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Fluvial Geomorphology and River Management

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Australian river landscapes offer many challenges for management. Much Australian river research is novel, but practical concerns have always had an influence on the research agenda. Australia’s distinctive contributions to fluvial geomorphology include recognition of the great age of many fluvially eroded landscapes; understanding complex levee, terrace and valley fill sequences; analysing the impacts of rare major floods; interpreting the effects of impoundment, mining and urbanisation; and understanding the great anastomosing inland river systems. River restoration is now a major theme in the literature of river engineering, fluvial geomorphology and landscape design. Great achievements are occurring in geo-ecological river management and engineering. Changing people’s thinking is becoming at least as important as gaining new scientific knowledge. The existing understanding needs to be more widely shared and enhanced by greater involvement with Asian countries where river management issues daily affect the lives of millions of people.

Many aspects of Australian river landscapes offer challenges for management, from protection against floods for inland and coastal towns, avoiding and mitigating salinity problems, and re-establishing or enhancing aquatic habitats and wetlands to dealing with urban sedimentation and water pollution (Gordon et al., 1992). River management has long been a contentious environmental issue concerned with conflicts such as those between flood mitigation and wetland preservation, and between irrigation development and aquatic habitats and fishing interests. There have been great changes in attitudes and practice in recent decades, however. Severe erosion and land degradation are not now seen as inevitable. Encasing river channels in concrete is no longer the obvious way to mitigate flooding. Large dams are questioned from the outset, and their downstream impacts and resettlement requirements are critically appraised early in the planning process.

Gradually, the concepts of fluvial geomorphology and their importance for river ecosystem management are reaching a wider public and people are learning to design river modifications with nature and to adopt ‘soft’ engineering techniques. River investigations are necessarily multi-disciplinary, but their essential core lies within hydrology, geomorphology and...

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ecology, subjects that are brought together in physical geography. The economic, social and recreational uses of rivers have legal, planning, cultural and even theological significance, but lie well within the realm of human geography. Thus geographers are studying many aspects of rivers and are to be found in the offices of government agencies, utilities, consultants and research organisations concerned with rivers.

In Australia, as elsewhere, geographical contributions to river investigations have been innovative, profound and sustained. Much of the research is novel and Australian in origin, but some has developed from critical external infusions, particularly through the influence of George Dury while he was Professor of Geography at The University of Sydney in the 1960s. Today there are global trends, even fashions (Jennings, 1973; Sherman, 1996), in fluvial geomorphology, but in Australia practical concerns have always had an influence on the research agenda.

Much work in geomorphology, hydrology and biogeography is driven by the distinctive nature of the country in which it takes place. A recent review of river morphology and management in New Zealand (Mosley and Jowett, 1999) adopted three main themes: the mechanics of gravel bed rivers; the climatic and tectonic controls of landform evolution; and instream habitat hydraulics, river ecosystems and interactions with riparian land use. To an infrequent visitor, the first two themes appear particularly characteristic of that country, with its dramatic landforms and powerful gravel rivers. The habitat and river ecosystem issue is more generic, symptomatic of the increasing application of geomorphology to river management throughout the world.

Australia’s distinctive contributions to fluvial geomorphology (Warner, 1988; Brizga and Finlayson, 2000) include the challenges of recognising the great age and slow rate of change of many fluvially eroded landscapes (Bishop, 1988; Young and Wray, 1999); understanding complex levee, terrace and valley fill sequences (Ferguson and Brierley, 1999); analysing the impacts of rare major floods, including large palaeoevents; interpreting the effects of impoundment (Knighton, 1988; Warner, 1988; Benn and Erskine, 1994), mining and urbanisation; and understanding meandering, palaeochannels and anabranching on the great inland river systems. The search for regularities in river patterns, for possible explanatory discharge magnitudes and frequencies has been as much bedevilled by the irregularity and power of major rain events, as were the journeys of the early European explorers into the interior. Even today, writers are commenting on how successive flood events vary greatly in size in rivers such as the Burdekin, and consequently how bedforms and channel morphology are normally out of equilibrium with the flow, and thus record the result of the most recent major events (Alexander et al., 1999).

The anabranching rivers of the Australian interior have long been seen as a combined feature of low angle slopes and irregular flow regimes. Studies of those on the Northern Plains in the Alice Springs region indicate that anabranching appears to be a stable river pattern that helps to maintain the throughput of relatively coarse sediment in low gradient channels characterised by an abundance of within channel vegetation and subject to declining downstream discharges (Tooth and Nanson, 1999).

These river landscapes of northern Australia have parallels in Africa and India. Indeed, many research findings from tropical Australia are applicable in parts of other tropical lands. The social responsibility of Australian fluvial geomorphology might therefore be seen as more one of sharing experiences with those in low latitudes than of exchanging ideas with colleagues in Europe and north America. Although socially generally a part of the ‘North’, the physical landscapes of Australia, as Griffith Taylor reminded people in the 1920s, are largely characteristic of those occupied by the peoples of the ‘South’ (Taylor, 1928).
River management and channel restoration
While the impact on vegetation of the use of fire by the first Australians is well known, less has been discovered about how these land cover changes affected fluvial processes and river morphology. In contrast, the effects of land clearance by European settlers are well documented. Careful examination of the changes in river channel patterns in Tarcutta Creek, New South Wales suggests that cumulative modifications of land cover and channel conditions lead, in that environment, to a probably irreversible change from a chain-of-ponds type of channel to a single thread sand-bed channel, incised a few metres below the original stream bed (Page and Carden, 1998). This incision phase, due to catchment disturbance since European settlement, occurred synchronously across eastern Australia (Prosser, et al., 1994; Brierley and Murn, 1997; Fryirs and Brierley, 1998). The case of the Snowy River (Erskine et al., 1999; Gale, 1999) illustrates the extreme conditions that arise when rivers lose much of their runoff.

The concerns for river management in Australia find parallels elsewhere. Problems of changes to rivers are, however, associated with the whole period of human agricultural, mining and urban activity. The Romans transformed landscapes in Europe and north Africa by building dams, aqueducts and terrace systems. A Chinese water diversion system on the Min River in Sichuan has been operating continuously for over 2000 years. In the northeastern United States, forest clearance and subsequent urban and industrial activity greatly changed rivers early in the 19th century (Donahue, 1997). Everywhere there are concerns over the degradation of rivers downstream of dams (Petts, 1984; Williams and Wolman, 1984; Brandt, 2000). Many European rivers are now complex managed entities, where one phase of rectification works has produced impacts which have had to be corrected by a second phase of engineering work (Douglas, 1971). In the Rhine rift valley, the Rhine channel has to have gravel added constantly to prevent undue scour occurring. The Piave River in the eastern Alps of Italy has witnessed remarkable channel changes as a consequence of decreased flows and sediment supply. The channel width has decreased to about 35 per cent of its original dimension, while in several reaches the planform pattern has changed from braiding to wandering (Surian, 1999).

By the 1980s, increasing demand for environmental sensitivity in river management, and the realisation that many hard engineering solutions were not fulfilling their design life expectancy, or were transferring erosion problems elsewhere in river systems, produced a momentum for changes in management practices. This momentum for changing river engineering was supported by the writings of such people as Dunne and Leopold (1978), Ritter (1979) and Brookes (1985). They provided the evidence and theoretical framework for a geomorphological approach to river management. In terms of controlling bank erosion, for example, two major changes in the perceptions and practices of river managers occurred in the UK. Firstly, practitioners started to consider bank erosion in the context of the total sediment dynamics of a river system, and thus began to examine the upstream and downstream effects of bank protection work. Secondly, river managers began to prescribe softer, more natural materials for bank-protection works, including both traditional vegetation such as willow, osier and ash, and the new geotextiles used to simulate or assist natural plant cover regrowth (Walker, 1999).

Applied research by Australian fluvial geomorphologists, environmental engineers and ecologists has emphasised the use of native plant species for channel rehabilitation, especially in the better-watered eastern part of the continent (Raine and Gardner, 1995; Webb et al., 1999). In their Rivercare manual, Raine and Gardner (1995) have provided a users’ guide for river maintenance and channel stabilisation, including an explanatory videotape. The establishment of Landcare and
Rivercare groups within the community are allowing landholders (and others) to be actively involved in management under the guidance of professional officers. Research centres, including The Centre for Catchment Hydrology at Monash University, Melbourne, and the Cooperative Research Centre for Catchment Hydrology and the Centre for Environmental Applied Hydrology, both at The University of Melbourne, are providing research answers to practical questions. For example, where along a river’s length will vegetation most effectively stabilise stream banks (Abernethy and Rutherfurd, 1998) and what are the effects of large woody debris on channel hydraulics (Gippel, 1995)?

Conservation has also become a major factor elsewhere in the choice of new river management techniques. In the UK, many rivers reaches have been designated Regionally Important Geological/Geomorphological Sites (RIGGS) and some fluvial features have been recognised as potential Sites of Special Scientific Interest as part of the Geological Conservation Review initiated by the then Nature Conservancy in 1977 (Gregory, 1997). Conservation motives as well as a desire to maintain public access prompted a thorough geomorphological analysis of a RIGGS site on the River Brock at Brock Mill in the Forest of Bowland, Lancashire, leading to a decision to relocate a footpath to allow the river to shift freely (Walker, 1999).

Although changing river management timescales and perceptions have made it easier to convince managers to use geomorphological knowledge, it remains difficult to make that knowledge readily available in emergencies or in relation to specific local needs. In many countries, more geomorphologists have come to be employed by national environmental agencies and consulting engineers. In the UK, the Thames region of the Environment Agency supports a national centre for geomorphological advice (Newson and Sear, 1998). Passionate books about managing urban streams and creeks are appearing with ever-greater frequency in the USA (A.L. Riley, 1998), but have yet to be integrated with the more formal academic literature.

River restoration is now a major theme in the literature of river engineering, fluvial geomorphology and landscape design. The need to understand the multiple benefits of urban river valley planning and management is now firmly enshrined in planning, river management and flood mitigation literature and policies (Brookes and Shields, 1996). For example, Greater Manchester in the UK has a structure plan for the valleys of the upper Mersey Basin that includes flood control, habitat restoration and recreational use of floodplains. In the same area, the Mersey Basin Campaign works to improve water quality and river valley amenities, including industrial land regeneration throughout the region (Struthers, 1997).

Since the 1970s, policy makers dealing with rivers in the USA have given greater emphasis to habitat preservation and restoration following the increasing public concern for environmental quality (Graf, 1996). These changes are aimed at reducing the impacts of human activities, especially on wildlife, by maintaining and improving entire riparian and fluvial ecosystems, through integrated basin management (Gore and Shields, 1995). In the USA, so much modification has gone on, especially the clearing of riparian vegetation to permit more land to go under agriculture, that state agencies, such as the Oklahoma Conservation Commission, have begun using the principles of fluvial geomorphology and natural channel design to control stream bank erosion (Dutnell, 1999).

Society is thus coming to emphasise particular objectives in river management. In countries like the USA and the members of the European Union, the emphasis tends to be on the preservation or restoration of ‘natural’ conditions that favour the achievement of goals related to fish and wildlife management, habitat restoration, recreation and aesthetics (Graf, 1996). In low latitude countries, the public pressure is for protection against flooding, adequate water supplies and reduction of
pollution (Douglas, 1993; Gupta and Asher, 1998).

In the rapidly developing countries of southeast Asia, demands for hydropower, municipal and irrigation water supplies, river navigation and irrigation water override most environmental considerations. Severe floods, such as those in southern Thailand in 1992 and in China in 1996 sound alarms about the need to protect and restore forests and reduce catchment degradation and may lead to new land management regulations. However, the local siltation of streams generally continues unabated. Measures to reduce erosion are written into many building construction and forestry regulations, but usually the control works are inadequate or absent.

Managing aquatic habitats

The need for trans-disciplinary integrated approaches to river management is reflected in the post-contact changes to the fluvial geomorphology of the Bega catchment in New South Wales, Australia (Fryirs and Brierley, 1999). Geomorphic changes to river structure have modified habitat availability throughout the catchment. The impacts have been least pronounced in headwater streams, but have been dramatic along virtually all river courses beyond the base of the Great Escarpment (Brierley et al., 1999). Lateral, longitudinal and vertical linkages within the river system have been altered, affecting the transfer of water, sediment, organic matter and nutrients, and altering biotic interactions.

With the acceptance of the idea that river design has to be addressed in a more holistic manner if conflicting interests are to be avoided, river engineers are seeking to integrate engineering concerns such as flood mitigation with the preservation and enhancement of habitats. This has produced a battery of new techniques, as well as requirements for guidance on the engineering consequences of ecological improvements. On the River Blackwater in Ireland, a programme of habitat reinstatement that introduced pools, spawning areas and nursery grounds to 350 reaches has led to localised increases in channel roughness. Overall values of Manning’s $n$ coefficients are much higher than those generally specified for efficient channel design (Ferguson et al., 1998).

A major weakness in work to restore or re-create aquatic habitats is the lack of monitoring following rehabilitation. There is thus little feedback on the consequences of past decisions (Brookes et al., 1998). Close monitoring of key, intensively used lowland rivers in conjunction with studies of surface and ground water is needed to understand some of these issues. The PIREN-Seine programme in France has done considerable work of this type, while the new Lowland Catchment Thematic Research programme in the UK will establish excellent facilities for long-term monitoring of channel morphology, habitat and wetland dynamics.

Coping with the legacies of mining

River management may often be a case of trying to assist nature to modify and reverse the damage done by human activities. Some damage may take hundreds or thousands of years to overcome. Examples of such long-term damage include the impacts of Roman lead mining on the upper reaches of the Tees in England and the consequences of mid-19th century gold mining on the Sacramento River in California. The Ranger Uranium Mine in Australia has facilitated much applied research in fluvial geomorphology, just as the NIREX investigations of potential deep storage sites for nuclear waste in the UK have led to many geomorphological and hydrological studies. Among the key issues at the Ranger mine have been the stability of mine tailings dams and ponds and possible impacts on the Alligator River system (S.J. Riley, 1995; 1998; Rippon and Riley, 1996; Willgoose and Riley, 1998). Mining leads to many long lasting impacts on other Australian rivers, while extractive industries modify channels and floodplains, especially for gravel working near urban areas (Brizga and Finlayson, 2000).
In Malaysia, the massive siltation of watercourses that accompanied tin mining activities during the latter half of the 19th century and the early decades of the 20th century is, fortunately, a thing of the past. From the limited evidence available, however, it would appear that rivers draining tin mining areas still carry relatively heavy suspended sediment loads. It has been estimated that there are at present over 200,000 ha of tin mine tailings in peninsular Malaysia, most of which remain unproductive. In Cambodia, alluvial gemstone mining in the catchment of the Battembang River is causing high sediment loads which are adding to the silting of the Tonlé Sap and the degradation of its fish stocks. Many other examples of mining impacts occur throughout the region, but the countries involved usually do not have the resources to carry out the rehabilitation works found in Europe and north America.

Pollution and sedimentation
Pollution and sedimentation are interlinked problems, whether related to seepage from landfills (Petrozzi, 1998), to the effects of storm sewer overflows (Brownbill et al., 1992; Rhoads and Cahill, 1999) or to leachates from contaminated land (Robinson and Gronow, 1996). Often contaminants are attached to sedimentary particles, and the dynamics of the sediment flux are the key to understanding the pollution problem. Organic matter attached to particles creates a sediment oxygen demand when combined sewers overflow into rivers during exceptional rain events. Where rivers are fast flowing, the depletion of oxygen is short-lived as the sedimentary particles are rapidly dispersed downstream. When the overflow is into a slow-moving water body, the organic matter builds up on the channel bed. When scourred by the next turbulent high flow, it can create a new phase of oxygen demand and have impacts upon aquatic life.

Metals attached to sewer sediments are another problem. In many cases, the sediments discharged during storm sewer overflows contain levels of Cr, Cu, Pb, Ni and Zn exceeding the concentrations deemed satisfactory by environmental agencies. Although these concentrations are rapidly diluted downstream of the source, there is much local variation in levels of these metals in the contaminated reaches. This local variability is related to reach-scale variation in fluvial-geomorphic conditions, which in turn produces differing patterns of sorting and organic content of bed material (Rhoads and Cahill, 1999).

Southeast Asia provides many examples of river management to cope with severe river sedimentation and flooding. In Kuala Lumpur, the Kelang River was channelised following the great flood of 1926, with a double trapezoidal cross-section created through the city centre. Yet the 1938 Department of Irrigation and Drainage Report attributed the annual recurrence of flooding in Kuala Lumpur at that time to the tin mining activity prevailing around the city. After the second great flood in 1971, further channelisation was undertaken, with the construction of a rectangular section of much greater capacity through the central city. The new works included ramps to allow excavation equipment to get into the concrete channel at low flows to remove accumulated silt and restore the capacity of the channel.

These new river training works merely serve to pass the water and much of the silt further downstream. While floods are alleviated in one reach, they may be aggravated elsewhere. Constant additions to such works are often required. For example, plans have been developed since 1995 to widen a stretch of the Kelang River near the mosque in Jalan Tun Perak in order to prevent flash floods in that part of the city.

The deposition of sediment in the channelised reach of the river through central Kuala Lumpur is only part of the story. The finer fraction of the sediment load is carried in suspension over the weir at Puchong downstream into tidal wetlands. Here, the new, often inert, quartzitic material blankets the fertile organic matter of the mangrove swamps, while urban heavy
metals (Sham, 1986) have a deleterious impact on the wetland ecosystem. Thus, not only does continued development on the hillslopes around the city add to and aggravate the sediment and flooding problems, but the control works serve to push the problems further and further downstream. Further consultations have been taking place since 1999 on ways of developing an integrated catchment plan for the Kelang, but this will only succeed if the environmental behaviour of both major construction contractors and tens of thousands of individual citizens is changed.

**Appropriate scientific advice and public perceptions of channel changes**

Effective management strategies have to be built on sound science and on an understanding of river dynamics (Brizga and Finlayson, 2000). Davis *et al.* (1999) showed how the renowned Eppalock catchment management project in Victoria, Australia may have been initiated on exaggerated estimates of the reservoir sedimentation risk due to a misunderstanding of gully dynamics following land clearance. In the Herbert River, north Queensland, local perceptions of increased channel sedimentation downstream of Ingham appear to be unsupported by field evidence and interpretations of the writings at the time of the first European settlement (Ladson and Tilleard, 1999). Such scientific and institutional uncertainty generally constrains the extension of river channel restoration to the whole of the active floodplain (Adams and Perrow, 1999). In the USA, the increasing wetness of the Concord Meadows in the mid-19th century was thought by farmers to be due to impoundment of water by the Billerica dam, but scientific advice led the state legislature to deny farmers a compensation case in 1862. The role of a rising watertable was not recognised, and vegetation and gravel accumulations in the meadows were blamed for flooding of the meadows (Donahue, 1997).

On the other hand, channel restoration, involving river flow augmentation, can lead to renewed channel adjustments. At sites where flows were augmented in tributary basins of the upper Arkansas River in Colorado, USA, channels tended to shift from highly sinuous meandering patterns to less sinuous or braided ones. Along augmented reaches, bankfull channel width and the width:depth ratio also increased (Dominick and O’Neill, 1998). Sound design has to consider these possibilities and to ensure that improvements in one place do not serve merely to push the problem further downstream.

**River basin planning and river management**

Australian geographers have made distinguished contributions to the analysis of the broad policy issues involved in managing water resources at the basin scale. Crabb (1997; 1999) has reviewed the resources of the Murray-Darling, while Hirsch (1998) and Mitchell (1998) have contributed to the critical analysis of plans for the future development of hydropower resources in the Mekong River Basin. Any success at the basin scale depends on the integrated management of the component parts. The salinity problems of the Murray (Murray-Darling Basin Ministerial Council, 1999) and the siltation problems of the Mekong (Douglas, 1997) have to be tackled at a range of scales from the field and roadside to the reservoir catchment and whole basin scales. In the Mekong Basin, sediment-laden wet season runoff, discharging into the Tonlé Sap, raises the bed of both the lake and the river leading to it from the Mekong. That sediment is derived from many parts of the catchment, and is temporarily stored at many points along the channel. Reaches between Luang Prabang and Vientiane have become sandier since 1980. Lao engineers at Vientiane complain that bank reinforcement work on the opposite, Thai, bank of the river is aggravating bank erosion on the Lao side. The river management at the basin scale thus brings the different elements of fluvial geomorphology into a context of economic and political geography. The vision and integrity of pioneering geographers working on water resources, such as Gilbert White (1967), is still needed in this context.
Conclusion
Many practical geomorphological inputs to river management are taking place throughout the world, and good examples are to be found in Australia. Great achievements are occurring in geo-ecological river management and engineering. Many authors emphasise that geomorphic and eco-hydrological manipulations have to be undertaken in the context of holistic environmental frameworks (Wilby, 1999). The ‘total catchment management’ concept has to be applied. Changing people’s thinking is becoming at least as important as gaining new scientific understanding. Many community catchment programme officers in Asia argue that there is no need for further field measurements and more detailed monitoring (Sharma, 1997). Instead there should be greater attention to the way people use the land and their understanding of erosion. Catchment management used to be seen as synonymous with soil conservation and erosion control, including reforestation. Today it is more closely linked to poverty alleviation and sustainable development of upland catchment areas (Sharma, 1997). People rather than the natural resources have become the foremost focus of catchment management.

The great need is to increase the availability of such inputs in low latitude countries, where the dynamics of rivers are often more intense, and processes such as bank erosion, channel aggradation and sediment deposition regularly affect millions of people. Examples of such applications have begun to emerge, but much still remains to be done.

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