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River styles: An integrative biophysical template for river management

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SUMMARY

River styles provide a geomorphic summary of river forms and processes within a reach. Assessment of river style is determined by channel geometry (size and shape), channel planform and the assemblage of landforms that make up a river reach (both channel and floodplain geomorphic units). Analysis of the character and condition of river styles, their downstream patterns, and their evolution, provides a biophysical basis to prioritorise river management strategies. The approach entails three stages, namely baseline survey of river character and behaviour within a catchment, assessment of river condition, and prioritorisation of management efforts at river conservation and/or rehabilitation. The river styles procedure has been trialed in various sand and gravel bed coastal river systems in NSW. There are no obvious reasons why this approach to catchment-framed analysis of river geomorphology could not be applied to river systems in any geographic setting.

MAIN POINTS

- River styles record the geomorphic character and behaviour of river reaches.
- River styles provide a template for integration of biophysical processes in rivers. The geomorphic template is considered to be the key determinant of habitat availability along river courses. Changes to the geomorphic structure of rivers has direct implications for the range and extent of habitat. Hence, geomorphic considerations must directly underpin management efforts to maintain biodiversity of river courses and strategies to implement principles of ecologically sustainable development.
- The analysis procedure for river styles is a nested hierarchical approach, showing the linkage of biophysical processes within a catchment.
- River styles are conditioned largely by the landscape units (or topographic setting) through which they flow.
- Individual river styles are made up of mosaics of channel and floodplain geomorphic units, conditioned largely by the valley setting.
- Downstream patterns, evolutionary trends and the relative condition (and recovery potential) of differing river styles form a biophysical basis for prioritorisation of management efforts at river conservation and rehabilitation.
- By extension, river styles could provide a catchment-framed biophysical template for water resource planning and decision making. For example, river styles provide a natural basis for monitoring programs to examine the impacts of water allocation strategies.

1.0 INTRODUCTION: A GEOMORPHIC TEMPLATE FOR RIVER REHABILITATION

Geomorphology provides an ideal starting point with which to evaluate the interaction of biophysical processes within a catchment, as geomorphological processes determine the physical structure, or template, of a river system (e.g. Newson, 1992; Brookes and Shields, 1996; Thorne, 1998; Thorne et al., 1997). River morphology, sediment character, the flow regime, and riparian vegetation are dynamically adjusted, such that change in one variable can modify other parts of the system. Catchment disturbance, and associated adjustments to flow and bedload quantity or calibre, can transform the structural integrity and physical stability of a river. This, in turn, will modify the pattern of riparian vegetation, the availability of habitat, and the production of nutritional resources for aquatic ecosystems.

Most Australian rivers are part of highly modified landscapes in which human activities are dominant (CSIRO, 1992). Indeed, the biophysical functioning of many Australian rivers has been transformed in the period following European settlement. Changes to the geomorphic character and stability of rivers have induced a range of secondary impacts on ecosystem functioning, modifying water temperature, availability of light (energy), and the production, processing and retention of nutrients and organic materials in river systems (Brierley et al., in press). In many instances, human impacts have been so pronounced that they have undermined the biodiversity of aquatic ecosystems, imposing critical constraints on efforts at river rehabilitation.

Understanding of geomorphic processes, and determination of appropriate river structure at differing positions in catchments, are critical components in effective, sustainable rehabilitation of aquatic ecosystems. Ecological sustainability will not be

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achieved by managing river systems on the basis of sustained low-moderate flows within a 'designed' equilibrium (i.e. stable) channel. If we wish to maintain a truly Australian river character, with naturally adapted flora and fauna, our target conditions for river management must replicate the natural variability in river structure and flow inherent to the Australian landscape. Hence, effective management of river ecology in Australia is contingent on improving our knowledge of geomorphological interactions with ecological functioning in aquatic ecosystems.

This paper outlines a generic procedure to carry out a geomorphic survey of river character and behaviour. River styles are identified for differing landscape settings within a catchment. From this, insights into river evolution are used to predict likely future river structure, and target conditions are determined for river conservation and/or rehabilitation.

In essence, the river styles framework can be differentiated into three stages:

1) **Baseline survey** of river character and behaviour: Catchment mapping of river styles
2) **Assessment of river condition**, framed in terms of river evolution and their recovery potential following disturbance
3) **Prioritorisation of management strategies** for river rehabilitation and conservation: A catchment-framed assessment based on the 'natural' character and behaviour of river styles, the condition of each river reach, and within-catchment linkage of biophysical processes (e.g. water and sediment transfer).

2.0 KNOW YOUR CATCHMENT!

One of the discussion points for this conference is "Do we know enough about Australian rivers to manage them effectively"? While our knowledge of rivers in southeastern Australia is substantial, it is constantly improving, and it is naive to assume that further fundamental insights will not be gained in the future. Although we have a solid conceptual grasp of controls on river morphology and adjustments since European settlement, the pattern of changes has not been consistent from catchment to catchment. This indicates some of the inherent dangers in making extrapolations from system to system without a rigorously defined procedure with which to make these extrapolations. The river styles approach provides a biophysical template through which comparisons of river character, behaviour and condition can be made both within- and between-catchments. This then forms a platform to evaluate and determine the most appropriate strategies for rehabilitation of river courses.

Rivers demonstrate remarkably different character, behaviour and evolutionary traits, both between- and within-catchments. Given this variability in river character, individual catchments need to be managed in a flexible manner on the basis of what is actually happening within that system. The underlying catchcry from the river styles work is "KNOW YOUR CATCHMENT".

3.0 BASELINE CATCHMENT SURVEY OF RIVER CHARACTER AND BEHAVIOUR

Assessment of river styles builds on the practical set of objective criteria used in river reach analysis by Kellerhals et al. (1976), Mosley (1987) and Thorne (1998) and the scalar, conceptual framework suggested by Frissell et al. (1986), Naiman et al. (1992) and Newbury and Gaboury (1993). River character and behaviour are assessed at four interlinked scales: catchments, landscape units, river styles, and geomorphic units. The approach effectively dissects a catchment, characterising river styles for differing landscape units. The distribution and connection of river processes are explained in terms of catchment-scale boundary conditions (e.g. geology, slope, etc), which determine topography, material character and supply and water availability. This results in a range of form/process associations within each reach, indicated by the assemblage of geomorphic units.

The river styles framework builds on the approach to river classification developed by Rosgen (1994, 1996). Definition of river styles is based on channel geometry (size and shape), channel planform, and the assemblage of geomorphic units (landforms) that make up a river reach (both channel and floodplain components). Geomorphic units are the building blocks of river styles (Brierley, 1996). These landforms represent specific associations between landscape morphology and the set of processes that produce that form. Examples include differing types of bar, sand sheets, pools, riffles, benches, levees, backswamps, valley fill, terraces, etc. In general terms, packages of genetically-associated geomorphic units can be determined for differing river styles. Explaining the character, distribution and assemblage of geomorphic units provides the key to explanation of river character and behaviour in each river style.

To date, the river styles procedure has been applied to un-regulated, non-urban streams, but there are no obvious reasons why the framework could not be extended to these settings. In the first instance, differentiation of river styles is based on the presence/absence of floodplains along river courses (i.e. alluvial versus non-alluvial rivers). Non-alluvial, bedrock-controlled rivers are differentiated into reaches with no floodplain (e.g. gorges and some upland headwater reaches which have various patterns of steps and pool-riffle sequences; see Montgomery and Buffington, 1997) and rivers with discontinuous pockets of floodplain (for which differing valley alignments may be discerned).

By definition, alluvial rivers are able to deform their own boundaries. A wide range of river morphologies have been identified for Australian rivers, some of which have broadened the continuum of alluvial river behaviour documented in the fluvial geomorphology literature (e.g. anabranching river behaviour, various discontinuous river patterns). Hence, rather than focussing solely on planform-based attributes, the river styles approach to river classification is based primarily on the geomorphic units which make up both the channel and the floodplain (cf., Brierley, 1996). The approach is open-ended, such that there is no definitive range of river styles. However, as research continues, a suite of alluvial river styles has been identified (see Cohen et al., 1998; Ferguson and Brierley, 1998 a, b; Fryirs and Brierley, 1998a, b).

The baseline geomorphic survey of river character and behaviour presented in the catchment-wide mapping of river styles not only provides insights into spatial relationships within catchments (e.g. reach-reach, and tributary-trunk stream relations), but also provides a dynamic perspective on river evolution. Ecological considerations are evaluated in terms of habitat availability as determined by the range of geomorphic units that comprise each river style.

Analytical procedures employed in the inventory of river styles include catchment-scale mapping and derivation of longitudinal profiles (using GIS), analysis of air photographs, and field analyses at representative reaches for each river style. River style boundaries are ratified in the field, and the distribution and character of geomorphic units are mapped for each river style. Representative valley-scale cross sections are surveyed for each river style, quantifying the dimensions of the channel and each geomorphic unit. Estimates of unit stream power are derived for each river style (see Ferguson, 1999).

4.0 ASSESSMENT OF RIVER CONDITION: RECOVERY POTENTIAL AND TARGET CONDITION FOR RIVER REHABILITATION

While the baseline survey of river styles provides insights into what type of ‘natural’ river is found at differing positions in landscapes or catchments, it does not provide a direct assessment of the geomorphic ‘condition’ of the river.’ In assessing river condition within the river styles framework, it is considered imperative to relate visual assessment of river morphology with analysis of why that condition has been adopted. As rivers are dynamic entities, river management procedures which are framed in terms of static appraisals of river condition are of limited application. Analysis of form without an appreciation of process will not yield sustainable river rehabilitation practices.

To assess the river condition, primary research into river evolution, including analysis of controls on river behaviour, must be undertaken. Ideally, the relative influence of human impacts are discerned from natural process variability. Within-catchment linkages of biophysical processes, such as sediment transfer, are examined, such that disturbances in one part of the catchment can be related to river responses elsewhere (considering both off-site impacts and lag effects).

There has been profound variability in river responses to human disturbances for differing river styles across Australia. Some river styles are inherently more sensitive to disturbance, while some parts of the landscape have been impacted much more profoundly than elsewhere. Using the evolutional and sediment budget analyses of river styles within a catchment, various stages of degradation of differing river style, and their associated stages of river recovery (if pertinent), may be defined (see Fryirs, 1999).

Recovery potential is defined here as the capacity of a river reach to attain a suitable river structure and function for the position it occupies in the catchment, and the boundary conditions under which it operates (cf. Fryirs, 1999; Fryirs and Brierley, 1998b; Simon, 1989; Brookes, 1995; Gore, 1985; Brookes and Shields, 1996; Brookes and Sear, 1996). Assessment of **recovery potential** is used to assess how far away from this structure and function differing reaches of river are, and the 'idealised' condition can be used as a target condition for management efforts at river rehabilitation. River rehabilitation is viewed as a process of recovery enhancement (Gore, 1985), or helping the river to adjust naturally. By enhancing recovery through appropriate rehabilitation works, the river style can attain a suitable structure and function that is appropriate for the setting of each reach.

Given that each river style operates under a specific set of boundary conditions (with respect to valley morphology, slope, upstream catchment area, etc.) and has a distinctive character and behaviour, natural recovery processes can be identified for each river style. In determining the target condition for each river reach, sites of the same river style are placed along a continuum of river condition (or recovery potential). Intact sites form the highest level, followed by sites with high recovery potential, moderate recovery potential and those sites that are degraded. In this approach, sites that exhibit intact or high recovery potential conditions are used as target conditions for sites that have moderate recovery potential or are highly degraded. Minimally impacted reaches are used as a guide for identifying appropriate channel character, geomorphic unit assemblage, channel alignment, vegetation associations and sediment regimes for each river style. In turn, each category represents the level of intervention required to attain a sustainable river structure and function and the level of risk associated with rehabilitation of each site.

In general, sites displaying high recovery potential require minimalist intervention strategies. These sites really only require works that will enhance the natural adjustment of the site. These will largely consist of vegetation strategies. In contrast, moderate recovery potential and highly degraded sites will require a greater level of intervention including structural works to put the river style 'back on track' and enhance natural recovery. These sites will also likely require sediment and vegetation management plans. The river rehabilitation strategy undertaken at each stage must not compromise the catchment-framed goal.

Target conditions for each river style must be designed within an integrative, catchment perspective, if they are to be sustainable over the long term (Kondolf and Downs, 1996). Due regard must be given to potential off-site impacts, ensuring that balanced perspectives on sediment transfer are determined (cf., Sear, 1996). For example, it may be pointless to expend significant effort and resource on 'fixing' a downstream reach if a large sediment slug sits immediately upstream, as the future geomorphological behaviour of the downstream reach will reflect river responses to the transfer and/or accumulation of those materials.

5.0 A CATCHMENT STRATEGY FOR RIVER REHABILITATION

As noted by Rutherfurd et al. (1998), many contemporary river management strategies tend to have:

- an overemphasis on river stability at the expense of ecological needs
- concentrated on channel forms, with limited appreciation of biophysical processes on floodplains
- limited sense of 'off-site' impacts
- learnt little from past mistakes, hindered by a lack of effective auditing procedures
- a bias towards the needs for river rehabilitation rather than a concern for river conservation.

Management efforts need to move beyond locally-based, reactive strategies to catchment-framed proactive frameworks. The character and behaviour of individual river styles, and their downstream pattern, provide an appropriate biophysical framework with which to develop river rehabilitation schemes that work with the natural behaviour of rivers. Ecologically sustainable river management strategies will only be achieved if adopted procedures work with the natural behaviour of river systems. Channel geometry and vegetation associations must be appropriately reconstructed before sympathetic rehabilitation of riverine ecology will occur (Newbury and Gaboury, 1993). Hence, river rehabilitation strategies must work towards river structures which fit the local environmental setting. This can be achieved within the river styles approach.

A biophysical approach to prioritorisation of rehabilitation efforts, based on river styles and geomorphic assessment of recovery potential of rivers is outlined below (see Rutherfurd *et al.,* this volume, Rutherfurd *et al.,* 1998).

Priority One: Conservation reaches. These are the least disturbed parts of the catchment. River structure and vegetation associations are relatively intact. Management strategies aim to maintain, or improve, the current river style.

Priority Two: Strategic reaches. In general, these reaches of river are sensitive to disturbance and may trigger off-site impacts. Pre-emptive management strategies are the most effective means of river conservation. Retaining, or improving, the present condition of these reaches is considered to be best management practice. Nick point management is a prime example; once incision is initiated, it may be almost uncontrollable without inordinate, impractical expense (e.g. Newson, 1992; Schumm et al., 1987).

Priority Three: Connected reaches with high recovery potential. If a reach shows signs of natural recovery, there is a high likelihood that management efforts that work with the behaviour of the river can achieve quick, visible success. While the 'do nothing' option may be viable at these sites, minimally invasive 'soft-engineering' approaches based on riparian vegetation management or stock exclusion will facilitate accelerated recovery. Following procedures employed in bush regeneration work, reaches attached to conservation sites are tackled first, 'building outwards' to other reaches. Rehabilitation strategies have a greater likelihood of success adjacent to high conservation reaches, as flow and sediment transfer are likely to be in-balance. Many of these upstream reaches also have a near-continuous cover of native riparian vegetation, from which seed sources can aid recovery of downstream reaches. Alternatively, where a reach in poor condition lies between higher priority reaches, there is significant likelihood of management success in rehabilitating the 'linking' reach.

Priority Four: Isolated reaches with high recovery potential. These reaches have high inherent recovery potential, but are isolated within the catchment. Minimally invasive rehabilitation strategies, based on management of riparian vegetation cover and/or stock exclusion, should suffice, aiming to assist the capacity of the river to 'self-adjust'. These reaches can form nodes for future broader-based efforts at rehabilitation.

Priority Five: Moderate recovery potential reaches. These reaches have reasonable potential to recover and can be rehabilitated at reasonable cost. River structure and vegetation associations require improvement. Invasive strategies are often required to change the character or behaviour of the reach. This aids natural recovery, providing a basis upon which improvement can occur. Direct planting is often required. Many sites will need on-going management, such as removal of weeds, replanting, or, in more extreme circumstances, shifting sediment accumulations or channel realignment. Adopted target conditions for river rehabilitation must replicate the natural variability in river structure associated with each river style. The simplest procedure to achieve this is to replicate the natural character of geomorphic, vegetation and habitat attributes of a reach of the same river style in a less impacted section of the catchment (see Fryirs, 1999).

Priority Six: Highly degraded reaches. These reaches of the catchment have little natural recovery potential. The river shows signs of continued degradation, such as accelerated sedimentation or erosion. Invasive, physical intervention is required. This is often expensive, with uncertain outcomes. Once destabilised, the most effective strategy may be to wait for the system to regain some sort of balance before adoption of physical intervention strategies.

The philosophical perspective which underpins this prioritisation strategy for catchment-based efforts at river rehabilitation is as follows (see also Rutherfurd, this volume):

1) **Conservation precedes rehabilitation**. Strategies for sustainable catchment management must balance efforts at conservation and rehabilitation of river courses. Since habitat conservation is the key to maintaining the biodiversity of aquatic ecosystems, preservation of remaining near-intact fragments of river courses is the first priority in the proposed framework. Given this perspective, in which maintaining the geodiversity of river structure is viewed to be the key to retaining ecosystem functioning, maximising the heterogeneity of river courses is critical in providing niche habitats. Refugia must be retained under differing flow conditions (e.g. ensuring that pools continue to support water under low flow conditions). The systematic, but inadvertent, destruction of habitat along many river courses makes existing remnants all the more precious in terms of their conservation and heritage values.

2) The next strategy is to work in those sections of the catchment with **high natural recovery potential**, thereby maximising the likelihood of management success. Whenever possible, the ideal sites to commence rehabilitation programs are connected to those parts of the catchment in which river character and behaviour are relatively stable (e.g. high conservation value reaches), such that longer-term strategies can build on greater lengths of river which have appropriate river structures for their setting. Less impacted sections of a river style are used to assess appropriate target conditions for more degraded river reaches of the same river style (cf., Rosgen, 1994, 1996; Fryirs, 1999). Strategies that mimic the ‘natural’ behaviour of the river for any particular landscape setting will be most cost-effective in the long term, and will require minimal on-going maintenance

3) **Consider more difficult tasks**. At unstable sites where the river may be undergoing a sustained period of readjustment, inordinate expense may not yield substantive outcomes, impacting on community confidence in terms of river management efforts. These longer-term rehabilitation programs require invasive rehabilitation techniques. Although conventional river engineering practices can be employed, the most effective strategy may simply be to wait for these reaches to regain some sort of physical balance before adoption of intervention strategies.

6.0 IMPLICATIONS

As rivers demonstrate remarkably different character, behaviour and evolutionary traits, both between- and within-catchments, individual catchments need to be managed in a flexible manner, recognising what forms and processes occur where, why, how often, and how these processes have changed over time. River styles present a catchment-framed reconnaissance survey of river character and behaviour. The explanatory and predictive basis of the approach provide a rigorous, physical basis for management decision-making.

Baseline surveys of river styles provide the catchment context within which Rivercare Plans can be designed and implemented, with due concern for off-site implications. These insights can be used to highlight areas or attributes of river condition that need to be addressed, prioritising management efforts and expenditure within an integrative framework. Application of the river style procedure enables managers and researchers to work more effectively with local groups on river rehabilitation programs by:

- more effectively prioritising resource allocation to sites for conservation and rehabilitation
- providing appropriate understanding of the nature and controls on 'problems', assisting in the development of proactive conservation and rehabilitation strategies
- assessing which techniques for river rehabilitation are likely to be most successful
- determining the most appropriate target condition for river rehabilitation, ensuring that site-specific strategies are linked within a reach and catchment-based 'vision'.

As the river styles framework records the physical template of rivers throughout a catchment, it provides a suitable approach to assess habitat availability along river courses. This template can be used to develop strategies that strive to maintain (or improve) existing levels of biodiversity for each river style (e.g. conservation of 'unique' habitat). These insights can be used to design the river morphology for each river style which maximises the ecological potential of river reaches across the range of flow conditions. This is especially important in terms of maintenance of viable refugia under low flow conditions. Furthermore, the river styles platform provides a representative sampling framework for ecological monitoring of rivers.

It is recognised implicitly that the river styles procedure is scientifically-based, while decision making on management efforts is a consultative processes, driven by a wide range of agendas from multiple stakeholders. The river styles approach provides no sense of landscape aesthetics, or political and/or community expediency in determination of what the river should look like. Rather, it provides a biophysical basis for prioritorisation of efforts in terms of river conservation and/or rehabilitation.

River management continues regardless of limitations of knowledge. As a general rule, the precautionary principle should be observed in the absence of background scientific understanding, and advice to community groups should not be prescriptive. Given the community focus of river rehabilitation projects in Australia, and the underlying emphasis on the return for dollars spent, working at sites with a high likelihood of success provides a sound management strategy in biophysical, socio-economic and environmental terms.

7.0 CONCLUSION

To date, river styles have only been analysed in coastal catchments in NSW (Cohen et al., 1998; Ferguson and Brierley, 1998 a, b; Fryirs and Brierley, 1998 a, b). However, the approach is generic, and there are no reasons why the procedure should not be applied elsewhere. Indeed, it could be argued that there is a greater need for research into river styles in other parts of Australia, where our knowledge of river behaviour is rudimentary. It would be inappropriate to transfer our existing knowledge to many of these river systems in an uncritical manner, as the fundamental controls on tropical or arid river systems, for example, are unlikely to replicate the better studied catchments of the southeastern corner of the continent.

The baseline survey of river geomorphology, assessment of river condition, and prioritorisation framework for management efforts provide a mechanism by which geomorphic insights into river character and behaviour can be readily applied by management groups. It is interesting to consider the potential outcomes for river rehabilitation programs if a catchment-framed geomorphic template is not utilised. Without this understanding:

- there is little sense of ‘vision’, and management efforts will always be reactive rather than proactive
- site- or reach-specific responses may not fit within a catchment frame
- rehabilitation strategies may not work with nature
- prospects for integrative biophysical approaches to river management are compromised
- the significance of a geomorphic template for ecological interaction in aquatic ecosystems will not be appreciated
- management efforts cannot be prioritorised in a cost-effective manner
- community groups who implement rehabilitation programs may become disillusioned by ‘failure’ of their efforts
- principles of best management practice are negated.

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