Valleys and Rivers, River and Valleys: How the interaction of valleys and rivers shape patterns of accommodation space and the implications for management

Vallées et rivières, rivière et vallées : comment l'interaction des vallées et des rivières façonne les configurations d'espaces de mobilité et les implications pour la gestion

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RÉSUMÉ

Grâce à leurs interactions mutuelles, les rivières creusent des vallées de formes et de tailles différentes, et les vallées façonnent la manière dont les rivières s'écoulent à travers le paysage. Les histoires géologiques, géomorphiques et anthropiques façonnent les modèles de relief des vallées et l'espace de mobilité, influençant ainsi les emplacements et les formes d'ajustement contemporain des rivières. Étant donné que la gestion des rivières englobe l'espace de mobilité et les techniques naturelles de gestion des crues, il est important de déterminer l'espace dont chaque rivière a besoin. Pour l'instant, aucun principe bien défini n'a été établi pour répondre à cette question. Pour évaluer cela, un cadre cohérent est nécessaire pour évaluer les effets cumulatifs de l'histoire avec les impacts en cascade du changement du système à l'échelle du bassin versant. Nous développons ici un cadre géomorphique qui prend en compte l'emplacement de l'espace de mobilité, les relations de connectivité et l'impact des modifications humaines. Notre approche peut être utilisée dans toute une gamme de contextes tectoniques. Nous développons et testons notre approche des rivières Tarawera, Rangitāiki et Whakatāne, rivières adjacentes de la zone de rift qui se jettent dans les plaines de Rangitāiki en Aotearoa Nouvelle-Zélande. Ces rivières ont des espaces de mobilité et d'ajustement très différents, fournissant ainsi une bonne étude de cas pour souligner l'importance des considérations contextuelles spécifiques au bassin versant.

ABSTRACT

Through mutual interactions, rivers carve out valleys of different shapes and sizes, and valleys shape the way that rivers flow through the landscape. Geologic, geomorphic and anthropogenic histories shape patterns of valley landforms and accommodation space, thereby influencing locations and forms of contemporary river adjustment. As river management embraces space to move and natural flood management interventions, it is important to determine how much space each river needs. As of yet, no well-defined principles have been established to address this question. To assess this, a coherent framework is required to evaluate the cumulative effects of history with the cascading impacts of system change at the catchment scale. Here we develop a geomorphic framework that considers the location of accommodation space, connectivity relationships and the impact of human modifications. Our approach can be used across a range of tectonic settings. We develop and trial our approach to the Tarawera, Rangitāiki and Whakatāne Rivers, adjacent rift zone rivers that drain to the Rangitāiki Plains in Aotearoa New Zealand. These rivers have vastly different patterns of accommodation space and river adjustment, thereby providing a good case study to highlight the importance of catchment-specific contextual considerations.

KEYWORDS

Accommodation space, catchment management, River Styles, space to move, valley landforms

Espace de mobilité, gestion des bassins versants, River Styles, espace de liberté pour les rivières, reliefs de la vallée

1 SPACE TO MOVE AND THE IMPORTANCE OF GEOMORPHIC CONTEXT

The formation of valleys and rivers is a constant dance where the creation and movement of one (choreography) shapes the movement of the other. Rivers, and the ecosystems they support, are products of the valleys through which they flow. At the same time, rivers carve out valleys of differing shapes and sizes. These mutual interactions play out in particular ways for each river system, in turn influencing the pattern of accommodation space, forms and rates of contemporary river adjustment, and connectivity relationships. Availability of flat land along valley floors (accommodation space) supports different forms of land use, often juxtaposing human infrastructure with the needs of the river. River management has traditionally focussed on controlling the river and holding channels in place through engineering means. This often results in profound degradation of waterways. Progressively, river management practices are embracing flooding and erosion regimes as part of space to move interventions that allow the channel(s) to adjust, use its own energy, and look after itself (Biron et al., 2014; Williams et al., 2020). These processes recurrently regenerate the dynamic physical mosaic of a river along an erodible corridor, the nature, character and connectivity of which is determined by catchment-specific conditions (Piégay et al., 2005).

Here we contend that a coherent framework is needed to assess the viability of space to move and natural flood management options for a given catchment. Our approach considers the cumulative effects of geological, geomorphic and anthropogenic histories on river adjustment, catchment-scale connectivity relationships, and the cascading impacts of change in the system, showing how legacy effects and path dependencies brought about by past human modifications shape the range of management options (Brierley et al, 2022; Downs & Piégay, 2019).

The controls on the pattern of accommodation space, sediment storage and forms of adjustment in a tectonically active landscape with short, steep catchments such as New Zealand, Philippines or Japan, will be different to the comparably stable continental interiors of Europe and North America. Considerable variability between and within catchments leads to variations in how much space the river needs in different parts of the catchment. Here we use a case study in Aotearoa New Zealand that assesses three key considerations in determining space to move needs and opportunities within any landscape:

- Pattern and extent of accommodation space that determines where rivers are able to freely adjust (Fryirs et al., 2016),
- Upstream-downstream (longitudinal) and tributary-trunk stream connectivity relationships.
- Impact of human activities and management interventions upon forms, rates, patterns, off-site impacts and legacy effects of river adjustment and changes to connectivity relationships.

2 RIVERS OF THE RANGITĀIKI PLAINS, NEW ZEALAND

The rivers of the Rangitāiki Plains in the Bay of Plenty region of Aotearoa New Zealand (Figure 1), have been extensively modified following European settlement in the 1890's, including wetland drainage, river straightening, construction of dams and stop banks, and gravel extraction. Located within the Whakatāne Graben of the Taupō Volcanic zone, the Tarawera, Rangitāiki and Whakatāne river catchments have been shaped by tectonic processes associated with subduction at the Hikurangi margin that has simultaneously created a rift zone, uplifted the Te Urewera Range to the east, and driven volcanic activity which has deposited hundreds of metres of volcanic ignimbrite deposits across the landscape.

Headwaters reaches of the central Rangitāiki River are incising through an ignimbrite landscape. This creates a pumice sand substrate. Gravel enters the system in the middle reaches, sourced from the Te Urewera Range. Tectonically controlled basins form localised pockets of accommodation space where reworked volcanic sediment has accumulated. Tectonic lineations from the uplifted Te Urewera Range control the drainage network of Whakatāne River to the east. There is high connectivity between hillslopes and channels, and as slope decreases downstream, the steep headwaters transition to a meandering gravel bed river. The Tarawera River to the west is lake-fed. Multiple breakout flood events associated with volcaniclastic dams have scoured the valley, subsequently infilling lower reaches and plains with reworked sediment.

When the rivers reach the plains, stop banks limit adjustment and prevent inundation of the floodplains. Communities are reliant on the infrastructure to prevent catastrophic flooding. Given unpredictable futures under climate change, the risk to these communities only grows. This increases the need for river management strategies that work with the river.

Although located side by side, the very different catchment histories of the three study rivers presents a helpful opportunity to develop and trial space to move requirements for different rivers, highlight the importance of contextual considerations in designing and applying space to move restoration strategies that work with needs and opportunities along each river.

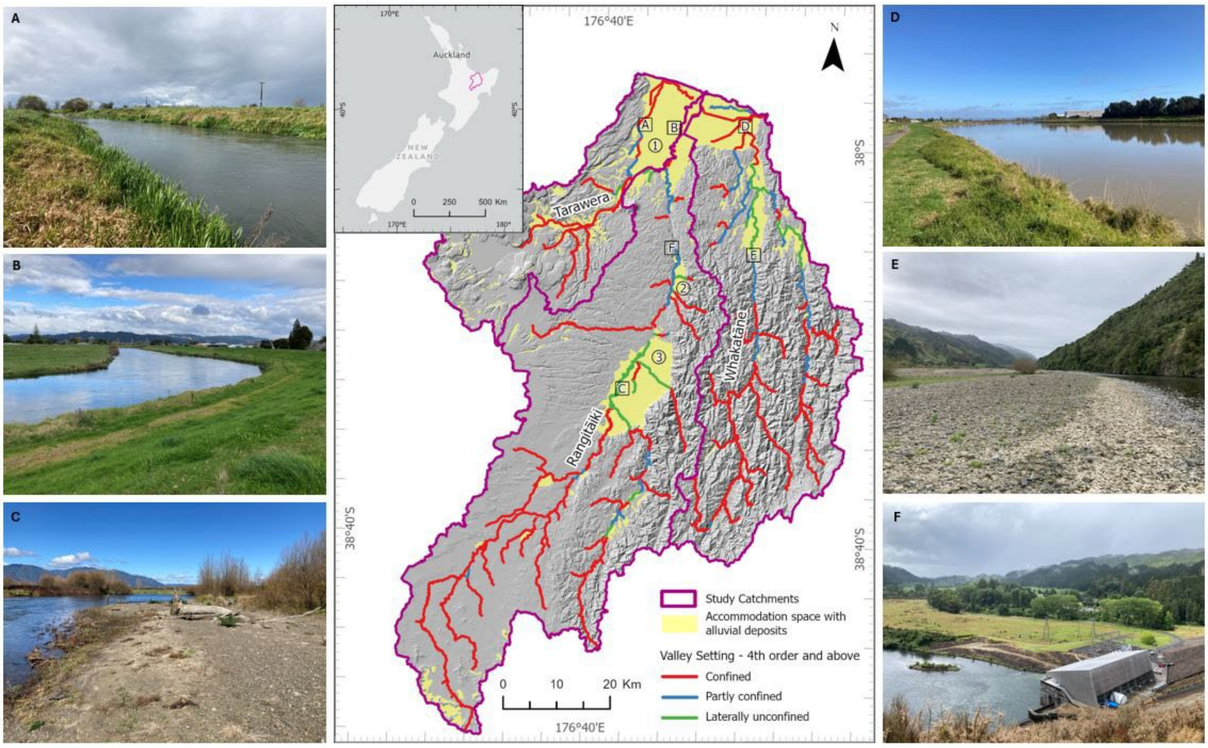

FIGURE 1: Distribution of accommodation space and alluvial deposits along the Tarawera, Rangitāiki and Whakatane Catchments. The main areas of accommodation space are 1) the Rangitāiki Plains, 2) Waiohau Basin and 3) Galatea Basin. Human modification has confined the lower reaches of all rivers between stop banks (A, B and D), and Dams have been constructed along the Rangitāiki River (F). Lateral adjustment occurs in the gravel reaches of the Rangitāiki River (C) and reaches with no anthropogenic confinement along the Whakatāne River (E).

3 HISTORY MATTERS

3.1 Pattern of Confinement and Valley Landforms

Geological landscape memory shapes patterns of accommodation space in the study rivers, with over 70% of the rivers confined in each catchment. Of the confined reaches, over 80% were confined by bedrock within the Rangitāiki and Whakatāne catchments. Approximately 50% of the Tarawera catchment were confined by terraces, with the remainder split evenly between bedrock and stop banks. The different lithologies, and the variable strength of the ignimbrite have shaped different valley landforms. Steep, V-shaped valleys dominate the Whakatāne catchment. The Rangitāiki, in comparison, has a combination of gorges and canyons cut through highly welded ignimbrite, while less welded ignimbrite have formed wide, stepped gullies.

3.2 Pattern of Accommodation Space

The partly confined and laterally unconfined rivers (including those now anthropogenically confined by stop banks), are located in two parts of the catchment. Firstly, rifting of the Whakatāne Graben opened up space in the landscape where reworked volcanic sediment from large rhyolitic eruptions has been deposited to form the Rangitāiki Plains. Previously wetland, today, low sinuosity rivers move across the plains to the sea. Secondly, the interaction of the extensional Taupō Volcanic Zone and normal faulting at the uplifting range has created local depressions along in the middle reaches of the Rangitāiki Catchment that have infilled with reworked volcanic sediment. The contemporary Rangitāiki River freely adjusts and reworks the stored sediment.

4 GEOMORPHIC RIVER STORIES AND MANAGEMENT CONSIDERATIONS

Catchment histories, the range of processes operating in each system and connectivity relationships determine types and patterns of River Styles (Brierley & Fryirs, 2005). In turn, the geomorphic river story told by each catchment has profound implications for fit-for-purpose, process-based management applications (Fuller et al., 2023).

4.1 Rangitāiki River

Variable adjustment potential is evident between the upper sand reaches and the lower gravel reaches. The weaker ignimbrite substrate is easily eroded by bed and bank erosion. Dams along the river alter longitudinal connectivity, leading to distinct breaks in sediment and flow regimes. Sand bed, low slope rivers on the lowland plains are subject to slow lateral adjustment. However, stop banks prevent floodplain inundation and enhance the power of flood waters.

4.2 Tarawera River

Entrenchment of the upper river into alluvial sediments limits lateral adjustment. Sediment stores within the main river and tributaries are being reworked, with bed and bank erosion being the dominant sediment source. Similar to the Rangitāiki River, lateral adjustment is slow, and the flood regime has been affected by stopbanks. However, pockets of wetland are inundated during floods.

4.3 Whakatane River

Bedrock confinement in the upper catchment limits adjustment. Within the partly confined and laterally unconfined valley settings, the mobile gravel bed river can freely adjust. There is high connectivity between hillslopes and the channel, and between tributaries and the main stem. The freely adjusting river needs space to move.

5 SUMMARY

Catchment histories matter. The mutual interaction between valleys and rivers over different timescales creates the pattern of accommodation space and confinement that influence contemporary channel adjustment. The principles applied here can be used on any river system to assess the factors controlling adjustment and how changes to flow, sediment and roughness regimes, from both natural and anthropogenic changes, will impact the system for targeted river management strategies. The successful implementation of space to move and natural flood management initiatives relies on understanding what has happened in the past as this shapes what is possible into the future. With ever increasing availability of high-resolution spatial data sets and improvements in automation, valley confinement mapping is getting easier, allowing for quicker identification of patterns confinement and accommodation space.

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