GUIDANCE FOR LARGE WOOD INSTALLATIONS IN NEW ZEALAND RIVERS

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This guidance document has been prepared as part of a Ministry of Business, Innovation & Employment Envirolink Medium Advice Grant project.

GUIDANCE FOR LARGE WOOD INSTALLATIONS IN NEW ZEALAND RIVERS

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1. Introduction and legislative context

New Zealand has several policies and legislative frameworks in place to manage and protect its freshwater resources. These policies aim to ensure the sustainable management of freshwater ecosystems, maintain water quality, protect biodiversity, and meet the needs of various stakeholders.

The **Resource Management Act (RMA)** is the primary legislation governing the sustainable management of natural and physical resources in New Zealand. It provides the legal framework for managing freshwater resources, including allocation, use, and protection, through regional councils and district authorities.

The **National Policy Statement for Freshwater Management (NPS-FM)** sets national objectives and policies for freshwater management under the RMA. It includes provisions for maintaining or improving water quality, protecting ecosystems and habitats, managing contaminants, and engaging communities in freshwater management.

Regional councils are responsible for developing freshwater management plans in accordance with the NPS-FM. These plans set objectives, limits, and rules for managing freshwater resources within each region, taking into account local environmental conditions as well as cultural and community values. These management plans include both regulatory and non-statutory approaches to achieving the desired outcomes.

The government has established **National Environmental Standards (NES-F)** under the RMA to set minimum standards for specific aspects of freshwater management, such as water quality, ecological flows, and nutrient management. NES-F provides guidance and a consistent approach to freshwater policy implementation.

Māori engagement and Treaty settlements play a crucial role, recognising and protecting Māori rights and interests in freshwater resources. The government commits to engaging with iwi and hapū in decision-making processes which includes cultural attributes under the National Policy Framework.

While not specific to freshwater, the **National Policy Statement for Indigenous Biodiversity (NPS-IB)** aims to protect and restore indigenous biodiversity across New Zealand, including terrestrial species that indirectly rely on freshwater environments.

There are also several climate change adaptation strategies that address the impacts of climate change on freshwater resources, ensuring resilience to changing conditions and protecting freshwater ecosystems for future generations.

These policies and frameworks reflect New Zealand's commitment to sustainable freshwater management, stakeholder engagement, and biodiversity conservation. They provide a comprehensive framework for addressing the complex challenges facing freshwater resources in the country while balancing environmental, social, cultural, and economic priorities. Due to their complexities a holistic approach is often needed to successfully implement them and attain the desired objectives.

The traditional approach of catchment contaminant load reductions only achieves measurable improvements in certain attributes and objectives. To fully satisfy the intention of the current freshwater resource management framework in-stream habitat and processes must be considered. This is particularly important when considering regional targets for biological metrics such as the Fish Index of Biotic Integrity (Fish IBI) and Macroinvertebrate Community Index (MCI) as well as ecosystem health, threatened species, mahinga kai and taonga species objectives.

Addition of woody material to rivers and streams

The strategic addition of instream woody material can enhance habitat quality, food availability, reproductive opportunities, water quality, flow dynamics, and ecosystem resilience, all of which contribute to higher Fish IBI and MCI scores as well as several threatened species and mahinga kai attributes. The ecosystem services provided by woody debris contribute directly to the enhancement of ecosystem health values and will help achieve National Objective Framework (NOF) attribute targets as well as regional specific attributes.

Considering the value of in-stream woody material, it can be used as an effective mitigation, compensation and offsetting tool. The current approach relies on the enhancement of riparian features as compensation/mitigation for in-stream impacts. Offset sites can include the provision of in-stream habitat but often favour rock structures rather than wood. Guidelines on effective installation of wood will facilitate the inclusion of woody material as a restoration tool in the resource consent process. The guidance will also inform more effective non-regulatory restoration projects.

Key definitions

The term ‘**large woody material**’ (**LWM**) encompasses all trees, branches, and root wads that have fallen into rivers.

Finer woody material including small branches, twigs and leaf litter are referred to as fine or coarse woody material (**FWM**).

2. Ecosystem services associated with large woody material

Woody material is a vital component of river systems, supporting multiple ecosystem services and functions (Donadi et al. 2019). However, with New Zealand's predominance of de-vegetated urban, peri-urban and rural streams, many lotic environments have lacked large woody inputs for decades. Large woody material (herein LWM) in some settings can lead to intractable flooding issues, such as where debris dams form upstream of vital infrastructure. However, unnecessary removal of wood and loss of LWM recruitment can severely impact both physical processes and ecological integrity, with knock on effects for human wellbeing, aesthetic appeal, and recreational value.

Habitat provision and diversity

Habitat provision is typically a primary goal of wood addition to streams and rivers. Woody material increases habitat complexity and diversity, providing critical habitat features such as shelter, cover, and nesting sites for fish and macroinvertebrates. Notably, large wood often creates pools that vary in area and depth and are associated with different species and life stages (Crichton et al. 2023). Not only does large woody material create identifiable habitat features, but the physical complexity associated with these features translates to heterogeneity of other stream characteristics, for example thermal refuges, and additional micro-habitats.

Retention of smaller woody material influences the nature of habitat features formed by LWM, by increasing habitat complexity and altering the hydraulics of the overall structure (Bilby and Ward 1991). Therefore, the focus of restoration should not solely be on the LWM itself, but also on its ability to capture and retain additional woody material if appropriate. Furthermore, capture of this smaller wood and organic residues is also important from an ecosystem function perspective: retained organic matter is food for microorganisms and macroinvertebrates, thus key to a fully functioning food web.

Large woody material helps create different-sized pools in rivers, providing resting places for fish and supporting aquatic organisms at different stages of their lives.

Native species

We know a lot about how salmonids respond to LWM additions (Crispin et al. 1993, Cederholm et al. 1997, Neumann and Wildman 2002), but far less about how native New Zealand fish respond, particularly those with unique life histories (Roni et al. 2015). For example, knowledge gaps exist regarding how LWM structures and the habitat features they create are utilised by climbing fish such as kōaro and kanakana (lamprey).

Habitats associated with wood make up a small portion of total aquatic habitat available naturally, but support some key native fish species including longfin eel (*Anguilla dieffenbachii*) and banded kōkopu (*Galaxias fasciatus*) (Baillie et al. 2013), with particular importance for specific life stages (Crichton et al. 2023).

Particular importance of wood in soft bottom streams

In soft bottom streams - a stream type that is prevalent throughout large parts of the North Island including the Bay of Plenty, Auckland and Waikato - large wood along with root complexes are some of the only semi-permanent habitats available to freshwater fauna.

Considering that the physical need for cover increases as fish grow, the availability of large wood complexes is critical for eel and large bodied kōkopu species. This is particularly the case in small soft bottom streams where the need for cover is often disproportionate to the size of the wetted habitat available.

In streams with soft bottoms, large woody material provides stable habitats for aquatic life.

Influence of LWM on channel form

When contemplating seeding waterways with LWM, the goal is typically to increase the amount and complexity of instream habitat. However, used strategically, LWM can also positively influence a stream’s channel form. This will be crucial in streams with mobile beds which have become run dominated and homogenous in depth through lack of woody contributions, or that have in some way been modified.

Localised zones of deepening in a stream can be created artificially by excavating bed materials, however these will infill with bed sediments relatively quickly. Alternatively, a LWM hydraulic control can create a ‘forced’ pool immediately downstream of the obstruction and maintain this depth for the life of the wood. For example, cross logs placed parallel to the flow direction can create greater depth variation by promoting localised scour.

The relationship between flow and sediment transport is complex. During channel-forming flows, partial mobility conditions prevail at a reach-scale, with pools experiencing net scour and riffles aggrading (Thompson and MacVicar 2022). LWM can be used to promote scour without increasing the risk of excessive, uncontrolled erosion. Just as with rock placed in hard bottom stream environments, LWM can also be installed to create a water level control in soft bottom environments and so prevent bed erosion from propagating upstream or downstream of the LWM feature.

In nature, only a small percentage of the LWM that falls into a stream will lodge at an angle that helps stable bank undercuts and pools form. Even trees and limbs that fall with promising trajectories (i.e., at right angles to the stream flow or parallel to the bank) can take many years to become embedded and assimilated in the channel cross section. Most LWM entering the active stream channel naturally as windfall will be swept downstream. We can substantially speed this process up by installing the wood ourselves and do so in a way that reduces the risk of dislodgement and that safeguards downstream infrastructure.

Streambank stabilisation

One of the primary functions of LWM is its ability to dissipate energy from flowing water, thereby stabilising streambanks. By acting as natural barriers, fallen trees and branches slow down the velocity of water, reducing erosion and preventing further degradation of the streambank. This process also facilitates sediment deposition, which can help rebuild eroded areas and promote the establishment of vegetation. Through these processes, LWM can also reduce lateral channel migration (Neumann and Wildman 2002).

Large woody material slows down and deflects the flow, helping to stabilise riverbanks and preventing them from wearing away.

Nutrient cycling

Nutrient retention by woody material in streams and rivers is a multifaceted process with several important implications for ecosystem dynamics.

LWM accumulates organic matter, including leaves, twigs, and other plant materials, within aquatic environments (Gurnell et al. 2002). As this organic material decomposes, nutrients such as nitrogen, phosphorus, and carbon are released into the surrounding water. This process is facilitated by microbial activity, primarily bacteria and fungi, which break down complex organic compounds into more simple, soluble forms (Suberkropp 1998). LWM also serves as substrate and habitat for these nutrient processing organisms.

Large woody material acts as a base for bacteria and fungi which are vital for biogeochemical processes like nutrient cycling.

These microorganisms are key components of the 'biofilm', providing food for invertebrates and thereby supporting the wider aquatic foodweb.

Nitrogen is released through microbial processes like ammonification and nitrification, converting organic nitrogen into ammonium and nitrate ions, respectively. Phosphorus is liberated as organic phosphorus compounds are hydrolysed into soluble phosphate ions. These nutrients become available for uptake by aquatic plants, algae, and other organisms. These bioavailable nutrients can follow various cycling pathways within aquatic ecosystems (Krause et al. 2014). They may be taken up directly by aquatic plants and algae for growth and metabolism, or, alternatively, nutrients may be incorporated into microbial biomass or recycled through detrital food webs, where they are consumed by detritivores and transferred to higher trophic levels.

LWM can create low flow environments that promote organic matter deposition (including fine particulate organic matter) and increased growth of primary producers (Schalko et al. 2021). This can create localised areas of nutrient enrichment that support enhanced biological activity and productivity, influencing the distribution and abundance of aquatic organisms (Zalamea et al. 2007). They may also contribute to spatial heterogeneity in nutrient cycling processes, leading to complex patterns of nutrient dynamics within aquatic ecosystems. Temporal variation in nutrient availability is also helped by retention and slow release of nutrients due to LWM structures (Bilby 2003).

Overall, the retention and subsequent release of nutrients by LWM plays a crucial role in regulating nutrient cycling within streams and rivers, influencing the structure and function of aquatic ecosystems (Krause et al. 2014). Management strategies aimed at conserving and restoring woody material habitats can help maintain the integrity and resilience of these ecosystems in the face of environmental disturbances and anthropogenic pressures.

Floodplain connectivity

Heightened floodplain connections, made possible by low bankfull heights, helps dissipate a stream's energy (and thus erosion potential) by letting floodwaters spill out over the surrounding floodplain. Conversely, rivers and streams that have been channelised or straightened will often incise downwards to return the stream to an equilibrium state. In this process, streambanks often become over-steepened and more prone to slumping. As floodplain connections diminish, erosive flood flows become more concentrated within the active channel and the process of stream downcutting, bank over-steeping and slumping becomes self-perpetuating. LWM can be used to help restore floodplain connections and to recreate the original length lost when the stream was straightened.

Water quality improvement

One significant contribution of large woody material to water quality improvement is its capacity to trap fine sediments and pollutants. As water flows through woody structures, suspended sediments settle out, reducing turbidity and depositing any contaminants which may be adhered to sediment particles (e.g. phosphorus, heavy metals)(Ongley et al. 1992). When contaminants are cohesive and settled, their ability to impact water chemistry is reduced, rendering them less harmful to aquatic life. Additionally, the porous nature of wood serves as a natural filter, capturing pollutants such as heavy metals, excess nutrients, and organic compounds. The porosity of xylem vessels within wood vary in diameter, with some small enough to entrap microorganisms such as *E. coli* and other potentially harmful bacteria (Ramchander et al. 2021).

Carbon sequestration

Woody debris plays a pivotal role in in-stream carbon sequestration through various mechanisms. It acts as a significant reservoir for carbon, accumulating organic material derived from trees along the riparian zone or introduced through natural processes like bank erosion. This organic matter, stored within fallen trees, branches, and logs, constitutes a substantial portion of in-stream carbon storage (Swanson et al. 2021). The slow decomposition rate of woody debris ensures the prolonged sequestration of carbon within stream channels (Wohl 2013). Unlike other organic matter that decomposes more rapidly, woody debris persists in streams and rivers for extended periods, effectively retaining carbon within aquatic environments. In particular, LWM stored within the soils of floodplains can increase the residence time of organic carbon (Ghaffarian et al. 2020)

Submerged woody debris provide shelter, foraging areas, and spawning grounds for aquatic organisms, all of which contribute to stream biodiversity while simultaneously acting as carbon sinks. Additionally, woody debris traps sediments and organic matter, facilitating carbon burial within streambeds. By preventing the immediate release of carbon back into the atmosphere through decomposition, submerged woody debris enhances in-stream carbon sequestration. Furthermore, woody debris influences nutrient dynamics within streams, supporting nutrient retention and recycling processes. As organic matter decomposes, nutrients and carbon are released into the water, contributing to in-stream carbon cycling and sequestration.

The role of woody debris in in-stream carbon sequestration underscores its significance in maintaining the health and resilience of freshwater ecosystems. Recognising the importance of woody debris in carbon cycling informs conservation and management strategies aimed at preserving stream habitats and enhancing carbon storage within aquatic environments. By conserving and managing woody debris in streams and rivers, we can promote in-stream carbon sequestration and contribute to the sustainability of freshwater ecosystems for future generations.

Recreational and aesthetic value

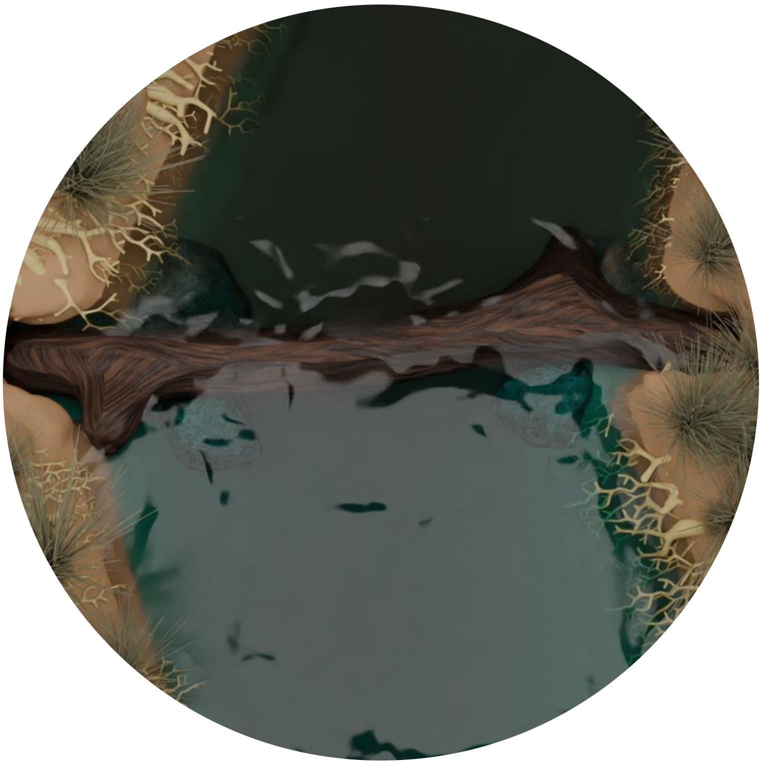
In addition to its ecological benefits, large wood can also enhance the aesthetic value of stream environments, creating visually appealing features that attract recreationists and wildlife enthusiasts. Planting around these structures can both enhance their stability and long-term utility, and can also further add to the aesthetic value of an area.

Public perceptions of LWM

The general public tends to hold negative views around large instream wood (Donadi et al. 2019). Landowners and recreationalists, in particular, tend to believe that large wood disrupts aesthetics and poses risks to life and property (Roni et al. 2015). However, the public's perception of how much instream wood is 'natural' has likely been drastically influenced by historical wood removal (Chin et al. 2008). International studies on instream wood perception have found that people from areas where wood loadings are high tend to have more favourable views toward instream wood than their peers from lower wood areas (Piégay et al. 2005). In New Zealand, perceptions have likely also been tarnished by issues associated with woody debris under exceptional weather events, notably Cyclone Gabrielle in 2023. In the restoration space globally, there has been a deliberate shift away from the term 'woody debris' when referring to instream wood, as this term often has unfounded negative connotations.

3. Large woody material as a restoration tool

Many streams throughout the country flow through open environments bereft of woody tree species and where the woody contributions have been absent for many years. The traditional stream restoration approach in NZ, which has mainly been limited to revegetating riparian margins, will eventually help to restore large woody material inputs to streams, and this recovery of natural dynamic processes at a catchment scale should be an overall goal of restoration (Nagayama and Nakamura 2010). However, natural wood additions may not be realised for many decades. We can circumvent this and expedite habitat provisioning by seeding wood into streams. The strategic addition of instream woody material can help achieve ecological health targets by enhancing habitat conditions and both ecological and physical processes that support healthy macroinvertebrate and fish communities.



By strategically placing large woody material in streams, we can boost river health and ensure provision of vital ecosystem services.

4. Spatial pre-feasibility analysis and engineering considerations

Incorporating large wood into stream restoration designs is a complex process that involves understanding the detailed biology, geomorphology, hydraulics, and engineering aspects of a project.

The following information is also available as an interactive storymap via the following link: https://storymaps.arcgis.com/stories/b0ef87cf6feb405e836b580c75fa894b

Here are some key guidelines for the planning, design, placement, and maintenance of large wood in stream restoration:

1. **Prefeasibility:** Use a prefeasibility assessment tool to determine the likelihood of success and risk in implementing large wood in a stream. A high risk does not exclude implementation of large wood, but implies more detailed study or local information would be needed to reduce risks.
2. **Assessment:** Evaluate the local stream's current conditions and determine the role of wood in the ecosystem. Consider the natural wood recruitment processes and the potential for wood to alter channel shape and form.
3. **Design:** Develop a design that considers the stream's morphology and hydrological regime. The design should aim to restore or enhance ecosystem processes and functions. Use both active (placement) and passive (recruitment and transport) methods for wood incorporation.
4. **Placement:** Strategically place large wood to create habitat complexity, store sediment and organic matter, and improve the overall ecological function of the stream. Ensure that the placement does not pose a risk to infrastructure or public safety.
5. **Maintenance:** Establish a maintenance plan to manage the wood that naturally enters the stream and to monitor the condition of placed wood structures. This will help to ensure the long-term success of the restoration efforts.
6. **Monitoring:** Implement a monitoring program to assess the effectiveness of the wood structures in achieving the desired ecological outcomes. Adjust the design and management strategies based on the monitoring results.

Prefeasibility

A prefeasibility assessment for installation of large wood in NZ rivers was conducted using the River Environment Classification - REC network (REC2 v5 2019). Multiple flow, width, stream characteristics, and anchoring related factors available through the NZ River Maps data (Whitehead and Booker 2019, Whitehead and Booker 2020) were used to rank the prefeasibility risk of installing large wood in river segments from very low to very high. To make the analysis manageable, only Strahler stream order classification greater than two were used. Key steps and factors used for this analysis are presented here as well as an interactive map. It is important to note that "very high" or "high" risk do not imply that the placement of large wood in that particular segment of a stream/river is not possible, it simply means that based on flow and stream characteristics, the installation of large wood requires further study in anchoring and local information to minimize risk of damage or loss of wood downstream.

Capturing flow change factors:

Flow factors were captured using these parameters:

- **Frequency (FRE3)** - the average number of events per year that exceed three times the median flow (events/year). Calculated from mean daily flows with no windows applied to account for peaks that occur in quick succession. Provides an estimate of flow flashiness. Lower values mean less frequent events.
- **Mean annual low flow (MALF)** (cumecs) - the mean of the annual low flow series after having applied a 7-day running average ($m^3 s^{-1}$). Lower values mean less flow.
- **Mean flow** (cumecs) - mean flow over all time ($m^3 s^{-1}$). Lower values mean less flow.
- **Width at mean annual low flow** (m) - wetted width across the river channel (m) at mean annual low flow. Lower values are less wide.
- **Width at mean flow** (m) - wetted width across the river channel (m) at mean flow. Lower values are less wide.

Normalized values for frequency, flow rates, and river width changes were estimated as follows (higher values = more risky/difficult for installing large wood in rivers):

A. Frequency of events a year: (FRE3/40) (0 is low flashiness, 1 very flashy - the max number of events is 40)

B. Flow rates: ((Mean_Flow - MALF)/ Mean_Flow) level of difference between low and mean flows. Lower numbers are stable rivers, higher numbers less stable.

C. Width: ((Width_at_mean_flow - Width_at_MALF) / Width_at_mean_flow) changes in river width between low and mean flows. Lower numbers are more confined rivers, higher numbers less confined.

A total value for flow factors is captured by multiplying all three weight values (A*B*C).

Adding flow volume and width factors

The higher the median flow volumes and the wider the river, the greater the difficulty in establishing large wood in a river. A normalised factor for the mean flow rate and width was added to the previous analysis to refine the prefeasibility analysis. Flow change factors were weighted by 70% and flowrate and width were weighted by a combined 30%. Larger rivers with high flowrates are now shown as having very high risk for large wood.

Capturing potential risks on bridges and culverts

The river (REC) segments that intersect the NZ road network were identified (Figure 1). These segments are assigned a value greater than 1 (i.e. 1.5) to indicate potential risk to structures in that segment. The value was then be multiplied by the flows and width factors to indicate overall prefeasibility risk level.

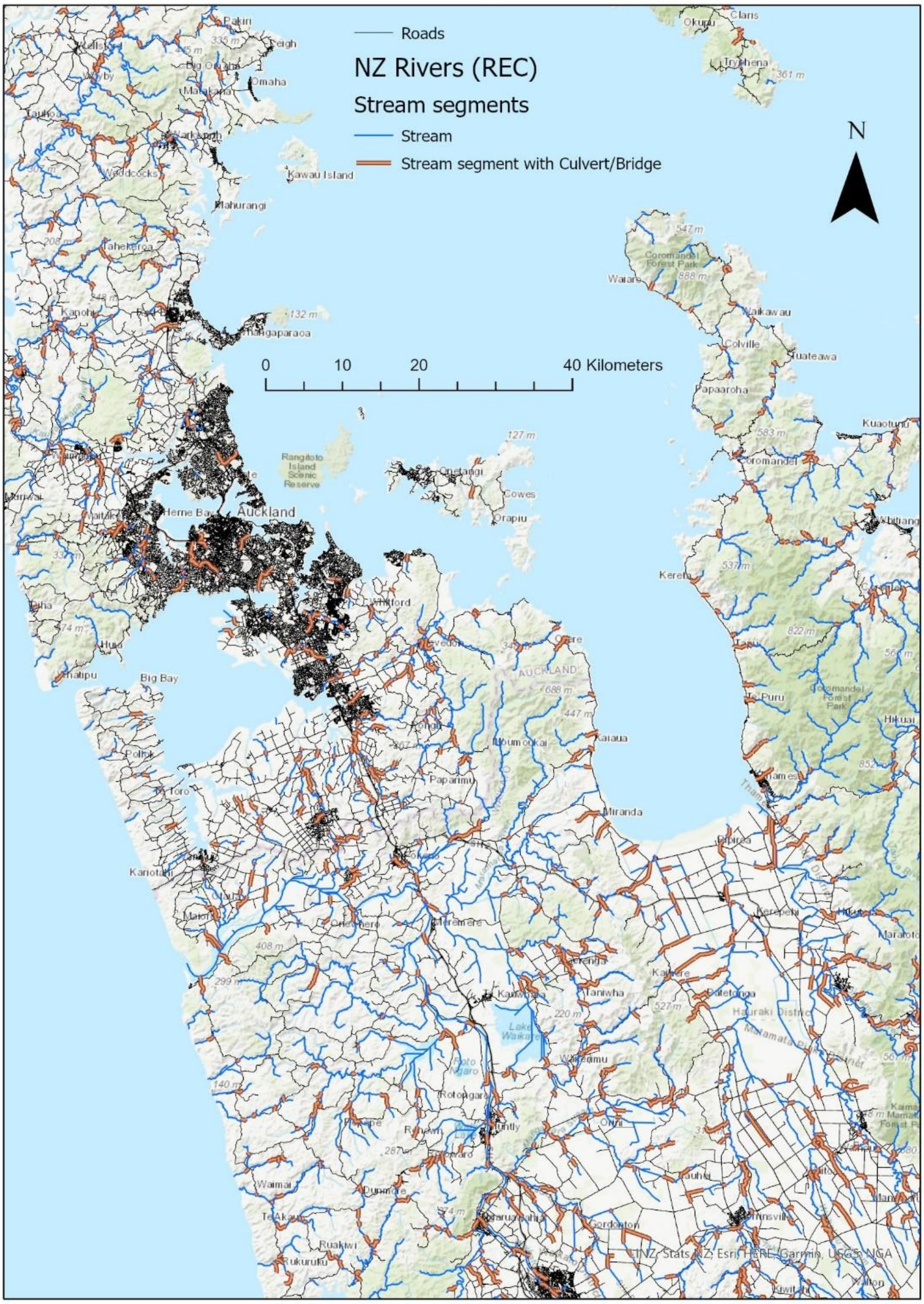


Figure 1. River (REC) segments with culverts or bridges in them (example of the Auckland area).

Results of this prefeasibility assessment are represented by categorizing values into very low, low, medium low, medium, high, and very high risk (Figure 2; Figure 3):

Risk level Potential	**Description**
very low	smaller, stable stream/river, minimal risk for large wood placement (but still need to check local conditions)
low	smaller, stable stream/river, only small risk for large wood placement (but still need to check local conditions)
medium low	Recommend local studies
medium	Recommend local studies
high	High potential risk due to flow, width, or downstream infrastructure. Detailed local study needed to evaluate viability and anchoring requirements.
very high	Very high risk due to flow conditions and width of stream/river and/or downstream infrastructure. Detailed local study needed to evaluate viability and anchoring requirements.

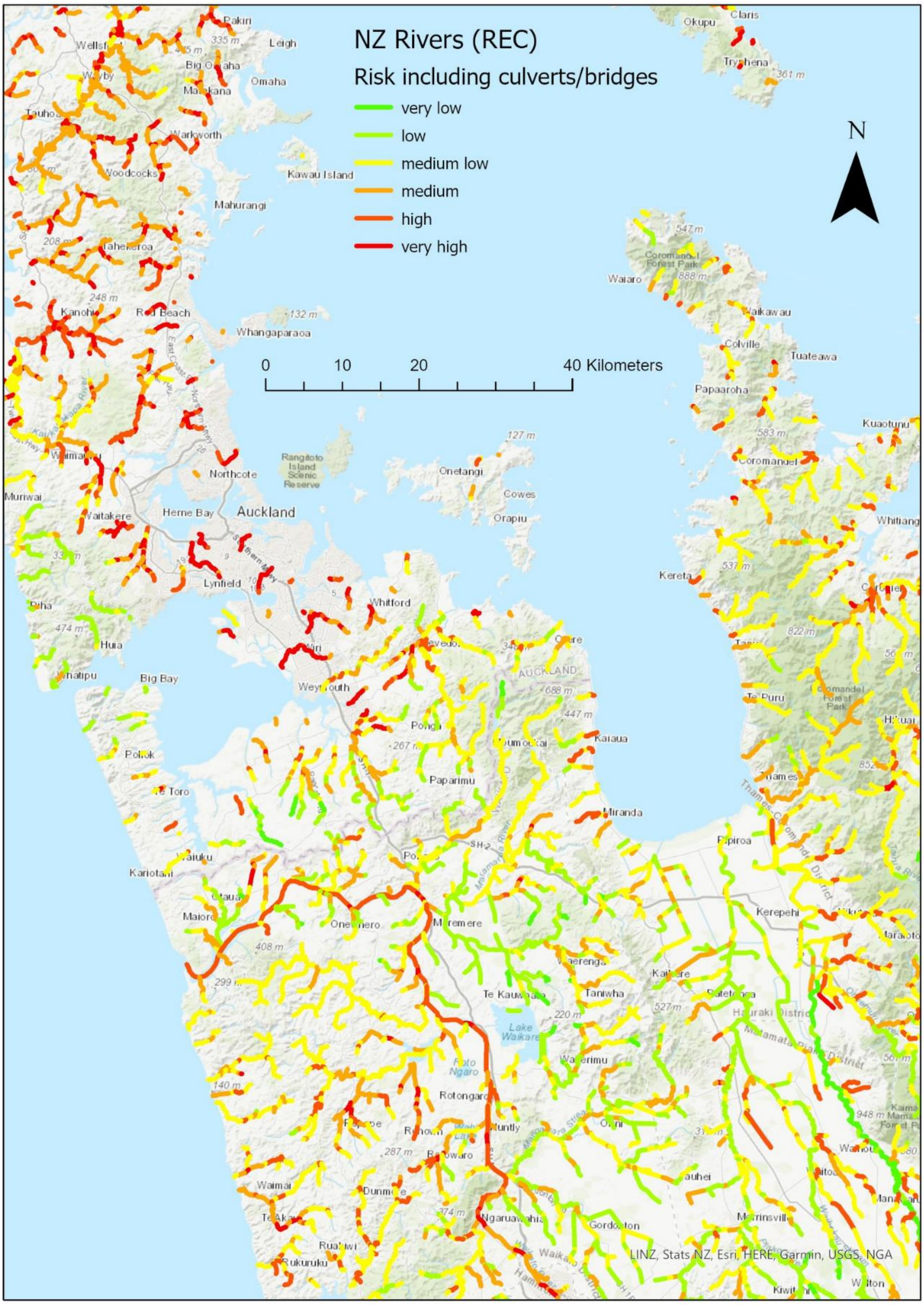


Figure 2. Risk level potential for installations of large wood in rivers around Auckland, including segments with culverts or bridges.

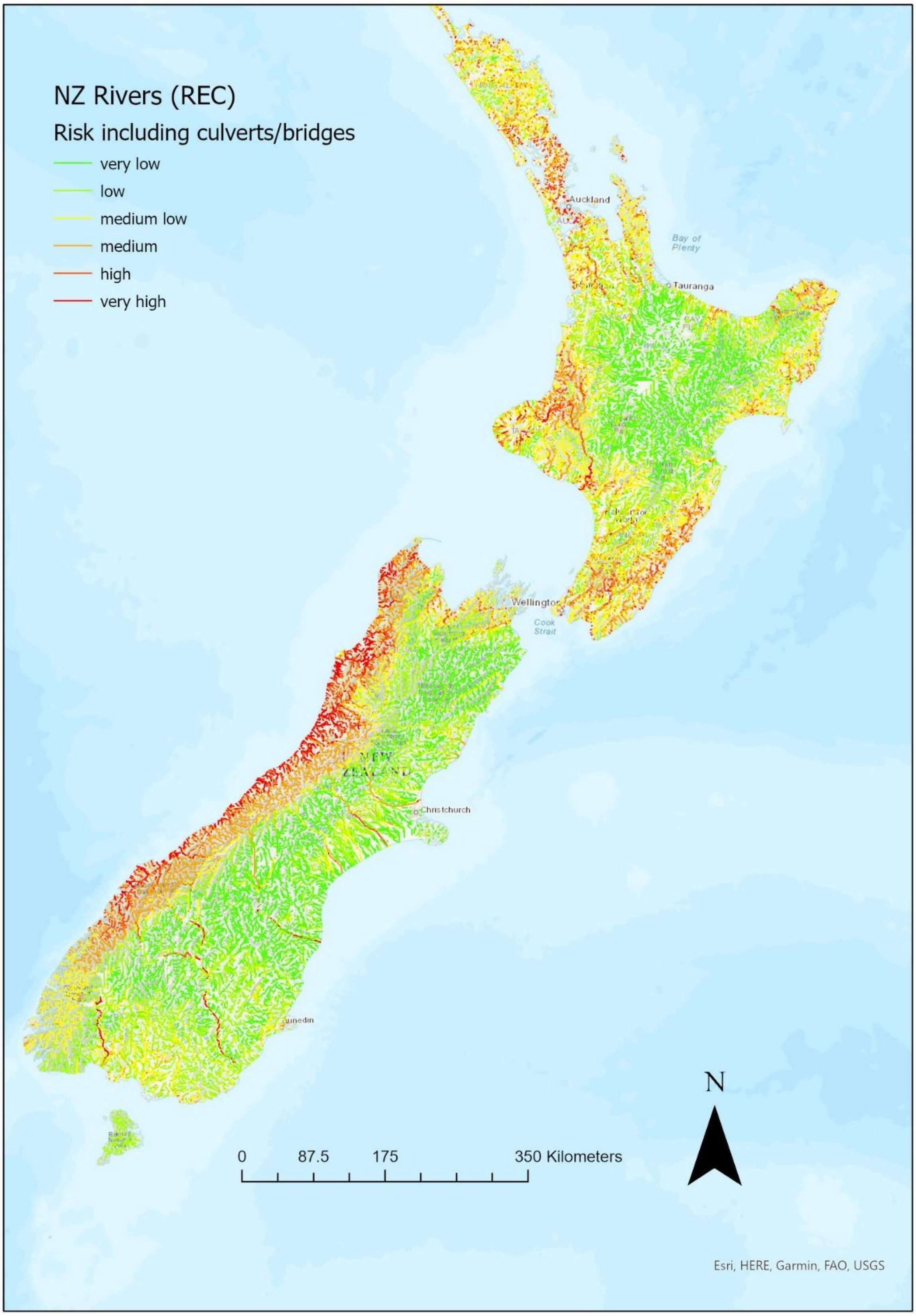


Figure 3. Risk level potential for installations of large wood in NZ rivers, including segments with culverts or bridges

Assessment

A more detailed assessment is needed to evaluate the stream's conditions and the wood's role in the ecosystem. In addition to an ecological assessment, the engineering aspects that need to be addressed are:

Hydrological and hydraulic factors

It is important to design stream corridor features to withstand specific discharge events and thus there is a need for accurate hydrologic data.

- Stream corridor features have to be designed to withstand specific discharge events with certain frequencies or return intervals.
- Design discharges can be determined using statistical analyses of data from nearby gauges or other techniques (i.e. modelling).
- Base flow conditions and flow duration curves are important considerations for design and analysis.
- The design event return interval is based on the design life of the structure, with larger events imposing larger shear forces.
- Peak velocities may be associated with more frequent events, such as bankfull events.
- The selection of design discharges should be consistent with risk analysis and the planned intensity of maintenance.

There is also a need for a detailed force balance analysis and hydraulic assessment. The use of 1D and 2D modelling tools for evaluating the impacts of large wood on flow characteristics is important.

- Well-designed large wood projects can withstand flows with average bed shear stresses of 50-170 Pa and velocities of 3 to 4 m/s.
- Designing large wood structures should be based on a detailed force balance analysis rather than average shear stress or velocity.
- Hydraulic analysis, including flow conveyance, sediment transport capacity, and velocity and shear stress assessment, is recommended.
- 1D modelling using tools like HEC-RAS can be used for rough analysis, while 2D simulations are more suitable for examining large wood effects.

Different approaches have been used to represent the hydraulic and hydrological effects of large woody material (LWM) in numerical models. The most common representations include the adjustment of channel roughness, the use of solid obstructions to simulate LWM features, the complexity of shape in hydraulic predictions, the limitations of representing porous structures as solid geometric features, the manipulation of roughness parameters, the combined approach of modifying channel geometry and roughness, the use of engineering equations for in-stream structures, the application of 3D modelling, and the under-investigated approach of using a porosity model. Here's a summary of the findings from recent studies presented in Addy and Wilkinson (2019):

- The most common representation of LWM in numerical models is through the adjustment of channel roughness.
- Altering channel geometry to create solid obstructions can capture the impoundment and deflecting effects of LWM, but it has limited validation and may not accurately represent permeability.

- Increasing roughness at the location of LWM or at the reach scale is popular for simulating increased flow resistance.
- The combined approach of modifying channel geometry and increasing roughness has been adopted in some studies, but its suitability is limited by the lack of validation.
- The use of engineering equations for in-stream structures is an appealing way to simulate artificial flow restrictors, but it may not reliably predict the hydraulic effects of complex natural or artificial structures.
- 3D modelling can fully represent the pores between timber members and provide detailed predictions of hydraulic effects, but it is time-consuming and computationally demanding.
- The application of a porosity model to capture water movement through LWM interstices is an under-investigated approach that can yield similar results to 3D modelling with less computational costs, but it may result in a loss of information.

Modelling has also been conducted to understand the effects of LWM on floodplain connectivity, sediment transport, and LWM management:

1. **Floodplain Connectivity:** A study investigated the effects of large wood on floodplain connectivity in a headwater Mid-Atlantic stream. The addition of large wood was found to increase floodplain inundation extent by 34%, increase inundation depth by 33%, and decrease maximum thalweg velocity by 10%. The study used field measurements and hydrodynamic modelling with HEC-RAS to quantify these effects.

2. **Sediment Transport Modelling:** Research reviewed the performance of the HEC-RAS model in simulating sediment transport mechanisms in stream channels. The paper highlighted the importance of sediment transport in influencing river morphology and the construction of hydraulic structures. HEC-RAS was recognized for its simplicity and free availability, making it widely used in research areas for modelling sediment transport.

3. **Large Wood Management:** A decision process for managing large wood in streams was proposed, which includes visual assessments to detailed numerical modelling with HEC-RAS. This process helps assess the benefits and hazards associated with individual wood pieces and accumulations of wood.

Risk factors

Risk is the product of the probability of an event occurring and the consequences it will have on infrastructure, property, habitat, public safety, or construction (Table 1).

- Risk assessments in stream restoration and river management can range from simple empirical guidelines to complex quantitative analyses.
- Professionals with knowledge of fluvial processes and regional streams are crucial for accurate risk assessments.
- Risk assessments can be as simple as placing functional wood in a protected/stable area or as complex as evaluating flood scenarios and wood decay rates.
- Changes in the natural and built environment, such as climate change and increased development, introduce uncertainty and may require more detailed analysis.
- Risk assessments are important for ensuring that stream restoration projects consider potential adverse consequences.
- The location, type, and characteristics of large wood placements can affect the level of risk to recreational users.
- Wood accumulations also can raise water elevations, which can increase the frequency and magnitude of overbank inundation. This provides very beneficial ecosystem services but can be problematic in areas where development has encroached into flood-prone areas.
- Mobile wood moving downstream can pose risks to human-made crossings, such as small bridge spans or culverts. Efforts to restore wood should be carefully planned to reduce downstream risks and consider the effects of wood accumulation on bridge piers. Most stream crossings (i.e., culverts and bridges) have not been designed to accommodate the passage of wood material. Actions that increase wood flux into inadequate crossings will increase the risk of blockages that could compromise the facilities or increase upstream flooding.

Table 1. Elements for consideration in risk assessments (modified from USBR 2016).

Element	Considerations
Infrastructure	• Are there bridges or culverts downstream of the project area? Do they have in-channel piers? What is their ability to convey large wood? • Are there stopbanks (levees) or revetments adjacent to or downstream of the project area? What is their condition? Were they designed to withstand extreme floods? • Are there buried utilities in the project area? How deep are they buried? If the channel avulses or migrates, are they likely to be exposed? • Are there public or private roads within the adjacent floodplain? If so, are they overtopped frequently and by how much flow depth?
Property	• Is the adjacent floodplain public or private property? How will large wood placements affect flood depths on adjacent properties? • Where is the project area located in relation to property boundaries? • What structures (houses, outbuildings, recreational facilities) exist within or downstream of the project area? • Is the channel actively eroding or migrating? How will large wood placements affect erosion and migration rates? Would channel migration into adjacent properties be perceived negatively? • Are there avulsion pathways through adjacent properties? How will large wood placements affect the likelihood of a major channel avulsion? Would a major avulsion through adjacent properties be perceived negatively?

Habitat	• What will happen if no project is completed? Will habitat conditions for the species of interest improve or decline? • How will large wood placements affect habitat conditions in the short (1 to 5 years) to long term (5 to 50 years)? • Will there be temporary impacts during the construction process? Will those create any permitting issues? • How will large wood placements affect future large wood recruitment?
Public Safety	• Would failure of infrastructure (described above) cause a threat to human safety or welfare? • Would erosion, channel migration, or avulsion (described above) cause a threat to human safety or welfare? • Does the reach experience recreational use? If so, what is the experience level of the normal user? Are most users accustomed to large wood hazards?
Construction	• How does the local regulatory environment view large wood installations? Will local policies/regulations and/or viewpoints affect how the large wood placements are located and constructed? (consent required?) • How will the large wood placements be constructed? How will sediment and turbidity be minimized? • Will de-watering be required? If so, is a de-watering plan feasible? What are the contingencies if the plan's de-watering method proves to be infeasible? • When will the large wood placements be constructed? Is there a risk of high flows during the construction window? If so, what would the consequences be? • Can a flood event (e.g., winter storm) pose a threat to construction? What is the probability and how can risk be minimized? • Is there a regulatory "fish-window" or timeframe the project will need to be constructed within? If so, is that timeframe sufficient to complete construction for all elements? • Will the construction methods generate significant noise that will affect nesting birds or wildlife, particularly threatened or endangered species? • Is buried wood expected within the excavation area during pile driving? If so, what is the plan or contingencies for how to handle? • Is bedrock expected in the excavation area during pile driving? If so, what is the plan or contingencies for how to handle this? • What level of design is being developed for the large wood placement? Has the contractor built large wood placements? How will change-orders be handled during the construction process? • How will the contractor access the site and are there constraints on that access posed by landowners, length of access route, traffic control, wetlands, stream channels, or soft soils?

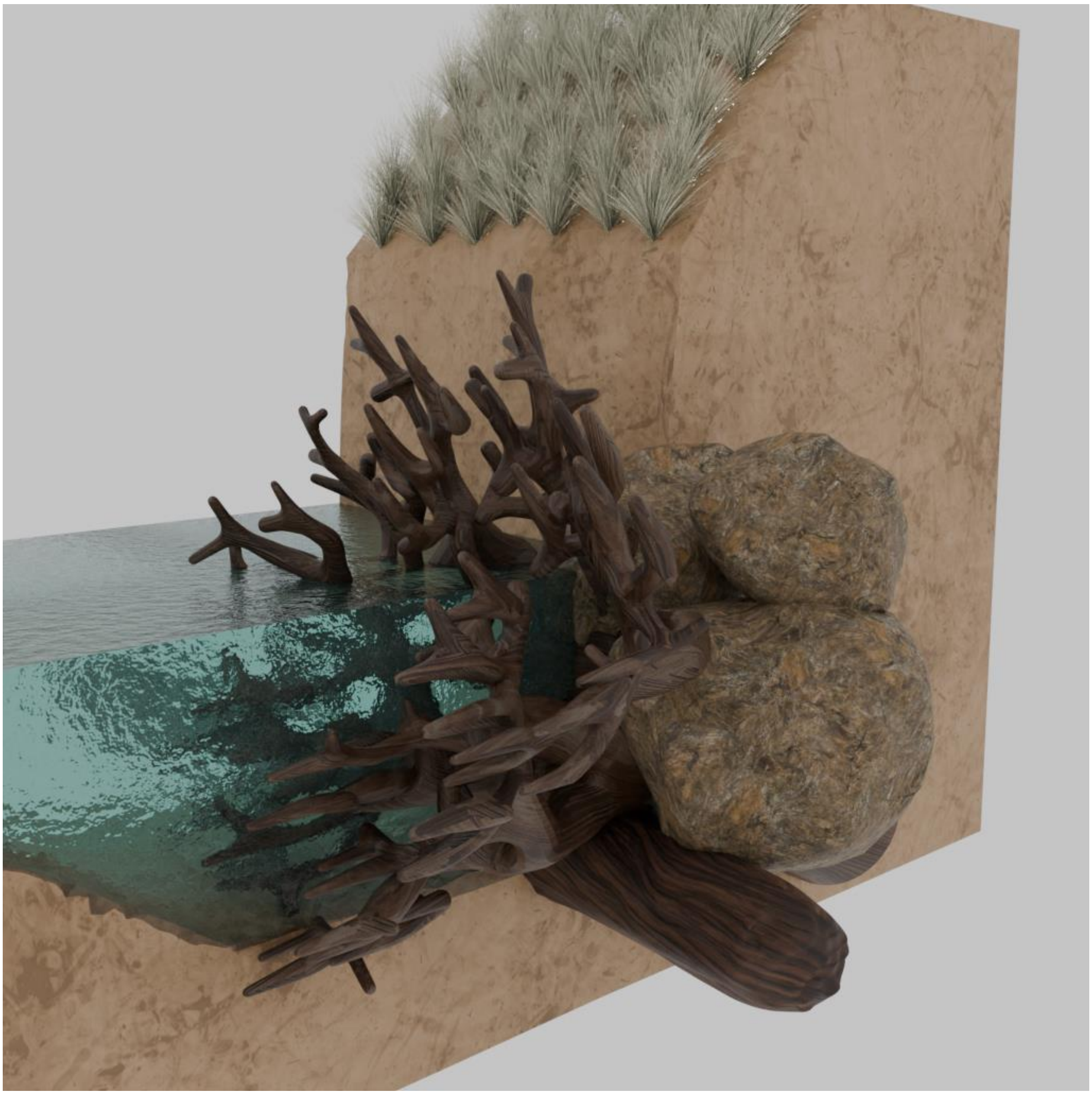
Design and Placement

Reach layout refers to the arrangement of large wood within the channel in river restoration projects.

- Target reaches, which have similar characteristics to the project site, can be used as design analogues for the amount and distribution of wood in the design reach.
- Large wood structures can be placed at various locations such as the head of a bar or an island, mid-channel, along the bank, or on floodplain surfaces.
- The size and type of large wood structures should be selected based on the project goals and the desired impact on channel avulsion, side channel development, bank erosion, sediment storage, and wood trapping.
- The placement of large wood structures should aim to improve habitat quality by adding woody substrate, cover, scour pools, and physical heterogeneity.
- The spacing of bed control structures should allow for backwater from one structure to reach the next during channel-forming flows.
- Bank erosion control structures can be continuous blankets or intermittent spur-type structures, and their spacing depends on the channel planform and the desired level of dynamism.
- Large wood structures can be used to control bank erosion, protect infrastructure, and enhance aquatic habitat.

Different types of engineered large wood structures commonly used in stream restoration projects. Each type of large wood design serves a specific purpose and is chosen based on the goals of the restoration project, the characteristics of the stream, and the needs of the local ecosystem . It's important to consider the ecological benefits, potential impacts, and maintenance requirements when selecting the appropriate type of large wood structure for a stream restoration project:

1. **Key Log Structures:** These are single logs placed across the stream to alter flow patterns and create habitat complexity.
2. **Log Jams:** These are accumulations of multiple logs that can stabilize stream banks, create pools, and provide cover for fish.
3. **Anchored Wood:** Logs or wood structures that are anchored to the streambed or banks to ensure stability and longevity.
4. **Engineered Logjams (ELJs):** These are designed structures that mimic natural logjams, often used to address specific issues like erosion control or habitat creation.
5. **Root Wads:** Tree root masses that are installed along banks to provide immediate bank stabilization and habitat structure.
6. **Habitat Logs:** Logs placed to provide direct habitat benefits, such as fish refuge or perching locations for birds.
7. **Instream Wood Complexes:** These are combinations of logs, root wads, and other wood materials to create a complex, multi-dimensional habitat.



Root wads can be installed to provide immediate bank stabilisation and habitat structure.

Wood dimensions

Minimum dimensions for woody materials in stream restoration include rootwad diameter, trunk diameter, and tree length, which are determined based on bankfull discharge depth and width.

Dimension	Minimum size
Rootwad diameter	Bankfull discharge depth
Trunk Diameter	0.5 x bankfull discharge depth
Tree Length	0.25 x bankfull discharge width

Guidance for large wood dimension in rivers from Cramer et al. (2002)

- Large wood materials may not always be available on site, and importation may be necessary to obtain logs of sufficient size.
- Complex woody material structures with numerous branches are preferred as they locally depress velocity and induce sediment deposition.
- Decay-resistant species like eastern red cedar, western red cedar, coastal redwood, Douglas-fir, and bald cypress are preferred, while rapidly decaying species like cottonwood, Southeastern pines, and alder should be avoided.
- In some cases, materials other than wood, such as large concrete jacks, rock, or synthetic wood products, may be used for anchoring or stream restoration.

Anchoring

As the risk of flows, river width, and downstream structures increase, anchoring of LWM becomes critical. A range of anchoring methods are summarised below together with their advantages and disadvantages:

Method	Technique	Advantages	Disadvantages
Burial	Trenching/backfill	Firmly embedded in streambed or marginal soil	Cost of excavation, disruption to streambed
Pinning (see cross log example below)	rebar/dowels	Inexpensive - use of small wood to build larger structures, wooden dowels are biodegradable	Wooden dowels do not work well with rotational forces. Rebar creates weak points that rot out.
Lashing	Use of rope, cable, chains	Group small/medium wood to create larger members. Quick install.	Rope degrades. If the structure washes away, it may get tangled up in downstream structures. Cable/chain can be a safety hazard.
Tethering	Cable or chain	Simple and low cost - usually applied to single logs to keep them from washing away	Limited habitat benefit, because single tethered logs usually rest above baseflow. Safety risk due to single tether, as no redundancy.
Mechanical anchors	Helical, rotating plates	Large holding force with small anchor	Poor holding capacity in alluvial soils, takes time to install.

Pile supported structures	Driven or placed in excavated holes and refilled (the latter required for placing piles with rootwads); sharpen piles for quicker driving	Small footprint, quick installation, low cost, high stability, can provide redundancy for larger installations	Must drive piles deep to avoid scour, subsurface obstruction
Entanglement on bank trees	Use of on-bank trees	no additional anchoring needed	Needs large trees in the bank, large wood should be longer than 2.5 times the width of the stream for permanent stability
Gravity anchorage	Structure (wood + ballast) is heavy enough to resist imposed forces during design flows	No additional anchoring or manufactured materials required; natural appearance	Structure height must be great enough that it is not submerged during design event; not feasible at many sites
Woven	Hybrid of pile-supported and gravity; horizontal logs are entangled with vertical piling logs; vertical piles used to counteract horizontal forces and ballast to counteract vertical forces	No additional anchoring or manufactured materials required; natural appearance.	Structure height must be great enough that it is not submerged during design event; not feasible at many sites
Unanchored	Placing wood directly in system	No anchoring required	Safety concerns, may dislodge in unexpected flows; requires large wood that is longer than ~2.5 times the channel width for permanent stability

Methods for securing large wood in fluvial systems (adapted from U.S. Bureau of Reclamation and U.S. Army Corps of Engineers 2016)

Maintenance and Monitoring

Large wood projects in instream and floodplain areas aim to create self-sustaining conditions for natural recruitment and retention of wood. However, decay rates of wood can be rapid. Maintenance needs should be assessed based on functional performance rather than appearance, as trends like loss of wood or ballast can indicate project failure. There are three main types of maintenance which need to be done: remedial maintenance, scheduled maintenance, and emergency maintenance.

- Remedial maintenance is triggered by routine inspections and addresses non-emergency maintenance needs.
- Scheduled maintenance is planned during project design and includes activities such as replenishing wood and controlling vegetation.
- Emergency maintenance requires immediate action to repair or prevent damage.

Typical maintenance activities for wood structures include removing or replacing large wood to maintain stability and habitat benefits. Vegetative components also require intensive maintenance.

The monitoring and adaptive management phase of large wood projects begins after environmental documentation is approved, permits are received, and construction is completed. The monitoring and adaptive management plan should have clear criteria for monitoring elements, frequency, and performance standards. Monitoring information will guide adaptive management actions and may lead to modifications in maintenance plans and schedules.

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