Bank erosion on the Coldwater River, Photo by Carie-Ann Lau

BANK STABILIZATION FOR FLOOD RESILIENCE AND HEALTHIER HABITATS IN BRITISH COLUMBIA

A literature review and practitioner workshop summary report.

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RESILIENT WATERS

WATERSHED WATCH SALMON SOCIETY

A project of MakeWay

DISCLAIMER

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region. This project was conducted under the mentorship of staff from Resilient Waters (a project of MakeWay Charitable Society) and the Watershed Watch Salmon Society. The opinions and recommendations in this report, and any errors, are those of the author and do not necessarily reflect the views of Resilient Waters, the Watershed Watch Salmon Society, or the University of British Columbia.

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The author acknowledges that the research for and facilitation of the online workshops outlined in this report took place on the unceded ancestral lands of the xwməθkwəy̓əm (Musqueam), Skwxwú7mesh (Squamish), and Səl̓ílwətaʔ/Selilwitulh (Tsleil-Waututh) First Nations. These First Nations and many others have practiced adaptive flood risk management throughout the Lower Mainland of “British Columbia” long before settlers arrived. Over time, their systematic exclusion from land management decisions has added to the bank erosion and stabilization management issues that we see today. While the recommendations made in this report offer specific suggestions based on the literature and workshop participant opinions, we also advocate for the need for increased stewardship of the Lower Mainland’s rivers by those First Nations who have long understood their behavior. Additionally, we advocate for greater uptake of stabilization options that can protect both humans and non-humans alike.

EXECUTIVE SUMMARY

Riverbank degradation is a major issue throughout the Lower Mainland of British Columbia (BC), occurring across the water course spectrum, from small creeks to the main branch of the Fraser River. Bank degradation can lead to a variety of environmental and societal losses, threatening river habitat, decreasing water quality, and placing properties and important assets at risk of erosion and flooding. There has been a long history of managing bank degradation issues in the province through 'hard engineering' bank stabilization techniques. In BC, this has primarily taken the form of spreading riprap (large boulders) along eroding riverbanks. Riprap and other hard engineering solutions are often installed as emergency works before or during high river flow events, where bank degradation can rapidly occur. While these hard engineering solutions have been widely employed, it has become clear that they also alter the natural behavior of river systems, and potentially decrease the habitat quality for key BC river species, including salmon.

Practitioners and stakeholders are now widely aware of the issues that accompany hard engineering options and are seeking out hybrid or more natural solutions that can strengthen banks, while also maintaining or improving habitats. These alternatives include practices such as bioengineering, revegetation, and hybridization of hard engineering installations. However, the guidance surrounding the design and implementation of these alternatives is somewhat unclear in BC, adding to the continued preferential use of hard-engineering options. Practitioners are seeking clearer pathways for alternative bank stabilization technique approval, along with additional funding streams to support these works.

This report offers a brief literature review on the topic of bank erosion: why it occurs, what it impacts, how it can be managed, and how it is being dealt with in BC. Following this literature review is a summary of the webinar workshop entitled: "Bank Stabilization Best Practices for Flood Resilience", which was hosted by Resilient Waters and other partner organizations in May 2024. This workshop involved the highlighting of exciting alternative bank stabilization projects that are being applied on BC's lower Fraser River waterways, and on Alberta's Bow River. These projects are presented in this report as a series of case study summaries. Additionally, workshop participants were engaged in both a brief survey and longer facilitated discussion to help ascertain what barriers currently prevent wider uptake of alternative bank stabilization methods, along with what some solutions might be.

Based on the workshop responses and literature review, we recommend a shift away from riprap use in BC. This shift can be facilitated through several measures including improved education on alternative method benefits, and improved resourcing and guidance for their approval and implementation. These changes should also be accompanied by further research into how hard engineered bank stabilization methods are impacting BC's river systems, along with how alternative bank methods are performing over time in the province. Finally, other bank stabilization methods including land use planning and catchment-scale sediment management need to be prioritized alongside localized bank strengthening efforts.

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Riverbank erosion is an ongoing problem throughout the Lower Mainland of British Columbia. The response in the past has been to implement hard engineering solutions such as riprap to try and entirely stop the lateral movement of river channels. Over time it has become clear that these hard engineering solutions to bank instability come with environmental and social impacts, primarily as they can decrease the health of salmon habitat. There are now calls for a widespread shift away from hard engineering solutions, instead employing alternative bank strengthening techniques such as revegetation or bioengineering.

2. INTRODUCTION

Rivers naturally adjust over time, eroding and depositing material in response to interruptions to their dynamic hydrologic conditions. As societies have established themselves around rivers, bank erosion has grown to be a problem, both due to its acceleration given anthropogenic drivers of erosion, and due to a decrease in public acceptance of lateral channel movement as their lives and assets grow to be at risk (Das et al., 2014; Mondal & Tripathy, 2021).

In some communities, accelerated riverbank erosion has become a leading public concern, with wide-spread impacts on human and non-human life. Bank erosion can lead to societal losses, through the damage of properties, infrastructure and other assets (Siddik et al., 2017). It can also lead to environmental losses as in-stream habitats become loaded with fine sediment due to channel widening, decreasing transport capacity, or through lowering water quality, leading to eutrophication and other issues (Hayes et al., 2023; Vietz et al., 2018). In the worst situations, communities may be forced to entirely relocate due to bank erosion issues (Das et al., 2014) (*Figure 1*).

To overcome bank erosion issues, societies have long been attempting to decrease the movement of channels, primarily through bank stabilization techniques. In the past, these techniques have mainly focused on hard engineering methods (also called engineering treatments or hard structures) which involve the use of “non-living materials in the construction of structures” (Polster, 2001) (e.g., riprap, concrete walls, etc.). However, as these hard engineering techniques have become more popular over time it has become apparent that they result in a suite of potential damages, primarily decreasing river habitat quality, while also being an expensive management option (Allen & Leech, 1997; Li & Eddleman, 2002). Instead, there has been a shift towards the use of ‘alternative bank stabilization methods’ including bioengineering, revegetation and hybrid techniques to manage bank erosion issues (Moreau et al., 2022).

Bioengineering is a technique that “incorporates the use of vegetation and engineering structures to increase slope stability” (Government of British Columbia, 2004, pg. 1). Revegetation involves the purposeful planting of native species on banks where vegetation is limited due to erosion or previous deforestation, while hybrid bank stabilization involves the combination of hard engineering measures such as riprap with vegetation elements to limit the environmental impact of a project (e.g., Lagasse, 2006).

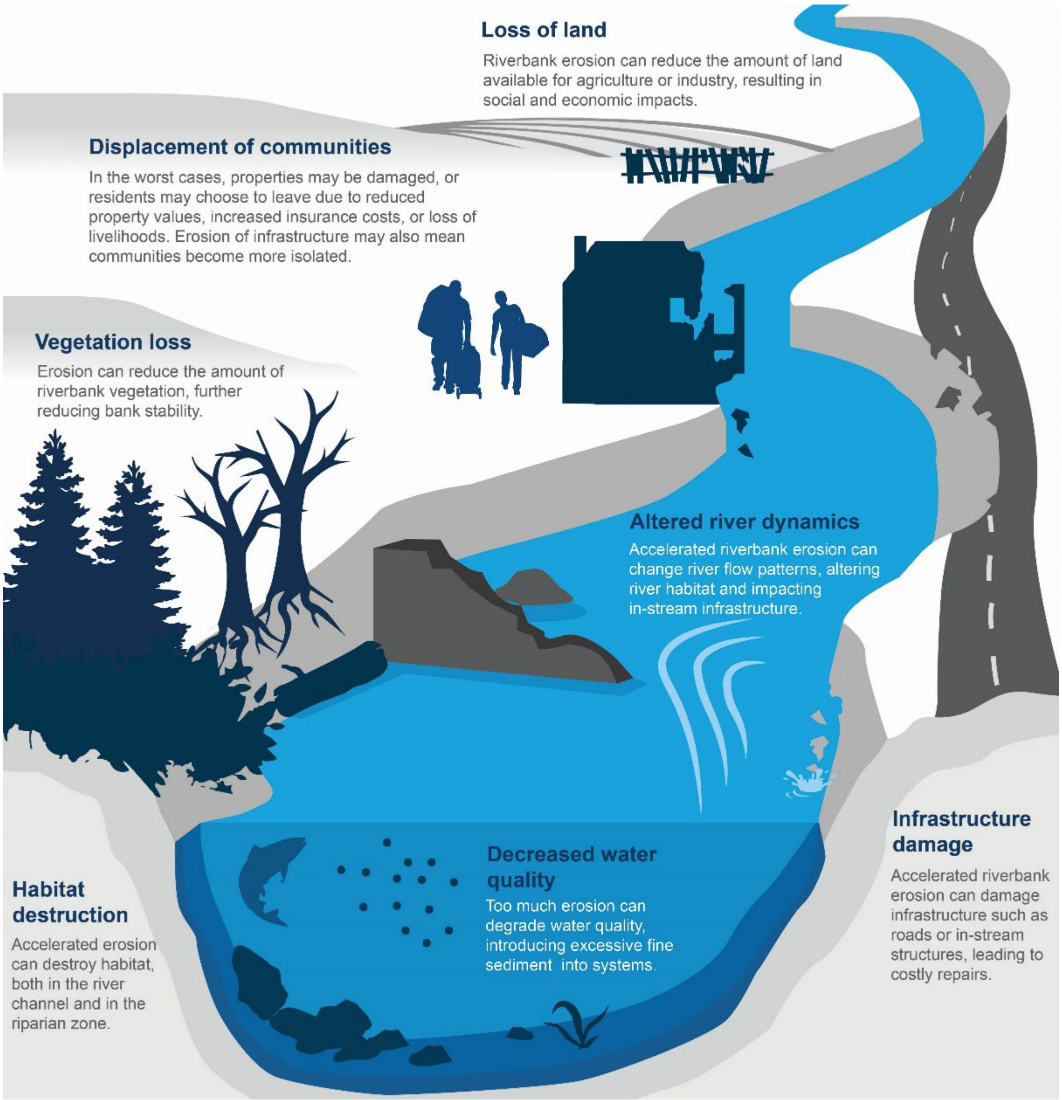


Figure 1. Some of the social, economic, and environmental impacts of excessive riverbank erosion.

Alternative bank stabilization methods can offer many benefits, including strengthening of banks through root systems, increased ecological health of river systems, improved costs when compared to hard engineering solutions, and improved stability of a system over time as vegetation continues to grow (Punetha et al., 2019). Despite these widely accepted benefits, in many areas there remain barriers that prevent uptake of alternative bank stabilization methods.

In the following sections of this report, different bank stabilization methods are discussed, with a focus on the variety of benefits that alternative solutions can offer, and the known disadvantages of hard engineering measures. Bank stabilization issues and management options are then placed into the context of British Columbia, Canada. Finally, the results of a workshop on bank stabilization alternatives in BC is summarized, including key success case studies from the area, and analysis of practitioner perspectives on the current barriers preventing greater implementation of alternatives, and solutions for how to move forward.

2.1 WHAT CAUSES BANK EROSION

Bank erosion is an ongoing and natural process in all rivers, with many important and significant benefits (Florsheim et al., 2008; Piégay et al., 2005). Rivers undergo erosion of their banks and bed to maintain an approximate state of equilibrium as fluctuations occur in both water and sediment supply (Pfeiffer et al., 2017). In upper reaches, there may be considerable down cutting with erosion of the riverbed, while downstream erosion of the riverbanks and lateral migration of the river channel becomes more prominent (Das et al., 2014; Florsheim et al., 2008). *Figure 2* displays the areas of the potential erosion that can be expected throughout a typical river system.

There are two dominant processes causing bank erosion: hydraulic action and mass failure (or geotechnical failure) (Fischenich, 1989; Posner and Duan, 2012). Hydraulic action is when the sediment particles from the riverbed and banks are moved by excessive shear force associated with the river's flowing water, with the shear force increasing with water velocity. Often hydraulic action is semi-constant, causing erosion over a longer time period (Papanicolaou et al., 2007). Mass failure is where a bank collapses, usually because a critical height and/or angle has been exceeded (Papanicolaou et al., 2007). Mass failure often results in sudden, excessive lateral movement of a riverbank. Riverbanks are particularly prone to mass failure in the moments after a high-water level event, when the channel waters have declined, but the bank is still saturated, causing high pore water pressure which destabilizes bank materials (Casagli et al., 1999).

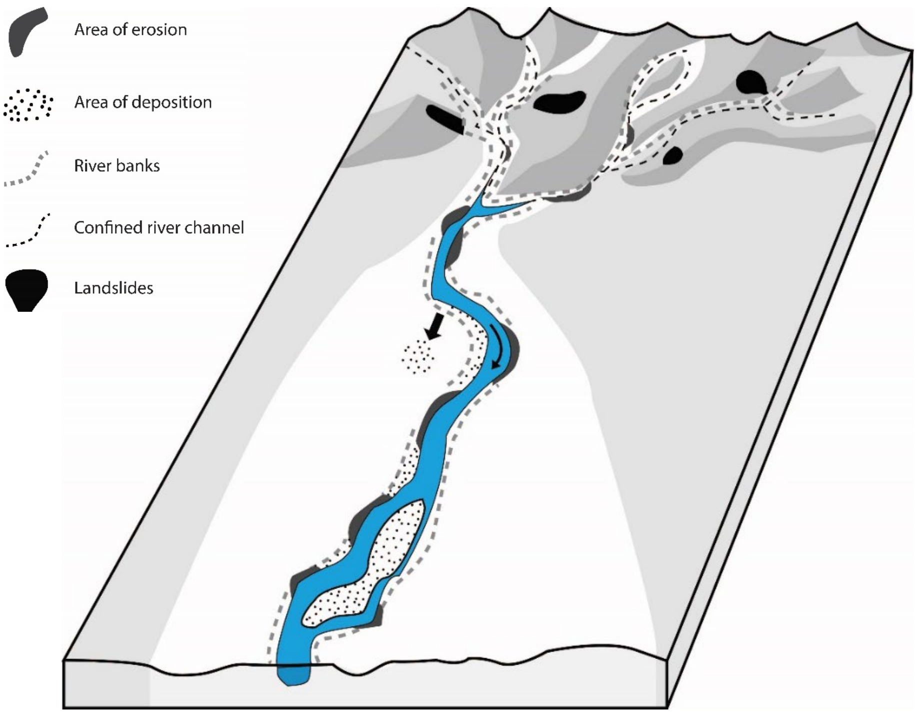


Figure 2. Diagram of the areas where erosion and deposition may be expected throughout a natural river system. This figure has been adapted from Florsheim et al. (2008).

Bank erosion in natural river systems is controlled by both long-term fluctuations in the hydrological cycle, and by sudden hazard events such as floods or landslides which may see drastic alterations in bank stability. However, both direct and indirect anthropogenic impacts also exacerbate bank erosion (Shields et al., 2000; Yamani et al., 2011). Direct anthropogenic impacts include things like livestock actively weakening slopes, or removal of the riparian vegetation that was providing root stabilization to a riverbank (Florsheim et al., 2008). Indirect anthropogenic impacts include other factors that influence the hydrology or a river, and the water's capacity to erode, for instance channel incision through dredging or gravel extraction, increased urbanization leading to greater runoff, or hard engineering bank stabilization structures increasing flow rate and causing erosion in other areas (Wohl, 2006). *Figure 3* displays some of the key ways in which anthropogenic influence can weaken river banks and increase the erosive potential of river flow.

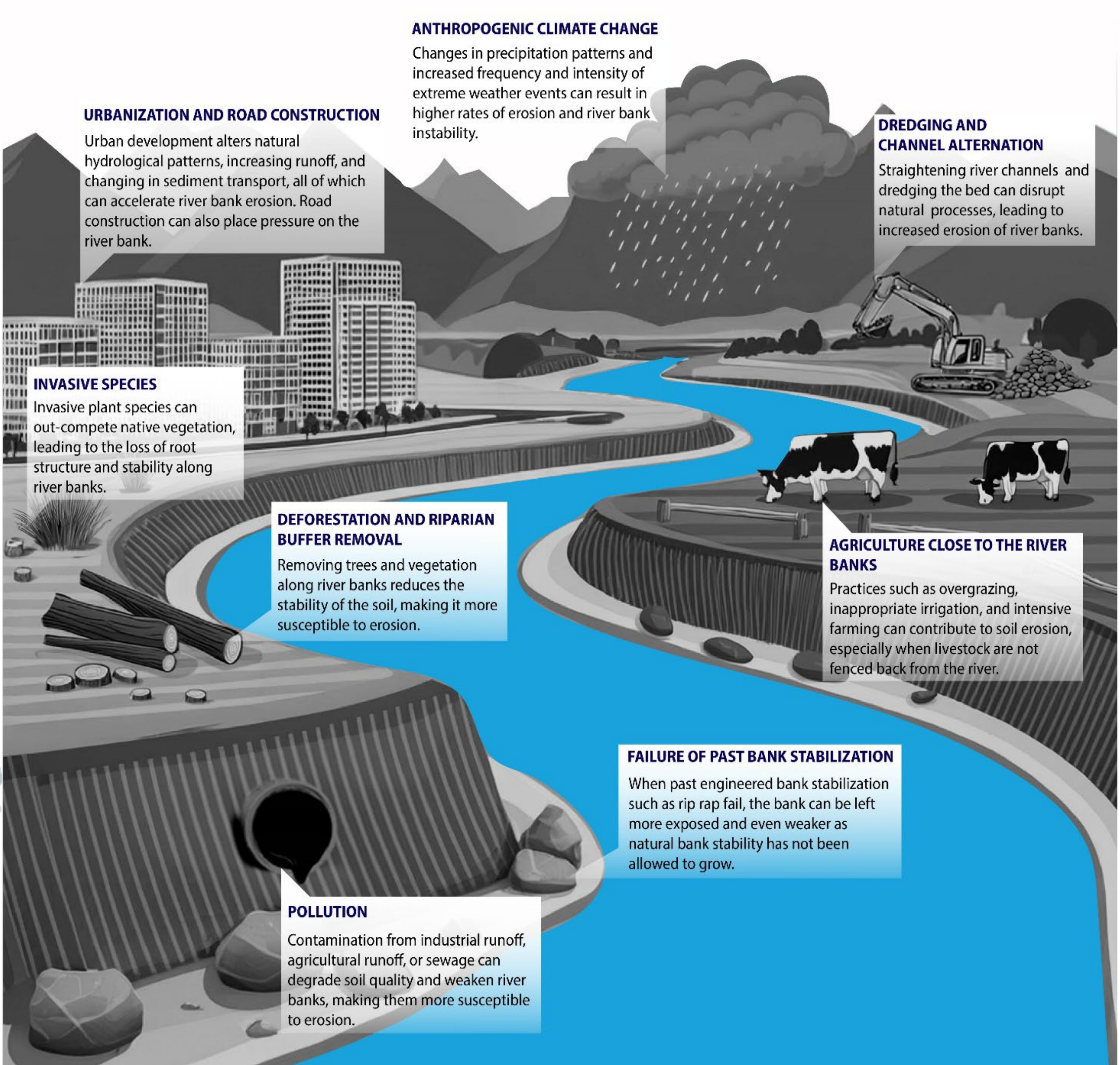


Figure 3. Anthropogenic factors which can exacerbate riverbank erosion beyond natural rates.

2.2 BANK STABILIZATION METHODS

When bank erosion is becoming an issue there are two main management options: (1) move away from the river, or (2) use different techniques to stabilize the riverbanks. Bank stabilization aims to protect riverbanks from further degradation and prevent lateral migration of the channel in areas where that is undesirable.

There are three main approaches to increasing bank stability:

1. **Increasing the stability and strength** of the bank locally through engineering, bioengineering, and revegetation approaches.
2. **Reducing the hydrodynamic forces** acting on the banks through the installation of flow control structures or wider catchment runoff-management.
3. **Land use planning**, preventing encroachment into riparian zones and alteration of a river system's sediment budget.

While the second two options are key solutions that need to be addressed, this report is focused on the first approach of bank strengthening methods that can be enacted at the local scale.

There are many different bank stabilization methods that are commonly used to stabilize rivers, ranging on a spectrum from solely hard engineering options (e.g., retaining walls, riprap, gabion cages), to hybrid (e.g., revegetated riprap), to bioengineering and revegetation efforts. In this report, bioengineering and revegetation techniques are differentiated, with the idea that revegetation is the relatively simple process of planting (whether live plants or seeds), while bioengineering requires an additional level of design and expert input.

Different bank stabilization methods can alter the behavior of rivers, along with the in-channel and riparian border habitat quality. Hard engineering solutions are known to have environmental, cultural and social consequences when relied on too heavily, while bioengineering and revegetation solutions can instead offer opportunities for environmental restoration and increased community engagement (Florsheim et al., 2008; Kondolf & Pinto, 2017; Martin et al., 2021). *Figure 4a* outlines some of the key issues that can arise from overuse of hard engineering bank stabilization options, while *Figure 4b* shows some of the known benefits that can come from the adoption of alternative stabilization methods.

Table 1 in Appendix One of this report provides a list of commonly used stabilization methods, with brief descriptions of their main features, along with a list of their commonly reported pros and cons. *Table 2* in Appendix Two also provides a list of grey literature reports that offer additional details on different bank stabilization options.

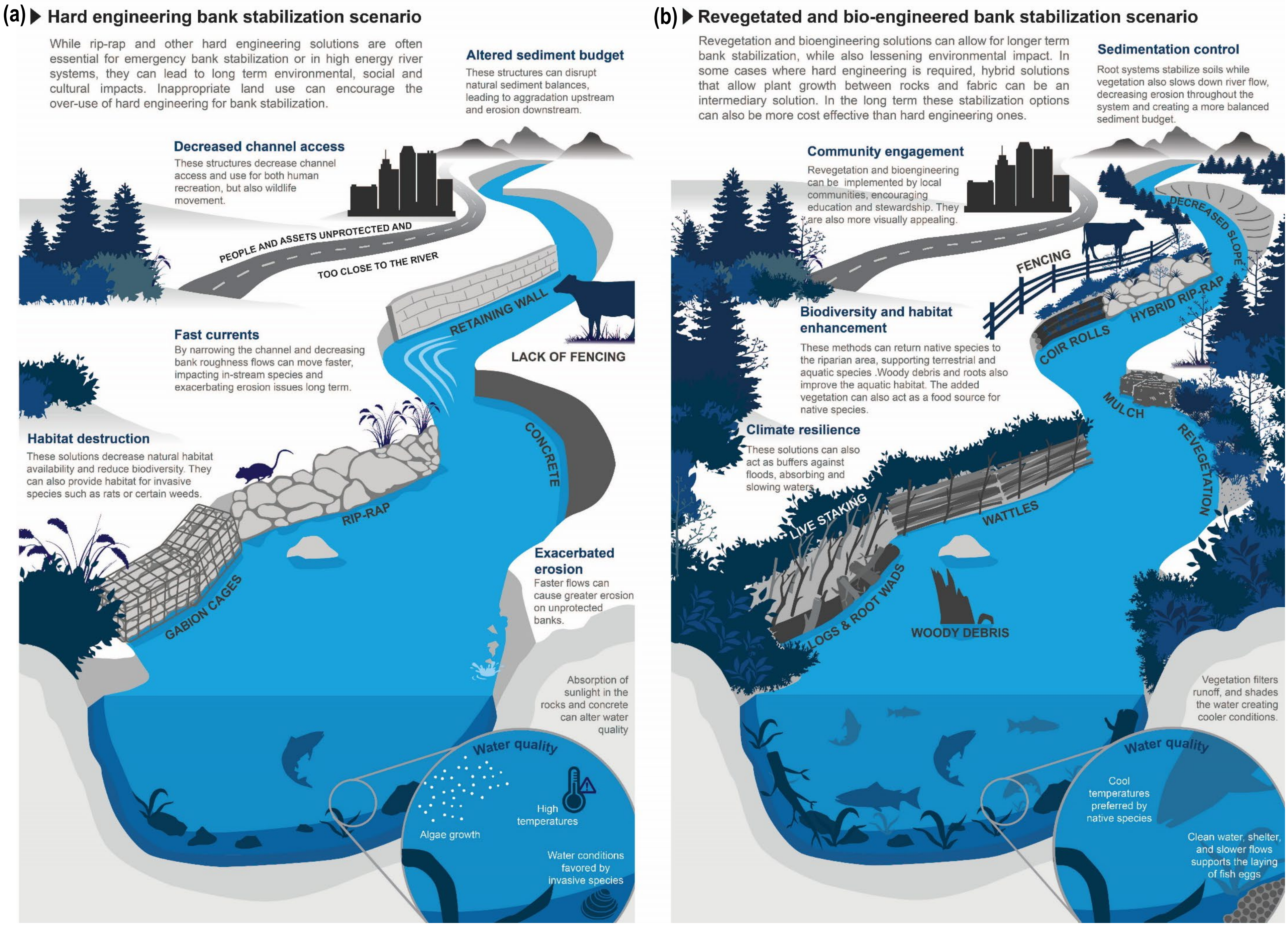


Figure 4. (a) A river with bank erosion issues where hard engineering techniques have been adopted. (b) A river system where revegetation, hybrid and bioengineering stabilization techniques have been adopted. Each figure outlines the resulting impacts on the surrounding area and environment.

3. BANK STABILIZATION IN BRITISH COLUMBIA

BC has many diverse river systems, each with their own unique hydrologic and sediment-supply conditions. In the headwater systems of many BC rivers the channels are carved through bedrock, so bank erosion is not a major issue. In areas where rivers pass through softer alluvial deposits or glacial till, the erosion is often more pronounced, and these areas tend to be in the lowlands where significant human development has occurred, further accelerating bank erosion beyond natural rates. Logging in BC has been widespread, and historically has occurred without protection of riparian zones (Rosenfeld et al., 2011). The practice of building roads relatively close to river channels has also led to increased sedimentation and decreased bank stability in many areas (Hogan et al., 1998; Jones et al., 2000). Significant aggradation of the riverbed in some downstream locations has also placed additional erosional pressures onto surrounding riverbanks, and it has long been a major restoration goal in the province to increase sediment stability (Hartman et al., 1996).

Climate change has, in recent years, added an additional layer of pressure into BC's river systems. Frequent wildfires have seen the loss of sediment-stabilizing vegetation (Eaton et al., 2010), while frequent and intense precipitation has led to extreme riverine flooding (Gillett et al., 2022), placing greater pressure on the riverbanks, resulting in frequent mass movement failures (Jakob & Lambert, 2009).

In BC, the use of riprap has been widespread, with high energy river systems and frequent flooding seeing the need for fast-to-implement strengthening options, with little time for the consideration of environmental damages. Riprap has become a marked feature of the riverbanks throughout BC. Along the Fraser River gravel reaches it was estimated that up to 57% of the channel bank had been hardened through riprap as of 2012 (Ham & Church 2012).

3.1 IMPACT OF RIPRAP ON BC'S SALMON HABITAT

The exact environmental consequences that riprap may be having in BC is difficult to define as there exists uncertainty surrounding the impacts that riprap may have on fluvial environments generally (Massey et al., 2017). Reviews of the topic suggest that riprap can have both positive and negative fish habitat impacts (Bigham, 2020). For instance, riprap can be used to increase bed slope and coarsen bed material in rivers that have already undergone human disturbance, conditions that are preferential to fish habitat (Massey et al., 2017). Riprap can also act as a year-round habitat for some Pacific Northwest fish species (Gidley et al., 2012), including juvenile salmon (Schmetterling et al., 2001). However, more and more of the literature is pointing towards the habitat loss this technique can cause for salmonid species (e.g., Reid & Church, 2015; Schmetterling et al., 2001).

Riprap can cause habitat loss, decreasing the amount of shallow water salmon and fish habitat (Jorgensen et al., 2013). It may also alter natural water flow patterns, causing increased scour or increased fines deposition, altering the bed texture that is required for salmon spawning (Reid & Church, 2015). Riprap also can cause heating of the water as the rocks act as a thermal conductor, while also offering far less vegetation cover when compared to natural banks, something that then decreases the amount of habitat complexity in the river channel (Massey et al., 2017; Thompson, 2002). Reducing the erosion of the bank toe altogether through riprap placement can also be negative as the undercut bank areas are often a key area of shelter for salmonid species (Beamer and Henerson, 1998). Finally, riprap may act as a fish migration barrier by creating back flows and decreasing channel complexity (Quigley & Harper, 2004).

While the impact of riprap on salmon is not always clear, researchers have found that it causes greater habitat damage in rivers where there has been less human alteration (Massey et al., 2017). Experts have recommended caution when installing riprap in the Canadian context (Quigley & Harper, 2004), limiting its use to areas that require absolute stabilization (e.g., by infrastructure) and in river channels that are already severely degraded (Reid & Church, 2015).

3.2 A SYSTEMATIC REVIEW OF THE LITERATURE ON BANK STABILIZATION IN BC

From a brief systematic review of the literature discussing bank stabilization issues in British Columbia (*Figure 5*) there appears to be a research gap when it comes to the comparison of different stabilization methods or analysis of the policies and governance issues that surround the management of bank stabilization in BC. Of 16 relevant peer-reviewed academic publications many were focused on the assessment and modelling of bank stability in the BC context (Eaton, 2006; Eaton et al., 2006; Eaton & Millar, 2004; Eaton & Millar, 2017; Huang & Nanson, 2007; McParland et al., 2016; Tunnicliffe & Church, 2015). Riprap was recognized as having a negative impact on local salmon species (Swales & Levings, 1989), with some authors testing riprap alternatives in the flume environment (Eaton et al., 2022). In terms of alternative method application, authors acknowledged the importance of including woody debris (Chen et al., 2008; Jones et al., 2011), maintaining riparian buffer zones (Richardson et al., 2010), revegetating riverbanks (Bailey et al., 2005; Rood et al., 2015), and wider watershed restoration (Phelps et al., 2004; Ward et al., 2008) for the purposes of increasing bank stability and environmental health in BC river systems.

Overall, the literature that specifically recognized that bank stabilization is an issue in BC was primarily concerned with how to best monitor and model the problem. While some researchers are publishing on the impacts of certain stabilization options, and testing the conditions required to employ more natural alternatives, there is still a lack of published research into the application of different stabilization methods in BC.

This brief review was somewhat flawed, with confined search terms. The author acknowledges that there may be other peer-reviewed literature on bank stabilization and erosion issues in BC that did not appear in this search.

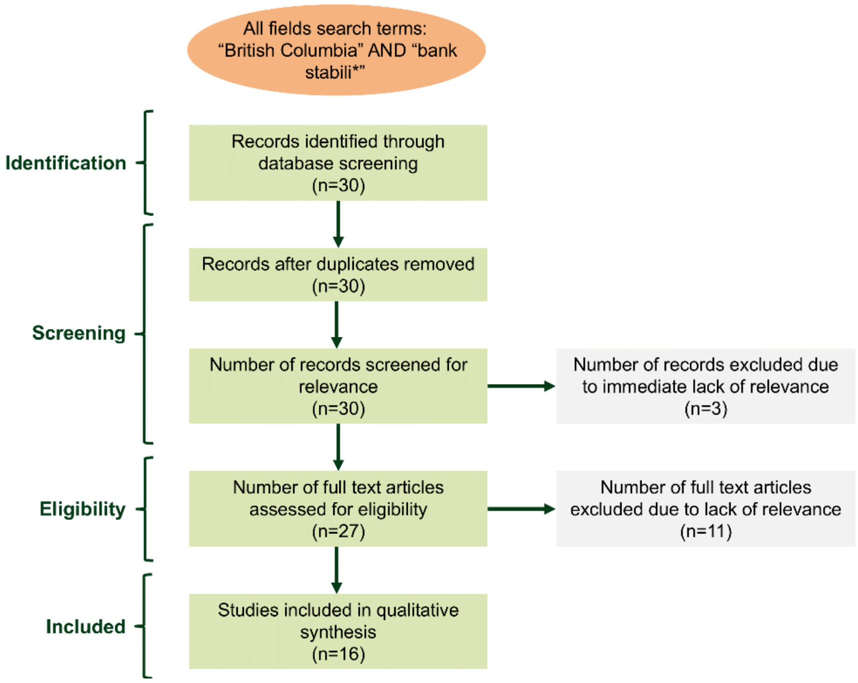


Figure 5. PRISM-style flowchart summarizing the systematic review of peer-reviewed literature mentioning bank stabilization in the context of British Columbia.

4. WORKSHOP ON BANK STABILIZATION MANAGEMENT AND PERSPECTIVES IN BC

Resilient Waters is a non-profit group who helps to catalyze collaborative flood resilience projects in the Lower Mainland of BC. One of their on-going projects, in partnership with Watershed Watch Salmon Society, is a series of online webinars and workshops aimed at addressing key flood resilience issues in BC (*Figure 6*). In May 2024, Resilient Waters and other key partners hosted a workshop on Bank Stabilization Best Practices, specifically looking to highlight successful methods for bank stabilization that can offer both bank strengthening and habitat improvement.

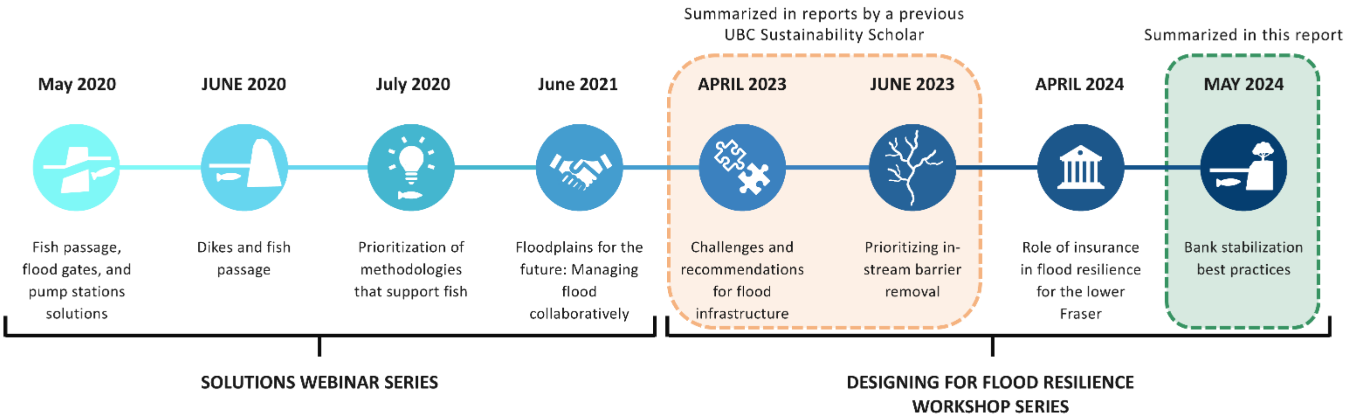


Figure 6. Timeline of Resilient Waters workshops and webinars between 2020 and 2024.

The workshop was centered on three presentations by experts on bank stabilization implementation who each presented on work being undertaken by their organizations.

The workshop also involved a short participant survey and a longer facilitated group discussion at the end of the workshop. The goal of the surveys and group discussion was to understand what challenges are being faced by practitioners who wish to implement hard engineering alternatives for bank stabilization in BC, and to capture recommendations for how to improve current management options.

4.1 METHODOLOGY

The workshop was attended by 106 people, 83 responded to the survey at the opening of the workshop, while 45 attended the facilitated group discussion at the end and were split into groups of 4-6 people with one facilitator per group. Survey responses were recorded through the Zoom app, while discussions were captured by facilitators through note taking and some audio recording. The responses to the facilitated discussions were transcribed and coded in NVivo software for assessment of emergent themes in participant responses. Key recommendations and challenges were drawn from the themes, along with key quotes taken from recordings. A limitation in this methodology was that coding was undertaken by an individual researcher due to capacity constraints.

A full copy of the survey questions and group discussion facilitation schedule can be found in Appendix 3 of this report. The facilitation schedule was only used to guide discussion when required.

5. CASE STUDIES OF SUCCESSFUL BANK STABILIZATION ALTERNATIVES

Three presenters spoke to the workshop attendees, each presenting on their organization's use of exciting alternatives to hard engineering bank stabilization methods applied to waterways in the lower Fraser River BC, and the Bow River in Alberta. In the following section, each of these three presentations has been adapted into a case study to summarize the key methods being used, along with any key implementation recommendations or key success findings that were shared by the presenters.

CASE STUDY ONE

Alternative bank stabilization techniques in the Fraser Valley

Fraser Valley Watersheds Coalition | Natashia Cox

AT A GLANCE

The Fraser Valley Watersheds Coalition is implementing bank stabilization methods that offer win-win solutions, decreasing bank erosion while also supporting fish and communities. Here three methods being used in the Lower Mainland of British Columbia are summarized, with photo examples and tips for success.

SUMMARY POINTS

1. **Rivers are dynamic** – erosion is a natural process (that can be influenced by human activity).
2. First identify the bank erosion challenge and **determine the stability objectives**.
3. It is often best to use a **variety of techniques,** applied together or separately. Each application is **unique to the site** and the objectives of bank stability project.
4. **Diversity targets** can be added into design and implementation plans.

KEY SOLUTIONS PRESENTED

- Altering bank slope
- Bioengineering (wattle fences)
- Replanting (live staking)
- Wood & bank revetment

In most cases different techniques are used in combination for best success.

ALTERING BANK SLOPE

Steep slopes lead to an elevated risk of erosion, so a key stabilization tool is to decrease slopes to a more stable 2:1 or 3:1 profile.

- This was undertaken in a Chilliwack Creek shown in Pictures 1-3.
- Originally there was a steep slope, and while there was vegetation it was mainly Blackberry and invasives whose roots were doing little stabilization work.
- Using an excavator, the slope profile was decreased, and everything was stripped back except any large wood.
- Burlap sacking also provided temporary erosion and weed barrier as revegetation with native plants was undertaken.
- Ten years later the large trees are growing successfully on the upper slopes and erosion has decreased, protecting the farm that lies next to the river.

PICTURE 1
Original steep bank with vegetation that was not helping stabilization.

PICTURE 2
Bank immediately after excavation, slope has been significantly decreased.

PICTURE 3
The bank 10years later, stable and with significant native vegetation growth.

FRASER VALLEY WATERSHEDS COALITION

Photos sourced from Natashia Cox – Fraser Valley Watersheds Coalition

BIOENGINEERING

Live plant materials can be used to stabilize and ultimately revegetate riverbanks through techniques such as Wattle Fences and Live Staking.

- Severe erosion was threatening a farm and its buildings, so bioengineering was implemented to increase bank strength.
- Soil that had been lost during erosion needed to be replaced, and then wattle fences were created along the bank.
- Metal fences were introduced as a temporary measure during the high river flow months to give the vegetation time to grow.
- After ~one year of growth, the bank is highly vegetated, and the farm is better protected.

KEY TIPS

- Use **pioneering species** (e.g., Willow, Dogwood and Cotton Wood)
- Collect during the **dormant season** (late fall/winter).
- Cut to the **correct size for your site**. Cutting size- from 50cm-5m long, >2.5cm in diameter.
- **Minimize transport** and storage.
- **Remove apical meristem** (growth tip).
- Consider site **conflicts that might decrease bioengineering survival** (e.g., allelopathic plants, herbivory impacts).
- Check materials for **pests and diseases**.
- **Growth hormone** can be implemented.

PICTURE 1
Highly eroded bank with the early wattle fencing being put in place.

PICTURE 2
The bioengineering in its initial growth phase, supported by metal fencing.

PICTURE 3
The bank ~1 year later with significant vegetation growth.

KEY TIPS

- You may need an **Instream authorization** (Water Sustainability Act, Fisheries Act, Navigable Waters Act).
- Add instream **large wood** to help deflect stream energy away.
- Ensure your **anchors/boulders are sized appropriately** to the system.
- Try to **use boulders that are smoother/rounded** to provide aquatic habitat benefits for salmon.
- Consider **monitoring for post-construction shifting**.

BANK REVETMENT AND LWD

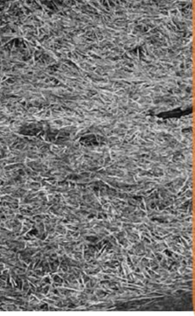
In the cases where hard engineering is required, there are options that result in bank stabilization, while still successfully improving fish and terrestrial habitat.

- Large woody debris (LWD) can be installed instream at the toe of riprap, decreasing erosion while increasing bank complexity and habitat potential.
- Soil wraps are a medium that can be driven into banks, drastically decreasing erosion, while allowing for vegetation growth through the material.
- Methods work best when combined with decreased slope.
- While these methods may be more labour intensive than riprap alone, they result in far less environmental or cultural impact.

PICTURE 1
LWD amongst riprap.

PICTURE 2
Soil wraps that allow plant growth through the material.

Photos sourced from Natashia Cox – Fraser Valley Watersheds Coalition



CASE STUDY TWO

Natural alternatives to conventional products for bank stabilization

S.A.Y Lands | Steve Clegg

AT A GLANCE

S.A.Y. Lands have been implementing natural alternatives to conventional synthetic erosion control materials. They have had great success in the river systems, using cheap and widely available materials such as straw and mulch to both increase slope strength, and provide an ideal substrate for rapid revegetation efforts.

SUMMARY POINTS

1. **Seek cheap and low-tech options** to allow expansive work and to encourage community involvement.
2. **Avoid options where you must return** to do additional works.
3. **Avoid plastic,** both for habitat quality, and for the usability and appearance of the river.

KEY SOLUTIONS PRESENTED

- Straw
- Hand spread seed
- Wood mulch

THE PROBLEM WITH CONVENTIONAL PRODUCTS

The environmental issues associated with riprap and other hard engineering erosion control measures are now being recognised, but other non-biodegradable materials are also causing problems.

- Erosion control mats are a common tool for stabilizing slopes. They are expensive, often full of plastic, don't lay tight to the soil and are hard to plant through.
- Silt fencing is another common tool, it is also expensive, plastic, does little to reduce erosion, leaves sediment piles, and acts as an animal migration barrier.
- These materials are widespread in BC, but despite being described as a temporary solution, they are often left at sites indefinitely.

ALTERNATIVES

Erosion Control Mat

Straw

Silt fencing

Mulch berms

STRAW AND HAND-SPREAD SEEDS

Straw offers a useful alternative to erosion control mats. Straw provides a barrier that protects soil, while also providing a medium that is ideal for revegetation efforts.

- S.A.Y. Lands is using straw and hand-spread seeds on banks, encourage rapid plant growth.
- The method is cost effective, with the common seed types being incredibly cheap, while the straw itself can be old and otherwise unusable.
- The method is being applied to steeper and shallower slopes.
- Rapid growth of Rye seeds provides almost immediate slope stabilization improvements, with tough roots that are difficult to remove.
- In the presented site, significant seed growth occurred within only 8 days, helped by the protective and nutrient-rich straw barrier.

Photos sourced from Steve Klegg- S.A.Y. Lands

PICTURE 1
Eroded bank with straw prior to spreading, seeds have been spread.

PICTURE 2
The bank after straw coverage.

PICTURE 3
The bank 8 days later, with visible plant growth and animals gathering.

KEY TIPS:

- **Fall rye** is an excellent cheap seed option that is hardy, when planting closer to the winter months **winter wheat** is more appropriate.
- **Old mouldy straw is good** as it provides additional nutrients, approach farmers for their old straw.
- **Hand spreading seeds** is simple, cheap and allows local communities easy involvement.

WOOD MULCH

Wood mulch can offer a useful alternative to silt fences, capturing overland sediment movement. They are easy to shape to a site, don't act as a migration barrier, and allow for vegetation growth.

- Wood mulch is being used in S.A.Y. lands projects to both build up berms, and to layer overtop a wider bank area.
- The method provides a protective barrier against erosion, while also providing beneficial bacteria and soil nutrients for revegetation efforts.
- The process involves the creation of an initial berm, building up the protective barrier and allowing sediment retention.
- A secondary layer of mulch is then draped over top of the area, this both locks the berm securely into the bank, and provides an ideal substrate for the staking of plants across a wide bank area.

KEY TIPS:

- Unlike with silt fences, the site **will not need to be returned to.** If the mulch is set up carefully you should be able to walk away.
- Mulch acts a **moisture preserver**, ideal for keeping more water in the system during times of drought. It can be implemented as a multi-benefit solution in river systems.

PICTURE 1
Creation of a wood mulch berm, prior to the spreading of additional mulch over the top surface.

PICTURE 2
Vegetation growth in the mulched area following direct staking.

Photos sourced from Steve Klegg- S.A.Y. Lands

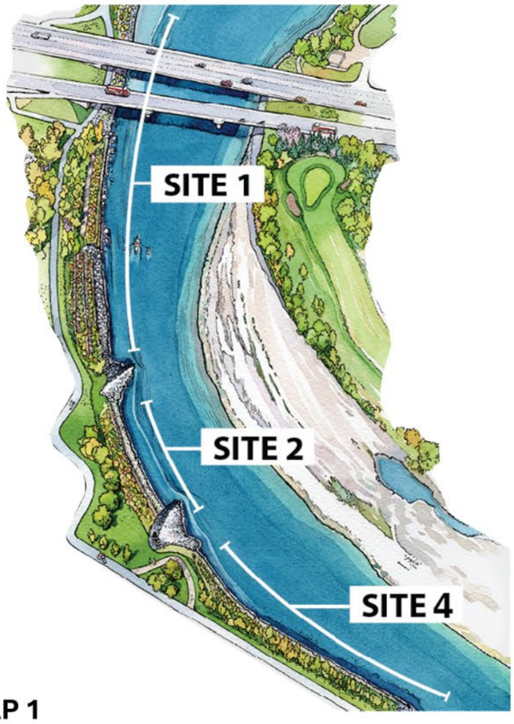
CASE STUDY THREE

Innovative bank stabilization measures on the Bow River in Calgary

Kerr Wood Leidal Associates | Mike Gallant

AT A GLANCE

During the 2013 Calgary floods there was extensive bank erosion and in turn, bank hardening. From 2016-2019 the Bow River Bioengineering Demonstration and Education Project (BDEP) has tested alternative strengthening measures at three different sites (1, 2 & 4). The three sites are being monitored for improvements until 2028.



MAP 1
Location of the three sites along the Bow River.

KEY SOLUTIONS PRESENTED

- Replanting (e.g., live staking)
- Bioengineering (e.g., fascines, crib walls, brush mattresses)
- Hybrid riprap

SUMMARY POINTS

1. Bioengineering, planting, and hybrid strengthening **methods are being tested on the Bow River**.
2. There has been a **high level of success** with these innovative techniques so far.

SITE ONE

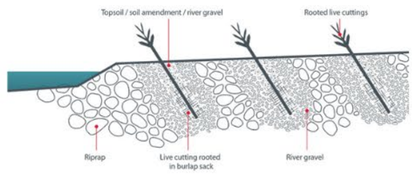
- Site one is ~370m in length

The site features three main methods:

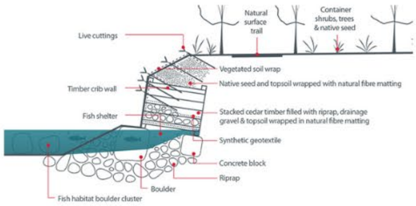
1. Rooted live cuttings
2. Timber crib walls (some with fish shelters)
3. Brush mattresses and brush layers

- A vegetated wildlife corridor has also been installed.

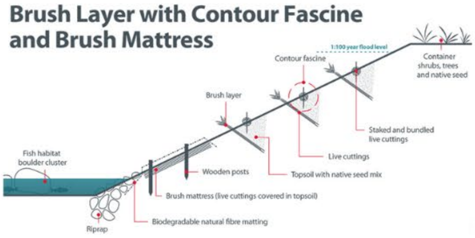
Rooted Live Cuttings



Timber Crib Wall with Fish Shelter



Brush Layer with Contour Fascine and Brush Mattress



PICTURE 1
Site 1 bank in 2017, prior to works.

PICTURE 2
Site 1 in 2023, following works.

KERR WOOD LEIDAL
consulting engineers

Photos sourced from Mike Gallant - Kerr Wood Leidal.
All maps and diagrams sourced from the City of Calgary BDEP website

SITE TWO

- Site two is ~120m in length at a site where significant erosion occurred during the 2013 Calgary floods.

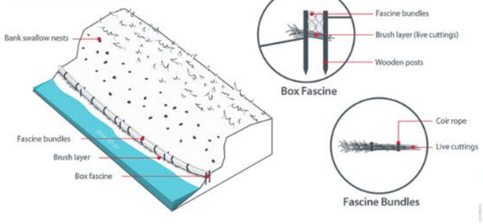
The site features three main methods:

1. Box fascine
2. Brush mattresses
3. Hedge brush layers
4. High density live staking

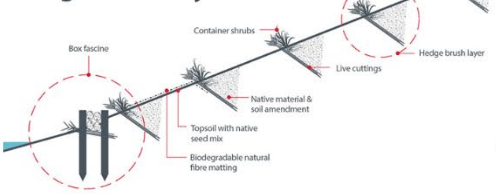
PICTURE 1
Site 2 bank in 2016, prior to works.

PICTURE 2
Site 2 in 2023, following works.

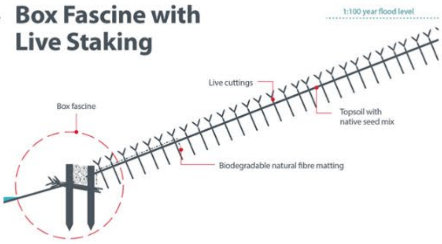
Box Fascine



Box Fascine with Hedge Brush Layer



Box Fascine with Live Staking



SITE FOUR

- Site two is ~360m in length and hybridization of pre-existing riprap is being tested.

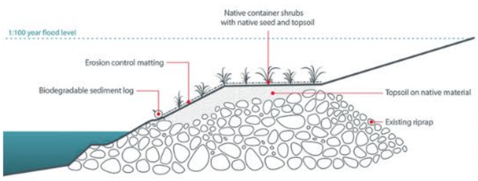
The site features three main hybrid methods:

1. Soil filled riprap with shrub plantings
2. Void filled riprap with plug plantings
3. Void filled riprap with live cut & other plantings (joint)

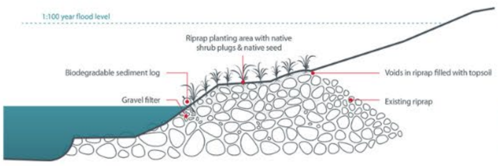
PICTURE 1
Site 4 bank in 2016, prior to works.

PICTURE 2
Site 4 in 2023, following works.

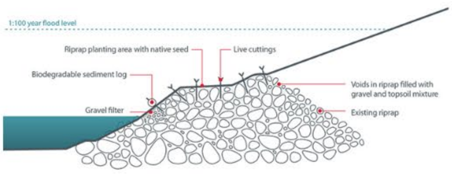
Soil Covered Riprap



Void-filled Riprap and Plug Planting



Void-Filled Riprap and Joint Planting



KEY MONITORING FINDINGS

- **Monitoring from 2019-2028** is considering bank strength, riparian health, and fish and wildlife habitat.
- From the 2023 monitoring it has been found that there are **more fish and wildlife in the area**.
- The growth of the vegetation is successful, with an **80% vegetation survival rate** in the first year .
- **Riparian health has increased** drastically from the original conventional riprap.
- So far there have been **no erosion, scour or displacement issues** to date, suggesting stronger banks.
- The success so far can be **directly attributed to the riparian planting and bioengineering works**.

For more on this project see:
Bioengineering Demonstration and Education Project website: www.calgary.ca/BDEP
RMP Final Program Report: www.calgary.ca/Riparian

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consulting engineers

Photos sourced from Mike Gallant - Kerr Wood Leidal.
All maps and diagrams sourced from the City of Calgary BDEP website

6. PRACTITIONER PERSPECTIVES OF BANK STABILIZATION CHALLENGES IN BC

6.1 SURVEY RESPONSES

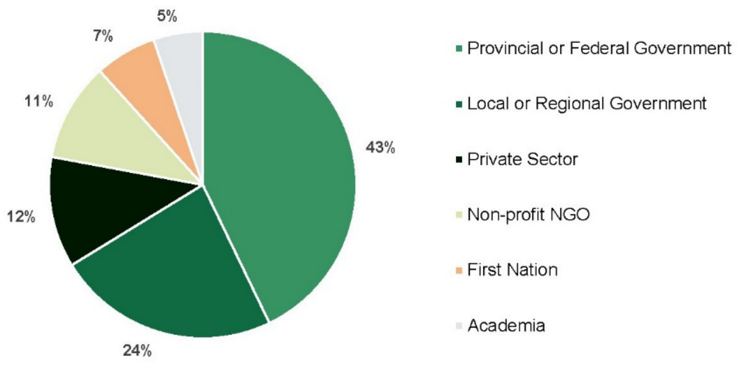

Figure 7. Organizations and sectors of workshop attendees.

Of the attendees who responded to the survey (n=83) the majority were from provincial or federal government, followed by local or regional government (*Figure 7*). When asked about how often bank erosion issues came up in their day to day lives participants reported that the issue was frequently on their minds, with 47% of survey respondents thinking about the issue at least once a week (*Figure 8*).

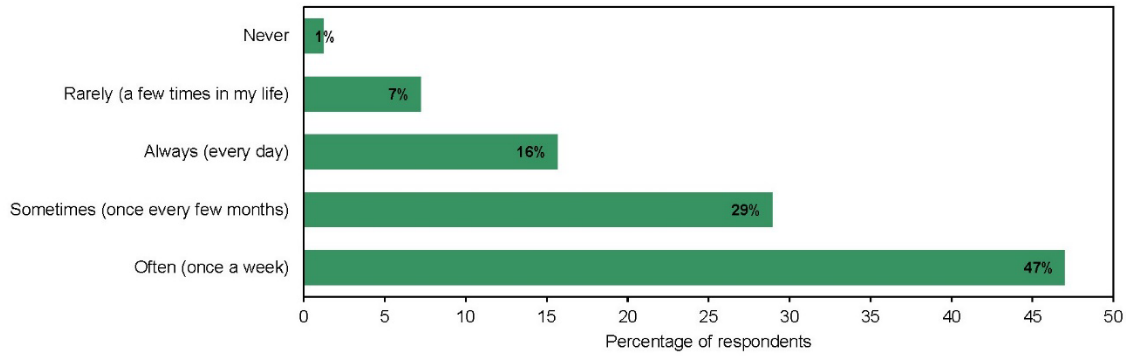

Figure 8. How often workshop attendees think about bank erosion issues through their job/work.

Workshop organizers were interested in what kinds of bank stabilization techniques practitioners are using. Unsurprisingly, the most used technique was hard engineering solutions (*Figure 9*), with 63% of respondents reporting that they used this solution. Encouragingly however, revegetation, hybrid methods, and bioengineering were all also being used, with 60%, 56%, and 49% of respondents using those methods respectively. Practitioners were most interested in learning about bioengineering, hybrid methods, and revegetation at 86%, 78%, and 77% respectively, while very few were interested in learning more about hard engineering solutions.

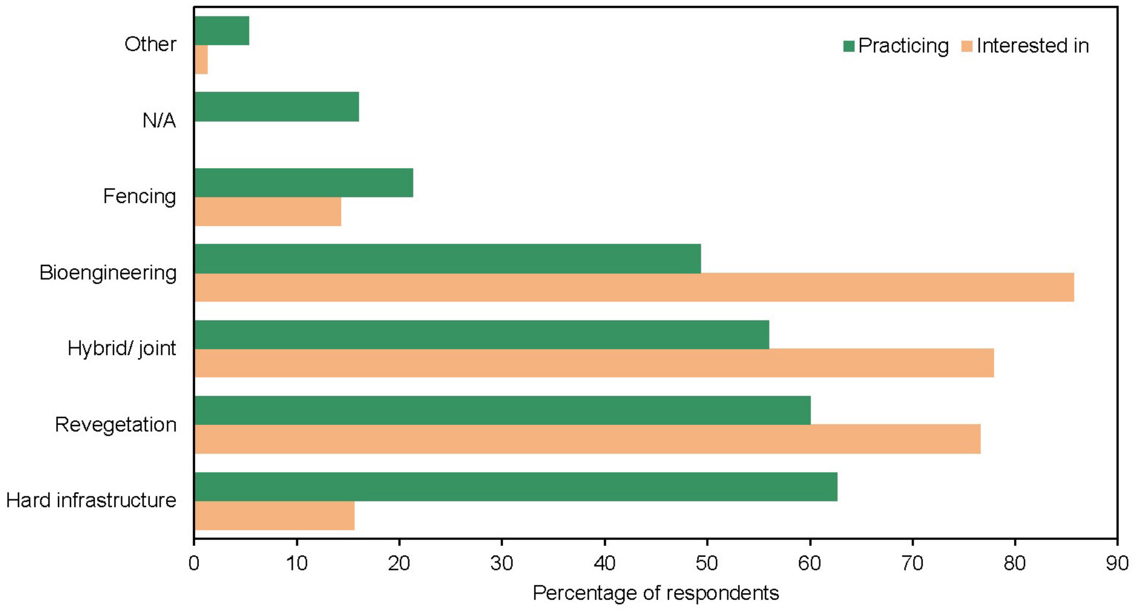

Figure 9. Percentage of workshop attendees who were practicing and/or interested in different bank stabilization technique categories.

Finally, workshop organizers wanted to understand whether participants were aware of any of the detrimental impacts that come with the widespread riprap use seen in BC. 64% of respondents said they had noticed environmental and/or social impacts resulting from riprap use, while 29% were unsure (*Figure 10*).

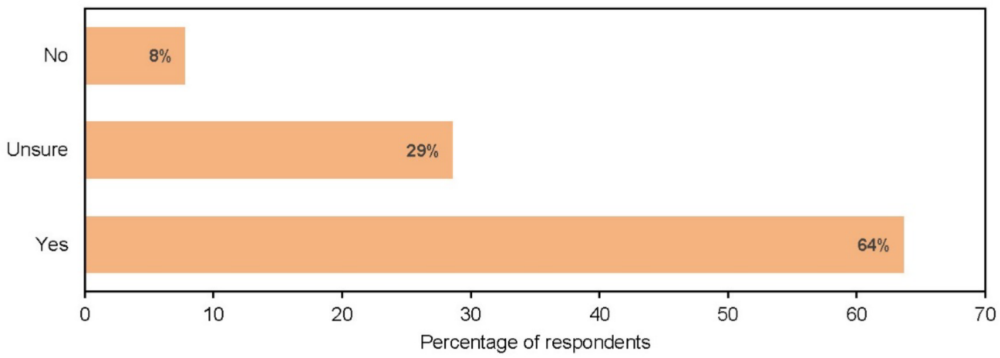

Figure 10. Percentage of workshop attendees who had witnessed adverse impacts from widespread riprap use throughout the BC Lower Mainland.

6.2 FOCUS GROUP RESPONSES

6.2.1 POSITIVE PERSPECTIVES OF ALTERNATIVE BANK STABILIZATION METHODS

Across the group discussion sessions several key themes emerged. Practitioners spoke positively about the use of bioengineering and revegetation methods, many pointing to a changing perspective amongst practitioners and regulators. Participants also identified instances they were aware of where riprap was damaging local environmental or social conditions, and many were aware of case studies around BC where bioengineering and revegetation efforts had been implemented successfully.

"We don't want to see sterile kilometers of riprap"

6.2.2 BARRIERS PREVENTING ALTERNATIVE METHOD IMPLEMENTATION

However, despite the positive opinions towards alternative bank stabilization methods, participants also identified a variety of barriers that are preventing them from implementing these methods. Barriers such as a lack of resources (including materials, funding, and guidance documents), difficulties in getting plans signed off, and poor public perception of 'softer' alternatives were all identified as major barriers preventing wider implementation. These barriers were suggested as exacerbating the current dependency on riprap in BC:

"We know riprap has a negative environmental impact, but it is well-known and there are lots of tools to make the design process easy and straightforward. That is not the case for many bioengineering treatments."

Participants noted that it was this path dependency that was causing many of the widespread riprap issues in BC, with the method being relied upon during 'emergency' scenarios when flooding was occurring. They suggest that these emergency works are being undertaken with little environmental consideration, and once implemented, there is no discussion of revisiting sites to remove or hybridize the riprap.

"The idea is that when emergency bank stabilization is required the permitting and compensation payments are meant to happen afterwards, but in reality this doesn't happen as the rock is placed and then everyone moves on. Risk often outweighs the restoration opportunities, and often excuses works from needing permits or compensation at all."

6.2.3 A NEED FOR SOME HARD ENGINEERING SOLUTIONS

Beyond the identified barriers some participants were not convinced that alternative bank stabilization methods were appropriate in all BC contexts. Many pointed to the need to balance risk and restoration of the environment, suggesting there are times where hard engineering must be used to protect people and assets:

> *“We have to remember that rivers are dynamic systems that are also embedded in a specific social and economic context. There are sometimes considerations related to ensuring societal needs are met that may take precedent and complicate the implementation of new projects.”*

Others also pointed to the many high energy river systems throughout BC, suggesting that hard engineering would always be required along rivers like the Fraser as vegetation or bioengineering alone wouldn’t be enough to prevent erosion. These people pointed to the fact that many positive case studies where alternative measures are being tested are along smaller streams and creeks and do little to inform us how these methods would work in bigger systems. However, these same people suggested that just because riprap may be required, there are better ways it can be implemented to minimize environmental impact, and potentially for it to be hybridized through plug planting and other measures:

> *“Riprap will always be required no matter what, but it’s about what you do with that riprap”*

6.2.4 SUGGESTED SOLUTIONS TO CREATE EASIER ALTERNATIVE METHOD IMPLEMENTATION

Along with the identified barriers, participants made suggestions for how to overcome some barriers, including widespread education, monitoring, funding and partnership efforts. One thing that was mentioned by many participants was the desire for a clear set of guidelines that indicate bioengineering and revegetation bank stabilization options, with clear instructions about their design and approval pathways. Participants were aware of some versions of these documents being currently put together, but there was a desire for additional instruction from regulators themselves.

Figure 11. summarizes the key barriers and solutions identified by workshop discussion group participants.

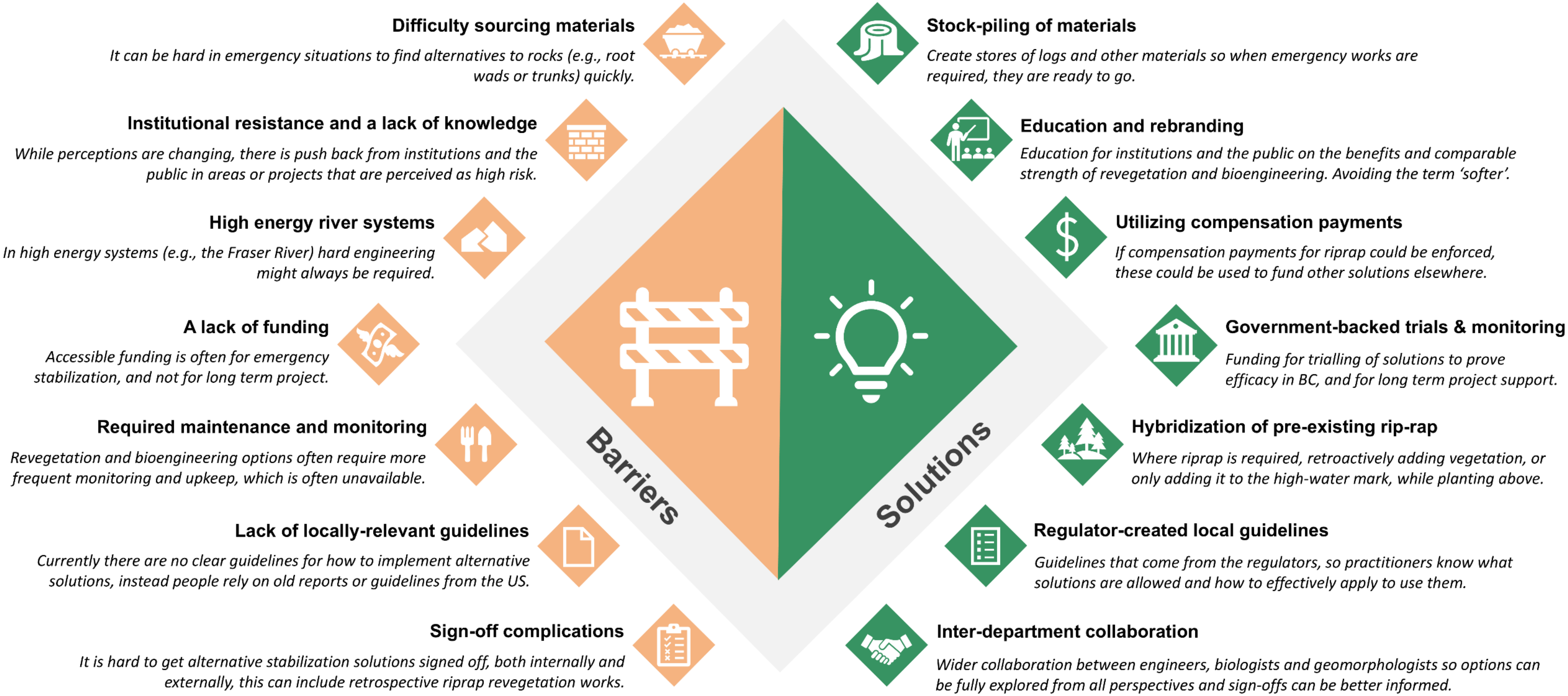

Figure 11. Summary of the main barriers identified by workshop participants as currently preventing wider up take of alternative bank stabilization methods (e.g., revegetation and bioengineering), along with some proposed solutions.

7. CONCLUSIONS

7.1 KEY WORKSHOP RECOMMENDATIONS

From the workshop, several recommendations for how to ensure greater use of alternative bank stabilization methods in BC emerged:

- There needs to be wider education and engagement with both the public and practitioners surrounding the importance and success of hard engineering bank stabilization alternatives. This education would also need to come with greater inter-department and/or inter-disciplinary collaboration to ensure alternative bank stabilization options are being fully supported and designed by both engineers and other specialists (biologists, geomorphologists etc.).
- The current approach to riprap use and installation in BC needs to change. While riprap may always be required in some contexts there are steps that could be taken to reduce the impacts that many practitioners have been witnessing. Things like taking advantage of compensation payments where the riprap is being installed, returning to sites post-flood and hybridizing existing riprap, or stock piling woody debris to act as an alternative in emergency bank stabilization scenarios are all tangible steps that could be taken.
- More resources are needed to support wide-spread uptake of bank stabilization alternatives. These resources need to include government-backed funding for bank stabilization works year-round (not just during hazard events), with opportunities for long term success monitoring. There also needs to be a clear set of design and approval process guidelines created by regulators, so practitioners understand the steps required to get a project approved.

7.2 KEY LITERATURE RECOMMENDATIONS

In addition to the recommendations made from workshop participant responses, several recommendations can also be made for the BC context based on the academic and grey literatures:

- There needs to be greater caution applied to the use of riprap given the known risks of environmental damage that can accompany its use. This is especially true for river systems that are relatively undisturbed, where the potential adverse impacts of hard engineering bank stabilization efforts will be greater.
- There needs to be more research into the potential impact that hard engineering bank stabilization methods may be having on BC's river systems, with a particular need for reported impacts on salmon.
- More research is needed into the success of bioengineering and revegetation bank stabilization techniques in BC, both for decreasing bank erosion, but also for improving river health.
- Other management options beyond bioengineering and revegetation alone also need to be explored in BC. Land-use planning and catchment-scale sediment-

management are just as important as local bank stabilization efforts. Rivers naturally erode, and in locations where it is possible, sometimes the best management option may be to let the river laterally migrate without impediment.

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APPENDIX ONE

Table 12 Summary of common bank stabilization techniques and their pros and cons from the literature.

	Technique	Description	Image	Pros	Cons
Hard Engineering	**Riprap**	Permanent placement of loose rocks to form a hard surface to protect underlying banks from wave/flow energy.	 Wiki commons (2024)	Cheap in comparison to other hard engineering techniques and 'immediate', this is why this bank stabilization technique has been favored in the past.	Can fail due to erosion of the material, or slope failure. It also reduces stream cover, increasing temperature and negatively impacting spawning habitat.
	Retaining walls	Large vertical structures built to withstand bank erosion or failure. Gravity walls, Cantilever walls, and Sheet pilling, are all examples. These options are typically used in urban settings.	 Phi Group (2024)	Reasonably effective at preventing further erosion. Often termed as allowing 'absolute' erosion control.	Offer no habitat at all, and typically cause degradation of the riverbed due to shifting of the erosion forces.
	Gabions	Gabions are rectangular wire boxes filled with stones and soil, often in areas that are too steep for riprap. There can be vegetation at the top of these structures.	 Gabion 1 (2024)	They are easy to install and relatively cheap, also working on steeper slopes than riprap.	Similar to riprap, the cages can fail, the immobility of the cages can also cause erosion in the areas surrounding them. They also create steep slopes when not paired with other interventions..
	Concrete mattresses	Precast concrete blocks typically held together with wire, often used in large rivers.	 Terre Armee (2024)	Are very effective at preventing erosion.	Offer no habitat benefits and can encourage erosion around their boundaries.
	Sacks and blocks	Soil or sand/cement filled blocks that are often used in emergency bank protection scenarios (but are often left semi-permanently).	 ArchiExpo (2024)	A short term, immediate, and cheap fix.	Can be carried off during flood conditions, are only a temporary fix and do not offer habitat benefits.
	Soil-cement	A form of erosion protection where concrete is spread or sprayed over top of a bank.	 U.S. Department of the interior (2013)	Economical and quick to employ.	Impermeable (can increase water flow) and sensitive to temperature change, offering no habitat.
	Rock toe	Placement of rocks along the toe (base) of the riverbank. This can be used in conjunction with re-vegetation efforts which help to stabilize the upper bank.	 Montgomery County (2024)	Often the greatest erosion occurs at the toe of the bank, so addition of a rock toe can create a rapid stabilization improvement.	Offer little habitat improvement when compared to other toe strengthening alternatives such as logs.

Revegetation	**Live staking/ pole plantings**	Live stakes (e.g., Willow) are planted in the banks and grow over time with the root systems strengthening the bank.	 University of Wisconsin (2024)	Relatively simple and cheap to employ.	It can take several seasons for the live stakes to establish their roots deep enough to stabilize the banks against high flow.
	Container/ root stock planting	Planting of container/ root stock meaning the germination or root establishment phase can be surpassed.	 UC Master Gardeners (2024)	Allows faster re-vegetation than other management options.	More expensive than other re-vegetation management options.
	Seeding	Application of seeds along the tops (or sides of low slope banks), to grow into future riparian vegetation.	 Thresh Seed Co (2024)	Very cheap and easy for non-experts to initiate.	Typically, this solution cannot be used as an erosion control solution alone, it needs to be paired with other interventions.
	Mulch berms	The use of mulch cover as an erosion control surface, building up protective berms that vegetation can be planted directly into.	 CalRecycle (2024)	A cheap solution to other more environmentally damaging methods such as silt fences and erosion control fabrics. Does not typically require any upkeep once installed.	Requires vegetation to help stabilize the berms in the long term and may not be appropriate in higher energy systems.
Bioengineering	**Wattles**	Bundles of live cuttings are placed into trenches along the bank to form terraces. Over time the vegetation takes root and stabilizes the bank.	 Green Communities (2024)	Protects the bank from runoff erosion and provides sediment control at a relatively cheap price. Can be implemented on reasonably steep slopes.	While it may provide some toe protection, it will be limited as the branches will not grow below the water level. Therefore, it needs to be combined with other toe protection (e.g., logs)
	Brush mattress	Live branches are bound together into mats and held in place with stakes or twine. Over time the mats degrade, leaving behind the new established vegetation.	 Wildscape Engineering (2024)	Useful in areas where high flows would otherwise prevent vegetation establishment.	Not appropriate for steeper slopes and requires a large amount of vegetation.
	Coir/ Fiber rolls	Made from fibrous material, these rolls are placed along banks and can allow for short term scour protection, and then longer-term substrate for vegetation growth.	 Erosion Control Products (2024)	Are flexible, easy to install and cause little site damage.	Not suitable for long-term bank toe protection, may need to be paired with rock toes or log crib.

	Tree revetments	Anchoring trees, typically through the cabling of live trees and brush together to form an erosion barrier and location for fine sediment to rebuild in the bank.	 Alaska Department of Fish and Game (2024).	Good for protecting the main bank between the toe and the top, offering dense vegetation cover.	Needs to be paired with other re-vegetation techniques for the top of the slope.
	Brush layering/ packing	Involves the horizontal layering of brush layers and soil layers, typically used for banks where there is severe slumping/failure. The technique can also be used in isolated holes.	 LaRiMit (2024)	Can be used to immediately strengthen slumping bank areas, or to spot-fill smaller holes, even on relatively steep banks.	Needs to be done in conjunction with other techniques and is not suitable for areas with failure that exceeds 1.2m deep or wide.
	Log cover	Logs can be placed crib-style to strengthen banks, and particularly the bank toe. Vegetation is then planted in between the logs. Non-crib log cover can also be used as an opportunity to increase fish habitat complexity.	 Terra Erosion Control Ltd. (2024a)	Cheap and good for strengthening the bank, bank toe, and providing fish habitat (if non-crib logs are added too).	Limited to about 2m in height for best effects and needs to be paired with other techniques (e.g., wattles) for upper bank protection.
Riparian area fencing		Useful in areas where there is livestock actively causing bank mass movement issues. This can protect the pre-existing vegetation and state of bank strength.	 Flickr.com	Can prevent degradation from worsening and can save money in the long term.	Can be expensive for landowners.
Joint Plantings (Hybrid)		Combining riprap with live staking or root plus to create a vegetated armored bank.	 Terra Erosion Control (2024b)	Can lessen the environmental impacts of riprap or other hard engineering measures and add additional root strengthening in the long-term.	It is difficult to encourage vegetation growth on riprap, and in the years, it takes for substantial growth to occur the same riprap issues listed above will be ongoing.
Flow Control Structures		These structures aim to reduce the hydrodynamic forces to decrease the need for additional bank stabilization. Groynes, Drop Structures and Guidebanks are some flow control examples.	 Carlton Edu. (2024)	Can prevent the need for engineering or other bank stabilization techniques entirely.	Can alter river behavior. While structures may slow down water velocity, reducing erosion, this may cause slower backwaters elsewhere, encouraging sediment deposition and fines accumulation, negatively impacting habitat and flood risk).

APPENDIX TWO

Table 13. Additional grey literature on bank stabilization methods, relevant to British Columbia.

Reference	Description	Web link
Ministry of Agriculture, Food and Fisheries. (2004). Ditch bank stabilization techniques. *Constructed Ditch Factsheet*. Government of British Columbia.	Offers a brief summary of commonly used hard and more natural ditch bank stabilization measures in BC. This factsheet also lists the common pros and cons of each technique, along with likely relative costs and maintenance requirements.	https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/water/drainage-management-guide/533430-1_ditch_bank_stabilization-drainage_guide_factsheet_no10.pdf
British Columbia Ministry of Forests. (2001). Best management practices handbook: hillslope restoration in British Columbia. *Resource Tenures & Engineering Branch.*	Offers a list of different bank stabilization approaches, along with their best practices. A little outdated but still useful.	https://www.for.gov.bc.ca/hfd/pubs/docs/mr/Mr096.htm
Ministry of Agriculture, Food and Fisheries. (2004). Bioengineering Techniques. *Constructed Ditch Factsheet.* Government of British Columbia.	A factsheet about bioengineering options in BC, offers quick summaries and diagrams for each. Created by the Government of BC.	https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/water/drainage-management-guide/533431-1_bio-engineering_techniques-drainage_guide_factsheet_no13.pdf
Polster Environmental Services. (2003). Alternatives for bank stabilization – literature review. *Prepared for Streambank Erosion BMP Steering Committee.*	A Canadian-wide perspectives. Offers detailed definitions, descriptions and images for each of the major bioengineering techniques.	https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/277708.pdf
Ministry of Forests, Lands and Natural Resource Operations. (2016). Appendix 4: RAR revegetation guidelines for brownfield sites. In *Riparian Areas Regulation Guidebook for Local Governments*. Government of British Columbia.	Offers good, relatively recent insight into specific bank stabilization approaches that can be used in BC Brownfield sites.	https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/fish-fish-habitat/riparian-areas-regulations/rar_reveg_guidebk_sept6_2012_final.pdf
United States Department of Agriculture. (2007). Treatment Technique Design. *Stream Restoration Design National Engineering Handbook.*	A US perspective but covers a wide range of techniques (soil bioengineering, large woody material, riprap, vegetated rock walls, etc.).	https://irrigationtoolbox.com/NEH/Part%20654/CHAPTERS/Chapter-14.pdf
Baird et al., (2015). Bank stabilization design guidelines. *Reclamation: Managing Water in the West.* U.S. Department of the Interior.	A wider Pacific Northwest perspective, but still useful for outlining the guidelines followed over the border in Washington.	https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/A-BankStab-final6-25-2015.pdf
South Coast Conservation Project. (2015). *Restoring habitat for species at risk on bc's south coast module 3 - stream and riparian communities*. Diversity by Design.	Has some more helpful information about revegetation efforts including when and where to plant, and the species which are reliant on riverbank areas.	https://sccp.ca/sites/default/files/resources/documents/Diversity%20by%20Design_MODULE%203_riparian_Single.pdf

City of Surrey. (2021). Habitat structures. *Biodiversity design guidelines.*	This recent publication is useful for considering the improvement of riprap areas.	https://www.surrey.ca/sites/default/files/media/documents/BiodiversityDesignGuidelines_HabitatStructures.pdf
Ministry of Transport and Highways. (1997). *Manual of control of erosion and shallow slope movement*. Vancouver Island Highway Project.	Information about stabilization options to minimize road impact in the BC context.	https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/engineering-standards-and-guidelines/environment/references/man_control_erosion.pdf

APPENDIX THREE

Workshop Survey Questions:

1. How much does bank degradation impact you in your work or life?
    a. I rarely think about riverbank degradation or bank stabilization.
    b. I sometimes need to consider bank degradation and stabilization, but only when there is a case of extreme erosion.
    c. I often think about bank degradation and use bank stabilization methods in my work/ to protect my property.
    d. Bank degradation and various bank stabilization techniques are a major part of my work or a major concern in my life.

2. What bank stabilization techniques had you employed/ been involved with in the past? (please select all applicable categories).
    a. Hard infrastructure bank stabilization (including riprap, retaining walls, gabion cages etc.).
    b. Hybrid/ joint plantings (hard engineering options such as riprap, but with vegetation planting included).
    c. Revegetation of the banks and immediate riparian area (live stakings, root planting, seeding).
    d. Bioengineering (including wattles, coir/fiber rolls, brush mattresses/logs, tree revetments etc.).
    e. Fencing alongside the bank.
    f. Not applicable to me.

3. What bank stabilization technique categories are you most interested in learning about/utilizing in the future? (please select all applicable categories).
    a. Hard infrastructure bank stabilization (including riprap, retaining walls, gabion cages etc.).
    b. Hybrid/ joint plantings (hard engineering options such as riprap, but with vegetation planting included).
    c. Revegetation of the banks and immediate riparian area (live stakings, root planting, seeding).
    d. Bioengineering (including wattles, coir/fiber rolls, brush mattresses/logs, tree revetments etc.).
    e. Fencing alongside the bank.
    f. None of the above options.

4. Have you noticed any detrimental environmental and/or social impacts from past bank stabilization efforts?
    a. Yes
    b. No
    c. Unsure

Workshop Group Discussion Facilitator Interview Schedule:

In your breakout groups please discuss the following questions. Please spend a maximum of ~6mins per question, assigning a timekeeper, if needed.

1. What major bank degradation issues are you noticing at the moment?
2. What problems are you see with typical bank stabilization methods (e.g., riprap) vs. softer revegetation or bioengineering bank stabilization solutions and everywhere in between?
3. In your perspective what would allow wider adoption of nature-based solutions in bank stabilization? (e.g., governance, policy, regulation, public opinion…)
4. Have there been any exciting projects or policies you are aware of where innovations in bank stabilization practices are occurring?

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