GOVERNMENT OF WESTERN AUSTRALIA

A REVIEW OF GROUNDWATER PUMPING TO MANAGE DRYLAND SALINITY IN WESTERN AUSTRALIA

DEPARTMENT OF ENVIRONMENT
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SALINITY AND LAND USE IMPACTS

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Environment

A REVIEW OF GROUNDWATER PUMPING TO MANAGE DRYLAND SALINITY IN WESTERN AUSTRALIA

by

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Department of Environment

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SALINITY AND LAND USE IMPACTS SERIES

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Cover photograph:

Discharge from Maxon Farm groundwater pumping trial by

Mary-Ann Berti

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Summary

Saline shallow watertables under most of the broad valleys of the Wheatbelt are the main cause of land and stream salinisation. Shallow watertables also prevent infiltration leading to inundation and waterlogging. Groundwater pumping, in appropriate conditions, could lower the watertable, prevent the further spread of salinity and, in the long term, recover saline land and freshen streams and rivers.

This report reviews the efficiency and effectiveness of groundwater pumping to delay, contain or reverse the spread of land and water salinity in Western Australia. The main conclusions and the following recommendations are based only on the case studies that are relevant to the hydrogeology, climate and topography of the WA landscape.

Conclusions

- Effective groundwater pumping depends mainly on aquifer characteristics. The lateral extent of the watertable lowering depends primarily on local hydrogeology and aquifer types.
- Groundwater pumping from palaeochannels will only be effective in reducing surface dryland salinity if the overlying layer is pervious and not confining.
- The response time of a shallow watertable to groundwater pumping depends on the degree of connectivity between the surficial sediments and palaeochannel sediments.
- Lowering the hydraulic head in semi-confined aquifers and the watertable in unconfined aquifers does not necessarily result in the reclamation of agricultural land and its return to production as it may be difficult to leach the salt from the soil profile even after a sustained period with the watertable at two metres below the surface.
- Groundwater pumping is often expensive compared to the local damage costs although it may be more economical than other engineering options for very valuable assets like the Wellington Reservoir water resource.
- Iron fouling reduces the life of pumps and pipes and increases the costs of pumping schemes significantly.

Recommendations

- Select groundwater pumping sites (preferably established sites in the Wheatbelt) that represent diverse landforms and different aquifer types.
- Implement monitoring programs to enhance the current projects and effectively monitor the impact of lowering the watertable on assets at risk. These sites should include agricultural land, rural towns and important public assets such as roads and water supplies, biodiversity conservation areas such as Toolibin Lake.

- Undertake a long-term pumping and monitoring project to evaluate the effectiveness of de-pressurising the deep aquifers in reducing soil salinity for various types of soils in the Wheatbelt. There are many sites with appropriate bores that could be used to address this gap in current knowledge.

- Conduct a comprehensive cost-benefit analysis encompassing all the impacts of groundwater pumping on various public and private assets on catchment and small-scale systems.

- In the next four years, monitor and analyse the effectiveness of the current projects (public and private projects e.g. rural towns, Maxon Farm) in terms of bore layouts.

- Run numerical models at small- and catchment- scales to find the most appropriate bore design to achieve the required outcomes.

1 Introduction

The salinisation of land and water is a major ecological and economic problem facing Australia. In the next 100 years about 12 million hectares of arable land, most of the water resources and wetlands in southern Australia will probably be affected to various degrees by increased salinity (Short & McConnell 2000). About seventy percent of this land and most of the wetlands and water resources occur in Western Australia. In addition, salinity damages public infrastructure including towns, road and rail systems.

The symptoms and processes leading to salinity in Australia are well researched and documented (Bleazby 1917; Wood 1924; Bettenay et al. 1964; Peck & Hurle 1973). There is a considerable body of research describing and analysing the different components of the hydrological cycle and the role of these in the development of dryland salinity (Peck & Williamson 1978; Allison & Hughes 1978; George & Nulsen 1985; Johnston 1987; Williamson et al. 1987; George & Frantom 1990a; Ruprecht & Schofield 1991a,b; Salama et al. 1993a, b; Salama et al. 1994).

Many studies have described the impacts of land clearing and the groundwater and surface water interaction on salinity development around Australia (Allison et al. 1990; Schofield et al. 1988; Schofield & Ruprecht 1989; Ruprecht & Schofield 1991a, b). Some of these studies date back to the beginning of the last century when railway engineers in Western Australia observed the increased salinity levels in dams and water courses (Bleazby 1917; Wood 1924). The scale of the problem and complexity of the processes are such that there are fewer studies into containing or reversing the spread of salinity. The likelihood of reversing or, even containing, salinity and recovering saline rivers is low for much of the south-west of Western Australia (George et al. 2001; Hatton et al. 2002).

Hydrological imbalance due to the excess water in the landscape is the primary cause of the dryland salinity problem. Managing this excess water has been the focus of many studies and various options have been promoted to restore the hydrological imbalance by reducing recharge (agronomical/vegetative solutions), enhancing discharge (engineering solutions including groundwater pumping) and combinations of both.

The National Dryland Salinity Program (NDSP) was established in 1993 in response to the scale of the problem. The aim of the program was to develop tools to help understand the nature and extent of salinity and to research develop and extend practical approaches to manage dryland salinity across Australia effectively. At a state level, the Salinity Strategy released by the Western Australian State Government in April 2000 recognised groundwater pumping as one of the tools to remove excess water from the landscape.

In 2002, the Western Australian State Government established the Engineering Evaluation Initiative to determine the effectiveness and efficiency of tools like groundwater pumping and drainage. This project is being coordinated by the Department of Environment in partnership with the Department of Agriculture (DoA), Department of Conservation and Land Management (CALM), the Commonwealth Scientific Investigation and Research Organisation (CSIRO), and Natural Resources Management (NRM) regional community groups. This four-year project will also consider the potential downstream impacts of these engineering tools.

2 Review objectives

This report reviews the efficiency and effectiveness of groundwater pumping to delay, contain or reverse the spread of land and water salinity in Western Australia. It specifically discusses and attempts to answer the following questions:

- What types of aquifers respond best to pumping?
- Do pressure reductions in confined aquifers and lowering the watertable in unconfined aquifers result in reduced salinity of soil?
- Are there simple tools, such as spreadsheets, to calculate the impact of pumping on the watertable in terms of depth and area of influence?
- Is pumping cost-effective and how long will it take to get a return on investment?
- If installing pumping bores, which designs and bore layout are most likely to be effective and require lowest running costs?

This report presents case studies relevant to the hydrogeology, climate and topography of the Western Australian landscape and draws general conclusions to address the objectives above.

3 Groundwater pumping

The aim of groundwater pumping for salinity management is to maximise the watertable fall while minimizing the volume of groundwater pumped. The removal of groundwater reduces groundwater storage in the aquifer. Once the watertable is drawn down to some distance from the natural surface, the groundwater stops discharging to the surface, wetlands and rivers, and the impacts of salinity are minimised. It is therefore important to understand:

- how the different types of water-bearing formations (aquifers) respond to groundwater pumping
- what effects lowering the watertable may have on the land and water bodies.

The economic viability of groundwater pumps for salinity management depends on the method of lifting groundwater from a bore. The pumps can be divided according to their power sources:

- electrically powered
    - electric submersible
    - compressed air driven
- combustion engine
- wind powered
- solar powered.

Unlike wind and solar powered pumps, the electrically powered pumps are characterised by relatively high yields due to their capacity for continuous pumping.

The description of the methods for lifting groundwater from a bore is detailed in the report prepared for National Dryland Salinity Program (SKM 2001) and so will not be discussed in this report.

4 Aquifer types in Western Australia

An aquifer is a geological unit that can store and transmit water at rates fast enough to supply reasonable volumes to a bore. Unconsolidated sands and gravel, sandstones, limestone, and fractured igneous and metamorphic rocks are examples of aquifers. Aquifers can be placed in three major categories: unconfined, confined and semi-confined (Kruseman & Ridder 1970). Aquitards are water-bearing formations that transmit insufficient volumes of water to allow the completion of production bores.

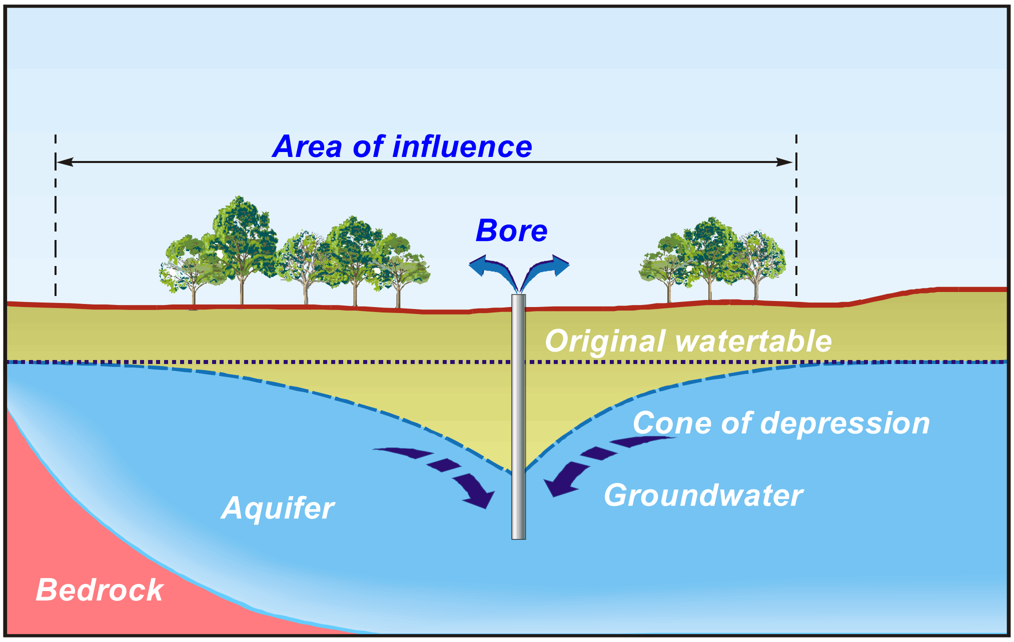

Figure 1. The cone of depression or loss of hydraulic head

(From ABC's of Groundwater, Centre for Groundwater Studies, 2000)

Brief descriptions of the three aquifer types relevant to the Western Australian landscape, and their responses to groundwater pumping follow.

- *Unconfined aquifers*: An unconfined aquifer is a permeable layer filled or partly filled with water and overlying a relatively impervious layer. The aquifer upper boundary is formed by a watertable at atmospheric pressure. The pressure of water in a bore penetrating an unconfined aquifer does not, in general, rise above atmospheric pressure. In fine-grained unconfined aquifers, which occur in some parts of the Wheatbelt, gravity drainage of pores is often not instantaneous; consequently, the water is released only some time after the water level falls. These are referred to as unconfined aquifers with delayed yield. The surficial sediments and sand seeps in the Wheatbelt are considered such unconfined aquifers.

- *Confined aquifers*: A confined aquifer is a completely saturated aquifer with impervious upper and lower boundaries. Completely impervious layers rarely exist in nature so confined aquifers are rarer than unconfined aquifers. The pressure of the water (i.e. hydraulic head) in confined aquifers is usually higher than atmospheric pressure so the water in bores rises higher than the top of the aquifer. The water in a confined aquifer is called confined or artesian water. The deep sedimentary aquifers of the Perth Basin are examples.

- *Semi-confined or leaky aquifer*: A completely saturated aquifer is bounded above by a semi-pervious layer and below by either an impervious or a semi-pervious layer. A semi-pervious layer is defined as a layer with a low, though measurable, permeability. Lowering the piezometric pressure in a leaky aquifer by pumping generates a vertical flow of water from the semi-pervious layer into the pumped aquifer. Most aquifers in the Wheatbelt, particularly in the valley flats, are semi-confined.

Reduction of the hydraulic head is the aim of groundwater pumping from semi-confined aquifers where groundwater is kept under pressure by overlying semi-pervious layers. The loss of hydraulic head caused by pumping propagates rapidly because the release of groundwater from storage is entirely due to the compressibility of the water and the aquifer material. So, the loss of head may still be measurable even a few hundred metres from the bore. Pumping relatively small volumes of water may have a significant impact on the groundwater hydraulic head far from the pumped bore (Figs 2, 3). The important characteristic of semi-confined aquifers is the relatively fast recovery of the hydraulic head once pumping stops.

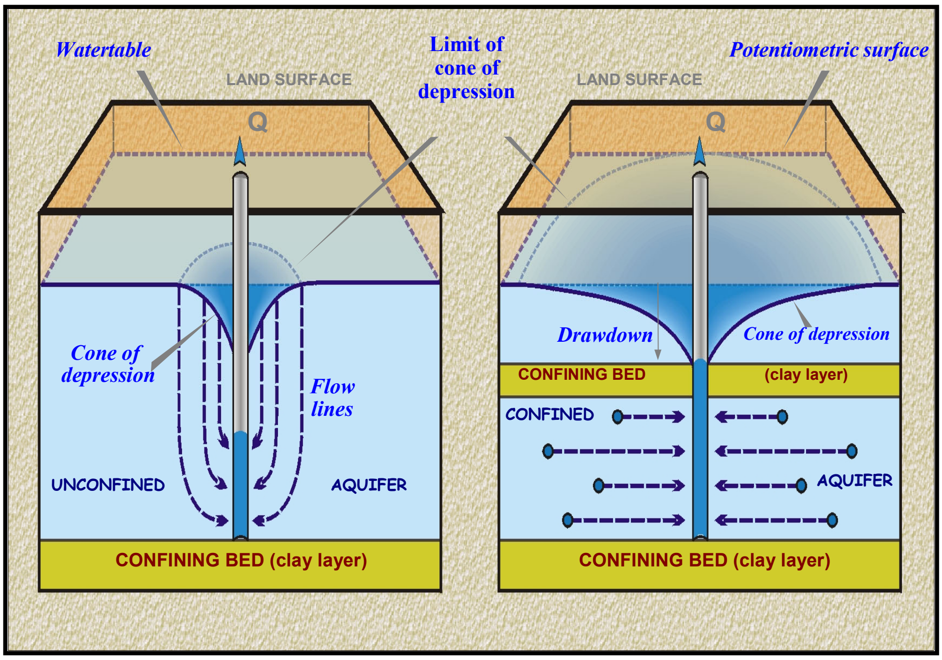

Figure 2. The responses of confined and unconfined aquifers to groundwater pumping

(From ABC's of Groundwater, Centre for Groundwater Studies, 2000)

The propagation of hydraulic head losses in unconfined aquifers is rather slow (Fig. 1). Since the release of water from groundwater storage in these is mostly due to dewatering the zone through which the water is moving, the loss of hydraulic head is measurable only fairly close to the pumped bores, certainly not more than 100 m (Fig. 2). The recovery of the watertable in unconfined aquifers is much slower than the recovery of the hydraulic head in confined aquifers. The response of semi-confined aquifers is intermediate between confined and unconfined aquifers. This point is significant as semi-confined aquifers represent the majority of deep aquifers in the Wheatbelt of WA.

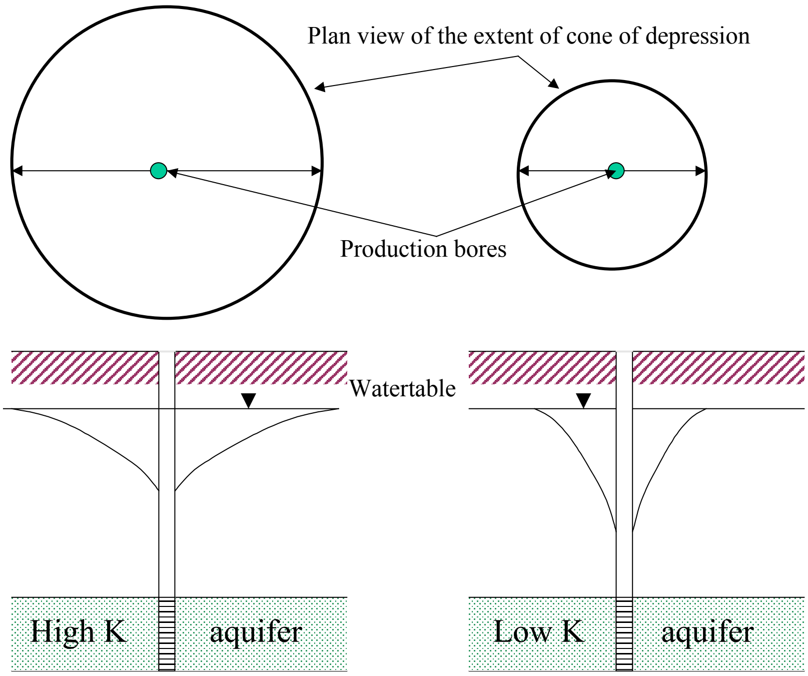

Figure 3. Drawdown cones for aquifers with high and low hydraulic conductivity

(From ABC's of Groundwater, Centre for Groundwater Studies, 2000)

As most case studies of groundwater pumping in eastern Australia were conducted on unconfined aquifers in the Murray–Darling Basin, their results are of limited value to studying the impact of pumping the semi-confined aquifers of the WA Wheatbelt. Most pumping tests for salinity management in the Wheatbelt of Western Australia were carried out in the low-lying areas of the Zones of Ancient and Rejuvenated Drainage (Fig. 4). This is not surprising as most salt-affected agricultural land occurs in the broad valleys (Fig. 5) of the Zone of Ancient Drainage (Short & McConnell 2000).

The Zone of Ancient Drainage occurs east of the Meckering line (Mulcahy 1967) and is divided into northern and southern zones based on the soil landscape mapping carried out by the Department of Agriculture. The Zone is characterised by a gently undulating plateau, wide divides, long gentle hill-slopes and broad flat valley floors 2–10 km wide that comprise alluvium and colluvium (Fig. 5). The valley floors have a low gradient (1:500 or less).

The Zone of Rejuvenated Drainage is west of the Meckering line where drainages are clearly defined and carry water each year (Fig. 4). The dissection of the lateritic profile gives moderately to gently inclined rises and low hills. The gradient is 1:500 to 1:100. The eastern part of the Collie River catchment that includes the Spencer Gully and Maxon Farm subcatchments occurs in this zone. The Darling Range Zone is characterized by defined drainage lines, and rivers such as the Blackwood River cut into the Range forming deep steep-sided valleys. Although salinity occurs throughout these three zones, most of the severely affected land occurs to the east of the Meckering Line (Fig. 4).

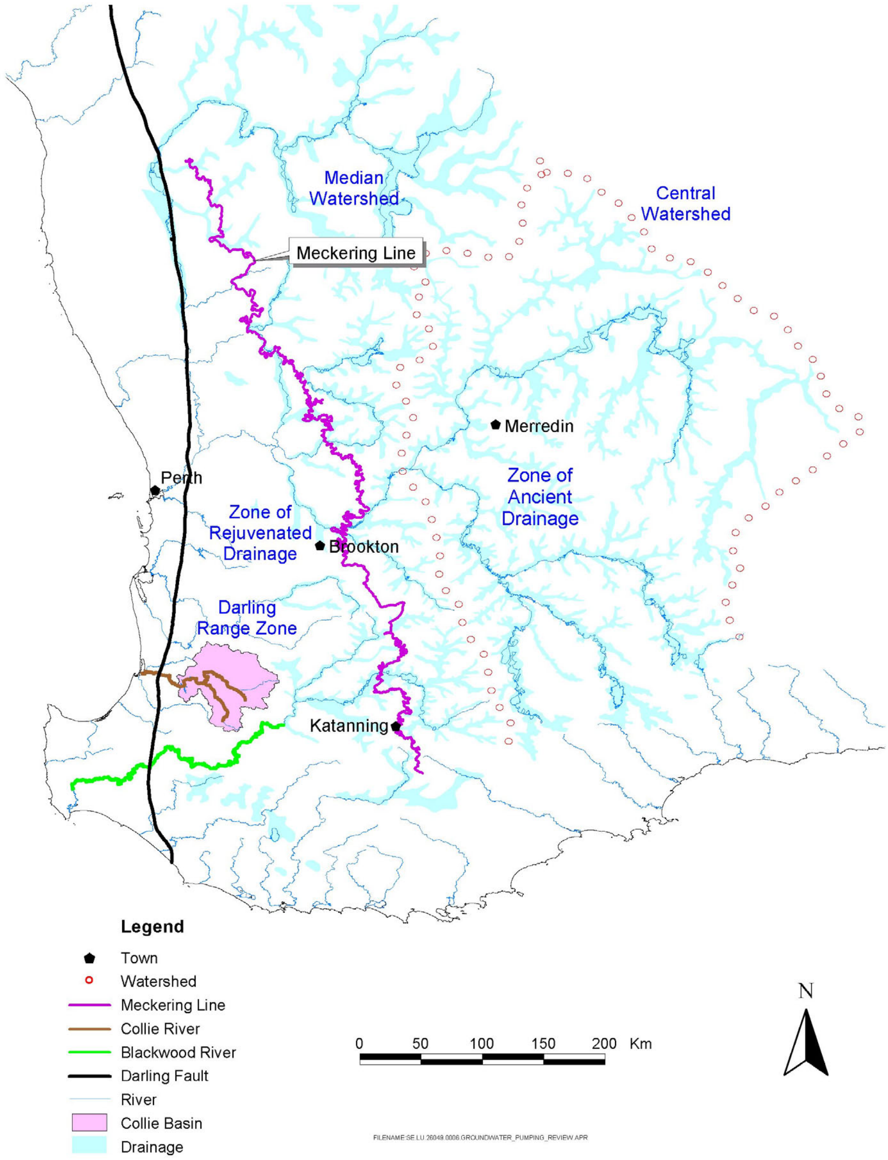

Figure 4. Drainage pattern in the south-west of Western Australia

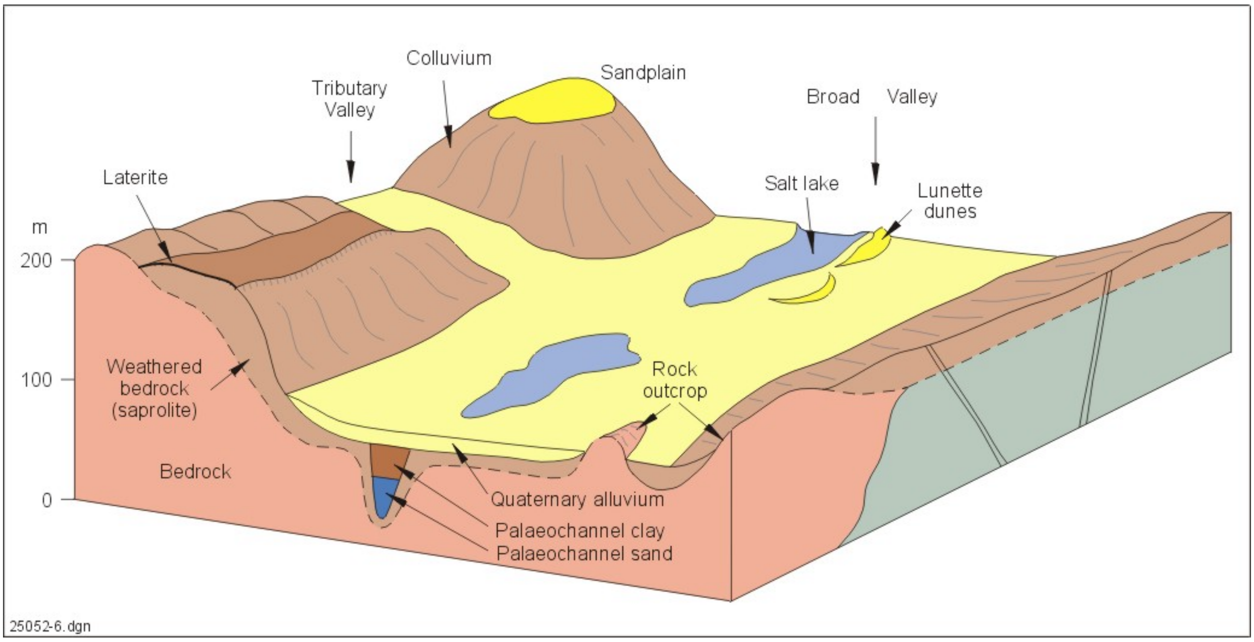

Figure 5. Typical WA Wheatbelt valley floor

5 Hydraulic properties of aquifers

Water-bearing formations contain voids filled with water and interconnected to some degree. The water in these voids is capable of moving from one void to another, thus circulating through water-bearing formations. The property of water-bearing formations to transmit water (rather than hold water) is called hydraulic conductivity and is an important factor in determining the impact of groundwater pumping on lowering the watertable in unconfined aquifers and reducing the hydraulic head in confined and semi-confined aquifers (Fig. 3).

Formations with a considerable volume of voids but without interconnectedness are called aquitards. These formations cannot convey water from one void to another and are characterised by low hydraulic conductivity (for example, dolerite rocks).

The void sizes are also important in determining the efficiency of flow within these formations. Sediments and weathered rocks with high clay content are characterised by very small voids through which water moves with difficulty, resulting in low connectivity and low hydraulic conductivity. Generally well-sorted sands and gravel have high hydraulic conductivity from 1–1000 m/d (Davis 1969), while the hydraulic conductivity of silty sand and fine sand are from 0.001–1 m/d (Davis 1969).

The hydraulic conductivity of the weathered granite profiles and sediments, including palaeochannel sediments, in Western Australia ranges from ~ 0.001 to ~10 m/d (George 1992; Peck et al. 1980; Clarke et al. 2000). The average hydraulic conductivities for the weathered granite and the overlying weathered clay material in the Wheatbelt range from 0.5 to ~ 1 m/d and 0.05 to 0.1 m/d respectively (Clarke et al. 2000). Surficial and palaeochannel sediments are characterised by higher hydraulic conductivity ranging from 1 to 100 m/d. The hydraulic conductivity determines the rate of groundwater movement into a production bore from the water-bearing formations and also the size of cone of depression (Fig. 3). For any given aquifer, the cone of depression increases in depth and extent with the duration of pumping. Drawdown at any point at a given time is directly proportional to the pumping rate and inversely proportional to hydraulic conductivity of the aquifer. As shown in Figure 3, aquifers of high hydraulic conductivity develop shallow cones of wide extent whereas aquifers of low hydraulic conductivity develop tight, deep drawdown cones.

6 Case studies

The high costs and environmental degradation caused by salinity are already well recognized by the communities that live with its effects. Catchment-scale surveys and salinity assessment tools such as Land Monitor show that rising saline groundwater also damages many public and private assets like agricultural land, water resources, wetlands (flora and fauna) and rural infrastructure (towns, roads, etc.). Containing or controlling the effects of salinity for each of these asset classes requires different strategies so this section categorises the evaluations of groundwater pumping according to the main objectives — recovering agricultural land, recovering water resources, minimizing the effects of saline groundwater on infrastructure and recovering biodiversity assets.

6.1 Recovering agricultural land

Most experiments in the management of dryland salinity in WA were carried out in the more undulating and dissected landscape of the western parts of the Darling Plateau in the hydrologic Zone of Rejuvenated Drainage and the Darling Range Hydrologic Zone (Fig. 4). The Collie River catchment has been the focus of many of these studies (Loh 1975; Loh & Stokes 1981; Schofield & Ruprecht 1989; Ruprecht & Schofield 1991a, b). In most of these experiments the aim was to reduce the natural groundwater discharge with vegetation systems like tree plantations and agroforestry systems such as alley farming. Partial reforestation of the natural drainage lines in the Collie River catchment to control rising surface water salinity was carried out in the late 1970s and early 1980s but the restoration of salt-affected land has not been demonstrated yet.

The lack of economically viable perennial vegetation to lower groundwater levels has resulted in individual farmers in the Wheatbelt (predominantly in the Ancient Drainage Zone, which encompasses most of the salt-affected agricultural land) opting to install drainage systems (primarily deep open drains). The rapid fall of the watertable and the potential to prevent further expansion of the saline areas are accepted as the major benefits but, because some of the salinity in the valley flats is due to the groundwater pressure in confined or semi-confined aquifers, the effectiveness of the drains is limited. The water levels and hydraulic head in deep aquifers cannot fall deeper than the bottom of the open drain. In such cases, groundwater pumping might be able to lower the watertable below the root zone across large areas.

Case study 1

George and Nulsen (1985) described the use of groundwater pumping to recover salt-affected land at Dalwallinu. The single production bore drilled into the weathered granite at Dalwallinu could produce 3 L/s (260 m^3/day). The reduction in deep aquifer head was observed up to 800 m from the bore, but the estimated maximum impact on the shallow watertable was only 200 m. This single bore was estimated to reclaim 20 hectares of the several hundred hectares of salt-affected surrounding land.

Case study 2

George and Nulsen (1985) described similar results from Frankland where the pumping bore produced only 0.5 L/s (43 m^3/day). The impact on the watertable was observed up to 250 m from the production bore and about 10 hectares of land were reclaimed.

Case study 3

Williamson et al. (2001) reported lower rates of pumping of 0.1–0.15 L/s (8–12 m^3/day) from palaeodrainage channels comprising Tertiary and Quaternary sediments near Dumbleyung. The pumping continued for 6 years and the watertable was lowered by 0.3 m/year to a distance of 30 m and 0.07 m/year at 350 m from the production bore respectively. The study concluded that, although the watertable was lowered to about 1 m below the natural surface at a distance of 350 m, this might not be enough to prevent movement of salt to the soil surface.

Generally, the critical depth to watertable at which salinity inhibits plant growth is 1 to 2 m (Teakle & Burvill 1945). Peck (1978), using the theory of steady isothermal upward movement of groundwater, concluded that the critical depth under dryland conditions was greater and generally 1–6 m. Therefore, one of the criteria for groundwater pumping to recover agricultural land is to lower watertable more than 2 m below the surface.

Case study 4

George and Frantom (1990a, b) and Salama et al. (1994) discussed the impact of groundwater pumping based on modelling the water balance of affected catchments. George and Frantom (1990b) suggested that a 5 ha saline seep in Wallatin Creek could be reclaimed by pumping at a rate of 0.2 L/s (16 m^3/day) from deeply weathered granite aquifers. Their estimation was based on the water budget of the salt-affected areas.

Case study 5

Salama et al. (1994) estimated the water balance at Cuballing, east Perenjori and Wallatin Creek catchments using the numerical model MODFLOW. The study suggested that a production bore capable of pumping 0.3 L/s (24 m^3/day) could eventually lower the watertable by more than 2 m within 600 metres.

Case study 6

Salama et al. (1989) evaluated the effectiveness of groundwater pumping in lowering the watertable in palaeochannel aquifers on the Salt River system within the Avon River Catchment. Three production bores approximately 50 m deep were installed into the palaeochannel system. Pump test data suggested that the hydraulic head in the deep aquifer was drawn down by up to 25 m. The study concluded that the deep aquifer was in direct hydraulic connection with the surficial sediments overlying the aquifer and that groundwater pumping (of the required volume) at a rate of 6 L/s (518 m^3/day) would reduce the heads in the aquifers for distances up to 3 km along the palaeochannel.

Case study 7

Eight months of pumping from a palaeochannel in Toolibin Lake resulted in no detectable lowering of the shallow watertable although the hydraulic head in the palaeochannel was lowered by 2 m at ~ 500 m from the production bores.

Informal cases

In addition to above studies, there are several sites where individual farmers installed production bores to limit the spread of salinity or to protect the family home and farm sheds.

Evaluating case studies

It is difficult to evaluate the effectiveness of the above cases for one or more of the following reasons:

- Aquifer types were not documented.
- Most of the cases involved only numerical modelling without any construction or actual pumping, so, their results are only indicative.
- The impacts of pumping in leaching salt from the soil were not documented.
- Sites were inadequately monitored.

6.2 Recovering water resources

Before the deep-rooted native vegetation was cleared, there was little seepage of deep saline groundwater to the natural drainage lines so the surface runoff generated in the south-west catchments was much fresher than now. Since clearing, groundwater recharge rates have risen more than a hundred-fold (Allison & Hughes 1978; Peck & Williamson 1987; Nulsen 1998). The enhanced recharge into the aquifers and the consequent rise of the watertable have greatly increased the base flow of groundwater to drainage lines. Shallow saline groundwater, induced by rising hydraulic heads in the deep semi-confined aquifer systems, has dramatically raised the salinity of rivers and their tributaries.

Since the enhanced natural discharge is caused by a change in the groundwater balance, the principal objective of groundwater pumping is to restore the groundwater balance by artificially enhancing the discharge rate to match the current recharge rate. The rate of groundwater pumping, therefore, depends on the scale of the salt-affected area. Theoretically, if the combined natural discharge and groundwater pumping is less than the recharge rate, the watertable will keep rising. On the other hand, if the discharge rate is greater than the recharge rate, the watertable will fall and seepage to the surface may stop. Because the response of water level to enhanced discharge in large-scale catchments is not instantaneous, it is possible to lower the watertable locally even if the discharge rates are lower than the recharge rate. So, understanding the groundwater dynamics and water balance is a pre-requisite to successful salinity management in this type of environment.

There are few case studies and little research into the effects of groundwater pumping on surface water salinity. The only long-term groundwater pumping scheme is on the River Murray 150 km north of Adelaide in South Australia (Telfer 1989). The Woolpunda and Waikerie groundwater schemes along the River Murray were initiated in the late 1970s. The aim of these large-scale schemes is to intercept saline groundwater before it discharges into the river. The schemes are important elements of an overall strategy to combat rising river salinity, rising water levels and expanding land salinisation throughout the entire Murray Basin. The intercepted groundwater is piped to evaporation basins about 10 km from the pumping site. Large volumes (thousands of cubic metres of groundwater annually) are pumped from the Murray Group, the unconfined limestone aquifer extending beneath the River Murray. The schemes have kept the groundwater level under the river for the last 20 years and stabilised it. Although these schemes highlight the effectiveness of groundwater pumping in controlling water level rise, the system design, the effects on river or soil salinity, the cost-effectiveness of the project or the environmental effects of disposal of these huge volumes of water have not been documented yet.

Numerical models considering catchment water balance were used recently in the Collie River catchment (Maxon farm subcatchment) to quantify the reduction of surface water salinity by groundwater pumping (Mauger et al. 2001).

Borefield design has an important bearing on the discharge rate. (Dogramaci et al. 2002a, b). The borefield at Maxon Farm is in the middle of the catchment and consists of 12 bores 200 m apart in two rows parallel to the natural drainage line. The model shows that, after two years of continuous pumping, the salt load discharged from the catchment will be reduced by approximately 20%. It is important to note that the hydrogeology and hydraulic properties of the aquifer in the Maxon Farm catchment are different from those in the Murray Basin. Some of the important differences are outlined in Table 1.

Table 1. Comparing aquifers of the Murray Basin and Maxon Farm

	Murray Basin	*Maxon Farm*
Scale	Regional scale catchment	Small scale catchment
Geological setting	Sedimentary basin	Weathered and fractured igneous rocks
Hydraulic conductivity	High (10–100 m/day)	Low (0.1–1 m/day)
Type of aquifer	Unconfined aquifer	Semi-confined aquifer
Surface water	Permanent flow	Ephemeral

6.3 Minimising the impact of saline groundwater on infrastructure

Dryland salinity causes extensive damage to town infrastructure like roads and railways, concrete structures, sporting grounds, dams and reservoirs and even threatens the existence of many rural towns in the lower rainfall areas (< 350 mm/year) of Western Australia.

Town site salinity should be considered separately from other locations within the landscape. While the causes of dryland salinity in rural towns are similar to those of agricultural lands, additional factors exacerbate the problem:

- the location of the towns within the surrounding catchment
- additional water imported into the towns
- artificial structures that form barriers to water infiltration or cause inundation and flooding.

Most of the rural towns were thought to have been on the extensive path network established by the Aboriginal people. These paths were often located on the valley floors. Most rural towns were established to support the transport by rail of agricultural products from farms to major ports and cities. The rail tracks and, therefore, the towns were established along valley floors — the parts of the landscape that are now groundwater discharge zones. Being low in the landscape has played a major role in the development of dryland salinity for some of these rural towns (for example, Tambellup). By contrast, rural towns, like Bruce Rock, not located low in the landscape do not have significant dryland salinity problems.

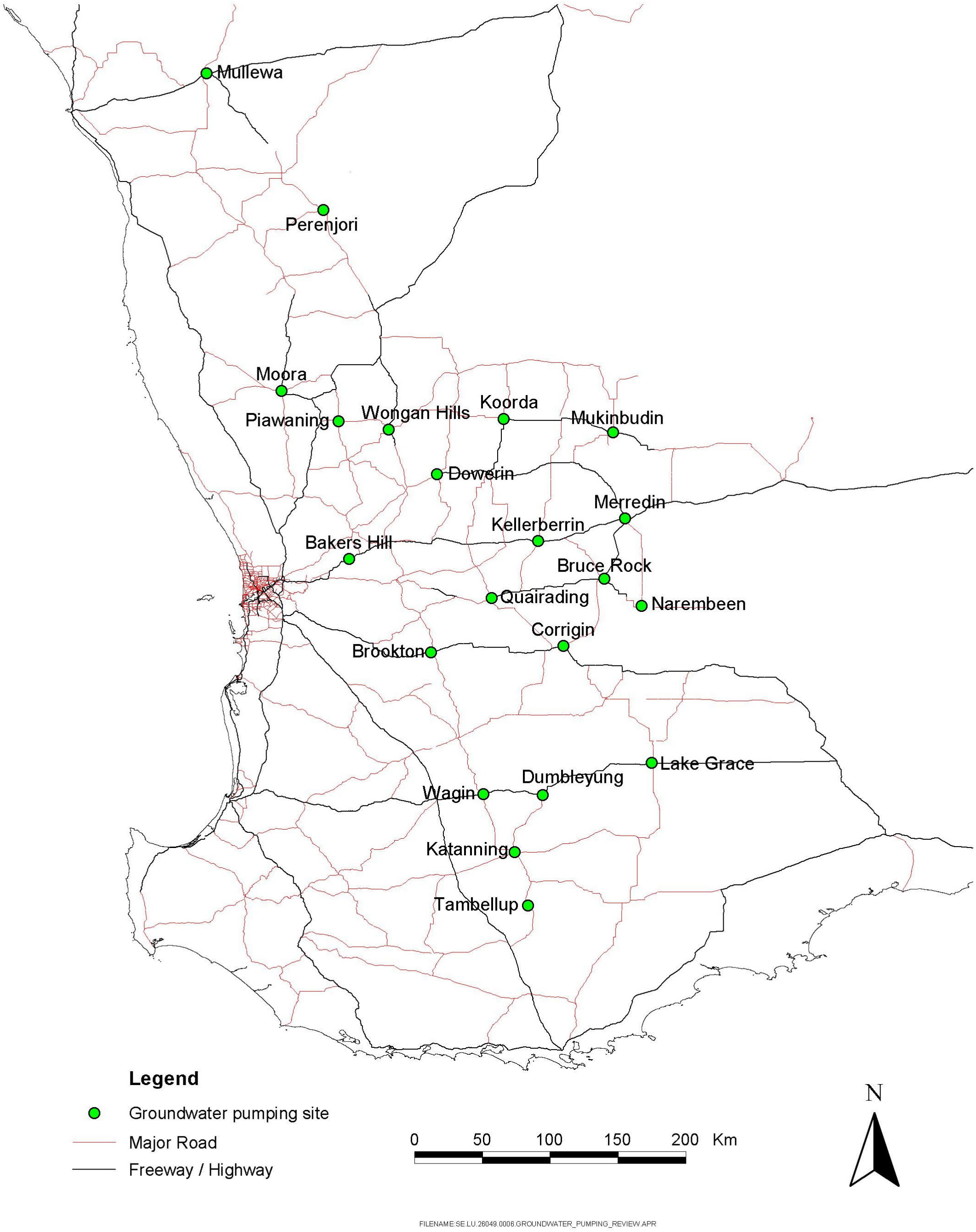

Figure 6. Groundwater pump test sites in south-west Western Australia

Salinity management strategies for 30 rural towns enrolled in the Rural Towns Program (an initiative of the State Salinity Council) recommend groundwater pumping as a way of minimizing the impact of salinity on town infrastructure (e.g. Matta 2000). Pumping tests, mostly for 72 hours, were conducted on bores in many of these towns (Fig. 6). The area of influence and the groundwater drawdown were modelled and so are only indicative. Modelled pumping tests for 22 towns (Table 1) indicated yields varying by more than one order of magnitude from 0.1 to 5 L/s (8–430 m^3/day) and cones of depression varying widely.

Table 2. Sites, aquifer characteristics and drawdown data for rural towns

	Town	*Geology*	*Depth of production bore (m)*	*EC (mS/m)*	*Modelled pumping rate (L/s)*	*Modelled lateral impact (m)*
1	Bruce Rock	Weathered granite	*30*	*2850*	0.4	*75–100*
2	Bakers Hill	Weathered granite	*15.3*	*1150*	0.2	*50*
3	Dowerin	Weathered granite	*30*	*1080*	0.3	*300*
4	Dumbleyung	Sediments and Weathered granite	*38*	*3070*	0.25	*N/A*
5	Kellerberrin	Sediments and Weathered granite	*55*	*4720*	2	*750*
6	Koorda	Weathered granite	*23*	*2900*	2.5	*300*
7	Lake Grace	Weathered granite	*24*	*1020*	0.15	*300*
8	Moora	Sediments	*32*		5	*150*
9	Mukinbudin	Weathered granite	*60*	*9110*	2	*300*
10	Mullewa	Weathered granite	*27*	*194*	0.3	*250*
11	Narembeen	Sediments	*65*	*7970*	2	*300*
12	Perenjori	Weathered granite	*29.7*	*1900*	0.3	*300*
13	Piawaning	Sediments	*26*		3.5	*100*
14	Perenjori	Weathered granite	*27*	*1900*	0.3	*300*
15	Quairading	Weathered granite	*38*	*636*	0.15	*200*
16	Tambellup	Sediments and Weathered granite	*27*	*3110*	0.5	*150*
17	Wagin	Sediments and Weathered Granite	*34*	*1320*	3.5	*500*
18	Wongan Hills	Weathered granite	*26.5*	*1830*	0.4	*200*
19	Merredin	Weathered granite	*45*	*1950*	5	*500*
20	Corrigin	Weathered granite	*35*	*800*	3	*300*
21	Katanning	Weathered granite	*24*	*1320*	0.6	*~150*
22	Brookton	Weathered granite	*31*	*1200*	1.5	*200*

- Eight bores had discharge rates lower than 0.3 L/s (24 m^3/day) with a cone of depression that extended only 100 m from the production bore.
- Another eight bores had higher discharge rates >1 L/s (85 m^3/day) with lateral impacts to 700 m.
- The other seven bores had discharge rates from 0.4 to 0.9 L/s (34–77 m^3/day).

Superimposing these towns on geological, landform or soil-type maps revealed no relationship between high yield and these attributes. The wide range of the discharge rates was entirely due to the aquifer parameters, hydraulic conductivity and aquifer thickness.

Furthermore, six months' monitoring of the pumping scheme at the Merredin townsite suggested that the area of influence was not uniform around the pumped bore (Matta 2000). The watertable fell by 5 m over ~ 80 m to the north of the bore but only by 3 m in the east-west direction. The asymmetric cone of depression around the bore is consistent with the variability of local aquifer parameters, such as hydraulic conductivity. The uncertainty in the extent and configuration of the cone of depression is an additional problem that might limit the use of groundwater pumping in rural towns.

Unlike Merredin, the Corrigin town site is located above highly fractured aquifers with a higher hydraulic conductivity. After pumping within the Corrigin town site, the watertable seems to have fallen by more than 2 m for about 300 m right around the production bore (Ron Colman, pers. comm.).

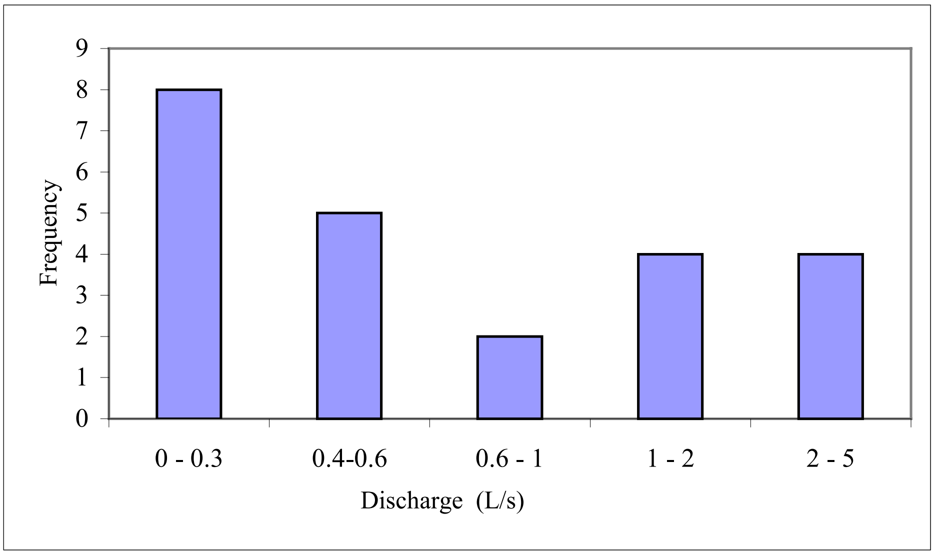

Figure 7. Distribution of groundwater discharge rates in rural towns

6.4 Recovering wetlands and other assets with high biodiversity value

Dryland salinity has already affected 8% of the Toolibin Lake catchment and severely threatens a wetland recognised internationally for its conservation importance (George & Dogramaci 2000). In addition to ~ 24% of the catchment, the entire lake complex and much of the surrounding reserve system are also threatened (Dogramaci et al. 2002a). In the long term, an integrated system of recharge and discharge control is essential to protect these assets; short-term groundwater and surface water management systems have been implemented to protect high value areas already in danger.

A borefield of 8 bores was installed into the weathered granite aquifer within the weathered profile at Toolibin Lake in the early 1990s. Three bores were also drilled into the palaeochannel system under the lake (Dogramaci 2000). The numerical modelling suggested that the groundwater pumping system could lower the hydraulic head in the palaeochannel and the shallow watertable within the lake (SKM 2000). The monitoring data from June 2001 to April 2002 (9 months pumping at a rate of ~ 300 m^3/d) suggested that, although pumping the palaeochannel system did not lower the shallow watertable, there were some benefits to conservation values from both types of engineering structures (surface water management and groundwater pumping schemes), particularly on the western half of the lake where the pumps are installed in the saprock aquifer. The fate of the lake depends on the groundwater pumping system working to plan and the continued (artificially improved) management of surface flows from its catchment.

The hydrogeological setting of Toolibin Lake is shown in Figure 8. The palaeochannel system runs north-south under the lake. The channel is approximately 200 m wide while the diameter of the lake is ~1000 m. The palaeochannel system is overlain by 8 m of lacustrine heavy plastic clay sediments. The lacustrine sediments in the western half of the lake contain a slightly higher percentage of sand. As the drilling records suggest there is a poor hydraulic connection between the lacustrine sediments and the palaeochannel in the eastern part of the lake, it is not surprising that pumping groundwater from the palaeochannel caused no detectable fall in the shallow watertable in the lacustrine sediments in the east.

The Toolibin Lake study shows the complexity of measuring and setting criteria for successful groundwater pumping schemes. The study also shows the importance of the local hydrogeological setting on a successful outcome which for this project was to lower the watertable in the shallow aquifers rather than depressurise the deep palaeochannel system.

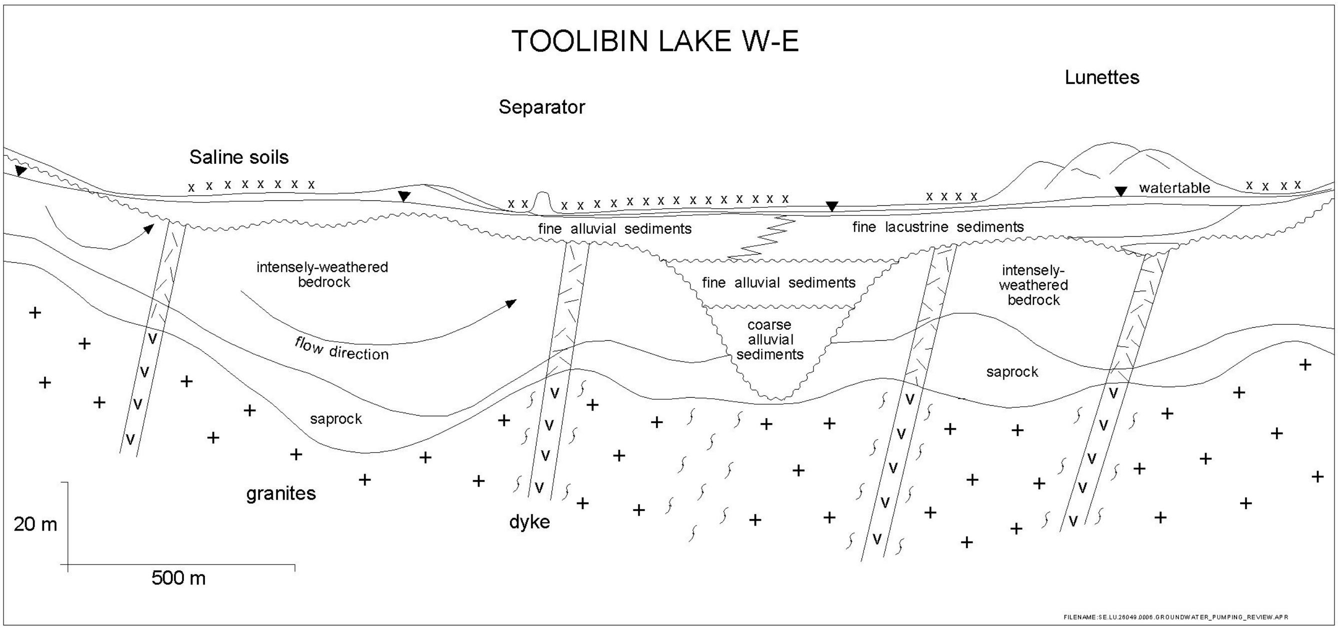

Figure 8. West-east hydrogeological cross-section of Toolibin Lake

7 Iron biofouling and bore maintenance

The accumulation of iron deposits in groundwater pumping systems is a well-known and widespread problem causing deterioration in bore performance and increased maintenance costs. This is a problem in all bores containing dissolved iron. Many domestic water supply bores in Perth are affected by iron biofouling that, as well as damaging pumps and piping, results in reddish stains on walls and pavements and, sometimes, the foul smell of rotting eggs (hydrogen sulphide gas H_2S). Bore biofouling is first stimulated by the redox gradient created around the production bore when oxygen is introduced during bore installation and development. Aerobic organisms grow in the redox gradient forming a living layer (called biofilm) on the pumps, well screen and the surrounding sediments. The operation of the pump promotes bacterial activity by increasing the supply of ions and oxygen and the biofilm gradually stratifies into a thin outer aerobic zone overlying a thicker inner anaerobic zone (Cullimore 1986). The inner zone provides a medium for the growth of filamentous iron bacteria (e.g. *Gallionella spp.*) which can corrode pumps, pipes and transfer station equipment. Corrosion is also accelerated by adverse electrochemical conditions in bore water induced by biofilm activity. Biofilm growth in the material around the production bore reduces the localised porosity of the aquifer and, consequently, lowers the well yield and specific capacity.

Many pumps in the Woolpunda Salt Interception Scheme in South Australia were found to accumulate iron rapidly around the bore and pumps, resulting in a specific yield reduction up to 45% in two months (Forward 1994). A detailed investigation at Toolibin Lake highlighted the importance of iron biofouling in lowering the production capacity of a third of the production bores. Preventative methods like chemical dousing have been used to reduce the degree of iron biofouling and the consequent clogging of the discharge pipes.

Iron biofouling can cause significant associated costs through increased capital costs of specialised control equipment, excess equipment capacity (larger screen opening and higher head pump) and premature replacement of various parts of the pumping system. Increased maintenance of system components is often not budgeted for in the design of the groundwater pumping projects and may reduce the economic life of the pumping schemes.

Groundwater from the weathered granite profiles in the Wheatbelt is generally characterised by a relatively high concentration of dissolved iron (up to 150 mg/L) which might provide an ideal environment for iron biofouling and bacterial growth in groundwater pumping systems. Treatments (biofouling cannot be prevented, only periodically cleaned out) include shock treatment with a chemical solution to eliminate bacteria in the bore and pumping systems. The South Australian Department of Engineering and Water Supply approach to chemical dousing was *in situ* generation of chlorine by electrolysis of the saline groundwater (Forward 1994).

8 Discussion and recommendations

Previous investigations have shown that groundwater pumping is an effective method for lowering watertables in a variety of hydrogeological settings and aquifers in WA. The response of groundwater to pumping is primarily dependent on the hydraulic properties of the aquifers. This is confirmed by the wide range of values obtained for the hydraulic conductivity of the water-bearing formations. Unfortunately, the lack of monitoring and data means that the effectiveness of these projects in terms of recovering assets cannot be properly evaluated.

The following sections outline the main questions and identify gaps that need to be addressed and discussed to achieve the objectives of this report. These sections also outline how the information from previous investigations can be used to formulate future needs in terms of gaps and lack of technical knowledge to better evaluate groundwater pumping as a potential option to manage salinity.

8.1 Which aquifers, landforms/valleys and geologies respond best to pumping?

The response of the deep-weathered granite aquifers to groundwater pumping can vary according to hydraulic conductivities and the overlying weathered profile. Pumping test results suggest that **even aquifers with very low hydraulic conductivity (0.01 to 0.1 m/day) can respond to pumping.** The only obstacle is the number of bores required to achieve the desired outcome. For example, the production bores installed in the Bakers Hill study (Rural Towns Program) had relatively low yields (17 m^3/d) and the area of influence extended only 50 m from the production bore. Based on the pumping test analysis, most of the land around the bore will have a watertable about 1 m below the surface. This is because of the low hydraulic conductivity, and, consequently, the steep cone of depression around the pumping bore (Figs 2 & 3). One metre might not be deep enough to recover agricultural land because of the upward movement of saline water by capillary action.

There are, however, many sites where **aquifers are characterised by higher hydraulic conductivity (0.5 to 10 m/d)** and groundwater pumping is very effective in lowering the watertable (e.g. Kellerberrin, Merredin, Table 1) with areas of influence extending up to 600 m.

The palaeochannel systems (relict drainages in the broad alluvial valleys) are widely distributed in the Western Australian landscape (Van De Graaff et al. 1977) but information on their extent and width (particularly in the Wheatbelt) is limited. Cross-sectional studies (Waterhouse et al. 1995; Salama 1997; Johnson et al. 1999) suggest that these channels are very narrow compared with the width of the valley and occur irregularly with respect to valley boundaries (Fig. 9). Most of the mapped palaeochannels in the Wheatbelt are based on extrapolation of the information at one location and very little is known about their width. Furthermore, the limited information on the stratigraphy suggests that the palaeochannels are covered by impervious to semi-pervious layers that restrict groundwater movement between the surficial layers and the palaeochannel aquifer (Johnson et al. 1999; Salama et al. 1989; Dogramaci et al. 2002a).

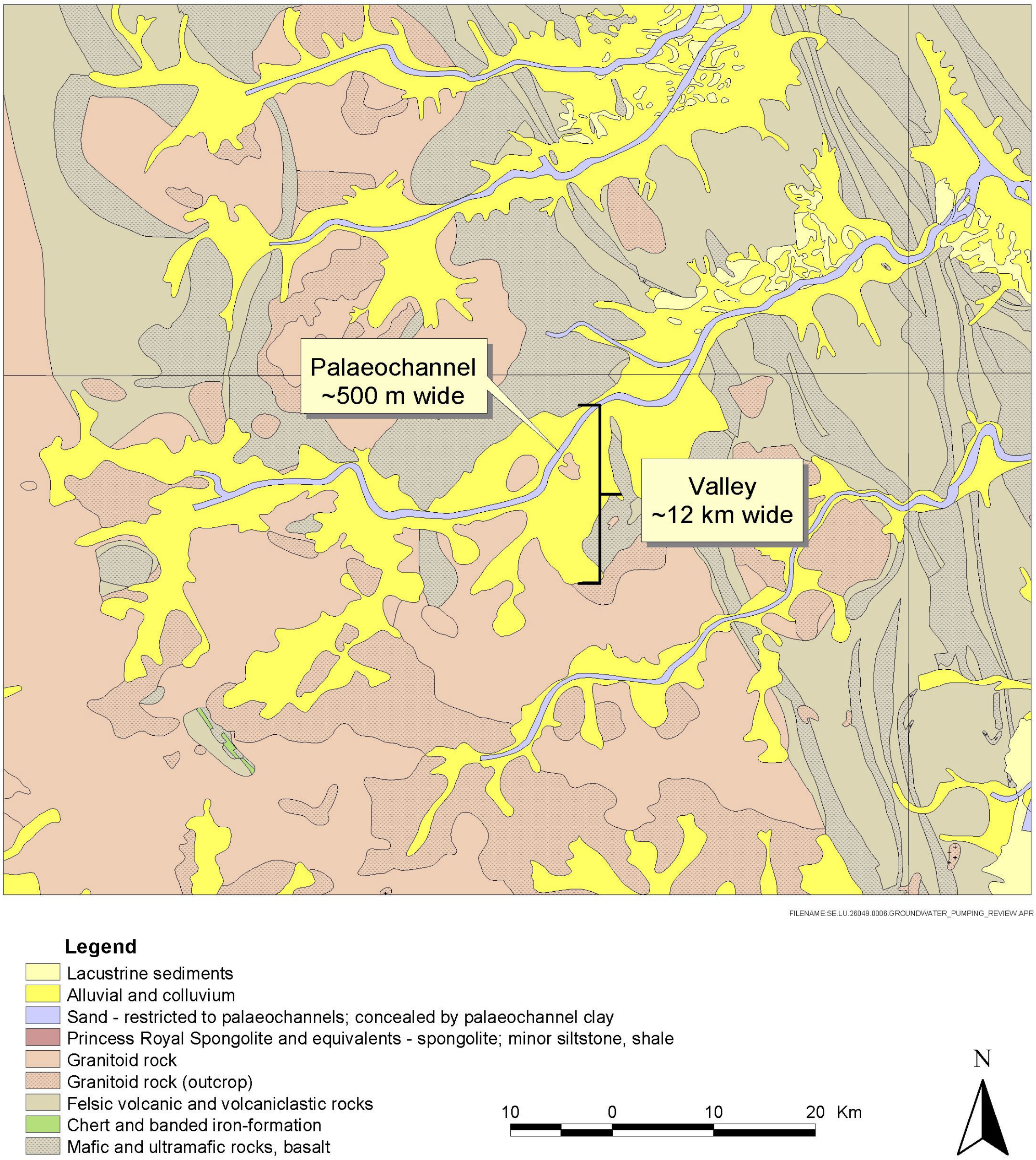

Figure 9. Hydrogeological map showing a section of palaeochannel system in Northern Goldfields. (Note the width of the palaeochannel and the valley). From Johnson et al. 1999.

The results from the case studies evaluating the impact of groundwater pumping from the palaeochannel on shallow watertable are therefore highly variable and difficult to interpret. This is because of the uncertainty regarding the location of the palaeochannel within the valley flats and variation in aquifer types. **Most of the palaeochannel aquifers where the primary water-bearing formation is the thick Tertiary (up to 60 m) and relatively thin (1–8 m) Quaternary sediments are suitable for**

groundwater pumping but the pumping rate and area of influence vary widely. For example, the production bores installed near Dumbleyung Lake (Williamson et al. 2001) into the sediments produced relatively low yields (7 to 13 m^3/d) and the area of influence only extended 50 m from the production bores. After 6 years of continuous pumping, the watertable was only about one metre below the surface in the vicinity of the production bores. The results suggest that the main aquifer tapped might represent the surficial sediments and not the palaeochannel system.

Salama et al. (1989), on the other hand, showed that groundwater pumping at a rate of 360 m^3/d can be sustained with measurable effects up to 2 km along the palaeochannel system of the Salt River in the Avon catchment. Similar results were obtained from palaeochannel system under Toolibin Lake with pumping rates up to 300 m^3/d. Lowering the hydraulic head in the palaeochannel aquifer had limited effects on the on the watertable in the overlying sediments because of the very low hydraulic conductivity of the lacustrine sediments at Toolibin Lake.

The results suggest that the variability of the hydrogeology and aquifers currently limits the division of the landscape to different categories with defined areas of influence. In summary:

1. Effective groundwater pumping depends mainly on aquifer characteristics. The area of influence, that is, a lower watertable, primarily depends on local hydrogeology and aquifer types.
2. Groundwater pumping from palaeochannels will only be effective in reducing surface dryland salinity if the overlying layer is pervious and not confining.
3. The response time of a shallow watertable to groundwater pumping depends on the degree of connectivity between the surficial sediments and palaeochannel sediments.

Recommendations

- Select groundwater pumping sites (preferably established sites in the Wheatbelt) that represent diverse landforms and different aquifer types.
- Implement monitoring programs to enhance the current projects and effectively monitor the impact of lowering the watertable on assets at risk. These sites should include agricultural land, rural towns and important public assets such as roads and water supplies, biodiversity conservation areas such as Toolibin Lake.

8.2 Do hydraulic head reductions at depth translate into reduced salinity in the root zone of plants?

Most of the groundwater in aquifers in the broad valley flats of the Ancient and Rejuvenated Drainage Zones (Fig. 4) is under pressure. The overlying soil profile is in hydraulic connection with these aquifers but the degree of connectedness varies even on a local scale. Technically, the long-term reduced pressure in these aquifers enhances drainage from shallow profiles into the deep aquifer and, in the long-term, enhanced recharge and leaching of salt from the soil might reduce the salinity of surface soil.

Leaching salts from surface soils and restoration of surface and subsoil structure and fertility are critical to the recovery of the land after removal of groundwater discharge problems. These are common factors limiting the success of all engineering options to remediate saline land. It is widely recognised **in WA that drainage of soils can result in increasing sodicity and associated problems for soil structure and drainage** (Moore et al. 2001). South Australian research has also highlighted that drainage of saline profiles can cause irreversible changes in subsoil chemistry and structure which then require extensive intervention to restore agricultural productivity (Fitzpatrick et al. 2002). These problems may also apply to saline soils in the WA Wheatbelt.

A pedon-scale (area 6 m^2 and 2 m deep) study was carried out by Bourgault du Coudray (1996) to investigate the degree of chloride leaching from a saline soil profile after lowering the groundwater hydraulic head at Wimmera near Kellerberrin. The methodology involved three stages: a small-scale field study, a laboratory simulation of leaching in a micro-porous system and system modelling based on the MACRO model (Jarvis 1994).

The data from the field study were used to calibrate the numerical model in three surface treatment management scenarios: (1) The soil surface treatment unchanged ‘the do-nothing scenario’ (2) The soil surface is continually ripped and (3) The soil surface ripping is followed by surface sealing.

The mean annual rainfall is 350 mm. The soil of the Kellerberrin study area is Solonchak (grey sandy loam) formed as a result of *in situ* granite weathering. The numerical study indicated that it would take at least 400, and possibly more than 200 000, years to leach the chloride from the soil profile to a depth of 1.5 m in the “do nothing scenario”. The time to leach chloride from soil profiles went down to 5 years if the dispersed and compacted soil layers in the top 250 mm of soil profile stayed ripped but, field studies showed that the ripped soil sealed again after rainfall. The results of the third scenario (ripping and surface sealing) were that **effective leaching to a depth of 1.5 m would take up to 100 years.**

This study is the only detailed study of the reduction in salt content in a soil after watertable fall in a dryland agricultural area in WA. Although the soil type is not representative of all saline soils in the WA Wheatbelt, the results highlight that there are difficulties in leaching the salt even after a sustained period with the watertable at 2 m below the surface. The result of this investigation suggests that lowering the hydraulic head in semi-confined aquifers and the watertable in unconfined aquifers does not necessarily mean reclamation of agricultural land and return to production.

Management of saline land after watertable fall by ripping the soil is considered a prerequisite to leaching the salt from the soil profile.

Recommendation

- Undertake a long-term pumping and monitoring project to evaluate the effectiveness of de-pressurising the deep aquifers in reducing soil salinity for various types of soils in the Wheatbelt. There are many sites with appropriate bores that could be used to address this gap in current knowledge.

8.3 Is pumping cost-effective and how long will it take to get a return on investment?

The variation in the scale and nature of the problem makes systematic analysis of the costs and benefits a complex issue. Groundwater pumping systems vary from catchment-scale (e.g. the Collie River catchment) to small-scale (e.g. lowering the watertable in the hotel cellars in rural towns). Between these extremes lie the small-to-medium-scale projects for land reclamation in the Wheatbelt.

In dryland salinity mitigation projects, the costs and benefits are mainly incurred by landowners, but benefits will spill over into the environment, the water quality and the economy of the region. However, most studies concerned with cost effectiveness of the engineering options only consider the internal costs and benefits and do not account for the external costs and benefits. A limitation for all cost-benefit studies is the reliable projection of the time taken to restore soils from the impact of high groundwater levels.

Two important conclusions of the Dames & Moore (2001) cost-benefit analyses of groundwater pumping for six rural towns in the Wheatbelt (Brookton, Corrigin, Cranbrook, Katanning, Merredin and Morawa) were:

- Groundwater pumping is expensive and difficult to justify currently compared to the cost of local damage.
- More analysis is needed to work out the optimum mixture of damage and control costs for these towns. For the Merredin town site they suggest that, in its current layout, the groundwater pumping should not be considered as an option.

Of the six rural towns reviewed for economic study, the Katanning town site clearly has the most saline-affected land and damage to infrastructure and buildings caused by rising groundwater. The predicted damage bill of $6.9 million works out to about $1800 per resident, although the distribution of the costs will be very uneven across the town. To put this figure into perspective, this damage bill for Katanning exceeds the combined potential damage costs for the other five towns in the study. The report concludes that to meet the damage costs without controlling and lowering the watertable will cost the town about $6.9 million (discounted at 7 per cent). By contrast, the estimated cost to prevent further rise and lower the existing groundwater levels by groundwater pumping will cost the town approximately $7.609 million (discounted at 7 per cent).

The simple cost-benefit analysis of groundwater pumping for reclaiming agricultural land can done using the Rural Land Value Spreadsheet (http://www.agric.wa.gov.au). This spreadsheet provides the land value for various agricultural regions. The lateral impact of the cone of depression can be calculated and multiplied by the recovered land value. The results will be compared with the implementation and running costs of the project. This very simplistic approach may provide a crude estimate of the cost effectiveness of groundwater pumping for different agricultural regions. Adding into the spreadsheet the time taken for recovery to occur would increase the reliability of this simple assessment approach.

The economic study of regional-scale salinity management options in the Collie catchment suggests that, when high value assets such as the water resources in the Wellington Dam are at risk, the groundwater pumping option may be preferable to other engineering options (Dames & Moore 2001).

In summary:

- Cost-benefit analysis of groundwater pumping has not been well studied and documented.
- The cost effectiveness of groundwater pumping depends on the value of the assets at risk and the scale of the problem.
- A simple spreadsheet calculation can estimate the costs and benefits of groundwater pumping for agricultural land.
- Groundwater pumping in the six selected rural towns is an expensive option compared with value of the assets at risk.

Recommendation

- Conduct a comprehensive cost-benefit analysis encompassing all the impacts of groundwater pumping on various public and private assets on catchment and small-scale systems.

8.4 If installing pumping bores, what designs are most likely to be effective and incur the lowest running costs?

Numerical modelling of selected catchments characterised by different hydrogeology and aquifer types will provide data into the appropriate design for the desired outcome. The modelling results of the Collie catchment (Mauger et al. 2001) suggest that, to lower the salinity in the East Collie catchment, the most appropriate borefield design is about ~750 bores in two lines parallel to the Collie River East. This design applies to bores with a minimum discharge rate of 15 m^3/d. If the bores have higher discharge rates, fewer may be needed to achieve the same outcome.

Recommendations

- In the next four years, monitor and analyse the effectiveness of the current projects (public and private projects e.g. rural towns, Maxon Farm) in terms of bore layouts.

- Run numerical models at small- and catchment- scales to find the most appropriate bore design to achieve the required outcomes.

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