CHAPTER 7

Synthesis, conclusions, and recommendations for management

7.1 Scale in hyporheic ecological research

The work presented in this thesis presents the first large-scale investigation of hyporheic and parafluvial ecology in an Australian regulated river. Globally, it is the first single study to examine hyporheic ecology at the subhabitat, habitat, site, and river scales. Since many hyporheic processes occur at more than one spatial scale along a river (Boulton *et al.* 1998), scale is a key consideration when drawing inferences from the results of ecological studies. The first part of this study (Chapters 3 and 4) was designed to assess the condition of the hyporheic ecology of the Hunter River. Collecting samples from 4 spatial scales (subhabitat, habitat, site, and river) at 5 times over a year allowed my analyses to detect patterns that may not have been visible if only one scale or time was sampled. For example, if sampling was only conducted at the river scale, then the differences in physico-chemical and nutrient properties of the upwelling and downwelling subhabitats would not have been evident. Further, by randomly located sampling points within a site without considering subhabitat, the results will vary depending upon where the specific samples are collected from. If I randomly located my sampling points within a site, it is possible that random allocation may place the majority of sampling points at Aberdeen within a downwelling zone, and the majority of sampling points at Bowmans Crossing in upwelling zones, leading to very different non-comparable results between the two sites.

In many previous ecological studies of the hyporheic zone, only on site has been sampled (e.g., Hendricks and White 1991, Fisher *et al.* 1998). However, the differences in interstitial nutrient and faunal dynamics of the Hunter River sites emphasise the spatial variability that exists betweens them. These results highlight the importance of using several sites when investigating the hyporheic ecology of a river and warn that single-site surveys cannot necessarily be scaled up to an entire river. Furthermore, the lack of distinct longitudinal trends for many variables, indicates that concepts like the River Continuum

Concept (Vannote *et al.*1980) do not necessarily apply to interstitial habitats where groundwater upwelling is an important factor in influencing ecological processes.

7.2 The Hunter River hyporheic zone

For the hyporheic zone to function efficiently it must continually exchange water with the surface stream. Monitoring gradients in physico-chemical and nutrient variables, and changes in faunal assemblages can indicate the efficiency of hyporheic filters. To prevent the isolation of the hyporheic zone from the stream through interstitial clogging, a certain degree of spatial and temporal dynamism is required. In streams, water level fluctuations that occur at varying intervals and magnitudes create key geomorphological changes (Chapter 1). Arguably, the most important impact that river regulation has on downstream environments is a reduction of natural flow variability (Kingsford 2000, Marchant and Hehir 2002). Despite this, there are regulated rivers that contain active hyporheic zones with a diverse invertebrate fauna (e.g., the Rhône River in France, Marmonier *et al.* 2000, South Platte River, Colorado, Ward and Voelz 1994). Following a pilot study in the Hunter River (Boulton 2000a), the current study is the first to examine the extent of hyporheic activity over a large section of a regulated river in Australia.

Of the 9 sites examined in this study (7 on the main river, and 2 on tributaries), all displayed varying degrees of hyporheic activity and filtration ability (Chapter 3 and 4). Most efficient were the two sites of Aberdeen and Denman, where sediments are coarsest but still contained significant amounts of fine and medium particles. The volume of sediments available for hyporheic use increased substantially with distance downstream as the lateral bars got bigger and the river widened. However, only the shallow, near-river sediments appeared to regularly exchange water with the stream and actively filter nutrients from the water. The most active areas of nutrient transformation were in the upper 40 cm of the hyporheic zone, and the first metre of sediments in the parafluvial zone. It is likely that deeper sediments, and more distant parafluvial habitats exchanged water less frequently, and acted as important temporary storage areas for nutrients. These areas contained reductive conditions, where important riverine processes such as denitrification occurred.

All sites (with the possible exception of Wollombi Brook at Warkworth, where invertebrates were not sampled), had rich invertebrate faunas comprising groundwater- and surface-dwelling taxa (Chapters 3 and 4). During the study, 71 invertebrate taxa were collected. These included eleven taxa of macro- or micro-crustaceans that were stygobites. Three syncarid families were collected during the study, with Aberdeen being the only site where all three co-existed. A diverse interstitial water-mite assemblage was apparent in the Hunter River sediments, dominated by *Partidomomonia* sp. and *Wandesia* sp. These two taxa were found along the length of the river in parafluvial and hyporheic habitats.

Of the two sandy sites, only Warkworth had impaired hyporheic filtration compared to the sites with coarse sediments, but both likely made significant contributions to stream metabolism by providing large nutrient storage zones. Fine sediment size was found to be a substantial determinant of hyporheic filtration ability. In coarser sediments at Aberdeen and Denman the hyporheic water exchanged more rapidly with the stream, and penetrated the sediments deeper. The fine sediments at Warkworth restricted regular exchange with the surface to the upper 40 cm of sediments, or perhaps even shallower (Chapter 4). Water at Sandy Hollow exchanged more readily between the sediment interstices and the stream. These sediments were coarser than those at Warkworth, and allowed water to flow through more rapidly.

7.3 Management of the Hunter River

There are two likely reasons why there is such an active hyporheic zone in the Hunter River, despite the presence of Glenbawn Dam. First, the river level is still able to fluctuate reasonably regularly. Although it stops much of the flow in the up-stream reaches of the Hunter River, Glenbawn Dam is upstream of the confluence with the Pages River, Rouchel Brook, and several other tributaries. These tributaries are able to provide sediment, and water for fluctuating flows. During this study a large flood occurred that scoured much of the bed of the river and then subsequently re-deposited sediment. Additionally, irrigation flows and water releases for power stations provide regular fluctuations. However, abstraction means that the volume of water, and therefore the magnitude of any fluctuations declines with distance from the source. Perhaps this is one of the reasons for the downstream decline in filtration efficiency. Second, is the strength of the groundwater connection to the river. Although no hydrological measurements were taken of groundwater contribution to flow in the Hunter River, the presence of stygofauna in the hyporheic zone at all sites indicates that it may be significant. As well as contributing to the biodiversity of the hyporheic zone, upwelling groundwater can provide hydraulic pressure that prevents sediment compaction and colmation.

7.3.1 Flow Rule 2

The aim of river restoration should be to re-establish ecological processes (Ward *et al.* 2001). One of the main inhibitors of ecological processes in regulated rivers is the loss of flow variability (Kingsford 2000). By returning medium to large flows to the river, Flow Rule 2 goes some way to restoring ecological processes in the hyporheic zone. The establishment of Flow Rule 2 ensures that at least 12 h of water is allowed to pass down the river during a flow event. This guarantees that a medium to high flow event will be able to flush hyporheic zones, bury organic matter, and stimulate microbial activity. Consequently, fluctuations in the water level expand and contract the lateral and vertical extent of the hyporheic and parafluvial zones through increased hydraulic pressure.

Two different experiments were conducted to test the effect that Rule 2 flow may have on the hyporheic zone. First, there was a medium-level flow release, during which Rule 2 was implemented. This appeared to have stimulated microbially driven filtration at three sites, but these results may have been compromised by an unplanned spate that preceded sampling (Chapter 5). At BOWM and MOSE, the release also increased the porosity of the sediments in the upper 20 cm of the bed. Second was a small scale flow diversion, designed to simulate the pulse crest of the Rule 2 hydrograph, which enhanced microbial activity and to some extent stimulated the release of SRP but otherwise failed to impact interstitial nutrient concentrations. The findings of this experiment indicate that a period of 12 h might be too short a time period for hyporheic nutrients to be significantly effected. Because Rule 2 does not specify a volume, the series of flows resulting from it are likely to all be different, and therefore have different effects on the hyporheic and parafluvial zones. As a range of different flows is required to prevent the hyporheic zone from clogging, it is strongly recommended that Flow Rule 2, with its inherent variability be maintained.

7.4 New ecological hypotheses stemming from this thesis

As this work was restricted to one regulated river system, further studies along other rivers are required to test the applicability of my conclusions to regulated rivers in general. In addition, it is essential to test the results of Chapter 5 against those of a similar study where there was no preceding spate.

Throughout this thesis, a number of ecological hypotheses have arisen; the investigation of which would substantially improve our understanding of hyporheic ecology:

Hypothesis 1: Parafluvial nutrient dynamics determine the early-stage floristics of gravel bar succession.

All of the gravel bars examined during this work were to some extent covered with terrestrial vegetation. There is a well-established link between hyporheic conditions and lotic macrophytes (White and Hendricks 2000), and the link between riparian vegetation and sediment bacterial activity is also well known (Duff and Triska 1990). However, more work is required on the interactions between temporary vegetation of mobile gravel bars, and the role of interstitial nutrients of vegetative succession. Nutrient-rich parafluvial water theoretically provides an abundant food source for such vegetation. Following scouring floods, when this vegetation is buried, it possibly acts as food for bacteria and invertebrates. It is possible that this vegetation is a key temporary sink for nutrients such as nitrate.

Hypothesis 2: Recolonisation of defaunated sediments by hyporheic invertebrates is not prevented by river regulation.

Invertebrate numbers and taxonomic richness were lower in February 2001 than they were in November 2000 (before the large bed-moving spate). However, by May both abundances and taxonomic richness had recovered. Since many of the invertebrates collected from the hyporheic zone of the Hunter River sites do not have aerially dispersing stages, the question arises: where do the animals come from? It is likely that the insect component recolonises via aerial dispersion, but this is not possible for non-insect taxa. Do they enter the Hunter River from unregulated tributaries, such as Rouchells Brook and

Pages River? Or do they migrate upward from the groundwater aquifer? The results from this thesis indicate that Glenbawn Dam does not impair the recolonisation of hyporheic zones in the Hunter River in its current condition, but the exact mechanisms of dispersal require further investigation.

Hypothesis 3: Flow Rule 2 has long-term benefits to the ecology of the Hunter River. There is no river in Australia where consistent long-term (greater than 10 years) research has been conducted in the hyporheic zone. The Hunter River offers an excellent arena for such research, and several years of sampling would critically strengthen our understanding of the effects of river management on the hyporheic ecology. Sampling conducted with and without Rule 2 in place would significantly enhance what is known about the specific effects this rule.

7.5 Conclusions

The importance of the hyporheic zone has been recognised in the NSW Groundwater Dependent Ecosystem Policy (Department of Land and Water Conservation 2002). This study marks the first large-scale investigation into the hyporheic zone of any large Australian regulated river, and has uncovered a rich invertebrate fauna and active microbial biota. Several recommendations have been made for the management of the Hunter River to ensure the maintenance of active hyporheic zones, including the maintenance of Flow Rule 2. It is also recommended that on-going monitoring be employed at least at Aberdeen, Moses Crossing, Bowmans Crossing, and Maison Dieu to cover as much river distance as possible. This will assist in river management by providing baseline data by which the impacts of different management decisions can be assessed. Before the findings of this study are applied to other rivers, future studies should investigate similarities in physico-chemical, nutrient, and biotic conditions of the hyporheic zones of the Hunter and those of other gravel bed rivers in the state.

CHAPTER 8

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