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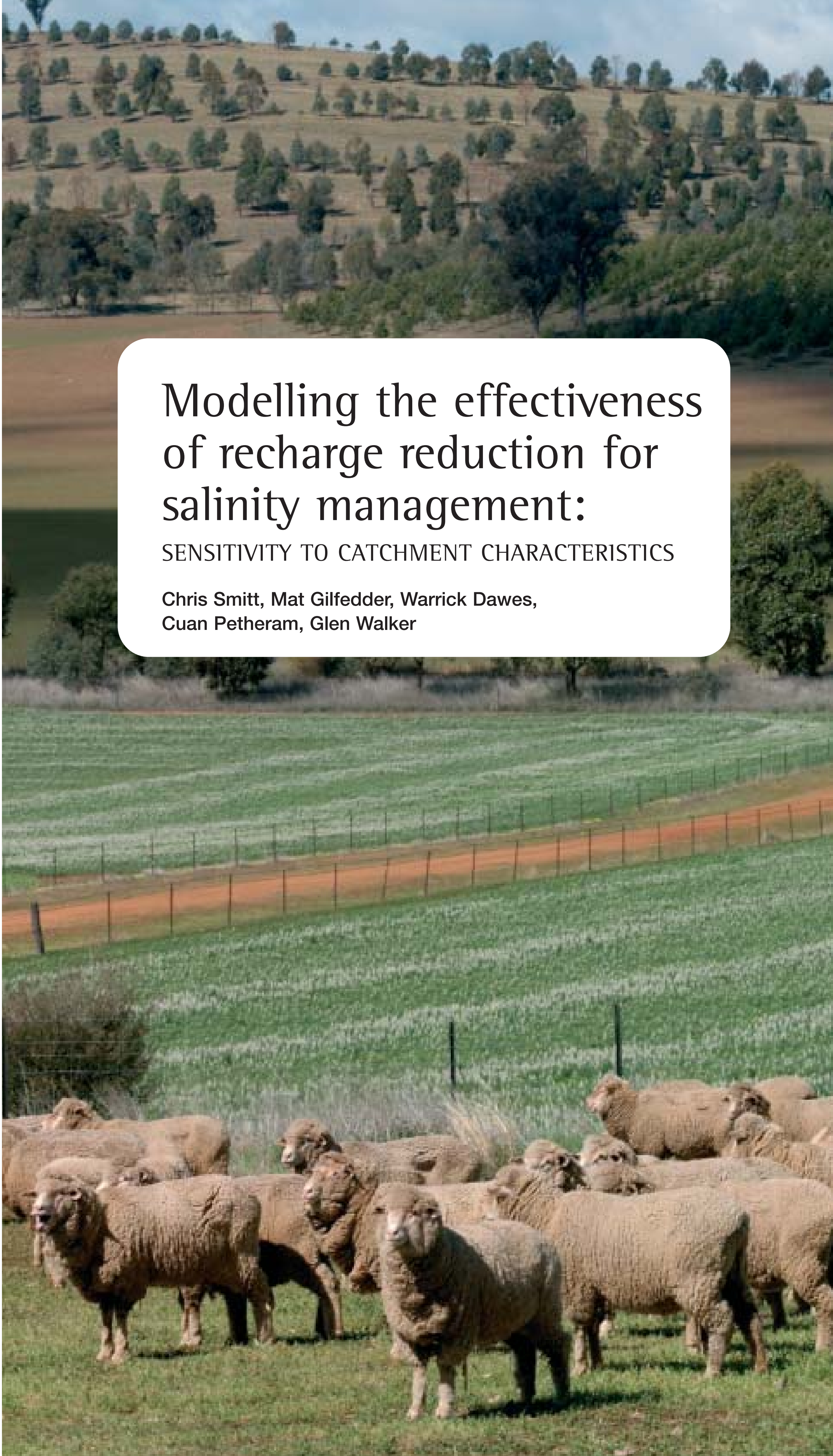

Modelling the effectiveness of recharge reduction for salinity management:

SENSITIVITY TO CATCHMENT CHARACTERISTICS

Chris Smitt, Mat Gilfedder, Warrick Dawes,
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MURRAY-DARLING BASIN COMMISSION

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CSIRO Land and Water Technical Report 20/03
CRC for Catchment Hydrology Technical Report 03/7
MDBC Publication 06/03

Published by: Murray-Darling Basin Commission

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Canberra ACT 2600

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ISBN: 1 876 830 51 4

Cover photo: Arthur Mostead *Margin photo: Mal Brown*

Acknowledgements

The authors acknowledge funding from the Murray-Darling Basin Commission through Strategic Investigations and Education projects (SI&E) Grant Number D9004: 'Catchment characterisation and hydrogeological modelling to assess salinisation risk and effectiveness of management options', and also through Grant Number D2013: 'Integrated Assessment of the Effects of Land use Changes on Water Yield and Salt Loads'. Thanks to the Project Steering Committees of both grants for taking time to provide feedback on direction.

Executive summary

The objective of this report is to use modelling to investigate the sensitivity of groundwater and other characteristics on the effect of recharge reduction on salinity management. This is a continuation of the work on recharge increase by Gilfedder et al. (2003). The emergent properties of a groundwater system are examined using scaling arguments that combine the effect of aquifer properties into a single dimensionless groundwater system similarity parameter *(G)*. This study will be based upon well-documented case studies used in the Australian Groundwater Flow Systems (Coram et al. 2000).

Dryland salinisation is recognised as a major degradation issue in southern Australia with rural and urban infrastructure, cropping and grazing lands, lakes, wetlands and rivers all directly affected. It has now become evident that management and control of salinity need to be developed and implemented so that this degradation of rivers and land does not continue to expand unabated. The effect of changes in land use on catchment yield or groundwater discharge is not instantaneous and there may be long time delays between any land use change and the subsequent changes in salinity. While the evaporated and runoff components may respond relatively quickly to a land use change, a reduction in recharge to a groundwater system may not express itself as a corresponding reduction in surface discharge for many years. The *timing* of effects of a large-scale land use change on catchment yield will be different for a range of groundwater systems within a catchment remains poorly understood. This timing is very important, especially when looking at the physical and economic viability of a range of possible management options, since groundwater discharge is the process, which mobilises salt to the land surface and to surface water bodies.

Strategies within this area of research have often been hampered due to a lack of measured data at catchment and regional scales, even in the well-studied parts of Australia's dryland regions. Therefore, any suitable approach that investigates the effect of land use change on groundwater discharge at this scale must be simple. One approach that offers a more rigorous estimate of a catchment's overall response to changes in land use for their component groundwater systems is to use a dimensionless similarity parameter (*G*) (Gilfedder et al. 2003). This allows the characterisation of a groundwater system to be simplified by combining transmissivity, specific yield, recharge, length and head. *G* can be visualised as the ratio of the system's *ability to fill* (t_V) compared to its *ability to drain* (t_H). As such, *G* gives an indication of the state of balance of a groundwater system. Relationship between *G* and groundwater response times caused by a reduction in recharge can then be examined using the FLOWTUBE groundwater model.

A simple approach has been developed to generate normalised groundwater system response curves following an increase in recharge, by using the time to drain (t_H) factor in combination with the amount of recharge change, to parameterise a simple discharge function. Predictions of groundwater response times are an essential part of predicting likely effects of land use change on stream salinity and salt loads into the future. In the absence of detailed hydrogeological and hydrological data at a regional scale, simple methods are needed. The *G* parameter provides a tool that can help simplify the investigation of catchment behaviour. It is not a '*silver bullet*', but will help improve the initial prediction of groundwater system responses across large areas without the use of process-based models.

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1. Introduction

Dryland salinisation is one of the main degradation issues in southern Australia (MDBMC 1999; PMSEIC 1999). Towns and cities, rural and urban infrastructure, cropping and grazing lands, lakes, wetlands, rivers and waterways are all directly affected by dryland salinity. The area already affected is around 5.7 million hectares, and the monetary value of damage caused as a direct result of dryland salinity has been variously estimated up to $0.5 billion per year (MDBMC 1999; PMSEIC 1999; NLWRA 2001). It has now become evident that more land and rivers will become more saline unless a plan which helps manage and control dryland salinity is developed and implemented.

The effect of changes in land use on catchment yield or groundwater discharge is not instantaneous and there may be long time delays between any land use change and the subsequent changes in salinity. While the evaporated and run-off components may respond relatively quickly to a land use change, a reduction in recharge to a groundwater system may not express itself as a corresponding reduction in surface discharge for many years. The *timing* of effects of a large-scale land use change on catchment yield will be different for a range of groundwater systems within a catchment remains poorly understood. This timing is very important, especially when looking at the physical and economic viability of a range of possible management options, since groundwater discharge is the process, which mobilises salt to the land surface and to surface water bodies.

Strategies within this area of research have often been hampered due to a lack of measured data at catchment and regional scales, even in the well-studied parts of Australia's dryland regions. Therefore, any suitable approach that investigates the effect of land use change on groundwater discharge at this scale must be simple.

One approach that offers a more rigorous estimate of a catchment's overall response to changes in land use for their component groundwater systems is to use a dimensionless similarity parameter (*G*) (Gilfedder et al. 2003). This allows the characterisation of a groundwater system to be simplified by combining transmissivity, specific yield, recharge, length and head. Relationship between *G* and groundwater response times caused by a reduction in recharge can then be examined using the FLOWTUBE groundwater model.

Another way of conceptualising *G* is as the ratio of two time factors. The first of these is the time factor for *groundwater discharge*. This time factor is related to the lateral draining of an aquifer and can be expressed as:

$$t_H = \frac{SL^2}{T} \quad , \qquad (1)$$

where t_H is the 'time to drain', *S* is the specific yield, *L* is the length of the catchment (m) and *T* is the transmissivity (m^2/yr).

The second of the time factors is that for *groundwater response to recharge*. This is related to the vertical filling of an aquifer in response to recharge and can be expressed as:

$$t_V = \frac{\Delta hS}{R} \quad , \qquad (2)$$

where t_V is the 'time to fill', Δh is the change in groundwater head (m) and *R* is the groundwater recharge (m/yr). The ratio of these two time factors provides a dimensionless parameter for the groundwater system:

$$G = \frac{t_V}{t_H} = \frac{\left(\frac{\Delta hS}{R}\right)}{\left(\frac{SL^2}{T}\right)} = \frac{\Delta hT}{RL^2} \quad , \qquad (3)$$

This type of analysis allows the simplification of a range of aquifer properties into a single similarity parameter (G), which gives a measure of the ratio of the system's *ability to fill* compared to its *ability to drain*.

1.1 Objective and outline

The objective of this report is to develop a simple method to predict groundwater system response to a reduction in recharge. This will be done through the use of modelling to investigate the sensitivity of groundwater and other characteristics on the effect of recharge reduction on salinity management.

The recent work on the impact of *increased* recharge (Gilfedder et al. 2003) will expanded upon. This study will be based upon well-documented case studies using the Australian Groundwater Flow Systems (Coram et al. 2000), which are described in more detail in the following section.

2. Catchment Case Studies

It is clear that management options are needed to mitigate dryland salinity. However, the options that are being trialled for managing dryland salinity by catchment groups around Australia are based mainly on the experience of the professionals involved and often have little scientific substance to support them. As a result, the Murray-Darling Basin Commission (MBDC) released a strategy, in September 2000 that takes a 100-year view of the salinity threats to Basin resources and the potential benefits of salinity control options (MDBMC 2000) to provide some scientific background to current and future management options.

Following this, the Prime Minister announced a *National Action Plan for Salinity and Water Quality in Australia* which identifies some immediate actions to address dryland salinity and deteriorating water quality in key catchments and regions across Australia. (Commonwealth of Australia 2000).

In January 2001, the National Land and Water Resources Audit (the Audit) was released with the aim of providing a nationwide assessment of Australia's land, vegetation and water resources, to support both present and future sustainable development. The Audit's Strategic Plan groups these natural resource issues into seven themes, each with its own work plan. The Dryland Salinity theme of the Audit (theme 2) is comprised of five distinct projects that address the current extent and predicted future risk of dryland salinity, the impact of land use practices on dryland salinity, and possible land management options.

Within Project 2 of the Dryland Salinity Theme, management options are targeted through the development of a national classification system or 'catchment characterisation'. Several case studies that are representative of key Australian landscapes prone to salinisation were chosen. The choice was made on the basis of the *Australian Groundwater Flow Systems contributing to dryland salinity* (Coram et al. 2000). This Groundwater Flow Systems approach builds on the earlier *National Catchment Classification* (Coram 1998). This hydrogeological framework groups catchments with similar groundwater processes operating and for which management options are expected to be similar. The framework is based on geology, geomorphology, spatial extent of flow system (local, intermediate, and regional) and other factors that are known to influence salinity occurrence.

In total, eight case studies were chosen to provide a national cross-section of the 11 groundwater flow systems identified by this framework (see Figure 2). The four catchments for the Audit's case studies were Billabong Creek (NSW; Baker et al. 2001), Kamarooka (VIC; Hekmeijer et al. 2001), Lake Warden (WA; Short et al. 2000), and Popes (a subcatchment of Wanilla: SA; Stauffacher et al. 2000). The four case studies under the Catchment Characterisation Project are Kyeamba Creek (NSW; Cresswell et al. 2003), Brymaroo (QLD; Smitt et al. 2003), Loddon Plains (VIC; Hekmeijer and Dawes 2003a), and Axe Creek (VIC; Hekmeijer and Dawes 2003b).

2.1 Australian Groundwater Flow Systems

Australian Groundwater Flow Systems (GFS) have been classified according to a two-step classification: 1 size. 2 geology.

The broadest classification of Australia's (GFS) is on the basis of size alone, and they have been named *Local*, *Intermediate* and *Regional* in order of increasing flow length and areal extent (Coram et al. 2000). This coarse description provides an indication of flow systems' general time to change between equilibrium states. **Figure 1** shows an idealised response of the three flow system types to a step change in a uniform recharge regime. Even with the most rapidly changing Local system there may be a time lag in response of a decade, and a total time to respond of many decades. Many Regional systems have only just begun to respond to changes made over 100 years ago.

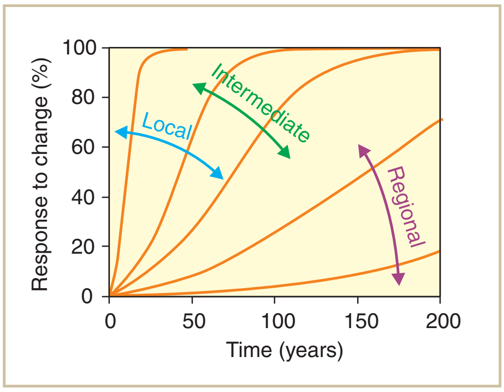

Figure 1. Generic time response of Local (solid), Intermediate (long dash) and Regional (short dash) groundwater systems. Source: Walker et al. 2003.

Figure 2 shows the Australia-wide distribution of Local, Intermediate and Regional systems. A large proportion of the Local systems, for example, are associated with coastal areas in the east, north and south of Australia, and with the Yilgarn Block in the west. Local systems may be present above both Intermediate and Regional systems, but there is not necessarily any connection between systems of different scale.

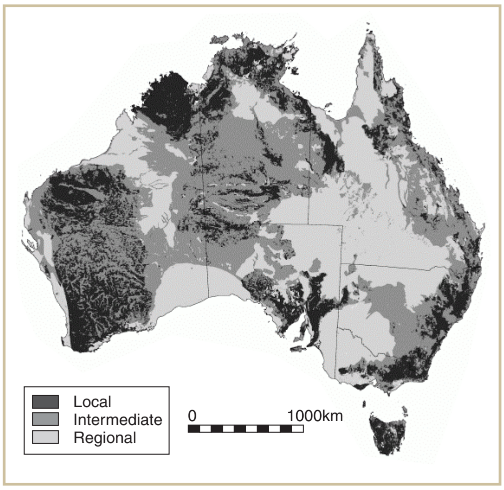

Figure 2. Distribution of Local, Intermediate and Regional groundwater flow systems across Australia Source: Coram et al. 2000.

The second stage of the flow systems classification is by parent geology.
The five significant hydrogeological provinces identified by Coram et al. (2000) are deeply-weathered Precambrian rock, Cainozoic sediments, Palaeozoic rocks, Mesozoic sediments and Cainozoic and Mesozoic volcanic. Of these, the deeply-weathered Precambrian rock type is associated with around 60% of the mapped dryland salinity expression, mainly in the coastal region of South Australia and the Yilgarn Block in Western Australia as seen in **Figure 3**.

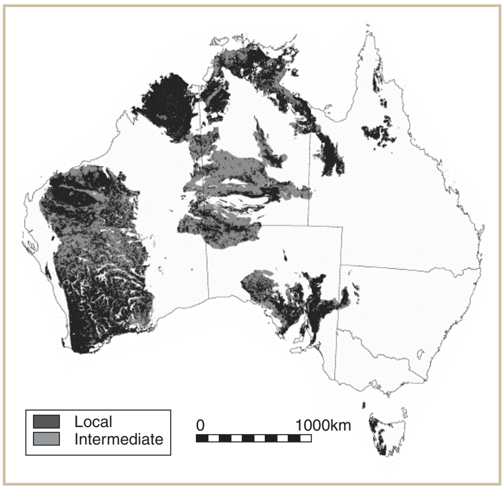

Figure 3. Distribution of Local and Intermediate groundwater systems in Precambrian rocks. Source: Coram et al. 2000.

The most significant GFS province for the eastern seaboard of Australia is the Palaeozoic rock. This covers a wide swathe from the South Australian-Victorian border north to Cairns in Queensland, the Lachlan Fold Belt extending through New South Wales, and much of Tasmania. This GFS covers much of the mapped dryland salinity in the eastern states (see **Figure 4**).

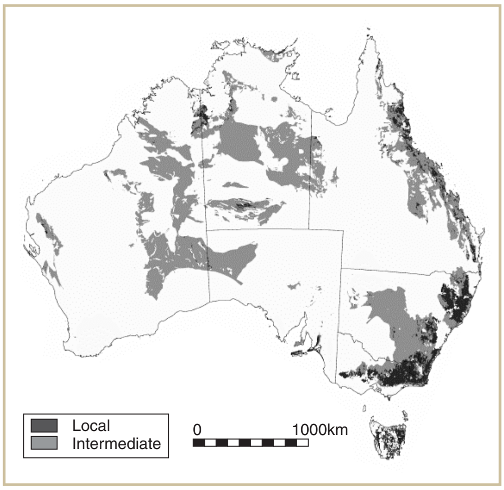

Figure 4. Distribution of Local and Intermediate groundwater systems in Palaeozoic rocks. Source: Coram et al. 2000.

2.2 Case studies

There are several groundwater system case studies across Australia. The locations of the catchments used in these studies are shown in **Figure 5** and their attributes are listed in **Table 1** and **Table 2**. These represent a range of groundwater system types, salinisation, and possible remediation strategies. **Table 2** gives the calculations of *G* for each case study using the parameters outlined in **Table 2**. For each case study, a *G* value corresponding to a recharge of 1 mm/yr and also for estimated current recharge (~20 mm/yr) have been given.

Figure 5. *Locations of Groundwater Flow Systems case study sites.*

TABLE 1. Simplified case study attributes used to calculate *G*.

Case study	K (m/d)	Thick [*D*] (m)	Specific yield [*S*]	Length (m)	Head drop [Δh] (m)	Recharge min/max [*R*]# (mm/yr)	t_H [SL^2/Kd] (yr)	t_V [$\Delta h\ S/R$] (yr)	G [t_V/t_H]
Kamarooka	1	20	0.06	4,500	24	2.45	166	588	3.53
						15.06	166	96	0.57
Billabong	10	10	0.05	52,000	168	3.13	3,704	2,684	0.72
						25	3,704	336	0.09
Popes	0.05	25	0.01	4,250	137	3	396	457	1.15
						24	396	57	0.14
Kyeamba	10	20	0.1	68,000	261	2.63	6,334	9,924	1.57
						21	6,334	1,243	0.20
Brymaroo	2	30	0.02	4,400	51	2.5	17.7	408	23.08
						20	17.7	51	2.88

 # Recharge is initially 1 mm/yr and changed to the increased rate given in this column at t = 0.
Source: Gilfedder et al. 2003.

TABLE 2. Catchment attributes for each of the case studies.

Catchment	Groundwater Flow System	Mean rainfall (mm/yr)	Estimated recharge (mm/yr)	Land Area (km^2)	Typical land use
Billabong	Regional groundwater flow system in Cainozoic alluvial sediment	700	21.5	3,000	Cropping
Kamarooka	Local groundwater flow system in deeply weathered fractured rock	427	15	100	Cropping and grazing
Lake Warden	Regional groundwater flow system in Cainozoic sediment	510	20	1,700	Cropping and annual pasture
Axe Creek	Intermediate groundwater flow system in weathered fractured rock	540	60	328	Grazing, pastures and production forestry
Kyeamba Creek	Intermediate groundwater flow system in fractured rock	650	21	602	Cattle pasture with some cropping
Popes	Local and Intermediate groundwater flow system in deeply weathered rock	520	24	180	Cereal cropping and grazing
Brymaroo	Local groundwater flow system in basaltic fractured rock	670	76	14	Grain cropping

3. Recharge Reduction

The first part of this section presents normalised modelled response curves for recharge reduction scenarios. The second part of this section provides a general discussion on the variability in the modelled behaviour and discusses hysteresis between these responses and those obtained by Gilfedder et al. (2003) for increased-recharge scenarios. The third part of this section proposes a simple discharge function which can be used to predict the timing of groundwater system response following a decrease in recharge.

3.1 Modelled response curves

Individual case studies

This section presents the modelled results from each case study catchment. **Figures 6 to 10** shows the normalised groundwater discharge response for three decreased-recharge scenarios against time.

FLOWTUBE was parameterised for each of the case studies using values from the detailed case study reports: Popes (Stauffacher et al. 2000), Brymaroo (Smitt et al. 2003), Billabong Creek (Baker et al. 2001), Kamarooka (Hekmeijer et al. 2001), Kyeamba Creek (Cresswell et al. 2003). It should be noted that each of these FLOWTUBES have varying widths and slopes.

In each case, the groundwater system was 'primed' by running the model to equilibrium with at the 'current' recharge rate (ranging from 15 to 76 mm/yr, depending on the catchment). This recharge rate was then reduced by 50%, 90%, or reduced back to 1 mm/yr (simulating a 'pre-cleared' condition). **Figures 6 to 10** show the normalised response of the groundwater system to a new equilibrium under each of these three recharge reduction scenarios.

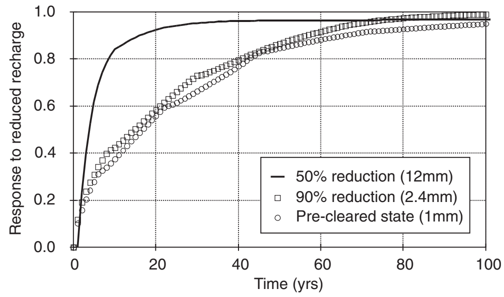

Figure 6. *Modelled FLOWTUBE response of Popes catchment groundwater discharge, to different amounts of recharge reduction. Reduction from 24 mm/yr recharge at time = 0.*

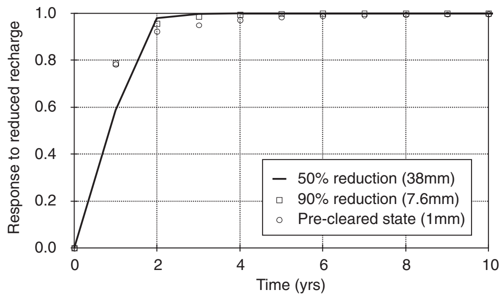

Figure 7. *Modelled FLOWTUBE response of Brymaroo catchment groundwater discharge, to different amounts of recharge reduction. Reduction from 76 mm/yr recharge at time = 0.*

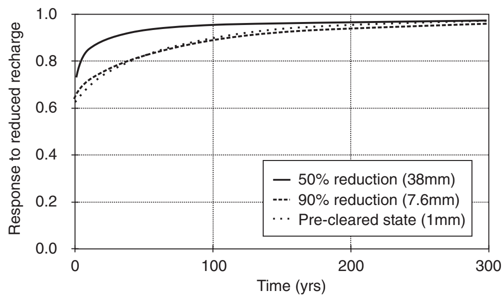

Figure 8. *Modelled FLOWTUBE response of Billabong catchment groundwater discharge, to different amounts of recharge reduction. Reduction from 21.5 mm/yr recharge at time = 0.*

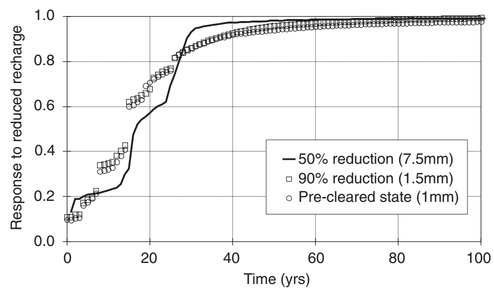

Figure 9. *Modelled FLOWTUBE response of Kamarooka catchment groundwater discharge, to different amounts of recharge reduction. Reduction from 15 mm/yr recharge at time = 0.*

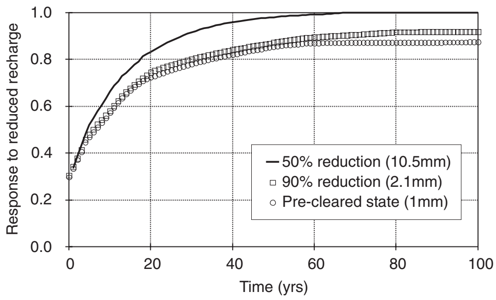

Figure 10. Modelled FLOWTUBE response of Kyeamba catchment groundwater discharge, to different amounts of recharge reduction. Reduction from 21 mm/yr recharge at time = 0.

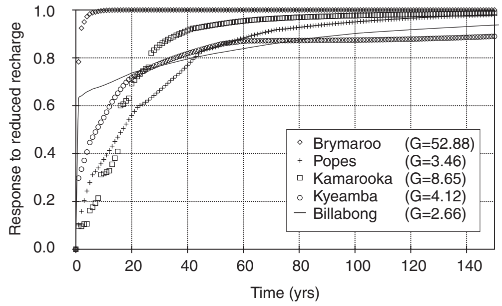

***Figure 11.** Modelled groundwater system response over time, for each case study catchment from current recharge rates (between 15–76 mm/yr) to a reduced recharge rate of 1 mm/yr.*

These FLOWTUBE modelling results show an almost instantaneous response which gradually slows down to reach a new equilibrium. Another point to note is that the response is affected by the *amount* of recharge reduction, as well as by the hydrogeological properties of each case study catchment. Smaller reductions in recharge come to equilibrium more quickly than larger changes do.

Comparison of case studies

The responses for each case study are shown as figures for two scenarios: (i) response to change from current recharge rates to 1 mm/yr, and (ii) response to change from current recharge rates to 50% of current rates.

The response to a change from equilibrium with current recharge rates (ranging between 15-76 mm/yr) to a recharge of 1 mm/yr is shown in **Figure 11**. The response to a change from equilibrium with current recharge rates (ranging between 15-76 mm/yr) to a recharge reduction of 50% is shown in **Figure 12**.

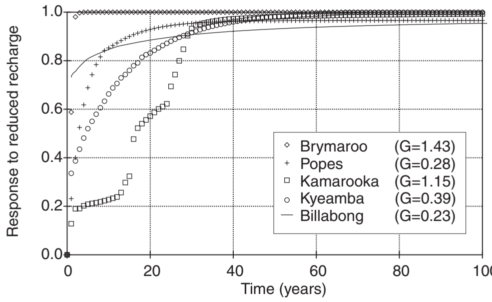

***Figure 12.** Modelled groundwater system response over time, for each case study catchment from current recharge rates (between 15–76 mm/yr), to a reduced rate of 50% current.*

The different response times for a reduction in recharge for each of the case studies are shown in **Table 3**. This table shows the time taken for 50% and 90% of a return to equilibrium (this is 0.5 and 0.9 on the y-axis of **Figures 11 and 12**). These results will be used in the next section of this report to build a method for predicting groundwater system response.

TABLE 3. Modelled response time, and G parameter time factors for reduction in recharge from current recharge rates to 1 mm/yr.

Catchment	Recharge (*R*) (mm/yr)	Time for 50% response (yr)	Time for 90% response (yr)	Time for system to fill (t_V)	Time for system to drain (t_H)	*G* (R=1 mm/yr)
Kamarooka	15.0	16	37	1,440	166	8.6
Popes	24.0	17	64	1,370	396	3.5
Billabong	21.5		95	8,400	3,704	2.3
Kyeamba	21.0	8	70	26,100	6,334	4.1
Brymaroo	76.0	1	2	1,020	18	57.7

TABLE 4. Relationships between catchment response time and the classification of the groundwater system operating in the catchment

Catchment	Classification	Scale	Modelled time for 90% response (yr)
Kamarooka	Local groundwater flow system in deeply weathered fractured rock	Local	37
Popes	Local groundwater flow system in deeply weathered sediment	Local	64
Billabong	Regional groundwater flow system in Cainozoic alluvial sediment	Regional	95
Kyeamba	Intermediate groundwater flow system in fractured rock	Intermediate	70
Brymaroo	Local groundwater flow system in basaltic fractured rock	Local	2

Analysis of groundwater systems shows a relationship between the response time and the scale of the catchment (**Table 4**). For example, a local system will respond quicker than a regional system. This provides confidence in the structure of the GFS framework.

3.2 Explaining case study response

The response of the case study groundwater systems to decreased recharge exhibits considerable variability when compared to the response to increased recharge. Some of the case study responses show hysteresis while others do not. This section discusses a conceptualisation of groundwater system behaviour, in an attempt to describe the modelled behaviour of the case studies.

Conceptualisation of recharge-discharge behaviour

A leaking-sided bucket conceptualisation has been used to help describe the modelled behaviour (**Figure 13**) in terms of which variables may be important at a given time for a given change in recharge. In this conceptualisation, D_0 is aquifer discharge, while D_s is discharge direct to the land surface, which occurs when the aquifer (bucket) is almost full.

For any given recharge rate the bucket system will come to a stable equilibrium. The behaviour of the system to a recharge reduction will depend on:

(a) whether there is significant surface discharge at the start ('3' in **Figure 13**), or

(b) whether aquifer discharge is the main form of response ('1' in **Figure 13**). For example, a decrease in recharge which results in the water level in the bucket system moving from:

- **'3' to '2':** Response dominated by surface discharge—relatively fast.
- **'2' to '1':** Response dominated by aquifer discharge—much slower.
- **'3' to '1':** Initial response fast, becoming much slower in the later stages.

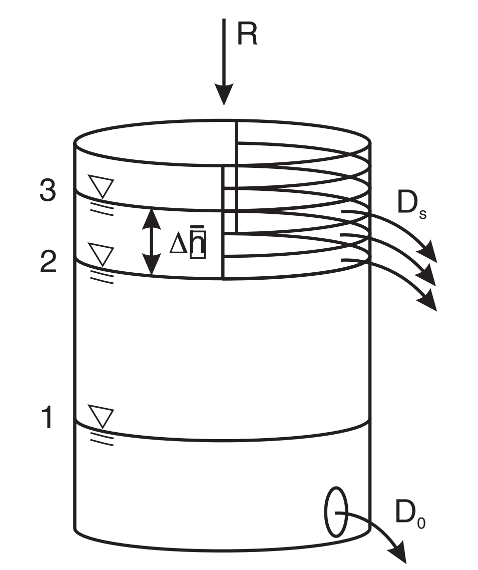

Figure 13. *Leaking-sided bucket conceptualisation of a groundwater system. [where* R *is recharge,* D_s *is surface discharge,* D_0 *is aquifer discharge, and* $\Delta\bar{h}$-bar *is a change in groundwater head which leads to a change in area of surface discharge].*

Hysteresis

Hysteresis is the ability of a groundwater system to fill compared to its ability to drain. There are many causes of hysteresis including catchment scale, catchment shape, underlying geology and soil moisture characteristics in the unsaturated zone. Results from two case studies are presented showing the hysteresis (see **Figures 14 and 15**). Brymaroo shows the greatest change in response with the groundwater system being able to drain much faster than it can fill. For example, for a 50% change in recharge, the Brymaroo groundwater system is able to completely drain within four years whereas it takes over 20 years to fill. It should also be noted that in the Popes case, there is a distinct difference in shape between the increased and decreased recharge.

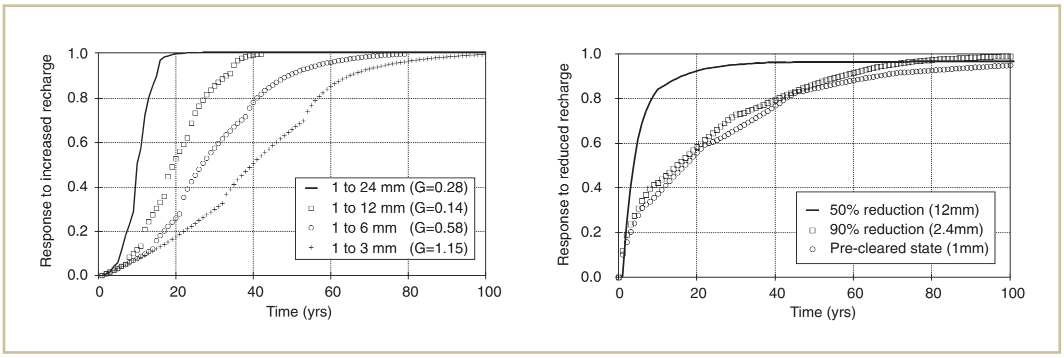

Figure 14. *Popes modelled FLOWTUBE groundwater system response to recharge change.*
(a) Increase from 1 mm/yr recharge. *(b) Reduction from 24 mm/yr recharge.*

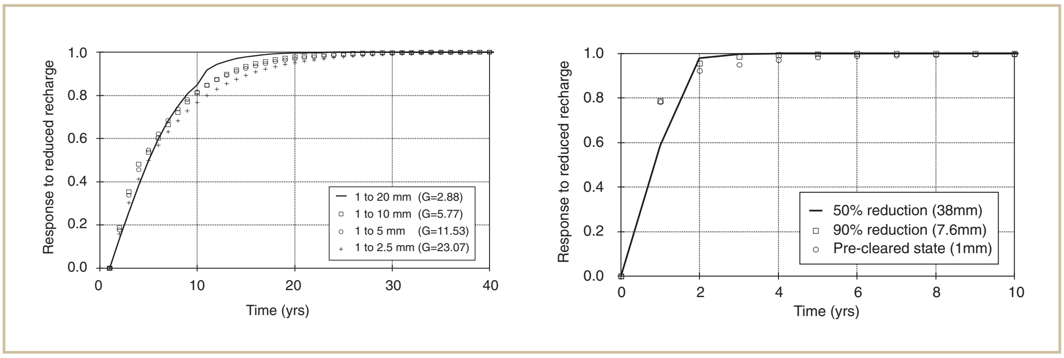

Figure 15. *Brymaroo modelled FLOWTUBE groundwater system response to recharge change.*
(a) Increase from 1 mm/yr. *(b) Reduction from 76 mm/yr recharge.*

3.3 Predicting case study response

This section of the report describes the formation of a simple method to generate response curves from simple catchment attributes. A two-part method is outlined which uses the results of FLOWTUBE modelling of five case studies. This method is used to generate parameters for a 1-parameter response function.

Response function

A simple model of response to decrease recharge was used. The effects of hysteresis described in the previous section mean that this function is different from the 2-parameter function used by Gilfedder et al. (2003) to predict the effect of increased recharge.

The response function chosen for recharge reduction weights the decrease in recharge to the subsequent decrease in discharge, according to a time scale and rate of change. A simple 1-parameter exponential function has been used.

$$D(t) = 1 - exp\left(-\frac{t}{t_{half}}\right) \quad , \qquad (4)$$

where t_{half} is the time when 50% of the response has occurred.

Parameterising the response function

The parameterisation involved two stages.

a) use groundwater system variables to predict the t_{half} parameter

b) use this to parameterise the discharge function in Equation 4.

The FLOWTUBE model was used to make predictions for catchment response to different reductions in recharge in **Section 3.1** of this report. It can be seen that the response time was affected by the groundwater system properties, and by the amount of recharge change. It should be noted that the catchment shape (convergent, divergent), and slope (convex, concave) will also affect this response to some degree. While the FLOWTUBE model takes these factors into account, the *G* parameter does not incorporate changes in width, and includes only an average slope. Despite this simplification, there was some correlation between these modelled predictions, and the 'time to drain' (t_H from Equation 1) for the five case study catchments, for both a 50% and a 95% reduction in recharge (**Figure 16**).

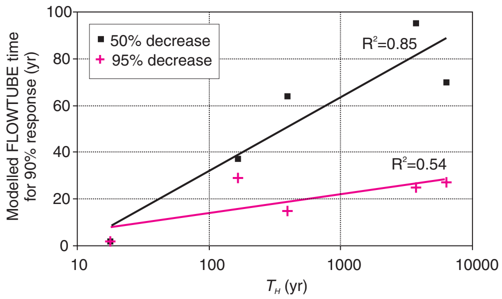

Figure 16. *Relationship between* t_H *and modelled FLOWTUBE response time for two different recharge reductions.*

Conceptually, the response of a groundwater system to a reduction in recharge is related to the system's properties, as well as to the amount of recharge change. Thus, Equation 5 scales the response time of the system (related to t_H), by the change in recharge. A logarithmic curve was used to obtain $T_{90\%}$:

$$T_{90\%} = 3\sqrt{\frac{R_{old}}{R_{new}}} \times ln\left(\frac{t_H}{15}\right) \quad , \qquad (5)$$

where $T_{90\%}$ is the time for 90% response (note: for Equation 4, $T_{half} = T_{90\%} / 2.3$), R_{old} is the recharge before the change, R_{new} is the recharge after the change, and t_H is from Equation 1. The comparison of FLOWTUBE results with the results of Equation 5 are given in **Figure 17**, showing the reasonable correlation between the prediction and the FLOWTUBE modelled results.

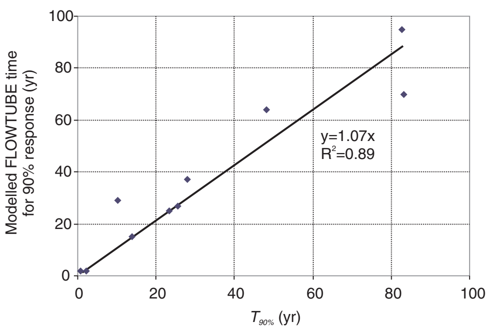

Figure 17*. Comparison between the results of Equation 5 and FLOWTUBE predictions.*

Figures 18 to 22 show the FLOWTUBE modelling results together with the predictions obtained using the method described in this section. For many of the case studies there is a close fit, while for others the fit is more tenuous. What is encouraging is that the approach is able to distinguish between very fast catchments (Brymaroo) and much slower ones (Kyeamba), and is also sensitive to large or small changes in recharge.

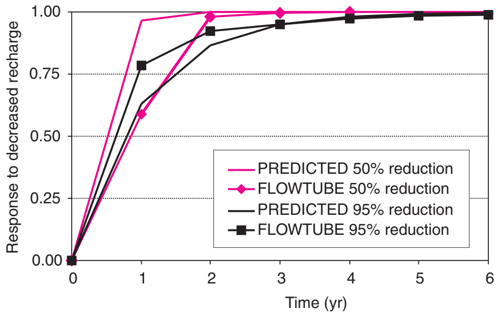

Figure 18. *Comparison between the FLOWTUBE modelling results and the prediction (using Equations 4 and 5) [for Brymaroo].*

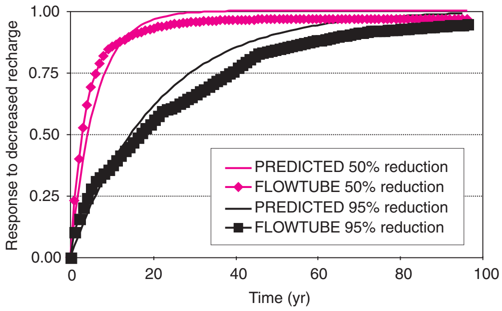

Figure 19. *Comparison between the FLOWTUBE modelling results and the prediction (using Equations 4 and 5) [for Popes].*

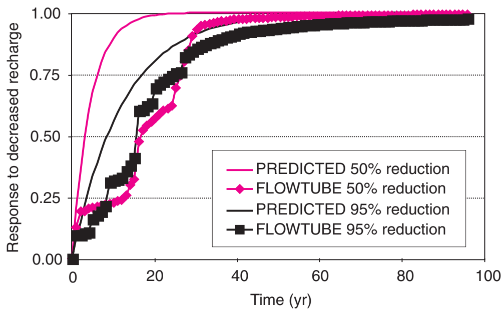

Figure 20. *Comparison between the FLOWTUBE modelling results and the prediction (using Equations 4 and 5) [for Kamarooka].*

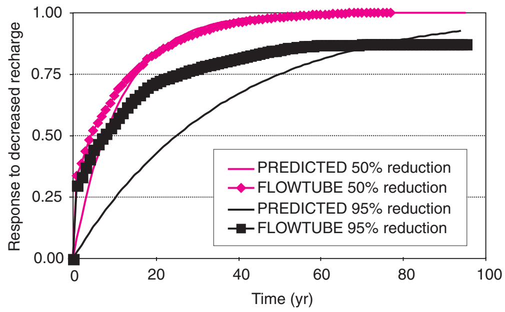

Figure 21. *Comparison between the FLOWTUBE modelling results and the prediction (using Equations 4 and 5) [for Kyeamba].*

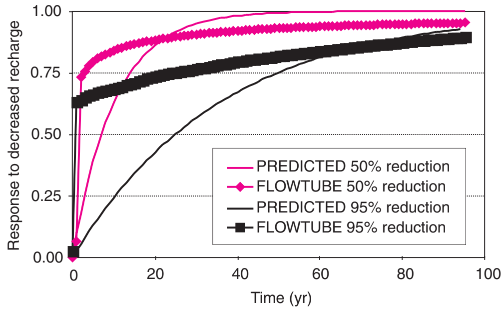

Figure 22. *Comparison between the FLOWTUBE modelling results and the prediction (using Equations 4 and 5) [for Billabong].*

4. Discussion

Large parts of Australia have a lack of detailed hydrogeological data on which to base future predictions of changes in land and river salinity. There is a need for relatively simple approaches to determine the effect of land use changes on the timing of salinity expansion or remediation at a regional or catchment scale. The simplified approach to characterising groundwater systems presented in this report is a step towards this end.

The simplification of groundwater system responses is a necessary step towards catchment or regional-scale prediction of the effects of land use change on the timing of changes in groundwater discharge. This leads on from the simplified modelling approaches used by groundwater models such as FLOWTUBE, which allow groundwater systems to be conceptualised one-dimensionally. Surface hydrologists have already tackled this type of simplified approach.

The scaling argument approach that was developed in Gilfedder et al. (2003) and used in the current report provides an approach for characterising groundwater systems. It can be seen that the modelled groundwater system response is affected by the amount of recharge change, and by the aquifer properties themselves. These properties have been combined through the use of a dimensionless similarity parameter (G) to reduce the complexity of the characterisation. G provides a measure of the ratio of a groundwater system's ability to drain compared to its ability to fill.

Prediction of groundwater system response to changes in recharge is complicated because of the hysteresis in the response between increases and decrease in recharge rate. Because of this, it is necessary to use different response functions, parameterised in different ways, in order to predict groundwater system response to a change in recharge.

A simple discharge function has been described which captures the basic variation in the response of the modelled case studies to decreased recharge. There are several assumptions which may limit the use and applicability of this method. These include:

- *Recharge to lower parts of the catchment arises solely from direct rainfall.* In other words, surface run-off (recharge rejection) is lost to the groundwater system and does not have the chance to infiltrate in the lower parts of the catchment.
- *Aquifers are unconfined.*
- *Recharge reductions take place over the entire catchment.* As discharge areas shrink following catchment-wide recharge decrease, they could begin to accept rainfall and run-on recharge directly to compensate, maintaining waterlogged conditions unless the discharge areas are highly revegetated.

This function should not be expected to accurately predict exact responses of particular groundwater systems, however it provides an objective means for assessing relative responses across large areas. This will make it a useful tool for prioritising areas within large catchments which may respond more quickly to land use change.

The parameterisation of the discharge function in this paper fits the case studies reasonably well. However, as more information and other case studies become available, it is likely that change will need to be made to this parameterisation.

The accuracy of this type of approach is difficult to verify, because of the long time scales involved, and also because of the lack of detailed actual measurements for different groundwater systems. As such, our ability to predict groundwater system response will depend on our knowledge of how actual hydrogeological parameters vary within and between systems.

5. Conclusions

The following conclusions have been made from this study:

- Catchment characteristics can be simplified by using *G*, a dimensionless similarity parameter that combines transmissivity, specific yield, recharge, length and head. By using this approach, an indication of the state of balance of a groundwater system is achieved as *G* is a measure of the ratio of the system's ability to fill (t_V) compared to its ability to drain (t_H).
- There seem to be clear relationship between the catchments response time and the scale of the catchment. For example, a local system will respond quicker than a regional system, if the same amount of recharge reduction was applied.
- A simple approach has been developed to generate normalised groundwater system response curves following an increase in recharge, by using the time to drain (t_H) factor in combination with the amount of recharge change, to parameterise a simple discharge function.

Further work to be undertaken in this study will include the effect of momentum, i.e. how are response times affected if a change in recharge is applied to the groundwater system when (i) it is in equilibrium and (ii) the system is still responding to a previous change. It is expected that the momentum of the groundwater will play an important role in determining response times for the catchment.

Predictions of groundwater response times are an essential part of predicting likely effects of land use change on stream salinity and salt loads into the future. In the absence of detailed hydrogeological and hydrological data at a regional scale, simple methods are needed. The *G* parameter provides a tool that can help simplify the investigation of catchment behaviour. It will help improve the prediction of groundwater system responses without the use of process-based models.

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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, taking the long-term view and aiming for stability in decision-making.
- We will take a Basin perspective and a non-partisan 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.