Advancing flood resilience and stream health: Whau catchment options and risk assessment

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Key points

- Decades of stormwater management that prioritised conveyance over natural process have left the Whau and Waitahurangi (Avondale) catchments in west Auckland incised, confined, and ecologically degraded, yet still required to function under increasing flood and climate pressure.
- An integrated assessment of nineteen reaches across 7.7 km of stream identified widespread channel degradation consistent with advanced Stream Evolution Model stages, with hydraulic hotspots concentrated in mid-catchment trunk reaches rather than at the catchment outlet.
- Despite extensive modification, several reaches retained meaningful recovery potential and can be guided toward both ecological and hydraulic recovery rather than treated as drainage infrastructure alone.
- A reach prioritisation framework and intervention toolbox were developed, structured around catchment, reach, and regulatory interventions and eight strategic approaches scaled to reach-specific condition and sensitivity.
- The integrated geomorphic–flood resilience framework is scalable and transferable to any urbanised catchment where practitioners are navigating conflicting priorities between flood risk management and restoring living rivers.

Abstract

Extreme weather events, including the 2023 Auckland Anniversary floods and Cyclone Gabrielle, exposed the vulnerability of urbanised waterways shaped by decades of development that prioritised flood conveyance over natural process. These catchments which were confined, incised, and ecologically degraded represent a challenge faced by stream managers globally: how do we work with rivers that have been fundamentally altered, yet must continue to evolve and function under increasing pressure?

The Whau Options and Risk Assessment evaluated approximately 7.7 km of stream across two urbanised Auckland catchments. Nineteen discrete reaches were assessed using hydraulic hotspot mapping, Channel Evolution Model (CEM) analysis, and River Styles classification, integrated with LiDAR data and hydraulic modelling to characterise geomorphic condition, sensitivity, and recovery potential.

The study identified hydraulic hotspots driven by impervious cover and channel confinement, widespread channel degradation consistent with advanced CEM stages, and reaches of variable but meaningful recovery potential. Key outputs included a reach prioritisation framework and an intervention toolbox spanning structural stabilisation, stream daylighting, riparian restoration, and catchment-scale stormwater measures.

This integrated geomorphic-flood resilience approach demonstrates that urban waterways need not be managed solely as drainage infrastructure, they can be guided toward ecological and hydraulic recovery simultaneously. The framework is scalable and transferable to any urbanised catchment where practitioners are navigating conflicting priorities between flood risk management and restoring living rivers.

Keywords

Urban streams, Geomorphology, Flood resilience, Stream Evolution Model, River Styles, Channel adjustment, Catchment management, Stream restoration, Hydraulic hotspots, Making Space for Water

Introduction

The 2023 Auckland Anniversary floods and Cyclone Gabrielle exposed in stark terms what decades of catchment science have long warned: urbanised waterways shaped by a drainage paradigm cannot absorb contemporary flow regimes. Combined property damage and recovery costs from these events approached $2 billion at the Auckland regional scale. These events served as a catalyst for a fundamental shift in how Auckland approaches its urban waterways, embodied in Auckland Councils Making Space for Water programme and grounded in conceptualisations of waterways as indivisible, living entities, a perspective shared by mana whenua (indigenous peoples) and increasingly reflected in contemporary global practice.

The Whau Catchment in west Auckland exemplifies the challenge facing stream managers globally. Like much of urbanised Auckland, the Whau and its tributary the Waitahurangi (also known as Avondale Stream) have been progressively confined, straightened, piped, and stripped of riparian function over more than a century of progressive development. Headwater streams have been replaced by stormwater pipes leaving remaining channels deeply incised, with little to no remaining waterway corridor. Floodplain encroachment by residential and industrial development has left habitable floor levels exposed to inundation during frequent flood events.

These conditions present a problem that is not unique to Auckland but is increasingly central to urban water management worldwide: how does society with rivers that have been fundamentally altered, yet must continue to evolve and function under increasing pressure? Conventional urban stream management has tended to treat the answer as binary, either accept the channelised drainage paradigm and harden it further, or attempt naturalisation in isolated reaches without addressing catchment-scale drivers of degradation. Neither approach has been proven as a long term sustainable solution.

An alternate path is to work with the river system to identify where intervention can guide the system toward both ecological and hydraulic recovery, and where rejuvenating what was lost (through daylighting or re-naturalisation) is realistic. This approach recognises that urbanised streams are neither purely natural systems to be restored to an ideal state, nor purely engineered systems to be optimised for conveyance. They are living, evolving entities that respond to the boundary and flux conditions imposed upon them.

This paper presents the methods and outcomes of the Whau Options and Risk Assessment, an integrated geomorphic and flood resilience study commissioned by Auckland Council in the wake of the 2023 storm events. The assessment evaluated approximately 7.7 km of stream across 19 reaches in two highly urbanised catchments, integrating hydraulic modelling, River Styles classification, Stream Evolution Model (SEM) analysis, and field-based geomorphic assessment to characterise condition, sensitivity, and future recovery potential. From this integrated assessment, a reach prioritisation framework and an intervention toolbox were developed to guide future investment under Auckland Council's Making Space for Water programme which had the primary goal of reducing risk to life and property.

Methods

Study area and reach delineation

The Whau Catchment lies in west Auckland, draining approximately 30 km^2 into the Waitematā Harbour. The catchment is heavily urbanised, with intensive residential, commercial, and industrial land use across the lower and middle reaches, transitioning to less dense residential land use in the upper catchment. Two principal trunk streams were assessed: the Waitahurangi (Avondale) and the

Whau Stream. Reach delineation followed natural breaks in stream condition, with further breaks defined where channels became committed to underground stormwater infrastructure. Nineteen reaches were identified across the two catchments - Reaches 1–10 within the Waitahurangi subcatchment (including two tributaries) and Reaches 11–19 within the Whau subcatchment.

Hydraulic assessment

Auckland Council 2D TUFLOW hydraulic model outputs (2 m grid) were used to extract velocity and stream power for the 50%, 10%, and 1% AEP events. Hydraulic hotspots were identified using DNRME (2014) stability thresholds: velocity thresholds of 1.5 m/s (50% AEP) and 2.5 m/s (1% AEP), and stream power thresholds of 60 W/m^2 (50% AEP) and 150 W/m^2 (1% AEP). Erosion potential was assessed against Fischenich (2001) permissible velocity thresholds, with a general threshold value of 1.0 m/s adopted to reflect the stiff clay and alluvial silt bed material observed in the field. Reach-wide erosion potential was calculated as the proportion of in-channel area exceeding the permissible velocity.

Flood risk was quantified as the proportion of each reach buffer (30 m from stream centre line) containing residential, commercial, or industrial property inundated by depths greater than 0.2 m. Velocity time series were extracted at representative cross-sections along the trunk streams to provide a general understanding of the duration and frequency of erosive flows over the flood hydrograph, providing context to the maximum-velocity hotspot analysis.

River Styles classification, condition, and sensitivity

The River Styles Framework (Brierley and Fryirs, 2005) was applied to characterise each reach by valley setting, planform, bed material, and assemblage of geomorphic units. A 2016 LiDAR-derived DEM and 2016 high resolution aerial imagery supported classification at the reach scale. Historical River Styles were also mapped using 1940’s aerial imagery, providing a partial baseline of pre-urbanisation conditions, reflecting agricultural and early residential modification.

Geomorphic sensitivity was assessed using the framework developed by Reid and Brierley (2015), ranking each River Style on a five-point scale from Low to High based on its capacity to rework riparian margins. Condition was scored against expected reference conditions using a modified Simon (1989) proforma, with each reach classified as poor, moderate, or good. Stream Evolution Model (SEM) stage was assigned following Cluer and Thorne (2014) to characterise where each reach sat on the disturbance–recovery trajectory.

Field verification and prioritisation framework

A field visit conducted in July 2024 covered 26 representative sites across both subcatchments. Two geomorphologists assessed each site directly to provide ground truth for desktop classification and to inform sensitivity, condition, and SEM scoring. Field observations focused on indicators of instability and adjustment, including bank erosion, incision, headcut development, undercutting, riparian condition, and the presence of legacy disturbance features.

The prioritisation framework integrated nine inputs: current condition, sensitivity, SEM stage, erosion potential under the 50% and 1% AEP events, flood risk under the 1% AEP, existing waterway corridor space, geomorphic recovery potential, criticality to project objectives, and supplementary benefits to upstream or downstream reaches. Each parameter was scored 0–5; reach scores were summed across parameters 1–7, with a 1.25 multiplier applied where supplementary benefits were identified. Criticality to project objectives acted as an override, with reaches meeting criticality criteria (flood and erosion risk) automatically classified as High Priority.

Findings

Catchment-wide patterns

Across both subcatchments, the integrated assessment revealed a stream network shaped almost entirely by its development history. No reaches retained pre-disturbance morphology in any meaningful sense, and historical River Styles mapping confirmed that the contemporary network is a substantially diminished remnant of the 1940's system itself already modified by pre-war agricultural and early residential development, post European settlement in the late 1800's. Eight contemporary River Styles were identified, all confined or partly confined, including two anthropogenic styles (Concrete Channel and Modified Drainage Line) and a Confined low sinuosity boulder-bed style associated with previous daylighting or stream naturalisation works.

Hydraulic hotspots and erosion potential were concentrated in confined, mid-catchment trunk reaches characteristic of hydraulically stressed urbanised catchments. This pattern reflects the legacy of stormwater management that has efficiently delivered upstream runoff into trunk channels with insufficient capacity to absorb it. In the most confined reaches, velocities exceeded 2 m/s under the 50% AEP, and stream power exceeded 1,000 W/m^2 at bends and constrictions, values consistent with active and accelerated channel erosion. Analysis of flood mapping showed the 1% AEP flood event failed to engage the floodplain across the majority of the longitudinal profile, indicating a highly constricted channel system. Velocity time series analysis showed exceedances of the 1.0 m/s permissible velocity threshold lasting approximately two hours during the 50% AEP event, indicating that erosive flows are not transient peaks but are sustained over hydrograph durations sufficient to drive material adjustment.

Waitahurangi (Avondale) Stream

Lower reaches (R1–R4): Reach 1 (Olympic Park), at the downstream extent, was located within parkland and showed the lowest erosion potential of the Waitahurangi trunk, with depositional rather than erosional behaviour. No flood risk was identified due to the public-land setting. Reaches 2 (Portage Road / Industrial Estate) and 3 (Blockhouse Bay) were the most severely affected of the entire study area: velocities exceeded 2 m/s under the 50% AEP, with concentrated stream power and active bank erosion observed during the field visit. Reach 2 was identified as the highest priority reach across the catchment due to the combination of severe condition, advanced SEM stage, intolerable flood risk to industrial and residential properties, and the cascading benefit of stabilisation to downstream reaches. Reach 4 (Suburbs Rugby Football Club) was partly confined with a wider valley setting and showed a more subdued response, classified as approaching SEM Stage VI (Quasi Equilibrium).

Mid reaches (R5–R7): Reach 5 (Titirangi Golf Course) returned the highest erosion potential of the mid-catchment Waitahurangi, with active incision, headcut development, and lateral bank failure observed in the field. The reach was classified as High Priority. Reach 6 (La Rosa Gardens) was an anthropogenically influenced confined boulder-bed reach where previous daylighting and naturalisation works have been implemented, providing a reference for what re-naturalisation can achieve under continuing upstream loading. Reach 7 (Godley Green) was the most upstream reach of the trunk stream and showed substantial flood risk under the 1% AEP, with residential encroachment driving the elevated risk score.

Upper reaches (R8–R10): The Waitahurangi headwaters comprised Reach 8 (Rahui Kahika Reserve) within public land, and two tributary reaches: Reach 9 (Craigavon Park) and Reach 10 (Titirangi Golf Course tributary). Reaches 8 and 9 did not register significant flood risk due to their public-land setting but exhibited high erosion potential under the 1% AEP. Reach 10 showed flood risk associated with residential encroachment along the tributary corridor. These upper reaches retained the most natural geomorphic character within the Waitahurangi system, dominated by confined, bedrock margin-controlled, low-sinuosity fine-bed channels, relatively undisturbed compared to the rest of the catchment.

Whau Stream

Lower reaches (R11–R13): The lower Whau was the most pressured part of the study area. Reach 11 showed substantial erosion potential and limited remaining waterway corridor. Reach 12 (Miranda Reserve) exhibited the most severe hydraulic hotspots of the entire Whau Stream with velocities exceeding 2 m/s and major stream power concentrated at confined bends during the 1% AEP alongside intolerable flood risk to adjacent residential properties. Reach 13 was a fully concrete-lined drainage channel with no remaining natural geomorphic function but contributed a disproportionate downstream impact through the efficient delivery of upstream flows. Both Reaches 12 and 13 were classified as High Priority.

Mid reaches (R14–R15): Reaches 14 (Modified Drainage Line) and 15 (Maungakiekie Golf Club) showed lower flood risk owing to their location within golf course parkland but represented opportunities for floodplain reconnection and naturalisation given the available space within publicly accessible land.

Upper reaches (R16–R19): The upper Whau included Reach 16 (Ramelton Reserve) and several tributary reaches (R17–R19). Like the upper Waitahurangi, these reaches retained more natural geomorphic character but were nonetheless affected by upstream piping and impervious cover. Reach 18, downstream of community tennis courts, was identified as High Priority due to residential encroachment along the tributary corridor and the criticality of the reach to upstream–downstream sediment and flow management.

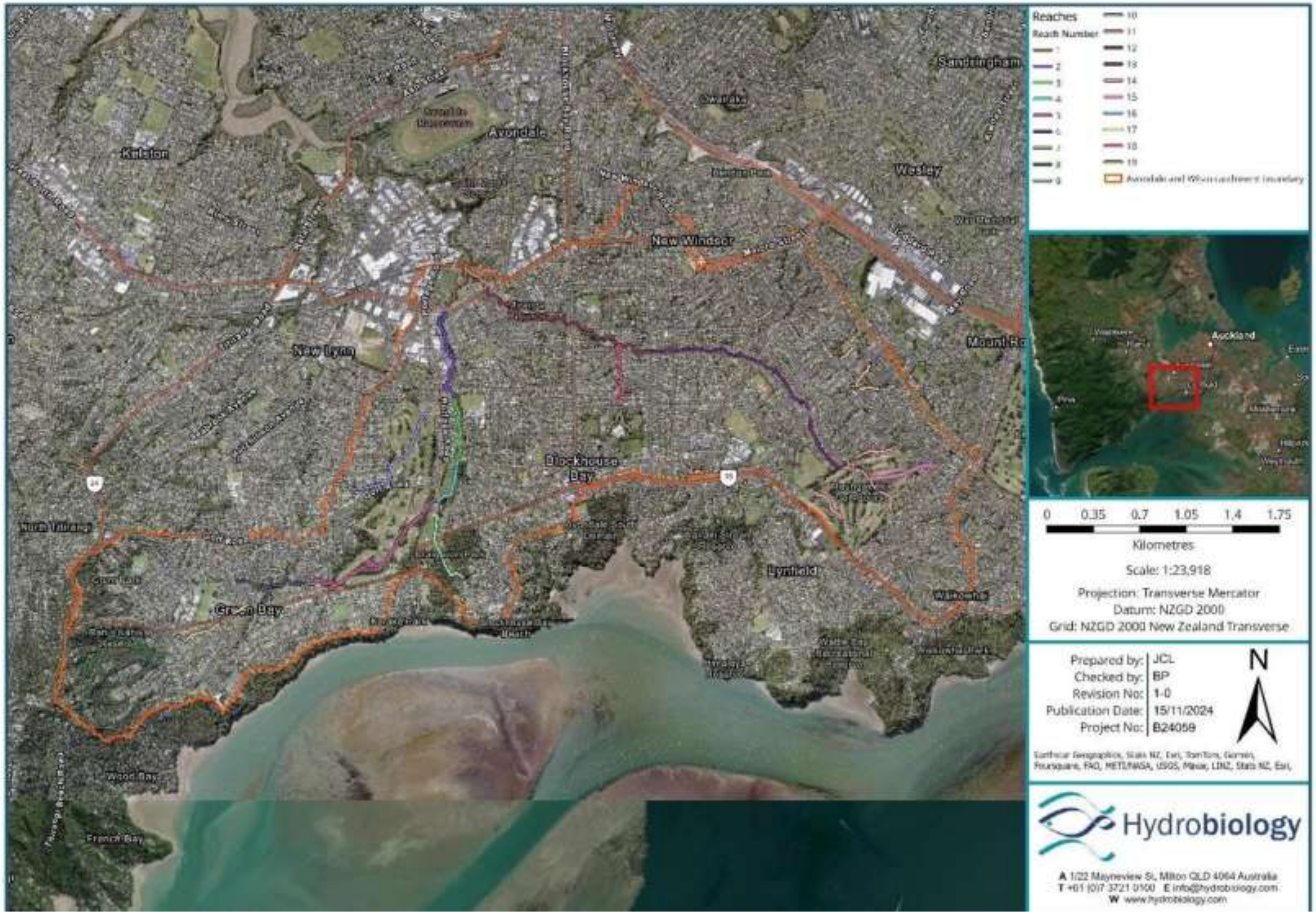

Figure 1 Reach classification map showing the nineteen assessed reaches across the Waitahurangi (Reaches 1–10) and Whau (Reaches 11–19) subcatchments

Discussion

A drainage paradigm produces predictable damage

The spatial pattern of channel degradation across the Whau and Waitahurangi catchments is not random, nor is it primarily driven by recent flood events. It is the predictable cumulative outcome of a stormwater management approach that prioritised conveyance over natural process for much of the past century. Headwater streams were piped to enable development; remaining trunk channels were confined, straightened, and stripped of riparian function to maximise drainage efficiency; and the resulting concentrated flows have produced incision, widening, and erosion in reaches that retained even a remnant of natural channel form. This pattern is consistent with the urban stream syndrome described by Walsh et al. (2005), the most severe degradation was not at the catchment outlet, where total flow volume is highest, but in mid-catchment trunk reaches where confinement is greatest and where altered upstream hydrology (piping and concrete channels) converges into a channel network incapable of absorbing it. This finding aligns with broader work showing that urban stream responses are often discontinuous because local controls, historical disturbance, and infrastructure modify channel sensitivity (Fryirs, 2017)

Recovery potential is real, but not universal

The integrated condition, sensitivity, and SEM analyses identified meaningful recovery potential in several reaches but also confirmed that recovery potential is not uniformly distributed. Where anthropogenic channel confinement was extreme, such as Reach 13, no process based in-channel recovery is realistically achievable without changing upstream catchment hydrological conditions and substantial reconstruction of the channel and waterway corridor, consistent with the approaches of the later stages of the River Styles Framework through identification of ‘strategic reaches’ (Brierley & Fryirs, 2005). Where confinement was partial and the channel retained connection to floodplain pockets, such as Reaches 1, 4, and the upper Whau, recovery is achievable through interventions that work with rather than against existing processes. Identifying these differences systematically, rather than assuming that all degraded reaches are equally recoverable, is critical to sustainable allocation of restoration investment.

Integration is not optional

The conventional separation of flood risk management and geomorphic restoration into distinct disciplinary streams has produced predictable failures in both workstreams. Flood management interventions that ignore channel adjustment trajectories such as implementing channel armouring and structural conveyance solutions compound downstream erosion and shift problems rather than solve them. Geomorphic restoration that ignores hydrology produces re-naturalisation works that fail under contemporary flow regimes. The Whau assessment was structured from the outset to integrate the two perspectives, reflected by the prioritisation framework. Reaches were prioritised for intervention not on geomorphic condition alone but on the spatial coincidence of geomorphic and flood-risk drivers. The intervention toolbox, developed to support process based restoration, spans reach-scale stabilisation, daylighting, riparian restoration, catchment-scale stormwater attenuation, and regulatory reform. Five High Priority reaches (R2, R5, R12, R13, and R18) emerged as a result of converging inputs aggregated through the use of a multi criteria assessment (see Figure 2).

Implications for management

The framework supports four distinct uses for Auckland Council and other catchment managers navigating similar challenges.

First, it enables targeted prioritisation of 19 reaches (Figure 2). Five emerged as High Priority for combined geomorphic and flood-resilience reasons, and focused investment in these reaches will deliver disproportionate benefit relative to uniform treatment across the catchment.

Second, it provides a defensible evidence base for decision-making at multiple scales. Catchment, reach, and regulatory interventions are structured as components of an integrated toolbox rather than alternatives, recognising that headwater piping, mid-catchment confinement, and downstream flood risk are different expressions of the same underlying drivers.

Third, it is adaptive. Inputs can be re-scored as land use, climate, and management context evolve and as monitoring data become available, and the High Priority designation is a starting point for sequencing investment in a catchment which requires rapid intervention rather than a final answer.

Finally, it is transferable. The methodological combination of hydraulic hotspot mapping, River Styles, SEM analysis, and integrated prioritisation is not novel in its individual components. All are drawn from established literature, and are structured around the explicit question of how to work with altered rivers, rather than against them.

Conclusion

The 2023 Auckland Anniversary floods and Cyclone Gabrielle made visible what was already evident to river managers. Urbanised catchments managed primarily as drainage infrastructure cannot deliver the flood resilience, ecological function, or community amenity that Auckland's residents, mana whenua, and the wider catchment community now demand from their elected council entities. The Whau Options and Risk Assessment demonstrates that this challenge has structured responses available. By integrating hydraulic, geomorphic, and condition assessments within a single prioritisation framework, the assessment identified five High Priority reaches (Figure 2) where targeted intervention can deliver coupled geomorphic and flood-resilience benefits, and provided an intervention toolbox structured around catchment, reach, and regulatory scales.

The fundamental shift this work supports is conceptual rather than technical. Urban waterways do not need to be managed solely as drainage infrastructure, they can be guided toward ecological and hydraulic recovery simultaneously, provided that the integration of those objectives is built into assessment and prioritisation from the outset. Where natural processes retain capacity, intervention should work with them. Where capacity has been lost, rebuilding may be required. Where neither is realistic, the legacy must be acknowledged and managed honestly with managed retreat considered a key response in these scenarios. The framework developed here offers one route to making these choices systematically across a catchment and is offered as a starting point for practitioners navigating similar conflicts between flood risk management and the restoration of living rivers elsewhere.

Figure 2 Catchment-level reach prioritisation map. High Priority reaches (red) reflect convergence of geomorphic condition, sensitivity, hydraulic stress, flood risk, and criticality to program objectives

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References

Brierley, G., & Fryirs, K. (2005). Geomorphology and river management: Applications of the River Styles framework. Blackwell Publishing.

Brierley, G. J., Hikuroa, D., Fuller, I. C., Tunnicliffe, J., Allen, K., Brasington, J., Friedrich, H., Hoyle, J., & Measures, R. (2023). Reanimating the strangled rivers of Aotearoa New Zealand. WIREs Water, 10(2), e1624. https://doi.org/10.1002/wat2.1624

Cluer, B., & Thorne, C. (2014). A stream evolution model integrating habitat and ecosystem benefits. River Research and Applications, 30(2), 135–154. https://doi.org/10.1002/rra.2631

DNRM. (2014). Queensland Urban Drainage Manual: Watercourse Stability Considerations. Department of Natural Resources, Mines and Energy, Queensland Government.

Fischenich, J. C. (2001). Stability thresholds for stream restoration materials. EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-29). U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Fryirs, K. A. (2017). River sensitivity: a lost foundation concept in fluvial geomorphology. *Earth Surface Processes and Landforms*, *42*(1), 55-70.

Reid, H. E., & Brierley, G. J. (2015). Assessing geomorphic sensitivity in relation to river capacity for adjustment. Geomorphology, 251, 108–121. https://doi.org/10.1016/j.geomorph.2015.09.009

Simon, A. (1989). A model of channel response in disturbed alluvial channels. Earth Surface Processes and Landforms, 14(1), 11–26. https://doi.org/10.1002/esp.3290140103

Vietz, G. J., Rutherfurd, I. D., Fletcher, T. D., & Walsh, C. J. (2016). Thinking outside the channel: Challenges and opportunities for protection and restoration of stream morphology in urbanizing catchments. Landscape and Urban Planning, 145, 34–44. https://doi.org/10.1016/j.landurbplan.2015.09.004

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: Current knowledge and the search for a cure. Journal of the North American Benthological Society, 24(3), 706–723. https://doi.org/10.1899/04-028.1

Wohl, E. (2019). Forgotten legacies: Understanding and mitigating historical human alterations of river corridors. Water Resources Research, 55(7), 5181–5201. https://doi.org/10.1029/2018WR024433