USING THE RIVER STYLES FRAMEWORK AS A PHYSICAL TEMPLATE UPON WHICH AN ANTHROPOPHYSICAL LAYER CAN BE DEVELOPED FOR URBAN STREAMS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acknowledgments

The term River Styles® has been trademarked by Macquarie Research Limited (MRL) on behalf of Macquarie University and Land and Water Australia (LWA). This does not prohibit the use of the term River Styles® in organisational promotions or correspondence. However, it does limit the undertaking of a River Styles® assessment to provisional and accredited River Stylers who have undertaken the River Styles® Short Course and have been trained in the principles of the framework.

This report builds on work completed by Kahli MacNab as a Vacation Scholar at Macquarie University in 2001.

1. INTRODUCTION

Over the last 150 years, engineers have been asked to control and manipulate rivers for the benefit of society. Long-term, or ecological consequences were not considered. However, during the last decade, engineers have increasingly been asked to rehabilitate rivers in a way that enhances their geoecological attributes. There is a desperate need for new tools and new concepts to help achieve this (Williams 2001).

Although the vast majority of streams have now been modified by humans (O'Keffe et al. 1994), the density of modification of streams in urban environments is particularly notorious, and the health of urban streams suffers particularly more than rural streams. The range of modifications found in urban environments tends to be distinct from that of rural environments, the sealing of the catchment area and floodplains with concrete has a particularly extreme impact on urban streams. Streams in urban environments require special consideration in their management with regard to the limited amount of space available for them, the high cost of space in urban environments, and the greater threats to life and property (Clifford 2001, Riley 1998). There is therefore a huge requirement for studies into the indirect effects of past river management strategies and modifications, and for the development of a basis, or information base, upon which decisions regarding the application of both new and remedial management strategies can be made.

It is considered that a system for the characterisation or classification of urban streams would provide an appropriate means for the identification of modifications and their impacts, and for the choice and application of appropriate management strategies through comparison of modified and unmodified rivers of the same type. Numerous fluvial classification systems exist, devised for a variety of purposes from fish habitat conservation to preservation of geodiversity (e.g. Jerie et al. 2001), assessment of recreational values and ecological wildlife studies (Mosley 1987). Unfortunately, the majority of these classification systems are not equipped to manage the special conditions that urban streams present. Only a handful of classifications suitable for application in urban environments exist, e.g. Anderson (1999), Fluvial Systems et al. (2000), Davenport et al. (2001), Erskine (1998). There are also a number of accounts of various facets of stream modification, such as Wesche (1985) describes instream fish habitat restoration measures, Charlton (1982) describes of bank protection measures, and Rutherford et al. (1999) documents instream and riparian restoration techniques.

To date, most fluvial classification systems have focused on the physical and biophysical characteristics of rivers, failing to take into account the anthropogenic influences. Meanwhile, those few schemes that recognise anthropogenic influences often fail to take into account biophysical, and especially physical influences on the effects of human modifications. The latter also often fail to properly incorporate scale factors into their framework. At present, the most comprehensive and integrated attempt to classify urban streams is presented by Davenport et al. (2001). However, this system is not without deficiency.

This report describes the development of a more proficient system for the characterisation and interpretation of the geomorphic responses of modification to urban streams, and provides a practical framework for undertaking such assessments. Given the deficiencies of pre-existing classification schemes, it is anticipated that a more proficient system of classification can be developed by extending a pre-existing system that already incorporates a number of these essential components, is proven to be workable, and is amenable to extension. The River Styles framework developed at Macquarie University by A. Prof Gary Brierley and Dr Kirstie Fryirs (Brierley and Fryirs, 2000, 2002; Thomson et al. 2001, Brierley et al. 2002) provides a suitable framework for this extension. River Styles is an integrated, hierarchical, biophysical template for river and habitat characterisation and has been applied throughout NSW, with extensions onto other states, for purposes such as the identification of rare and unusual geomorphic features, vegetation and habitat assessment, and the derivation of water licensing and environmental flow and water quality policies (Brierley et al. 2002). This report discusses how River Styles can be extended to include an anthropophysical layer, and how this is applied. The following section gives a little more information on the nature of human modifications to streams and a few considerations in their classification.

2. HUMAN MODIFICATIONS TO FLUVIAL SYSTEMS

Human modifications to the biophysical characteristics of fluvial systems can be direct or indirect, intentional or inadvertent, and positive or negative. They cause changes to rivers by modifying and interacting with the underlying physical characteristics. Direct modifications can produce both offsite and lagged indirect effects. Direct modifications often include structural engineering changes to rivers and their floodplains, while their indirect influences can include changes to discharge and sediment regimes, erosion, sedimentation and changed velocity. Modifications, and their effects, can be either intentional or inadvertent. For example, the direct, structural change undertaken with the installation of a pipe outlet into a stream or onto a floodplain is merely intended to remove stormwater from human environments, it is not intended to impact upon the stream, but inevitably does. On the other hand, channelisation, has clear, intended, direct impact upon streams in the form of changed channel geometry, velocity increases and reduced overbank flooding (e.g. Keller 1980). Intended modifications also often result in a range of unintentional effects. Following on from the channelisation example, this includes reduced habitat and species diversity. Modifications with both intended direct and indirect impacts tend to be hydraulic engineering structures such as concrete lining and bank protection strategies, while structures that are not intended to impact upon streams (but inevitably do), tend to be civil engineering structures, e.g. pipe outlets, bridges.

Modifications can also have positive or negative effects on the integrity or condition of streams. In the past, engineered structural changes to channels and their floodplains were aimed at controlling and utilising the fluvial environment for the benefit of the broader community. Such structures and changes included dams, levees, channelisation, piping, and lining and were undertaken for purposes such as flood control, water supply, and stability enhancement. However, the ecological damage caused by these modifications, their limited economic feasibility and high maintenance requirements, have increased awareness of our limited capacity to control the natural environment. There has been a resulting shift in ethos from one of controlling the natural environment to one of working with nature, finding compromises between the needs of both riparian communities and the environment. Contemporary structures may be divided into ‘hard’ and ‘soft’ engineering approaches reflecting the materials used and the degree of manipulation of rivers (e.g. Clifford 2001)). Efforts are being made to ensure not only that new developments proceed in an environmentally sensitive way, but also to try to check and heal the damage caused by past management practices. With regard to the latter intention, the aims behind more recent management strategies are to restore, rehabilitate, or enhance fluvial environments either by returning rivers, to some degree, to their former character, or by establishing a new, yet geoecologically functional environment (Fryirs and Brierley, 2000; Fryirs, 2001).

A broadly applicable classification scheme needs to be able to account for as many modifications as possible, therefore it will need to somehow incorporate both direct structural modifications and their indirect effects on the character and behaviour of streams, whether they are intentional or inadvertent, positive or negative.

2.1 Physical, biological and anthropogenic characteristics, and physical templates

In the past, depending upon their purposes, many classification schemes have focused on either the physical, biological or human characteristics of rivers. However, given the interrelatedness of these three components of fluvial systems, without considering all three and the processes that link them, no classification system would be able to sufficiently break down the full diversity of rivers, nor be able to cope with their dynamism. Classification systems should not only incorporate physical, biological and human factors, but should actually maintain the division at each level of classification (e.g. Brierley 1999; Brierley and Fryirs, 2000) so as to enable a greater understanding of rivers by reflecting the natural organisation and functioning of fluvial systems therefore leading to the generation of more suitable river typologies. To address this issue, the River Styles framework is based on developing a physical template atop which direct modifications, biological and other parameters can be measured.

2.1.1 Biophysical Templates

Collection and analysis of biological and ecological information relevant to rivers in a manner that meaningful summarises the spatially diversity and temporal dynamism of rivers is difficult. However, this should not constrain our attempts at developing frameworks to meaningfully collect and analyse geoecological information. In the past, many classification systems have fallen into the trap of examining the biophysical interactions between rivers and individual species at a scale that limits their power to explain bio-geo-ecological patterns across the landscape (Naiman et al. 1992).

The taxonomic type and distribution of plants and animals is fundamentally determined by the type, distributions, and viability of physical habitat as determined by the physical environment, or more specifically, geomorphology (Thomson et al. 2001). Many studies have quantified and validated this link between geomorphology, habitat, and species distributions and abundance (e.g. Thomson et al. 2001; Bisson et al. 1982). In other words, geomorphology is the template upon which biophysical interactions occur (Brierley et al. 2002, Thomson et al. 2001, Brierley and Fryirs 2000, Brierley 1999). Therefore, if classification is to be deployed in a physically meaningful way, geomorphological classification should precede consideration of biophysical interactions.

Geomorphology provides an ideal starting point with which to evaluate the interaction of biophysical processes within a catchment, as geomorphological processes determine the structure, or the biophysical template, of a river system. Understanding of geomorphic processes, and determination of appropriate river structure and function at differing positions in catchments, are critical components in sustainable rehabilitation of aquatic ecosystems. The geomorphic structure and function of many rivers are tied innately to vegetation cover and composition, and the loading of large woody debris. These interactions induce direct controls on the distribution of flow energy, dictating the local-scale pattern of erosion and deposition at differing flow stages. When tied to sediment availability and flow variability, geomorphic structure dictates the diversity of hydraulic units and associated habitats along river courses, and many other facets of aquatic ecosystem functioning (e.g. nutrient flow, transfer of organic materials, etc., see Thomson et al. 2001). Based on these considerations, river morphology and vegetation associations must be appropriately reconstructed before sympathetic rehabilitation of riverine ecology will occur.

Stage One of the River Styles framework provides a baseline survey of river character and behaviour upon which other layers of information can be collected, analysed and interpreted in a meaningful manner. These layers of information can include, habitat assessment, urban modifications, biological and ecological compositions etc.

2.1.2 Anthropophysical Layer

In comparison to biological data, ***direct impacts*** on fluvial systems are easy to observe and record. The types and distributions of direct modifications can be considered, to some extent, to be determined by the conditions of the physical environment, i.e. determined upon an anthropophysical template. Due to both the topographic and sedimentologic characteristics of floodplains, the majority of human settlement exists upon floodplains, alongside rivers. At the same time, the type of river can influence the type of modifications that humans make to it. For example, bank stabilisation techniques are largely reserved for alluvial rivers with unstable banks, while many forms of infrastructure, e.g. bridges, dams, are located upon bedrock extrusions and/or points of maximum lateral bedrock confinement. However, there are also many forms of modification that are seemingly located independently of physical characteristics of rivers. These tend to be direct, but inadvertent modifications, for example, pipe outlets. It is therefore better to consider the distributions of types of modifications to be an independent characteristic in the fluvial system.

Indirect responses to modification are defined as those physical characteristics of a stream or catchment that change as a result of modifications along the reach. The same direct modification can invoke different indirect responses in different streams (Naiman et al. 1992). For example, concrete lining a bedrock channel is unlikely to have a significant impact upon the stability of that stream as it was already highly stable. On the other hand, concrete lining an alluvial channel will significantly increase its stability. In both cases however, the concrete lining will decrease the roughness of the channel margin and will therefore cause velocity increases in both circumstances. Likewise, dams are usually associated with downstream erosion of the channel bed and banks.

From these examples then, it can be seen that direct modifications are superimposed upon the underlying biophysical characteristics of streams (Fluvial Systems et al. 2000). The effects are then dependent primarily upon the nature of the direct modification from which they stem and secondarily on the biophysical characteristics of the stream. Geomorphic responses are the result of interaction between direct modifications and physical processes i.e. geomorphic responses to modification are determined through an anthropophysical framework. The River Styles framework addresses these issues by assessing the importance of both the sensitivity of rivers to disturbance, and the degree of modification.

Because the impacts of modifications are determined upon an anthropophysical layer, any classification system based on the influences of human modifications without consideration of the biophysical conditions will be insufficient. Without the physical template there is not means to interpret responses to modification and the causes of change. It also allows investigation into, and prediction of, the influence of particular modifications on particular types of river, and how the river will adjust in the future. More meaningful understanding of river character, behaviour and effects of modification can be gained in a scheme that incorporates both biophysical and human controls on stream characteristics. Indeed, it is expected that the some types of modification inflicted on a stream will coincide with the type of river, reflecting its capacity to adjust on the valley floor. For example, it is expected that certain types of modification were installed to address certain types of geomorphological issues. For example, bank erosion along meandering rivers, or incision along a sand bed stream may have been addressed with a rock wall or certain types of bed control structure respectively. In contrast, along a bedrock-controlled river these forms of modification would have been inappropriate. Given that most urban stream classification schemes have been applied independent of the type of river and the physical structure of that river, it is not surprising that these notions have not been tested or formally documented.

Given the scale of most modifications, a geomorphic template will provide a suitable platform for examining human impacts on the geoecology of rivers (Brierley and Fryirs 2000). An exemption from this small scale nature of urban modifications is that of general urbanisation at the catchment scale. This modification is of a large spatial scale and can have a major effect on both the sediment and discharge characteristics of streams by decreasing infiltration, resulting in increased runoff, decreases in the time runoff takes to reach channels, and decreases in subsurface flows. The impact of this on the discharge regime is to increase the flashiness and extremes of flow as water levels in the channels rise much faster than under natural conditions and peak discharges are higher, while baseflows are lower. Although there may be increases in sediment loads to channels during the construction phase, this soon ceases and in most cases, widespread urbanisation ultimately seals up important sediment sources. Many urban streams are deeply incised and greatly disconnected from their floodplains with floodwaters impinging on developments. Even small-scale urban development within catchments can have a significant impact on stream characteristics.

If classification schemes are to be able to be widely used for a variety of purposes, they should use physical, biophysical and anthropophysical characteristics from a hierarchy of scales that are functionally linked. In the past, classification systems have been limited in the scales they worked at, have had a narrow focus, and have focused on structural characteristics rather than the dynamics of fluvial systems. The narrow focus of these schemes is reflected in the large number of systems that have been generated for a variety of purposes. It is significant that very few systems have been open enough to allow for classification of modified streams, and urban streams in particular. This is significant, especially in Australia. This is where the strength of the River Styles framework lies. The River Styles framework provides a basis for explaining geomorphic responses to modification and interpreting the causes/reasons for modification rather than just documenting the symptoms. In addition, because it is catchment based, it allows off-site impacts and linkages throughout a catchment to be examined.

3. AN ANTHROPOPHYSICAL APPROACH TO URBAN STREAM CLASSIFICATION

An anthropophysical classification of rivers based on their physical characteristics and their direct modifications provides the ideal layer for the gathering of information that could be used to assess the indirect geomorphic effects of various modifications in various settings and to recommend appropriate management strategies.

However, the majority of previous accounts fail to mention the type of river in question. In addition they fail to fully describe the type of modification, its purpose and its geomorphic affect. The modifications to streams are hugely diverse in their functions, the titles they are given require standardisation (many modifications, e.g. weirs/sills, have more than one name). Given that the indirect effects can span upstream, downstream and laterally, it is important to consider all the direct modifications in a catchment not alone, but in combination. Due to the huge diversity of modifications, the range of combinations can be complex. Hence, in addition to facilitating the generation of information regarding the geomorphic implications of stream modifications, an anthropophysical classification system also requires predictive capacity such that the impacts of modifications on various river types could be considered where they have not yet been encountered or recorded. This requisite collides with that of ensuring that the classification system utilises functionally linked characteristics and requires that modifications be viewed in the way that they interact with geomorphological processes, i.e. they need to be viewed in a geomorphological context.

Other authors have provided classifications of urban streams, however they all fall short of the above criteria. Davenport et al. (2001) provide a system based on the nested hierarchy of Frissell et al. (1986), that focuses on linkages between human modifications, physical conditions and habitat availability. Modifications are assessed on the basis of their type and extent, and substrate, bank material and bank protection type is recorded at 50m intervals along the length of the modification. However, the scheme is limited by the range and scales of modifications it can consider and the scales that it works at. It currently only allows for assessment of longitudinal channel-marginal modifications such as channelisation, lining, and bank protection strategies that fall at the 'stretch' scale, which lies within the 'sector' scale. Stretches are said to be between 100 and 500m long. Sectors are delimited on the basis of major tributary junctions. However, the work of Wadeson and Rowntree (1994) suggests that major tributaries do not necessarily constitute a change in the biophysical conditions of rivers. This therefore suggests that the sectors used by Davenport et al. (2001) may not necessarily be biophysically distinctive and therefore modifications are not necessarily being assessed within their biophysical boundaries. This is because the scheme is not based on the type of river that has been modified.

Even if the defined sectors in Davenport et al. (2001) were biophysically meaningful, and if the system were extended to recognise modifications at smaller (biophysically meaningful) scales, it is still limited in that it recognises and classifies streams as units defined by the boundaries of modifications, rather than characteristic assemblages of geomorphic units. As a result, the way in which the data is collected limits the ability to explain geomorphic responses to modification in this scheme.

4. USING THE RIVER STYLES FRAMEWORK AS A PHYSICAL TEMPLATE UPON WHICH AN ANTHROPOPHYSICAL LAYER CAN BE DEVELOPED FOR URBAN STREAMS

4.1 Introduction: Background to the River Styles framework

The River Styles framework, developed at Macquarie University, provides an integrated, hierarchical, biophysical template for river and habitat characterisation (Brierley 1999, Brierley and Fryirs 2000, Thomson et al. 2001, Brierley et al. 2002). It is generic and open-ended and has been applied successfully in NSW and a range of other states (Brierley at al. 2002). Applications of the framework have not yet been applied in an urban context, although due to its structure, there is no reason why it could not be adapted for use in such a setting. Given that the River Styles framework is a proficient and well-established system, it provides an ideal physical template for the development of an anthropophysical layer for use on urban streams.

The advantages of the River Styles framework are:

- It provides a coherent basis for ordering information with varying levels of detail (through use of a nested hierarchy).
- Given the structure of the framework, and the procedures used to identify River Styles, it is replicable.
- It provides a physical template upon which a range of other layers can be added (e.g. habitat assessment, urban streams etc.)
- It is catchment-framed allowing linkages of geomorphic impacts to be interpreted.
- It is based on assessment of river behaviour, allowing the causes rather than the symptoms of change to be interpreted.
- It has predictive power.
- It allows for design of management strategies that work with the type of river and its natural character and behaviour.

It is hoped that developing the anthropological layer as an extension to a well-established biophysical framework, and building on the contributions and observations of other authors, will enable the anthropophysical layer to be both comprehensive and well integrated.

4.2 Types of direct urban modification

In this assessment scheme, only direct, structural modifications are examined. There are dozens of forms of structural modification that have been used on urban streams. It is beyond the scope of this report to review all these types. Instead, it is recommended that these types of modification be identified for the specific catchment under investigation and be fully documented, characterised and photographed in the field so that a database can be built up over time. The Urban Proformas developed in this report will go some ways towards this documentation. It is hoped that through the work that Steve Dudgeon is compiling on forms of modification that this database can be initiated.

Wesche (1985) and Charlton (1982; **Figure 1**) provide classifications of instream habitat restoration and bank protection works respectively. Erskine (1998) provides a scheme of classification of many modifications, however it is a single-level classification, based only on the known names, or types of engineered structures and only on those found within the Hawkesbury-Nepean system. Riley (1998) provides a classification of common flood-control channel designs, while Snelder et al. (1999) have considered channelised streams alongside natural stream types. Anderson (1999) and Rutherfurd et al. (1999) provide comprehensive lists of modifications. There is no reason why more cannot be added to the system as they are found to be important.

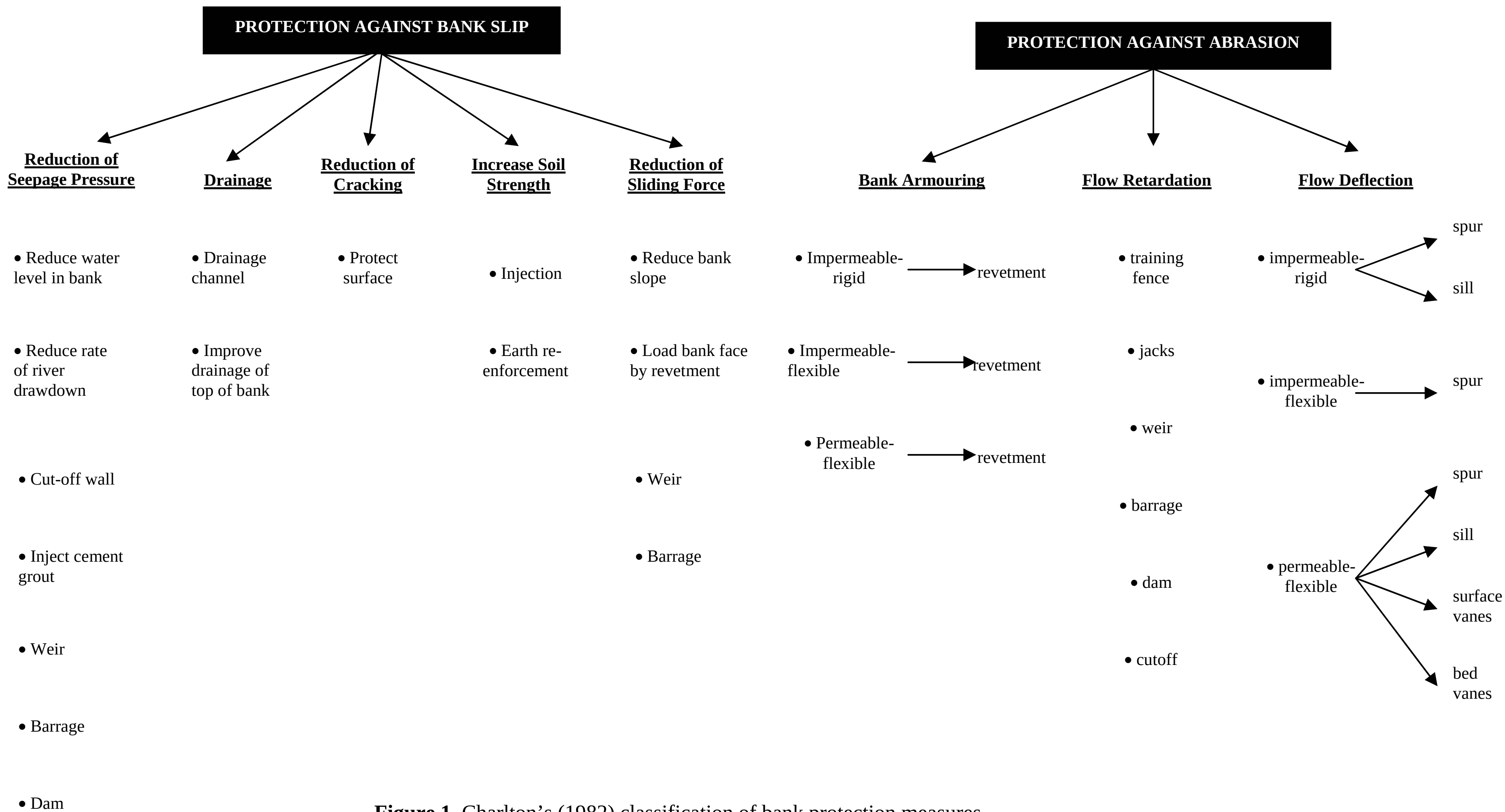


Figure 1. Charlton's (1982) classification of bank protection measures.

4.3 Layers of information that build up an anthropophysical assessment for urban streams

The anthropophysical layer for urban streams is structured in a way that allows the practitioner to acquire detailed information within a relatively short period of time after Stage One of the River Styles framework has been completed. This information is then compiled in a manner that is used to explain the extent of modification and interpret geomorphic responses to modification within a reach, between reaches, along river courses and across a catchment (**Figure 2**). It is only when this information is in hand that implications for stream rehabilitation can be assessed.

Figure 2: Information required in the anthropophysical layer for urban streams

CHARACTERISATION

Type and position of modification (positional attribute)
⇓
Extent of modification (dimensional attribute)
⇓
Massive structural characteristics (permeability etc.)
⇓
Finer structural characteristics (roughness etc.)

⇓

INTERPRETATION

Geomorphic impacts – along the reach
⇓
Geomorphic impacts – off-site
⇓
History of modification
⇓
Explanation of catchment patterns of modification and their geomorphic responses

Positional attributes of modifications are the first level of analysis (i.e. whether they are on the floodplain, the channel bed or the channel banks), followed by their ***dimensional*** nature (i.e. whether they are essentially a ***point*** feature, a ***linear*** feature, or a blanketing or ***areal*** feature). The dimensional ***extent*** of a modification should be measured as its proportion of the biophysical unit it is nested within.

- For modifications that extend along a streamline, extent will be measured ***linearly*** as the proportion (percent) of the River Style length that has been modified, and number of occurrences along the River Style. Forms of modification would include pipes, localised bank protection works (e.g. rock walls), rock/boulder riffles, bed control structures etc.
- ***Areal*** modifications should be measured as the proportion (percent) of the total area of different geomorphic surfaces (floodplains, channel bed/banks, benches, bars etc.) that have been modified, and number of occurrences along River Style. Forms of modification will include floodplain fill,

concreted floodplains (e.g. carparks, residential, industrial etc.) and concrete/rock channel (canal where the entire bed and/or banks are covered).

- For the extent of ***point impacts*** a measure of ***frequency*** is sufficient for the interpretation. Forms of modification will include stormwater outlets, culverts, bridges, dams, sewage man holes etc.

Modifications that line the channel margin over a large proportion of the River Style, e.g. concrete lining, should be considered an areal modification. Where these features are localised however (e.g. protecting one section of a bank), such modifications will be considered as linear features.

The ***massive structural characteristics*** includes measures such as permeability, flow obstruction and deflection, and relationship to physical geomorphic features. ***Finer structural characteristics*** include measures such as the roughness of individual modifications and orientation.

As mentioned above, it is important that modifications be viewed in a geomorphological context, i.e. to envisage the processes they interact with, the way in which they change them, and hence their possible indirect effects on streams. This is vital to allowing the scheme to remain open-ended and generic such that no extra information other than visual assessment is required in order to gain an understanding of a modification, i.e. no extra research is required if the name or purpose of the modification is unknown. This should also allow greater on-the-spot interpretation of the combined effects of modifications and the various influences of modifications as they are applied in disparate settings. While other classifications of urban and modified streams do not attempt to do this, the anthropophysical layer developed here attempts to do so by removing modifications from their human context (i.e. their name and purpose) and using their structural characteristics to interpret their geomorphological influences. This classification will therefore place those modifications that have the same ***direct geomorphic impact*** on streams into the same group, i.e. it will generate geomorphic types of modifications. Different modifications, such as say, a causeway and dam, can have the same impacts on streams. The same modification can also have different influences depending upon the type of stream and the conditions at various stages over time. For example, bridges have been known to be associated with both scour and aggradation (e.g. Cardoso and Bettess 1999, Johnson et al. 2001) and while a single bed control structure may have quite an impact on flow and sediment continuity during low flow, as the flow stage rises, those effects will become less and less, until at peak flow, the stream may be behaving in a way very similar to its pre-modified behaviour for that level of flow.

Working in a geomorphological context, ***direct geomorphic impacts*** are assessed in terms of changes to river planform, roughness, grain size distribution, geomorphic unit assemblage and channel capacity. ***Indirect geomorphic impacts*** are considered in terms of flow, sediment transport and vegetation associations. With regard to flow, it is important to consider how modifications interact with the quantity of flow, how they alter flow depth and width, their effects on velocity and turbulence, and the position of the thalweg and slackwater areas (**Table 1A**). When considering sediment transport, it is important to consider how modifications affect the transport rate, quantity and calibre of sediment, and also the locations of erosional and depositions areas (**Table 1B**). With regard to both sediment and water transport, it is also important to consider the stage that modifications begin to interact with the geomorphology of streams. For vegetation associations, it is important to include the impact of modification on the coverage and composition of vegetation in the channel and on the floodplain (**Table 1C**).

Table 1A – Flow/water regime

Flow Attributes	Modification Attributes
Volume	Impoundment, permeability, diversion
Width and Depth	Cross-sectional shape and size
Velocity	Planform, roughness, bed slope
Turbulence	Roughness
Thalweg Position	Flow obstruction and deflection; orientation
Slack Water Areas	
Stage Effected	Position – channel and floodplain

Table 1B – Sediment regime

Sediment Load Attributes	Modification Attributes
Rate	Sediment protection/ loosening/exposure
Volume	Impacts on flow characteristics, especially velocity and power
Calibre	
Sorting	
Distribution of erosion and deposition	Flow obstruction and deflection; orientation
Stage Effected	Position – channel and floodplain

Table 1C – Vegetation associations

Vegetation associations Attributes	Modification Attributes
Coverage	Flow obstruction and deflection; orientation. Impacts on flow characteristics, especially velocity and power
Composition	Impacts on water quality and ecological attributes.
Stage Effected	Position – channel and floodplain

Table 1A, B, C Characteristics of modifications important in the determination of the geomorphic influences of modifications and therefore characteristics that should be used for an anthropophysical classification of modifications.

Geomorphic off-site impacts are defined as the physical characteristics of a stream or catchment that change as a result of modification in an upstream or downstream reach. Such factors must be assessed on a catchment-by-catchment and reach-by-reach basis. In the River Styles framework, within-catchment linkages of physical processes 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). By adding an urban layer to the assessment, the upstream and downstream responses to modification can be assessed and interpretations made on the future responses of modifications elsewhere within a catchment. In this assessment, off-site impacts are assessed in terms of the changes induced in response to changes to the water and sediment regimes and seed sources/exotic incursions within the catchment. Adoption of appropriate measures to minimise the impacts of these constraints (addressing underlying causes rather than the symptoms of problems relating to sediment exhaustion, flow management; depleted vegetation and seed sources, etc) is key to effective river rehabilitation/management.

Geomorphic responses /changes should be placed in context of the ***history of modification***. In this way, the practitioner can interpret why a certain type of modification was installed (assessing the causes rather than just the symptoms), the time it has taken for a the fluvial system to respond (i.e. almost instantaneously in terms of a canal, or over years in terms of a bed control structure), and the effectiveness of the modification (i.e. did it fulfil its purpose). This moves the assessment beyond purely a visual documentation of the type and extent of modification.

To ***explain the geomorphic impacts of modification within a catchment*** tables and figures should be used to describe and explain the patterns of modification seen across the catchment. The types of questions that should be answered include:

- Are certain types of modification found for different types of river?
- Are some River Styles more modified than others?
- What has been the history of modification across the catchment?
- What have been the overall geomorphic responses to modification in the catchment? Do any patterns emerge?
- To what extent is the catchment 'modified' versus 'unmodified'?
- What are the river management implications in this catchment?
- What insights can be gained into how the impacts of modifications on various river types could be considered where they have not yet been encountered or recorded?

5. APPLICATION OF AN ANTHROPHYSICAL URBAN LAYER WITHIN THE RIVER STYLES FRAMEWORK

5.1 Introduction

The identification of River Styles is undertaken in Stage One of the River Styles Framework. The River Styles procedural tree (**Figure 3**) is used to identify rivers in different valley-settings. Depending on the valley-setting in which a river is found, a different set and sequence of attributes are measured and interpreted to derive the River Style. For each catchment, a catchment-specific River Styles naming tree is derived (e.g. **Figure 4** has been developed for coastal NSW). Given that the River Styles framework is open-ended and generic, rivers that are identified in new environmental settings can be added to the naming tree, incorporating new variants as they arise.

Figure 3 The River Styles procedural tree (from Brierley and Fryirs, 2002).

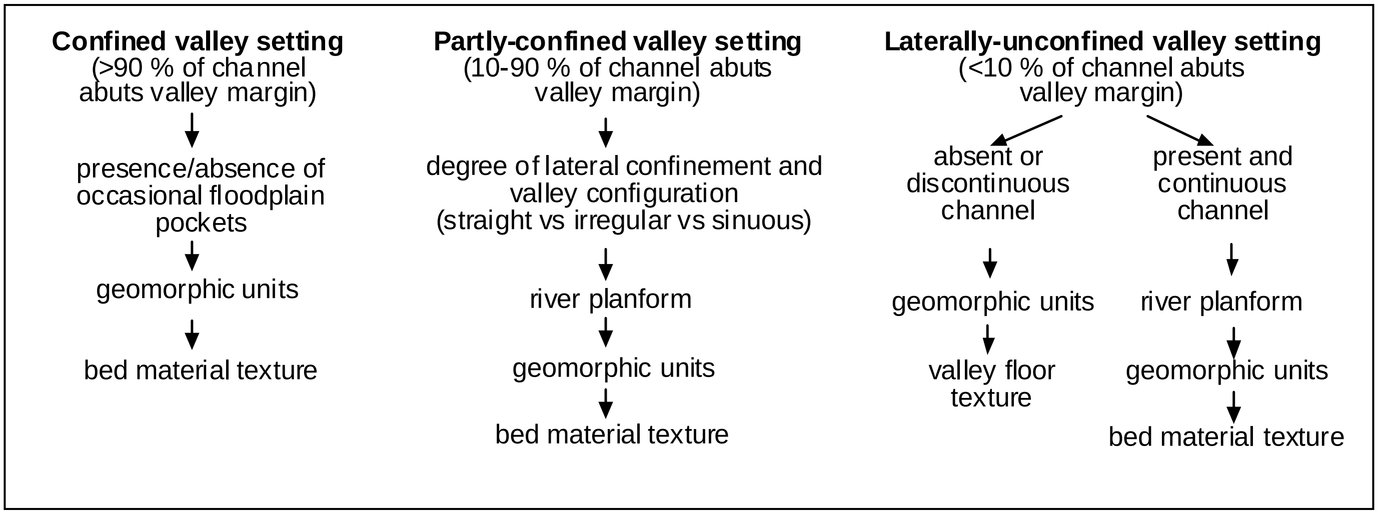
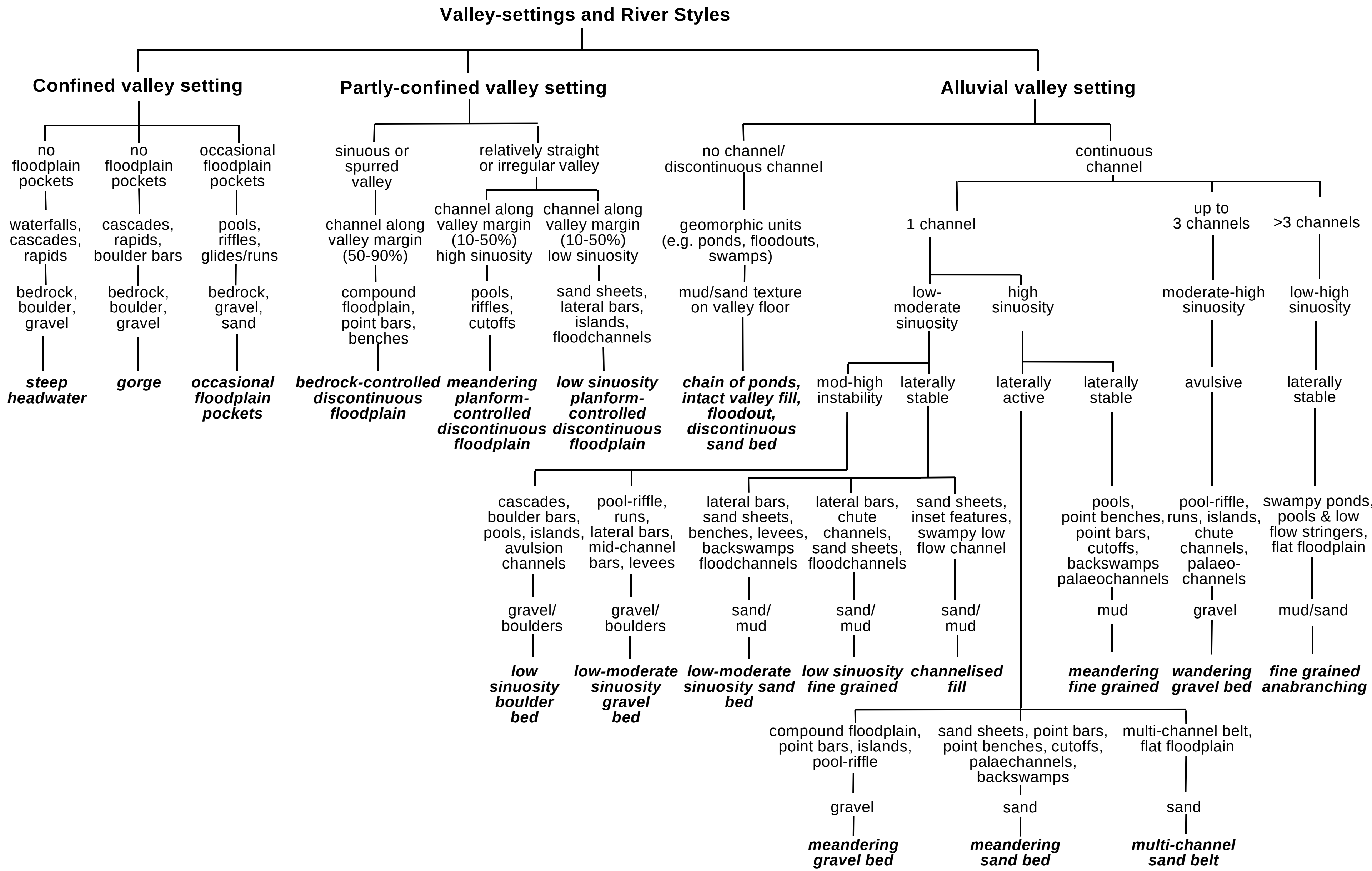


Figure 4 The River Styles naming tree for rivers in coastal NSW (from Brierley and Fryirs, 2002)

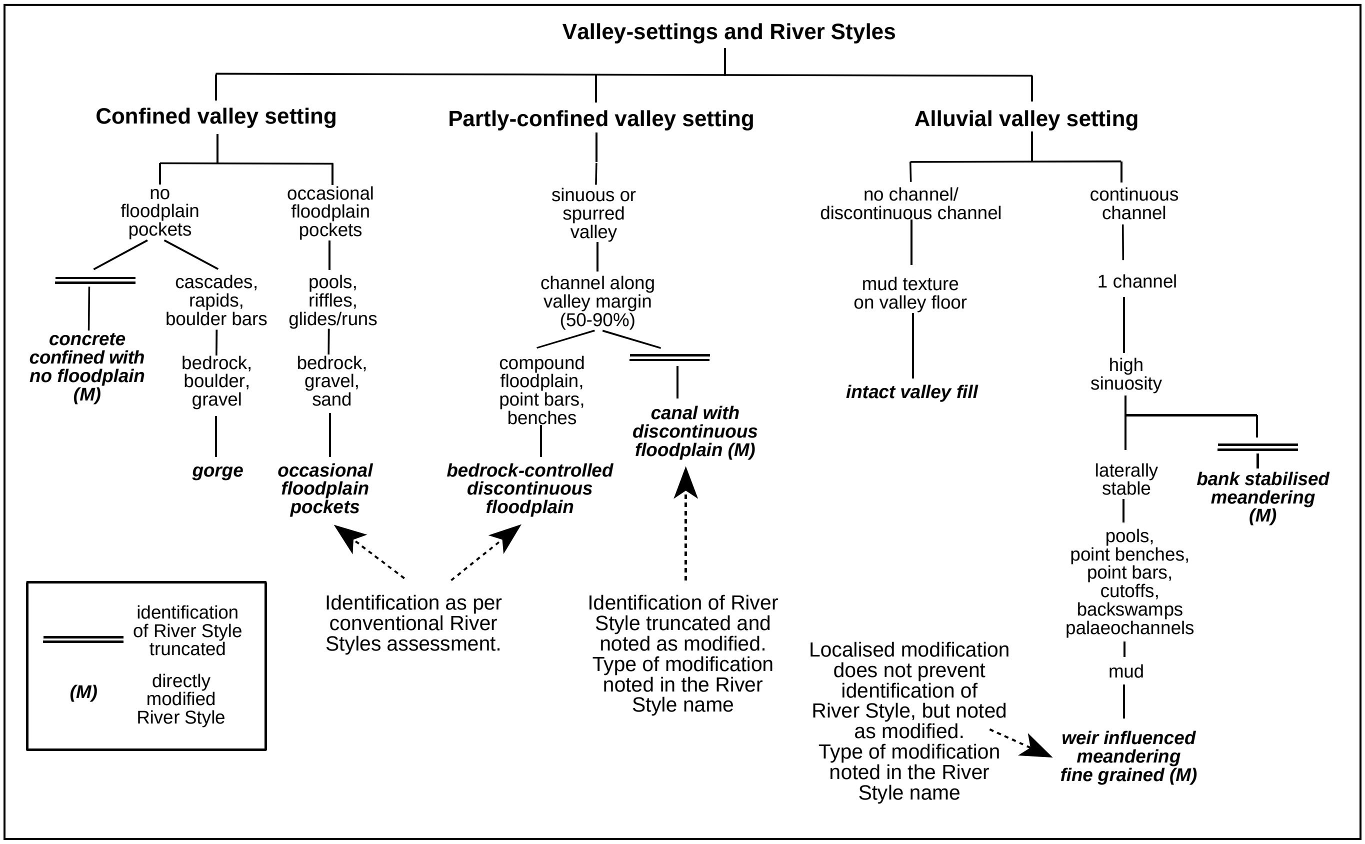


5.2 Modification of Stage One analyses: Identification of River Styles in urban settings

In an urban setting, Stage One of the River Styles framework provides the physical template upon which the urban layer is subsequently added. Stage One of the River Styles framework must be applied as it was designed. However, the following modifications and sequence of procedures are recommended for identification of River Styles in urban settings:

1) All reaches in a catchment continue to be classified using the conventional biophysical River Styles framework.
2) Those River Styles that can be fully identified and contain no direct urban modifications will be recorded as per conventional River Styles.
3) For other sections of river, run through the River Styles procedural and naming trees are far as possible, to identify the biophysical characteristics of each River Style.
4) Those River Styles that can be fully identified, but contain point modifications or modifications along a localised section will be recorded as 'Modified' and a (M) will be noted at the end of the River Style name.
5) Given the nature of some urban modifications, it may not be possible to identify a River Style down to its geomorphic unit level or finer. If movement through the River Styles tree is terminated (i.e. direct modification prohibits the identification of a 'full' River Style, the name given to the modified River Style will reflect the truncation of the process of identification and the type of modification. For example, in some instances, movement beyond say planform attributes for an alluvial river will be difficult. Therefore, the river may simply be noted in Stage One of the framework as 'Piped meandering (M)' (if bed material texture and geomorphic units are obscured) (**Figure 5**).
6) The River Styles templates produced in Stage One will characterise as best as possible the geomorphological attributes of the stream. For unmodified rivers, standard River Styles templates, planform maps, cross-sections and photographs are expected. For modified streams, it may only be possible to fill in certain sections of the River Styles proformas. No-where in these proformas should mention be made of the types or extent of modifications. This template is purely geomorphological, and description of other attributes appear in the urban proforma (described below).
7) A catchment-specific River Styles tree will be developed. This tree will reflect the termination of identification of some River Styles (e.g. **Figure 5**).
8) A coloured catchment base map will be produced noting the distribution of all modified and unmodified River Styles.
9) All rivers that have an (M) at the end of their names (denoting that direct urban modifications occur along the river) will be further characterised using the urban proforma.

Figure 5 Example of a catchment-specific River Styles tree including modified River Styles



5.2.1 Products from application of Stage One of the River Styles framework

As per standard River Styles report requirements. The catchment map will have modified rivers noted with an (M) after their names, and the River Styles proformas will be filled in as best as possible.

Unmodified reaches will simply be characterised by their biophysical characteristics, while modified River Styles will be described using both biophysical (as per Stage One of the River Styles framework) and anthropophysical characteristics (as an additional layer).

5.3 Application of an anthropophysical urban layer

The following proforma should be filled out for each ‘Modified’ River Style. Where the variability in modifications differs for the same River Style in different sections of the catchment, multiple proformas will be filled out. The proformas are set out according to the ordering of information that provides the backbone of the anthropological urban layer.

The extent of modification will be reflected in the River Style name. If a ‘full’ modified River Style could be identified, direct modifications are likely confined to localised sections of river course or point sources. If a ‘full’ modified River Style could not be identified, and significant distinguishing geomorphic attributes are obscured, the extent of modification is likely significant. This in effect, reflects and establishes the extent of modification.

URBAN MODIFICATIONS PROFORMA (CHARACTERISATION)

River Style name

Reach name and subcatchment found

Details of analysis – time, practitioners

Resources used – field, maps, reports

Type, position and dimensional extent of modification

Channel bed	Presence/absence
Channel bank	Presence/absence
Floodplain	Presence/absence
Extent, frequency and position of modification along the River Style	***Channel bed*** Point Linear Areal ***Channel bank*** Point Linear Areal ***Floodplain*** Point Linear Areal

Character of each type of modification

Massive structural characteristics	
Material composition and permeability of each type	Wood, concrete, etc.
Flow obstruction and deflection	
Relationship to physical geomorphic features/units	E.g. bridges at bedrock spurs, bed control structures on alluvial bars, pipes on benches, straightening through meander bends
Finer structural characteristics	
Orientation and shape of each type	
Roughness of each type	

Photographs of each type of modification

Type/extent	**Channel bed**	**Channel bank**	**Floodplain**
Point			
Linear			
Areal			

URBAN MODIFICATIONS PROFORMA (INTERPRETATION)

Geomorphic responses of manipulation along the River Style

Direct geomorphic impact (primary)	***Planform attributes*** – lateral stability, sinuosity, number of channels ***Roughness -*** of channel bed, banks and floodplain ***Grain size distribution*** (bed, banks, floodplains) ***Geomorphic unit assemblage*** (induced increasing heterogeneity or homogeneity) ***Channel capacity*** – size and shape
Indirect geomorphic impacts (secondary)	***Water regime*** – How has the formative discharge and inundation frequency of different surfaces changed due to modification? Influence on velocity and turbulence, position of thalweg etc. ***Sediment transfer*** – how has the sediment transfer/storage processes changed along the River Style due to modification? (Rate, quantity, calibre, location of depositional or erosional areas etc.). ***Vegetation associations*** – how have vegetation associations changed in the channel and on the floodplain due to modifications?, distribution of natives and exotics (e.g. are exotics concentrated around stormwater outlets?)

Geomorphic responses of manipulation in upstream and downstream reaches

Offsite geomorphic impacts	***Water regime*** – e.g. frequency of flooding, changes to flood hydrograph ***Sediment transfer -*** e.g. sediment starvation or increased supply ***Vegetation associations*** – lateral and longitudinal connectivity of vegetation along the river course, changes to seed sources

History of modification

When installed	
Why installed	

Sketch map showing the distribution of different types of modification along the River Style

Use the planform map presented in Stage One as a basis to add the position and extent of each type of modification.
Add a key for each type of modification.

Other information

5.3.1 Products from the urban layer

For each River Style:

- The Urban Modifications Proforma must be filled out. Where the variability in modifications differs for the same River Style in different sections of the catchment, multiple proformas will be filled out.
- Photographs of each type of modification.
- Sketch map showing the distribution of different types of modification along the River Style.

For the catchment summary of stream modification:
To ***explain the geomorphic impacts of modification within a catchment*** tables and figures should be used to describe and explain the patterns of modification seen across the catchment. The types of questions that should be answered include:

- Are certain types of modification found for different types of river? Develop a matrix showing the types of modification for each River Style (i.e. to identify those types of modification that are specific to a certain River Style and those that are 'common' across a range of River Styles.
- Are some River Styles more modified than others? Text describing the extent of modification of each River Style.
- What has been the history of modification across the catchment?
- What have been the overall geomorphic responses to modification in the catchment? Do any patterns emerge?
- To what extent is the catchment 'modified' versus 'unmodified'?
- What are the river management implications in this catchment?
- What insights can be gained into how the impacts of modifications on various river types could be considered where they have not yet been encountered or recorded?

6. CONCLUSION

This anthropophysical urban layer on top of the River Styles framework has yet to be tested and it is undoubtable that it will require a number of refinements and additional sections added as specific circumstances arise. A number of theoretical issues are already becoming apparent, such as the characterisation and naming of geomorphic units associated with particular forms of modification and how different the impacts of various modifications are along different river types. Attempting to describe new modifications and explaining their geomorphic responses for different types of river will provide a good test of its capabilities.

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