The identification of and development of management principles for laterally active coarse-grained rivers in Victoria, Australia

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Key Points

- Laterally active coarse-grained rivers have been identified as being particularly problematic in Victoria, Australia.
- There is approximately 3,500km of this waterway type across Victoria, with over one third located in Northeast Victoria.
- These are high energy systems subject to flood related lateral channel adjustments.
- These stream systems co-exist with high value agriculture and floodplain infrastructure and provide for high value ecological processes and assets.
- The stream systems are over-represented in flood related damage in Northeast Victoria.
- Despite their high ecological value, high consequence of economic loss associated with channel change and high rate of channel change, there is no agreed approach to the management of these streams.
- Guiding principles and approaches to strategy, policy, and technical management of these streams are discussed.

Abstract

This paper describes the outcomes of an investigation to identify the location of, and develop management principles for, laterally active, coarse-grained rivers in Victoria. Laterally active coarse-grained rivers have been identified as being particularly problematic in Victoria. These stream systems are characterised by unconfined or partly confined channel boundaries and the presence of gravel or cobble stream beds. The applied bed shear stress during flood events in these systems is often less than the shear resistance of the armoured bed material, making the stream bed resistant to channel incision. However, the bank material, not subject to the armouring process, is vulnerable to accelerated erosion in the absence of protective riparian vegetation. Most of these systems in Victoria have been cleared of their native riparian and floodplain vegetation that limited their lateral movement. This has rendered these stream systems vulnerable to ongoing flood dominated active channel movement. This movement has created management problems for adjoining landholders and impacted on instream aquatic values. The investigation identifies the location and extent of these stream systems in Victoria, describes the characteristics of the systems and discusses proposed integrated river and floodplain management principles required to manage these systems to meet broad community aspirations.

Keywords

Active, coarse-grained, meandering, rivers, management, Victoria.

Introduction

Victoria is characterised by an array of geomorphological stream types. These stream types include both confined systems (e.g. gorges and confined headwaters) and unconfined systems such as cut and fill systems (e.g. chains of ponds), anabranching systems, and single-channel meandering rivers.

Laterally active, coarse-grained rivers are one such stream type in Victoria and remain one of the most problematic streams for management. These systems have high levels of in-stream unit (specific) stream power and have been found to have high rates of channel change during flood events.

The authors of this paper undertook an investigation to review the definition, location, and management of laterally active, coarse-grained rivers in Victoria (Alluvium 2020). This paper describes the approach and outcomes from that investigation.

Definition and key processes

Laterally active, coarse-grained rivers are typically found in valleys, downstream of confined reaches of their catchments. They have high sinuosity, are laterally active and are characterised by features such as active lateral bars, active point bars, mid-channel bars and pool-and-riffle sequences (Brierley & Fryirs, 2005) (Figure 1). Many of these features can be readily identified in the field or from aerial photography (Henshaw et al., 2019). Because of their dynamic nature, these rivers are highly sensitive to changes in drivers (flow regimes) and environmental conditions (floodplain and channel attributes) (Teo and Marren, 2015).

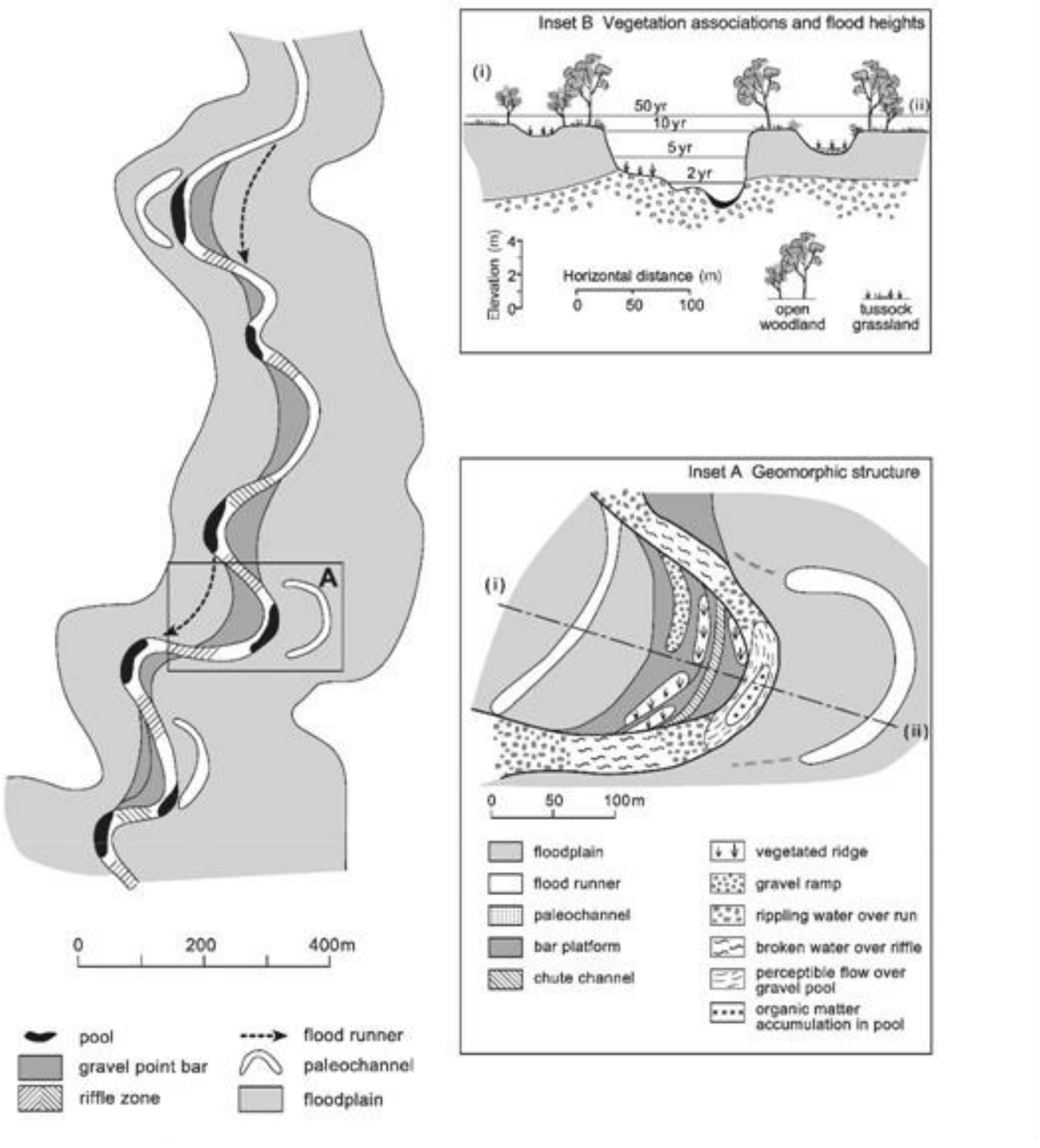

Figure 1. *Meandering gravel bed River Style is an example of laterally active coarse-grained river. Figure taken from page 33 in Brierley & Fryirs (2005).*

The coarse-grained bed material can armour the bed, preventing incision. Lateral channel migration due to erosion and reworking of coarse-grained (gravels or sand) and the relatively non-cohesive floodplain banks, leads to a meandering planform. The meandering process results in a lowering of bed grade and a lowering of energy. These rivers are inherently dynamic, and subject to high rates of channel change either through continual adjustment over time (migration) and rapid changes (avulsions or meander cut-offs).

Laterally active coarse-grained rivers can be distinguished from passive meandering rivers, where banks tend to comprise silt and clays, which are cohesive, thus limiting the ability of channels to adjust laterally. These systems tend to be dominated by suspended sediment transport. Bedload transport needed for development of point bars is often lacking (Brierley & Fryirs, 2005). The concentration of stream power is therefore lower and the exposure of banks to channel scour is less. In our definition of laterally active, coarse-grained river we have excluded anastomosing systems, which have multiple interconnected channels. However, we note that anastomosing systems and single-channelled system could both be considered as laterally active, coarse-grained rivers, both of which have high rates of channel change due to migration and avulsions.

Table 1. Laterally active, coarse-grained rivers (From Table 5.4 in Brierley & Fryirs, 2005).

River type (sediment regime)	Dominant instream geomorphic unit assemblage	Resultant channel shape
Meandering gravel bed (mixed load)	Bank-attached depositional dominated (compound point bar–riffle–pool–lateral bar assemblage)	Asymmetrical in bends, symmetric al at inflection points
Meandering sand bed (bedload)	Bank-attached depositional dominated (point bar–lateral bar–run assemblage)	Asymmetrical in bends, symmetric al at inflection points

History of land use change and management in Victoria

Understanding the history, processes and response to management intervention is key to setting effective river management objectives and developing strategies for management. Importantly, the understanding of the history, processes and response of these stream systems will be essential for the type of stakeholder engagement that is necessary to achieve effective management of these systems.

Prior to European settlement, with intact stream systems, rates of channel change in coarse-grained river systems was mitigated by:

- Gravel beds that were and remain resistant to incision processes.
- Streambanks with high levels of native vegetation acting to protect the streambank from erosion processes.
- High levels of in-stream wood, which reduced channel velocity and in-channel stream flow and redistributed water onto the adjoining floodplain (thereby limiting in-stream unit stream power).
- Dense floodplain vegetation, providing resistance to high shear stresses and reducing the potential for floodplain scour.
- Limited catchment disturbance, and managed fire regimes, limiting sediment supply.

Since European settlement, many river systems have been subject to significant change including the clearing of adjoining floodplains for agriculture. Clearing of the floodplain in the high energy environment of these river systems commonly resulted in floodplain scour during large flood events. Management responses in Victoria and in laterally active, coarse-grained rivers elsewhere, sought to improve the drainage capacity of these river systems often via the removal of large in-stream wood and riparian vegetation, in an attempt to limit floodplain inundation and floodplain scour adjoining these high energy systems (Rutherfurd, 2000; Teo & Marren, 2014, 2015). Uncleared riparian vegetation has often been subsequently lost or degraded through grazing pressure. These channel ‘improvements’ were undertaken from the 1900’s through to the 1970’s across Victoria and were often undertaken by Victoria’s river improvement trusts (Rutherfurd, 2000).

Channel erosion was initiated by these works and active lateral movement (erosion) continues in these systems. Active lateral erosion has been managed in these systems through techniques such as brushing with native vegetation, willow planting, alignment training using pile and rail structures and more recently pile fields, rock beaching and native vegetation establishment.

These management approaches have often been applied at site scales, in reactive programs, following flood events. The river response to the phases and forms of management has been varied. However, accelerated rates of channel change and floodplain scour remain a problem in the stream systems for managers of public assets, landholders, and waterways (Alluvium, 2010, 2011; Teo & Marren, 2014).

Issues arising with these past approaches have include:

- Willow: the features of willow that resulted in its use for erosion control have become the features that render the species a major management problem for Victoria’s streams. These features have included establishment by cuttings, rapid growth, absence of predators, and widespread root network These features have resulted in the colonisation of river systems with willow, and associated blockage of flow paths. In turn these blockages have resulted in the subsequent outflanking of (erosion behind) the willow.
- Rock beaching: Rock beaching is expensive and limits opportunities for in-stream ecological outcomes and natural rates of channel change essential for channel ecological function.
- Native vegetation establishment: Native riparian vegetation has been found to be resistant to erosion but has been found to be slow growing and often requires additional protection during the establishment phase to prevent loss due to minor flood events.
- Reactive programs: Landholder support for programs of management will require integration of river processes and management with floodplain processes and management. While flood events can generate stakeholder interest in river processes, the period immediately following flood events are not well suited to the development and implementation of carefully considered, programs of management.

Issues identified from a review of relevant literature and industry workshop

Physical processes and management implications associated with laterally active coarse-grained rivers were identified through literature review and an industry workshop. The industry workshop was held in December 2019 to discuss the literature review and to plot a pathway for the improved management of these stream systems.

Attendees of that workshop included representatives from DELWP, representatives from four of Victoria’s Catchment Management Authorities (CMA’s) with significant issues arising in laterally active coarse-grained rivers (North East CMA, East Gippsland CMA, West Gippsland CMA and Goulburn Broken CMA), industry researchers and consultants with experience in Victoria’s laterally active coarse-grained rivers including the authors of this paper. Some of the processes and implications of processes identified through the literature review and the workshop are set out below.

Flood events drive channel change in these stream systems and tend to move rivers towards equilibrium. Periods of high rainfall and floods are often linked to regional hydroclimatic conditions and teleconnections (La Nina in particular), which are cyclical and somewhat predictable in terms of frequency. Climate change will exacerbate this through increased frequency and amplitude of ENSO cycles (Cai et al., 2014).

Flood event channel hydraulics can reveal where high rates of channel change is most likely. The concept of geomorphic effectiveness of an event (e.g. the amount of stream power during an event relative to the background hydraulics) may provide a useful concept for identifying problematic reaches. Similarly, the concept of excess shear stress and a related cumulative probabilistic failure analysis can identify the potential for channel change and the likelihood of that channel change within defined management periods.

The characteristics of riparian vegetation can impact on the extent to which the vegetation modifies the flood hydraulics and resist flood induced channel shear and hence the rate and extent of channel change. Similarly, the floodplain character and vegetation characteristics impacts on the likelihood of floodplain scour and abrupt channel change.

Longitudinal processes including sediment supply, transport and deposition impact on the location and rate of channel change. Similarly, lateral processes impact on the processes at work. The relative proportion of in-channel versus floodplain flow, and the location of excess shear stress impacts on the sediment deposition processes, channel migration and floodplain scour.

Consequently, management of the river reach cannot be isolated from the management of its catchment or the adjoining floodplain. Management activities at the reach scale should be embedded within a larger-scale strategy for improving river robustness and resilience whereby management seeks to:

- increase resistance to erosion,
- reduce the exposure to erosion and
- establish intrinsic robustness to return the system or reach from flood-related perturbations.

Such management should

- focus on restoring floodplain function and allow the river to undergo adjustments.
- provide for the establishment and management of native riparian vegetation as a key long-term strategy to increase resistance and resilience. However, these are dynamic systems and strategies for establishing vegetation must be carefully designed and require a different approach to those pursued in less active river systems.
- avoid disturbance to armour layers and thereby reduce the likelihood of channel incision. Such disturbance can occur as a result of activities such as vehicle access to the gravel bed and mechanical sediment extraction activities.
- Seek to restore and/or maintain the natural sediment supply and hydrologic regime of these river systems.

Identification of laterally active coarse-grained rivers in Victoria

Identifying and mapping laterally active meandering rivers in Victoria

Classification and identification of river types is useful across a range of management activities (Fryirs & Brierley, 2018). According to Fryirs & Brierley (2018) classification provides a basis for;

- identifying locations that function in similar ways,
- defining objectives that are aligned with river function,
- communicating issues, risk and policy amongst landholders, practitioners, land managers, and researchers, and
- designing solutions tailored to local geographic setting.

A GIS workflow was developed to identify the location of laterally active, coarse-grained rivers in Victoria. The aim was to use available spatial datasets to isolate those rivers that satisfy a set of criteria for laterally active, coarse-grained rivers. The steps for identification comprised geoprocessing of spatial data followed by a visual assessment using 30cm aerial photography. We took a landscape-scale approach and focussed on identifying the landscape positions where these rivers are most likely to be present.

The logic behind the workflow is that the rivers must meet four basic criteria that are likely to apply to laterally active, coarse-grained rivers:

- They flow through unconfined valleys as defined within Victoria's Index of stream condition assessments. In other words, there is room for lateral migration.
- They are upstream of low energy reaches on flat open plains, which we identify from the index of valley bottom flatness (Gallant & Dowling, 2003). This criterion defines the downstream limit of this river type.
- There are located on depositional lithologies (alluvium, colluvium and aeolian deposits). This has been kept broad in the first instance to include rivers located on sandy deposits.
- The substrate is mapped as sand or coarser in the index of stream condition 2010 (ISC, 2010).

An additional step of manual filtering using 30 m resolution imagery was considered appropriate given that there is evidence that this type of imagery can used effectively to discriminate between active and passive meandering rivers (Henshaw et al., 2019). For smaller streams and in streams with dense vegetation, this visual interpretation using imagery is not effective.

There are likely to be inaccuracies in the mapping that stem from the limitations in what can be achieved from spatial data alone, the quality of the spatial data and the assumptions that went into the GIS workflow. Refinement of this classification and improvement in accuracy could come from exploration of bankfull unit stream power to discriminate between low, medium, and high energy rivers, and the development of field assessments for identifying these types of river.

The analysis provided a basis for high-level summaries of the distribution these river systems across the different catchment management authorities (CMAs) in Victoria.

The results of the classification show that laterally active, meandering, coarse-grained rivers are concentrated in the eastern part of Victoria in rivers with steep headwaters with an expansive network of confined and high energy rivers. The dissected uplands of eastern Victoria are a landform that is conducive to the formation of relatively steep floodplains that support this river type. There are high rates of bedload transport from headwaters, which provides coarse-grained alluvium, and which maintains the relatively steep valley slopes.

Through the analysis we have identified 3,717 km of laterally active coarse-grained rivers across Victoria. The largest concentration of the laterally active coarse-grained rivers is in northeast Victoria, i.e., within the region of the North East CMA (NECMA). Northeast Victoria has 1300 km (approx.) of laterally active coarse-grained rivers, approximately one third of the length of these waterways across Victoria, with an equivalent length as the combined length of laterally active coarse-grained rivers in the next most prevalent regions, the Goulburn Broken CMA and West Gippsland CMA.

Laterally active, coarse-grained rivers in Victoria include the Upper Macalister River (Licola), the Buchan River (Buchan), the Wonnangatta River (Dargo), Nariel Creek (Colac Colac), the Mitta Mitta River (downstream of Dartmouth), the Kiewa River, the Ovens River (Harrietville to Markwood) and the King River (Cheshunt to Moyhu).

There is likely to be considerable variation in how these rivers function and the magnitude and processes of change. Reaches of the Glenelg River, for example, which have been identified as a laterally active, coarse-grained in our GIS exercise, is a very different river to the Upper Ovens River or Upper King River. These differences that emerge in rivers identified under the classification scheme in Figure 2 are a consequence of data availability, data quality and the need to generalise accordingly. There are opportunities to refine the classification and develop approaches to discriminate between river reaches that are more problematic than others. Removal of sand bed systems would assist to refine the data sets to the particularly problematic higher energy gravel bed systems. This is probably better achieved using intensive site-scale data analysis, field assessments, local data, and input from local practitioners.

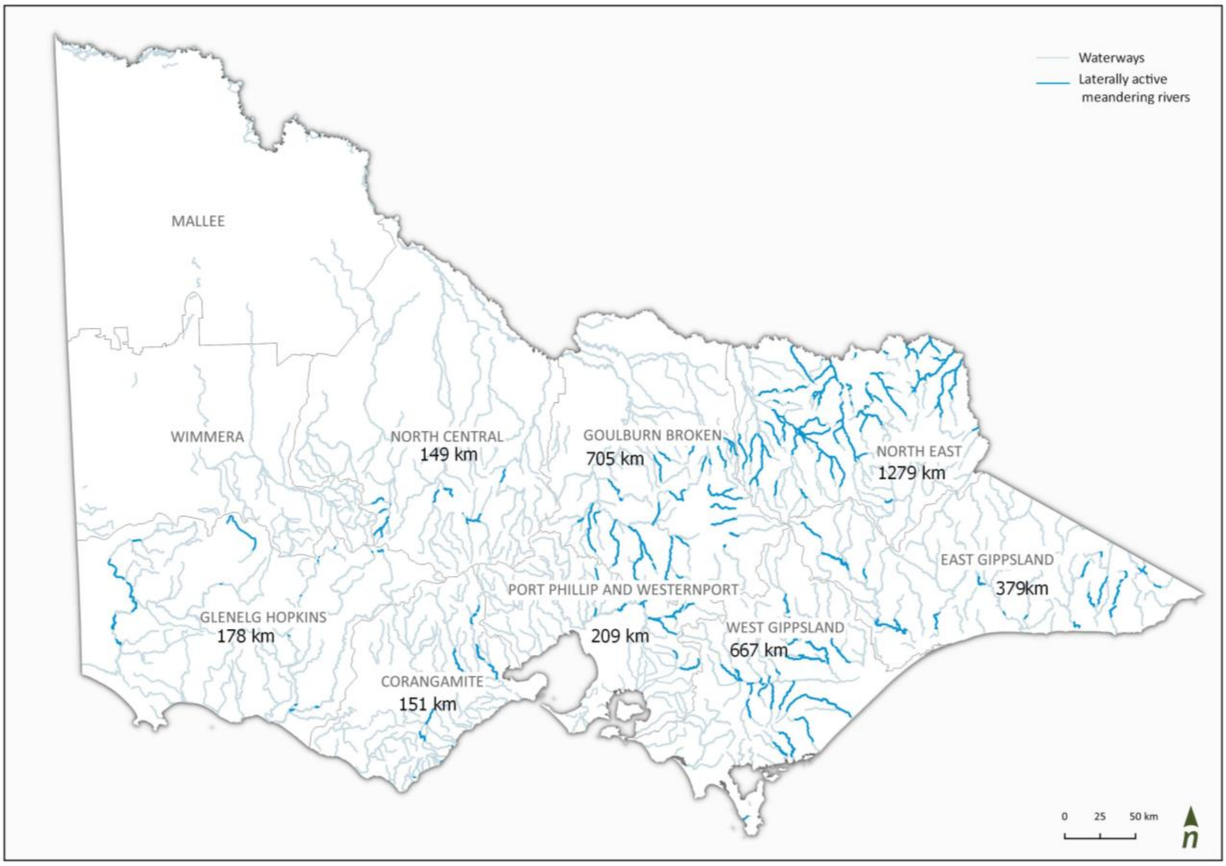

Figure 3. *Laterally active, coarse-grained rivers in Victoria. Map shows total length of these river for each CMA.* The data are supplied to DELWP as a shapefile.

Relationship between laterally active coarse-grained rivers and sites with significant flood damage

We undertook further analysis of available spatial data to identify any association between laterally active coarse-grained rivers and reported flood damage. Spatial data on river reaches with flood damage or significant channel change were obtained from the NECMA and mapped alongside the locations of laterally active coarse-grained rivers, with the objective to examine relationships between river attributes and flood damage in north east Victoria.

A database of problematic locations on rivers in NECMA was compiled from two datasets:

- Channel change mapped as part of post 2010 and 2011 flood study by Alluvium (2011) (136 points).
- Post 2016 flood recovery works funded by the funding Natural Disaster Relief and Recovery Arrangements (NDRRA) including earthworks (111 points) and waterway structures (made available by NECMA) (70 points).

These data include reaches with significant channel change and flood recovery earthworks (e.g. rock armouring, rock chutes, rock beaching) and structural works (e.g. installation of logs and pins, removal of woody debris, timber revetment). All data were grouped into a single layer termed ‘problematic’ points. There were 317 problematic locations mapped in total. Using the available data, we identified the proportion of problematic points in north east Victoria that are located on rivers that have been classified as laterally active coarse-grained rivers.

We found 282 out of the 317 (90%) sites of significant flood damage and issues related to channel change in Northeast Victoria were located on rivers identified as laterally active coarse-grained rivers. Many of the remaining problematic locations are located on incising streams. While erosional issues may be present in these incising systems, and management responses not fully applied, a successful approach to the assessment and management (bed grade and stream power analysis, accompanied by grade control and revegetation programs) of these systems has been developed and can be applied. However, we are not aware of an agreed approach to the management of laterally active, meandering, coarse-grained rivers in Victoria. Thus, most of the management issues identified in this relatively simple analysis remain unresolved. Guiding principles for the management of these river systems have been identified and developed by the authors and are set out below.

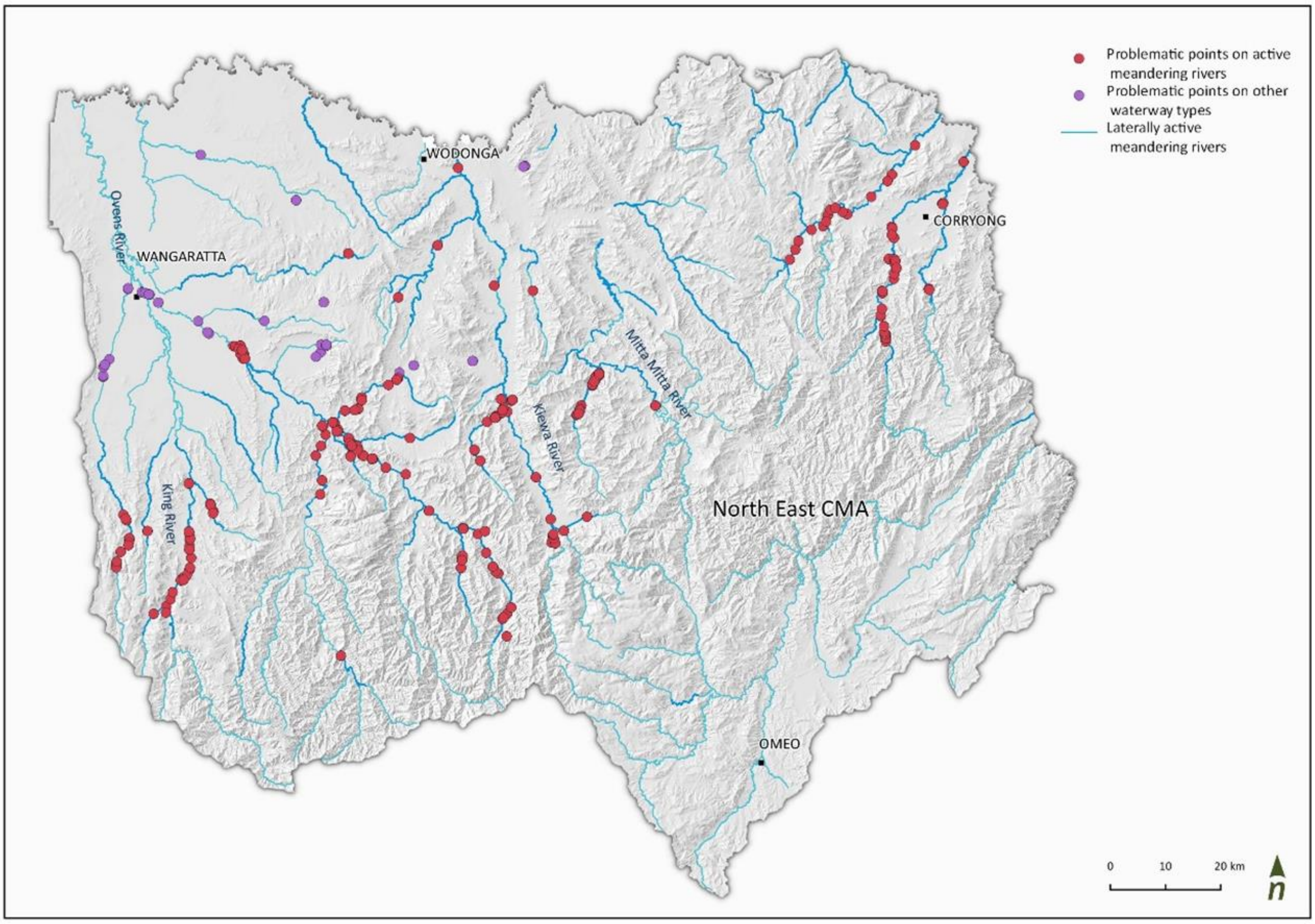

Figure 5. *Problematic points in NECMA in relation to rivers that have been classified as laterally active coarse-grained rivers.*

Guiding principles for management

Various approaches have been applied to the management of laterally active, coarse-grained rivers. Some techniques and tools applied to other waterway management issues can be applied to these systems. However, we found no evidence of, nor are we aware of, an agreed documented approach to the management of major channel movement and avulsion of these systems within Victoria’s waterway management industry.

A set of guiding principles have been developed for the management of these systems based on the literature review, and an industry workshop held 5 December 2019. This workshop included representatives from Victoria's Department of Environment, Land, Water and Planning (DELWP) CMA's, waterway management consultants and academia. These principles have been further developed by the authors and include:

- Channel change in laterally active coarse-grained rivers is inevitable during floods. Even in the presence of established riparian vegetation and in-stream wood loads, these rivers are dynamic and require space to move. The river system should be defined by the river corridor, not just the channel.
- Clear definition of management objectives is necessary and requires careful consideration of the economic, social, and ecological values for which management is proposed. These objectives may not be a return to pre-disturbance conditions. Similarly, objectives may not reflect a continuation of current management. Objectives for management should reflect broad community aspirations and include reduced rates of channel change, while achieving improved social, cultural, ecological, hydrologic and water quality outcomes.
- The history of management of these stream systems must be understood, to better predict their behaviour and hence provide better management into the future.
- Managing the risk associated with channel change is largely about adaption, by building awareness, developing strategies for community participation, and through targeted asset protection. There is a need to promote a more effective bridging of the technical and social challenges through communication, partnerships, and funding mechanisms. Evaluating and demonstrating the cost and benefits of alternative intervention is key, as well as building a shared understanding of the scale of the issue, timeframes for management, targets, and sustainable funding mechanisms.
- Strategies and policy should align flood recovery programs with long term river management objectives.

There are examples of successful management strategies of laterally active coarse-grained rivers in Victoria, Australia and internationally that can help provide a reference for an effective management response to laterally active rivers.

Recent changes in flood recovery programs have limited Victoria's waterway managers access to flood recovery investment. The lack of funding mechanisms to address issues post-flood provides an opportunity to develop a strong policy around the management of laterally active, coarse-grained rivers. That policy should be developed in time to be included in Victoria's next waterway management strategy due in 2021/22 and guide how, when, and where to invest funding in the management of laterally active, coarse-grained systems. That policy development should include an economic evaluation and consideration of the public versus private, costs and benefits associated with managing these systems.

Conclusion

Laterally active, coarse-grained rivers remain one of the most challenging streams for management because of their highly dynamic nature and their tendency to be co-located with highly productive agricultural lands. These types of rivers are inherently dynamic systems with channel change occurring through channel migration and avulsions across the floodplain.

We identified over 3,500km of laterally active, coarse-grained rivers in Victoria, with over one third of these located in northeast Victoria.

Extensive clearing of the floodplain has amplified the rates of channel change. Many rivers are still adjusting to geomorphic impacts linked to the vegetation clearing that has occurred since European settlement. In attempts to reduce erosion there have been periods of misguided and poorly targeted efforts e.g. willow planting, channel straightening. Such efforts have often been ineffective, and sometime counterproductive, with adverse ecological impacts.

These rivers are ecologically important, supporting distinct assemblages of fauna and flora, whilst providing high value for recreational use. The vulnerability of communities and landowners to channel change in this river type is also high because the valleys are typically narrow with much overlap between the river corridor and assets such as productive agricultural land, roads, towns, and other infrastructure.

We found over 90% of reported damage following flood events in northeast Victoria were associated with Laterally Active Coarse-grained rivers.

Yet, despite their high ecological value, the significant social and economic risks that they represent, and their high representation within reported flood damage, we found no evidence of an agreed framework, strategy, or technical approach for the management of laterally active coarse-grained stream systems.

There is a clear demand for a strategic approach to management of laterally active, coarse-grained rivers in Victoria. Key steps are to consolidate existing knowledge, experience, and river management frameworks (drawing from relevant national and international examples) and then use this synthesis to guide the development of a strategic management approach. The approach should sit within an integrated catchment management framework, and include the establishment of clear management objectives, the development of an understanding of the processes at work that impact on these objectives, the development and review of options for management, the implementation of a preferred suite of integrated management activities, and the monitoring and evaluation of these activities.

Successful waterway management can include the establishment of land management agreements with adjoining land managers, the management of in-channel unit stream power, the management of floodplain flow velocity and excess shear stress, in-stream stabilisation works, and the replacement of instream and riparian willow with structurally diverse native riparian vegetation within acceptable levels of risk. There may be other options identified through consolidation of Australian and international knowledge and expertise.

A strategic management approach should outline how management activities can be justified and prioritised based on key biophysical and socio-economic factors. The approach needs to be tested, refined, and documented on laterally active coarse-grained river and should be supported by policy that encourages and rewards proactive management toward clear long-term and strategic objectives, in favour of, reactive post-flood recovery works.

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