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Nature-based Solutions for flood mitigation in Australia - Book 3: Practical Guide

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Acknowledgement of Country

The Australian National University acknowledges, celebrates and pays our respects to the Ngunnawal and Ngambri people of the Canberra region and to all First Nations Australians on whose traditional lands we meet and work, and whose cultures are among the oldest continuing cultures in human history.

The Nature-based Solutions Guidelines 2025 also acknowledges the ongoing and unique relationships and responsibilities that First Nations Australians have with river and other Country across Australia, and recognises their leadership in NbS initiatives including the work of Jagun Alliance as featured in these Guidelines.

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The Nature-based Solutions for flood mitigation in Australia series has been peer reviewed, ensuring high standards of academic excellence and quality. The series comprises of the following books:

- Nature-based Solutions for flood mitigation in Australia - Book 1: National Guidelines
- Nature-based Solutions for flood mitigation in Australia - Book 2: Catchment Studies
- Nature-based Solutions for flood mitigation in Australia - Book 3: Practical Guide

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Introduction

Australia's flood risk is increasing due to climate change and development that is reshaping the landscape. Nature-based Solutions offer a practical and cost-effective approach to working with natural systems, rather than against them, to reduce flood impacts while delivering broader environmental and community benefits.

Nature-based Solutions for flood mitigation in Australia - Book 1: National Guidelines provide practical, evidence-based advice and tools to support the design and implementation of Nature-based Solutions (NbS) for flood mitigation. The guidelines translate evidence sourced from the international literature, together with *Book 2: Catchment Studies* in partnership with local councils and communities.

The Guidelines were developed by an interdisciplinary team from the Australian National University (ANU), local council experts, and communities in regional Australia. They specifically focus on applying NbS to Australia's unique ecosystems.

Book 3: Practical Guide serves as a concise, actionable companion, designed for practitioners, policymakers, and decision-makers. It distills the most critical guidance on implementing Nature-based Solutions for flood mitigation.



Flooding in Australia

Australia's floodplain rivers have evolved with the boom-to-bust cycle of drought and flood, driven by our highly variable climate. Australia's native plants and animals have evolved alongside episodes of drought and flooding rains. While flood events can be destructive to human settlements, they are vital natural phenomena that play a crucial role in maintaining healthy river ecosystems, biological productivity, and reproduction of many plants and animals.

First Nations Australians have been making use of floodplain productivity for tens of thousands of years. They have been leading conversations about Indigenous water rights, culturally informed water management, and the responsibilities of managing flooding events in Australia. Any flood mitigation approaches that consider NbS should involve early conversations with local First Nations Australians about how best to care for land and water.

Since the 1800s, Australia's landscapes have been dramatically altered in ways that have reduced its ability to manage floods through:

- extensive land clearing and soil compaction
- drainage of wetlands
- levee banks separating floodplains from rivers
- erosion and modification of streams
- infrastructure such as roads and railways creating barriers to flood waters
- urban development on flood-prone land.

As a result, floodwater travels faster downstream, creating larger and more damaging floods and dramatically increasing risks to people and property.

In Australia, floods cause significant damage to homes, businesses and infrastructure, disrupting community wellbeing. Riverine flooding occurs when water inundates land that is normally dry - that is, when a river's waters surge beyond its banks. These river-related flood events create extensive damage to infrastructure, homes and businesses, and disrupt agricultural production and economic activities. Flash flooding occurs when intense downpours cause water levels to surge, usually within minutes to hours. These rapid floods typically affect smaller geographic areas and catchments. Flooding in larger river catchments occurs when rain accumulates over extended periods, causing water to spill onto the floodplain. This flooding can submerge vast regions, with floodwaters potentially remaining for months.

Climate change is increasing the probability of intense rainfall, making floods more frequent, severe and unpredictable. As climate change intensifies and development pressures mount, communities need evidence-informed decisions, deliberative planning and skilled design to be protected while maximising limited resources.



What are Nature-based Solutions and how do Nature-based Solutions mitigate flooding?

NbS approaches use natural processes to address challenges such as flooding, while simultaneously delivering environmental, social, and economic benefits. Inspired and powered by nature, NbS work with - rather than against - natural systems to protect communities, enhance resilience, and provide multiple co-benefits that traditional engineering solutions often cannot match.

Conventional, or grey flood control relies on limiting land uses on floodplains or building engineered infrastructure such as dams, barriers, and levees. Engineering solutions often require costly maintenance and eventual replacement, may have adverse environmental impacts and limited adaptability, and generally increase flood risk where there is expanded urban development on 'protected' floodplains.

Carefully designed NbS may grow stronger over time, becoming more effective. They may also deliver multiple co-benefits, such as improved water quality, biodiversity conservation, enhanced recreational spaces, climate change adaptation, ecosystem service provision, and increased property values.

NbS include measures such as afforestation, re-establishment of riparian vegetation, wetlands, flow barriers such as leaky weirs, and restoration of palaeochannels, as described below.

Planning of NbS for riverine flooding needs to occur at the catchment scale. The water flowing past any point in a river represents the accumulated runoff from all the land upstream, not just the immediate surroundings. This means that isolated urban interventions, while helpful for local drainage, cannot address the full scale of the problem. By working with the natural landscape across the whole catchment, we can slow water movement at multiple points, store excess water in appropriate locations, and reduce peak flows before they reach vulnerable communities downstream. The natural features within a catchment - such as upstream forests, riparian vegetation, minor upstream floodplains, wetlands and major floodplains - can play a crucial role in flood management. Often, the most cost-effective flood management often occurs far upstream from the urban areas experiencing flooding. Protecting urban areas from floods with NbS is much more effective when implemented at the catchment scale.

With careful planning and design, combined NbS can effectively mitigate moderate floods (up to a 1-in-20 year flood) and reduce the impacts of rare floods (a 1-in-100 year flood). NbS are less effective in mitigating very rare floods (over a 1-in-1,000 year flood), and single NbS may often only mitigate the impacts of moderate flood events.

For example, carefully planning a combined NbS design for the Bremer River catchment in Queensland, including riparian vegetation, reafforestation, leaky weirs and urban permeability, led to a modelled 80% reduction in flood depth in urban areas in a 1-in-50-year flood. Substantial co-benefits include improvements in water quality and carbon sequestration.

NbS operate to reduce flood risk through three fundamental strategies:

1. **detaining** floodwater at upstream sites (these areas act as localised storage of potential floodwaters)
2. **reducing** the energy and speed of floodwater (storage decreases flow generation, slowing water movement, spreading water through the catchment system and holding back the excess water)
3. **diverting** floodwater (altering the floodwater's route) away from target areas.

These strategies can work together to lower peak flood levels and reduce flood extent in vulnerable areas.



Types of NbS

Landscape solutions focus on modifying and optimising how (1) catchment areas, and (2) streams and floodplains can be used to enhance natural processes. These types of NbS reduce the energy and speed of floodwaters, and also detain water by diversion and by infiltration - for example, by afforestation or within dense riparian vegetation.

- **Catchment-based solutions** are NbS that optimise vegetative land cover - including forests, grasslands, and agricultural land - and enhance surface permeability.
- **Stream and floodplain-based solutions** involve interventions that manage floodplain connectivity, storage, and conveyance. They include measures to enhance stream channel management, improve river-floodplain connectivity, and restore riparian vegetation.

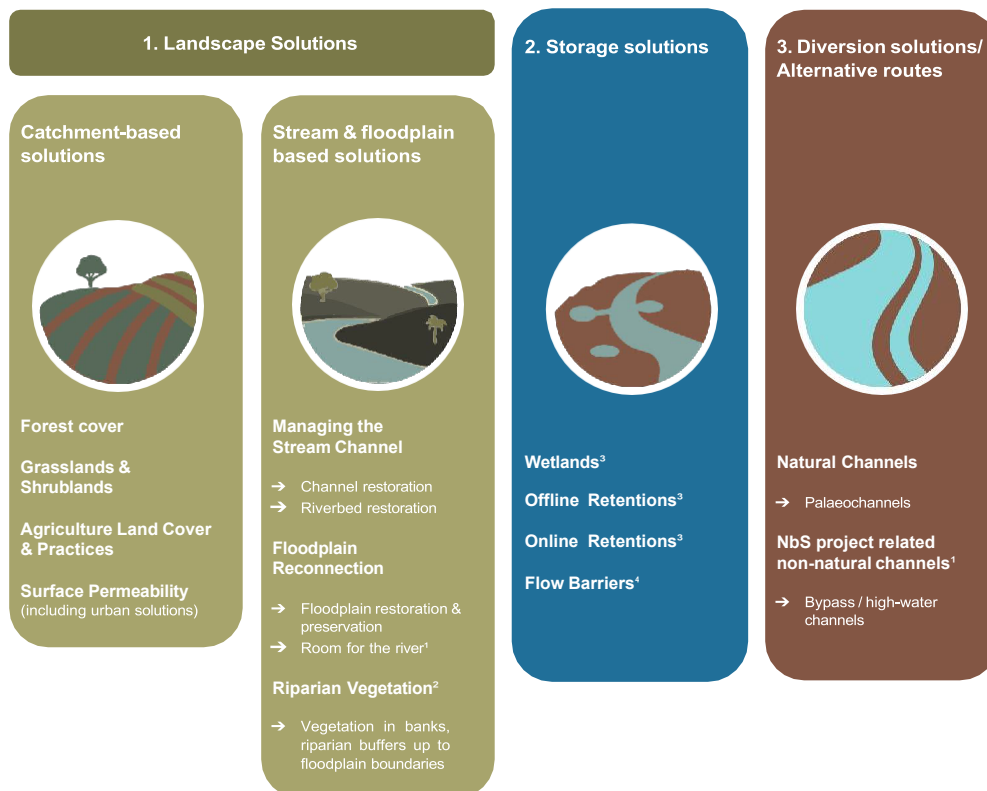
Storage solutions address the critical need to retain and manage water effectively within the landscape, largely by detaining water.

Diversion solutions concentrate on redirecting and channelling water flows through alternative pathways to protect vulnerable areas.

Combined NbS involve more than one type of NbS used together.

Hybrid NbS are a mix of green (natural) and grey (engineered) infrastructure used together.

Nature-based Solutions for Flood Mitigation



1. High-water channels can be included in both Room for the River and NbS project-related non-natural
2. Some riparian forest types can be included in forest cover.
3. Wetlands (online/offline) can also be categorised as online and offline water retention.
4. Flow barriers in storage solutions can also be categorised as managing stream channels.



Catchment-based solutions

Forest Cover

What are forest-based NbS?

Forest-based NbS involve the strategic conservation, restoration, and expansion of forested areas within catchments. Forests act as natural water regulators, using their root systems, canopy, and forest litter to capture rainfall, enhance infiltration, and reduce surface runoff. They moderate water flow and improve soil water retention.

How do they reduce flooding?

Forests mitigate floods primarily in 2 ways: by detaining floodwaters and by reducing their energy. Dense forest canopies intercept rainfall, while roots improve soil structure, boosting infiltration and water retention. Forests also increase surface roughness, slowing the flow of water over land and reducing peak discharge downstream. This combined effect helps delay flood peaks and spread water more evenly across the catchment.

How effective are they?

The effectiveness of forest-based NbS depends on forest type, coverage, maturity, and catchment conditions. Mature forests are highly effective at reducing flood peaks, especially during extreme rainfall events. Deforestation can lead to large increases in flood intensity, while afforestation can gradually decrease peak flows over time as they grow and mature.

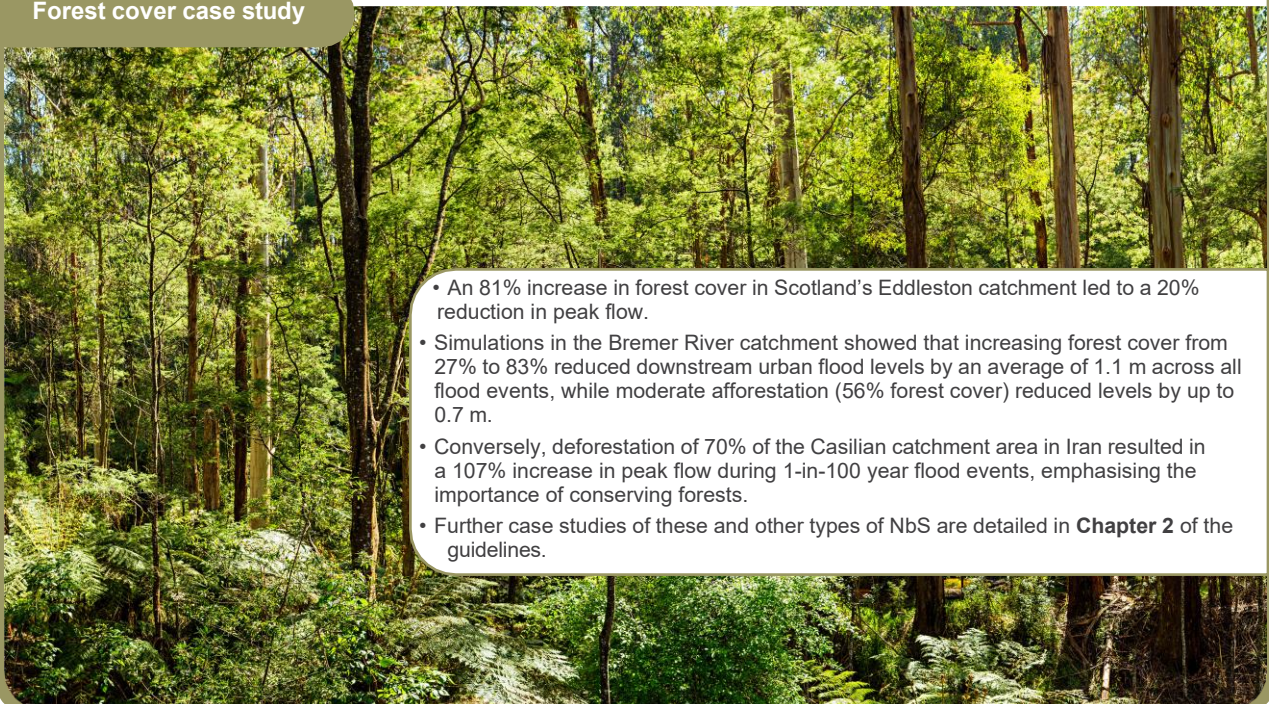
What are the key design considerations?

Designing forest-based NbS requires consideration of local climate, soil, landscape, and vegetation types. You should optimise planting density and integration with existing features. Strategic placement, long-term planning, and maintenance of access are key to sustaining flood resilience over time.

Where might these measures work best?

Restoring and managing forest cover in upstream and mid-catchment areas maximises flood mitigation potential. Forest-based NbS are particularly beneficial in areas prone to rapid runoff or landslides, or with degraded soil or steep slopes, as they help reduce erosion.

Forest cover case study



- An 81% increase in forest cover in Scotland's Eddleston catchment led to a 20% reduction in peak flow.
- Simulations in the Bremer River catchment showed that increasing forest cover from 27% to 83% reduced downstream urban flood levels by an average of 1.1 m across all flood events, while moderate afforestation (56% forest cover) reduced levels by up to 0.7 m.
- Conversely, deforestation of 70% of the Casilian catchment area in Iran resulted in a 107% increase in peak flow during 1-in-100 year flood events, emphasising the importance of conserving forests.
- Further case studies of these and other types of NbS are detailed in **Chapter 2** of the guidelines.



Catchment-based solutions

Grasslands and Shrublands

What are grassland-based NbS?

Grassland/shrubland-based NbS involve the restoration, enhancement, and sustainable management of ecosystems dominated by grasses or shrubs, such as pastures and shrublands. These systems use dense ground cover and extensive root networks to support water infiltration and slow surface runoff. Grasslands offer a practical solution for flood mitigation, as they are faster to establish and less complex than forest ecosystems.

How do they reduce flooding?

Grasslands and shrublands reduce flood risks through two key strategies: detaining water and slowing its movement. Their dense root networks improve soil structure, boosting infiltration and enhancing the soil's capacity to hold water. The surface vegetation adds roughness to the landscape, reducing the speed of overland water flow. This helps lower flood peaks and delay their arrival downstream.

How effective are they?

Grasslands are effective for managing smaller flood events. Their rapid growth offers faster initial benefits compared with forests, although their total water retention capacity is lower. The effectiveness depends on vegetation density, species selection, and management practices such as grazing intensity. For example, well-managed grasslands have demonstrated substantial reductions in peak flow and delay in flood peaks, especially during frequent, moderate rainfall events.

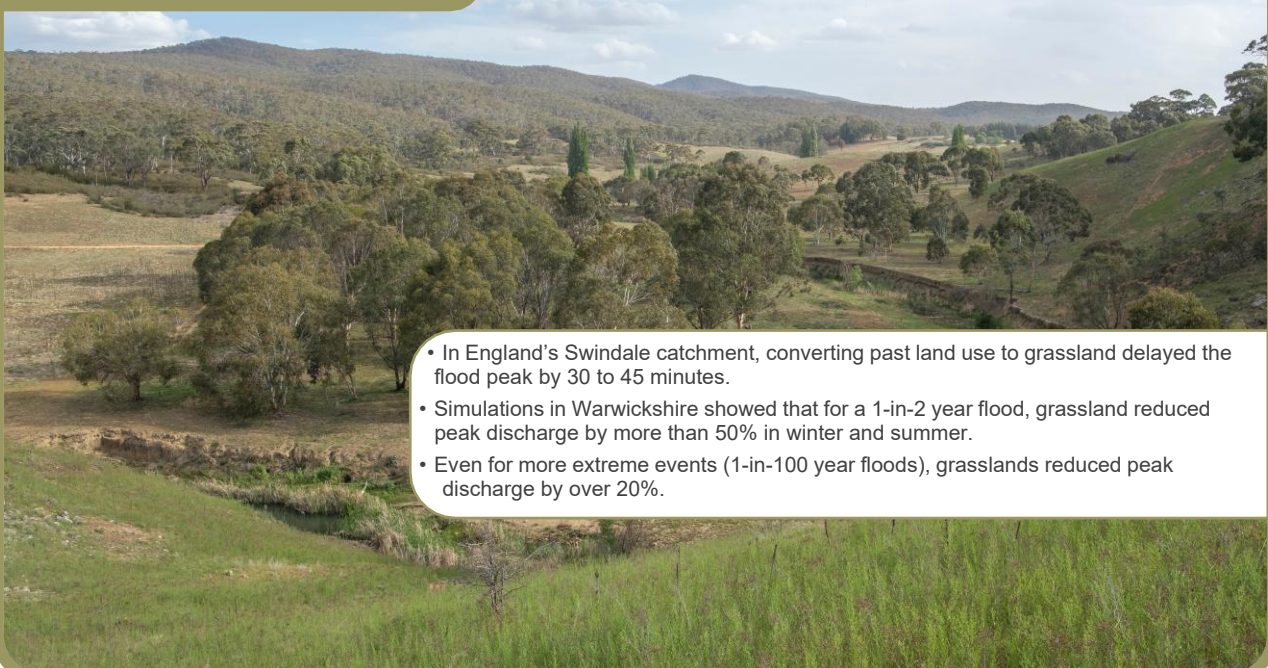
What are the key design considerations?

You should select species that enhance surface roughness and soil stability, optimise vegetation density, and integrate planting with existing land use. Grazing management must be tailored to preserve vegetation cover and soil structure. Grasslands are best integrated with surrounding land uses and may be combined with other NbS, such as buffer zones or riparian vegetation, to increase their effectiveness. Seasonal maintenance is important to ensure year-round effectiveness.

Where might these measures work best?

Grasslands are especially useful in locations with shallow soils or limited space where trees can't be grown. They are suited to landscapes where year-round ground cover is required to prevent erosion or where rapid vegetation growth is needed to stabilise soil and improve water retention. Open catchments, steep hillsides prone to runoff, and transitional zones between agricultural lands and waterways are ideal locations.

Grassland and shrubland case study



- In England's Swindale catchment, converting past land use to grassland delayed the flood peak by 30 to 45 minutes.
- Simulations in Warwickshire showed that for a 1-in-2 year flood, grassland reduced peak discharge by more than 50% in winter and summer.
- Even for more extreme events (1-in-100 year floods), grasslands reduced peak discharge by over 20%.



Catchment-based solutions

Agricultural land cover and practices

What are agriculture-based NbS?

Agriculture-based NbS involve using sustainable land management practices to reduce flood risks while maintaining productive farming. They include crop rotation, cover crops, agroforestry, terracing, managed grazing, and paddy fields. These practices enhance the soil's natural ability to retain water, slow runoff, and stabilise the land. They integrate flood resilience into working farms.

How do they reduce flooding?

Sustainable farming reduces flood risk by increasing infiltration and detaining water in the landscape. Deep-rooted crops and cover vegetation break up compacted soils, allowing water to penetrate the ground instead of running off it. Terracing and contour farming help slow and store water on hillsides. Agroforestry systems add vertical vegetation layers, boosting canopy interception and root density. Managed grazing preserves ground cover, improving roughness and reducing surface runoff. Together, these approaches transform farmland into sponge-like land that absorbs and slowly releases water.

How effective are they?

The effectiveness of agricultural practices varies widely depending on the techniques used, local conditions, and the intensity of land use. Well-managed agricultural land can significantly improve infiltration and reduce peak discharges. Changes, such as excluding grazing from agroforestry systems, can increase soil infiltration by over 450%. Overall, agriculture-based NbS are most effective when multiple techniques are combined for a cumulative effect.

What are the key design considerations?

Agricultural NbS techniques need to be matched to slope, soil type, and climate. Selecting suitable cover crops, designing contour-aligned terraces, and establishing appropriate buffer widths around waterways are crucial. Balancing productivity with flood protection is also important – interventions should maintain yields while restoring hydrological function. Integration with farm water management plans, erosion control strategies, and seasonal grazing schedules further supports effectiveness.

Where might these measures work best?

These solutions are suitable for landscapes where conventional farming practices have degraded the soil or increased runoff, and in sloping or hilly terrain. Agricultural NbS are especially valuable in transition zones between farmlands and waterways, where buffer zones and infiltration-friendly practices can reduce flood impacts locally and downstream.

Agriculture and flood control case study



- Terracing in the Czech Republic's Libouchec runoff area cut flood peaks by up to 68% during moderate storms.
- In the UK, fencing to exclude grazing on pasture increased infiltration rates more than fourfold.
- In contrast, practices such as heavy grazing and rotational burning in the Coverdale catchment were found to increase peak flows by as much as 86%, illustrating the risks associated with poor land management.



Catchment-based solutions

Increasing surface permeability and urban NbS

What are urban permeability solutions?

Increasing surface permeability and urban NbS reduces flood risk by increasing the absorption and retention of water in urban landscapes. Hard, impermeable surfaces, such as concrete and asphalt, are replaced with permeable alternatives, such as porous pavements, permeable pavers, green roofs, rain gardens, and bio-retention systems. These NbS align with the principles of Water Sensitive Urban Design and the concept of 'sponge cities'.

How do they reduce flooding?

Urban NbS involves detaining water where it falls, increasing infiltration and slowing runoff. Permeable surfaces allow rainwater to seep into the soil, reducing the volume and speed of water entering urban stormwater systems. Green roofs and rain gardens temporarily store water, delaying its movement downstream. Spreading and slowing water flow across the landscape reduces the energy and volume of floods, helping to prevent urban flash flooding and relieving pressure on drainage networks.

How effective are they?

Effectiveness varies by location, rainfall intensity, and how extensively these measures are implemented. In cities with 40–70% impervious cover, improvements in permeability can significantly reduce flood risks. However, the effectiveness of urban NbS declines in highly urbanised areas with very little available space or during extreme rainfall events that exceed their storage capacity.

What are the key design considerations?

Urban NbS need to be placed strategically in areas where runoff is most intense, such as roads, parking lots, and rooftops. Design must consider the load-bearing needs of traffic areas, existing drainage systems, and underlying soil infiltration rates. Maintenance is important, as permeable surfaces can become clogged and lose effectiveness over time. Urban flood mitigation plans should integrate these measures with broader city planning, considering land use, topography, and connectivity to existing green spaces and waterways.

Where might these measures work best?

Urban permeability-based NbS are especially useful in urban and peri-urban areas with high imperviousness, where development has disrupted natural drainage. Areas with 40-70% imperviousness show the most significant potential for improvement.

Surface permeability case study



- Modelling in Ipswich, Queensland, showed that implementing a suite of sponge city measures, including permeable pavements, rainwater tanks, and green roofs, cut peak flow in Deebing Creek by nearly 20% for major and minor flood events.
- In the Glinščica River catchment in Slovenia, replacing 6 km² (35.5%) of a river catchment's built-up area with permeable concrete reduced peak discharges by up to 42% during common, smaller floods.
- In the Bonis basin in Italy, soil sealing of just 1.5% of the surface increased peak flows by over 6%.



Stream and floodplain- based solutions

Managing the stream channel

What is stream channel management?

Traditional engineering approaches treat vegetation and natural features as obstructions to the flow of water. Stream channel management, in contrast, enhances a stream's natural structure to better manage floods. It includes actions such as meandering and remeandering straightened channels, re-profiling banks, adding in-stream vegetation, installing snags (fallen wood), deepening or raising streambeds, and restoring channel widths. These types of NbS restore the hydrological and ecological functions of river systems while improving their ability to handle floodwaters.

How do they reduce flooding?

Well-managed stream channels reduce flood risk in 3 main ways. Remeandering increases the length of the channel, which slows water flow and reduces peak discharge. Re-profiling and modifying banks or beds increases temporary storage within the channel, holding more water upstream. Increasing roughness by adding vegetation and natural debris increases flow resistance, dissipating energy and delaying downstream flood peaks. Collectively, these measures slow, store, and redistribute water more effectively during flood events.

How effective are they?

Stream channel management is especially effective when combined with other floodplain or upstream interventions. Effectiveness depends on the design, placement, and hydrological context. Effectiveness may decrease during very large flood events unless channel changes are integrated with other NbS across the catchment.

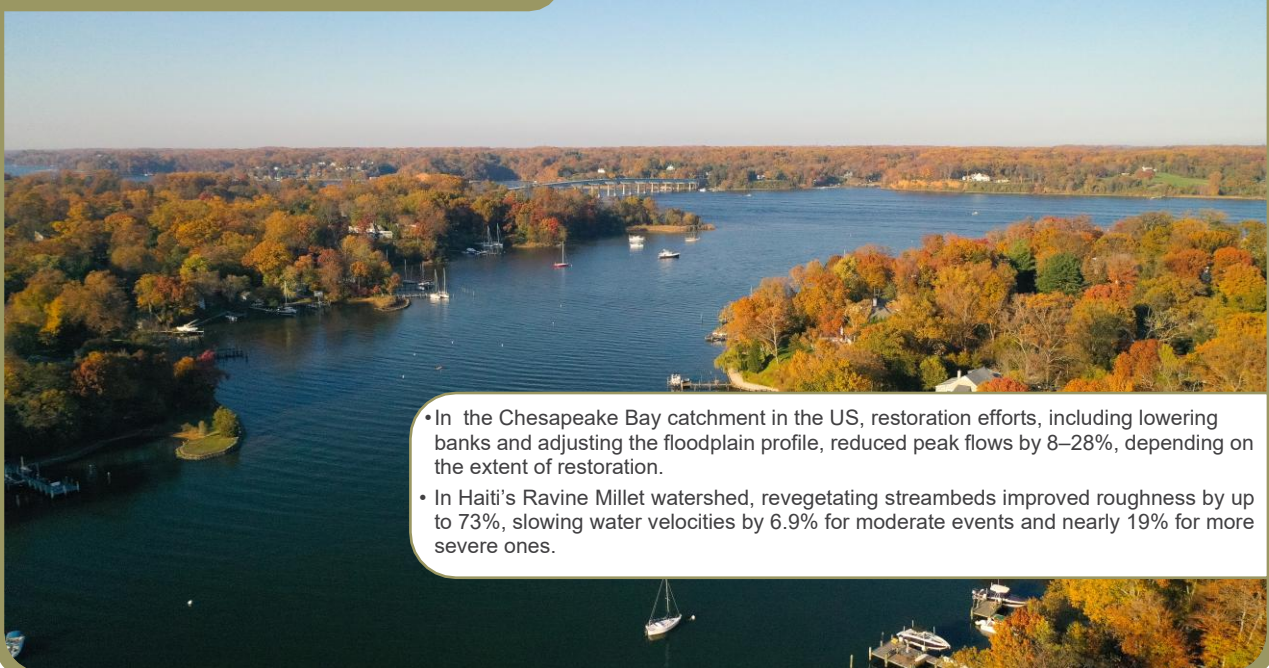
What are the key design considerations?

Designing NbS interventions related to stream channel management requires an understanding of the channel's gradient, morphology, and catchment characteristics. Designs need to manage sediment, accommodate infrastructure, maintain ecological function, and account for seasonal flow variations. Space must be available to allow remeandering and widening. Maintenance access is also important.

Where might these measures work best?

Stream channel management works best in areas where natural river processes have been disrupted, such as historically channelled rivers or areas of urban or agricultural activities. It is useful in upstream and midstream areas where slowing the flow can protect downstream areas.

Stream channel management case studies



- In the Chesapeake Bay catchment in the US, restoration efforts, including lowering banks and adjusting the floodplain profile, reduced peak flows by 8–28%, depending on the extent of restoration.
- In Haiti's Ravine Millet watershed, revegetating streambeds improved roughness by up to 73%, slowing water velocities by 6.9% for moderate events and nearly 19% for more severe ones.



Stream and floodplain- based solutions

Floodplain reconnection

What is floodplain reconnection?

Floodplain reconnection is the process of restoring or enhancing the natural connectivity between rivers and adjacent floodplains. It reverses conventional flood control methods, such as levees and channelisation, that have isolated rivers from their floodplains. NbS may include setting back or removing levees, widening rivers, lowering floodplain land, or reconfiguring dykes and groynes. They aim to allow rivers to overflow safely into their floodplains during high flows, using the landscape to naturally store and slow floodwaters.

How do they reduce flooding?

Reconnected floodplains manage floods in 3 ways. First, they detain floodwater by providing space to temporarily store excess water. Second, they reduce flood energy as the water spreads out, loses speed, and is absorbed by vegetation and soil. Third, they divert floodwater by redirecting flow away from vulnerable infrastructure and towards lower-risk zones. This creates a buffer that absorbs flood peaks and lowers water levels downstream.

How effective are they?

Strategically placed floodplain reconnections have been highly effective at reducing water levels and flood extents, particularly for frequent and moderate events.

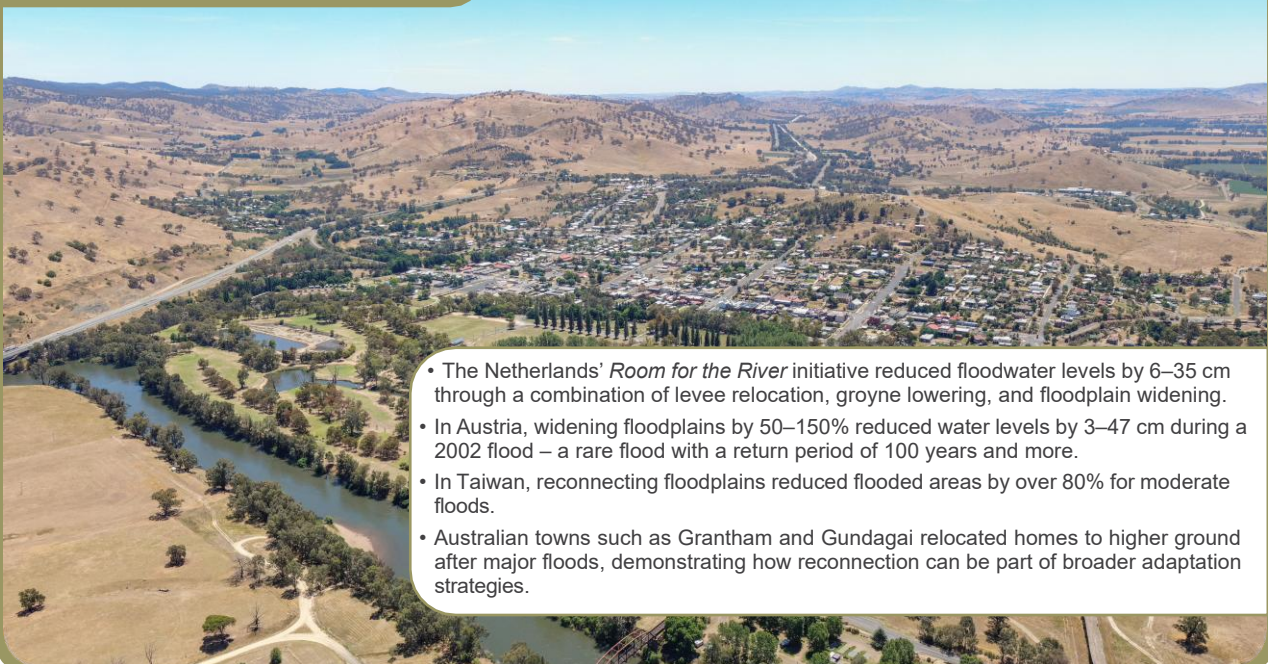
What are the key design considerations?

Strategic sites need to be selected, ideally in midstream and downstream zones. Planning should consider a thorough assessment of local conditions, water availability, and infrastructure compatibility. Designs should be scaled to flood risk levels. Engagement with stakeholders is essential.

Where might these measures work best?

Floodplain reconnection is most effective in areas where river-floodplain links have been disrupted and ample space is available for restoration. It is most effective in midstream and downstream areas with wide floodplains and relatively gentle slopes. Reconnection would benefit urban fringes, agricultural valleys, and coastal bottlenecks where river mouths trap floodwaters.

Floodplain reconnection case studies



- The Netherlands' *Room for the River* initiative reduced floodwater levels by 6–35 cm through a combination of levee relocation, groyne lowering, and floodplain widening.
- In Austria, widening floodplains by 50–150% reduced water levels by 3–47 cm during a 2002 flood – a rare flood with a return period of 100 years and more.
- In Taiwan, reconnecting floodplains reduced flooded areas by over 80% for moderate floods.
- Australian towns such as Grantham and Gundagai relocated homes to higher ground after major floods, demonstrating how reconnection can be part of broader adaptation strategies.



Stream and floodplain- based solutions

Riparian vegetation

What is riparian vegetation?

Riparian vegetation includes grasses, shrubs, and trees that grow along riverbanks, streams, and floodplain edges. These riparian buffers, or riverine forests, form a buffer between the land and water, stabilise banks, trap sediment, filter pollutants, and slow floodwaters.

How do they reduce flooding?

Riparian vegetation reduces floods by detaining and slowing floodwaters. Deep and widespread root systems improve soil structure, increasing their capacity to hold water and stop erosion. The vegetation also increases surface roughness, which creates resistance to flow and reduces the energy and speed of water moving overland or in channels. This helps reduce flood peaks, delay the time to peak, and lower downstream water volumes during storm events.

How effective are they?

Riparian vegetation is effective in attenuating floods, especially for frequent or moderate storm events. Its performance is influenced by buffer width, vegetation maturity, and continuity along watercourses.

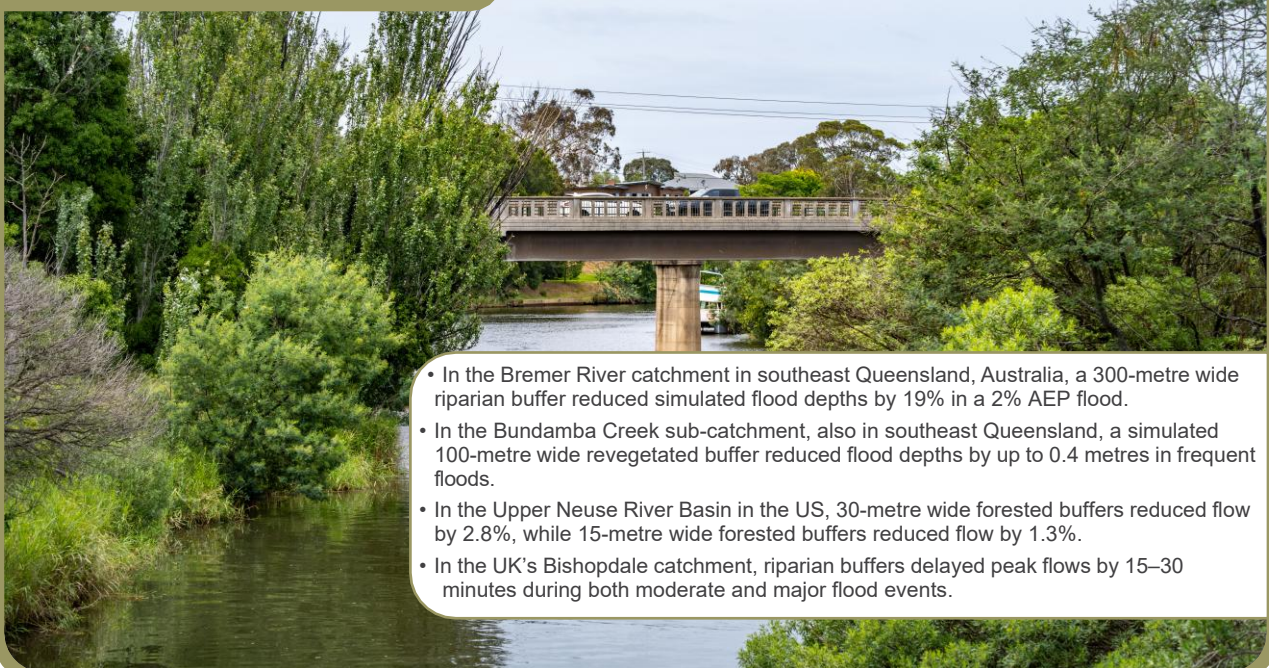
What are the key design considerations?

Riparian vegetation for flood mitigation should be tailored to local conditions, ideally with native species and appropriate buffer widths. Buffers should form continuous, connected corridors along channels. Planning must also account for vegetation maturity, maintenance needs, and downstream impacts. Integration with existing landscape features and flood management infrastructure enhances effectiveness.

Where might these measures work best?

Riparian vegetation is most effective in areas adjacent to rivers, streams, and drainage channels. It is particularly effective in upstream or midstream zones, where streambank erosion is a problem, or where sediment and nutrient runoff need to be filtered. Catchments with intermittent streams or seasonal flows can also benefit from riparian planting.

Riparian vegetation NbS case studies



- In the Bremer River catchment in southeast Queensland, Australia, a 300-metre wide riparian buffer reduced simulated flood depths by 19% in a 2% AEP flood.
- In the Bundamba Creek sub-catchment, also in southeast Queensland, a simulated 100-metre wide revegetated buffer reduced flood depths by up to 0.4 metres in frequent floods.
- In the Upper Neuse River Basin in the US, 30-metre wide forested buffers reduced flow by 2.8%, while 15-metre wide forested buffers reduced flow by 1.3%.
- In the UK's Bishopdale catchment, riparian buffers delayed peak flows by 15–30 minutes during both moderate and major flood events.



Storage solutions

Wetlands

What are wetlands and how do they work?

Wetlands are natural or constructed areas that store water, typically featuring saturated soils and water-tolerant vegetation. They can occur in floodplains, coastal zones, or as standalone features within catchments. Wetlands help manage floods by functioning as natural retention basins, where they hold water during storm events and release it slowly afterwards. There are 2 main types relevant to flood mitigation: online wetlands, which are directly connected to streams and rivers, and offline wetlands, which are positioned away from the main flow path and store runoff before it reaches waterways.

How do they reduce flooding?

Wetlands mitigate floods by detaining water, slowing its energy, and occasionally diverting flow. During rain events, wetlands temporarily store water, reducing the volume that reaches downstream channels. Their dense vegetation and irregular terrain increase surface roughness, slowing water movement and reducing peak discharges. Some riparian wetlands also divert floodwaters into secondary flow paths or back into groundwater systems, further reducing concentrations of flow.

How effective are they?

Wetlands are highly effective at reducing flood risks, especially for smaller catchments or during the early stages of storm events, before they become full. Their performance depends on location, size, depth, and type. Wetlands in upstream or midstream positions tend to provide greater mitigation than those downstream, though results vary with local conditions.

What are the key design considerations?

Wetlands should be strategically placed and sized based on expected flood volumes. Design should consider soil and groundwater connectivity. Maintenance and sediment management plans are needed for the long-term.

Where might these measures work best?

Wetland restoration is most effective in areas with suitable topography, soil, and groundwater connectivity, especially where historically drained wetlands can be reestablished or integrated with river systems.

Wetlands case studies



- Increasing the depth of wetlands in the Eagle Creek watershed in the US reduced flood area by 55%, peak flow by 26% and flood velocity by 15% in a 1-in-100 year flood.
- In the Black Creek basin in Canada, distributed wetlands reduced overland flow by 21% and peak runoff by 5%, transforming a 1-in-100 year flood into a 1-in-35 year flood.



Storage solutions

Offline water retention measures

What are offline water retention measures?

Offline water retention measures are engineered or enhanced natural structures that prevent excess water from reaching the main river channels during floods. Measures include detention ponds, dry ponds, seasonal lakes, and natural pools that are not directly connected to streamflow in normal conditions. They are activated during high-flow events to temporarily detain water, allowing it to infiltrate or be released slowly. They mimic natural depressions and wetlands and can provide additional water storage capacity.

How do they reduce flood risk?

Offline water retention systems capture floodwater before it reaches downstream areas. They help reduce the energy of floodwaters by allowing water to spread out and move slowly. Some well-positioned offline measures can divert flow from vulnerable areas into safer storage basins. They delay runoff peaks and reduce the volume of water overwhelming urban or agricultural drainage systems.

How effective are they?

Offline retention measures are particularly effective in small to medium flood events, especially when distributed across a catchment. Their performance depends on size, volume capacity, placement, and connection to overland flow paths. The benefit is reduced during large floods if the ponds reach capacity before the peak arrives, but a collective network of offline measures is particularly effective.

What are the key design considerations?

Offline retention areas should be placed along major flow paths, a safe distance from critical infrastructure. Their storage capacity should be calculated based on flood magnitudes, and soil conditions and vegetation cover should be considered. Maintenance access is needed for long-term functionality.

Where might these measures work best?

Offline water retention is most suitable in rural catchments, agricultural areas, and suburban fringes where space exists to build or restore water storage basins. They are highly effective in moderate rainfall regions and in places with natural depressions or redundant agricultural land. Areas with frequent but moderate flooding (1-in-2 to 1-in-10 year events) benefit most, especially where upstream interventions are needed to reduce flow into towns or sensitive ecosystems.

Offline retention case study



- In Northumberland, England, a 300–1,000 m³ upstream to midstream offline storage pond reduced peak flow by 12% for a 1-in-2 year event, while downstream offline ponds reduced peak flow by over 30%.
- In Scotland, 500 m² midstream ponds operated as offline features in normal conditions and functioned as online buffers during more severe floods.
- In the Caribbean's Saint Maarten, a 27,000 m² detention pond in the Cul de Sac catchment reduced water volume by nearly 10,000 m³ and significantly lowered downstream flood depths.



Storage solutions

Online water retention measures

What are online water retention measures?

Online water retention measures include inline ponds, reservoirs, attenuation basins, and connected wetlands. They are integrated directly into river systems or floodplains to temporarily store excess water during floods. Unlike offline structures, they are always connected with streams or rivers. They act as part of the natural drainage system and are designed to capture, detain, and gradually release excess water, smoothing out flood peaks and reducing downstream pressure.

How do they reduce flood risk?

Online systems reduce flood risk in three ways. First, they detain floodwater in the main channel or adjacent storage areas, providing immediate buffering during storm events. Second, they reduce flood energy by slowing discharge through controlled release structures, converting sharp flood peaks into extended, lower-volume flows. Third, they may also divert water into designated overflows or floodways, offering added flexibility during extreme events.

How effective are they?

Online water retention solutions are effective at managing frequent or moderate floods, especially in upstream and midstream locations. It depends on storage volume, location within the catchment, and design features such as flow control gates or overflow spillways. They are most successful when part of a coordinated network, rather than isolated installations. Their effectiveness during extreme events may decline if they reach capacity early.

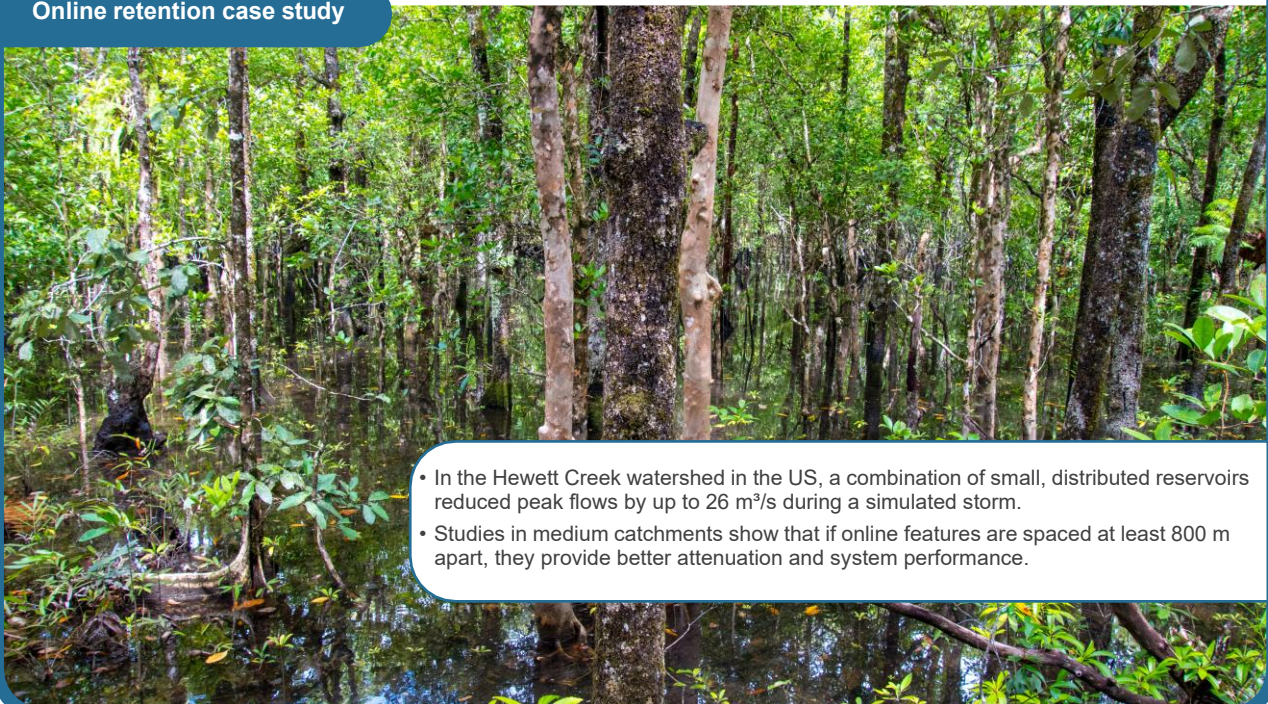
What are the key design considerations?

Flood storage measures should be strategically positioned and sized according to catchment characteristics and flood patterns, ensuring integration with river morphology. Planning should consider upstream and downstream impacts and include control structures to manage both frequent and extreme events.

Where might these measures work best?

Online retention is well-suited for upstream or midstream areas with adequate channel capacity and appropriate river morphology. They are particularly beneficial in medium-to-large catchments that benefit from a series of linked flood management features.

Online retention case study



- In the Hewett Creek watershed in the US, a combination of small, distributed reservoirs reduced peak flows by up to 26 m³/s during a simulated storm.
- Studies in medium catchments show that if online features are spaced at least 800 m apart, they provide better attenuation and system performance.



Storage solutions

Flow barriers

What are flow barriers?

Flow barriers are natural or engineered structures placed within streams, gullies, or catchments to slow and redirect water. They include leaky weirs and barriers, as well as woody debris dams that allow some water to pass through. These barriers act as speed bumps for flowing water, reducing its velocity and providing temporary upstream storage without completely obstructing flow.

How do they reduce flood risks?

Flow barriers mitigate floods by reducing energy and detaining water. As water encounters these structures, its velocity drops, and the flow becomes more dispersed. This results in lower peak discharge rates, allowing more time for soils to absorb water. In small channels, barriers create micro-storage areas, resulting in controlled, gradual release downstream. They are often designed to contribute to diverting flow across the floodplain or enhance channel-floodplain connectivity.

How effective are they?

Flow barriers are most effective for smaller-scale flood events and in headwater or midstream areas. While a single barrier has a limited effect, networks of barriers distributed across tributaries or gully systems can significantly attenuate floods. Their effectiveness diminishes in large floods unless they are part of a broader, integrated system. They also offer ecological benefits, such as restoring stream morphology, rehydrating landscapes, and promoting vegetation growth.

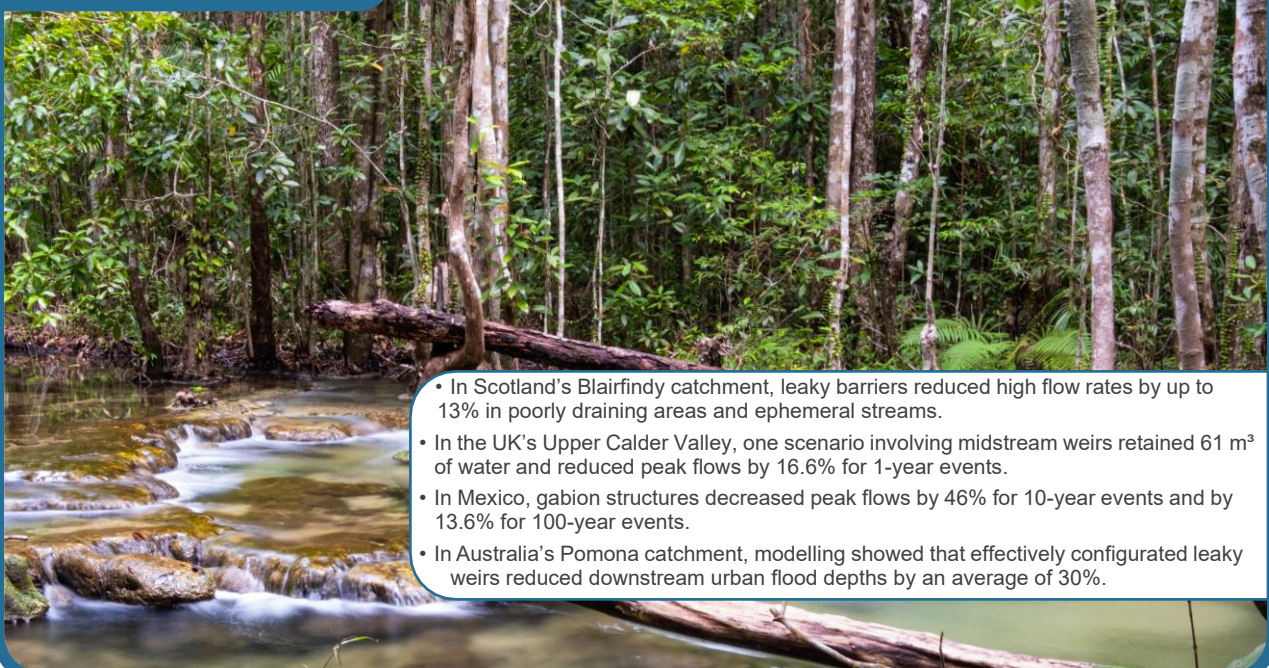
What are the key design considerations?

Flood barrier systems should be planned with optimised heights, spacing, and storage volumes tailored to flood scenarios and channel characteristics. Designs must use durable materials, allow maintenance access, preserve ecological connectivity, and manage frequent and extreme flood events.

Where might they work best?

Flow barriers are most effective in smaller-scale channels, such as gullies or minor streams, with manageable flow volumes and lower velocities. They work best when distributed across tributaries, especially in upper and midstream areas, using natural materials. They are also useful in rural areas prone to soil erosion or rapid runoff.

Flow barriers case study



- In Scotland's Blairfindy catchment, leaky barriers reduced high flow rates by up to 13% in poorly draining areas and ephemeral streams.
- In the UK's Upper Calder Valley, one scenario involving midstream weirs retained 61 m³ of water and reduced peak flows by 16.6% for 1-year events.
- In Mexico, gabion structures decreased peak flows by 46% for 10-year events and by 13.6% for 100-year events.
- In Australia's Pomona catchment, modelling showed that effectively configured leaky weirs reduced downstream urban flood depths by an average of 30%.



Diversion solutions

Diversion-based NbS

What are diversion-based NbS?

Diversion-based NbS redirect floodwaters through alternative pathways to reduce pressure on urban areas. They use natural features, such as palaeochannels and floodrunners, and constructed systems designed to mimic natural flows, such as bypass channels and secondary floodways. They spread and steer floodwater away from populated or critical zones while maintaining ecological integrity and water connectivity.

How do they reduce flood risk?

Diversion solutions reroute excess flow from the main watercourse to a lower-risk area, where it can be stored, infiltrated, or safely dispersed. This reduces peak flow volumes and discharge rates at downstream bottlenecks. Some diversion systems also facilitate groundwater recharge by spreading water into permeable landscapes.

How effective are they?

Diversion strategies can be effective in reducing flood impacts, especially when integrated into wider catchment-scale plans. Their success depends on catchment location, gradient, and design integration.

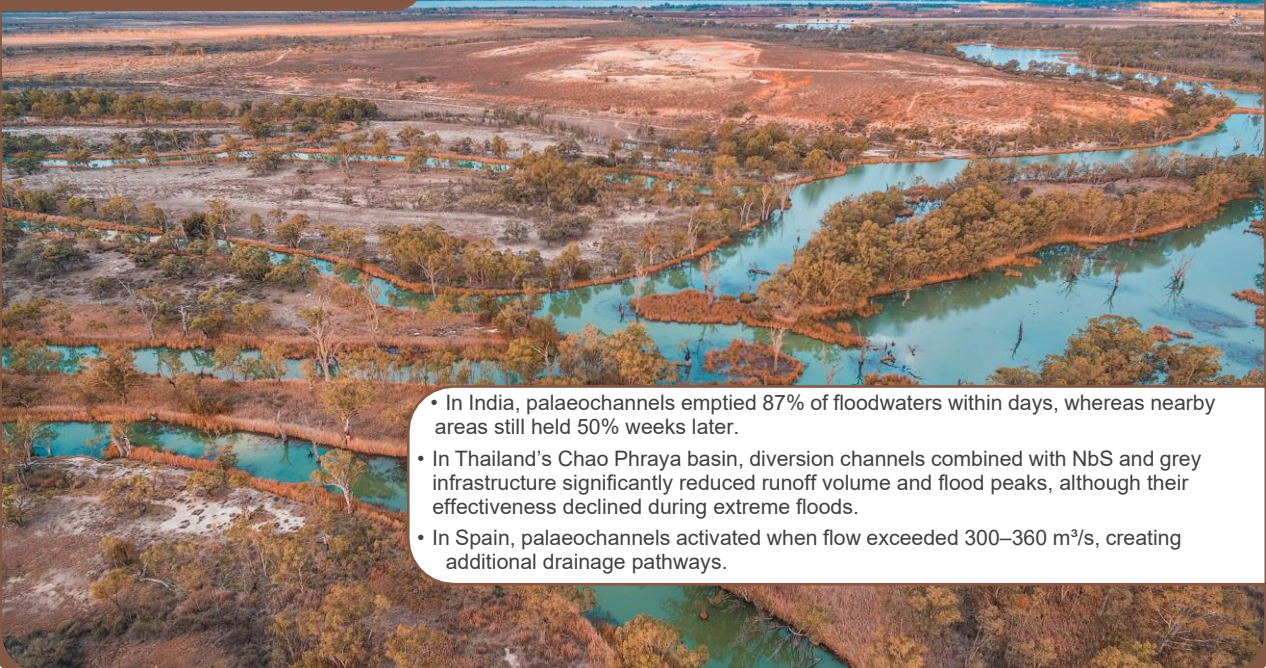
What are the key design considerations?

Design should identify historical flow paths using tools like digital elevation models. Successful implementation requires integration with broader flood strategies, thorough environmental assessments and sustained stakeholder and community involvement.

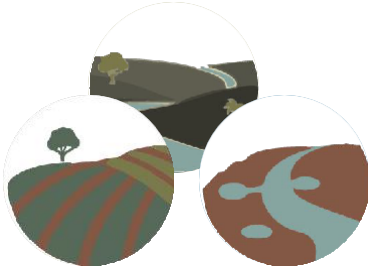
Where might they work best?

Midland palaeochannels show faster discharge rates compared with lowland channels due to favourable gradients.

Diversion solutions case study



- In India, palaeochannels emptied 87% of floodwaters within days, whereas nearby areas still held 50% weeks later.
- In Thailand's Chao Phraya basin, diversion channels combined with NbS and grey infrastructure significantly reduced runoff volume and flood peaks, although their effectiveness declined during extreme floods.
- In Spain, palaeochannels activated when flow exceeded 300–360 m³/s, creating additional drainage pathways.



Combined NbS

What are combined NbS?

Combined NbS integrate multiple nature-based interventions across a catchment to enhance overall flood mitigation. Combined approaches leverage the strengths of several interventions. For example, integrating riparian buffers, afforestation, and retention basins within the same catchment can simultaneously slow, store, and divert floodwaters more effectively than a single measure.

How do they reduce flood risks?

Combining different types of NbS provides benefits from the multiple mechanisms that work at different spatial and hydrological scales, reducing flood risk. Combining solutions also increases redundancy, making the catchment more resilient during extreme events.

How effective are they?

Combined approaches can be more effective than single interventions, especially when properly distributed across upstream, midstream, and downstream areas.

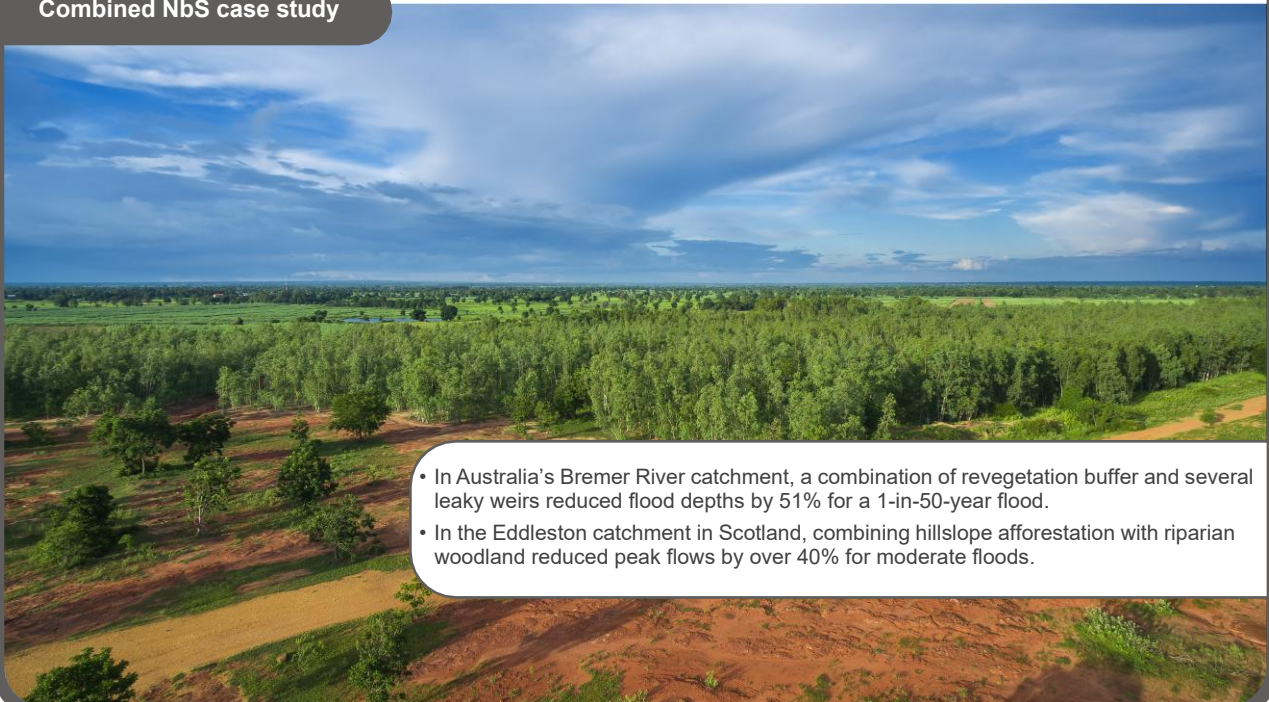
What are the key design considerations?

Effective design of combined NbS must consider how different solutions interact, both positively (synergies) and negatively (e.g. unintended local flooding). Long-term monitoring is crucial for assessing performance, adapting strategies, and maintaining function as conditions change.

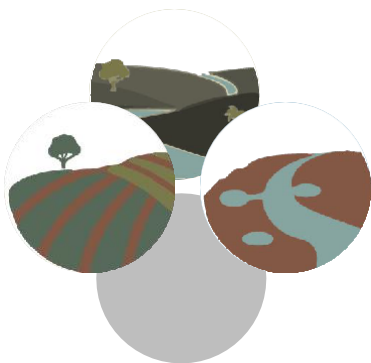
Where might they work best?

These integrated approaches are ideal for large, complex catchments with a mix of land uses and flood risks. They are especially beneficial where no single solution is sufficient.

Combined NbS case study



- In Australia's Bremer River catchment, a combination of revegetation buffer and several leaky weirs reduced flood depths by 51% for a 1-in-50-year flood.
- In the Eddleston catchment in Scotland, combining hillslope afforestation with riparian woodland reduced peak flows by over 40% for moderate floods.



Hybrid NbS

What are hybrid NbS?

Hybrid NbS combine green infrastructure (natural or semi-natural systems such as wetlands, forests, and vegetated buffers) with grey infrastructure (engineered structures such as culverts, levees, weirs, and detention tanks). They enhance flood resilience by combining the flexibility and environmental co-benefits of NbS with the reliability and control of engineering. This integration is especially valuable in urban or densely developed areas where space, risk, and infrastructure constraints limit standalone NbS.

How do they reduce flood risks?

Hybrid systems reduce flood risk by allowing green components to slow, absorb, and store water, while grey components provide structural control, redirection, and overflow management. Together, these systems reduce peak discharge, extend lag time, and prevent infrastructure failure under flood conditions.

How effective are they?

Hybrid approaches have proven effective in densely developed regions or where flood risks are extreme. The flexibility of hybrid systems allows them to function across a range of event intensities.

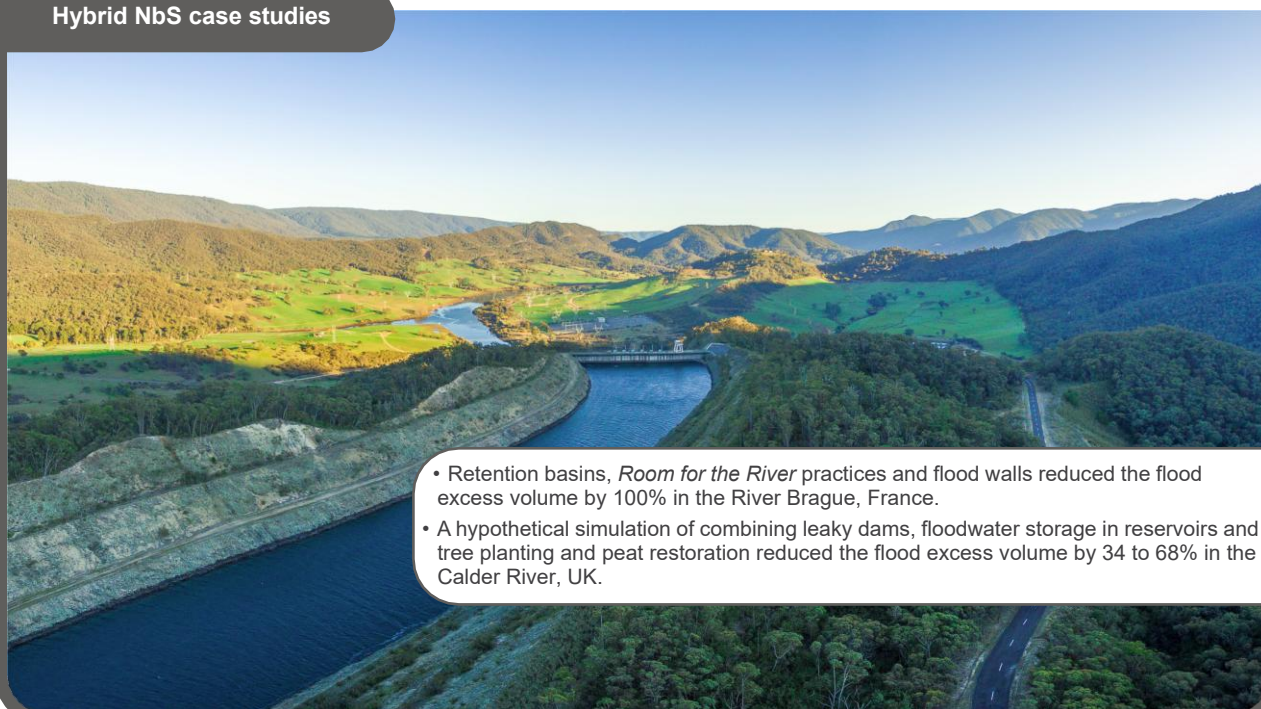
What are the key design considerations?

Designing hybrid NbS requires strategic spatial planning, consideration of scale, integrated monitoring and comprehensive maintenance, a balance of green and grey infrastructure coordinated for maximum synergy, and flexible designs that support long-term adaptation.

Where might they work best?

Hybrid solutions are effective in urban areas, transport corridors, and densely populated floodplains where a single NbS is not feasible. Hybrid NbS can bridge gaps between rural upstream interventions and downstream urban flood protection.

Hybrid NbS case studies



- Retention basins, *Room for the River* practices and flood walls reduced the flood excess volume by 100% in the River Brague, France.
- A hypothetical simulation of combining leaky dams, floodwater storage in reservoirs and tree planting and peat restoration reduced the flood excess volume by 34 to 68% in the Calder River, UK.



The NbS assessment framework

These guidelines outline an assessment framework that supports the planning of NbS for flood mitigation. It is a structured approach to guide you in selecting and designing NbS to address urban flooding in your catchment.

The framework consists of 9 major components that are interdependent (**Figure 1**). While the components are discussed in sequence here, each stage is iterative in practice. Insights from one stage may affect decisions in another, and some tasks (particularly engagement and monitoring) are ongoing throughout the project lifecycle.

This framework is not a prescriptive method, but a flexible set of tools that can be adapted to local conditions and priorities.

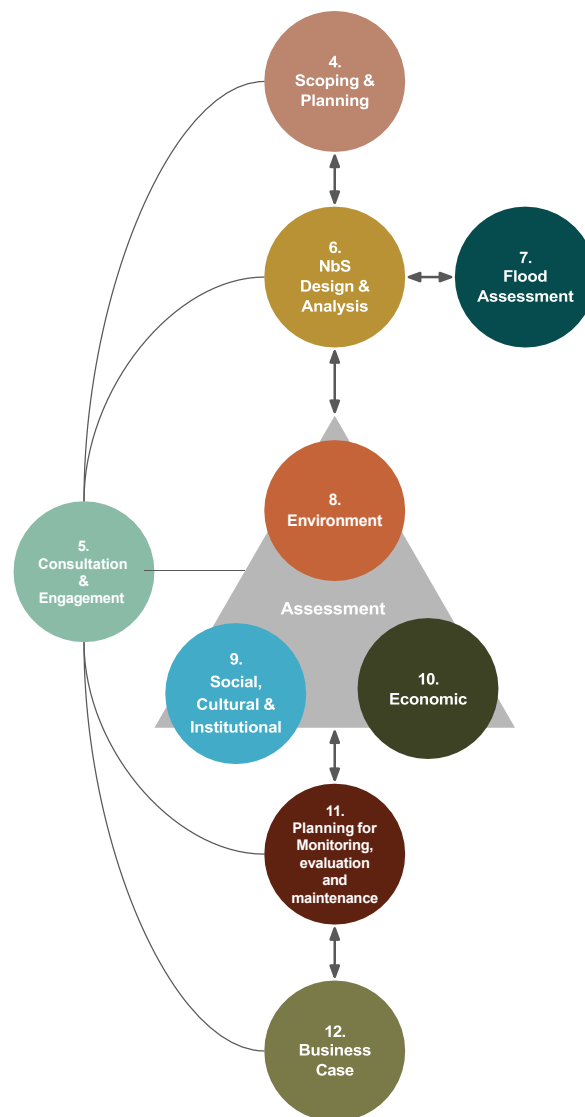


Figure 1. The Guidelines assessment framework.

Scoping and planning

The first phase in assessing the use of NbS for flood mitigation involves scoping and planning. This helps to define the problem and identify the most appropriate approach based on local needs and requirements. Scoping and planning should consider technical and historical information about the catchment, social needs, and feasibility.

The steps for scoping and planning include:

1. **Identify the target location for NbS** based on need and consultation with relevant stakeholders.
2. **Collect background information and data** to help understand the social and environmental context of the catchment and its flooding patterns (for example, frequency of flooding, land use, and landscape features that contribute to the present flood dynamics).
3. **Collaborate with stakeholders** to understand local flood risks, define aims and objectives, and shortlist potential NbS options that align with local and regional strategic objectives. Collaboration and engagement should occur at all stages of an NbS project.
4. **Understand the catchment** to gain insights into flood behaviour, risks (such as nearby buildings, cropland or other physical assets) and the potential role of NbS in managing floods.
5. **Define aims and objectives** that are realistic, cost-effective and feasible. In most cases, the aims and objectives will involve reducing flood risk and impacts, protecting, restoring or enhancing hydrological and geomorphic processes, and/or delivering environmental and social co-benefits.
6. **Identify opportunities and constraints** to optimise the project's effectiveness, maximise co-benefits, and reduce issues later in the project. Cultural, governance, practical, social, environmental, strategic or financial aspects should be considered.
7. **Shortlist NbS options** for further investigation. Shortlisted NbS should be: (1) likely to reduce flood risk issues, (2) appropriate to catchment characteristics, and (3) leverage opportunities to address broader catchment issues and deliver co-benefits.

Summary of Chapter 4 of the *Nature-based Solutions for flood mitigation in Australia: National Guidelines*.

Consultation and engagement

Consultation and engagement with relevant stakeholders should be undertaken during scoping and planning as well as throughout the assessment, implementation and monitoring, evaluation and maintenance of NbS. We recommend that you plan community engagement during the initial stages of the project with clear objectives, timing, methods and allocation of resources. The process should be tailored to suit the stakeholders, scale, complexity and implications of the NbS.

Who are the stakeholders?

The types of stakeholders will vary depending on many factors, including proposed NbS location, land use, and ownership. Stakeholders may include First Nations Australians with relationships and responsibilities to the region, residents, business owners, land managers, recreational fishers, community organisations or experts.

Why consult stakeholders for NbS?

During the scoping and planning stages of NbS for flood management, engaging with stakeholders is essential to:

1. understand the attitudes and likely reactions of the people affected
2. identify local Landcare groups, First Nations groups and other community groups who may already be implementing or planning to implement NbS
3. make sure every practical and viable policy alternative has been considered
4. confirm the accuracy of the data on which your analysis was based
5. ensure there are no implementation barriers or unintended consequences
6. help affected groups feel that you have listened to them and considered their views
7. incorporate stakeholder values and concerns into the design.

In some cases, engagement with First Nations Australians and the broader community may also be a legislative requirement. It is important to be aware of cultural, legal, intellectual property and Indigenous cultural and intellectual property, Free Prior and Informed Consent, Indigenous data sovereignty considerations when engaging with First Nations Australians. Further information and recommendations on engaging with stakeholders, particularly First Nations Australians, are discussed in **Chapter 5** of the guidelines.

Three criteria guide effective consultation and deliberative processes – the process should:

- have the ability to influence policy- and decision-making
- be representative of the population and inclusive of diverse viewpoints and values, providing equal opportunity for all to participate
- provide open dialogue, access to information, respect, space to understand and reframe issues, and movement towards consensus.

Opportunities for engagement throughout the project lifecycle may include monitoring and data collection activities, as well as monitoring, evaluation, and maintenance (MEM), depending on local capacity and capability.

Summary of Chapter 5 of the *Nature-based Solutions for flood mitigation in Australia: National Guidelines*.

NbS design and analysis

After scoping, planning and undertaking stakeholder engagement, the next stage is to design and analyse your shortlisted NbS (**Figure 2**).

The design and analysis phase begins with a preliminary flood assessment, before moving on to high-level design, and eventually, detailed design of the NbS.

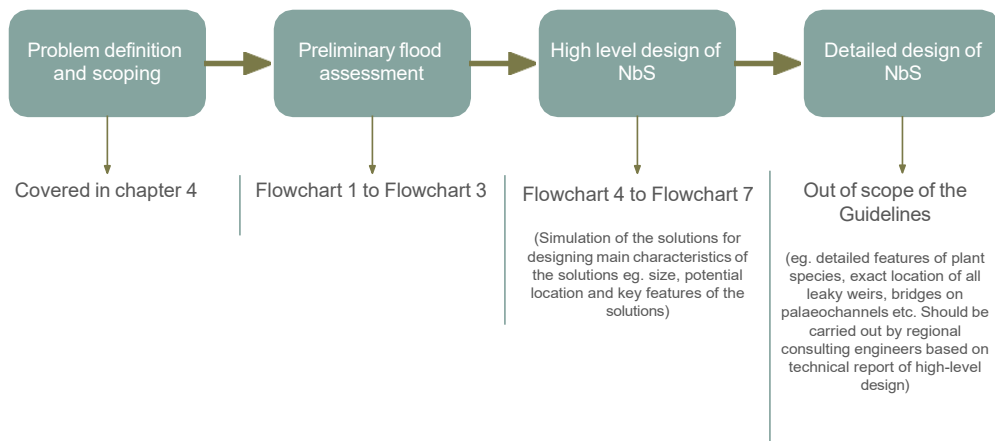


Figure 2. Key steps in planning NbS for flood mitigation.

Preliminary flood assessment

What is the aim of the preliminary flood assessment?

The aim of the preliminary flood assessment is to identify prospective NbS for effective flood mitigation in a given study area. This enables the prioritisation of efforts, exclusion of poor options, and focuses efforts on options likely to have the most beneficial impacts. This ensures that the measures are likely to mitigate flood risks effectively before detailed and costly engineering design processes are performed.

How do I perform a preliminary flood assessment?

The steps of the preliminary flood assessment phase vary depending on the category of NbS (i.e. landscape solutions, storage solutions, or diversion solutions).

The guidelines have developed a series of assessment flowcharts, designed to guide you through the preliminary flood assessment phase and help you gauge the impact of the proposed solution, without requiring high-resolution flood modelling and detailed feasibility assessment.

An example flowchart for a preliminary flood assessment for one category of NbS, landscape solutions, is shown in **Figure 3** below. Flowcharts that guide the preliminary assessment of other NbS categories (e.g. storage solutions and diversion solutions) are available in **Chapter 6** of the guidelines.

Flowchart 1

Preliminary flood assessment of land-use solutions

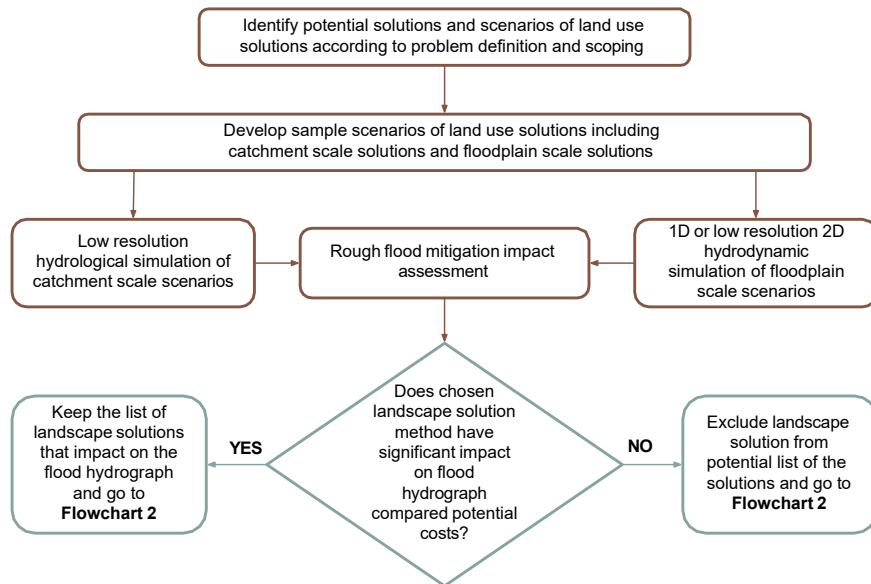


Figure 3. Preliminary flood assessment flowchart for landscape solutions.

High-level design

What is the aim of high-level design?

While preliminary flood assessment helps to refine prospective NbS options, the high-level design phase ensures technical feasibility and effectiveness in flood risk reduction.

How do I perform high-level design?

High-level design processes vary depending on the approach being explored (e.g. the type(s) of NbS or other solutions) and the project's scale, scope, and budget.

The key steps for high-level design of the 3 major NbS categories are summarised below. This generally includes discussion with an expert panel, which may include the local community or First Nations peoples. To accompany these key steps, the guidelines provide a series of flowcharts, designed to help you navigate the high-level design of different NbS. Example flowcharts for high-level design of landscape solutions and combined solutions are shown in **Figure 4** and **Figure 5**, respectively. Flowcharts that guide high-level design of other NbS categories (e.g. storage solutions and diversion solutions) are available in **Chapter 6**.

Flowchart 4

High-level design of shortlisted landscape solutions

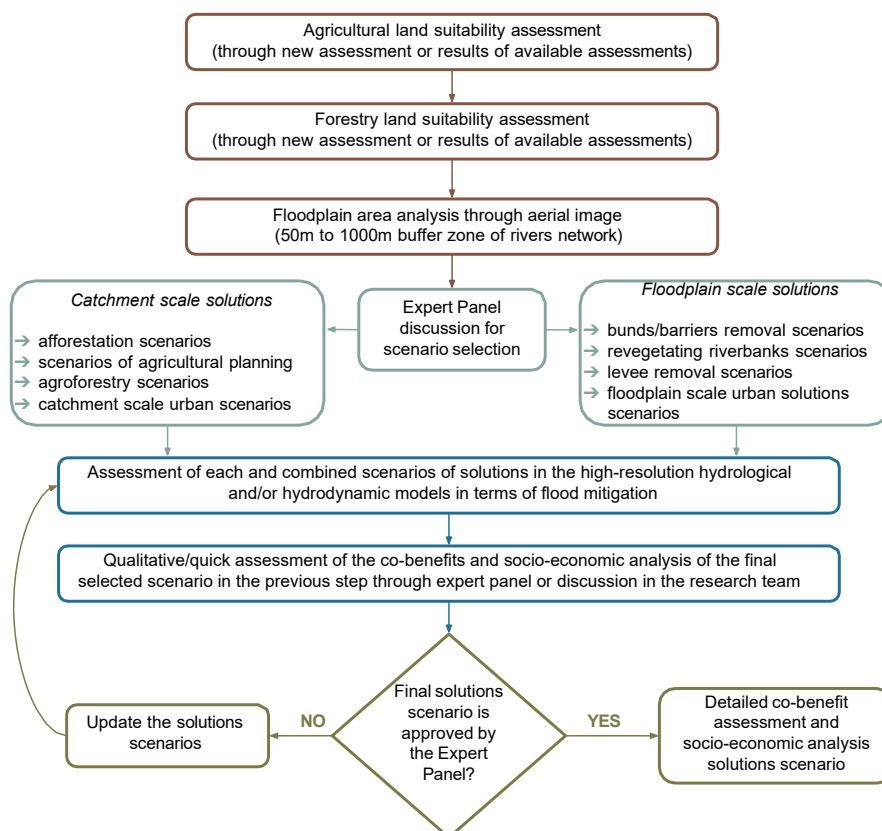


Figure 4. High-level design flowchart for landscape solutions.

Key steps for high-level design of landscape solutions

The key steps for high-level design of landscape solutions are:

1. Conduct an agricultural land suitability assessment (ALSA) to guide planning and implementation of efforts (e.g. strategic placement of buffer zones, riparian vegetation, or flood-tolerant crops).
2. Where forest cover is shortlisted as a catchment-scale solution, conduct a forestry land suitability assessment to identify optimal land for revegetation based on soil quality, climate conditions, and topography.
3. Conduct a floodplain area analysis if any floodplain-scale solutions are shortlisted. Depending on the approach, this can be conducted using GIS-based hydrological tools (e.g. for revegetation) or aerial imagery/DEMs (e.g. for barrier removal).
4. Assess the shortlisted options under a range of Annual Exceedance Probabilities (AEPs) using high-resolution hydrological or hydrodynamic models in consultation with an expert panel or stakeholder reference group.
5. Conduct a quick assessment of the co-benefits and socioeconomic aspects.
6. Incorporate the panel's recommendations in the solution scenario.
7. Undertake a detailed co-benefit assessment and socioeconomic analysis of the final design.

Key steps for high-level design of storage solutions

The key steps for high-level design of storage solutions are:

1. Identify suitable storage locations using high-resolution DEMs, which provide detailed insights into hydrological processes and terrain features. Free, web-based national databases such as ELVIS can provide high-resolution digital elevation data specifically designed for local flood risk management.
2. With the expert panel, review these locations for their potential to store floodwaters and mitigate impacts, using GIS-based tools to refine site selection.
3. Simulate the selected options for their ability to mitigate floods under a range of Annual Exceedance Probabilities (AEPs) using high-resolution hydrological and hydrodynamic models.
4. Undertake further storage analyses as required (e.g. assessment of storage capacity of leaky weirs).
5. Undertake a quick assessment of the co-benefits and socioeconomic aspects with the expert panel.
6. Incorporate the panel's recommendations in the solution scenario.
7. Undertake a detailed co-benefit assessment and socioeconomic analysis of the final design.

Key steps for high-level design of diversion solutions

The key steps for high-level design of diversion solutions are:

1. Identify flood runners and palaeochannels using high-resolution satellite imagery, DEMs, spectral images or sedimentological and stratigraphic analysis.
2. Plan any modifications to the size and connectivity of the flood runners and palaeochannels, guided by high-resolution hydrodynamic modelling.
3. Insert the designed diversion solution into the hydrodynamic model to simulate its flood mitigation impacts under a range of Annual Exceedance Probabilities (AEPs).
4. Undertake a quick assessment of the co-benefits and socioeconomic aspects with the expert panel.
5. Incorporate the panel's recommendations in the solution scenario.
6. Undertake a detailed co-benefit assessment and socioeconomic analysis of the final design.

Key steps for high-level design of combined solutions

Combined NbS integrate multiple flood mitigation strategies to maximise resilience and efficiency. For example, the spongy catchment approach combines multiple measures at the catchment and floodplain scales, enhancing the landscape's natural ability to absorb, retain and manage water.

The key steps for combined solutions are to:

1. Insert all solutions into the hydrodynamic model, such as rain-on-grid (RoG), to enable comprehensive simulations under a range of Annual Exceedance Probabilities (AEPs).
2. Have the expert panel review the hydrodynamic modelling results to assess the likely effectiveness of the proposed hybrid solution. Amend the solution if the panel does not approve the design.

3. Undertake a quick assessment of the co-benefits and socioeconomic aspects with the expert panel.
4. Incorporate the panel's recommendations in the solution scenario.
5. If needed, undertake a detailed co-benefit assessment and socioeconomic analysis of the final design.

Flowchart 7

High-level design of shortlisted combined solutions

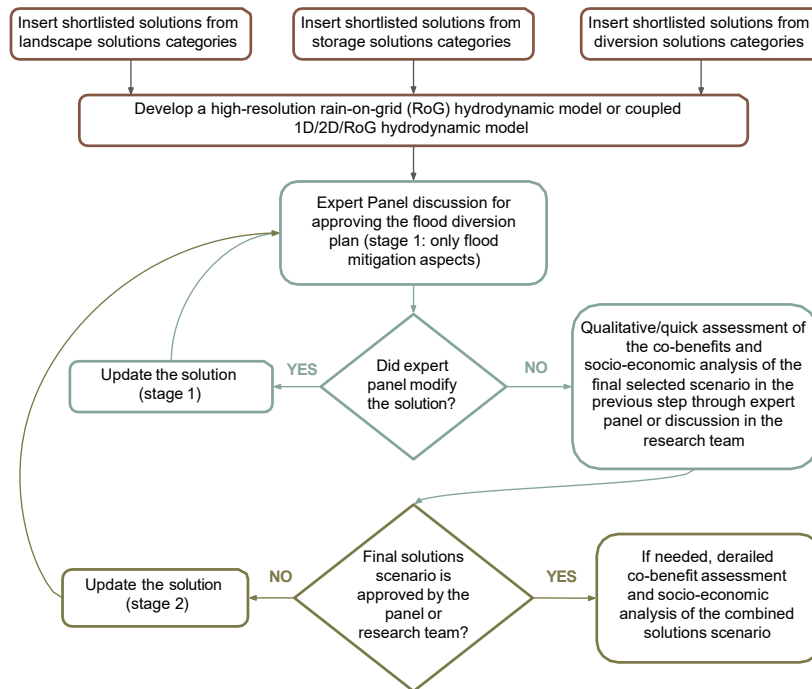


Figure 5. High-level design of shortlisted combined solutions.

Using insights from the high-level design phase, specialist engineering and environmental teams with local expertise can then perform detailed design.

Summary of Chapter 6 of the *Nature-based Solutions for flood mitigation in Australia: National Guidelines*.

Flood assessment

What data do I need for flood assessment?

During NbS design and analysis, you are likely to need to perform hydrological and hydrodynamic modelling. There are essential data and information prerequisites for effective NbS modelling using hydrological and hydrodynamic tools.

These include:

- **Precipitation data:** including daily, sub-daily, gridded, real-time and extreme rainfall data. This can be obtained from the Bureau of Meteorology.
- **Processed rainfall events:** the Australian Rainfall and Runoff guidelines and the Designed Rainfall Data System provide a comprehensive framework for estimating design storms, rainfall intensities, and runoff.
- **River flow records:** from State and territory hydrometric databases. These recorded data are usable for calibration and verification of the flood models.
- **DEMs:** 3D terrain representations of varying resolution and type, sourced from the ELVIS database, international datasets, and local councils.
- **Land use land cover (LULC) data:** essential for hydraulic roughness assessment in flood modelling. Available through the national and state map platforms.
- **Soil data and maps:** critical for estimating infiltration rates and assessing the co-benefits of NbS. Accessible through national and state sources for effective flood mitigation planning.
- **Reservoir and storage area data:** crucial for NbS flood mitigation modelling. This includes bathymetry and operational information, accessible through various state-specific agencies.
- **Other required data:** for example, this could include structure surveys, pit and pipe data, pollution sources, cultural values, stakeholder constraints, and detailed GIS data.

What flood modelling tools and techniques should I use?

There is a wide range of tools and techniques you can use to model the flood-mitigating effects of NbS. These include:

Flood frequency analysis (FFA)

In most cases, FFA is a prerequisite for the next steps of flood modelling. FFA methods provide insights into the recurrence intervals of floods and can help you to understand the probability of flood events and their impacts. This information can help guide the design of interventions such as wetlands and flood retention basins.

Hydrological and hydrodynamic modelling

Hydrological and hydrodynamic modelling provide insights into flood behaviour and help predict flood extents and water levels. Mathematically based hydrological and hydrodynamic tools are the most widely used and reliable for practical flood simulation and evaluation in Australia.

More information about the technical specifications, strengths, limitations and optimal uses of each model can be found in **Chapter 7** of the guidelines. Please also refer to the **Australian Rainfall and Runoff guidelines** for a comprehensive industry guide on flood impact assessment.

How do I incorporate hydrological and hydrodynamic modelling into NbS planning?

A framework for integrating NbS into hydrological and hydrodynamic modelling for flood analysis (**Figure 6**) includes the following steps:

- Design NbS scenarios, such as reforestation or wetlands, alongside baseline conditions.
- Use a rainfall-runoff model to simulate the catchment's response to rainfall events, producing flood hydrographs for both baseline and NbS scenarios.
- Feed these outputs into 1D, 2D or coupled 1D/2D hydrodynamic models to simulate overland flow and water movement across the catchment (for RoG models, steps 2 and 3 are combined). 2D models are preferred for final analyses, while 1D models are useful for initial assessments. Generate hydraulic maps that display flood extents and depths for both baseline and NbS scenarios.
- Conduct a comparative flood damage analysis to evaluate how NbS impacts flood patterns, such as changes in flood depth and extent.
- Present the results to decision-makers to help them decide whether the proposed NbS should be adopted or refined.

It is essential to acknowledge the uncertainties and limitations involved in modelling NbS for flood mitigation. While there are various ways to improve flood modelling, the inherent limitations mean that adaptive approaches to planning and execution are needed.

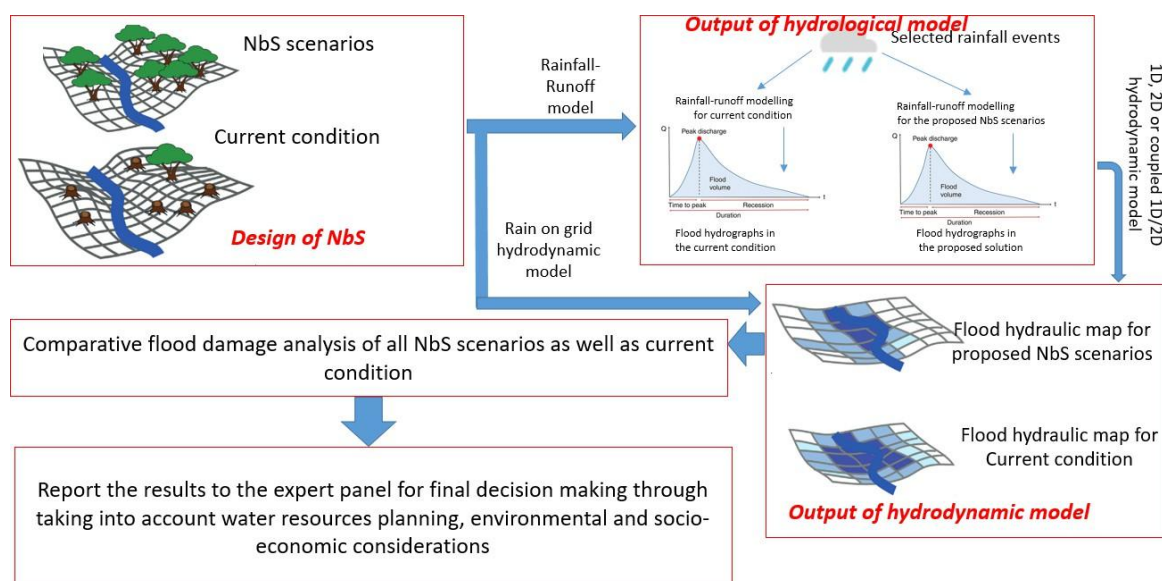


Figure 6. A framework for integrating NbS into hydrological and hydrodynamic modelling for flood analysis

Technical modelling recommendations for different NbS are outlined in **Chapter 7** of the guidelines.

Summary of Chapter 7 of the *Nature-based Solutions for flood mitigation in Australia: National Guidelines*.

Assessing environmental, social and economic co-benefits and impacts of NbS

Co-benefits can be significant for natural flood management projects. Based on these benefits, projects can engender support from a wider range of stakeholders and attract project funding if they improve landscape and meet social and economic goals.

Environmental, social and economic benefits generated from NbS projects are referred to as co-benefits because they are additional to the primary flood mitigation benefits.

1.1.1. Environmental assessment

Why perform an assessment of environmental co-benefits?

Environmental assessment aims to help decision-makers understand the potential environmental effects of NbS projects, including their prospective value, impacts and risks.

Aligning projects with the objectives of global, national, state, regional and local environmental strategies and plans (such as Australia's National Strategy for Nature 2024–2030 and the National Soil Strategy) can help ensure environmental co-benefits are relevant, meaningful and readily communicated.

In some cases, an environmental assessment is required by law if the proposed action is likely to have a significant impact on the environment. You should check whether formal environmental assessments are required by law in your particular context.

Examples of environmental co-benefits

Environmental co-benefits are the long-term environmental improvements provided by NbS projects (**Table 1**). The benefits will depend on the type of NbS measure.

Table 1. Examples of co-benefits that may be generated from NbS projects

NbS measure	Examples of potential environmental co-benefits
Riparian revegetation	• Improved aquatic and terrestrial habitat, habitat connectivity and biodiversity • Improved water quality (reduced coarse sediment and associated pollutants [e.g. nitrogen and phosphorus], shade provides cooling effect) • Carbon sequestration
Floodplain re-engagement	• Increased groundwater recharge • Reduced instream velocities and bank erosion
Catchment revegetation	• Increased habitat, habitat connectivity and biodiversity
Increased vegetation cover and soil management	• Increased soil moisture holding capacity • Reduced erosion
Natural wetland re-engagement	• Increased wetland extent and condition • Increased biodiversity • Increased nutrient cycling and pollutant removal
Flow barriers (e.g. leaky weirs)	• Increased land cover and reduced erosion • Increased groundwater recharge • Reduced instream velocities and erosion • Improved water quality

Environmental co-benefits may include improved aquatic and terrestrial habitats, enhanced habitat connectivity and biodiversity, improved water quality, a cooling effect, carbon sequestration, and ecological improvements.

How do I undertake an environmental co-benefit assessment?

In the environmental assessment, you should:

- a. describe the natural assets being protected or enhanced
- b. explain how the project achieves these co-benefits
- c. demonstrate that the selected NbS is environmentally appropriate
- d. draw links between the NbS measure and environmental outcomes
- e. highlight how the NbS measure addresses existing pressures and issues in the catchment
- f. describe the level of confidence associated with projected outcomes and provide evidence to support this.

You may wish to supplement your argument with predictive modelling to estimate the quantified impact of interventions on the environment.

Assessment should be pragmatic and tailored to the project scale and requirements. Its level of detail will depend on the stage of the project, the level of available data and resources, and funding requirements and availability. The primary objective is to provide a robust analysis of the expected environmental benefits of an NbS project. **Chapter 8** of the guidelines provides examples of tools and resources that may be useful for assessing environmental co-benefits.

Social and institutional assessment

Aligning NbS with state and territory flood planning frameworks and guidelines

The cross-disciplinary nature of NbS means they span multiple government agencies and policy frameworks, from floodplain management to public infrastructure. Relevant policy documents at project initiation should be reviewed to ensure your planned NbS aligns with flood planning guidelines from state and territory governments.

Early engagement with regulatory, planning and policy agencies can help identify potential alignment or conflicts between NbS proposals and flood planning requirements.

Chapter 9 of the guidelines contains an outline of several key state and territory flood planning frameworks with brief comments on how they align with NbS as well as potential barriers and enablers that may be relevant to you. These examples are designed to assist you with interpreting your local policy frameworks and guidelines.

Why perform an assessment of social co-benefits?

Recognising and planning for social, cultural and institutional dimensions enhances the effectiveness, inclusivity and long-term viability of NbS projects. A social co-benefit assessment may strengthen the business case, political justification and social acceptance of NbS interventions.

Examples of social co-benefits

Social co-benefits may include recreational opportunities, aesthetic improvements, public health benefits, cultural and educational benefits, noise attenuation, social cohesion and tourism. However, social co-benefits do not always strictly fall into one category and may span across multiple categories (e.g. environmental and economic co-benefits as well).

How do I undertake a social co-benefit assessment?

The assessment of NbS co-benefits can be undertaken in a variety of ways. The method chosen should be appropriate for the scale and type of proposal. In general, you should:

- a. **Identify the social co-benefit to be assessed**, in consultation with stakeholders.
- b. **Choose the method to measure co-benefits**, such as stated preference, revealed preference, benefit transfer/value transfer, or replacement cost methods.

Many social co-benefits are frequently considered in monetary valuation approaches. However, qualitative approaches (such as interviews, focus groups, or co-design workshops) also play a crucial role in measuring the co-benefits of NbS, particularly where the benefits are difficult to quantify or assign a market value.

Chapter 9 in the guidelines outlines many of the methods that you can use to assess NbS social co-benefits.

Economic assessment

Why perform an economic assessment?

Economic assessments using benefit-cost analysis enable decision-makers to understand the trade-offs between investing in different NbS options, or between NbS options and grey infrastructure solutions, or deciding not to invest.

Components of economic assessment

Economic benefits can be 'tangible' (improvements that clearly have identifiable human impacts and market values) or 'intangible' (improvements that cannot be reliably measured or expressed in monetary terms).

Examples include:

- **Tangible benefits:**
 - reduced flood impacts on human activities and assets
 - reductions in loss of private and social assets (e.g. damage to housing, farms, schools)
 - reductions in avoidable expenditure (e.g. costs of emergency responses).
- **Tangible co-benefits:**
 - lower sediment load in rivers, which may reduce the costs for industry downstream (e.g. reduced dredging, improved agriculture, etc).

- **Intangible co-benefits:**

- human and social benefits from reduced experience of flooding (e.g. trauma, economic and social dislocation, effects of healthy environments on human physical and mental health)
- environmental benefits (e.g. improved habitat and biodiversity).

The economic assessment paradigm

For costs:

1. Describe and estimate the value of **tangible costs**:

- these should be the focus in your calculation of total costs
- these costs must be discounted to a common base (e.g. 2025 \$A).

2. Describe and estimate the value of **intangible costs**:

- the description of these costs will typically be most powerful
- an estimated range of values may be useful supplementary information about the scale of these costs.

For benefits:

1. Describe and estimate the value of **tangible benefits**:

- these should be the focus in your calculation of total benefits
- these benefits must be discounted to a common base (e.g. 2025 \$A).

2. Describe and estimate the value of **intangible benefits**:

- the description of these benefits will typically be most powerful (e.g. the projected increase in koala habitat and population, rather than an estimated value of this increase to humans)
- an estimated range of values may be useful supplementary information about the scale of these benefits.

How do I undertake an economic assessment?

The key steps for undertaking an economic assessment are to:

1. clearly articulate the intended outcomes of the NbS proposal
2. clearly specify the baseline and NbS options
3. identify and describe all benefits resulting directly from flood mitigation
4. identify and describe all co-benefits resulting indirectly from flood mitigation
5. identify and describe all capital and operating costs associated with implementing the NbS
6. forecast all quantifiable costs and benefits over an appropriate time period for the NbS
7. assess the present value of costs and benefits
8. calculate the benefit-cost summary statistics: the net present value (NPV) and benefit-cost ratio (BCR)
9. undertake sensitivity analysis.

Further details on each of these steps are available in **Chapter 10** of the guidelines.

Summary of Chapters 8, 9 and 10 of the *Nature-based Solutions for flood mitigation in Australia: National Guidelines*.

Monitoring, evaluation and maintenance

Why perform MEM?

A monitoring, evaluation, and maintenance (MEM) framework outlines how NbS projects will be monitored and evaluated for the purposes of steering, management, or governing, and how the necessary maintenance will be organised and delivered. MEM is vital to ensure the project is adaptive to a changing climate, evolving conditions, and ecosystem variability.

When should MEM be performed?

The MEM framework should be developed during the design stage and completed before implementation of the NbS begins.

Some NbS require active involvement throughout the project's life cycle. For these projects, MEM requires adaptive decision-making throughout the project's life cycle, including modifying and/or adapting the original NbS design.

What is involved in MEM for NbS?

MEM for NbS has 3 main components: planning, implementation, and operation. These are shown below (**Figure 7**).

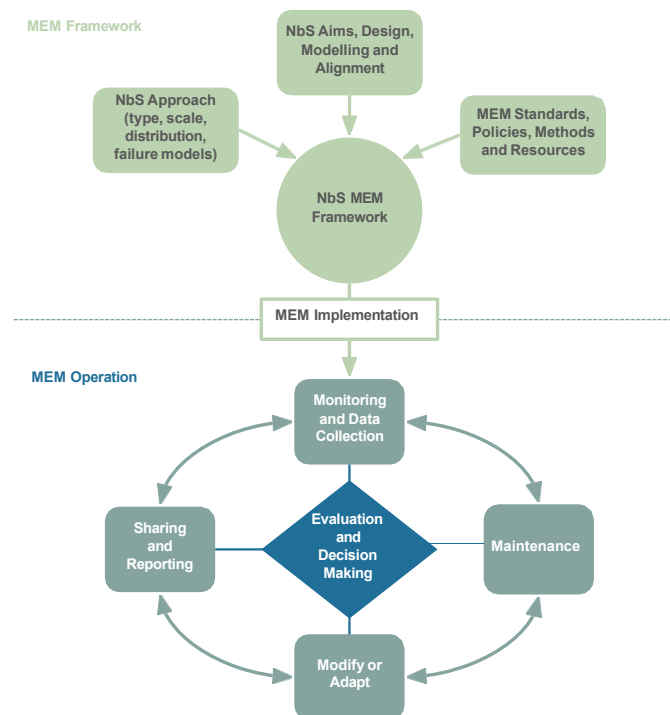


Figure 7. General approach to NbS MEM planning and operation

MEM planning

Planning for MEM must align with the category or type of NbS used, and its scale, scope and aims. When planning MEM, you should consider:

- **Alignment** with the aims and objectives of the NbS to ensure that the correct data are being collected and monitored. You should also consider alignment with broader MEM frameworks, standards, and policies.
- **Metrics** that need to be captured and measured to support evaluation and decision-making (e.g. runoff, peak flow, soil moisture, water quality, property damage value, loss of life, etc.).
- **Baseline** information for future comparison and evaluation.
- **Failure modes** to ensure that the data collected supports risk mitigation.

MEM implementation

Once finalised, the NbS MEM framework should be clearly documented and ready for implementation. Ensure that it is shared with the relevant groups and stakeholders, as detailed in the stakeholder collaboration strategy developed during the planning phase.

MEM operation

MEM operation commences as the NbS is established and operates in accordance with governance arrangements. Key areas for ongoing MEM operation include:

- Community and stakeholder engagement to provide ongoing opportunities for local engagement after the initial design.
- Data collection to gather the minimum amount of data required to support decision-making in line with the NbS aims and co-benefits.
- Evaluation and reporting to support decision-making relating to changes, adaptations, or modifications required.
- Maintenance, which may consist of further interventions such as re-planting or removing damaged or dangerous vegetation.
- Sharing and reporting outcomes from monitoring and evaluation activities through regular reporting to key stakeholders, agencies, governments, and communities.

Further information on each of the components of the MEM framework can be found in **Chapter 11** of the guidelines.

Summary of Chapter 11 of the *Nature-based Solutions for flood mitigation in Australia: National Guidelines*.



Business Case

In order to successfully execute the proposed NbS, you will need to understand the authority of the decision-makers who will approve and/or fund your NbS proposal. In particular, you will need to understand what policy and planning frameworks must be complied with. To create a sound business case, you need to include:

1. a compelling reason for the proposed intervention
2. a rigorous analysis of feasible options and risks
3. a specific request of what the decision-makers will decide
4. evidence of adequate consultation and support
5. financial and ownership requirements
6. an achievable method for implementing the proposal
7. an evaluation strategy for whether the decision is implemented successfully
8. analysis of the ongoing costs and benefits.

Further information on creating a strong business case for an NbS proposal is detailed in **Chapter 12** of the guidelines.

Summary of Chapter 12 of the *Nature-based Solutions for flood mitigation in Australia: National Guidelines*.



Case study: Bremer River catchment

We used the assessment framework outlined in this practical guide to analyse NbS for flood mitigation, providing local government authorities (LGAs) with evidence-based information for future council planning. The case study below is an example of how an NbS approach was used to balance flood risk reduction with ecological, economic, and social benefits across the Ipswich LGA.

The Bremer River catchment (2,032 km²) is part of Southeast Queensland's Brisbane River system, with downstream urban areas of Ipswich highly prone to flooding.

- **Scoping and planning:** Between October 2022 and August 2023, we engaged with Ipswich City Council and community members and experts to define the scope, understand the catchment, establish objectives, gather information, and identify constraints. Our study focused on opportunities to minimise flood impacts of the Bremer River, Warrill Creek, Bundamba Creek and Purga Creek on downstream urban areas of Ipswich.
- **Community engagement:** Residents supported floodplain restoration and green solutions but wanted more information before endorsing specific NbS.
- **Option design and analysis:** Preliminary assessments found that a **spongy catchment** integrating multiple NbS was the most effective approach for flood mitigation in the area.
- **Flood assessment:** We used hydrodynamic models employing rain-on-grid approaches (TUFLOW HPC and HEC-RAS 2D) to assess various NbS alternatives under a 2% AEP flood scenario. A 300 m riparian buffer alone reduced flood depth by 19%. The addition of leaky weirs increased the reduction to 51%. Incorporating 83% afforestation further elevated flood depth reduction to 78% and increasing urban permeability by 50% slightly enhanced the reduction to 79%. The integrated approach achieved the greatest impact, reducing flood depth from 1.3 m to 0.27 m.
- **Environmental, social and economic assessment:** Environmental assessments led to the identification of priority actions, including protecting existing riparian vegetation, strategically revegetating channel networks. Community analysis revealed strong environmental values and interest in NbS approaches. Water quality simulations showed that riparian buffers reduced total suspended solids (TSS) and total nitrogen (TN) by 50%. With 83% afforestation, TSS was further reduced by 45% and TN by 33%. These combined NbS demonstrate significant potential for improving both flood resilience and water quality.
- The economic analysis demonstrates how tangible water quality benefits would likely exceed the NbS flood mitigation cost, via reductions in sewage treatment plant operating costs (reduction in end-of-Bremer total nitrogen load) and Port of Brisbane dredging costs (reduction of total suspended load).

A spongy catchment approach, which combines riverbank revegetation, leaky weirs, afforestation, and increased urban permeability, was found to collectively enhance flood resilience across the Bremer catchment, to provide considerable co-benefits and offers valuable insights for nature-based flood mitigation strategies.

Figure 8 illustrates a potential spongy catchment concept used in the Bremer River case study.

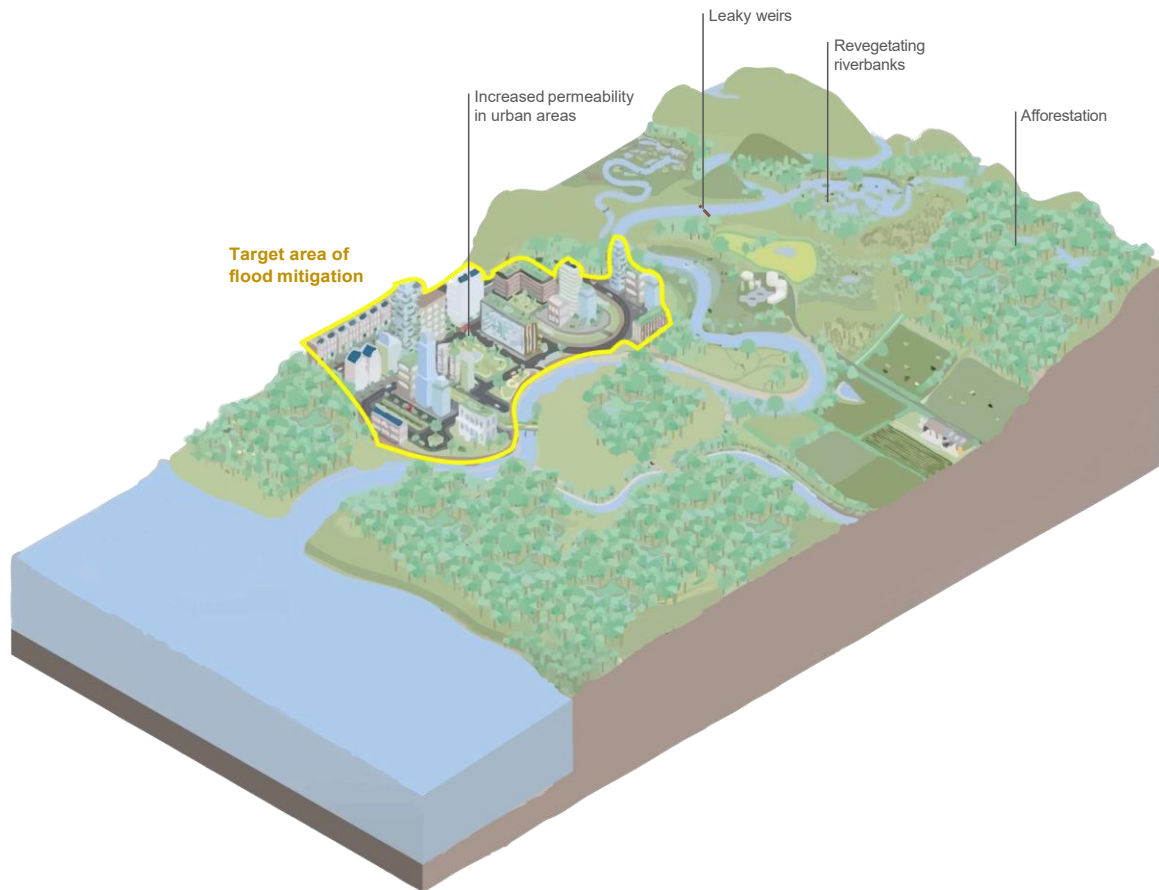
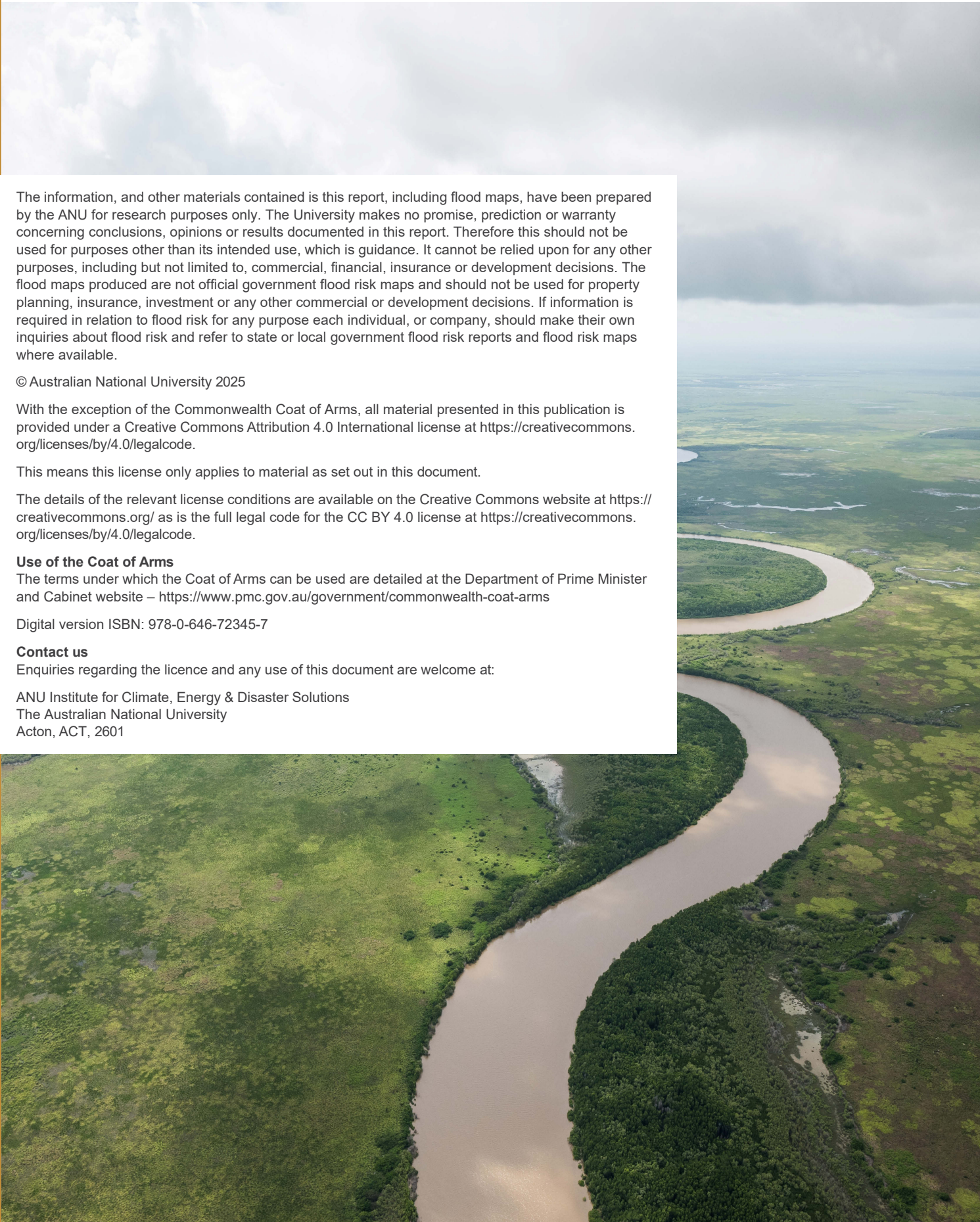


Figure 8. A potential spongy catchment concept used in the Bremer River catchment study.

You can find more information about the Bremer River case study and other catchment studies in Australia and abroad in **Chapter 13** of the guidelines.

Summary of Chapter 13 of the *Nature-based Solutions for flood mitigation in Australia: National Guidelines*.



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