and the National Land and Water Resource Audit have all warned what may happen in the future under the *status quo* (no change) scenario. Unfortunately, the catchments for which salinity is likely to be worst are not necessarily those where control of the problem is feasible. In fact, it is often the opposite, so these *status quo* reports alone are not a particularly good basis for ranking catchments for urgent action.

The GFS Framework ranks catchments on the basis of groundwater factors – the key driver of salinity. It brings together the salinity province maps, conceptual models, and understanding of groundwater and salinity management options from detailed case studies.

These salinity province maps relate the case studies to other catchments that share similar critical attributes such as geology, geomorphology, topography, land use and climate. In an ideal world we could then directly transfer information from the case studies across to the same salinity province type. Unfortunately this simple approach is not without its challenges and limitations:

- At the detailed level the GFS classes are sufficiently sensitive to scale that we really need to describe sub-classes. Hence there are many more GFS classes than the 15 at the national scale. However, the hierarchy of flow system types still provides broad direction to the useful transfer of information. For instance, a well-studied local flow system is more informative for other local systems than it is for regional systems.

- Not all of the fifteen GFS classes have a corresponding case study.

- Detailed local planning and management calls for regional salinity province maps, as there is generally too much variation within a salinity province at the national scale. Whilst there are regional maps for the Murray-Darling Basin, there is little for the remaining eighty-six per cent of Australia.

- All detailed management options will always require site-specific information.

Thus, transferring certain information within the GFS Framework is seldom as simple as just direct transfer from the case study to salinity provinces of the same type.

So we can see that the GFS Framework provides an *initial* approach to prioritisation at the regional scale, allowing us to divide options into those that have a low, medium or high likelihood of success. With further field work and modelling we can then determine the actual *feasibility* of particular management options before the *design* stage.

Choosing management options

Regional groups in the MDBC Tools project used this style of ranking, in conjunction with a salinity province map, to show where in the catchments a particular management option might have the most impact. The results of these workshops are incorporated in Regional Information Packages for improved salinity planning and management (to be available at www.ndsp.gov.au).

A decision support tool for engineering options also fits the GFS Framework. This provides salinity province guidelines for choosing and designing drainage and pumping approaches to salinity management. It is also available at www.ndsp.gov.au.

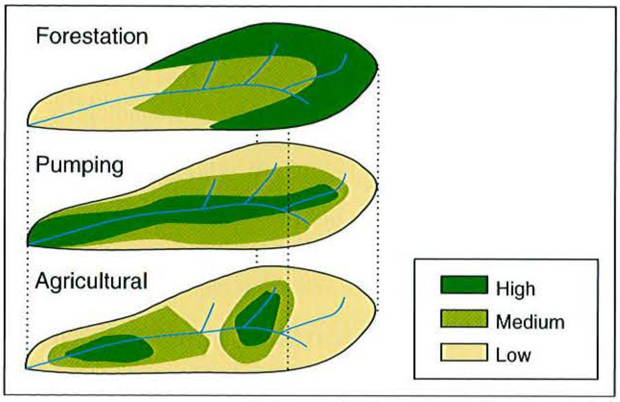


Figure 14: *Targeting and ranking management options within a salinity province*

Whilst groundwater might drive salinity, it is not the only consideration. Management plans must also take account of a region's economic, environmental, social and other biophysical factors. Typical of these might be:

- a need to protect urban assets, water resources and unique environmental areas

- the capacity for land use changes, particularly as the size of the change may be unacceptable to the catchment community if they do not perceive a net benefit

- biophysical factors such as rainfall and soil properties (affecting possible agronomic options)

- particular land uses that may affect not only salinity but also other resource issues, and

- the agricultural systems causing the problem are generally profitable, whereas those that might prevent it are not.

Therefore, any ranking process should combine salinity province maps with spatial information on these various factors to which we must assign appropriate weighting

Options	Ranking for management options		
	Salinity Province 1	Salinity Province 2	Salinity Province 3
Reducing recharge—farming systems			
Perennial pasture establishment	Moderate to High (rainfall < 600 mm)	Moderate	Moderate
Improved water use in croplands	Low	Low	Low
Introduction of woody perennials	Low to Moderate	Moderate	Moderate
Plantation forestry	Moderate to High (rainfall > 600 mm)	Low	Low
Engineering—water table management			
Surface drainage	Moderate	Low	Low
Subsurface drainage	Low	Low	Low
Groundwater pumping	Low to Moderate	Moderate	Moderate
Living with salinity			
Halophytic vegetation	Low	Low	Low
Salt-tolerant grasses	Moderate	Moderate to High	Moderate to High
Saline horticulture and silviculture	Moderate	Low to Moderate	Low to Moderate
Salt harvesting	Low	Low	Low
Saline aquaculture	Low to Moderate	Moderate	Moderate

Table 5: *Example of ranking used in the MDBC Tools project to determine effectiveness of different actions.*

indices. Inevitably, natural resource management decisions will demand trade-offs between catchment objectives and the feasibility of the various management options.

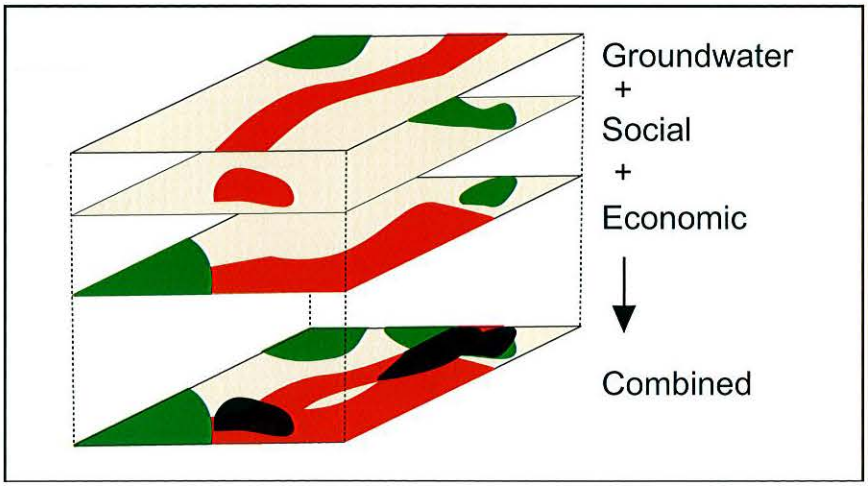


Figure 15: *Combining spatial information that influences management decisions*

Overall impacts

The GFS approach considers individual groundwater systems that eventually come to a dynamic equilibrium, either in the natural course of events or in response to changes that land managers institute. Since different groundwater flow systems respond at varying rates to changes in land use, different parts of the landscape will, as a result of past major vegetation clearance, be at different stages of the transition from the 'old equilibrium' to the 'new equilibrium'.

Similarly, modelling can allow us to look into the future, seeing how quickly different parts of the landscape will respond to major land use or management change.

But what is the overall impact of all these changes at the regional scale, or at the Basin and national scales? What level of change is needed to meet regional and Basin targets and are these changes themselves achievable in the real world?

With the GFS Framework we can use quite simple mathematical tools to aggregate the responses of all these individual systems. If, at equilibrium, certain groundwater systems have, say, 5% of the area with shallow water tables, while others have 30%, we can aggregate these areas to estimate the total area at risk regionally. Similarly, we can aggregate salt loads entering streams from groundwater.

The impact of salinity management on stream water quality is a vital issue and one that needs to take account of both surface hydrology and groundwater factors:

- Changes in land use can affect run-off and hence the dilution of salt in rivers. Higher-rainfall catchments are likely to deliver potable water, whereas medium- to low-rainfall catchments tend to contribute higher-salinity water. Revegetation as a tool to reduce recharge over a large area of a high rainfall catchment will reduce surface water yield, but in some salinity provinces will have little effect on salt load and increase salt concentration in streams.

- Salt washed off the land surface generally occurs at times of higher stream flows and so there is significant dilution. Releases of high-quality water for irrigation or other purposes can also have a major impact on stream salinity and salt load.

Adapting to change

Our understanding of salinity processes continues to advance as data is collected and processed and as experiences are shared. Management strategies then need to adapt to this new knowledge as it is validated.

Groundwater trends are a vital data set that we must monitor in response to land use and land management changes. But monitoring is time consuming and costly so it must be well targeted to collect the most important data where it will deliver the greatest benefits.

This is a formidable task, given that:

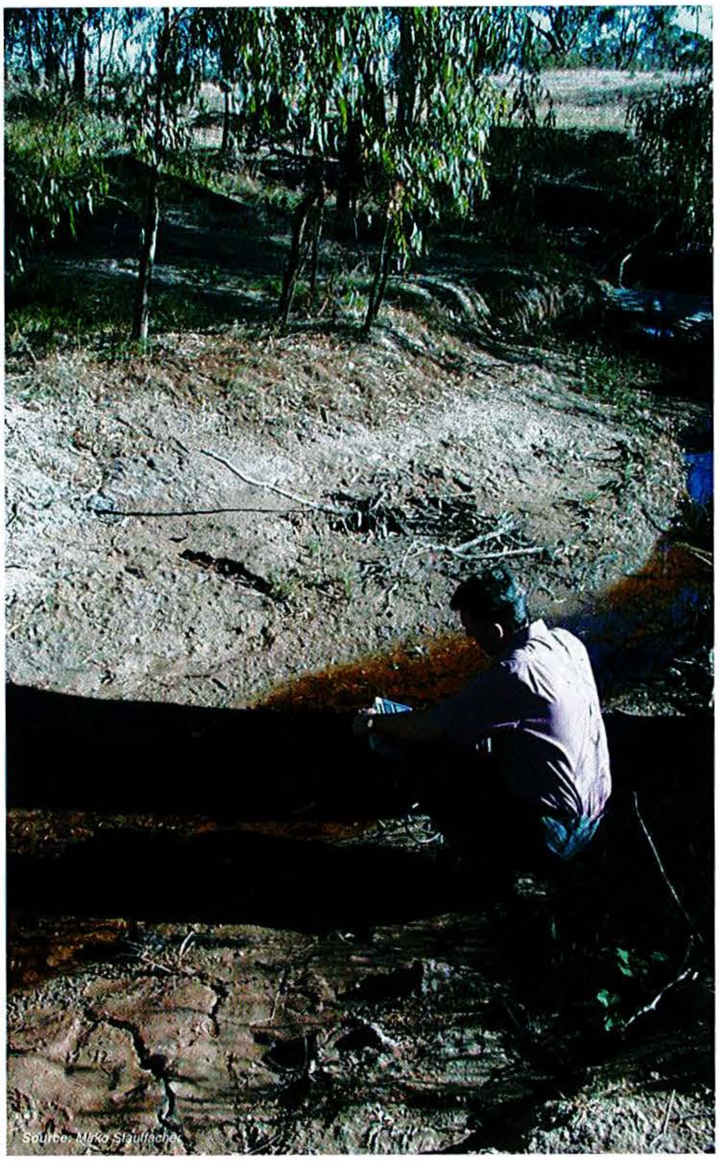
- bore and piezometer readings to describe groundwater trends can be misleading unless the bores and piezometers are appropriately sited

- land use responses are difficult to distinguish from environmental effects such as climate and weather events, and

- trends are difficult to interpret without a good understanding of prevailing geological and hydrological features.

The GFS Framework provides a sound basis for locating bores and piezometers at the most appropriate sites in the key groundwater systems. Because current groundwater data is so sparse it makes more sense to concentrate our monitoring in particular catchments rather than spread them thinly across a vast landscape. The case study catchments described in this project are excellent examples where monitoring should be continued and enhanced. Furthermore, they serve as prototypes for other areas where monitoring should be installed.

The GFS approach also helps frame research questions in a way that acknowledges variability across the landscape. Regional planners can then direct the research effort



Source: Mirko Stauffacher

towards those issues that make a difference and towards salinity provinces where little is known but where the salinity risk is significant.

Testing and refining the Framework

The Groundwater Flow Systems Framework helps catchment managers and regional planners to turn plans into action by supporting decisions on key issues.

The Groundwater Flow Systems approach is still maturing but already provides a powerful framework for salinity management. But we must remember that it is not a unique characterisation that is right or wrong, but rather an approach that brings the information together.

It will continue to develop as new data comes in and as researchers test and reassess hypotheses. In the same way we will continue to reassess and adapt regional strategies in the light of new data and improved understanding.

The GFS Framework has several components, each of which will respond to fresh ideas and new data. In particular, monitoring requirements and the need to demonstrate management options will stimulate more case studies that are relevant to the salinity provinces in regional maps.

Those who use the GFS Framework will expect to know the level of confidence that they can assign to its outputs. This confidence level relates to the within-class variability of the GFSs that for some salinity provinces is significant. To reduce within-class variability we need to subdivide the class, but can do this only where the data and understanding of processes permit. At the same time, we need to recognise that some catchment variables will have greater impact on groundwater processes than others, something we must test through sensitivity analyses.

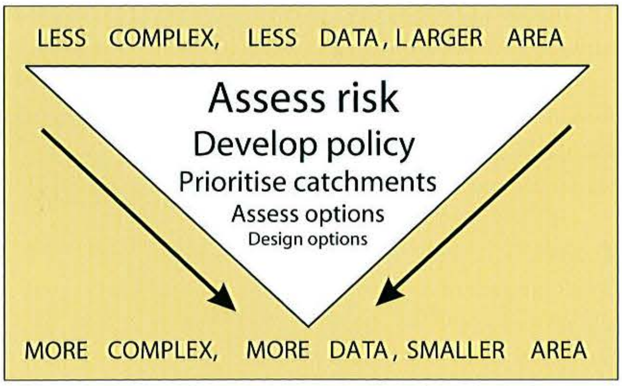
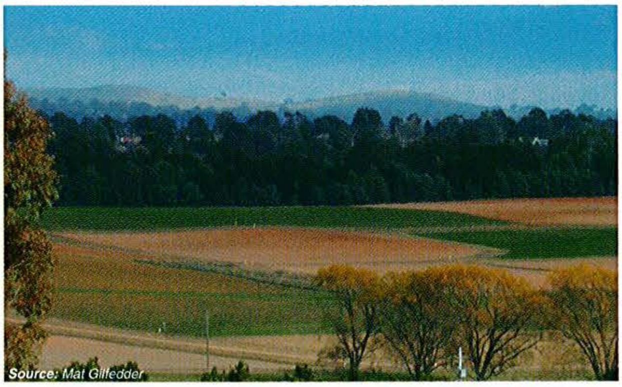
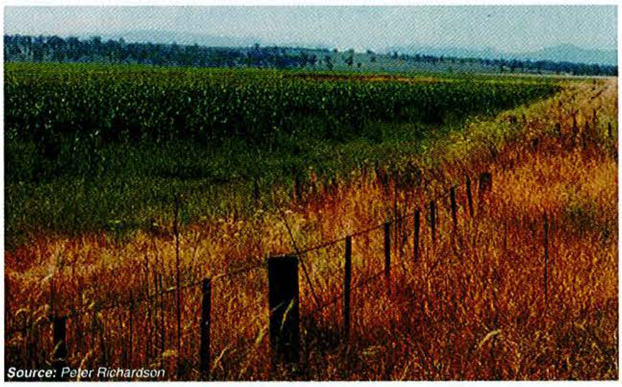


Figure 16: *At all times we must recognise the trade-off between confidence in the results and the complexity of the framework.*


Source: Mat Gilfedder


Source: Mat Gilfedder


Source: Peter Richardson


Source: Mat Gilfedder


Source: Mat Gilfedder

Conclusion

Australia's dryland salinity problem has been likened to 'sitting on a time bomb'. This analogy draws quite properly on two dominant features of the process:

- The action is essentially underground, out of site and somewhat mysterious.
- We are yet to see the worst and we don't really know when it will 'go off' – just that it will.

Should this appear pessimistic, we take courage from the researchers and investigators who now understand the workings of the most commonly encountered 'bombs' – the typical groundwater flow systems that have been conceptualised in the National Catchment Classification. We are also able to locate and map, with some certainty, where similar groundwater flow systems might be found – the salinity provinces.

Our general understanding of groundwater flow systems now enables sound national policies based on risk assessment for priority regions. In parts of the Murray-Darling Basin, for which relatively good data is available, it is often possible to go further and make an assessment of broad management options.

The GFS Framework thus continues to benefit from the ever growing knowledge base.

This is powerful knowledge that in turn enables regional natural resource management planners to prioritise their response to the salinity threat based on:

- the assets at risk
- the time scale for further salinity increase
- where best to target remedial action
- the time scale for remediation
- the social and economic cost of mitigation, and
- how and where to effectively monitor progress.

The next step is to map salinity provinces at a local scale, for example at the sub-catchment or even property level, where on-ground action must occur.

But the hydrogeologist faces a challenge familiar to the meteorologist. It is one thing to predict the general weather conditions for a region, but something else to make detailed and accurate predictions for a district let alone a town. However, as better data is collected more often and at higher spatial density, predictions become more specific and more reliable.

So too for the hydrogeologist. As we move from the regional scale down to the sub-catchment and paddock, groundwater flow systems break up into components. Interpreting GFS at this level calls upon considerable skill and experience, but we are assisted by the increasing accessibility of supporting data. Where detailed data is available the GFS Framework allows us to be quite specific about the salinity risk and where in the landscape different management options are likely to deliver the best results. This has been well illustrated in the case studies.

There is always danger inherent in extrapolating from a relatively small number of case studies and assuming that these can be trusted elsewhere. But we should recognise that many hydrogeologists have accumulated vast experience over a great number of other catchments. They bring this experience, and the deductive reasoning it supports, to each new catchment.

Having first determined the geological and geomorphic framework, hydrogeologists can then introduce groundwater information and make reasoned judgments about the flow system.

In this way the Framework provides catchment managers and regional planners with the tools to develop sound plans with technically supported priority actions.

The power of the Framework will grow as new data becomes available and as researchers test and reassess hypotheses. In the same way we will continue to reassess and adapt regional strategies in the light of new data and improved understanding.

The immediate challenge is to capitalise on the existing national and Basin-wide frameworks and the available regional information to guide the delivery of the National Action Plan and Natural Heritage Trust, together with the MDBC's Integrated Catchment Management Policy Statement and Basin Salinity Management Strategy.

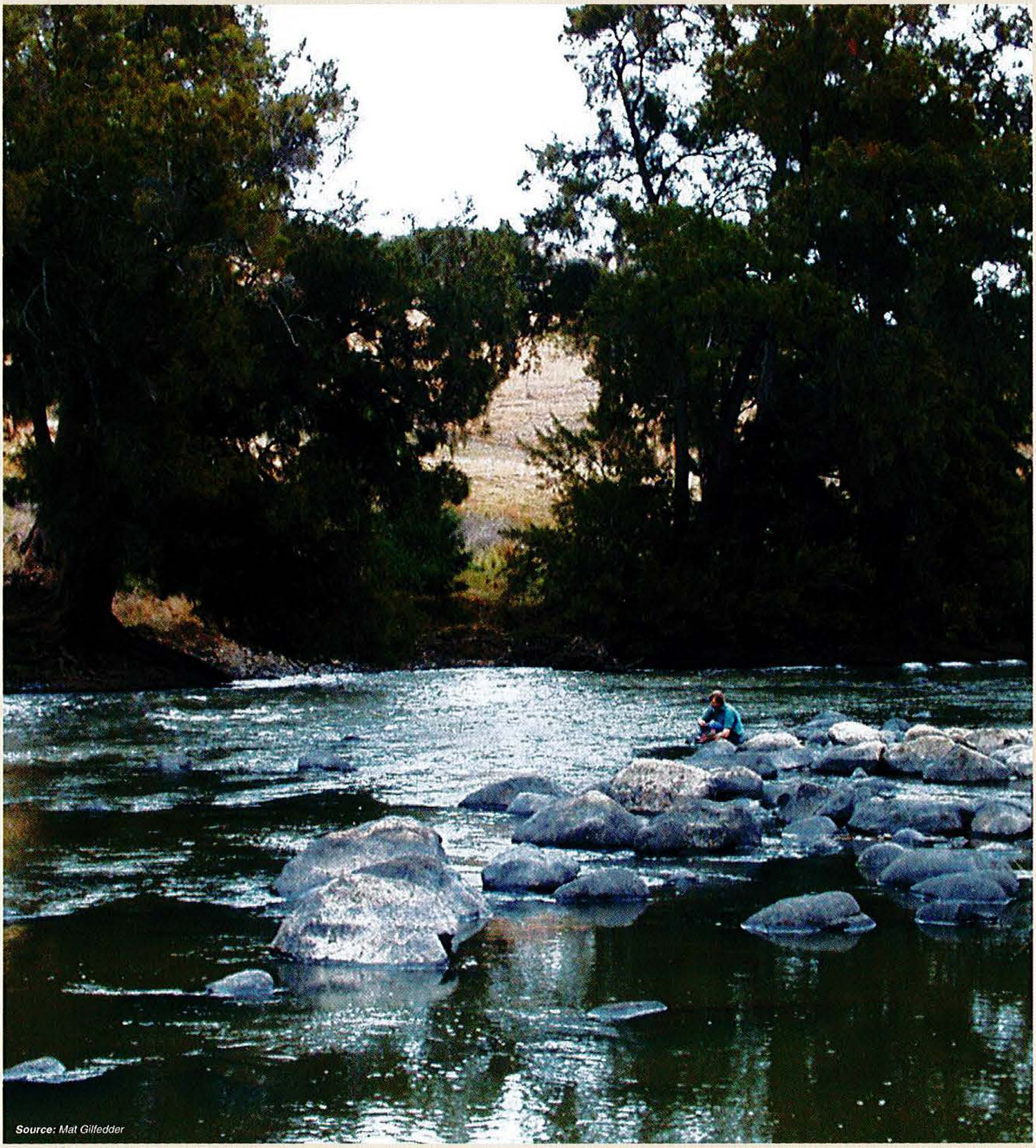
These achievements should then be built upon by developing more detailed catchment, sub-catchment and property level information. The Framework will then allow us to extrapolate from successfully managed catchments and to take advantage of rapidly growing and increasingly accessible natural resource data.

The Groundwater Flow Systems approach is still maturing but already provides a powerful framework for salinity management. But we must remember that it is not a unique characterisation that is right or wrong, but rather an approach that brings the information together.

It will continue to develop as new data comes in and as researchers test and reassess hypotheses. In the same way we will continue to reassess and adapt regional strategies in the light of new data, new demands and improved understanding.

The GFS Framework has several components, each of which will respond to fresh ideas and new data. In particular, monitoring requirements and the need to demonstrate management options will stimulate more case studies that are relevant to the salinity provinces in regional maps.

Those who use the GFS Framework will expect to know the level of confidence that they can assign to its outputs. This confidence level relates to the within-class variability of the GFSs that for some salinity provinces is significant. To reduce within-class variability we need to subdivide the class, but can do this only where the data and understanding of processes permit. At the same time, we need to recognise that some catchment variables will have greater impact on groundwater processes than others, something we must test through sensitivity analyses.



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Integrated catchment management in the Murray-Darling Basin

A process through which people can develop a vision, agree on shared values and behaviours, make informed decisions and act together to manage the natural resources of their catchment: their decisions on the use of land, water and other environmental resources are made by considering the effect of that use on all those resources and on all people within the catchment.

Our Values

We agree to work together, and ensure that our behaviour reflects that following values.

Courage

- We will take a visionary approach, provide leadership and be prepared to make difficult decisions.

Inclusiveness

- We will build relationships based on trust and sharing, considering the needs of future generations, and working together in a true partnership.
- We will engage all partners, including Indigenous communities, and ensure that partners have the capacity to be fully engaged.

Commitment

- We will act with passion and decisiveness, takingthe long-term view and aiming for stability in decision-making.
- We will take a Basin perspective and a nonpartisan approach to Basin management.

Respect and honesty

- We will respect different views, respect each other and acknowledge the reality of each other's situation.
- We will act with integrity, openness and honesty, be fair and credible and share knowledge and information.
- We will use resources equitably and respect the environment.

Flexibility

- We will accept reform where it is needed, be willing to change, and continuously improve our actions through a learning approach.

Practicability

- We will choose practicable, long-term outcomes and select viable solutions to achieve these outcomes.

Mutual obligation

- We will share responsibility and accountability, and act responsibly, with fairness and justice.
- We will support each other through the necessary change.

Our principles

We agree, in a spirit of partnership, to use the following principles to guide our actions.

Integration

- We will manage catchments holistically; that is, decisions on the use of land, water and other environmental resources are made by considering the effect of that use on all those resources and on all people within the catchment.

Accountability

- We will assign responsibilities and accountabilities.
- We will manage resources wisely, being accountable and reporting to our partners.

Transparency

- We will clarify the outcomes sought.
- We will be open about how to achieve outcomes and what is expected from each partner.

Effectiveness

- We will act to achieve agreed outcomes.
- We will learn from our successes and failures and continuously improve our actions.

Efficiency

- We will maximise the benefits and minimise the cost of actions.

Full accounting

- We will take account of the full range of costs and benefits, including economic, environmental, social and off-site costs and benefits.

Informed decision-making

- We will make decisions at the most appropriate scale.
- We will make decisions on the best available information, and continuously improve knowledge.
- We will support the involvement of Indigenous people in decision-making, understanding the value of this involvement and respecting the living knowledge of Indigenous people.

Learning approach

- We will learn from our failures and successes.
- We will learn from each other.