TECHNICAL NOTE 2010/03

Department for Water

COMPARISON OF SURFACE WATER–GROUNDWATER INTERACTIONS IN CLEARED AND PRISTINE CATCHMENTS

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May 2010

ISBN 978-1-921528-87-3

Preferred way to cite this publication

Green G, 2010, *Comparison of groundwater–surface water interactions in cleared and pristine catchments,* DWLBC Technical Note 2010/03, Government of South Australia, through Department for Water, Adelaide

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INTRODUCTION

This technical note summarises the results of investigations into the spatial extent of surface water–groundwater interconnectivity in pristine and cleared catchments and provides recommendations for appropriate management strategies to address conjunctive water use scenarios for interconnected surface water–groundwater systems.

Between 2006 and 2010, surface water–groundwater interactions were studied in a number of contrasting hydrologic environments in the Mount Lofty Ranges (MLR) and Kangaroo Island (KI). These were primarily areas of fractured rock hydrogeology, with some sedimentary groundwater systems. The areas studied were:

1. the catchment of Rocky River, KI, which has undisturbed, 'pristine' native vegetation
2. the catchments of Cox, Lenswood and Kersbrook Creeks, three fractured rock catchments in the Western MLR, largely cleared of native vegetation
3. the whole of the Eastern MLR Prescribed Water Resource Area (PWRA), which includes both fractured rock and sedimentary aquifers and is also largely cleared.

Hydrochemical methods, including analyses of the stable isotopes of water, major and trace ions, radon and strontium isotopes, together with measurements of stream flow and groundwater levels, were used to reveal the spatial and temporal variations in connections between groundwater and surface watercourses. The results of these investigations are described and analysed in detail in three DWLBC reports: *Interactions between groundwater and surface water systems in the Eastern Mount Lofty Ranges* (Green & Stewart 2008), *Groundwater–surface water interactions in the Cox, Lenswood and Kersbrook Creek Catchments, Western Mount Lofty Ranges, SA* (Banks 2010a), and *Surface water–groundwater interactions in the Rocky River Catchment, Kangaroo Island, SA* (Banks 2010b).

SUMMARY OF INVESTIGATIONS

CLEARED CATCHMENTS

In the fractured rock catchments of the Eastern and Western MLR, our investigation showed surface water–groundwater interactions to be widespread. Throughout many of the catchments studied, surface water systems either gain from, or lose water to, the underlying fractured rock aquifer system. This was much as expected. Creek lines in these catchments are incised into fractured rock landscapes, creating abundant conduits for water to transfer between the two systems. However, the flux of water between systems is highly spatially and temporally variable.

The conditions for interaction between systems are 1) the intersection of conductive features of the geology (such as fractures or permeable sedimentary media) with the land surface; and 2) a groundwater head elevation that is higher than the land surface elevation. The first of these conditions leads to spatial variability in connections between the surface and groundwater systems, while the second leads to temporal variability in fluxes between the systems.

In the surface water systems of the cleared fractured rock catchments of the MLR, there is a high temporal variation in flow between summer and winter. Widespread cessation of flow occurs during the summer, indicating that groundwater levels drop to a level at which groundwater no longer discharges to watercourses. The removal of native vegetation in these catchments has contributed to shortening the duration of summer flows by enhancing the rate of runoff into and through surface watercourses. Watercourses in these cleared catchments generally have much less organic debris and detritus than observed in the pristine Rocky River catchment. As a result, water is retained in watercourses for a much shorter time. Much of the rain falling during winter runs off rapidly and groundwater discharging into gaining stream reaches flows largely unimpeded through the system.

In most catchments, there is not an obvious point of discharge from the groundwater system into surface watercourses. 'Gaining stream' interaction is evidenced by a progressive down-stream increase in stream flow rate and presence of water with hydrochemical characteristics that indicate its groundwater origin. 'Losing stream' interaction is evidenced only by a progressive down-stream reduction in flow. There are however a few points of major gain or loss between the surface and groundwater systems in the MLR, where volumes of water in the order of megalitres per day transfer between surface and groundwater systems. These locations require particular attention for conjunctive resource management. While they are few in number in the MLR, imprudent management of the surface or groundwater resource in the vicinity of these locations could lead to significant impacts on the connected water resource. For example, in the fractured rock catchment of the Angas River in the Eastern MLR, large volumes of groundwater discharge into the river at the town of Macclesfield, in the upper catchment. This was shown to be the only source of water flowing in the upper Angas River during summer. Macclesfield is an area with a high demand on the groundwater resource for domestic and stock purposes. If groundwater extraction from the fractured rock aquifer here were to cause a significant drop in the groundwater level, the sustained summer flow in much of the Angas River would be under threat.

A few catchments in the Eastern MLR PWRA have primarily sedimentary groundwater systems, particularly in areas of Permian Cape Jervis Formation sand and gravel deposits. These catchments are mostly cleared of native vegetation and in many cases turned over to dairy pasture. Aquifers in these catchments are mostly unconfined and diffuse recharge occurs through a permeable vadose zone. The clearance of vegetation in these areas has enhanced recharge, reduced root water uptake from shallow groundwater, and resulted in increased stream flow due to an increase in groundwater discharge. Conversely, surface stream flow in this environment can be severely impacted by high levels of groundwater extraction, including root water uptake by plantation forestry.

PRISTINE CATCHMENTS

The largely undisturbed catchment of Rocky River was selected as a study catchment intended to provide a comparison with cleared fractured rock catchments in the MLR. As well as having almost pristine native vegetation cover, Rocky River is known to flow year-round in most years, suggesting flow sustained by groundwater through the summer. Regional basement rock in this area is mostly covered by a deep layer of weathered basement material, which is largely impermeable. However, the steep topography with deep valleys in the upper catchment and the perennial nature of surface flow there suggested that conduits must exist between the underlying fractured rock groundwater system and the river.

Contrary to these expectations, extensive hydrochemical sampling in the lower and central Rocky River catchment showed that there were minimal, if any, interactions between the surface water system and the deeper underlying fractured rock groundwater. It is apparent that this is essentially a 'disconnected' catchment, in which there are no significant connections between the surface water system and the underlying fractured rock aquifer system. While there was scope for tributaries of Rocky River to be fed by groundwater slowly seeping from the deep weathered basement, samples of groundwater taken from this were significantly more saline than the water in the river.

This presents a counter-intuitive finding, in which Rocky River has no connections with the regional groundwater system and yet flows perennially, while many of the surface water systems in cleared fractured rock catchments in the MLR are shown to have strong surface water–groundwater connections but do not flow perennially.

Further hydrochemical sampling and piezometric measurements in the headwater catchments of Rocky River showed that the perched shallow groundwater in a thin (<3 m) quaternary surface layer overlying the weathered basement layer was of the same water quality as the surface stream water and may provide a source of the summer flow in Rocky River. However, this layer represents a much smaller water storage capacity than the fractured rock aquifers that discharge to streams in the MLR. Furthermore, the extensive native vegetation is expected to transpire a large proportion of the shallow groundwater stored in thin surface layer, leaving even less capacity for this layer to sustain stream flow.

COMPARISON OF PRISTINE AND CLEARED CATCHMENTS

Further investigation was enabled by an extensive bush fire in the Rocky River catchment in December 2007. This allowed access through the previously impenetrable bush of the upper catchment, enabling observations that were critical to the understanding of water dynamics in this catchment.

The creek lines in the headwater catchments of Rocky River catchment were found to be punctuated by large areas of wooded swamps with thick organic sediments of peat and woody detritus (Figure 1). In these environments, which were extensive along creek lines in the headwater catchments, fallen trees and large amounts of organic detritus effectively dam the creeks, causing water to spread out laterally. This results in an expanse of highly fertile riparian zone with dense vegetation. The resulting chains of swamp environments cause a marked increase in the residence time of the water in the surface system compared with the open channels observed in cleared catchments.

Figure 1. In-stream swamps in the headwater catchments of Rocky River, KI

Water sourced from winter rain, occasional summer rain, and the slow discharge of groundwater from the thin perched quaternary aquifer is thus buffered in this multitude of swamp systems, facilitating year-round flow of the surface water system without the need for connection to the regional groundwater system.

In marked contrast, watercourses in cleared catchments are often incised into the landscape due to the rapid, erosive flow that occurs through them in the absence of riparian vegetation, resulting in a single narrow stream channel which rapidly drains the catchment of surface runoff and groundwater-derived baseflow (Fig. 2).

Figure 2. Incised watercourse in a cleared MLR catchment

These findings explain why stream flow duration is often greater in Rocky River catchment, with apparently low groundwater storage capacity, than in the cleared fractured rock MLR catchments where there is relatively high groundwater storage capacity. The presence of in-stream swamps in the undisturbed and disconnected catchment of Rocky River results in perennial surface stream flow due to extensive water storage capacity in the surface system rather than the subsurface fractured rock groundwater system. In disconnected catchments such as this, groundwater extractions from the regional fractured rock system will not have a significant impact on flows in surface watercourses. Similar geological conditions to the upper Rocky River catchment exist in the Southern Fleurieu. There, surface water systems are separated from the regional groundwater system by a thick layer of deeply weathered basement material, giving rise to the surface water features known as Southern Fleurieu Swamps (Barnett & Rix 2006).

These conclusions lead to a further question of whether the fractured rock catchments in the MLR would retain water in the same way if they had retained their native vegetation cover. Surface topographic relief is a key factor, but is similar in many of the MLR catchments to the Rocky River catchment. While native vegetation may transpire more water than a cleared landscape, the additional winter transpiration is small compared to the recharge flux during winter, which represents the majority of annual recharge. Hence, in a fractured rock environment in which recharge processes are rapid, the reduction in recharge resulting from transpiration by native vegetation would be relatively small. If the MLR fractured rock catchments retained their native vegetation, it would slow the rate of surface runoff, potentially increasing recharge. Thereafter, if deposited vegetation detritus were to slow the drainage of baseflow through the surface system during summer, similarly to the Rocky River catchment, the duration of surface stream flow would be significantly greater than in the current cleared state of these catchments.

CONCLUSIONS

The investigations and observations made here present us with some contrasting findings:

1. In a catchment where there is no significant connection with the regional groundwater system and the only surface water–groundwater interaction is with water in shallow (<3 m deep) perched aquifer systems close to creek lines, there is perennial flow. Here, summer flow is sustained by water stored mainly in the surface water system and extensive fringing swamp zones.
2. In a similar climatic environment, but with strong connections to extensive fractured rock groundwater system, flow continues through summer in some creeks due only to discharge from the regional fractured rock system.
3. While other studies (e.g. Benyon, Theiveyanathan & Doody 2006) have indicated significant interception of runoff and recharge occurs in areas of plantation forestry, a key impact of the undisturbed native vegetation cover in the Rocky River catchment is to retain water in the landscape, resulting in a far more sustained flow in the river system. While the amount of water transpired by vegetation in the Rocky River catchment must be greater than in an otherwise identical cleared catchment, the loss is offset by the much lower end-of-system runoff in the undisturbed catchment compared to the cleared catchment.

Interactions between surface and groundwater may appear on superficial inspection to be more prevalent in undisturbed catchments with pristine native vegetation. However, this may be a misleading impression. Evidently, surface flows may persist through summer in creek systems without connection to deeper groundwater systems, even in the semi-arid environments of southern South Australia. In most cases, and particularly in fractured rock environments, there are significant connections between surface and groundwater systems. However, the flux of water between systems is dependent on groundwater levels, which may vary significantly between summer and winter. The clearance of native vegetation seems to further polarise this variation between summer and winter flows, by reducing the capacity for water to be stored in surface water features of the landscape.

RECOMMENDATIONS

The recommendations for appropriate management strategies that can be drawn from these findings are summarised in the following points.

1. In catchments with fractured rock groundwater environments, there are likely to be many connections between surface and groundwater systems. Any impact on groundwater levels, due for example to groundwater extraction, will have an immediate impact on stream flow, with implications for downstream water users and water dependent ecosystems. If stream flow rates are to be preserved, conjunctive resource management strategies for these systems should include a limiting of groundwater allocations to a maximum of the annual catchment recharge volume minus the annual total groundwater-derived baseflow volume in all significant streams. In addition, the application of buffer zones between streams and groundwater extraction points is essential to prevent direct impacts on stream flow.

2. A groundwater management framework that does not seek to maintain flows to surface watercourses remains an option in these connected environments. However, where the surface water system is also exploited as a resource for human uses, the management framework for the surface water resource must then take account of the reduction in baseflow that may occur due to the proposed groundwater extraction, rather than (as is often

the case) be based on an assumption that historic baseflow rates will continue. In many cases, the health of aquatic ecosystems is predicated on a continuation of typical levels of stream baseflow. In the context of the MLR, groundwater discharge is essential in many streams to provide at least a residual water supply to in-stream pools that act as ecosystem refuges through summer.

3. In areas with unconfined sedimentary aquifer systems, groundwater extraction limits and buffer zones around connected watercourses are similarly important.

4. Where points of major flow between surface and groundwater systems exist, an understanding of the importance of this flow to the receiving system is required. The amount of flow that is considered to be 'major' is subjective, and depends on the scale of the surface and groundwater resources in comparison to the rate of the flow between systems. Additional restrictions on resource exploitation may need to be tailored for these locations, according to the significance of the flow volume, the human demands and the dependence of ecosystems on the connected water resources.

5. In disconnected catchments, where a substantial weathered layer separates the surface and groundwater water systems, impacts of groundwater extraction on surface watercourses are less likely. In this environment, extraction limits and buffer zones may be more liberal. However, care must be taken to confirm disconnected conditions, which are not common in fractured rock environments.

6. In catchments where undisturbed native vegetation exists, removal of this vegetation creates a severe risk of causing erosion to shallow surface sediments that may provide much of the water buffering capacity of the catchment and act as the primary source of stream base flow between rain events.

7. Extended conserved riparian zones, sufficient to allow natural dams and swamp systems to form, can be effective in increasing the residence time of water in a watercourse. This is particularly valuable in extending stream flow duration in ephemeral creek systems.

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