Playbook to Guide Landscape Recovery Strategies & Priorities for Salmon Habitat Following Major Wildfires

Version: 1.2
October 2024

PACIFIC SALMON FOUNDATION

FOREWORD

Described regularly as 'iconic', Pacific salmon populations have been, and continue to be, relevant to cultures, economies and ecosystems across British Columbia (BC). For millennia, their value, abundance and availability shaped Indigenous cultures. This carried forward into 'post contact' cultures when commercial canneries strategically dotted BC's coastline. Humanity's enduring value and esteem for these stocks is well placed and, to this day, salmon remain central to Aboriginal, recreational and commercial fisheries.

Salmon populations usually migrate from low nutrient spawning and/or rearing habitats to distant and highly productive marine environments, where they access abundant prey and rapidly mature. Pink salmon emerge from spawning gravels as ¼ gram fry, immediately migrate to the Pacific Ocean and, in just over two years, can return as 2.2-kilogram adults—a 9,000-fold weight gain! And the size of the returning runs can be as sensational. In 2010, 28.2 million sockeye salmon returned to the Fraser River and delivered over 85 million pounds of biomass upstream. Those that avoided harvest and predation enroute to the spawning grounds, ultimately expired, decomposed and fertilized the Fraser River Basin, to the benefit of their offspring and the entire ecosystem. Collectively, salmon populations can be viewed as autonomous conveyor belts that deliver vast quantities of ocean-derived nutrients, against prevailing currents, to the benefit of freshwater watersheds and their associated food webs. This has earned them the reputation of being keystone species, meaning their fundamental inputs often shape the ecosystems they occupy. As profound, their nutrient inputs fertilize ecosystems and supercharge forest growth, which enhances carbon sequestration and combats climate change.

Sockeye—delivering beauty and nutrients (Photo credit: Pacific Salmon Foundation)

Beyond their ecological contributions, salmon exemplify the interconnectedness of marine and freshwater ecosystems and give meaning to the expression “think globally, act locally”. As their fortunes rise and fall, so too do those of coastal and inland ecosystems. Similarly, the interconnectedness of economies is also revealed, as nations and cultures strive to share the bounty, while attempting to avoid overharvest and what Gareth Hardin famously termed the ‘Tragedy of the Commons’.

While the traditional challenges relating to the management of harvests and habitats have only increased with human population growth, salmon populations now face the alarming spectre of a warming planet. Our current geological age, proposed by some as the ‘Anthropocene’, is described as a stage when human activity is the dominant influence on climate and the environment. No longer theoretical, climate change has already altered temperature regimes, increased the frequency of severe weather events and changed precipitation patterns the world over. This has impacted even the mightiest of BC’s rivers and compounded pre-existing limitations—be they natural or human-caused. In BC, the wildfire seasons of 2017, 2018, 2021 and 2023, and the heat dome and flooding of 2021, are all consistent with climate change predictions and have negatively impacted watersheds and salmon habitats.

It should come as no surprise, therefore, that many BC salmon populations are in trouble, especially those that spawn and rear in the larger river basins that drain the warmer and drier regions of the province and where low flows and heightened water temperatures have traditionally limited salmon productivity. While the Fraser and Columbia Basins will spring to mind, the Skeena and southeast Vancouver Island watersheds are also experiencing droughts and/or low flows with greater frequencies. As a result, the list of potential ‘at risk’ salmon populations is growing. As of June 2024, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) had undertaken status assessments and identified 45 Designated Units for BC salmon in BC as falling into Special Concern, Threatened, Endangered or Extinct categories. This includes 22 Chinook, 1 coho, 20 sockeye and 2 steelhead Designated Units. Predictably, most of these populations spawn and rear in the aforementioned basins/areas.

The recent wildfires in BC have brought new climate change-related vulnerabilities into focus. Individual fires have exceeded 100,000 hectares (ha) in size and have engulfed entire watersheds at scales and intensities that signal a possible shift in the disturbance patterns experienced in the 20th century. The resultant alterations in soils and the loss of vegetation combine to influence stream flows and temperatures, channel morphology and water quality, and these impacts threaten to push some salmon populations beyond their ability to adapt. This is especially true for those populations that are already ‘at risk’ and limited by factors worsened by wildfire.

Despite these challenges, there remains room for optimism and action. Salmon populations have proven to be both adaptive and resilient. They have evolved to exploit dynamic, even ephemeral, freshwater habitats shaped by complex sets of environmental processes and pressures. Natural selection continues to groom freshwater life histories by tailoring migration, egg deposition and rearing strategies to suit prevailing, yet dynamic, conditions. And climate change is redistributing opportunities. While populations of coho, Chinook and steelhead stubbornly return to historic habitats in northern California watersheds, other salmon populations are actively colonizing streams that now flow where glaciers once stood. We are now bearing witness to the expansion of Chinook, coho, sockeye, chum, and pink salmon into the Arctic Ocean and its rivers. These shifts surely come as a mixed blessing, but they suggest the survival of 'salmon' may not be the immediate challenge; rather, it is the loss of individual populations across historic ranges.

This Playbook is founded on the belief that salmon populations are resilient, and that, in the aftermath of wildfires, people can come together to make meaningful, on-the-ground changes to accelerate salmon habitat and population recovery at watershed scales. Strong forces are working to the detriment of salmon in many portions of their historic range. However, with increasing regularity, First Nations, governments, agencies, industries and stakeholders are organizing themselves and collaborating in support of environmental imperatives. Resources, expertise and a diversity of world views are at hand and new models for creativity, cooperation and empowerment continue to emerge. These are the ingredients that must be drawn together if we are to maintain ecosystems and salmon populations and secure opportunities for following generations.

Foreword provided by Jeff Morgan, MSc, RPBio

EXECUTIVE SUMMARY

Wildfires are expected to become larger, more intense and more frequent in British Columbia (BC), yet the province has lacked a specific framework to guide the integration of initiatives for watershed and salmon habitat recovery at both strategic and operational levels. Accordingly, the *Playbook to Guide Landscape Recovery Strategies & Priorities for Salmon Habitat Following Major Wildfires* (hereafter, the Playbook) proposes a 'framework', which borrows from long-established approaches to watershed planning, risk management and habitat restoration, with salmon placed at its centre.

Today's challenges occur in the context of the climate change signals, which include: 1) decreased snowfall and snowpacks; 2) earlier spring runoff; 3) increased rainfall and rainfall intensity, with higher frequency of extreme runoff, atmospheric rivers and flood events; 4) increased frequency of heatwaves; and 5) increased drought frequency. These changes invariably interact with existing human-caused impacts and alter watershed processes in a way that can negatively affect river channel morphology, habitat quality, and water availability, quality and temperature in important salmon streams.

One of the most striking climate change implications has been the recent wildfire trend. Wildfire-climate models for BC have predicted a higher frequency of large wildfires, and this has come to pass. Between 1990 and 2001, BC wildfires burned an average of 30,000 ha per year. In the 2017 and 2018 wildfire season records were set, when 1.2 million ha and 1.4 million ha, respectively, were burned. The total area burned in 2021 again approached those figures, while the fires of 2023 shattered all records, as the total area burned exceeded 2.8 million hectares.

Wildfire impacts combine and interact with pre-existing human disturbances and impact fundamental watershed processes and the salmon habitats they sustain. Thus, any attempt to recover a watershed and its salmon habitat values must be founded in an understanding of how these variables interact and what the implications for salmon and their habitats might be. Wildfire and other disturbances impact watershed controls and this, in turn, influences the quality and quantity of salmon habitats and our ability to recover them. In many cases, a return to 'what was' may not be possible, and salmon recovery teams will have to probe 'what is possible' and 'what is desired' based on environmental trajectories and the resources at hand. Therefore, watershed and salmon habitat recovery initiatives should be founded in a strong mechanistic understanding of watershed and salmon habitat dynamics. This highlights the need to develop an approach to assess both salmon habitat values and the processes by which they may be placed at risk. This then sets the stage for investments in additional quantitative information and risk management considerations.

Given the scale, complexity and importance of watersheds, recovery initiatives can consume large amounts of human resources and capital. Recovery teams and individual practitioners are asked to sort through arrays of information involving values, impacts and risks and then devise and implement cost-effective mitigation and recovery-oriented treatments and strategies. The Playbook directs practitioners to important information sources, assessment techniques and risk management tools that will guide information gathering and acquisition processes and promote the use of risk management frameworks to organize strategic,

watershed-level thinking, which can then inform and align the selection of treatments and strategies and the development of plans at all levels.

A listing and description of treatments, strategies and implementation advice is provided to help recovery teams as they grapple with many values ('at risk elements'), impacts and risks within highly variable operational environments. Treatments were organized into immediate, process-based and form-based categories as a means to place them, and their utility, in the context of watershed processes and real-world challenges. Beyond treatments, the Playbook describes 'strategies', which coordinate a variety of treatments to address common values and elements at risk within the watershed.

Ultimately, the 'art' of watershed recovery involves pairing treatments and strategies to the impact and risk factors that will, or may, affect the known watershed values and elements at risk at appropriate scales and in a manner that produces the desired benefits. Therefore, *en route* to objective setting, post-wildfire recovery initiatives must recognize and quantify the watershed values of interest and the current impacts and risks that may affect them. This involves placing impacts, risks, values and elements at risk within a spatial context to support decision making. Further, planning and recovery interventions for salmon must be coordinated with the management of other resource values and they must be designed and implemented in a manner that recognizes the rights, authorities and interests of others and pre-existing legal obligations, policy, agreements and plans. Planners and decision makers must also contend with many practical considerations including: 1) cost-effectiveness; 2) expected benefits over time; 3) potential risks/impacts that the treatments pose to the watershed and other resources; 4) logistics (e.g., access); and 5) community values.

Beyond goals and objectives, plans at all scales must clearly articulate a vision for implementation. This vision may be expressed in many forms, but a road map for the continuance of the planning cycle and a willingness to continually monitor outcomes and adapt (as required) are key. Above all, the planning process should be flexible and prepared to absorb change. While recovering from one wildfire may be the task at hand, it is likely that other perturbations will occur before recovery, by any definition, is achieved. Thus, having the ability to adjust and compliment, or accommodate, new impacts and challenges will be a critical asset.

The planning process must also set the stage for implementation and monitoring. Continuous adaptive management, particularly for larger plans with longer timelines, relies on taking careful management actions, continuously monitoring to track progress, and generating learning opportunities to improve upon the design of treatments, models, strategies, implementation activities and monitoring methodologies.

Unique combinations of watershed characteristics, wildfire impacts, salmon populations and habitat values, authorities, rights holders and interests will emerge within post-wildfire settings, and highly varied circumstances will lead to differing recovery processes and solutions. With this complexity in mind, the overarching goals of the Playbook are to:

- provide advice on recovery of salmon habitats and watersheds and promote its integration into post-wildfire responses;
- provide a strategic/framework approach to help guide the recovery of salmon watersheds following major wildfires;
- show members of the restoration community how and where they fit into the ‘big picture’ and how they can most effectively influence recovery; and,
- instill a sense of community by fostering collaboration among the various entities that have roles and responsibilities relating to salmon and their habitats.

The specific objectives of the Playbook are to:

- consolidate information and provide a framework with advice to support planning processes and recovery actions for wildfire-impacted watersheds including:
    - an overview of salmon habitat requirements, the watershed processes that shape them, and relevant wildfire impacts;
    - an overview of resource management governance and roles and responsibilities;
    - advice for developing effective and appropriate multi-party relations and land-use planning processes (strategic to operational);
    - guidance on the development of risk management approaches to accelerate salmon watershed and habitat recovery. This approach includes the acquisition and use of both relevant Indigenous Knowledge and existing western sources of information (e.g., geospatial information, scientific and technical information, assessment and monitoring techniques, policy, and restoration strategies and methodologies);
    - a toolbox that outlines treatment options and management strategies for consideration in post-wildfire recovery situations;
    - guidance for the development and implementation of watershed recovery plans at many levels; and,
- identify opportunities for improvements in information, science, policy, and processes that are relevant to post-wildfire watershed recovery.

The unfolding reality of climate change is altering watershed processes and impacting many economic, social and cultural values that relate to Pacific salmon. Beyond salmon, many other valued ecological goods and services, such as biodiversity, water quality and quantity, and community safety, are also being affected. In BC, these values have long been managed by four levels of government (First Nations, federal, provincial, and local) and further influenced by rights holders, stakeholders, and non-government organizations. Accordingly, if the stewardship of salmon populations and their watersheds is desired, the many different, yet interlocking, authorities and influences must work effectively and cooperatively in the development and implementation of any watershed management plans and/or habitat recovery projects. Accordingly, the guidance found in this Playbook is intended to draw *all* governments, agencies, authorities, rights-holders and stakeholders together so that salmon-focused recovery activities can be structured, understood and executed to maximum effect and coordinated with the many actions that address other existing values. It is hoped that, in its totality, this work will facilitate the integration of salmon habitat recovery efforts into post-wildfire planning and operational activities, empower all participants and advance the concept of a 'watershed recovery community'. If ever there was a time for unity and action for the sake of Pacific salmon and their watersheds, it is now.

ACKNOWLEDGEMENTS

Jason Hwang and Jeff Morgan of the Pacific Salmon Foundation (PSF) developed the vision for *Playbook to Guide Landscape Recovery Strategies & Priorities for Salmon Habitat Following Major Wildfires* (the Playbook) and provided constant guidance during the development of this document. Jeff also served as the managing editor and a contributing author for the Playbook.

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The development of the Playbook relied on the dedication, thoughtfulness and experience of its Management Advisory Committee, Working Group and Advisory Body to help the project through its various stages. The Management Advisory Committee provided strategic advice relating to the goals, objectives, scope, presentation and tone of the document. The Working Group provided operational advice that was scientific/technical in nature or presentation related. By providing both strategic and operational advice *after* the Playbook was in draft form, the Advisory Body contributed to content improvements and provided an important final check.

Members of the Management Advisory Committee, Working Group and Advisory Body, who provided input, feedback and advice, as individuals or from within federal and provincial agencies, non-government organizations (NGOs), various First Nations entities, academics, and consultancies, are recognized in the acknowledgements that follow. This level of participation helped to garner the diversity of expertise and perspectives required to deliver a product of this nature. That stated, participation in no way 'binds' individuals or their organization to the Playbook's content. While the PSF is grateful for the wisdom and advice received, it is solely responsible for the content and tone of this document. Finally, it must be recognized that the PSF is an NGO with no resource management authority. Accordingly, the Playbook and all associated products must be viewed as 'advisory'.

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The project to develop the Playbook, including the associated *Catalogue of Existing Information*, was funded by a grant from the British Columbia Salmon Restoration and Innovation Fund (BC SRIF) to the PSF.

DEDICATION

This document is dedicated to the memory of Todd French (1966 to 2022), a devoted aquatic scientist and kind soul, who left this world too soon. As the Original Managing Editor of this project, Todd worked tirelessly to manage, research, compile the work of contributors, and write numerous sections for this timely and critically important document, the *Playbook to Guide Landscape Recovery Strategies for Salmon Habitat Following Major Wildfires*.

Todd's career spanned more than three decades, focusing on the study and management of aquatic ecosystems and watershed health, working in both academic research and consulting. He was well known and respected by many. Todd was genuine. He cared immensely about people and the environment and always wanted to make a positive difference. Todd's enthusiasm for environmental research and learning something new, his willingness to share his immense knowledge, and his readiness to help or mentor others, are just a few of the things for which he will always be admired and remembered. Todd leaves behind a tremendous legacy in the biological science community; he made a difference and will be missed dearly.

The Todd French Memorial Award, a scholarship created to help students further their studies in the aquatic sciences, has been established at the University of Northern British Columbia (UNBC). To donate, please visit www.unbcgiving.ca.

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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
ABCFP	Association of BC Forest Professionals
AS	aggregate stability
BC	British Columbia
BC MoE	British Columbia Ministry of Environment
BC MoELP	British Columbia Ministry of Environment, Lands and Parks
BC MoFLNRO	British Columbia Ministry of Forests, Lands, and Natural Resources Operations
BEC	Biogeoclimatic Ecosystem Classification
CAP	Channel Assessment Procedure
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CU	conservation unit
CWAP	Coastal Watershed Assessment Procedure
DFO	Fisheries and Oceans Canada
DU	designated unit
ECA	Equivalent Clearcut Area
ECCC	Environment and Climate Change Canada
ECCS	British Columbia Ministry of Environment and Climate Change Strategy

Acronym/Abbreviation	Definition
EGBC	Engineers & Geoscientists of British Columbia
EMCR	British Columbia Ministry of Emergency Management and Climate Readiness
ERP	Ecosystem Restoration Plan
ESI	Environmental Stewardship Initiative
FDIS	Field Data Information System
FFHI	Fish Habitat Inventories
FHAP	Fish Habitat Assessment Procedure
FHIIP	Fish Habitat Inventory & Information Program
FIDQ	Fisheries Inventory Data Queries
FISS	Fisheries Information Summary System
FREP	Forest and Range Evaluation Program
FRPA	*Forests and Range Practices Act*
GIS	Geographic Information System
Gov. BC	Government of British Columbia
HRU	hydrological response units
IAP	Interim Assessment Protocol
IWAP	Interior Watershed Assessment Procedure
LiDAR	Light Detection and Ranging
MOF	British Columbia Ministry of Forests
NDT	natural disturbance types
NGOs	non-governmental organizations
OCF	Office of the Chief Forester
PAH	Polycyclic aromatic hydrocarbons
Playbook	Playbook to Guide Landscape Recovery Strategies & Priorities for Salmon Habitat Following Major Wildfires
PSF	Pacific Salmon Foundation
RAB	Resource Analysis Branch
RAMS	Risk Assessment Methodology for Salmon
RIC	Resource Inventory Committee
RISC	Resource Information Standards Committee
SARA	*Species at Risk Act*
SIFT	Soil Information Finder Tool
SRZ	Special restoration zone
SWAT	Soil & Water Assessment Tool
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
USGS	United States Geological Survey
WAP	Watershed Assessment Procedure
WHPOR	Watershed Health Project Omineca Region
WLRS	British Columbia Ministry of Water, Land and Resource Stewardship
WRP	Watershed Restoration Program
WSC	Water Survey of Canada
WSEP	Watershed Status Evaluation Protocol

1 INTRODUCTION

With climate change, wildfires are expected to become larger, more intense and more frequent in British Columbia (BC). Yet, the province lacks a specific framework to guide the integration of initiatives for salmon habitat recovery at both strategic and operational levels. As such, this *Playbook to Guide Landscape Recovery Strategies & Priorities for Salmon Habitat Following Major Wildfires* (hereafter, the Playbook) proposes a 'framework', which borrows from long-established approaches to watershed planning, risk management and habitat restoration, with salmon placed at its centre. Various combinations of watershed values and impacts and social and economic factors will produce unique and watershed-specific challenges, opportunities and solutions. However, a consistent *approach* to developing and executing watershed and salmon habitat recovery strategies will be of value and is outlined herein.

Effective recovery initiatives should be founded on informed and well-reasoned restoration activities. Less obvious is the need for guidance on the identification of impacts and risks to salmon habitats and how to devise, prioritize and implement strategies and treatments that address factors most limiting to salmon. It is hoped that the guidance found in this Playbook will draw *all* governments, agencies, authorities, rights-holders and stakeholders together such that salmon-focused recovery activities can be structured, understood, and executed to maximum effect and coordinated with the many actions that address other existing values, human activities and watershed recovery.

In pursuit of this vision, the Playbook is intended to provide comprehensive guidance for practitioners and teams involved in the restoration of salmon (i.e., Chinook, coho, sockeye, chum and pink salmon and steelhead trout) habitats within wildfire-impacted watersheds. While scientifically defensible, this Playbook is not overly technical. Instead, it presents overview information and a framework that describes how concerned authorities, people and disciplines can come together, structure their thinking and take action. All members of the 'recovery community' should see how they fit into the big picture, through the various authorities and disciplines, from strategic to operation, and from policy to action.

This document focuses on post-wildfire responses. The value of pre-wildfire planning at strategic and tactical levels cannot be over-emphasized. Stand structure, species composition and forest-type juxtaposition are but a few of the variables that could be considered. While these pre-wildfire planning concepts are generally beyond the scope of the Playbook, some overlap with post-wildfire responses does occur—especially as we consider reforestation and the inevitability of future fires within the watersheds we would hope to recover. As such, these topics are identified in Section 5.3, which addresses the amalgamation of treatments into post-wildfire strategies. Similarly, while this document does convey the need to address the interaction of wildfire impacts within the context of pre-existing cumulative effects at all scales, it does not provide commentary on existing resource use practices, including wildfire suppression, or planning that might occur prior to wildfire disturbance. Again, based on the importance and interconnectedness of these concepts, it is likely that climate change will compel new practices and approaches to land use planning; however, these topics are beyond the scope of this document.

1.1 RATIONALE FOR A PLAYBOOK

Climate change signals observed in BC include: 1) decreased snowfall and snowpacks; 2) earlier spring runoff; 3) increased rainfall and rainfall intensity, with higher frequency of extreme runoff, atmospheric rivers and flood events; 4) increased frequency of heatwaves; and 5) increased drought frequency. These changes often combine with human-caused impacts and alter watershed processes in a way that can negatively affect river channel morphology, water quality, temperature and water availability in important salmon streams.

One of the most striking ecological implications of climate change has been the recent wildfire trend. Wildfire-climate models for BC predicted a higher frequency of large wildfires, and it would seem this has come to pass.[1] Between 1990 and 2001, BC wildfires burned an average of 30,000 ha per year. In the 2017 and 2018 wildfire season records were set, when 1.2 million ha and 1.4 million ha, respectively, were burned. The total area burned in 2021 again approached those figures and the fires of 2023 shattered all records as the total area burned exceeded 2.8 million hectares. At 619,000 ha, the 2023 Donnie Creek wildfire is BC's largest wildfire on record. While it did not involve salmon-bearing watersheds, other wildfires of the same order of magnitude have occurred in the Columbia, Fraser, Stikine and Liard River Basins.

In addition to the effects of climate change, forest management and fire prevention activities have often resulted in increased fuel loading, which in turn have increased the proportion and frequency of high severity wildfires.[2] In the past, wildfires have played an important ecological role that involved trade-offs for salmon—especially when viewed over large areas and longer time periods. However, as BC wildfires have trended upwards in size (and possibly severity) and consumed large portions of watersheds that are important to at-risk salmon populations, it is likely that the productivity and viability of many salmon populations will be placed at increased risk.

The fires that occurred in BC between 2017 and 2023 were roughly clustered in to five distinct geographic areas, with the largest cluster involving critical spawning and rearing areas for Pacific salmon in the upper and middle Fraser River sub-basins (Figure 1). The spatial pattern of the recent wildfires in BC (Figure 1) aligns with the province's natural disturbance types presented in Figure 2. More specifically, forests that are 'initiated' or 'maintained' by fire (i.e., natural disturbance types [NDT] 3 and 4) occur in the drier areas of the province and are more prone to wildfire. The large wildfires of 2017, 2018 ,2021 and 2023 were concentrated in these NDTs.

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[1] Nitschke and Innes 2008; Nitschke and Innes 2012; Hanes et al. 2019

[2] Forest Practices Board 2023

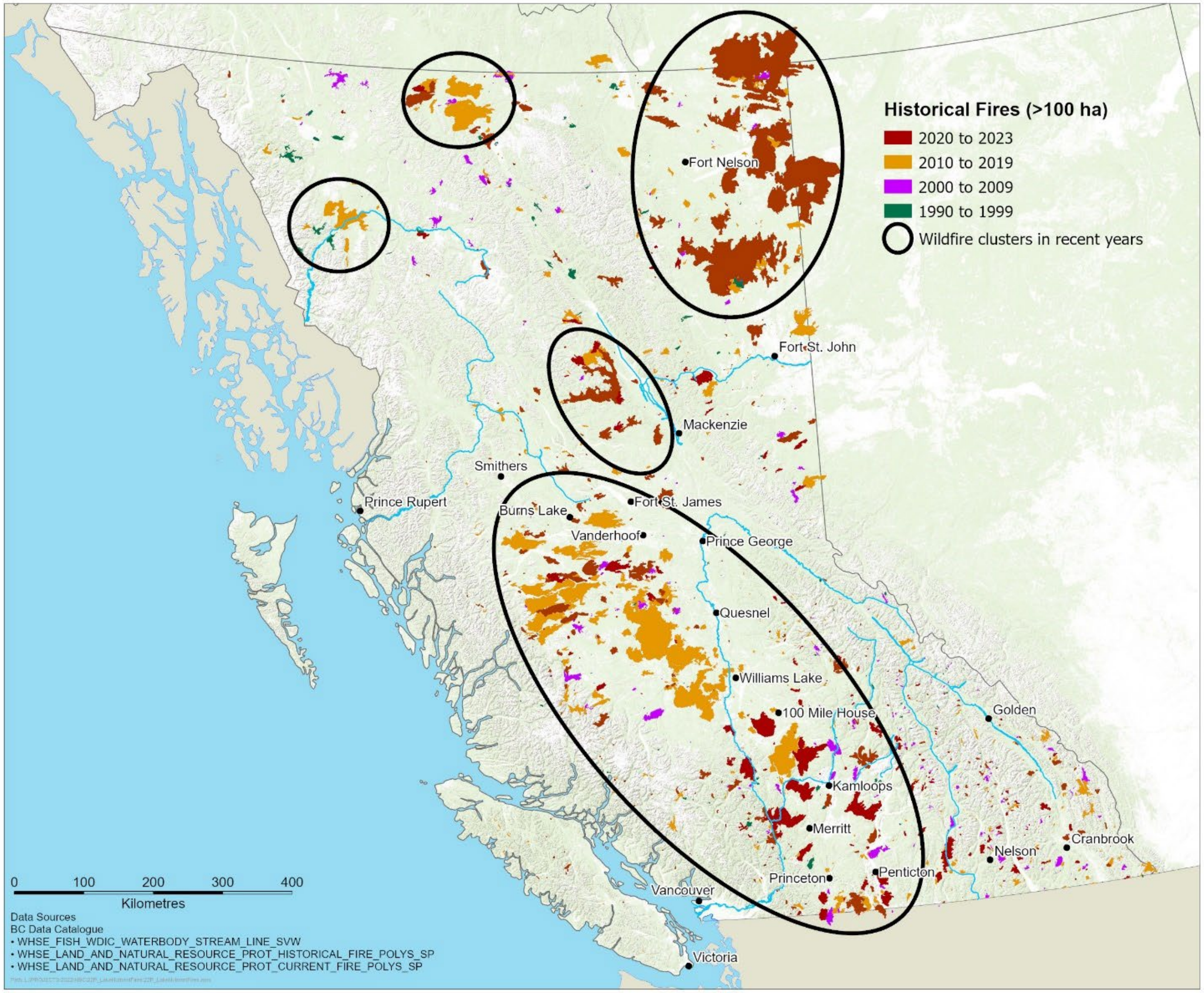


Figure 1. Distribution of BC wildfires greater than 100 ha for the period of 1990 to 2023.

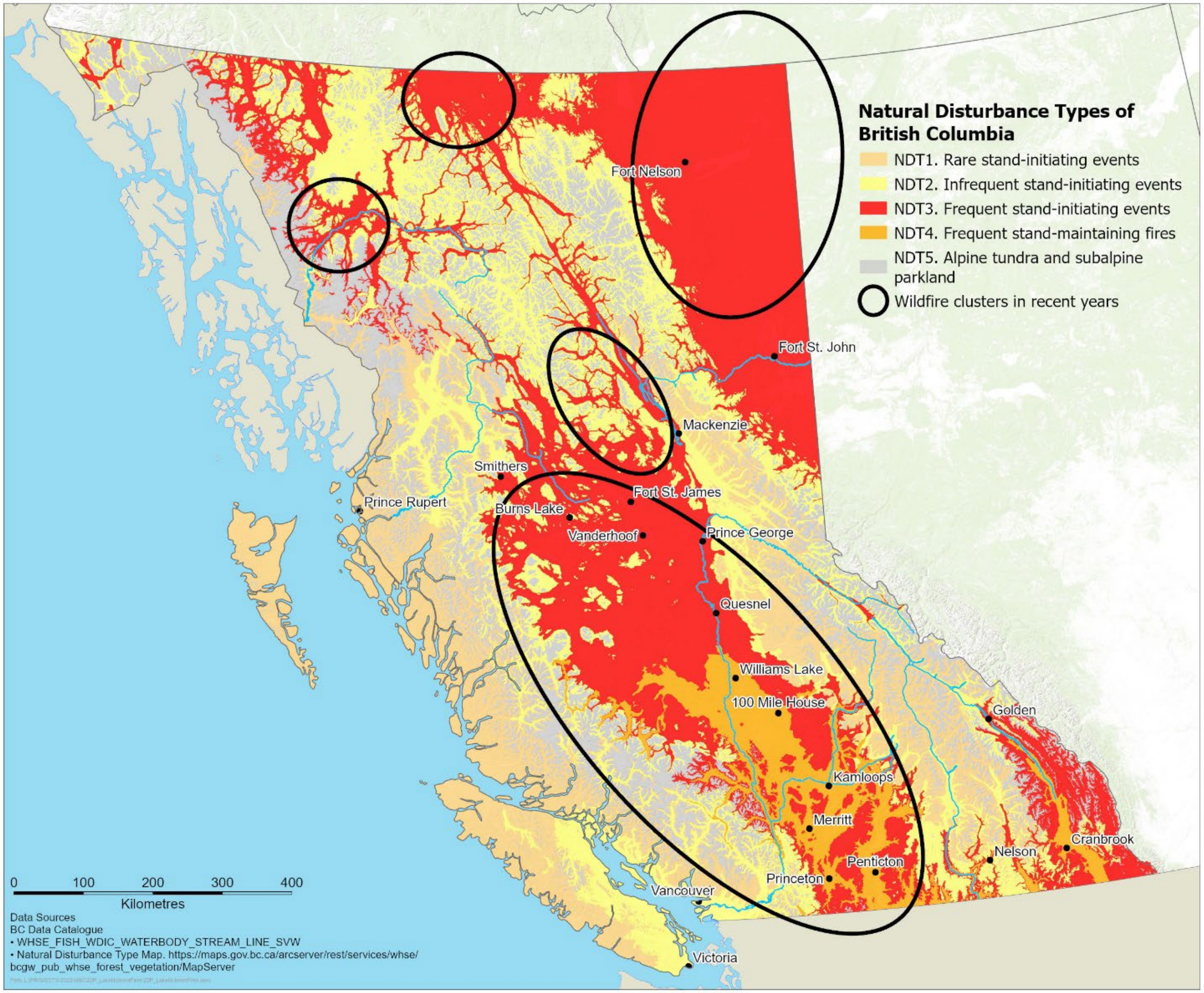


Figure 2. British Columbia's natural disturbance types.

Even before climate change and wildfires were top-of-mind, many salmon stocks in BC's drier and hotter regions were already limited by freshwater-related habitat variables, including seasonal low flows and elevated water temperatures. In addition, the province's interior has been extensively developed and, as such, its watersheds often come with complex sets of impacts associated with urban development, agriculture, hydroelectricity, linear developments, forestry and mining. Further, past wildfire suppression practices may have increased fuel loading and subsequent severity of wildfires in the NDT 3 and 4.[3] In their totality, these impacts are especially relevant for those species—namely Chinook, coho, sockeye and steelhead—that rear freshwater habitats. Currently, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has assessed 45 Pacific salmon populations that fall into Special Concern, Threatened, Endangered or Extinct categories and are now under consideration for listing under the *Species at Risk Act* (SARA). This includes 22 Chinook, 1 coho, 20 sockeye and 2 steelhead Designated Units. The majority of these populations return to spawn in watersheds within the NDT3 and NDT4 zones in the BC interior (Figure 3).

While this Playbook has been created in response to the many recent wildfires in the province's dry interior and wildfire prone forests, most of its guidance will be universally applicable. Wildfires can, and do, occur in all disturbance types and their scope, trends and impacts require management actions across BC. At its core, the Playbook provides a structured and reasoned framework for the restoration of wildfire-impacted salmon watersheds, wherever they may occur. It can also serve as a process template for the management of other watershed-based ecological values.

[3] Brookes et al. 2021; Baron et al. 2022; Hoffman et al. 2022; Greene 2021

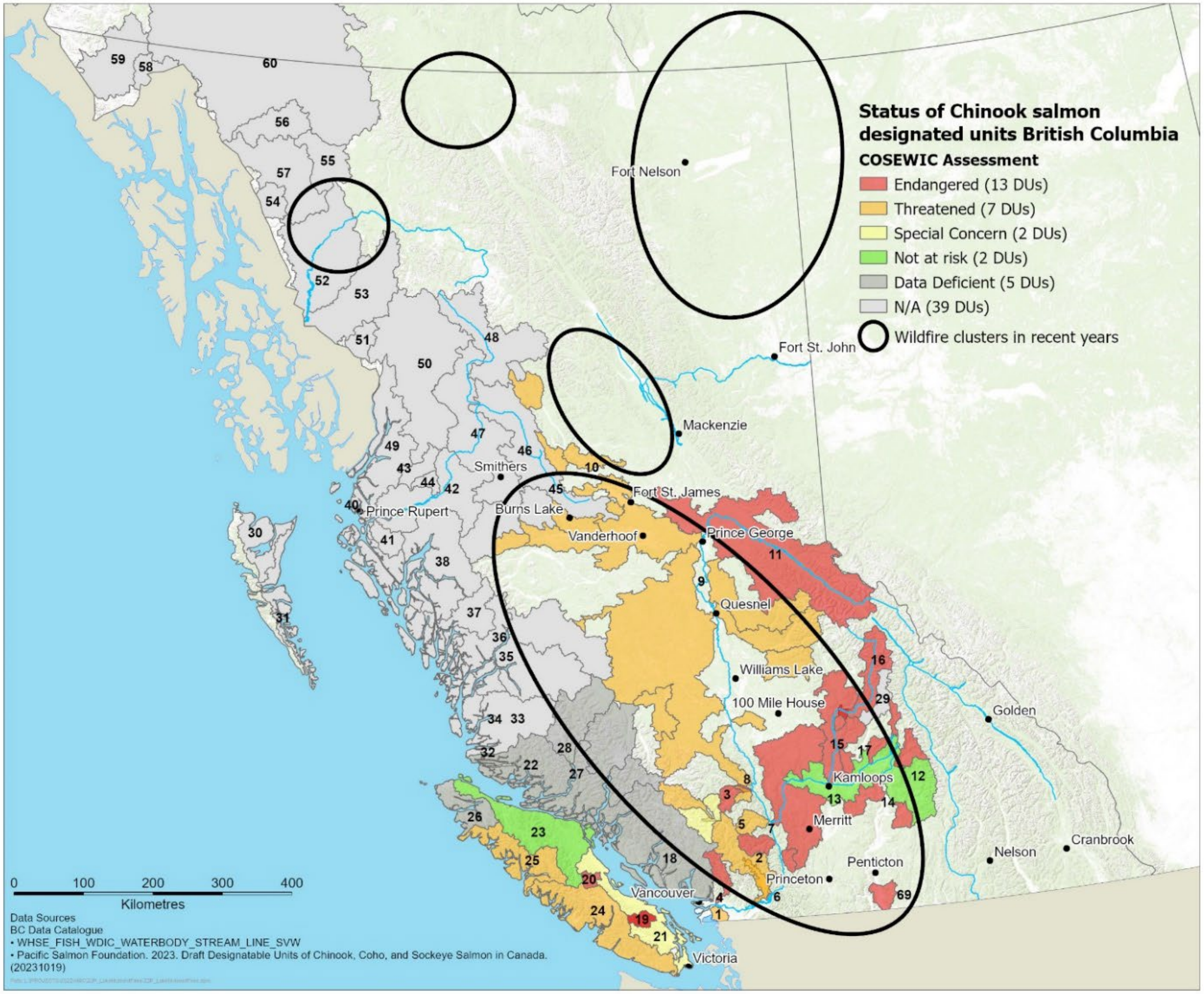


Figure 3. Status of Chinook salmon designated units in British Columbia.

1.2 GOALS AND OBJECTIVES

The management of salmon-bearing watersheds and their constituent habitats is currently set within resource specific, often compartmentalized, resource management systems that span various levels and forms of government. These systems must grapple with complex, sometimes competing, sets of objectives for a variety of natural resource values, including salmon and salmon habitats. As climate change, wildfires and human development converge, the need to include salmon and salmon habitat considerations in post-wildfire land-use decision making, and leverage and coordinate expertise, resources and actions, has never been greater.

While this document focuses on salmon habitat recovery, it is recognized that, ultimately, watershed processes affect this end goal, and other related values and objectives such as biodiversity, water quantity and quality and flood protection. Accordingly, the overarching goals of the Playbook are to:

- provide advice on recovery of salmon habitats and watersheds[4] and promote its integration into post-wildfire responses;
- provide a strategic/framework approach to help guide the recovery of salmon watersheds following major wildfires;
- show members of the restoration community how and where they fit into the 'big picture' and how they can most effectively influence recovery; and,
- instill a sense of community by fostering collaboration among the various entities that have roles and responsibilities relating to salmon and their habitats.

The specific objectives of the Playbook are to:

- consolidate information and provide a framework with advice to support planning processes and recovery actions for wildfire-impacted watersheds including:
    - an overview of salmon habitat requirements, the watershed processes that shape them, and relevant wildfire impacts;
    - an overview of resource management governance and roles and responsibilities;
    - advice for developing effective and appropriate multi-party relations and land-use planning processes (strategic to operational);
    - guidance on the development of risk management approaches to accelerate salmon watershed and habitat recovery, including the acquisition and use of existing western sources of information including geospatial information, scientific and technical information, assessment and monitoring techniques, policy, and restoration strategies and methodologies;
    - the respectful acquisition of relevant Indigenous Knowledge;

[4] In this document, the term 'watershed recovery' is used in a limited fashion and relates to the recovery of the ecological, hydrologic and geomorphic conditions that influence watershed processes and salmon habitat conditions.

    - a toolbox that outlines treatment options and management strategies for consideration in post-wildfire recovery situations;
    - guidance for the development and implementation of watershed recovery plans at many levels; and,
- identify opportunities for improvements in information, science, policy, and processes that are relevant to post-wildfire watershed recovery.

1.3 INFORMATION SOURCES AND USING REFERENCES PROVIDED

This document was prepared during a dynamic and increasingly literature-rich environment. Publication trends related to wildfires have been found to be positively correlated with temporal wildfire trends in western North America. At the time of writing, over 500 documents and media sources relevant to the goals and objectives of the Playbook were located, without a search preference for time period. With document dates ranging from 1976 to 2024, the vast majority (i.e., greater than 85%) were published between 2002 and 2024, with generally increasing numbers of references available annually during this period (see the Catalogue, defined in the bullet list below, for additional details).

An overview of existing scientific information, case histories, policies and best management practices, along with advice from subject-area experts, have been combined in this Playbook to inform the development of a framework on watershed and salmon habitat recovery following major wildfires. As such, this document provides an overview of many current resources. ***Within the Playbook itself, citations are provided as footnotes and are linked to online sources. By clicking on the specific citation within the footnote at the bottom of the page, the reader is taken to an online source, when available.*** Various references in text and tables also contain hyperlinks to online sources, particularly after Section 3; these links are identified using blue text. Note that every effort has been made to provide effective hyperlinks to external documents/webpages, but internet resources are ever-changing. If a hyperlink to a document does not work, please enter the document title into an internet search engine (e.g., Google) and this will help you reach the required document.

For those readers interested in additional reading, direct links to external resources have also been included within the Playbook's companion documents and presentations, which include:

- *Workshop on Salmon Watershed Recovery in Post-Wildfire Environments: From Theory to Practice* (June 2022); and,
- *Catalogue of Existing Information: A Companion to the Playbook of Guide Landscape Recovery Strategies & Priorities for Salmon Habitat Following Major Wildfires* (the Catalogue) (June 2024).

2 WILDFIRE RECOVERY PLANNING AND DECISION MAKING

Salmon habitat recovery initiatives have not commonly been integrated into post-wildfire responses, which have primarily focused on priorities such as public safety and infrastructure, water, private land values, the rehabilitation of wildfire suppression features and range and timber values. Given the effects that wildfires can have on fundamental watershed processes, and the importance of Pacific salmon to the people and ecosystems of BC, it is hoped that watershed and salmon habitat restoration will become a cornerstone in post-wildfire restoration planning.

Salmon are subject to several layers of authority, involving First Nations, federal, provincial and local governments and, as such, their management relies on the effective and coordinated execution of interlocking authorities and resources. While the federal government regulates fish harvest and any works that can harm fish habitat, the provincial government regulates almost all of the land-based activities, such as forestry operations, that have the potential to impact salmon habitats. Similarly, local governments provide oversight for land developments that occur within their boundaries. First Nations have Constitutional rights, and can have Treaty rights, associated with salmon and salmon habitats and often have salmon-related objectives for the lands and waters that fall within their traditional territories.

The integration of salmon-related values into post-wildfire land use planning initiatives requires all actors to align and coordinate actions such that multiple values and objectives can be addressed in concert. Large wildfires often span watersheds, jurisdictional boundaries, tenures and First Nations territories and impact many resource values. Water, timber, grazing, biodiversity, wildlife habitat, and recreational, spiritual and heritage values are all ‘in the mix’ and many of the treatments for these individual values will have a direct bearing on the others. As such, all governments, industry and non-governmental organizations (NGOs) can aspire to accelerate watershed and salmon habitat restoration effectively when they coordinate their actions at scales that range from the ‘site’ to the ‘watershed’ level.

2.1 WILDFIRE RECOVERY AND THE PLANNING CYCLE

Wildfires bring levels of uncertainty and confusion that persist well after the flames subside. Fires threaten lives and damage possessions, infrastructure and ecosystems, and they often create or elevate risks that can manifest themselves in the weeks, years or decades to follow.

Immediately after the fire, there is often a rush to identify and quantify impacts and risks and to remedy them—even if the fix is only temporary. This urgency is understandable, as fires disrupt transportation, communications and infrastructure and jeopardize many values. In many cases, human-centred values take centre stage; however, impacts to fish habitat values may also require immediate and urgent attention. Wildfire impacts, coupled with biological imperatives such as migration, spawning and rearing, may compel ‘real time’, emergency mitigation measures that can be both reactive and proactive (e.g., preparation for events in areas where it is *likely* they will unfold in short order). Such work may not be guided by an established plan, and urgent actions may be required prior to the completion, or even initiation, of longer-term planning processes. Communication will be key during this period. Those with an interest in salmon habitat are advised to initiate communications with rights holding First Nations, government agencies and other stakeholders as quickly as possible to consider actions, options, the activities associated with other values, and opportunities for coordination, collaboration and synergies.

The immediate aftermath (Photo credit: Jeff Morgan)

After the immediate post-wildfire concerns have been addressed, longer-term planning opportunities will emerge and, at this point, watershed and fish habitat recovery can become more measured, prominent and proactive. Through communication and collaboration, common information needs and overlapping objectives will become apparent. It will often fall to the various groups involved in restoration to make the case for the appropriate level(s) of planning and to find resources that support the necessary planning processes and restoration activities.

Planning processes should be devised and tailored to address the watershed-specific arrangement of values, people, resources, rights and interests that are in play. One size will not fit all, and a universal planning strategy is not advised. Instead, a very general framework based on a ‘Planning Cycle’ (Figure 4) is provided to guide thinking and structure processes.

This cycle, which breaks down team building, problem solving, action and adaptation stages, underpins the structure of the Playbook itself and has been broken into the following key stages (as depicted in Figure 4):

1. Scope the problem and begin team building (Section 2).
2. Understand the elements at risk and sources of harm (Section 3).
3. Assess values and frame impacts and risks (e.g., become familiar with risk management and supporting assessments) (Section 4).
4. Identify and understand treatment options for recovery (Section 5).
5. Evaluate options and create a recovery plan (Section 6).
6. Implement the plan, monitor outcomes and adapt the plan (if required) (Section 7).

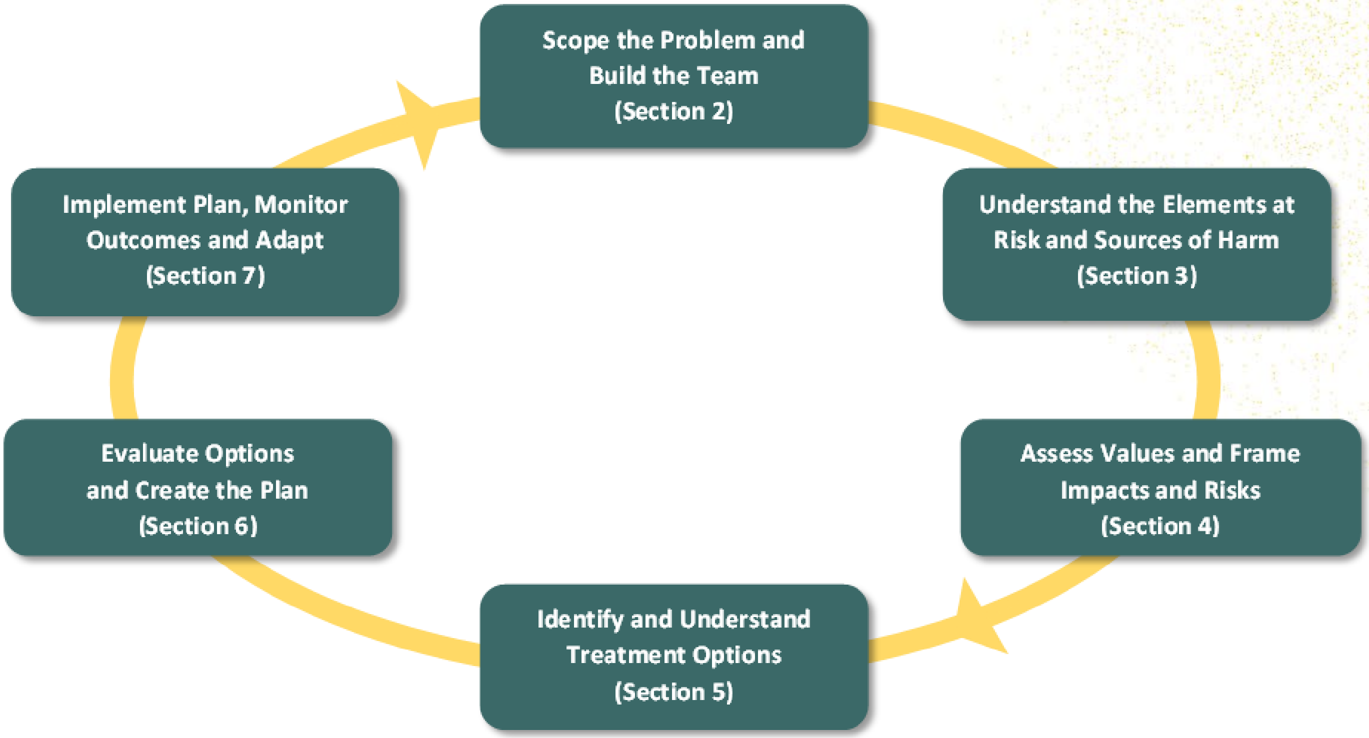


Figure 4. Generalized Planning Cycle.

This generalized cycle seeks to convene the appropriate people and authorities to: 1) allow for collaboration and integration/coordination, 2) make informed and durable decisions, and 3) promote adaptations based on desired outcomes and science-based feedback mechanisms. While the figure shows a sequence, in reality, it is an approach to problem solving that benefits from iterations and informed backtracking. Furthermore, this approach is universally applicable, can be used at multiple scales and, in the context of a multi-scale plan, concurrent cycles can be employed simultaneously. Finally, this approach can serve different time periods of restoration from ‘urgent and reactive’ to ‘methodical and proactive’. Box 1 provides links to key documents that relate to planning.

Box 1
Key Planning Documents

Watershed-Based Fish Sustainability Planning: Conserving BC Fish Populations and their Habitat by British Columbia Ministry of Forests (BC MoF), British Columbia Ministry of Environment, Lands and Parks (BC MoELP) and Department of Fisheries and Oceans Canada (DFO).

Joint Professional Practice Guidelines – Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector by Engineers & Geoscientists of British Columbia (EGBC) and Association of British Columbia Forest Professionals (ABCFP) (2020).

Watershed Restoration Planning and Priority Setting: An Emphasis on Fish Habitat by WRP (2004).

Key Points to Consider When Pre-planning for Post-wildfire Rehabilitation by Pike and Ussery (2006).

Ecological Restoration Guidelines for British Columbia by Forest Renewal BC (not dated).

2.2 RECOVERY PLANNING – SCOPE THE PROBLEM AND BUILD THE TEAM

Those involved in advancing salmon habitat recovery in post-wildfire watersheds will be required to work and collaborate with other entities involved in wildfire responses, resource management and other activities. This section is intended to outline the various entities that may be involved and some of the considerations that inform how the various rights, interests, authorities and expertise can come together in planning and operational environments (Figure 5).

Engaging the right people and entities may be the most important step in the generalized planning cycle. It will set the tone for inclusion, build relationships, increase understanding and influence the resilience of emergent 'teams'. In addition, effective communications at this early stage (and beyond) will promote trust by allowing various individuals and groups to be heard and to consider their level(s) of involvement.

Post-wildfire teams will come in a variety of forms and address various levels of complexity. Some may be formal and involve regular meetings and structured governance models. Others may be far less complex and defined by the relationships that exist between a proponent and the various statutory authorities and First Nations referral and engagement teams. The role of rights holding First Nations in land use planning and in developing responses to wildfire has become increasingly important over the last decade. Both the federal and provincial governments have endorsed the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) and its articles are permeating resource management cultures and influencing protocols and practices. UNDRIP's sweeping impact is exemplified by Article 26 (2), which states: "*Indigenous peoples have the right to own, use, develop and control the lands, territories and resources that they possess by reason of traditional ownership or other traditional occupation or use, as well as those which they have otherwise acquired*."

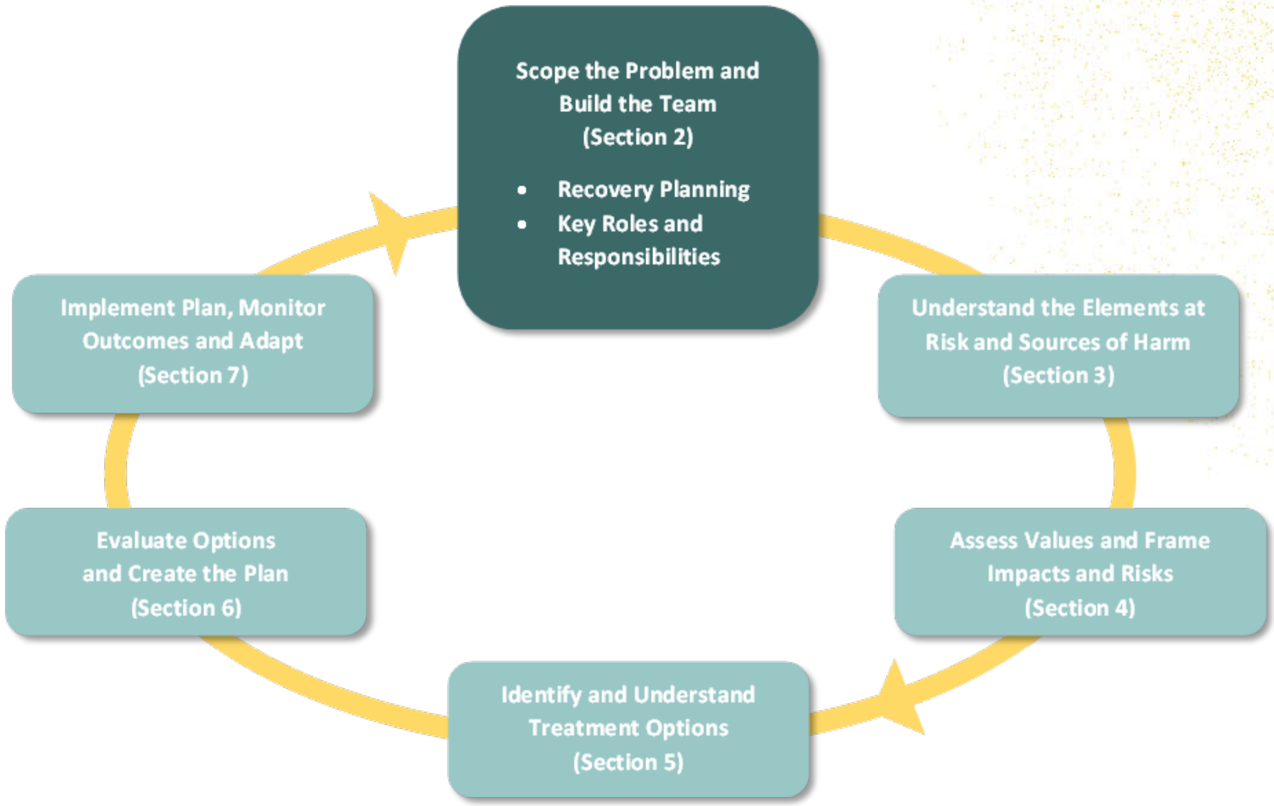


Figure 5. **Highlight of Planning Cycle activities addressed in Section 2.**

Who Will be Involved?

For larger wildfires, First Nations and natural resource agencies will often constitute the fundamental building blocks of the emerging team. This will typically involve the rights-holding First Nations governments on whose traditional territories the fire has occurred, and agencies within the provincial government (e.g., Ministry of Forests [MOF], Ministry of Emergency Management and Climate Readiness**,** Ministry of Environment and Climate Change Strategy (which includes BC Parks) and Ministry of Water, Land and Resource Stewardship [WLRS])[5]. In addition, Fisheries and Oceans Canada (DFO) is increasing its involvement in site and landscape level post-wildfire recovery initiatives. Industry stakeholders and NGOs may choose to engage immediately, depending on economic and recovery interests, or they may be drawn in at later stages. In defining 'stakeholders', it will be important to bear in mind that watershed recovery activities can come with positive and negative consequences depending on the resource or interest at hand. Stakeholder participation can be motivated by both hopes for restoration and, conversely, concerns for harm that a given management action might bring. This tension will likely change over time and may influence the make up of a given team. The structure of the team will also vary depending on circumstances. For example, processes that involve First Nations can be expected to vary depending on the Nation's particular customs, values, governance structures, capacity and leadership.

[5] BC WLRS and BC-First Nations Water Table 2023

Beyond governments and agencies, wildfire impacts and recovery efforts can affect a broad array of entities with rights, interests and subject matter expertise (i.e., the potential partners) including:

- non-rights holding First Nations entities, such as Tribal Councils, fisheries commissions, provincial and multi-band organizations, corporations and partnerships, that play roles in the management or harvest of resources;
- NGOs that work to protect and restore watersheds and salmon habitats;
- landowners that hold access rights;
- tourism businesses that rely on watershed values;
- tenure/license holders and industries;
- recreation enthusiasts (e.g., anglers); and,
- academic entities and researchers.

Potential participants in planning initiatives are identified in Table 1. For additional details on the roles and responsibilities of these potential participants, please see Appendix A.

A high-level graphic overview of the recovery community entities in BC is depicted in Figure 6. It does not depict who should be represented on a planning team. Instead, it identifies the provincial scale restoration community from which organizations and individuals may be identified for participation. In this context, the term ‘stakeholders’ is an umbrella term meant to include NGOs, industry and user groups (e.g., fishing lodge owners).

Table 1. Potential members of the recovery community and planning initiatives (non-exhaustive list).

Federal Government	Provincial Government	First Nations
Fisheries and Oceans Canada (DFO)	Ministry of Forests (MOF)	Band Councils, Hereditary Chiefs (in some cases), and Staff (representing the Rights Holding Nation)
Parks Canada	Ministry of Water, Land and Resource Stewardship (WLRS)	Tribal Councils
Environment and Climate Change Canada	Ministry of Environment and Climate Change Strategy (ECCS) including BC Parks	Multi-Band Organizations
	Ministry of Emergency Management and Climate Readiness	First Nations Corporations

Local Government	Stakeholders	Consultants/Academia
Municipalities	Non-government organizations (NGOs) and their Subject Matter experts	Facilitators
Regional Districts	Residents and Landowners	Subject Matter Experts
	Tenure and License Holders	Planners
	Tourism and Recreation Oriented Businesses	

Figure 6. Recovery community entities in BC.

In the aftermath of a wildfire, teams are often structured to address urgent tasks based on the immediate understanding of impacts and risks. The immediate assembly of baseline and reconnaissance level information helps to frame the pressing impacts and risks and identify relevant authorities/rights holders or those who are impacted to determine the scope of post-wildfire planning and operations and those who will be involved. Examples of the immediate, sometime cursory, information needs are:

- extent of the fire;
- severity of the fire;
- resources and infrastructure that are impacted or placed at heightened risk;
- environmental impacts and risks;
- existing or exacerbated geological hazards;
- First Nations rights holder impacts; and,
- stakeholder impacts.

This information will position entities and emerging teams to consider immediate steps *and* the path forward over the longer term. A large wildfire, involving significant impacts and risks to different resource values, infrastructure, private property, rights holders and interests, may compel more ambitious planning processes compared to a small fire with impacts that are less varied and more confined. It must also be recognized that through time, and as more information becomes available, restoration challenges and opportunities will change, and this will often compel changes to the membership of planning teams.

The following questions are proposed to help recovery teams with the vision setting process:

- What values are to be addressed in the plan?
- Do these values compete with, or compliment, one another? What trade-offs will be involved?
- In addition to what is desired, what is *not* desired and how might this relate to recovery efforts?
- Is the relative importance of the various values understood?
- What entities need to be represented (based on rights, authorities, interests)?
- Are these entities obvious and proximal or might they be less obvious and situated well downstream?
- Who will represent those entities?
- What authority will the representatives have?
- What expertise will the representatives have?
- What additional talent will be needed to support the process?
- What impacts and risks will require immediate attention?
- What type of plan(s) need to be developed?
- Are there different planning processes needed to address differing impacts and risks, resource values, spatial scales or timelines?
- What are the relationships between the various planning processes?
- What are the necessary governance structures for the various planning processes (e.g., leadership, decision making)?
- What government to government (G2G) processes or agreements must be accounted for?
- What Indigenous rights and/or title are involved?
- Are Treaties involved?
- Will the planning process benefit from several interacting teams, such a technical committee, a planning team and process support team?
- What resources are available (for planning and for operations)?
- What are timeframes for planning and operations?

Based on the answers and information generated, a variety of post-wildfire responses can be anticipated. Large wildfires will require multiparty processes that *may* lead to ambitious planning initiatives. However, depending on the mix of resource values, responsibilities and desired outcomes, it may be more efficient to pursue multiple projects and/or plans that are under the influence of separate entities and/or processes.

Some plans might be overarching and relate to an entire watershed, while others may address one sub-basin, reach or site within the context of the watershed, or they may address separate resource values, such as water use and fish habitat. In general, site-specific plans should be consistent with any relevant/paramount overarching plans. Despite this variability, all participants (including approval agencies and referral teams) should understand what interactions and communications are required to make sure plans are compatible with one another from the time of their drafting through to implementation stages.

The level of involvement for team members can be variable based on the impacts, risks and opportunities that present themselves. For example, more peripheral team members may request notices and engagement opportunities only when a specific interest may be threatened. Similarly, depending on the breadth and consequences of a recovery actions, public communications may be disseminated to serve the broader community. When it comes to salmon, not all streams are created equally. Some will be inhabited by populations that are culturally, economically or ecologically important (e.g., 'at risk') while others may not. This will, and should, influence salmon-based investments in planning and recovery.

Teams will benefit from members that have a solid understanding of their own organization (e.g., rights, mandates, goals and objectives, priorities, and capacity) and the resource management challenges at hand. It will also be important to integrate the planning process with the appropriate levels of decision-making authority. This applies to the resource management decisions that will come or the support that is necessary for the planning initiative itself.

When developing a vision for an appropriate recovery planning process, emergent teams are advised to ask the following questions:

- Is the plan intended to influence future actions over a broad area or be a site-specific project plan?
- Will the plan involve zones or sub-basins with goals, objectives and timelines for management actions and completion?
- Will the plan identify restoration risks and priorities that will be used to guide decisions on future assessments and/or operations and projects?
- Will the plan be:
    - used to establish legal objectives (e.g., watershed sustainability plan);
    - aligned with legal orders established under legislation (temperature sensitive streams or fisheries sensitive watershed established under the Government Actions Regulations of the *Forest and Range Practices Act*); or,
    - aligned with other legal plans (forest landscape plans)?
- How will the planning process regard and address Indigenous rights and title?
- How will the plan and process demonstrate alignment with existing G2G (i.e., government to government) agreements (or ongoing processes), UNDRIP, and the BC *Declaration of the Rights of Indigenous Peoples Act*?

- If the plan (or portion of it) is exercising influence rather than legal authority, are the statutory decision makers and rights holding First Nations in support?
- Will the plan outline an 'agreed to' process for implementation and monitoring and identify subsequent decision-making processes and authorities?

Governance and decision-making within the planning process itself will also need to be established and articulated during this early stage. Authorities for decision-making should be clearly defined. For example:

- Will a proponent be seeking approvals for a project-level (site scale) initiative? If so, how, and from whom?
- Will a First Nation or an agency be seeking input from the planning team while retaining decision-making authorities and/or management prerogatives?
- Within a particular team setting, will decisions be made by consensus or majority vote?
- Will decision-making authorities vary depending on the resource value at hand?

The roles and responsibilities for the individuals on any team should be clear and a 'terms of reference' can help to capture the various details. Agreement and a common understanding of roles, responsibilities (e.g., chair, secretary) and conduct are critical to maintaining a highly functioning team and for navigating any roadblocks or difficult topics that may arise. The resources and individuals/expertise that are required to sustain the planning process should be articulated, secured and continuously updated.

2.3 KEY ROLES AND RESPONSIBLITIES IN WATERSHED RECOVERY INITIATIVES

All phases of post-wildfire watershed recovery can be costly. A diversity of programs, standing industry operations, legal obligations and funding sources often exist and can be coordinated to support watershed and salmon habitat recovery. In addition to the implementation phases, external funding is often used to initiate early planning phases, including team development and assessments. As such, an understanding of the various resources, and how they can be accessed, is necessary to inform all phases of the planning cycle. The major entities and programs that are likely to play a large role in resourcing wildfire responses are outlined in this subsection.

Within provincial forest settings, the MOF is responsible for maintaining forest services roads, including their bridges and culverts, to provincial standards. The MOF will often undertake actions that control or influence roadway sediments, surface flows and fish passage. This ministry may also assume responsibility for reforestation of burned areas. Further, MOF is responsible for rehabilitating lands impacted by wildfire suppression activities, such as fire roads and fire breaks, after the fire is out. Ministry representatives are well-equipped to provide expertise for post-fire natural hazard (hydrological and geomorphic) assessments, which may contain information highly relevant for fish and fish habitat. Finally, the MOF is the principal regulator of forestry operations and leads the approval, permitting and monitoring of forestry-related activities that are carried out on the land base.

The Ministry of Water, Land and Resource Stewardship (WLRS) in BC is directly responsible for the effective development of water, land and marine use policy and planning, as well as biodiversity and ecosystem health, including species at risk policy and program management. In addition, WLRS has recently been assigned authorities under the *Water Sustainability Act* and is responsible for water-related permitting functions and development of drought management strategies. This ministry is also responsible for developing a new vision for water, land and resource management with First Nations that will embrace shared decision making as part of reconciliation with Indigenous Peoples in BC. Among other things, an Intentions Paper for a Watershed Security Strategy and Fund has been jointly released by WLRS and the BC-First Nations Water Table (see Appendix A for more details). The WLRS directs work across natural resource ministries to develop solutions to sector-wide challenges and advance dedicated sector-wide policy, including managing for cumulative effects, improving permitting and authorizations, as well as providing dedicated secretariat support for effective governance of the natural resource sector. Salmon and watershed-specific tasks include the advancement of the Watershed Security, Coastal Marine and Wild Salmon Strategies.

The Ministry of Environment and Climate Change Strategy (ECCS) is responsible for the effective protection, management and conservation of BC's water, land, air and living resources. It leads work on climate preparedness and adaptation and helps with plans to meet greenhouse gas reduction targets. Beyond these priorities, ECCS includes BC Parks, which manages the provincial parks and protected areas.

The Ministry of Emergency Management and Climate Readiness (EMCR) is the primary coordinating agency for reducing climate risk impacts and responding to provincial-level emergencies and disasters in BC. The Ministry provides "*cross-ministry coordination to enhance British Columbia's readiness and resilience towards climate and disaster risks and working towards a comprehensive and interconnected approach to achieving climate and disaster risk reduction. The Ministry leads provincial emergency management through the four-phased approach of mitigation, preparedness, response, and recovery in close collaboration with First Nations, local authorities, other provinces and territories, federal departments, industry, nongovernmental organizations, and volunteers*."[6]

Fisheries and Oceans Canada (DFO) is the federal government department tasked with managing Canada's fisheries, habitat protection, and providing science advice. It is positioned to play a significant role in watershed recovery in the Pacific Region and brings considerable expertise to both strategic/landscape and site level activities and presides over important funding sources (in-house and grants) that are available to support watershed recovery initiatives. For example, the 2023–2024 Departmental Plan lists salmon habitat restoration to mitigate climate change impacts as one of the areas of focus through actions, such as the implementation of the Pacific Salmon Strategy Initiative and creation of a Restoration Centre of Expertise.

Forest licensees are responsible for maintaining the status roads and associated infrastructure within their tenured areas. This responsibility pertains to infrastructure maintenance, which can be critical in mitigating impacts to fish habitats. In post-wildfire environments, forest licensees also undertake salvage harvest of

[6] Gov. BC 2024

merchantable timber within their operating areas. While this activity has the potential to exacerbate wildfire impacts, it comes with some opportunities. For example, forest licensees are obligated to reforest the stands they salvage, and this involves planting trees and potentially using soil treatments (e.g., scarification), both of which can have hydrologic benefits. Forest licensees and their contractors also bring expertise and machinery to post-wildfire settings as they set about to manage infrastructure and salvage timber. This presents an opportunity for cooperation regarding the timely management of damage and risks associated with the wildfire itself, roading and infrastructure and wildfire suppression legacies.

The cattle industry is often involved in wildfire response initiatives. Very often this involves re-establishing fencing to control cattle movements, to provide public safety and manage rangelands and other ecosystem values. Interests can compete as short-term foraging opportunities can be reduced by wildfire; however, fires return vegetation communities to earlier successional stages and this can quickly increase forage availability and quality in areas that were previously forested. Grazers, who are often involved in irrigated forage production, also have an interest in the availability of water through the summer months and the protection of intakes and irrigation lines. In the bigger picture, grazers can be expected to have an interest in the recovery and stewardship of watersheds and healthy vegetation communities.

In many watersheds, private landowners will also be key stakeholders. The logistics associated with private land access can make or break projects at a variety of scales and emphasizes the critical importance of bringing landowners onside with plans for watershed recovery. This can be achieved by inviting the landowner(s) to participate in the planning process at the early stages, providing landowners with the opportunity to contribute to the vision and for the entire team to consider opportunities for aligning objectives. Landowners will often be interested in protecting their property and, therefore, in addressing those aspects of the watershed that pose a threat. Creative solutions that tackle both fish habitat and private property values are best achieved though collaboration. Further, many landowners in rural areas are also tenure holders (e.g., water rights, grazing permits and woodlots) and, as such, their influence will often extend beyond their property lines.

Local governments (e.g., municipalities and regional districts) are often responsible for the procurement of water and its distribution to their citizenry. They are also responsible for regulating and permitting development in a manner that is consistent with federal and provincial statutes and regulations, such as the *Fisheries Act* and the *Riparian Areas Protection Regulation.* Local governments also have an interest in the ecological values that radiate outward from the communities for a diversity of reasons relating to quality of life and economic opportunities. As such, effective collaboration in watershed planning will often be achieved through the integration of local governments and recognition of relevant authorities, interests, expertise and resources.

Non-government organizations can play a key role in drawing together resources and aligning authorities and activities within post-wildfire environments. For example, the Society for Ecosystem Restoration in Northern BC has provided financial, technical and management support for habitat-related responses to the 2018 Shovel Lake (92,412 ha) and Island Lake (20,966) wildfires, which occurred in central BC. Local salmon enhancement NGOs can bring resources and expertise to specific projects and broad provincial of federal societies (e.g., the BC Wildlife Federation) can be a source of funding for specific restoration and enhancement projects. In many cases, certain funding is only available to NGOs. Accordingly, NGOs represent a significant bank of expertise and resources.

Rights holding First Nations and other First Nations entities (e.g., Tribal Councils, Commissions and Corporations) are sources of scientific, technical and traditional expertise and knowledge that are well positioned to lead or make significant contributions to post-wildfire recovery efforts. In addition, First Nations are often positioned to receive monies that are available only to them (e.g., Aquatic Habitat Restoration Fund) or that favour First Nations leadership or involvement. Further, First Nations communities are often situated within the fires themselves and immediately adjacent to salmon streams. While the health of salmon populations can be paramount, First Nations communities often take action to protect people and property, heritage and other environmental values (e.g., water) and these activities can integrate well with watershed-scale recovery initiatives.

A vast array of funding programs exist that can provide financial support for post-wildfire habitat assessment and restoration initiatives. Most are supported by websites that provide information on application intake schedules, requirements for leverage funding (cash or in-kind), funding priorities and funding eligibility. Entities that most commonly provide funding include government agencies, local governments, and NGOs. The pursuit of funding can be a highly creative process and involve the alignment of overlapping interests and the integration of activities. Sources of funding to address such things as education, economic development, water security and related ecological values can emerge. As wildfires create extensive damage to a variety of interlocking resources, it can be possible to align several funding sources and projects within one overarching process. For example, funding for reforestation activities may address upslope objectives, while other sources of funding may be applied to instream ecological objectives. Funding for infrastructure (e.g., bridges) and education may also fit into, or be linked to, watershed restoration actions and plans.

Based on the broad array of standing programs, industry practices and obligations, expertise and funding, considerable resources will be available to recover wildfire-impacted salmon watersheds. In most cases, success will depend on the dedication, cooperation and creativity of the many parties that must come together in a respectful manner, build on strengths, find synergies, and create and execute plans in an efficient, coordinated and effective manner.

2.4 SUMMARY AND KEY STEPS

This section has introduced a generalized Planning Cycle and divided it into the following stages:

1. Scope the problem and begin team building.
2. Understand the elements at risk and sources of harm.
3. Assess values and frame impacts and risks (e.g., become familiar with risk management and supporting assessments).
4. Identify and understand treatment options for recovery.
5. Evaluate options and create a recovery plan.
6. Implement the plan, monitor outcomes and adapt the plan (if required).

This approach to problem solving and planning is both cyclical and iterative and is suited to a variety of scales and subject matters. As the size and complexity of the planning challenge increases, the creation of adjacent or hierarchical cycles can be used to manage teams and what they undertake.

Scoping the problem and team building can be a complex challenge. Answering the following questions might help sum up this stage in the Planning Cycle: What values and risks do we hope to manage or influence? Who has rights, authorities or interests in these values, or in the potential actions that relate to them? How should they be involved in the planning process?

Wildfires happen in real time and often pose immediate threats to human safety, infrastructure, property and many different resource and ecological values—including salmon. Many different recovery responses will address different values over similar timeframes. Those with interests that lie with salmon and their habitats are advised to seek partners and collaborate with others who will have different but related interests. Many recovery actions will not always be carried out with the luxury of time and benefit from a thorough planning process. Reactive and timely responses will often be required. Nevertheless, the Planning Cycle provides a basic approach to problem solving that can be used to guide decision making.

3 SALMON HABITAT, WATERSHED PROCESSES AND WILDFIRE IMPACTS

Effective post-wildfire salmon habitat and watershed recovery efforts must be grounded in an understanding of salmon ecology, fundamental watershed processes, wildfire impacts and cumulative effects (Figure 7). If the many post-wildfire strategies and treatments (see Sections 4 and 5) are to accelerate salmon habitat recovery, they must be tailored to the watershed processes at play and designed and implemented in a manner that prioritizes the freshwater habitat factors most limiting to the productivity of the salmon population(s) of concern. This section outlines these concepts and how they connect.

Throughout this document, the various freshwater habitat features and conditions that are likely to limit a given salmon population *and* be negatively impacted by wildfire and other forces are often termed 'elements at risk'. Those factors and events that could negatively impact habitat features will often be referred to as 'sources of harm' or 'hazard'. This language will be tied into the development of a risk management framework, which is described in Sections 4 and 6.

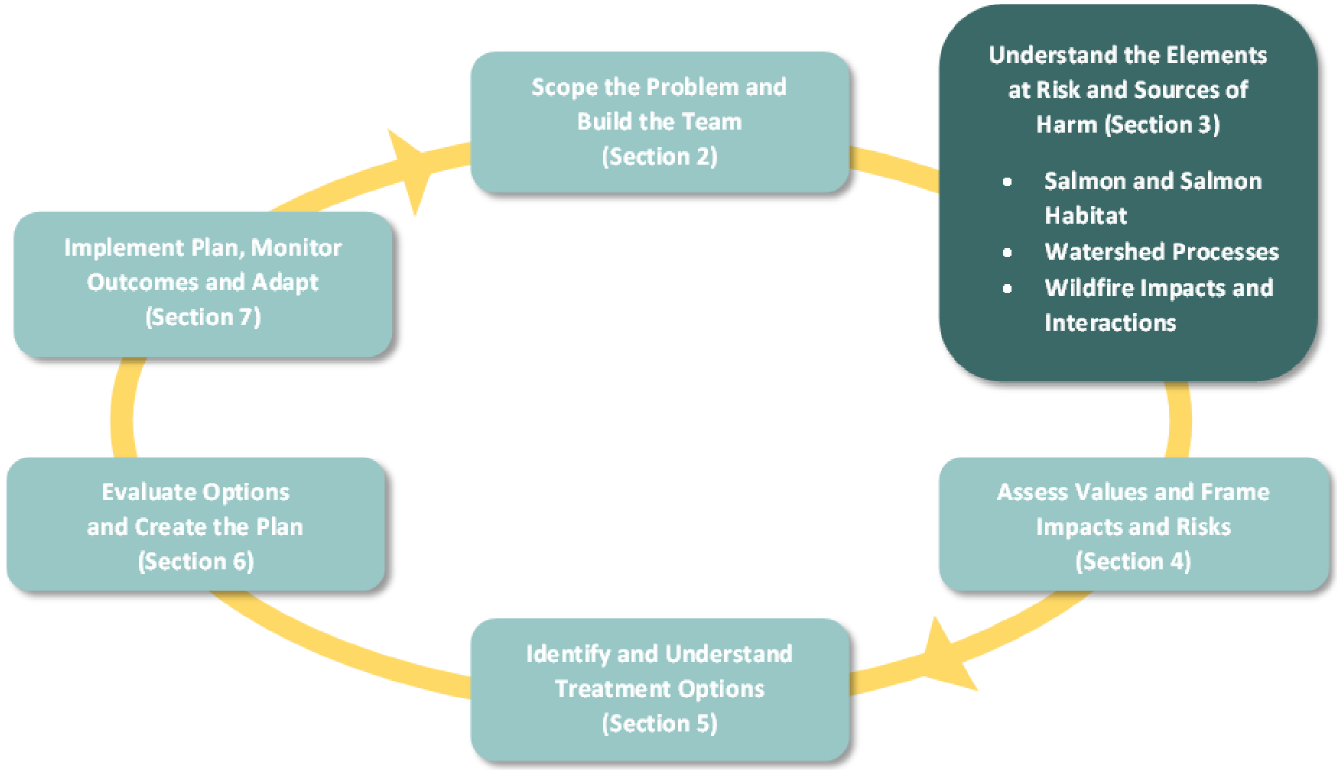


Figure 7. Highlight of Planning Cycle activities addressed in Section 3.

3.1 SALMON AND SALMON HABITAT – UNDERSANDING THE ELEMENTS AT RISK

The five species of Pacific salmon found in BC are:

- Chinook salmon (*Oncorhynchus tshawytscha*);
- coho salmon (*Oncorhynchus kisutch*);
- sockeye salmon (*Oncorhynchus nerka*);
- pink salmon (*Oncorhynchus gorbuscha*); and,
- chum salmon (*Oncorhynchus keta*).

This document also addresses steelhead (*Oncorhynchus mykiss*), which is a large, ocean-going trout with freshwater habitats that extend from coastal watersheds into BC's interior watersheds via major river systems, such as the Fraser and the Skeena. These species all belong to the same genus (*Oncorhynchus)* and generally employ an anadromous life history strategy, meaning the adults migrate to freshwater for spawning and the juveniles migrate to marine environments where they mature to adulthood. Hereafter, they are collectively referred to as 'salmon'.

Salmon populations rely on relatively cool and clean freshwater habitats to fulfill critical life history requisites including migration, spawning, egg incubation and larval development. Immediately after their emergence from freshwater gravel substrates, chum and pink salmon fry migrate to marine or estuarine environments. In contrast, juvenile Chinook, coho and sockeye salmon and steelhead trout rear in freshwater habitats for a period prior to their migration out to marine environments. During this period of survival and growth in freshwater, these four species and/or their habitats can be negatively impacted by random weather events, human-caused habitat impacts, invasive species, predation, climate change, wildfires or combinations thereof. Non-rearing chum and pink populations can face specific threats that can be exacerbated by wildfire. For example, chum salmon often spawn in relatively low gradient reaches that can be vulnerable to sediment deposits associated with post-wildfire conditions. Thus, watershed recovery planning requires a knowledge of population and life stage habitat requirements and watershed specific vulnerabilities at various scales.

Chinook juveniles (Photo credit: Pacific Salmon Foundation)

For management purposes, over 400 salmon conservation units (CUs) have been established for the five species of Pacific salmon in BC. These CUs are spatially based on watersheds (or groupings of watersheds) that are occupied by a grouping of wild Pacific salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to recolonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations[7]. Each CU is an aggregate of very similar salmon populations, which can range in number from 1 to about 170! Distinctions between CUs (and populations) are based on a variety of factors such as genetics, ecology and life history strategies that are defined by:

- age of maturity (i.e., time spent in the marine environments);
- timing of adult migration (e.g., early and late runs);
- amount of time spent rearing as juveniles in freshwater or estuarine environments; and,
- timing of seaward migrations.

Another categorization system is the 'designated unit' or DU, which is used by COSEWIC. As stated on its website[8], the COSEWIC defines a DU as a unit of Canadian biodiversity that is discrete and evolutionarily significant, where 'discrete' means there is currently very little transmission of heritable (cultural or genetic) information from other such units, and 'evolutionarily significant' means the unit harbours heritable adaptive traits or an evolutionary history not found elsewhere in Canada. This category is used to assess and define populations below the level of species. It is also used by the federal government (Environment and Climate Change Canada and Fisheries and Oceans Canada) when developing recovery potential assessments and other documents that pertain to the *Species at Risk Act* (SARA).

When devising a salmon habitat or watershed recovery initiative, it is important to keep in mind that several populations, CU or DUs can co-exist within a common watershed (e.g., summer and fall runs of the same species). As such, species-based generalizations on life history and habitat requirements are tenuous and exceptions to any given rule will abound. For example, most sockeye populations rear in lakes, while some rear in rivers. Many Chinook populations rear in streams for over a year, while others migrate to marine environments within weeks of their emergence as fry. Even within populations, life history choices can vary. For example, while most of the juvenile Chinook in the Okanagan River (in Canada) migrate to marine environments to mature, a portion of that population behaves as though landlocked and matures to adulthood in freshwater.

Habitat selection patterns are also highly diverse and vary by population, life stage, season and environmental conditions. For example, the selection of spawning gravels within a given watershed will vary by species, population and environmental conditions (i.e., flows). Seasons also influence rearing habitat preferences as fry migrate to specific foraging habitats that are used only while conditions remain suitable. This can include lakes, oxbows, side channels, inundated flood plains, small ephemeral streams, and even ditches. The use of these rearing habitats may change from year to year, depending on conditions. Similarly,

[7] DFO 2005

[8] COSEWIC 2020

while overwintering habitats meet *some* common criteria, they are highly diverse and can differ markedly from the spawning and rearing habitats used in other seasons within the same watershed.

Based on the diversity described, those interested in watershed recovery and habitat restoration work are advised to thoroughly understand the habitat requirements of the known, or suspected, salmon populations within the watershed of interest. This will broaden and add precision to the existing knowledge base and help to identify what elements within a watershed may be at risk and in need of management attention. Important questions to ask include:

- What species, CUs, DUs and/or populations are present within the watershed?
- What is the COSEWIC and/or SARA status of the DUs?
- What portions of the watershed are occupied by salmon?
- What life history stages are present, when and where?
- What types of habitats (e.g., spawning, rearing, overwintering) are required?
- Where are (or were) the various habitat types located in the watershed and are they being used?
- What are the habitat types that limit the salmon population in question?
- What are the vulnerabilities of the habitat types that limit the salmon population in question?
- Based on the types and locations of disturbance, what are the habitat types or elements that are most vulnerable or at risk?

When dealing with 'at risk' salmon populations, many of the above questions may have already been answered in a DFO Recovery Potential Assessment or RPA (e.g., Interior Fraser Coho Salmon Recovery Potential Assessment). Similarly, COSEWIC Status and Assessment Reports provide a treasure trove of invaluable information (e.g., COSEWIC Assessment and Status Report on the Steelhead Trout *Oncorhynchus mykiss*). Both types of reports can kick start an understating of a population's status and existing risks and reference useful information.

The relative importance of the various salmon populations within a watershed should also be considered or determined, because the various recovery efforts and treatments are not likely to benefit all populations equally. Treatments designed to benefit one population could be detrimental to another. Salmon populations are often valued based on human-centred factors, such as historic catch by First Nations, commercial and recreational fishers and/or tourist appeal. Some species may also have high spiritual significance, while others may have specific importance within an ecological food web (e.g., Chinook as prey for the Southern Resident Killer Whale population). The value of a given species may be further influenced by a COSEWIC 'at risk' categorization, which asserts an 'existence value' and pairs this with risks to viability.

Recovery teams will also have to consider where and how efforts are best spent. Restoration should always be viewed from a watershed scale perspective, and linked to watershed processes, even if treatment actions are spatially limited. Priority-setting exercises should address: 1) the vulnerability of specific populations or habitats, 2) the habitats or habitat components (i.e., the elements at risk) that are most limiting (Section 3.2), and 3) the cost-effectiveness and practicality of available treatment options (see Section 6.2.3). In some cases, hard decisions and triage approaches may be required to guide the use of limited resources most effectively—and this *may* favour certain watersheds or salmon populations over others. Such stark decisions may be tempered by the reality that, while habitat requirements for specific populations often differ, the restoration of natural watershed processes often create the diversity of habitat types that benefit multiple species.

Climate change has further compounded many pre-existing freshwater habitat factors that have historically limited salmon populations. In 2019, DFO acknowledged that:

> *"… Canadian Pacific salmon and their ecosystems are already responding to climate change. Northeast Pacific Ocean warming trends and marine heatwaves like "The Blob" are affecting ocean food webs. British Columbia and Yukon air and water temperatures are increasing and precipitation patterns are changing, altering freshwater habitats. The effects of climate change in freshwater are compounded by natural and human-caused landscape change, which can lead to differences in hydrology, and increases in sediment loads and frequencies of landslides. These marine and freshwater ecosystem changes are impacting Pacific salmon at every stage of their lifecycle. Some general patterns in Canadian Pacific salmon abundances are emerging, concurrent with climate and habitat changes. Chinook numbers are declining throughout their BC and Yukon range, and sockeye and Coho numbers are declining, most notably at southern latitudes. Salmon that spend less time in freshwater, like pink, chum, river-type sockeye, and ocean-type Chinook, are generally not exhibiting declines. These recent observations suggest that not all salmon are equally vulnerable to climate and habitat change. Improving information on salmon vulnerability to changing climate and habitats will help ensure our fisheries management, salmon recovery, and habitat restoration actions are aligned to future salmon production and biodiversity".*[9]

If, after a wildfire, watershed and salmon habitat restoration is actively pursued, the cumulative effects of climate change, including wildfire and human-caused disturbances on salmon habitats, must be taken into consideration and placed in the context of watershed processes.

[9] Grant et al. 2019

3.2 WATERSHED PROCESSES

Most BC watersheds were profoundly reshaped by the glaciers of the last ice age and are currently being affected by climate change and human activities. At the retreat of the Cordilleran ice sheet, some 10,000 years ago, salmon recolonized the newly available habitat.[10] Today, the interplay between geology, climate and biology continues. Pacific salmon spawn and rear in southern BC watersheds (and in Washington, Oregon and even California), where the combined effects of climate change and human disturbance are most detrimental to their viability. This resiliency and adaptability to changes in watershed characteristics will continue to serve the salmon populations as they contend with adverse conditions across BC.[11] This subsection addresses how wildfire can impact watershed processes and how this relates to salmon habitat values.

Watersheds are dynamic entities that are controlled and shaped by various natural forces including local climate, geology/soils, biology and ecology. Vegetation influences watersheds by providing ground surface cover, regulating water movement through the landscape and through its influence on soil characteristics. Wildfires can significantly alter both vegetation and soils, which in turn influence important watershed processes such as the interception and moderation of precipitation, shading, water infiltration, runoff patterns, stream flows and erosion (see Section 3.3.1). These processes play fundamental roles in regulating the evolution, condition and availability of salmon habitats.[12] The linkages between watershed controls and watershed processes and how they can interact with major wildfires to affect key components of salmon habitat are summarized in Figure 8.

[10] Waples et al. 2009

[11] Healey 2009; Bisson et al. 2009; Waples et al. 2009

[12] Beechie et al. 2008

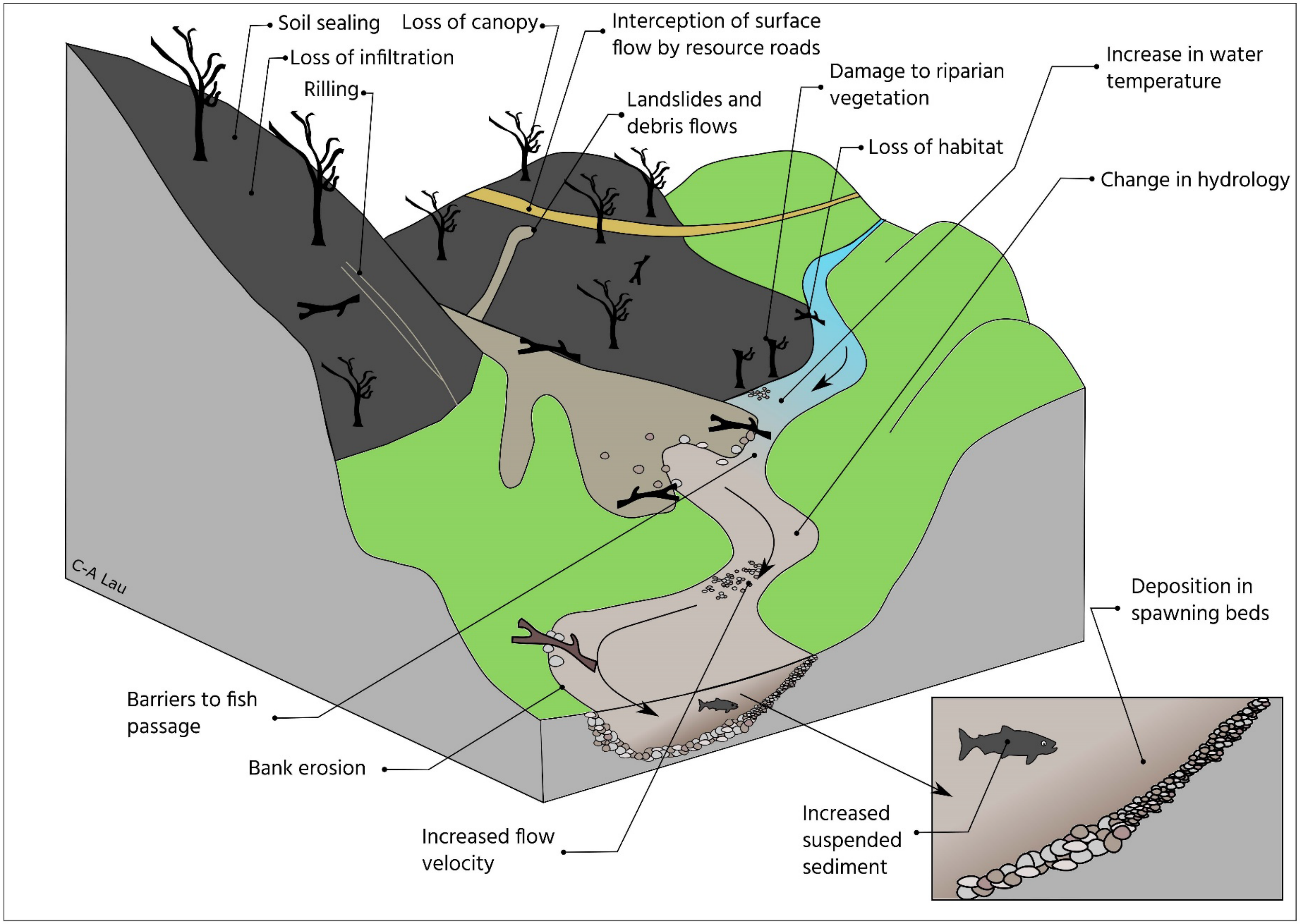


Figure 8. **Potential linkages between watershed controls and watershed processes and how they interact with major wildfires to affect key components of salmon habitat.**

Watersheds continuously move water as well as organic and inorganic materials. As such, rivers and streams are often classified into **three general stages** based on their geomorphic role in generating, transporting or receiving sediments:

1. Headwater sections of low stream order act as sediment source zones, where erosion dominates over deposition. They have steeper gradients and coarser streambed sediments and are often confined in narrow valleys. This means that they have limited ability to migrate laterally, and any sediment mobilized on the hillslopes is likely to be delivered directly to the channel (i.e., the hillslope and channel are geomorphically connected or coupled).

2. Intermediate order sections are considered sediment transfer zones, where both erosion and deposition are important, and have moderate slopes and stream-bed sediment size. They have somewhat wider valleys, are confined only in some sections, and, therefore, are able to migrate laterally and are somewhat buffered from hillslope sediment inputs, which get deposited along the valley margins.

3. Higher order sections play the role of sediment deposition zones, because this process dominates over erosion. These sections are characterized by low gradients and finer streambed sediments and typically flow in wide, unconfined settings, including alluvial fans, wide floodplains, deltas and estuaries where they are free to migrate laterally and are unlikely to be affected by hillslope sediment sources.

This is a greatly simplified conceptual model of the characteristics of natural streams and rivers. In reality, watersheds in BC tend to be much more complex, with abrupt changes related to geology and related factors such as tributary influences. In some cases, the downstream progression, as outlined, may be rearranged due to the legacies of glacial erosion and deposition.[13]

The three distinct geomorphic zones are used to explain a watershed's 'sediment budget', the processes by which sediments are continuously eroded, transported and deposited. As the amount eroded tends to equal the amount deposited, the system is often described as a 'dynamic equilibrium'. In fact, a watershed's post-wildfire recovery might be framed as a process for adapting to a new equilibrium or an eventual return to the former equilibrium. As wildfires reorganize sediment movements, they redefine salmon habitat types and values, and what will qualify as an impact or a remedy in lower order sections will differ markedly from those in intermediate to higher order sections.

[13] Church 2002; Rice 1998; Brardinoni and Hassan 2006; Brardinoni and Hassan 2007

Pitt River Lower Mainland (Photo credit: Melanie Wilson)

The interplay between climate and topographic controls has a significant bearing on salmon productivity and life history strategies. Stream flows over time (i.e., the hydrograph) differ depending on the timing and processes by which precipitation makes its way to a given stream. In the interior of BC, the flows of many streams are sustained by snow melts, which progress to increasingly higher elevations over the course of the summer. In these 'snow-melt dominated' hydrographs, low snow packs often translate to reduced flows in the summer and fall months. In contrast, stream flows in low-lying coastal areas are influenced more directly by precipitation in the form of rainfall. In these 'rain dominated' hydrographs, spring and fall rains sustain flows and can minimize the summer low flow period; however, these systems can be without backup sources of water in those years when the rains do not come as per usual. Areas with high elevations and frequent precipitation events (e.g., BC's Coastal Range) can contain significant amounts of glacial coverage, which, historically, expand and recede and release water depending on temperatures and precipitation events over the course of the year. As one might suspect, glacial dominated hydrographs often experience low flows in the colder months and higher flows in warmer months. The reality, of course, is that many watersheds are a hybrid between these three basic types[14], and many will be altered by climate change and/or wildfire.

[14] Shanley et al. 2015

Observations on hydrographs may seem far removed from stream restoration work, but if a particular stream experiences predictable and sustained low summer flows, then it might be better to invest in restoration efforts designed to delay snow melt, store water or facilitate ground water recharge than to pursue work in channels with uncertain flows.

Idealized salmon streams are often *characterized* as being relatively stable with clean, cool water, but this is not always the case. For example, BC interior watercourses can experience high water temperatures while the glacial rivers occur along BC's North Coast are often dynamic and turbid.[15] Salmon are adept at taking advantage of a diverse habitat mosaics to survive in a wide range of conditions, owing to their genetic diversity and behavioral plasticity, varied life history strategies, and opportunistic habitat use.

The resilience and adaptability of salmon have prompted some to ask: “Are wildfires always *bad* for salmon?” The scientific community has answered “not necessarily”. For example, researchers in Oregon have found that, in some cases, native salmonids contend with, or even benefit from, wildfire disturbance.[16] In past centuries, more frequent, small, patchy and mixed severity wildfires and/or Indigenous burning practices[17], have continuously shaped forests at watershed scales. While these fires probably came with some localized and short-term negative impacts, such as high sediment inputs and slope failures, they are also known to have brought longer-term benefits. With sediments come important spawning gravels, and while vegetative cover may be temporarily lost, the input of large organic debris can shape and improve channel complexity. Under this scenario, salmonids had the option to move to less impacted habitats more readily and, with time, watershed processes would organize the beneficial fire-born inputs and renew habitats. Wildfires can also increase nutrient inputs (e.g., dissolved organic carbon, nitrites and phosphorous) and sunlight penetration into streams, which can stimulate primary production and increase the productivity of salmonid populations. This dares us to examine our preconceptions. Terms such as ‘watershed recovery’ and ‘habitat rehabilitation’ imply the effects of fire are always negative and a return to the pre-existing state is always desirable. However, not all parts of a watershed or stream network will be impacted equally by fire and a natural and continuous process of change, involving destruction and renewal, is always at play.

[15] Healey 2009

[16] Flitcroft et al. 2016

[17] Copes-Gerbitz et al. 2023

Fire-derived, large organic debris and stream channel complexity (Photo credit: John DeGagne)

The previous discussion highlights the need for caution when contemplating the effects of wildfire on fish: in the absence of carefully designed assessments and a monitoring program, assumptions based on simple conceptual models could be misleading. To be useful, understanding of long-term watershed disturbances and processes must account for the individual watershed's characteristics (i.e., geology, climate and ecology) and be framed within the context of the natural range of variability of the fire regime as well as past and current trends. Climate change is expected to increase the frequency of extreme climatic events, including large, severe and less patchy wildfires, major floods and droughts. Future shifts in the frequency and magnitude of floods, and the amplifying effects of wildfires, could modify the geomorphology of streams and alter sediment source, transport and deposition zones and habitats within watersheds. In combination, these factors have the potential to alter the biological communities within watersheds and have even further long-term consequences for salmon populations, especially for those that rear in freshwater. Based on the current intersection of existing human land use practices and disturbance patterns, climate change and wildfires, outcomes for many BC watersheds are uncertain.

What happens when…

- a high-intensity/severe wildfire impacts a significant proportion of a watershed;
- a salmon population within that watershed is already on the verge of extirpation; and/or,
- few refugia with spawning and/or rearing habitats remain or access to them is not possible?

The answer, though equally uncertain, is that it will depend on geology, topography, climactic factors, weather and the severity (i.e., impacts to vegetation and soils), extent and spatial pattern of the burn. It will also depend on the ecology of the system, the habitat requirements and conservation status (population trend) of the salmon population in question. It will also depend on the ability of human intervention to: 1) shift some of the watershed controls and processes back toward what naturally occurred, 2) restore critical habitats, and 3) steward the remaining and newly created habitats. More philosophically, it will depend on a collective appreciation for the watershed's ecological services, the resources at hand, the vision for what could be and the will to take action toward that end.

If interventions are to be successful, they will have to address the habitat requirements of the individual salmon populations in question—down to the levels of species, populations and life stage. They should also address those freshwater habitat factors or 'at risk elements' that are most limiting to salmon productivity. This may extend beyond typical post-wildfire recovery actions and address other disturbances and cumulative effects, which necessitates an understanding of the individual and evolving watershed processes in post-wildfire environments. Timelines for habitat recovery will be based on the evolution and recovery of the watershed as a whole. The restoration of 'what was', at any point in time, may not be possible—or even desired.

Further, the success of freshwater habitat interventions may be tempered by productivity and mortality factors that occur in distant marine and migratory habitats. Projections for the success of any freshwater plan or set of activities should be framed in a realistic appraisal of how they fit into the entire system.

3.3 WILDFIRE IMPACTS AND INTERACTIONS – UNDERSTANDING SOURCES OF HARM

This subsection qualitatively describes key wildfire impacts on watersheds and salmon habitat and on the processes that shape them. Impacts will be characterized in the context of watershed processes in different parts of the watershed (e.g., hillslopes, riparian zones, stream channels) and at different temporal scales to provide insights into the appropriateness of the various treatments and management strategies described in Section 5. Ultimately, watersheds are dynamic entities and recovery efforts should attempt to re-establish normative physical and biological processes. That said, the recovery community may also have to consider climate change and the possibility of 'continuous change' and new limits within freshwater habitats.

As stated in the *Joint Professional Practice Guidelines: Watershed Assessment and Management of Hydrologic and Geomorphic Risk in the Forest Sector*[18]:

> "*Combined with increased variability in weather, these changes* [associated with climate change] *may also affect hydrologic and geomorphic processes. For example, terrain stability may change (improve in some regions and worsen in others) in conjunction with changes in precipitation, snowmelt patterns, windthrow, and forest species. Stream hydrographs are expected to continue adjusting in response to changes in temperature and precipitation. Depending on the stream flow regime, forest cover changes may exacerbate or compensate for these hydrograph changes*."

Thus, a projection of climate change trends may compel heightened precautions and innovative habitat recovery strategies and actions. While, at watershed scales, it may not be possible to predict future climate regimes with precision, if climate change is expected to worsen habitat conditions that already limit salmon, then it may be necessary to adapt traditional management actions.

Throughout this Playbook, 'wildfire regimes' refers to a combination of fire characteristics such as frequency, size, seasonality and intensity.[19] Wildfire regimes vary substantially across BC, reflecting geographical patterns of climate, type of vegetation/fuel, and topography. For forest management purposes, wildfire regimes in BC are commonly classified using the NDT system (see Section 1.1). This classification focuses on fire frequency (distinguishing between frequent, infrequent, and rare) and severity (stand-initiating versus stand-maintaining fires). A more nuanced system, used often in scientific research is called the Historical Natural Fire Regime, also recognizes mixed-severity fires and sometimes factors in other relevant conditions, such as topography. The fact that the latter classification rests primarily on the frequency and low/mixed/high severity, makes it broadly similar to systems currently used in the United States. This category reflects the increasing recognition of the historically widespread nature and importance of mixed-severity fire regimes in the region.

To clarify, classification terms need to be described in more specific terms. Fires referred to as 'frequent' fires may burn every few years to few decades. In 'infrequent' (or rare) fire regimes, the intervals between fires may be counted in hundreds of years. Fire severity focuses primarily on the type and proportion of the affected vegetation cover. In 'low' severity regimes, fire consumes mostly surface fuels, but most of the trees in the burned stand survive. 'High' severity regimes, on the other hand, involve crown fires in which most of the trees are killed by the fire, essentially initiating secondary succession within the burned stand. A 'mixed' severity regime is one in which severity may be variable in different burned patches within the same fire.

[18] Engineers & Geoscientists of BC (EGBC) and the Association of BC Forest Professionals (ABCFP) 2020

[19] Marcoux et al. 2013; Hall 2010

3.3.1 HYDROLOGICAL IMPACTS

The hydrological impacts associated with wildfire stem from altered soils and the loss of vegetation, both of which are highly influenced by the severity of the fire and its patchiness. Intense fires alter the properties of soil, including its permeability. This determines the proportion of precipitation that infiltrates the soil versus the amounts that travel quickly over its surface. Soil is a mixture of mineral and organic materials and contains solids and pore spaces that permit the infiltration and movement of air and water within soil layers. Unburned forest soils absorb water and slowly transfer it downslope to waterbodies. In contrast, burned soil organics and vegetation generate ash that, when wetted, expands into the soil's pore spaces. This 'infilling' limits water infiltration and the soil's capacity to absorb and store water. In parallel, when wildfires burn vegetation, the resultant hydrophobic organic compounds can coat soil particles with waxy substances. This 'soil sealing' causes the formation of a water repellent layer that further decreases water infiltration rates and the soil's capacity to absorb water.[20] Water repellency will typically persist for two to five years after the wildfire[21].

Beyond the hydrophobicity, another potential wildfire impact to soils relates to changes in aggregate stability, which can influence susceptibility to erosion. "*Aggregate stability (AS) refers to soil structure resilience in response to external mechanical forces. Many authors consider soil aggregation to be a parameter reflecting soil health, as it depends on chemical, physical and biological factors. The response of AS to forest fires is complex, since it depends on how fire has affected other related properties such as organic matter content, soil microbiology, water repellency and soil mineralogy. Opinions differ concerning the effect of fire on AS. Some authors have observed a decrease in AS in soils affected by intense wildfire or severe laboratory heating. However, others have reported increases*."[22]

Beyond soils, vegetation is a profoundly important nature-based control, or regulator, of a watershed's hydrology. The removal of forest and grassland vegetation by wildfire eliminates an important filter within the water cycle that intercepts precipitation and directly returns this water to the atmosphere through evaporation. In post-wildfire conditions, a greater proportion of precipitation hits the ground, travels to streams and increases flows. In forested watersheds, 10% to more than 50% of precipitation can be intercepted by vegetation.[23] This interception slows water movement toward the forest floor and enhances the diversionary effects of evaporation (which returns the water to the atmosphere). Vegetation also draws water from the soil, via rooting systems, and transfers it back to the atmosphere through transpiration. Both phenomena, collectively referred to as 'evapotranspiration', serve to reduce the amount of water that is ultimately transferred to streams. Forest canopies also regulate snow accumulation, snow melt and the subsequent rate of evaporation. The removal of a forest canopy and its shading have led to a 60% increase in snow accumulation (total snow-water equivalent) with higher accumulation occurring in large burn sites

[20] Ebel and Moody 2020

[21] Curran et al. 2006

[22] Mataix-Solera et al. 2011

[23] Musy and Higy 2011; Brooks et al. 2012

and in topographic depressions.[24] Further, forest canopy loss increases the amount of solar radiation that reaches the ground, and has been associated with earlier snowmelts, increased rates of melt and more intense spring freshets.[25] [26]

Hydrological impacts of wildfires are variable and influenced by fire severity, the proportion of watershed area burned (catchment ratio), type of vegetation loss, soil types, terrain and weather events. However, the lower rates of infiltration and evapotranspiration after a fire can serve to increase the amounts of water that is transported directly to the stream. A general trend, immediately after a wildfire, is a significant increase in streamflow, whether it is measured as peak flow, basal flow, annual yield or runoff coefficient.[27] Following wildfires, stream flows have been reported to increase by 20% to 120%, sometimes more, with the hydrologic effects of wildfires being most pronounced in small watersheds.[28] In addition, a faster release of water to streams during precipitation events, often described as runoff 'flashiness', is commonly observed.[29] These effects are most pronounced in extreme precipitation events, such as atmospheric rivers and/or rain on snow events.[30]

Hydrological impacts due to losses of forest cover are difficult to remedy in a timely manner, especially when a large portion of a watershed or major sub-basin has been lost to wildfire. In some circumstances it has been found that, at the stand level, a regenerating forest will probably not achieve 90% hydrologic recovery (i.e., original ability to attenuate peak flows) until it has regrown to within 60% of the original stand height and, depending on the productivity of the site and burn severity, this could take well over 50 years to achieve[31]. At the watershed level, forest managers often attempt to manage clearcut equivalency within a watershed (or portion thereof) to be less than 30% by area at any given point in time. In contrast, large wildfires have the potential to elevate this number to 100% for smaller, and even medium sized, sub-basins.

The aforementioned hydrologic impacts affect many other processes and elements within watersheds, including terrain stability and mass wasting, sediment delivery to channels and in-channel sediment transport, water quality, habitat connectivity, riparian function and channel erosion and structure. It is for this reason that many ecologists regard the hydrograph as the 'master habitat variable', meaning it is *the* variable that controls, influences or relates to almost all freshwater habitat variables. Peak or flood flows influence salmon steams profoundly. High flows can: 1) scour or incise channels and simplify them by reducing sinuosity in deposition zones, and 2) remove large organic debris and reduce in channel complexity (e.g., pool-riffle-run) in transport zones. They can also lead to an excessive deposition (i.e., aggradation) of

[24] Winkler et al. 2010; Burles and Boon 2011; Maina and Siirila-Woodburn 2020; Pimentel and Arheimer 2021

[25] Burles and Boon 2011; Owens et al. 2013; Uecker et al. 2020

[26] Seibert et al. 2010; Mahat et al. 2016

[27] Moody and Martin 2001a, Moody and Martin 2001b; Seibert et al. 2010; Mahat et al. 2016; Hallema et al. 2017; Havel et al. 2018; Blount et al. 2020; Niemeyer et al. 2020; Wangenbrenner et al. 2021

[28] Mahat et al. 2016; Hallema et al. 2017

[29] Pimentel and Arheimer 2021; Saxe et al. 2018

[30] Neary et al. 2005

[31] Winkler and Boon 2017; Crampe et al. 2021

substrates in deposition zones. High flows can also create velocity barriers to fish movements and divert fish into temporarily flooded areas, which can then become traps that cause stranding and mortalities.

While hydrologic recovery will serve to attenuate peak flows, regenerating forest stand types (i.e., species, density, age, crown closure) can exacerbate summer low flows. Research is suggesting that dense younger age stands can intercept substantial amounts of precipitation and potentially draw too much water from the soils.[32] Thus, while regenerating stands may serve to attenuate peak flows as they recover hydrologically, they have also been linked to summer low flows that can reoccur for many decades following the initial disturbance (e.g., forest harvest). The magnitude and mechanisms of this effect in post-wildfire environments is not well understood; however, the process is likely to be similar to that identified for harvested areas.

Low flows in a coastal system (Photo credit: Jeff Morgan)

Root systems of standing vegetation play an important role in maintaining both soil porosity and infiltration rates. They provide physical protection and anchoring of the soil (bio stabilization) and soil cohesiveness (i.e., resistance to erosion).[33]

[32] Jones et al. 2022; Segura et al. 2020; Gronsdahl et al. 2019

[33] Sidle and Bogaard 2016; Jackson and Roering 2009

By altering soil *and* vegetation, wildfires can deliver a 'one-two punch' that significantly alters watershed hydrology, which then influences the biophysical characteristics of stream channels and salmon habitat conditions. The reduced ability of soils to absorb, retain and slowly move water downslope after a wildfire leaves more water on the soil's surface, which, through overland flow, is delivered more rapidly to the nearest waterbody. More rapid overland flows increase the erosive potential of water and serve to concentrate, in time, the amount of water received by the streams—higher sediment transport and peak flows being the result.

Typically, the effects of wildfires on watershed hydrology subside over time, but recovery periods can span decades, depending on the recovery of the vegetation community, especially forests.[34] Process-based restoration, described in more detail in Section 5, tries to re-establish magnitudes and rates of various processes (e.g., physical, chemical and biological) that create and sustain the ecosystems of rivers and floodplains.[35] As the watershed's hydrograph can be viewed as the master habitat variable, post-wildfire restoration efforts should seek to re-establish vegetative cover, especially the forest canopy. Though more difficult, some measures, such as ground scarification (see Section 5), can be used to address infiltration rates, but this has to be weighed against potential implications for sediment mobilization. Over time, hydrologic recovery will have profound benefits to watershed processes and will influence the sequencing of other watershed and fish habitat recovery treatments that can be implemented.

3.3.2 HILLSLOPE SEDIMENT TRANSPORT AND MASS WASTING

The partial or complete consumption of the vegetation cover and forest floor organics by wildfire allows precipitation to impact hillslope soils directly and at full force. Furthermore, intense burns reduce organic matter content within soils and can render them less cohesive and more susceptible to erosion.[36] In drier climates, dry ravel (i.e., the rolling and sliding of soil particles down a slope) has been identified as an important mechanism of sediment transfer on hillslopes. This hillslope sediment transfer is elevated further when precipitation or snowmelt events are combined with soil repellency and loss of plant rooting systems.[37] The post-wildfire changes in ground surface properties allow water to run off burned landscapes more quickly, which, in turn, increases the erosion of surficial soil layers. These erosion risks are particularly high during intense and long-duration rainfall events.[38] While these risks are most acute in the period immediately after the wildfire, many risks (e.g., from mass wasting events) can remain elevated for decades.

[34] Hallema et al. 2017; Blount et al. 2020; Niemeyer et al. 2020; Robinne et al. 2020

[35] Beechie et al. 2010

[36] Curran et al. 2006

[37] Florsheim et al. 2016; DiBiase and Lamb 2020

[38] Neary et al. 2005


Sediment 'bulking' in gully (Photo credit: Jeff Morgan)

Intense rainfall and rapid snowmelt events in burned areas can result in greatly elevated overland flows that can deliver large volumes of sediment to stream channels. In some watersheds, the surficial hillslope erosion rates (rill, inter-rill and drainage erosion combined) increased approximately 200-fold immediately after a wildfire, but returned to baseline in about three years.[39] Ash, eroded sediment and woody debris can all be incorporated into overland surface flows on steeper gradients and deposited when the flow spreads out across low-gradient areas. Through this same process, sediments can be eroded from the hillslope, combine with sediments, boulders and logs within a gully or water channel, progressively 'bulk' and then transform into a debris flow, which is a very rapid to extremely rapid surging flow of saturated debris in a steep channel[40]. Debris flows are highly destructive and slow the recovery of stream channel complexity, riparian habitats and invertebrate populations. Once in streams, the delivered sediments are transported through transport zones (where the power of the flow is usually sufficient to keep sediments in suspension) and deposited in the slower, lower course deposition zones.

Through a different process known as rill erosion, surface flows on steep slopes with loose soils can create very small channels or rills that erode and then carry sediments downslope. This erosive process can progressively increase the size and convergence of the rills and can form gullies. Depending on the slope, soils and concentration of water, rills and gullies can quickly conduct significant amounts of sediment and material to downslope streams and/or initiate slope failures.

[39] Moody and Martin 2001
[40] Hungr et al. 2014

Gully formation and slope movement (Photo credit: Jeff Morgan)

A post-wildfire increase in overland water flows can also infiltrate and saturate soils and further increase the risk of slope failures. This can be exacerbated by the removal of trees and the binding lattices their root systems provide to hillslope soils and materials[41]. Once initiated, slope failures (or landslides) often transform into debris flows and terminate in valley bottom waterbodies. Impacts on stream morphology and salmon habitats may be confined and relatively short-lived; however, slope failures have the potential to deposit massive and long-lived amounts of material into streams.

Sediments from various described sources can enter streams and negatively impact both the quality and quantity of spawning substrates/gravels. The suitability of spawning gravels can be compromised by the deposition of fine sediments (e.g., clays, silts, and sands) and infilling of gravels, which reduces dissolved oxygen concentrations and the movement of metabolic wastes, resulting in egg and alevin mortalities. Sediment can also directly entrap and kill alevin and emerging fry within spawning gravels. Depending on the qualities and amounts of the deposited sediments, the qualities of the spawning substrates and the flushing rates due to stream flows, the impacts of sediment deposition will vary with time. Further, sediment and other mass wasted materials that are too coarse to be delivered to the sediment deposition zone lower in the drainage network can remain in transport zones to cause long-term issues, such as barriers to fish passage.

[41] Calhoun 2022

Excessive suspended sediment concentrations in the water column can directly impact salmon health (e.g., gill trauma and effects on osmoregulation, blood chemistry, reproduction and growth) and behaviours (e.g., predator avoidance, territoriality, foraging and predation, and migration), which can cause or lead to mortalities and/or reduce populations productivity.

Beyond the direct implications, sediments play a role in the transport of many deleterious chemicals from upland to in-stream habitats. For example, fire retardants can come to rest on the soil surfaces and subsequently become integrated into sediments that are delivered through erosive processes to aquatic environments. These chemicals often enter aquatic ecosystems through sediments, such as silt, where they enter spawning and rearing substrates.[42] Aquatic life, including salmonids, that are exposed to these compounds through the consumption of contaminated food and water, experience adverse effects and increased mortality, particularly Chinook salmon undergoing the parr-smolt transformation.[43]

These chemicals can pose very serious threats to salmon and their food webs and yet treatments to mitigate their effects are not yet employed on an extensive basis. Accordingly, sediment control initiatives can be viewed as a defence against the effects of sediments and the chemicals they may contain.

3.3.3 STREAM CHANNEL MORPHOLOGY IMPACTS

Channel morphology and streambed texture, two fundamentally important elements of salmon habitat, are largely determined by sediment and large woody debris inputs during storm events, when flows have sufficient power to transport coarse sediment and wood down the channel.[44] A stream's normal sediment budget is important in maintaining salmon habitat values; however, large wildfires can increase the frequency and magnitude of flood events, which can change the nature of a watershed and the quality of habitats within it. For example, very high flows and downward channel erosion (incising) within flood plains can drain seasonal off-channel habitats and reduce habitat connectivity, arrest the seasonal cycle of floodplain enrichment and slow the recovery of riparian vegetation.

In BC, salmon often spawn and rear in transport zone stream networks that can consist of alternating habitat types including runs, riffles, pools and lateral habitats such as back channels. All types play ecological roles, contribute to salmon habitats and are selected by salmon for use at various life stages and at different times of the year.

Elevated flood flows, especially when combined with stream banks that are more susceptible to erosion, can scour and simplify streams. This can greatly reduce the quality of, or eliminate, some habitat types (e.g., pools) and reduce the diversity of habitat types that are required by salmon as they advance through their life stages.[45] High flows and downward channel erosion can also negatively impact spawning habitats by

[42] Hale et al. 2003

[43] Buhl and Hamilton 2009; Dietrich et al. 2012

[44] Chen et al. 2005

[45] Eaton et al. 2010

mobilizing suitable spawning substrates and depositing them downstream. Under this circumstance, the ability of channel transportation reaches to hold spawning substates can be reduced, pending the hydrologic recovery of the system. In addition to the habitat implications, post spawning scouring events can directly impact salmon by flushing, grinding and killing eggs and alevin.

Elevated flows may also impact larger substates such as cobbles and boulders that provide habitat complexity in streams, including cover and resting areas for juveniles and migrating adults. These substrates also facilitate water, nutrient, and biological (e.g., microorganisms) exchanges. Excessive flooding and scouring events can disrupt and negatively affect the habitat variables that are in place, at least in the short term. Over the mid and longer term, with scouring and deposition, habitats will eventually re-emerge; however, this plays out in time and space according to the hydrologic recovery processes.

Aggradation and some lateral erosion (Photo credit: Jeff Morgan)

With channel incising and the transport of steam bed materials in higher gradient reaches comes the prospect of downstream aggradation (sediment deposition) in lower gradient reaches. Depending on the watershed, and salmon species present, this *can* come with some positive trade-offs such as the creation of new spawning habitats. Very often, however, negative effects can span short to long timeframes. The downstream movement of sediment (cobble and gravel loads, or 'wedges'), can eliminate stream channel complexity, scour and destabilize banks, promote lateral erosion, destroy riparian habitats and impede fish passage. Even when in lower gradient deposition zones, high and sudden sediment influxes can reduce channel complexity and, when combined with high steam flows, can lead to lateral streambank erosion, widening shallows and moving stream channels (avulsions).[46] Finally, the transport and eventual deposition of finer sediments, such as silts, overtop of gravel beds can reduce water quality, place hardships on fish and eliminate or negatively impact spawning substrates.

Low intensity wildfires can, however, benefit channel morphology, as some trees die and then make their way into the stream. This woody debris adds structure and stability to stream channels that often contributes to habitat complexity (which is positively correlated with species diversity) through the creation of steps and

[46] Davidson and Eaton 2018

pools, diversified water velocities and deposition of spawning gravels at very localized scales. In contrast, high-intensity and widespread wildfires can kill *all* trees that are proximal to the stream. Though not well documented, the mass removal of trees has the potential to limit the recruitment of woody debris in the decades that follow and this could directly reduce habitat diversity, in-channel structure and the stream's resiliency to peak flow events.

3.3.4 HABITAT CONNECTIVITY IMPACTS

Major wildfires, through their impacts on watershed hydrology and terrain stability, can result in barriers to the movement of salmon within the watershed. Slope failures and debris flows can block channels and infrastructure and preclude fish movement. Similarly, concentrated course sediment aggradation at tributary confluences can block fish passage. Where more widespread, aggradation can broaden stream beds and create shallows that can: 1) directly block or impede fish movement, 2) increase metabolic expenditures, 3) increase the risk of stranding and/or losses to predation, and 4) increase water temperature.[47]

Heightened peak flows in post-wildfire environments can create waterfalls, large steps, debris jams, thermal barriers and velocity barriers, which can potentially prevent or delay salmon migrations and spawning. In addition, habitat connectivity impacts due to human causes (e.g., perched culverts and collapsed infrastructure) are often exacerbated by the heightened peak flows and debris movements that follow large wildfires.

Stream morphology impacts can also have consequences for connectivity. Incising can alter or eliminate the natural connectivity between the stream channel and the adjacent flood plain habitats. Alternatively, excessive deposition can preclude access to important thermal refugia, such as side channels.

3.3.5 IMPACTS TO RIPARIAN ZONES AND FOOD WEBS

Riparian zones are transitional ecosystems located between surface water bodies (e.g., streams, lakes and wetlands) and upland habitats, such as forests or grasslands. They are typically composed of vegetation adapted to damp soils and periodic flooding. As these zones tend to be relatively damp, low intensity wildfires can leave riparian zone vegetation largely intact. However, the intense heat generated by many of the recent wildfires in BC have resulted in the loss of riparian zone vegetation (e.g., Elephant Hill and Lytton Creek fires). These vegetation losses can affect: 1) organic inputs and food web functions, 2) vegetation cover and shading functions, and 3) rooting systems and bank stability.

Depending on the geomorphology of the watershed, a proportion of the coarse woody debris important to channel morphology can originate in riparian zones. Coarse woody debris can trap finer woody debris and organic materials, which are then consumed by invertebrates and microorganisms. In headwater streams, riparian areas contribute most of the organic matter that provides energy and nutrients to the aquatic food

[47] Poole and Berman 2000

web.[48] The deposition of insects and leaf litter, small woody debris and seeds all represent external contributions that feed rearing salmon or their prey.

Riparian trees and shrubs also intercept sunlight, which helps to regulate water temperatures. The amount of shading and thermoregulation provided by riparian vegetation is related to stream size, vegetation type, forest structure and age, and season. Typically, riparian vegetation plays a greater role in the maintenance of temperature in smaller streams because the vegetation spans a higher proportion of the channel. Following the removal of forest cover, research has shown that it can take up to 15 years for daily fluctuations in water temperature to return to baseline conditions[49]. A similar duration of thermal recovery might be expected following major wildfires. As is the case for most aquatic organisms, the metabolic functions of salmon are, to a large extent, determined by water temperature.[50] Temperature influences energetic demands during migration, habitat selection for spawning, incubation and embryonic development, growth and feeding rates, and survivorship. Water temperature also affects the timing of adult migrations, egg incubation periods, juvenile maturation and out-migration. Overly warm water temperatures can affect the timing and success of adult migrations, reduce fecundity, decrease egg survival, inhibit the growth of fry and smolts, decrease predator avoidance, increase susceptibility to disease, and decrease the ability of juveniles to compete with other species for food.[51] Additionally, the effects of warm water temperatures on salmonids are cumulative, with longer exposures to thermal stress resulting in reduced long-term survival.[52]

High water temperatures can also decrease the amount of dissolved oxygen in surface water, which can affect salmon at different life stages[53]. Low concentrations of dissolved oxygen adversely affect the swimming performance of adult salmon during spawning migrations, force habitat avoidance and can even stall migration, which can increase the likelihood of pre-spawning mortalities in adults and spawning failures. In juveniles, low dissolved oxygen can limit swimming efficiency and, thereby, reduce foraging success and predator avoidance. Very low levels of dissolved oxygen (3 mg/L) have been shown to cause mortalities in juvenile salmonids.

Riparian vegetation plays additional roles relating to erosion, sediment control and flow velocity dissipation. Depending on the nature of the stream, the roots of trees, shrub and forbs provide a matrix that serves to bind soils and other stream bank materials and make them less susceptible to erosion during flood events. Tree roots can provide a natural armouring that can secure and maintain stream banks even during overflow flood events.[54] Riparian vegetation can also intercept the surface flow sediments and mitigate their introduction into the stream. During flood events, trees in riparian zones provide vertical structure that can

[48] Richardson et al. 2010

[49] Johnson and Jones 2000

[50] Ligon et al. 1999

[51] Spence et al. 1996; McCullough 1999

[52] Ligon et al. 1999

[53] Carter 2005

[54] Cienciala 2021

intercept and retain organic debris, which can then dissipate flows, increase lateral flows over floodplain habitats and reduce water velocities. This, in turn, reduces the risk of down cutting (incision) and stream channel simplification.

Depending on their severity, wildfires can alter energetic pathways (nutrient sources and the transfer of nutrients through food webs) in stream ecosystems. When riparian ecosystems are intact, much of the organic carbon that promotes biological production in streams comes from external sources such as insect drop, leaf litter, organic detritus, twigs and larger woody debris. Biological production in streams that depends on external nutrient sources is termed 'allochthonous production'. Shredders, such as cranefly and limnephilid caddisfly larvae, stonefly nymphs and amphipods[55], tend to dominate macroinvertebrate communities in streams that that receive most of their organic carbon from external sources.[56] When riparian ecosystems are consumed by major wildfires, there is a shift from allochthonous production to 'autochthonous production' that is dependent on within-stream nutrients.[57] Periphyton, which extract nutrients from the water column, are important sources of organic carbon in streams that have been severely impacted by major wildfires. In these streams, scrapers and grazers, such as mayfly nymphs, gastropods and glossosomatid caddisfly larvae, tend to dominate the macroinvertebrate community; these feed on periphyton and other components of biofilm.[58] Salmonid species that are adapted to wildfire prone environments can generally feed on a wide variety of benthic invertebrates, including species that have shredder, scraper and grazer feeding strategies.

3.3.6 WATER QUALITY

Soils contain many naturally occurring elements and compounds and when these soils are eroded, they can carry them to surface waters and salmon streams. Soil erosion after major wildfires can deliver large quantities of dissolved organic carbon, particulate organic carbon[59], and inorganics such as aluminum, arsenic, barium, chloride, chromium, copper, iron, mercury, potassium, magnesium, manganese, nitrogen, sodium, nickel, phosphorus, lead, sulfur and zinc[60] to streams. Particulate organic carbon, nitrogen and phosphorus can stimulate biological production in streams; nutrient (e.g., nitrogen and phosphorus) pulses that enter streams following major wildfires can stimulate primary productivity (e.g., photosynthetic periphyton) and fish production. However, some metals, such as arsenic, barium, chromium, copper and

[55] Cummins and Klug 1979

[56] Minshall et al. 1997

[57] Minshall et al. 1997

[58] Cummins and Klug 1979; Minshall et al. 1997

[59] Emelko et al. 2011; Hohner et al. 2016; Hohner et al. 2019; Burd et al. 2018; Uzun et al. 2020

[60] Emelko et al. 2011; Smith et al. 2011; Stein et al. 2012; Coombs and Melack 2013; Silins et al. 2014; Evans et al. 2017; Hohner et al. 2019; Mansilha et al. 2019; Basso et al. 2020; Robinne et al. 2020; Sequeira et al. 2020

mercury, can have inhibitory effects on production, and the increased water temperatures that often follow large wildfires can adversely affect salmon while rearing and migrating.[61]

While soils and sediments are important post-wildfire vectors for chemicals to surface waters, chemically-enriched ash is often *the* main factor that causes the concentrations of organic and inorganic chemicals to increase in surface waters following wildfires.[62] Polycyclic aromatic hydrocarbons (PAHs) can be highly concentrated in post-wildfire ash.[63] Some polycyclic aromatic hydrocarbons can have toxic effects, including carcinogenicity and mutagenicity.[64]

3.3.7 CUMULATIVE EFFECTS

Watersheds in BC are rarely affected by a single disturbance and, instead, have experienced a succession of many different disturbances of varying magnitude that are either natural or human caused. The combined effects of all past and ongoing disturbances (natural and human caused) are referred to as 'cumulative effects'. Common human-caused disturbances that occur in BC can be associated with:

- wildfires and wildfire suppression activities;
- forestry;
- agriculture;
- oil and gas (i.e., well sites and pipelines);
- mining;
- dams and water diversions;
- linear developments (e.g., roads, railways, electric transmission lines, pipelines);
- urban and other residential development;
- insect infestations;
- spread of invasive species;
- landslides and other types of mass wasting; and,
- pollution.

A description and evaluation of the various practices that are associated with the aforementioned disturbance types is beyond the scope of this Playbook. However, recovery teams should evaluate and consider the implications of all relevant and consequential disturbance types as a critical step in the planning process.

[61] Burton 2005; Emelko et al. 2011; Silins et al. 2014; Carvalho et al. 2019; Ré et al. 2020

[62] Bodí et al. 2014; Hohner et al. 2016; Brito et al. 2017; Nunes et al. 2017; Nadel-Romero et al. 2019; Alexakis 2020; Alexakis et al. 2020; Basso et al. 2020; Ré et al. 2020

[63] Campos et al. 2019; Chen et al. 2018; Harper et al. 2019; Kohl et al. 2018; Simon et al. 2016

[64] Achten and Andersson 2015; Balcioğlu 2016; Behera et al. 2018; CCME 2010; Manzetti 2013; Nunes et al. 2017

The cumulative effects of disturbances to watershed function can be additive (i.e., the total impact equals the sum impact of each disturbance) or multiplicative (i.e., the total impact exceeds the sum impact of each individual disturbance). In some cases, the interactions of two or more effects can serve to cancel or dampen the combined effect. An example of this 'antagonistic' cumulative effect could be a water diversion/impoundment that serves to offset a very high peak flow. Based on the amount of development in much of BC, interacting disturbances are the norm and wildfire impacts almost always combine with the pre-existing and human-caused impacts to forest canopies, soils, runoff patterns, and riparian function. At the same time, climate change has already increased peak flows in some watersheds in BC and caused a general trend towards reduced flows over more extended periods in the BC interior.[65] The cumulative effects of climate change in concert with the many forms of forest removal can be expected to increase the frequency and magnitude of flooding and drought events.

Road networks can also exacerbate the hydrologic impacts of wildfire. Their extremely low infiltration capacity increases the potential for surface runoff, while their linear nature and associated ditches lead to the interception of overland and subsurface flow from upslope areas.[66] These characteristics increase hydrological connectivity and lead to faster, flashier streamflow responses to precipitation and snowmelt.

Debris buildup upstream of culvert inlet (Photo credit: Pacific Salmon Foundation)

Road infrastructure at creek and river crossings (e.g., culverts and bridges) is often vulnerable to high flows and/or debris, which can lead to debris jams, blocked or damaged culverts and/or road failures, all of which can impact fish passage. Further, damaged or inadequate drainage structures can increase the probability of road failures near streams, which can lead to surges in flow, channel erosion and sedimentation events. When blocked or overwhelmed by post-wildfire flows, culverts and ditching can also divert and concentrate water onto unstable slopes and, thereby, increase the risk of slope failures. Diverted water can also overload smaller watercourses and thereby cause erosion within the channel and/or trigger slide events. Conversely, even when operating well, road crossings can decouple streams from important sources of sediments (e.g., gravels) and woody debris.[67]

[65] Zhang et al. 2001; Pike et al. 2010

[66] Megahan and Clayton 1983; Ziegler and Giambelluca 1997

[67] Cienciala et al. 2022

As previously addressed in Section 3, wildfires often increase the likelihood of high flows and debris transport that place existing infrastructure, such as bridges, culverts and roads, at greater risk, which then increases risks to salmon. Among infrastructure-related cumulative impacts that need to be considered are those related to contamination and water quality at the wildland-urban interface. Damage from wildfire or from post-fire flooding or erosion to residential homes and commercial or industrial facilities can lead to, or exacerbate, the release of toxic contaminants to the surrounding soils and freshwaters. Runoff and erosional processes will promote additional dispersal of these substances, which can be a threat to humans and salmon alike. Important facilities to consider are waste disposal sites (e.g., landfills), water treatment facilities, industrial parks, mines, hospitals, and various contaminated sites.[68]

Ironically, even the infrastructure (e.g., fire trails, fire guards, helipads) and chemical fire retardants that are associated with wildfire suppression can negatively impact salmon habitats. For example, sediments can be mechanically disturbed and become available for transport, surface flows can be rerouted and elevate geomorphic risks, fish passage can be impeded, riparian habitat can be destroyed and deleterious chemicals can be introduced to fish habitat.

Water redirected by fireguard (Photo credit: Bob Redden)

[68] Schulze and Fischer 2020; Jech et al. 2024

Overall, the cumulative effects of wildfires and other existing or ongoing watershed disturbances greatly increase the chances of widespread overland flow, flooding, severe erosion, decreased water quality and increased contaminant transport.[69] Watersheds are unique and will react differently to disturbances, and not all wildfire impacts will be destructive. The challenge is that, in combination, climate change, wildfires and pre-existing human-caused disturbances can alter watershed function beyond what salmon can adapt to—and very often this compels management actions. Based on this complexity, post-wildfire recovery efforts depend on an identification of salmon habitat values (elements at risk) and a solid understanding of all impacts and risks. Further, recovery teams will be required to assemble known sources of information (including Indigenous Knowledge) and use qualified professionals to undertake assessments and develop strategies to manage risk and prioritize restoration actions.

3.4 UNDERSANDING HOW WILDFIRES CAN IMPACT SALMON – A SUMMARY

Within the context of a changing climate, wildfires interact with pre-existing human disturbances to impact both watershed processes and the salmon and salmon habitats they sustain. Any attempt to recover a watershed's salmon habitat values must be founded in an understanding of how these variables have interacted in the past, how they are likely to interact in the future and what the implications for salmon and their habitats might be.

Wildfire and other disturbances impact fundamental watershed controls and this, in turn, influences the quality and quantity of salmon habitats and our ability to recover them. In many cases, a return to 'what was' may not be possible—especially with the spectre of a changing climate. Salmon recovery teams will have to probe 'what is possible' and 'what is desired' based on environmental trajectories and the resources at hand. Therefore, watershed and salmon habitat recovery or restoration initiatives should be founded in a strong mechanistic understanding of watershed and salmon habitat dynamics. Pivotal to this is the need to develop an approach to evaluate salmon and salmon habitat values within the watershed of interest and explain how these values may be harmed and placed at risk. This then sets the stage for the assembly of baseline information, investments in additional quantitative information and the risk management considerations described in Section 4.

[69] MacDonald and Larson 2009

4 RISK MANAGEMENT, INFORMATION SOURCES AND ASSESSMENTS

In the aftermath of a major wildfire, communities often manifest a strong desire to quickly restore the environment and salmon habitat values. However, to be effective and reliable, watershed recovery efforts must be informed by an understanding of: 1) the size and locations of the values that were in place prior to the wildfire, 2) the level of impact caused by the wildfire and other potential impactors (e.g., cumulative effects), 3) the watershed's potential for recovery over the short to long-terms, and 4) ongoing risks to the remaining and recovering values.

Risk management processes help recovery teams make proactive restoration plans based on assessment of both the likelihood and consequences of post-wildfire landscape hazard scenarios. For example, they can be used to compare alternative management actions and costs and forecast returns on investment. Risk assessments require an understanding of watershed processes and are used to address ecosystem function and the habitat requirements of salmon. Not surprisingly, multi-disciplinary recovery teams often collaborate in these exercises, and the professionals who operate within these teams have practice guidelines that incorporate risk management principles into their work (e.g., Engineers and Geoscientists of BC, Forest Professionals of British Columbia, BC Institute of Agrologists, College of Applied Biologists British Columbia).

A generalized risk management framework that can be applied to wildfire recovery is described in Section 4.1 (Figure 9). Watershed recovery is a complex and often daunting challenge. The framework provides a structure that can explicitly link management actions to quantified impacts and risks over different timeframes. From a project management perspective, it also serves to define project components, workflows, and information management. The various sources of baseline information and assessments that are, or can be, used in post-wildfire situations in BC are then described in Section 4.2.

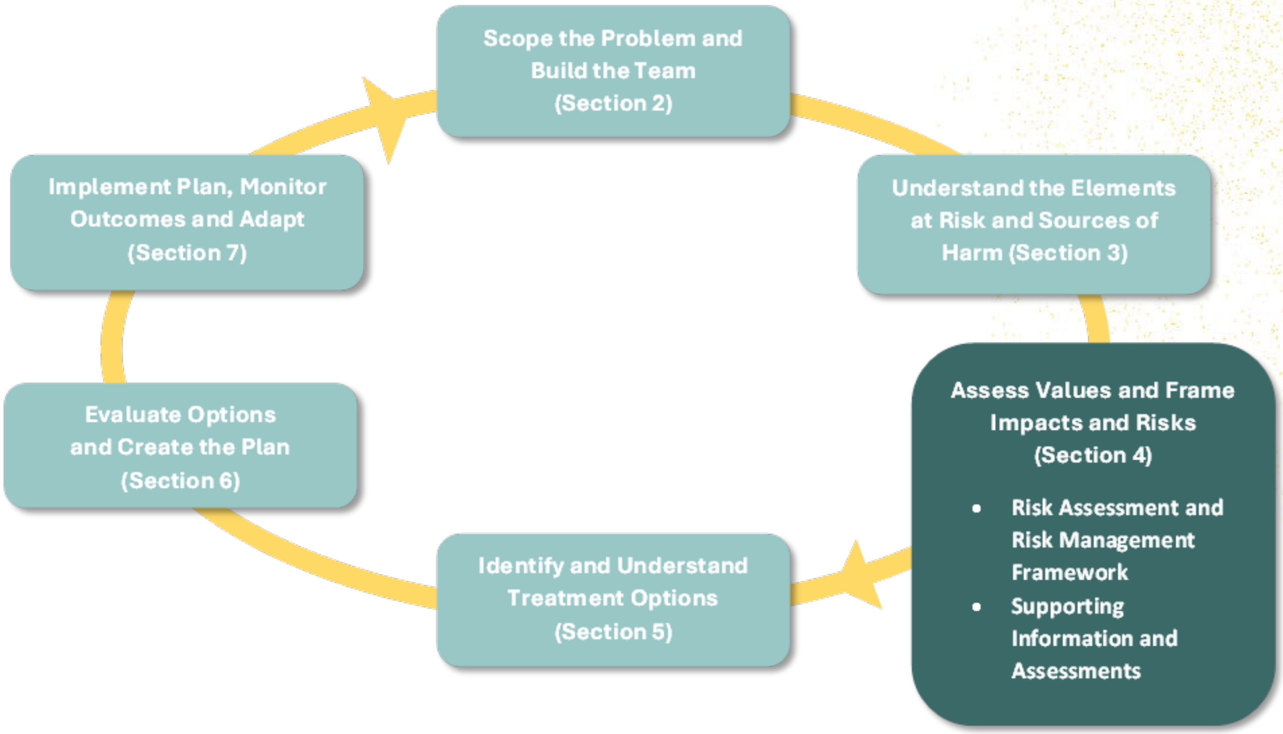


Figure 9. **Highlight of Planning Cycle activities addressed in Section 4.**

4.1 RISK ASSESSEMENT AND A RISK MANAGEMENT FRAMEWORK

4.1.1 RISK MANAGEMENT FRAMEWORKS

Prior to introducing a risk management framework, it is helpful to understand the various aspects of risk to provide consistent terms throughout this document. In its most basic form, ‘risk’ is a function of the likelihood of a particular hazard and the consequence of that hazard. However, this simple formula is influenced by a variety of factors. Figure 10 illustrates the various aspects of risk and their interrelationships, which includes the following concepts:

- Hazard(s): processes, with varying magnitudes and likelihoods, that are a source of harm in a post-wildfire landscape.
- Element(s) at risk: specific things of value (e.g., known spawning habitats for a specific salmon population) that could potentially suffer damage or loss due to a hazard.
- Undesired outcomes: a hazard scenario that an element at risk *could* be exposed to and that *could* have a negative consequence.
- Vulnerability: negative outcomes that are tied to a specific element at risk and are influenced by the magnitude, intensity, duration and timing of the hazard (e.g., direct fish mortality or a loss of habitat type that limits a specific salmon population of value).

- Exposure: a measure of how much the element(s) at risk is exposed, in time and space to a hazard, such as the size, quality and quantity of spawning reaches that are impacted by a hazard at the time of spawning.
- Consequence(s): estimate of the realized loss for element(s) at risk, considering both their exposure and vulnerability.
- Risk: is the intersect where an element at risk may be exposed to an undesired outcome that will have negative consequences. Risk ratings are the probability that a particular negative consequence will occur within the planning cycle or some other predefined period of time.

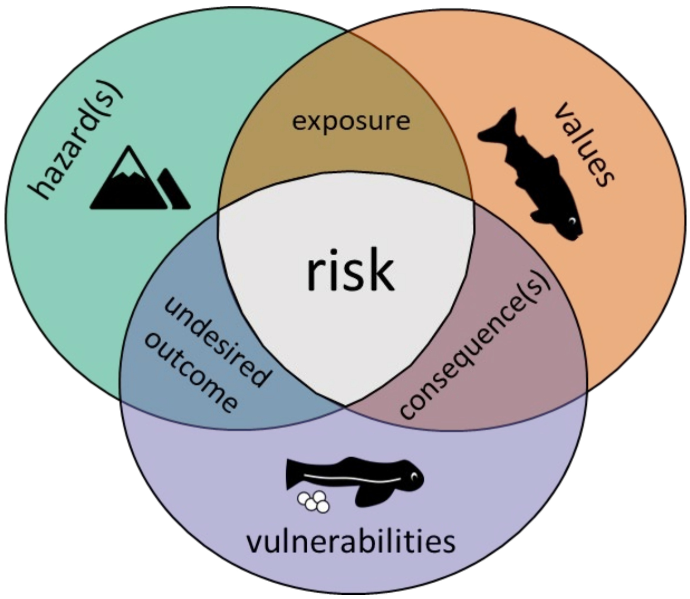


Figure 10. Overview of considered aspects of risk assessments.

Owing to the inherent complexities, risk management frameworks have been developed to provide systematic methodologies for recognizing important watershed values, identifying risks to these values and guiding land management decisions and actions. An excellent guide for the development of a risk management framework in BC, *Watershed Assessment and the Management of Hydrologic and Geomorphic Risk in the Forest Sector*[70], has been jointly prepared by EGBC and ABCFP. The content of this document is, in part, summarized in the following paragraphs; the reader is advised to seek out this document for more detailed information. While this risk management framework is often used to guide the amount of human-caused disturbance that is acceptable over a specified time period within a watershed, it can also be used to inform treatment selection or mitigation works for risk reduction in post-wildfire environments. Some have suggested it could be more positively referred to as an 'opportunity management framework'.

A **Risk Management Framework**, as defined in *Watershed Assessment and the Management of Hydrologic and Geomorphic Risk in the Forest Sector*[71], is a process that results in ***"... a written document that provides***

[70] EGBC and ABCFP 2020

[71] EGBC and ABCFP 2020

the context, scope, and standards for managing Risks from Forest Management Activities in a Licensee's operating area. A framework is intended to optimize the use of organizational resources by focusing the greatest efforts on the areas of greatest concern." This framework approach is readily adapted to an entire watershed or to individual sub-units. A risk management framework can be a separate document that forms the backbone of any given plan, or it can be seamlessly integrated into a plan.

Several steps, as illustrated in Figure 11 and described in subsequent text, are recommended for the preparation of a framework for post-wildfire recovery projects and are founded on the basic planning cycle described in Section 2. Generally, these steps include establishing the risk management context, risk assessment, risk treatment and implementation. Note that these steps are intended to be set within a monitoring feedback loop and within an effective external communications process.

Risk management frameworks are valuable because they create a *process based conceptual model* for understanding how a watershed has been impacted and ranking the risks and effectiveness of proposed treatments (or combinations thereof) through time. The risk management framework provides an overarching conceptual model that relies on a variety of component assessments, which are nested hierarchically and used to project how a watershed can be expected to behave based on past experiences in similar watersheds. The Playbook's general approach, when developing or informing a risk management framework, is to use readily available assessment procedures and sources of information to generate cost-effective and timely information and begin decision-making and treatment implementation.

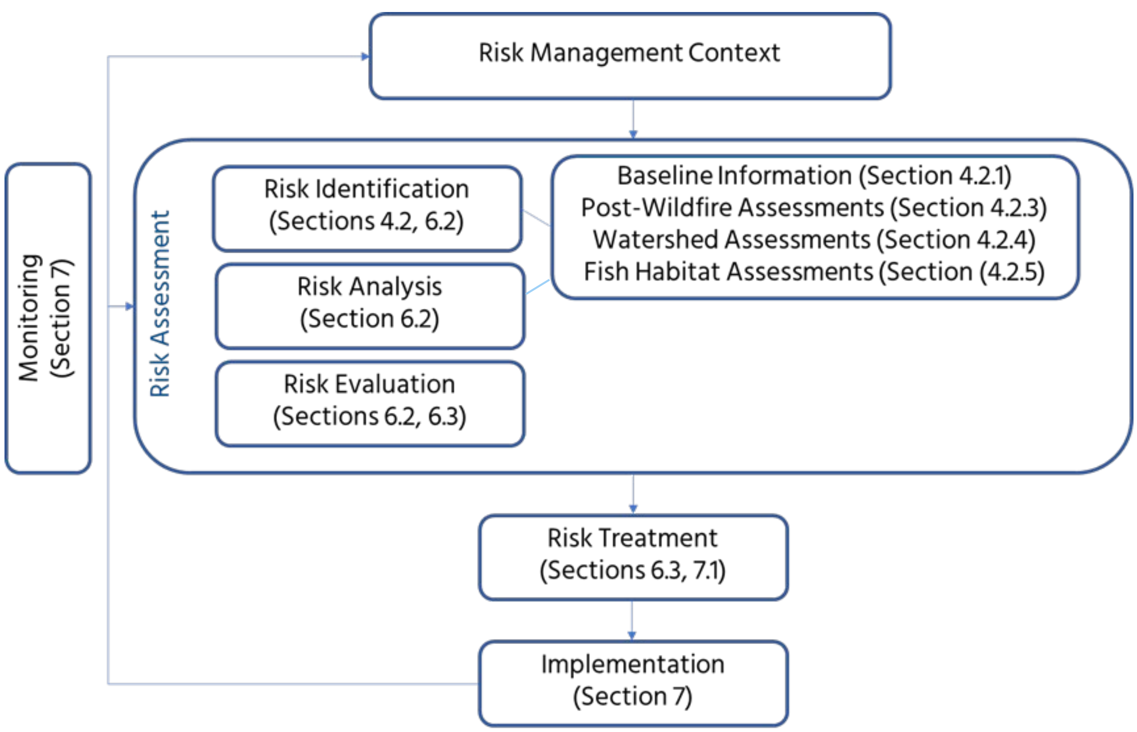


Figure 11. Framework for the management of risk, identifying relevant sections of information in this Playbook. Note: figure adapted from EGBC and the ABCFP 2020.

The **Risk Management Context** step involves the identification and delineation of: 1) a watershed's values and characteristics, 2) management roles and responsibilities, 3) existing guidance, and 4) existing challenges that, when combined, inform the development of risk management strategy and shape its delivery. This step asks the practitioner or recovery team to begin to identify the values that may be at risk or placed at risk—at which point they become known as 'elements at risk'. Representative hazard scenarios may be selected for assessment that control decision-making across a broader range of elements than are practical to assess.

The assessments themselves should be designed to address individual elements at risk separately. This recognizes that cause and effect relationships will differ between the many combinations of values (and/or elements at risk) and hazards (and/or sources of harm) within a watershed. For example, coho salmon spawning habitat conditions (an element at risk) may be impacted by sedimentation, while coho rearing habitat (a separate element at risk) may be impacted by the removal of cover and increased water temperatures. These linkages of disturbances/impacts with elements at risk are usually based on pre-existing knowledge of watershed and salmon habitat responses to disturbance, which determines what information needs to be gathered or generated to support the risk assessment. This can involve pre-existing, or baseline, information and it will also involve assessments that are undertaken to measure the status of the risk element or the source of harm. The outcome of the Risk Management Context step is typically a terms of reference and/or a workplan to undertake the risk assessment, treatment and monitoring.

The **Risks Assessment** involves the following three steps:

1. The **Risk Identification** step involves identifying the elements at risk that are present and any sources of harm to those elements (i.e., exposure) and undesired outcomes. For example, if important coho spawning substrates are known to exist below a highly mobile source of sediments, a sedimentation risk would exist. The outcome of this step is a dataset that can be used to view the aspects of risk (Section 6.2.1) and analyze risk.

   An important component of the risk identification step is selecting credible hazard scenarios that could result in undesired consequences. This task can potentially reduce the number of considered sources of harm/hazards and distill down to the ones that are most likely to impact limiting factors.

   Beyond understanding the immediate impacts that are caused by wildfire, it is also necessary to understand the ongoing risks that any sources of harm may impose. For example, an immediate source of harm could be the loss of riparian habitat and the shade it provides, which could then immediately lead to elevated stream temperatures. Further out in time, this same impact could have consequences for channel and bank stability as root networks eventually decompose and give way. Holistically, these are referred to as a 'cascading hazard' or an 'impact pathway'.

2. The **Risk Analysis** step estimates the level of risk, either categorically (e.g., Very Low to Very High) or quantitatively (e.g., 50% likelihood of post-wildfire debris flows during a 10-year planning cycle/time horizon resulting in a 35% loss of salmon spawning habitat) (Figure 12). The analysis estimates the nature of harm that could be done (i.e., the consequence) to an element at risk combined with the

likelihood of the source(s) of harm/hazard occurring in a period when the element at risk is vulnerable. For example, this analysis would quantify the amount and nature of the sediments, the probability (i.e., hazard likelihood) that it would be deposited over spawning habitats in a period of time when they are needed, and the damage or consequence of the deposition, which in combination would determine risk.

In summary, risk is determined with the following basic equation for each element at risk[72]:

Risk = Likelihood of Hazard × Consequence of Hazard

The outcome of this step is a risk estimation for each element at risk/hazard combination that is identified (also see Section 6.2.2).

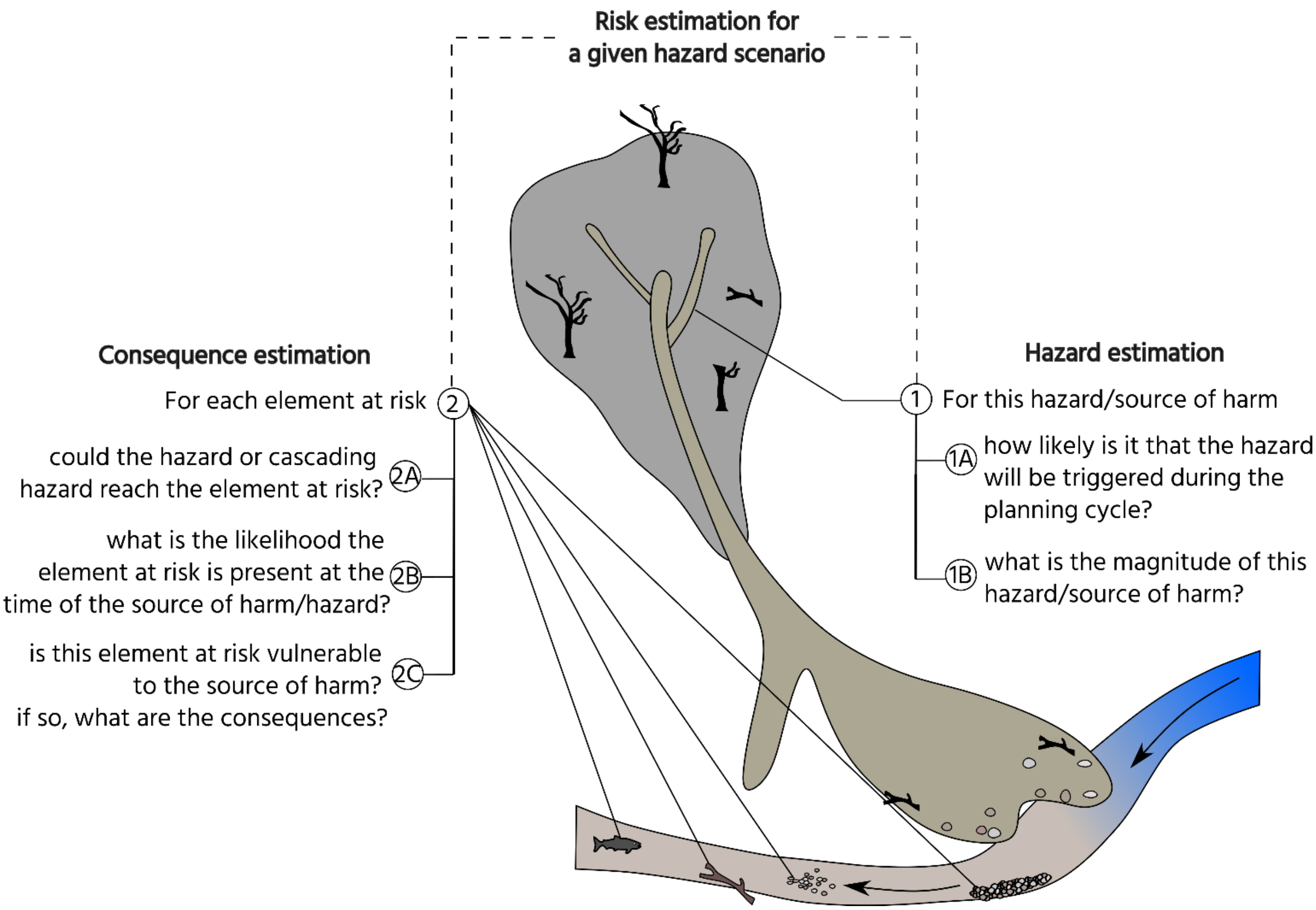


Figure 12. Example of a risk estimation scenario for a single hazard and multiple elements at risk.

[72] van Westen et al. 2006; Duggan et al. 2015; Lewis et al. 2016; Klassen and Allen 2017

3. The **Risk Evaluation** step involves a comparison between the risk level estimated in the Risk Analysis with Risk Tolerance Criteria, to determine if the risk is acceptable, tolerable, or unacceptable. Risk Tolerance Criteria are used to define levels of risk and inform decision making. These criteria are generally not pre-set and, as such, they must be developed and set by recovery teams and are used to complete the risk analysis. The outcome of this step is a checklist of items that are considered highest priority to treat and monitor (Section 6.3).

Risk Assessment typically relies on interdisciplinary teams of practitioners, local knowledge experts and Indigenous Knowledge holders to quantify the values (elements at risk) and the sources of harm (hazards), estimate consequences, develop and undertake watershed specific risk assessments and build out a risk management framework (with defendable actions relative to the prevailing levels of risk). In some cases, risk assessments can be undertaken collaboratively, where informed judgement is used in each aspect of the risk assessment. Accordingly, risk ratings (e.g., high, medium low) usually involve a distillation and combination of objective and subjective sources of information. The information, logic, assumptions, projections and tolerance for risk that are used to complete the risk assessment should be documented and made available. This allows for a re-evaluation and refinement of the risk assessment procedures for a given watershed as information comes in over time.

The **Risk Treatment** step develops management actions for reducing risk that are aimed at either reducing the probability (hazard likelihood) of occurrence or reducing the severity of the consequence (e.g., increasing resilience). For example, if the source of hazard is the sedimentation of spawning substrates, then measures may be taken to reduce the risks of sediment availability and/or transport. Alternatively, enhancing spawning substrates elsewhere may serve to reduce the harm to specific salmon populations at the watershed scale. Section 5 outlines examples of these measures.

The **Risk Implementation** step involves deciding and acting upon the risk reduction treatment(s) selected by the recovery team (Section 6). As treatments are implemented, the changes in risks should be monitored to evaluate if the selected risk reduction measures were effective (Section 7).

Much of the 'framework thinking' fits well with a salmon-specific methodology known as the *Risk Assessment Methodology for Salmon* (RAMS). The RAMS is designed to determine and prioritize the factors that limit the productive capacity of Pacific salmon populations at a variety of scales[73], including the watershed scale. The RAMS and risk management framework processes are not competitive and can readily compliment one another. In general, RAMS is a process for salmon management that uses population status and an understanding of limiting factors and treatment options to develop an Action Plan. It relies on an integration of expertise to achieve consensus on risks and actions and then to develop action plans through a repeatable process that is intuitive, scalable and adaptive. The action plans are noted for being precautionary; however, in risk management terms, this would be addressed by the team's tolerance for risk.

[73] adapted from Hobday et al. 2011

One of the most influential concepts introduced by the RAMS process is the idea of a 'limiting factor', which requires an understanding of the ecology of a particular salmon population within a watershed. Within streams, there can be one habitat factor that most limits the size and/or health of a particular salmon population. In some streams, this may be the availability of quality spawning habitat, while in others it may be the availability of quality rearing habitat. In systems where spawning and rearing habitats are well balanced, it may be difficult to tell which factor is most limiting. This may also vary from year to year, depending on conditions (e.g., water level) or population size/density. Importantly, this approach encourages recovery teams to develop population recovery objectives and establish habitat recovery priorities that are most beneficial to a particular salmon population. This sets up a 'first things first' way of thinking and informs the selection and priority setting for treatment options. For example, while the enhancement of Chinook spawning habitats may be intuitively appealing, it will not increase smolt production if overwintering habitat is the limiting factor within that particular system.

Increasingly, more rigorous and user-friendly watershed modelling approaches are being developed to consider stochasticity (random events) and probability within a given watershed and make projections for target endpoints, such as the resilience of fish populations, based on differing management scenarios. They rely on an understanding of how watersheds generally respond to disturbances and on more detailed watershed-specific data/information and system feedback to elucidate linkages (i.e., cause-and-effect relationships). For example, the Habitat Assessment and Restoration Planning (HARP) model[74], is a scientifically rigorous approach that allows for the creation of a customized watershed-specific life cycle model for Pacific salmon that: addresses the linkages of many variables (e.g., state and output), can offer greater precision and is designed to be continuously improved based on monitoring and feedback loops. Similarly, the Cumulative Effects Model for Prioritizing Recovery Actions (CEMPRA) is a cumulative effects modelling framework.[75] The CEMPRA uses a series of standardized stressor-response functions to link environmental attributes to the system capacity and productivity of a target species or system. The associated framework is general, simple and versatile so that users can apply the model to various geographic regions, contexts, systems and species.

These models are underpinned with their own risk management frameworks and, increasingly, readily available information can be drawn together to assess risk and evaluate recovery options. The Playbook has focused on easily accessed and commonly used assessment procedures to 'feed' a risk management framework. As climate change (including wildfires), ecological values, human demands and technologies converge, it is expected that the use of detailed models (such as those described) will be commonly used to refine our understanding of watershed and habitat processes and provide more accurate management advice.

[74] Beechie 2023

[75] Bayly et al. 2023

4.1.2 LINKING SALMON-SPECIFIC ELEMENTS AT RISK WITH SOURCES OF HARM/HAZARDS AND CONSEQUENCES

The first step in evaluating risks to salmon and salmon habitats is to assess the watershed and habitat features and processes that could have been adversely impacted by the wildfire[76], including the new set of cumulative effects. This will involve an identification of the elements at risk and the potential sources of harm/hazards. Again, it must be recognized that the changes brought about by wildfire are not always negative and can, in fact, be positive. From a salmon and salmon habitat perspective, sources of harm due to wildfire can be grouped into three basic process categories including:

- upland habitat-forming processes (e.g., soil evolution and function and hydrologic patterns) that occur within the landscape (outside of stream channels);
- in-channel salmon habitat, including stream banks and riparian habitat (e.g., structural diversity, pool-riffle-run sequencing, and over-channel and in-channel cover); and,
- stream ecosystems/food webs, including those that support Pacific salmon and other salmonids.

Of the three categories, most assessment and management efforts are applied to upland habitat-forming processes and in-channel and riparian habitats.

When assessing risks to salmon populations or their habitats, it is essential to clearly define the elements at risk, their vulnerabilities and how they will be impacted by a potential hazard. The established element at risk should be a habitat value that limits salmon survivorship or productivity **and** has been, or can be, negatively impacted. Elements at risk will vary from stream to stream depending on the salmon populations and life stages present and on what factors are limiting (as per the RAMS). For example, rearing habitat availability, which is often a function of stream flow, may be considered an ‘at risk’ element in one stream for a particular salmon population, but not in another.

Risk assessments also require clear definitions of the potential source(s) of harm and undesired outcomes, and this involves an explicit understanding of the pathways and factors that define both the likelihood of the hazard and the consequence of the hazard. For example, one habitat impact pathway could start with a loss of forest cover, which could then: 1) increase the probability of slope failures, 2) increase the availability of fine sediments, 3) increase the transport of ‘fines’ to a stream and the sedimentation of spawning substrates, and 4) ultimately lead to reduced oxygen transfer and reduced salmon egg survival. The assessment team must choose direct, practical and measurable hazards that come with specific negative outcomes and identify what factors contribute to their occurrence and likelihood. In the previous example, high flow/oxygen rich spawning substrates could be identified as the element at risk and the sedimentation (deposition of fines) of spawning substrates as the undesired outcome that is associated with the hazard (i.e., slope failure). In this case, it will be important to quantify the many other related factors (e.g., loss of forest cover, terrain stability, probability of weather events) because they will influence the likelihood of the hazard. Similarly, other factors

[76] see review by Hope et al. 2015

may be used to define the consequence of the hazard (e.g., size of the slope failure, proximity of the failure to spawning substrates, slope steepness, channel gradient, flows/flushing, sediment size, or the relative proportion of the spawning substrates impacted within the watershed or assessment unit).

An additional pathway, such as that induced by soil sealing, may well have a similar consequence (e.g., the sedimentation of spawning gravels). This may tempt assessment teams to roll-up several pathways and produce an overarching risk assessment for spawning gravels; however, this is generally not advised. Risk frameworks are intended to link specific treatments that target specific hazards and hazard pathways. That said, practical options for reducing the assessment workloads can include workshopping impact pathways and developing, where appropriate, common impact scenarios that can span sub-basins. For example, it may not be necessary to evaluate the soil sealing response of every burned watershed against the likelihood of sedimentation in the nearby and coupled/connected spawning gravels, when proxy measurements or scenarios can serve for several watersheds.

Table 2 lists six examples of biophysically-imposed wildfire hazard pathways that are relevant to salmon habitat-forming processes, in-channel salmon habitat, and the structure and function of stream ecosystems and the potential consequences of these hazards on salmon and salmon habitat. The examples serve to illustrate the various impact pathways and interacting factors that can cause or influence impacts to salmon habitat. The hazards can have multiple consequences that, depending on vulnerabilities, can impact fish and fish habitats in multiple ways and result in a variety of specific risks. The challenge for recovery teams will be to decide on the most probable and consequential hazards and to then assess the risks that are associated with them.

Table 2. Examples of potential biophysical wildfire hazard pathways and consequences.

Biophysically Imposed Hazard	Potential Consequences
1. Losses of landscape vegetation	↑ precipitation fall through (increased rain splash on exposed soils); ↓ evapotranspiration; ↑ overland flow rates; ↓ soil cohesiveness (root damage); ↓ delivery of organic matter (energy) to streams; ↑ landscape erosion; ↑ mass wasting; ↑ sediment and debris delivery to streams; ↑ sediment and debris transport within streams; ↑ chances of barriers to fish passage forming; ↑ probability of flood flows; ↑ channel incision; ↑ channel erosion; ↓ rearing habitat; ↑ channel aggradation; ↑ fine sediment accumulation in spawning gravels; ↓ water clarity; ↓ water quality; ↑ direct fish mortality (depending on life stage and species vulnerabilities)
2. Soil sealing	↓ soil water infiltration; ↓ groundwater recharge; ↑ overland flow rates; ↑ flood events during runoff periods; ↑ water deficits during basal flow periods; ↑ landscape erosion; ↑ mass wasting; ↑ sediment and debris delivery to streams; ↑ sediment and debris transport within streams; ↑ chances of barriers to fish passage forming; ↑ probability of flood flows; ↑ channel incision; ↑ channel erosion; ↑ sediment deposition on spawning gravels; ↓ habitat complexity; ↓ water clarity; ↓ primary production; ↓ water quality; ↑ direct fish mortality (depending on life stage and species vulnerabilities)
3. Thick ash layer	↑ chemical concentrations (e.g., phosphorus, metals, and polycyclic aromatic hydrocarbons) in erodible surficial soil layers; ↑ solids and chemical delivery to streams; ↑ solids and chemical transport within streams; ↑ fines deposition on spawning gravels; ↓ water and sediment quality; ↑ toxicity potential; ↑ direct fish mortality (depending on life stage and species vulnerabilities)
4. Reduced riparian function	↓ over-channel shading; ↓ organics (energy) delivery to streams; ↓ woody debris recruitment to streams; ↓ habitat complexity; ↓ chemical retention on land; ↑ water temperature fluctuations; ↓ channel bank stability; ↑ channel bank erosion; ↓ water quality; ↑ direct fish mortality (depending on life stage and species vulnerabilities)
5. Mobilization of hazardous materials from contaminated soil and infrastructure	↑ delivery of hazardous materials to streams; ↑ transport of hazardous material to streams; ↓ water and sediment quality; ↑ toxicity potential; ↑ direct fish mortality (depending on life stage and species vulnerabilities)
6. Infrastructure collapse into streams	↑ habitat contamination; ↓ water and sediment quality; ↑ chances of barriers to fish passage forming; ↑ sediment and debris delivery to streams; ↑ direct fish mortality (depending on life stage and species vulnerabilities)

↓ = decrease; ↑ = increase

Note: The biophysically-imposed hazards and consequences were identified from a review of the wildfire literature (see the Catalogue that is a companion to this document). These consequences are referred to as 'potential', reflecting the fact that they do not always manifest themselves, and not all of them will arise in any given case.

Beyond assessing the usual sets of hazards and risks that wildfires can impose on watersheds, it is important to consider and account for changing 'climate-related vulnerabilities' to specific salmon populations. Climate change alone be expected to change habitat factors, such as lower flows and/or higher water temperatures, and place selective pressure on life history strategies and, in some cases, exacerbate limiting factors and even influence population viability. Any plan or strategy to maintain or increase salmon productivity will have to account for the reality of Climate Change. Such thinking is thoroughly addressed in *Climate Vulnerability Assessment for Pacific Salmon and Steelhead in the California Current Large Marine Ecosystem*.[77]

[77] Crozier et al. 2019

4.2 SUPPORTING INFORMATION AND ASSESSMENTS – UNDERSTANDING VALUES, IMPACTS AND RISKS

Wildfire impacts to watersheds are often assessed by comparing post-wildfire to pre-wildfire conditions. Pre-existing, historic and Indigenous knowledge is usually available to help characterize pre-wildfire conditions. Post-wildfire conditions are determined through field assessments and remote sensing, and assessment methods employ standardized and repeatable methods and procedures. The use of baseline information and post-wildfire assessments allow recovery teams to:

- identify how and to what degree a wildfire has affected salmon and salmon habitat through 'before and after' comparisons;
- set objectives and priorities for restoration on spatial and temporal scales; and,
- assist with the evaluation and prioritization of restoration actions.

This information also helps with the bigger picture goal setting, such as establishing restoration goals (i.e., desired outcomes) including those for:

- water quality (e.g., sediment loads, nutrient concentrations);
- channel structure (e.g., channel-floodplain coupling, over-channel and in-channel cover, location and frequency of pool-riffle-run sequences);
- habitat connectivity (e.g., barriers to fish passage);
- soils (e.g., organic content, consolidation, water infiltration and water storage capacities);
- hydrologic pattern (e.g., peak and low flows, flow flashiness, runoff timing);
- landscape plant communities (e.g., stand structure, densities); and,
- fish communities (e.g., species composition, abundance, distribution, growth rates).

Once the post-wildfire impacts and risks are understood and a recovery vision is starting to take shape, decisions on the development and integration of various treatments and recovery strategies (discussed in Section 5) can begin. Very often 'before and after' wildfire comparisons highlight the need for more in-depth assessments regarding the nature of the impacts and the ongoing risks that are in place. A variety of information and assessment tools to support decision making are outlined in the next subsection. These methodologies can be used to identify and quantify salmon-related: 1) values and elements at risk, and/or 2) impacts, sources of harm, hazards and risks.

4.2.1 PRE-WILDFIRE BASELINE INFORMATION

In addition to providing reference conditions from which the impacts of wildfires can be estimated, baseline data and information can be used to make decisions regarding the desired future state and long-term monitoring. Baseline information is useful when visualizing and developing phased and end-point recovery goals, which are the targeted outcomes of restoration work. Recovery teams will have to contemplate whether re-establishing pre-wildfire baseline conditions is realistic, or even desired, or if some alternate ecosystem state should be the goal. For example, given the reality of climate change and how it will impact tree growth, reforestation and hydrologic recovery targets for a given watershed may differ from what existed in the past. Conversely, based on cumulative effects, the pre-wildfire state may have been far from desirable. In all cases, land use decisions balance objectives and risks considering desired outcomes—which can be expected to vary over time.

In addition to describing 'what was', baseline information can provide the basis for pre- and post-wildfire comparisons and can help to quantify impacts and risks. In the absence of consistent pre- and post-wildfire monitoring information, it may be necessary to draw together various and disparate sources of pre-wildfire information. Pre-existing baseline information can come in many forms (e.g., Indigenous Knowledge, scientific and technical reports, inventories and previous assessments). In addition to these sources, many readily available layers of relevant Geographic Information System (GIS) baseline information are presented in Table 3 and in Appendix B.

Table 3. Common Geographic Information System (GIS) data layers that can be used in risk assessment and to parameterize GIS-based decision-making tools.

GIS Data Layer	Information Type
BC Freshwater Atlas	Hydrologic features, watershed boundaries, stream, lake and wetland connectivity, stream order and size, drainage density.
BC Digital Road Atlas	Transportation network, land use, access points.
BC Fish Observations and Distributions	Fish observances (updated regularly), identification of fish-bearing streams, lakes and wetlands. Includes data from BC Fisheries Information Summary System (FISS), Fisheries Inventory Data Queries (FIDQ).
BC Obstacles to Fish Passage	Known barriers to fish passage. Includes records from FISS, Fish Habitat Inventory & Information Program (FHIIP, Rauhe and Reid 1986), Fish & Fish Habitat Data & Information, Field Data Information System (FDIS), and Resource Analysis Branch (RAB) inventory studies.
BC BEC Zones	Biogeoclimatic ecosystem classification zones/subzones/variants, natural disturbance types, seed planning zones.
BC Digital Geology	BC's bedrock geology at 1:50 000 and 1:250 000.
BC Surficial Mapping	Surficial (e.g., soils) texture, composition, chemistry, consolidation, stratigraphy, 3-dimensional geometry, morphologic expression.
BC Digital Elevation Model – CED – 1:250 000	TRIM Digital Elevation Model (DEM) converted to Canadian Digital Elevation Data format. Ground or reflective surface elevations, slope, aspect.
BC Soil Mapping Data Packages	Soil composition (mineral or organic), soil texture, coarse fragments content, drainage, soil layer thicknesses and characteristics, physical and chemical properties, landform and parent material.
BC Soil Information Finder Tool (SIFT)	SIFT has links to a library of soil survey data, reports and maps and to two GIS data layers: *Soil Project Boundaries* and *Soil Survey Polygons*.

GIS Data Layer	Information Type
BC Land Use Planning Spatial Data	Land-use goals, planning zone designations, objectives and strategies.
BC Environmental Remediation Sites	Known and potentially contaminated properties (potential for habitat contamination after major wildfires).
BC Range Tenure	Grazing and hay cutting licences and permits. Areas where *Range Act* tenure applies.
BC Wildfire Perimeters (Current)	Wildfire perimeters for the current wildfire season (active and inactive wildfires).
BC Wildfire Perimeters (Historical)	Wildfire perimeters for wildfire seasons prior to the current wildfire season.
BC Wildfire Burn Severity (Historical)	Burn severity of historical wildfires (2015 to present).
BC Vegetation Resource Inventory	Vegetation data dictionary, data models and standards. Recent data includes an integration of 854,000 ha of wildfire-impacted forest inventory, timber mortality.
BC Harvested Areas (Consolidated Cutblocks)	Cut block boundaries and year of harvest.
BC Forest Cover Reserve (Results)	Reserve of retention area associated with a silviculture system, forest patches or individual trees retained during harvesting, riparian, wildlife tree patches.
BC Drinking Water Sources (Surface Water PODs)	Drinking water source points of diversion, water licences (element at risk by wildfires).
BC Energy Regulator	Oil and gas extraction and processing sites (elements at risk by wildfires).
First Nations Communities	Locations of BC First Nations communities.
LiDAR (Light Detection and Ranging) *LiDAR BC*	Terrain information that can be used to assess baseline ground structures and post-wildfire erosion and mass wasting.
Pacific Salmon Explorer	A tool that provides access to available data for salmon conservation units in BC.
SARA Critical Habitat of Species at Risk	Critical habitat for species categorized as being endangered or threatened under the *Species at Risk Act* (SARA).
Regional District Mapping Apps (e.g., the Columbia-Shuswap Regional District and the Thompson- Nicola Regional Districts)	Mapping apps that provide LiDAR and other mapping services within the main website.
USGS EarthExplorer	Landsat 8 imagery for pre-wildfire and post-wildfire periods.
West Coast Water Authorization Station Discharge	Hydrometric data for flow gauging stations that are maintained by west coast water authorizations.
BC Cumulative Effects Framework - integrated roads and human disturbance layers	Data layers that identify road locations (and densities) and human disturbance.

Beyond GIS datasets, much information can be gleaned from many other sources of information. For example, Water Survey of Canada (Environment and Climate Change Canada) provides real-time and historical streamflow data. Various First Nations entities maintain their own datasets that can include valuable biophysical and cultural information. However, some of this information may be sensitive and not publicly available, but data sharing agreements can sometimes be structured to support collaborative efforts.

While it is important to collect as much relevant baseline information as possible, limited information should not deter impact or risk assessments. In cases with little pre-wildfire data, restoration teams may have to make cautious inferences based on similar, intact (i.e., unburned), and neighbouring watersheds to estimate some baseline conditions.

4.2.2 UNDERTAKING ASSESSMENTS TO QUANTIFY VALUES, IMPACTS AND RISK

With the many sources of relevant pre-wildfire baseline information in hand, investments in post-wildfire information and assessments allow for 'before and after' comparisons and an understanding of impacts. Assessments can provide a detailed understanding of impacts and often address watershed processes, which allows for a characterization of ongoing risks to habitat forming processes, in-channel salmon habitat and stream ecosystem status. Accurate comparisons are best made when similar assessment methodologies are used in both the pre-wildfire and post-wildfire situations.

Assessments can range from site-specific to strategic levels and can be costly. However, the information they generate is often critical in: 1) understanding a watershed's most pressing recovery needs, 2) developing plans and risk management frameworks, and 3) selecting and prioritizing treatment options. Decisions on treatments must be based on a proper diagnosis.

Investing in knowledge (Photo credit: Melanie Wilson)

Assessments should be selected and tailored to address the specific salmon population(s) and their relevant elements at risk for specific locations within a watershed (or sub-basin). This requires experience and knowledge of the watershed processes and salmon ecology. It will also require specific knowledge of existing hazards and possible consequences, such as the sites of deleterious sediment inputs. To assess risk, the specific sources of harm (or hazards) must link the specific impact (consequence) to the element(s) at risk. The number of harm-impact combinations can be high and harm-impact pathways can be complex and interrelated (as per Table 2). The relationship between a source of harm/hazard and an element at risk may be direct (e.g., a loss of pool riffle habitats due to a channel incising event) or related via a more sequenced watershed process related pathway (e.g., loss of forest canopy increases peak flows and the probability of channel incising). Several different pathways, and their resultant consequences, can impact the same element at risk (e.g., a loss of riparian area and slope failures may both impact the same element at risk), but it is best to assess risks (i.e., the paired hazards and consequences) separately. This is because: 1) one particular hazard may have a far greater consequence than the others, and/or 2) the treatments will vary depending on the consequence and its pathway.**Error! Reference source not found.** Table 4 lists some hypothetical examples of relationships between elements at risk, sources of harm and consequences/impacts to salmon populations that can go into various post-wildfire assessments. While watersheds will respond differently depending on their controls and individual sets of cumulative effects, some cause-and-effect relationships (e.g., equivalent clearcut area and high flows) are directly, or indirectly, built into the assessment procedures that are discussed in subsequent sections. Often the likelihood of a hazard (e.g., the occurrence of high flows) is addressed in detail, while the consequence receives less (or no) attention, owing to the additional and detailed information required.

Table 4. Examples of common elements at risk and their potential relationship to possible consequences and the impact pathways.

Element at Risk	Possible Consequence	Pathway Leading to the Consequence
Coho spawning substrate loss (or diminished quality) in the steeper gradient transport zones of Reaches 2, 4 and 7 in River X	Incision of channel and downstream transport of spawning substrates	Extensive loss of forest canopy within the watershed reduces snow interception, shading and infiltration. Snowmelt is more concentrated in time and carried more efficiently to steams. Freshets are earlier and more pronounced, and channel-forming high flows erode steep and even moderate gradient reaches downward (incising).
Chum salmon spawning substrate loss (or diminished quality) in Reaches 2, 4 and 7 of River Y	Deposition of fines over low gradient spawning habitats, which inhibits oxygen transfer results in egg mortality	Loss of vegetation cover allows exposed hillslope sediments to more readily be mobilized and transported overland and into tributaries and the mainstem. The finer sediments (e.g., silts) are deposited over spawning substates in lower gradient reaches.
Steelhead rearing habitat loss (or diminished quality) in the mainstem of Reaches 1, 4 and 8 of River Z	Aggradation of sediments over top of rearing habitats and loss of channel depth and complexity	Loss of vegetative cover and soil sealing, in combination with heavy sustained rainfall, lead to riling, gully formation and slope failures that carry fine to course sediments to the stream's mainstem, which are them transported and deposited in moderate to low gradient reaches (depending on the size of the sediment).

Element at Risk	Possible Consequence	Pathway Leading to the Consequence
Chinook salmon loss of access to side-channel rearing habitats that are connected to Reaches 6 and 11 of River X2	Aggradation of sediments in the mainstem that block access to adject side-channel rearing habitats	Aggradation (as per previous example) leads to a build up of gravels and cobbles that block fish passage into important side-channel rearing habitats.
Pink salmon loss of access to spawning habitats in Reaches 4, 7 and 9 of River Y2	Low flows prevent salmon from accessing important spawning reaches	Thirty years after a major wildfire, a watershed is dominated with even-aged, dense and vigorous conifer stands that remove water through evapotranspiration. This reduces the amount of groundwater carried to the streams and results in low flows in the late summer/early fall period.
Chinook salmon loss of access to rearing habitats in small tributaries of River Z2	High water temperatures prevent Chinook salmon from entering small stream rearing habitats	Immediately after a wildfire, the loss of riparian vegetation over smaller rearing streams increases their exposure to direct sun light and results in temperature increases and oxygen deficiencies that are beyond the tolerance for Chinook fry.
Chinook salmon *gain* high quality juvenile rearing and overwintering habitat in lower floodplain of River X3	Increased in-channel, large organic debris improves the complexity and quality of rearing and overwintering habitats for juvenile Chinook salmon.	Post wildfire tree mortality, slope instability, and higher flows in low to mid order stream drainages result in localized slope failures and debris flows that increase the amount of large organic debris that are introduced into the stream and carried to important low gradient rearing habitats where it increases channel/habitat complexity.

The quantification of impacts and risks to salmon habitat values/at risk elements is a critical step in the risk management framework. This step often involves established procedures that provide quantitative, repeatable, and scientifically defensible data and information. Some of the supporting assessments described in the following subsections may seem somewhat removed from salmon habitat values. However, ‘impact pathways’ are a combination of conditions and triggering events that ultimately impact salmon habitat values. For example, geomorphic events, such as landslides and debris flows, arguably cause some of the greatest risks to salmon habitats in burned over watersheds. Thus, a holistic and multidisciplinary understanding of watershed processes and risks is required to inform the development of treatment options over time.

Information in subsequent subsections is provided on highly applicable assessments within the following categories:

- post-wildfire natural hazards risk assessments;
- watershed assessments;
- fish habitat assessments; and,
- other related assessments.

These assessment examples are not exhaustive. However, they do include those that are commonly used, most applicable and/or have been shown to be effective for assessing conditions following wildfires. The information provided on each assessment is intended to allow individual recovery teams to understand how each assessment relates to salmon habitat and consider which assessments best suit their needs.

As the title implies, the 'post-wildfire natural hazards risk assessments' category includes assessments that are specifically tailored to post-wildfire circumstances. The other assessment categories are more universal in application and can be used in a variety of circumstances. Pre-wildfire assessment information, if available, is important baseline information and many of these assessment methodologies can be repeatedly used at set intervals to monitor changes/recovery over time. Many of the assessments involve several component assessments that address different hazard categories. Depending on the relationships between potential hazards and elements at risk, the recovery team may decide to undertake only some of the assessments or component assessments.

Recovery teams will need to decide which assessments work best given the situation (i.e., the elements at risk, the hazards, and the anticipated levels of risk). Details provided for each example assessment in subsequent subsections will generally include:

- the name of the assessment and the information/insights it is intended to provide:
    - source/authors of the assessment and the location on the internet (e.g., URL), if available;
    - elements at risk, hazards and risks assessed;
    - baseline information or impact assessment;
    - sample design and intensity (e.g., can it be varied to suit a budget?);
    - strategic versus operational information or guidance;
- a brief description of any preliminary information required by the assessment and whether GIS layers and/or field work are required;
- the circumstances and scales that the assessment is best suited for (which can include an understanding of information requirements, costs, ease, training requirements, and time);
- the relationships between any component assessments and the information/ on values and risk they are intended to provide; and,
- the relationships between hierarchical/tiered sub-assessments and the information/insights they are intended to provide. These tiered sub-assessments are more detailed and often rely on field work to provide more precise information. They are usually triggered by a less detailed GIS-based assessments that raise concerns.

4.2.3 POST-WILDFIRE NATURAL HAZARDS RISK ASSESSMENTS

Following a wildfire, one of the most pressing concerns is the identification and rating of the geohazard risks that relate to human life, infrastructure and economic values to prioritize mitigation responses and recovery efforts. While risks to salmon are not commonly identified in geohazard risk assessments, the methodologies can be used to understand the likelihood of a change in sediment delivery, positive and negative, to salmon habitats. Importantly, these assessments are often undertaken immediately in the days and weeks that follow the wildfire. A spatial understanding of such hazards is a critical step in determining where risks may be most prevalent. This informs the prioritization of watersheds, sub-basins and reaches for more precise assessments and recovery efforts. In general, natural hazard risk assessments are undertaken to understand the following issues after a wildfire:

- increased likelihood of geohazards (debris flows, debris floods, and landslides);
- magnitude of geohazards (sediment volume, peak flow);
- spatial impact of geohazards (runout, deposition zones, erosion); and,
- consequences of these geohazards.

Within BC, the most common post-wildfire geohazard risk assessment method is the Post-Wildfire Natural Hazards Risk Analysis in British Columbia (*Land Management Handbook 69*)[78]. It provides a step-by-step approach for the assessment of many wildfire-associated elements at risk, hazards and consequences. This method allows for the qualitative assessment of life-threatening risks, referred to as a 'reconnaissance assessment', with risks being investigated further in prioritized watersheds via a 'detailed assessment'.

Outside of BC, the United States Geological Survey (USGS) uses a similar, but more quantitative, framework for the emergency assessment of post-wildfire debris-flow hazards[79] and uses empirical tools to estimate the likelihood and magnitude of post-wildfire debris flows. A third emerging framework for post-wildfire geohazards includes assessing sediment cascades within and downstream of wildfire scars[80].

All three of these assessment methods generate or rely on the following data:

- vegetation and soil burn severity;
- delineated watershed boundaries;
- total area burned;
- burned area compared to watershed area;
- terrain including elevation, slope aspect, slope steepness and slope distance, and surficial geology; and,
- biogeoclimatic conditions including soils, climate, and vegetation.

Table 5 summarizes the characteristics of the three different assessment approaches, which are further outlined in subsequent subsections.

[78] Hope et al. 2015

[79] USGS 2018

[80] Murphy et al. 2019

Table 5. Summary information on post-wildfire hazard assessments.

Hazard Assessment	'Risk' or 'Condition' Variables?	Strategic or Operational Value?
British Columbia Post-Wildfire Natural Hazards Risk Assessment	Both	Strategic
(USGS) Post-Wildfire Debris Flow Hazard Assessments	Condition	Strategic
Post-wildfire sediment cascades[81]	Condition	Strategic and operational

4.2.3.1 British Columbia Post-Wildfire Natural Hazards Risk Assessment

The Post-Wildfire Natural Hazards Risk Analysis in British Columbia (*Land Management Handbook 69*)[82] provides a systematic framework for prioritizing geohazard risks following a wildfire (referred to as a 'reconnaissance assessment') and considerations for 'detailed assessment(s)' in prioritized watersheds. Once the wildfire is under control, BC MOF staff or qualified consultants initially perform a reconnaissance assessment of wildfires in sufficiently steep terrain larger than 50 ha. The reconnaissance assessment may identify element(s) or watershed(s) at high risk and recommend a subsequent detailed assessment. Reconnaissance assessments may cover very large areas (e.g., large wildfire complexes), while detailed assessments may only examine a select number of watersheds. While the level of detail varies between the two assessments, both procedures use a risk-based framework to understand changes in geohazard risk following a wildfire. An overview of the post-wildfire natural hazard risk analysis is available from the Province of BC. The goal of these assessments is to generate a qualitative (e.g., 'Low' to 'Very High') partial risk (i.e., only considering exposure to post-wildfire geohazards) rating for each element at risk.

In conducting a post-wildfire natural hazards risk assessment, both the reconnaissance and detailed assessment consider the following information:

- inventory of elements at risk (buildings, infrastructure, water supplies, agriculture, recreational sites, and other significant social or environmental values);
- delineated watershed boundaries;
- compiled hydrometric and terrain data;
- maps of vegetation and soil burn severity (typically derived from remotely sensed imagery and confirmed by field observations); and,
- identification of hydrologic and geomorphic hazards (debris flows, debris floods, erosion, sediment transport, floods, landslides, snow avalanches).

The reconnaissance and detailed assessments generate an inventory of elements at risk and their likelihood of being impacted by the geohazards. The reconnaissance assessment more broadly describes these (e.g., houses on debris flow fan) and the detailed assessment specifically describes them (e.g., House A is near the

[81] Murphy et al. 2019

[82] Hope et al. 2015

debris flow fan apex and has a high likelihood of being impacted by a debris flow). Reconnaissance assessments broadly estimate the likelihood of post-wildfire geohazards from a helicopter survey of the burned watersheds and field inspection of soil sealing response. Detailed assessments more closely examine each watershed's likelihood of producing a geohazard following the wildfire, including consideration of past geohazard events and several field inspections of soil and vegetation burn severity and soil sealing. In both assessments, qualified professionals examine post-wildfire response in watersheds of similar biogeoclimatic areas with similar soil and vegetation burn characteristics to estimate the likelihood of post-wildfire geohazards. With respect to magnitude and spatial impact of post-wildfire geohazards, reconnaissance assessments typically defer to the detailed assessments to examine these elements further. In some cases, it may be necessary to quantify the changes in peak flows under post-wildfire conditions. Regarding the spatial impact of geohazards, during a detailed assessment, the practitioner may choose to qualitatively describe the relationship between the sediment and element at risk (e.g., in the depositional area) or may choose to conduct runout simulations (e.g., HEC-RAS, PRODF, FLO-2D).

While the Post-Wildfire Natural Hazards Risk Analysis assessment is a useful procedure for identifying the likelihood, spatial impact and consequences of post-wildfire geohazards, the procedures for qualitative exposure estimation are based on qualified professional judgement and require extensive knowledge, training and experience to undertake these projects. Additionally, the hazard and exposure ratings ('Very Low' to 'Very High') are not specifically defined by the handbook and require definition by the qualified professionals. The vulnerability or resilience of each element at risk is not considered in the assessment.

The reconnaissance assessment procedure could be modified to include salmon habitat as an element at risk and prioritize watersheds or sub-basins for more detailed assessments and/or restoration efforts. The more detailed assessment could then include considerations of site-specific changes to channel morphology or sediment transport rates. However, both levels of assessment generate spatial information on sediment delivery hazards that could be combined with existing spatial information on salmon habitat values and vulnerabilities. Importantly, the information within a detailed assessment can describe potential salmon habitat risk mitigation measures (e.g., hillslope treatments or engineered structures) to protect against damages from post-wildfire geohazards.

Sediment transport to the roadway and riparian area below (Photo credit: Richard Bailey)

4.2.3.2 United States Geological Survey Post-Wildfire Debris Flow Hazard Assessments

On an annual basis, the United States, particularly the western states, experience more frequent and intense wildfires than BC. As a result, the USGS coordinates emergency assessments of post-wildfire debris flows, typically through the Burned Area Emergency Response (BAER) program. The primary objective of these assessments is a series of watershed maps that show the likelihood, magnitude (volume) and combined hazard rating for a given design storm (typically 15-minute rainfall intensity of 24 mm/hr). These emergency assessments are high-level and quantify hazards, but do not assess spatial impacts or risks from these hazards. Maps of completed assessments are available on the USGS Post-Wildfire Hazard Assessment Viewer webpage. The scientific basis for the emergency assessment is available on the USGS landslides webpage.

The USGS emergency assessments rely upon empirically derived estimates of likelihood and magnitude, developed from observations of post-wildfire debris flows in the western states of California, Colorado and Arizona[83]. As severe fires spread into more coastal biogeoclimatic zones, work is underway to refine these estimates in geographies that are like BC (e.g., Washington, western Oregon, northern California). The advantage of the USGS emergency assessment model is that it can take only a few days to produce maps, even over large fire areas, and uses readily available burn severity maps, topographic data, soil erodibility maps and information on design rainfall. Once produced, these maps guide geohazard management decisions and, because they are linked to triggering rainfall characteristics, are used as the basis for impacts-based weather forecasting of debris flows. Estimated debris-flow volumes and peak flows can be used to model the runout of these geohazards and their impacts to people, infrastructure and valued community assets.

Significant opportunities exist to adapt the rapid nature of the USGS emergency assessment procedure to assess post-wildfire watershed geohazards more rapidly in BC. Watershed maps of debris-flow likelihood could be used to identify detailed assessments, or perhaps prioritize watersheds for restoration activities. A preliminary likelihood model, developed in the 2021 Lytton Fire area, suggests that burn severity mapping and Melton ratio could be used as a simple model to estimate these geohazards[84]. The USGS volume model has a broad prediction interval that spans two orders of magnitude. In BC, practical experience indicates that the USGS model typically overpredicts volumes and can be scaled by a factor of 0.18 to 0.5 to arrive at a realistic volume estimate[85]. A more rigorous approach would be to develop a BC-specific volume and likelihood model, similar to efforts underway in Utah, Oregon and Washington. If developed, these maps could be used in BC to understand where sediment pulses are most likely to originate and impact salmon based on known habitat values and vulnerabilities.

[83] Cannon et al. 2010; Staley et al. 2016; Gartner et al. 2014

[84] Lau et al. 2022

[85] e.g., BGC Engineering Inc. 2021

4.2.3.3 Post-Wildfire Sediment Delivery

While the BC and USGS assessment methods both identify the likelihood of dramatic and often life-threatening post-wildfire geohazards, neither method explicitly assesses where sediment from these geohazards will end up—either in temporary sediment storage areas (e.g., debris flow fans or transport zone streams) or distribute further into larger channel networks. As previously discussed, the spatial redistribution of mobilized sediment has important implications on channel geomorphology and salmon habitat.

Although not a defined assessment procedure, a framework for assessing sediment delivery/cascades following a wildfire was recently developed by Murphy et al. (2019). This assessment used the USGS emergency assessment procedure to determine which watersheds were most likely to produce significant sediment (i.e., debris flows) and the magnitude of these sediment volumes. Data inputs to this assessment were burn severity, topographic data, field surveys of grain size data and stream hydrographs. By simulating the redistribution of sediments from the burned watersheds through a geometric and sediment routing model, the authors were able to demonstrate that most of the mobilized sediment was 'trapped' at tributary outlets or pinch points within the main stem stream morphology. This assessment presents a unique study that integrates the knowledge gained from geohazard assessments of post-wildfire debris flows into practical considerations that could readily be applied to salmon habitat management and promote salmon-related advancements and linkages in this methodology.

4.2.4 WATERSHED ASSESSMENTS

Cumulative watershed effects result from changes in watershed processes, such as runoff regimes, sediment delivery and riparian function, because of land use activities and natural processes. Changes in these watershed processes create various hazards, which can then affect water quality and channel morphology, directly impacting fish habitat and aquatic ecosystems (see Table 2). As with the previously discussed geohazard risk assessments, an understanding of the hazards relating to salmon and their habitats is critical in determining risks.

Past concerns for the impacts of land use disturbances on watersheds have led to the development of a variety of watershed assessment procedures with differing utilities depending on the circumstance. The Coastal and Interior Watershed Assessment Procedure (CWAP/IWAP) Guidebook[86] was developed under the Forest Practices Code with the intent of assessing potential hazards associated with the cumulative effects of forestry practices on aquatic environments. This assessment allows resource managers to make recommendations to prevent or mitigate the impacts of forestry-related activities, including restoration, in the watershed.

[86] Ministry of Forests 1999

In addition to the CWAP/IWAP guidebook, several other approaches have been developed for watershed assessments in BC. These watershed assessments generally fall into the category of Tier 1 (desktop) studies or Tier 1 *and* Tier 2 (field-based) studies, and include:

1) Forest and Range Evaluation Program (FREP): Watershed Status Evaluation Protocol (Tiers 1 and 2)[87];
2) Forest and Range Evaluation Program (FREP): The Routine Watershed Assessment[88];
3) Interim Assessment Protocol (IAP) for Aquatic Ecosystems in British Columbia – Standards for Assessing the Condition of Aquatic Ecosystems under British Columbia's Cumulative Effects Framework[89];
4) A GIS Indicator-based Watershed Assessment Procedure for Assessing Cumulative Watershed Effects[90]; and,
5) The Watershed Health Project Omineca Region (WHPOR).[91]

Despite their many similarities, this Playbook is presenting the methodologies that are commonly used in BC so that the reader can consider their differences and their applicability to a given scenario. **In general, the identified approaches are focused on providing hazard rankings that are associated with potential increases in peak flows, sediment delivery and riparian disturbance based on quantitative metrics/indicators, many of which are GIS-based.** These hazard ratings can then be used with consequence ratings derived from downstream ecological values to derive a risk rating. Example metrics/indicators include:

- Equivalent Clearcut Area (ECA) = a calculated metric that relates the influence of forest cover disturbance (e.g., clearcuts) to changes in stream flow. The ECA includes the area of land that has been harvested or otherwise cleared. Natural disturbance, such as wildfires, is included in ECA calculations to account for increases in surface water runoff due to changes in forest structure and function. Hydrologic recovery curves reflecting changes in flows resulting from the regenerating forest are used to modify the ECA values[92];
- presence/absence of lakes and wetlands;
- road density = total length of roads divided by the total watershed area (km/km^2);
- road density on potentially unstable slopes;
- number of stream crossings;

[87] Gov. BC not dated

[88] Nordin and Malkinson 2020

[89] Provincial Aquatic Ecosystems Technical Working Group – Ministry of Environment and Climate Change Strategy and Ministry of Forests, Lands and Natural Resource Operations and Rural Development 2020

[90] Lewis et al. 2016

[91] Provincial Aquatic Ecosystems Technical Working Group – Ministry of Environment and Climate Change Strategy and Ministry of Forests, Lands and Natural Resource Operations and Rural Development 2020

[92] Hudson and Horel 2007; Winkler and Boon 2015; Winkler and Boon 2017

- riparian disturbance = total length of stream within a given distance of disturbance divided by the total length of streams in the watershed; and,
- total number of existing landslides.

The aforementioned watershed assessments were developed to evaluate the cumulative effects of Crown land forestry and rangeland practices on aquatic environments. However, they can also be adapted to consider natural disturbances (e.g., mountain pine beetle infestations), can be used to guide mitigation works and are well positioned to assess wildfire-impacted watersheds. For example, the GIS accounting for a burned riparian corridor might be similar to the logging of that same corridor (at least based on the GIS-based metrics considered in the watershed assessments). Similarly, wildfire-related vegetation losses might be accounted for in a manner similar to the hydrologic impacts of clearcut logging. However, it must be recognized that wildfires and forest harvest practices are dissimilar disturbance types with differing sets of impacts to soils and vegetation. The potential for increased erodibility and reduced infiltration capacity of soils, particularly those with a high to moderate severity burn class, would be an important additional indicator to consider including in a post-wildfire watershed assessment. To date, some practitioners have included burn severity coefficients in ECA calculations[93], although a standard provincial approach has yet to be developed.

The watershed assessments used in BC share a very common holistic framework in that they semi-quantitatively assess potential hazards, including increases in peak flows, sedimentation and riparian disturbance. In other words, the watershed assessments represent conceptual models or a simplified representation of the system. They consist of concepts used to help people understand or simulate the variables the model represents. However, in the case of watershed hydrology, these assessments do not specifically quantify the potential increase in peak flow or changes in the annual hydrograph. Instead, they are used to develop more generic risk ratings based on past experiences across many watersheds.

Table 6 summarizes the most used watershed assessments in BC. These assessments are described in more detail in subsequent subsections.

Table 6. Summary Information on watershed assessments.

Watershed Assessment	'Hazard' or 'Condition' Variables?	Intended Watershed Size	Strategic or Operational Value?
FREP-WSEP (Tiers I &II)	Both	50–500 km^2	Strategic
CWAP/IWAP	Both	5–500 km^2	Both
IAP	Both	Up to 10,000 km^2	Strategic

[93] Palmer. 2022. Post-fire watershed assessment to inform prioritization of fish habitat protection and rehabilitation efforts – Deadman River Watershed [Report]. Prepared for Skeetchestn Natural Resources Corp.

4.2.4.1 Forest and Range Evaluation Program: Watershed Status Evaluation Protocol (WSEP; Tiers I and II)

The Watershed Status Evaluation Protocol (WSEP) was designed as an effectiveness monitoring and assessment tool under the Ministry of Forests' Forest and Range Evaluation Program (FREP). The WSEP is focused on the concept of watershed status, where the status of a watershed is considered 'good' if the overall state of watershed processes is considered intact and sufficient to provide resilient fish habitats and support a high diversity of associated aquatic and riparian-dependent species. Within the WSEP, watershed status is not defined directly, but is instead reflected indirectly through a quantified two-tiered assessment of landscape-scale habitat pressure indicators that together can influence water quality, water quantity and aquatic habitat.

The Tier I assessment evaluates readily available remote-sensed data that serve as proxy data for assessing overall watershed health. This assessment measures a variety of indicators that relate to four primary impact categories: Peak Flow, Surface Erosion, Riparian Buffer, and Mass Wasting. It also identifies additional indicators such as habitat connectivity, low flow regime and other developments (e.g., non-forestry activities) that could potentially be incorporated into the assessment. Climate change is also identified as a potential impact category; it is advised in this procedure that future Tier 1 indicators be developed that address: 1) warmer air and water temperatures, 2) reduced snowpack, 3) changes in seasonal precipitation (potentially more intense and concentrated), 4) changes in streamflow volume and seasonal timing (potentially higher in early spring, lower in summer), and 5) increased extent, severity and frequency of wildfires. Quantitative hazard ratings in these impact categories that exceed specified benchmarks (i.e., a high level of habitat pressure) help focus Tier II assessments, which are more detailed field-based assessments.

The Tier II assessment incorporates field-based data (collected at sites selected through randomized sampling) to understand the current condition of fish habitat in the watershed. The WSEP consists of three field modules that evaluate: 1) riparian and stream channel function, 2) sediment delivery processes, and 3) habitat connectivity for fish. This protocol builds on and incorporates existing provincial assessment protocols, which are addressed later (e.g., FREP Riparian [and Channel], Water Quality, Fish Passage). All three components are considered independently important to the overall watershed status. A green score indicates the condition is within the range of natural variability, a yellow score indicates that the moderate threshold has been exceeded, and a red score indicates that the highest threshold has been exceeded.

The WSEP assessment, if taken to a Tier II level, requires trained individuals, a rigorous sample design and is expensive. It measures the watershed status and randomized habitat conditions, but it does not explicitly measure cause and effect relationships at small scales (e.g., site or reach). Its sample design does not explicitly and geographically link habitat values and conditions with the assessed metrics and, as such, it provides a status report of a watershed and habitat conditions and generates general watershed-level recommendations only. Thus, the assessment will identify and quantify the existing pressures to salmon habitat and habitat conditions that could be addressed by restoration activities; however, it will not spatially identify all potential locations for treatment due to the randomized nature of the field work, which limits the utility of this approach.

4.2.4.2 Coastal and Interior Watershed Assessment Procedure Guidebook (Tier 1 and 2)

While the CWAP/IWAP guidebook is no longer cited in regulation[94], it is still used by practitioners. In conducting a Watershed Assessment Procedure (WAP), the practitioner undertakes the following assessments:

- peak flow and hydrological recovery: the ECA calculations discussed previously;
- sediment source survey: a reconnaissance-level inventory of significant contributors of fine-grained and coarse-textured sediment within the watershed;
- reconnaissance channel assessment procedure: channel stability is evaluated along mainstem alluvial stream reaches and major tributary channels; and,
- riparian assessment: determines the role of riparian vegetation and wood debris in maintaining channel stability and structure, and how this role has been affected by logging.

The assessments include a mixture of GIS-based calculations, aerial photograph observations and field assessments. From these assessments, the practitioner develops a watershed report card, which is a summary of specific environmental indicators. The practitioner then uses the report card, together with field assessment maps, to develop hazard ratings (low, moderate, high, and very high) for peak flow, sediment sources, riparian function and channel stability. These hazard ratings are typically used to make specific recommendations for forest development planning. To accommodate the hydrological differences that exist between the coast and the interior of the province, the WAP differs slightly in some of its components.

The CWAP/IWAP guidebook states that the assessment must also consider the cumulative effects of sediment sources, riparian conditions and peak flow increases on stream channel stability and on the sensitivity of the watershed to further forest development. However, specific direction on how to achieve that goal is not provided.

The former Forest Practices Code suite of guidebooks also includes the directly associated Channel Assessment Procedure (CAP), which is typically initiated when the WAP raises red flags (especially regarding channel stability). The CAP involves some desk-top work and more rigorous 'Tier 2' field assessments and is used to confirm the status of small to medium sized streams. It is most commonly used to evaluate the channel condition and the impacts that are associated with forest development; however, it could be readily adapted to evaluate stream channels in post-wildfire environments. Similarly, the associated Forest Practices Code Gully Assessment Procedure has been used to quantify hazards associated with the logging of gullies in

[94] The *Forest and Range Practices Act* (FRPA) and its regulations took effect on January 31, 2004. This Act replaced the *Forest Practices Code of British Columbia Act* and regulation.

coastal areas. Though not as rigorous a geotechnical assessment, elements of this procedure may be useful in the evaluation of post-wildfire geomorphic and hydrologic hazards.

The CWAP/IWAP and the associated CAP address the watershed's biophysical conditions and hazards only and do not quantify the existing risks to salmon habitat and habitat conditions that could be addressed by restoration activities. However, as the assessments include a field component, they are well positioned to identify potential locations for treatment. The utility of these assessments can be greatly enhanced by coordinating the information gained through the CWAP/IWAP processes and a fish habitat assessment that generates spatial information on values and the status of salmon habitats. Using the examples provided in the EGBC and the ABCFP 2020 guidelines, a qualitative risk rating could readily be developed by practitioners.

4.2.4.3 Interim Assessment Protocol for Aquatic Ecosystems in British Columbia (Tier 1)

The IAP is intended to provide the initial foundation for a consistent high-level approach to province-wide watershed assessments employing standardized GIS-based methodologies and consistent data sources.[95] The GIS indicators are intended to broadly characterize the type and extent of land use activities and watershed characteristics that influence watershed processes and contribute to cumulative watershed effects. This GIS-based methodology provides a relatively efficient, cost-effective and repeatable approach to assess hazards within numerous watersheds over broad geographic areas (up to 10,000 km^2). As such, results can be used to inform a variety of strategic-level applications where broad-scale considerations are involved, such as prioritizing watershed restoration or rehabilitation activities with limited budgets.

The core and supplemental indicators described in the IAP reflect a range of sediment production and transport processes; hydrologic processes; the composition, structure, and dynamics of upslope vegetation cover; and riparian conditions that could be affected by land management activities within a watershed. The objective of the IAP is to identify potential impacts to the watershed aquatic ecosystem, which is conceptualized to be comprised of three components: water quantity, water quality and aquatic habitat. The conceptual model for the aquatic ecosystem links the selected core and supplemental indicators to identified aquatic ecosystem components, functions, processes and factors within a nested hierarchy (Figure 13).

[95] Provincial Aquatic Ecosystems Technical Working Group – Ministry of Environment and Climate Change Strategy and Ministry of Forests, Lands and Natural Resource Operations and Rural Development 2020

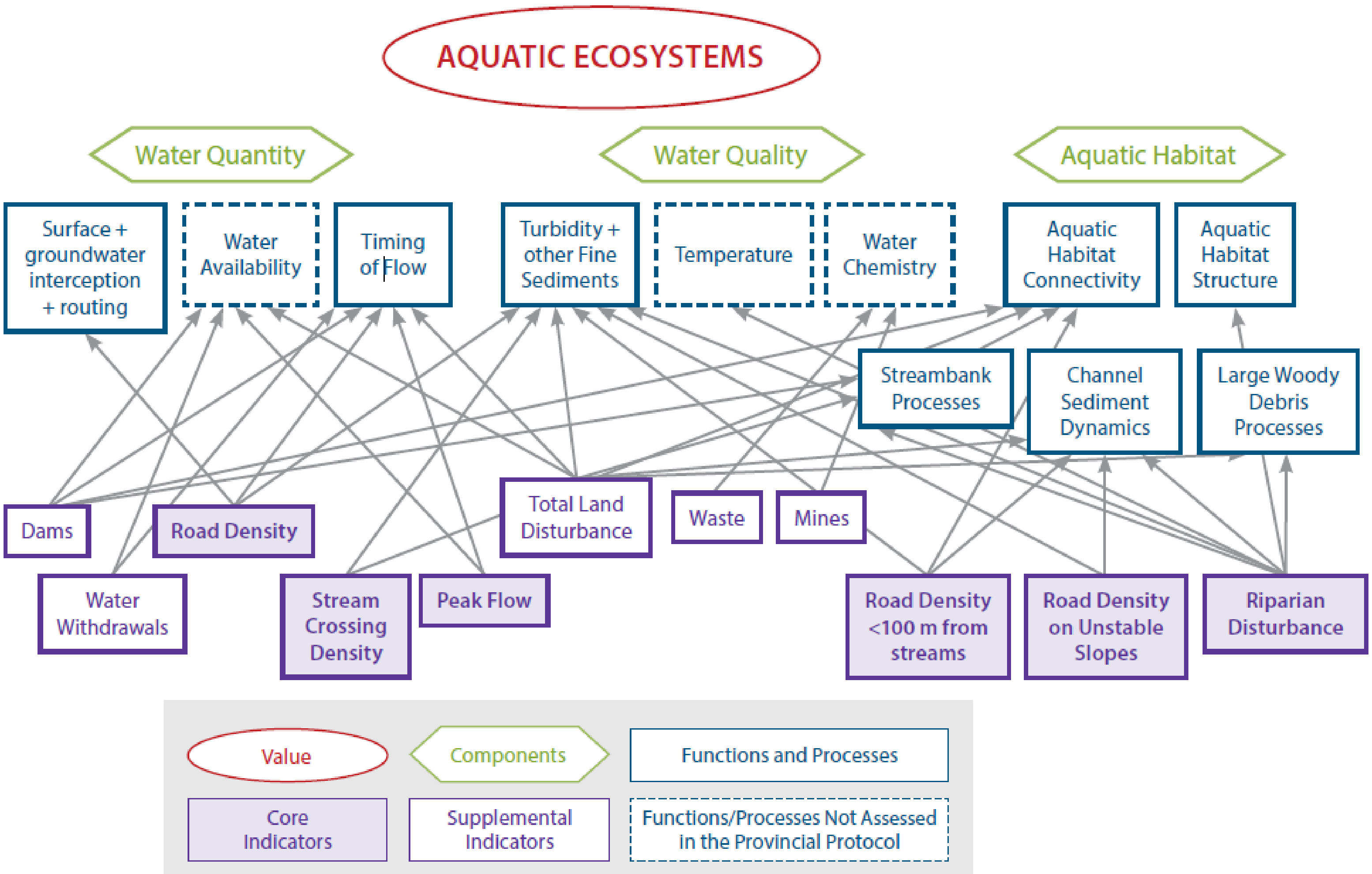


Figure 13. Detailed conceptual model used to describe aquatic ecosystems in the Interim Assessment Protocol.

Source: Provincial Aquatic Ecosystems Technical Working Group – Ministry of Environment and Climate Change Strategy and Ministry of Forests, Lands and Natural Resource Operations and Rural Development 2020

The IAP describes how each of the core indicators is calculated and provides benchmarks that allow for a qualitative hazard rating (low, moderate, and high) for each core indicator. Benchmarks have not yet been defined for the supplemental indicators, although the intent is that benchmarks would be included in future versions of the Protocol.

All components are assumed to be equally important in terms of aquatic ecosystem function. The component with the highest hazard category is generally considered to be the highest concern within each aquatic unit and thus it is the highest ranked component represented in the overarching aquatic ecosystem value. This type of representation allows for a coarse-level review and comparison across many watersheds with the ability to immediately identify those that might require special management or assist in directing limited resources (e.g., riparian restoration, road rehabilitation efforts). Additional investigation into the specific components and indicators can then be conducted for the watersheds of interest. From a post-wildfire perspective, this assessment methodology would be a useful tool to discriminate between affected watersheds over a broad regional area[96].

The Lewis et al. (2016)[97] and WHPOR[98] high-level methodologies are very similar to the provincial IAP, but were developed for specific regions of BC: the snowmelt-dominated hydrologic regime of the Southern Interior in the case of Lewis et al. (2016) and the central interior for the WHPOR. The latter was initiated in 2016 to assess the condition of watersheds in the Omineca Region that had experienced more than a decade of disturbance from the mountain pine beetle epidemic and subsequent salvage harvesting. Both procedures include additional and/or enhanced indicators that have been developed using regional subject matter input and review processes that reflect regional specificity for the value.

All three of these methodologies (i.e., the IAP, the WHPOR and Lewis et al. [2016]) are high level assessments based on GIS information only. As such, they do not link any spatially explicit hazard and consequence relationships and could not be used to identify specific locations for treatments. However, it is possible that these methodologies could be employed at a sub-basin level to identify specific areas that should be evaluated in further detail with field studies.

For additional information on post-wildfire watershed assessments, the BC Government has loaded the wildfire reports completed in 2021, 2022, and 2023 on a SharePoint site.

[96] e.g., the Lytton Creek Fire in 2021

[97] Lewis et al. 2016

[98] Provincial Aquatic Ecosystems Technical Working Group – Ministry of Environment and Climate Change Strategy and Ministry of Forests, Lands and Natural Resource Operations and Rural Development 2020

4.2.5 FISH HABITAT ASSESSMENTS

Assessments of the risks and impacts that wildfires have on salmon and salmon habitat are necessary to plan and prioritize post-wildfire responses. Fish habitat assessments have a monitoring function and can be used to provide an understanding of the conditions that existed pre-wildfire (baseline or reference) and how conditions are impacted afterward. These assessments are also critical in developing an understanding of the current habitat values within a watershed, which allows recovery communities to understand the elements at risk. This information, when paired spatially with hazard assessments information (e.g., watershed assessments), can be used to evaluate risk.

Assessing fish habitat (Photo credit: Jen Steele)

Fish habitat assessments that efficiently cover entire watersheds are ideal for establishing baselines and for monitoring watershed recovery. However, implementing effective habitat restoration projects will require a detailed understanding of the habitat requirements and limiting factors for the species, populations and life stages of salmonids that exist in the watershed. A variety of fish habitat assessments have been developed in BC to address resource management needs that range from broad area planning to site-specific fisheries management and impact issues. Three examples of watershed-level fish habitat assessments that are well suited to understanding risks and impacts of wildfires are Fish and Fish Habitat Inventories (FFHI), the Fish Habitat Assessment Procedures (FHAP), and the Watershed Status Evaluation Protocol's (WSEP) Riparian Protocol[99] (Table 7).

[99] The WSEP is also discussed in a broader context within Section 4.2.4.1.

Table 7. Summary information on fish habitat assessments.

Fish Habitat Assessment	'Risk' or 'Condition' Variables?	Intended Watershed Size	Sample Design/Intensity	Strategic or Operational Value?
FFHI	Condition	1:50,000/1:20,000 map base scale	Sample-based	Both
FHAP	Condition	Third to fourth order basins, 1:50,000 map base scale	Purposive design/ Variable intensity	Both
WSEP Riparian Protocol	Condition	50-500 km^2	Random/Variable	Strategic

The FFHIs were developed to gather data about fish species distributions and habitat characteristics where little data were available. The inventory methodology includes fish sampling and habitat measurements and provides useful baseline information that is a prerequisite to more detailed, restoration focused assessments like the FHAP. The FHAP is one of many assessments procedures that were developed as part of a process-oriented approach to watershed restoration that includes watershed, channel and riparian assessments. The focus of the FHAP is the identifications of physical habitats that limit the abundance and distribution of fish within a watershed. The WSEP Riparian Protocol is a relatively new, field-based assessment that evaluates the functioning condition of stream and riparian habitats. It provides a broader assessment of stream ecosystem health that incorporates aspects of biomonitoring. The WSEP Riparian Protocol was developed to monitor the effects of forest harvesting on stream conditions and would also be a useful assessment of the functioning of the overall condition of habitat in post-wildfire situations.

Several other approaches have been developed for fish habitat assessments in BC:

- Resource Inventory Standards Committee (RISC) for fish habitat, which are general standards for measuring habitat that apply to all BC government assessments, but are not protocols for habitat assessment[100];
- Sensitive Habitat Inventory Mapping (SHIM for Salmon)[101], which is an urban counterpart to the Reconnaissance (1:20,000) Fish and Fish Habitat Inventory method; and,
- Habitat Suitability Index (HSI)[102], which involves very detailed and intensive surveys, designed for fine scale modeling of the total habitat available to a species under specific streamflow scenarios.

[100] Gov. BC not dated

[101] Mason and Knight 2001

[102] Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Information Paper 12. U.S.D.I. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-82/26. 248 pp.

4.2.5.1 Fish and Fish Habitat Inventories (FFHI)

The Overview Fish and Fish Habitat Inventory (Overview Inventory) and Reconnaissance (1:20,000) Fish and Fish Habitat Inventory (Reconnaissance Inventory) are efficient, whole watershed surveys that describe fish community and distributions and classifies habitat for interpretations of sensitivity and capability for fish production. Overview and Reconnaissance inventories use many of the same procedures, field data forms and database management systems, but were intended for different landscape scales and levels of detail. Overview Inventories are low intensity surveys that cover very large areas (e.g., many watersheds) and Reconnaissance Inventories are sample-based surveys that cover smaller watersheds in more detail. Past inventory reports can be searched for on the EcoCat database (Table 8).

Overview and Reconnaissance Inventories include pre-field planning phases, a field program and project reporting. Planning phases include reviewing and analysing existing data, developing working maps, and planning for the field program and reporting. Planning for contemporary inventories should incorporate historical inventory data, satellite imagery, mapping, GIS and fisheries data available from provincial databases or other sources (Table 8). In an Overview Inventory, field sampling sites are chosen to provide the most critical and useful information with minimal effort. In Reconnaissance Inventories, all lakes and stream reaches are classified during pre-field planning phases and a subset of lakes and stream reaches are sampled in the field based on a statistical sampling design. Sampling at field sites includes the collection of physical habitat characteristics and fish sampling to characterize the diversity and relative abundance of species present. Overview and Reconnaissance inventories make inferences about fish and fish habitat in a watershed based on data collected from sample sites. However, the Reconnaissance Inventory interprets fish distributions and stream channel characteristics in more detail through a model-based extrapolation of field data.

The FFHIs are efficient assessments that would be useful for assessing post-wildfire impacts, such as new barriers to fish passage. The Overview and Reconnaissance Inventories provide essential baseline information required for more detailed, restoration focused assessments like the FHAP and could be used for recovery monitoring.

Table 8. Information/data sources that can be used to help establish in-channel (habitat) baselines (pre-wildfire) for BC streams and rivers.

Source	Information/ Data Format	Information Type
Drinking Water Sources Points of Diversion by Gov. BC	GIS data layers	Drinking water source points of diversion and water licences (element at risk by wildfires).
EcoCat: The Ecological Reports Catalogue by Gov. BC – Ministry of Environment	Searchable database	A catalogue of technical reports, data reports, and field assessments on fish habitat attributes.
Environmental Monitoring System by Gov. BC	Searchable database	Water and sediment quality (physical and chemical variables) datasets for streams, rivers and lakes. In many cases, federal and provincial data have been combined in the Environmental Monitoring System.

Source	Information/ Data Format	Information Type
Environmental Remediation Sites by Gov. BC	GIS data layers	Properties that are known to be impacted by contamination/pollutants (potential for habitat contamination after major wildfires).
Field Data Information System (FDIS) by Gov. BC	Searchable database	Used to view and work with habitat inventory data (Fish Renewal BC program) over the period 1997-present (NOTE: many versions of FDIS are in use).
Fish & Fish Habitat Data & Information by Gov. BC	Searchable database and GIS data layers	Fish habitat data and information.
Fisheries Information Summary System (FISS) by Community Mapping Network	Searchable database	Spatially represented summary-level fish habitat data.
Fisheries Inventory Data Queries (FIDQ) by Gov. BC	Searchable database	Fish habitat data (lakes, streams, and rivers).
Freshwater Atlas by Gov. BC	GIS data layers	Hydrologic features, watershed boundaries, stream, lake and wetland connectivity, stream order and size, drainage density.
Habitat Wizard by Gov. BC	Searchable database	Data and information on fish habitat assessments.
Historical Hydrometric Data Search by Government of Canada	Searchable database	WSC collects suspended sediment concentration data at some of their river/stream gauging sites.
LiDAR (Light Detection and Ranging) by Gov. BC	GIS data layers	GIS datasets that can be used to assess baseline ground structures and post-wildfire erosion and mass wasting.
LiDAR (Light Detection and Ranging)- Open LiDAR Data Portal by Gov. BC	GIS data layers	GIS datasets that can be used to assess baseline ground structures and post-wildfire erosion and mass wasting.
Obstacles to Fish Passage by Gov. BC	GIS data layers	Known barriers to fish passage. Includes records from FISS, Fish Habitat Inventory & Information Program (FHIIP[103]), Fish & Fish Habitat Data & Information, Field Data Information System (FDIS), and Resource Analysis Branch (RAB) inventory studies. Source acknowledges that not all obstacles have been identified.
Real-Time Hydrometric Data Text Search by Government of Canada	Searchable database	WSC collects real-time, suspended sediment concentration data at some of their river and stream gauging sites. Real-time data are subject to quality assurance/quality control verification).
Salmon Explorer by Pacific Salmon Foundation	Searchable database	Data and information related to fish inventory assessments.
West Coast Water Authorization Station Discharge by Gov. BC	Searchable database and GIS data layers	Hydrometric data for flow gauging stations that are maintained by west coast water authorizations.

103 Rauhe and Reid 1986

4.2.5.2 Fish Habitat Assessment Procedure (FHAP)

The FHAP was developed to identify opportunities for fish habitat restoration in disturbed watersheds and would be very useful in a post-wildfire scenario. The FHAP is one of a series of Technical Circulars developed under the Watershed Restoration Program (WRP). The WRP was a provincial initiative under Forest Renewal BC to restore the productive capacity of fisheries, forest and aquatic resources that were adversely impacted by historical logging practices. The Technical Circulars in the WRP were intended to be implemented together to efficiently address all aspects of watershed restoration. Many similarities exist between the impacts of wildfires and earlier logging practices (e.g., loss of forest cover), but the WRP was not designed specifically for post-wildfire recovery. That said, FHAP remains relevant and could be used in combination with other more contemporary watershed assessments and restoration procedures that are adapted for wildfires.

The FHAP assumes that fish distribution and abundance are limited by the quality and quantity of physical habitats in a disturbed watershed and that these limiting habitats can be identified through comparison with similar undisturbed watersheds. The FHAP could also be used as a comparison of baseline and post-wildfire fish habitat condition in the same watershed. The FHAP quantitatively describes current fish habitat conditions and evaluates them to identify opportunities for effective rehabilitation. The FHAP does not include procedures for assessing fish distribution and abundance before, or monitoring them after, restoration projects.

In practice, the FHAP consists of an overview assessment and more detailed, quantitative field assessments. The FHAP focuses on the habitat requirements of salmonids within a disturbed watershed with the intent to guide recovery actions. Its overview assessment can address the species and life stages at risk in a watershed, but this is derived from fish and fish habitat inventories and other assessments that involve fish sampling. Existing information about fish distribution is used to identify areas of concern and preliminary restoration strategies. The overview assessment for contemporary applications of the FHAP should incorporate information from FFHIs, satellite imagery, mapping, GIS, and fisheries data that are available from online provincial databases and other sources (Table 8). Field assessments examine high priority reaches for restoration projects that were identified in the overview assessment and are conducted at two levels of detail. Level 1 field assessments provide reconnaissance level information needed to characterize and evaluate habitat conditions. Priority reaches and options for restoration are identified from the Level 1 assessments. Level 2 field assessments provide more detailed, site-specific information needed to select, plan and implement restoration projects.

4.2.5.3 Riparian and Stream Channel Assessment Protocols

The Riparian and Stream Assessment Protocol (Riparian Protocol) is one of a series of stand-alone field-based assessments that have been incorporated into the WSEP (see Section 4.2.4.1). The Forest and Range Evaluation Program developed the WSEP Riparian Protocols to evaluate the condition of streams beside or within cutblocks.

The WSEP evaluates watershed status through a two-tiered approach. The Tier I approach incorporates readily available remote-sensed and broad-scale habitat data to assess the potential risk to watershed habitats from landscape pressures. The Tier I protocols provide a contemporary list of watershed datasets and GIS resources that are required for the Riparian and Stream Channel Assessment Protocol. These updated resources should also be considered for the planning phase of the FFHIs and the FHAP overview assessment. Tier II monitoring is a combination of more intensive assessments of current watershed condition that is evaluated through field-based modules including the Riparian and Stream Channel Assessment Protocol, Water Quality Protocol and Fish Passage Protocol.

The Riparian and Stream Channel Assessment Protocol evaluates the riparian and stream channel condition over an entire watershed based on indicators for the stream channel and adjacent riparian area. The basic sampling units are stream reaches, selected through a stratified, random sampling design. The required sample size depends on the desired precision and variability within strata, but the default recommended sample size for all strata is 30 sites.

The Riparian and Stream Channel Assessment Protocol summarizes the average and range of functioning conditions observed in the streams and riparian areas across a watershed. The functioning condition of stream and riparian habitats is related to their ability to support fish at a macro level. The protocol helps to identify and distinguish between impacts from the local area and those that are derived from upslope or upstream processes. However, detailed information about cause and effect, risks, the absolute value of habitats and priorities for restoration are not clearly identified. The WSEP Riparian Protocol was developed to assess the post-harvest effects of forestry operations on stream ecosystems and could be used for monitoring after a wildfire and the implementation of restoration projects. Understanding the functioning condition of fish habitat after a wildfire will help in prioritizing and timing recovery efforts and evaluating the impacts of restoration efforts.

4.2.6 OTHER RELATED ASSESSMENTS

Wildfires affect an array of related values that have a bearing on salmon and their habitats. Watersheds provide for all manner of life forms, from algae and fungi to vertebrates. Watersheds also provide water for human consumption, and the demand for this commodity is increasing while water supply is becoming increasingly insecure in many portions of the province. As with salmon populations, the status of these other (often interacting) values can be viewed as watershed health indicators. In addition, other values, such as water quality, can be an important component of salmon habitat. As with fish habitat assessments, related assessments can be critical in developing an understanding of the values within a watershed and this allows recovery communities to understand the elements at risk and their vulnerabilities. Other types of assessments, such as an upland vegetation inventory, can provide import information on the status of conditions that relate to hazards. Accordingly, other assessments can provide additional information relating to hazards and consequences and enhance understanding of risks and treatment options.

In this subsection, several related assessments are identified, together with their website locations and the entity that is responsible for housing them. In addition, when an entity houses many assessments (e.g., Resource Inventory Standards Committee, Forest and Range Evaluation Program), a brief introduction to the entity and lists of the more commonly used assessments and protocols are provided.

4.2.6.1 Fish Passage

Fish passage is an important consideration in the aftermath of a wildfire. In addition to suppression activities, which can alter roadways and trails, fire-induced debris flows and slides can have immediate impacts on fish passage and habitat connectivity. The Province of BC has developed a *Field Assessment for Fish Passage Determination of Closed Bottom Structures*[104] to assess fish passage stream crossings throughout the watershed; this link provides details on assessing, recording and summarizing Fish Passage Protocol indicators for a sample site and Fish Passage Protocol field assessment form examples. In addition, Fish Passage assessment spreadsheets can be downloaded from the Fish Passage Technical Working Group website.

The cumulative score across the suite of passage indicators for this Fish Passage Protocol is used to determine whether a sampled culvert is considered to be: 'Passable', 'Potential Barrier', or 'Barrier'. The protocol has been built as a component of the WSEP Tier II. It is used to evaluate closed bottom culverts only. A standardized provincial protocol for evaluating fish passage more broadly has not been developed. However, DFO has published a document entitled the *Practitioners Guide to Fish Passage*.

4.2.6.2 Forest and Range Evaluation Program (FREP)

The FREP was established in 2003 as a foundational element of the *Forests and Range Practices Act* (FRPA). The FREP's overarching mandate is to promote the sustainable management of British Columbia's forests and range resources under the FRPA by developing standards and monitoring and evaluating the condition of 11 FRPA resource values within operational settings. The data collected under FREP provides a foundation of science-based evidence to evaluate the effectiveness of current forest and range management practices and policies, informs resource managers and enables the continuous improvement of forest and range stewardship in the province. The 11 FRPA resource values include: 1) Fish/Riparian, 2) Water Quality, 3) Biodiversity – Stand and Landscape Level, 4) Cultural Heritage Resources, 5) Visual Quality, 6) Timber (Stand Development), 7) Forage and Associated Plant Communities, 8) Resource Features (e.g., Karst), 9) Wildlife, 10) Soils, and 11) Recreation.

In addition to the many FREP protocols for watershed assessments and fish habitat assessments/protocols that have been previously identified, FREP has developed monitoring protocols for many other values that are associated with watershed health, including wetlands, soils, stand development, rangeland health and water quality. In general, the FREP protocols should be regarded as routine effectiveness monitoring

[104] MOE 2011

protocols that are designed to monitor the condition of variables within the context of a forest that is being harvested over time and according to FRPA standards. The FREP protocols were not designed to monitor changes in watershed and fish habitat values over time or in response to specific restoration activities in wildfire-impacted watersheds. Accordingly, their utility in these situations is something that should be carefully considered.

4.2.6.3 Resource Information Standards Committee (RISC)

The RISC was established in 1991 as the Resources Inventory Committee (RIC). It was initiated in response to the Forest Resources Commission recommendation that the province undertake a commitment to complete inventories for all renewable forest resource values using standardized compatible systems. The RISC is responsible for establishing standards for natural and cultural resources inventories, including collection, storage, analysis, interpretation and reporting of inventory data.

Key aquatic ecosystem-oriented monitoring RISC guidelines include:

- *Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia*
- *Continuous Water Sampling Programs: Operating Procedures*
- *Lake and Stream Bottom Sediment Sampling Manual*
- *The Canadian Aquatic Biomonitoring Network – Field Guide*
- *Freshwater Biological Sampling Manual*
- *Manual of British Columbia Hydrometric [flow measurement] Standards*

The RISC standards include a variety of other monitoring and assessment guidance that addresses wide ranging ecological values with direct relevance to watershed health such as: 1) groundwater, 2) terrain stability, 3) fish collection, 4) fish identification keys, 5) vegetation inventory, 6) inventory for wildlife (including amphibians) and rare plants, 7) ecosystem mapping standards, 8) archaeological assessments, and 9) recreational assessments.

4.3 A SUMMARY OF INFORMATION GATHERING AND RISK MANAGEMENT FRAMEWORKS

Given the scale, complexity and importance of watersheds, initiatives that are intended to facilitate their recovery can consume vast amounts of human resources and capital. Some situations will demand immediate attention—especially when they pose immediate threats to human safety, property and infrastructure. In other situations, recovery teams and practitioners are asked to sort through complex arrays of information involving values, impacts and risks and then devise and implement cost-effective mitigation and recovery-oriented treatments and strategies. Questions often arise, such as “Where do we begin?” or “How do we know what treatments are going to be most effective?”

The intent of this section was to direct practitioners to important information sources, assessment techniques and risk management tools that will guide information gathering and acquisition processes and promote the use of risk management frameworks to pursue strategic, ‘watershed level’ thinking, which can then inform and align the development of plans at all levels. This would include:

1. selection of the most cost-effective treatment and strategy options;
2. appropriate placement of treatments and strategies in both space and time;
3. development of treatments and strategies with specific, measurable and timebound goals;
4. planning, implementation and monitoring of treatments and strategies; and,
5. use of adaptive management principles.

These topics are addressed in detail in the sections that follow.

5 TOOLBOX: TREATMENT OPTIONS FOR RECOVERY

The road to recovery following major wildfires can be a daunting task due to the complexity and diversity of impacts associated with post-wildfire conditions on salmon and salmon habitat. Consistent with the development of a risk management framework, once the impacts and risks imposed by a wildfire, within the context of cumulative effects and climate change, are understood, the selection, prioritization and sequencing of recovery treatments and strategies can begin in earnest (Figure 14).

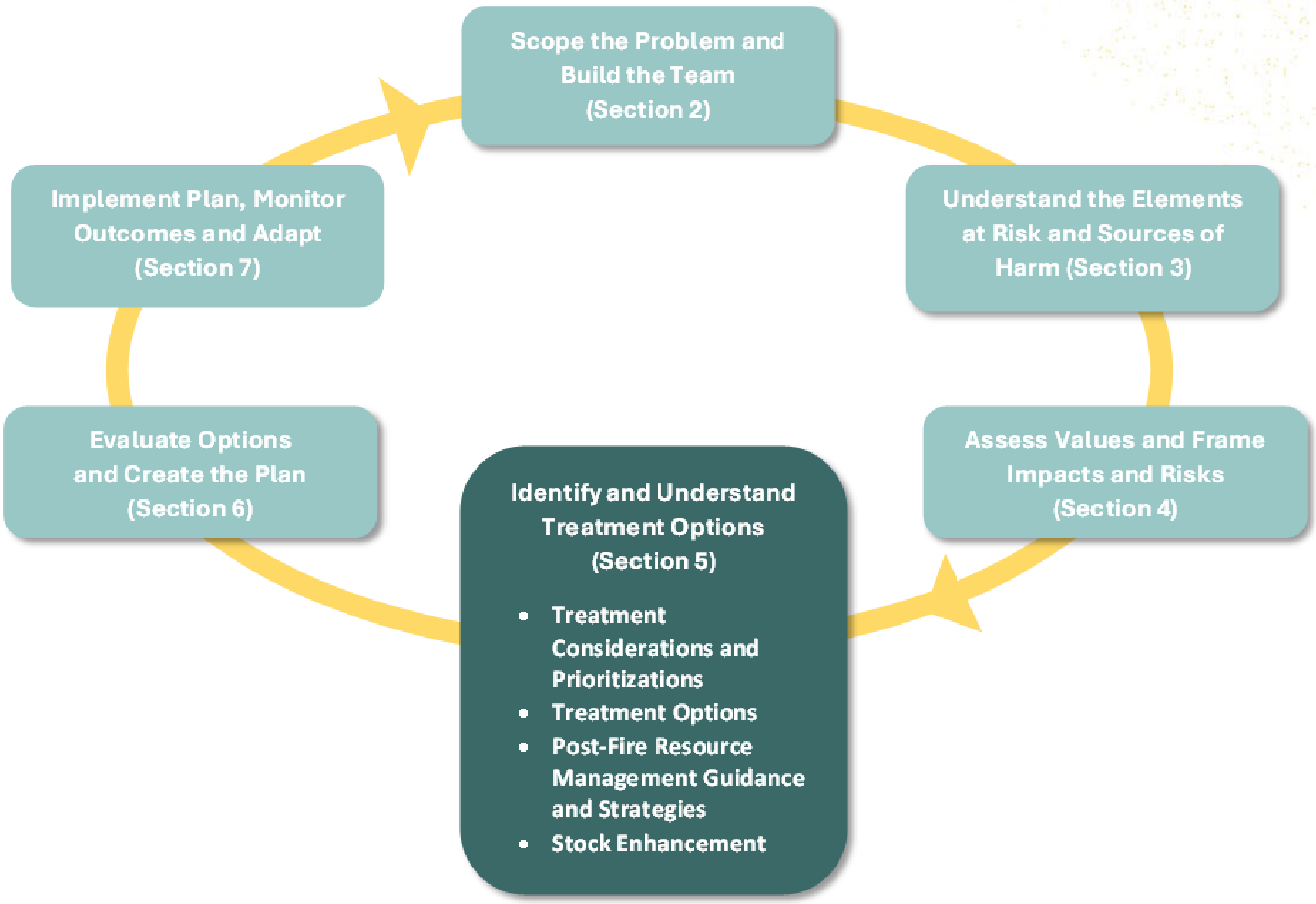


Figure 14. Highlight of Planning Cycle activities addressed in Section 5.

While there will often be a need to react to immediate risks to salmon habitats, such as barriers to fish passage, recovery teams should take the time to consider what is needed, what can be done and what will produce the greatest returns on investment. Not all wildfire impacts are deleterious and time and natural processes may well be the best prescription. Further, wildfire impacts (e.g., burn severity) will differ widely within most fires. Treatments desperately needed in some portions of a burned watershed may do harm in others. Resources will often be limiting. Accordingly, basic questions should address the intent behind a given treatment or strategy and the potential for negative effects.

The impacts of large and intense wildfires are presented in Section 3.3. In summary, burned watersheds are susceptible to a range of effects that directly impact salmon habitats or influence habitat-forming processes and, subsequently, influence the formation, evolution, structure and function, stability and recovery of habitat features. Habitat features or watershed processes potentially affected by wildfires include, but are not limited to:

- hydrologic patterns (e.g., elevated peak flows and flooding and reduced low flows);
- changes to sediment movements, including erosion and sediment movement;
- habitat complexity (e.g., channel morphology, within-channel flow velocity variation and pool-riffle-run sequences, bottom substrate texture and composition);
- riparian habitat (e.g., cover and shading attributes, reduced organic inputs, and loss of stream bank stabilizing root networks);
- water temperature regulation; and,
- water and sediment quality (e.g., nutrient, suspended sediment concentration, and pollutant concentrations).

Many watershed and salmon habitat recovery methods were initially developed to mitigate impacts from activities related to:

- forestry (e.g., logging, silviculture, road building);
- agriculture (e.g., land clearing for crops);
- ranching (e.g., livestock grazing and contaminated runoff);
- water diversions (e.g., for domestic, industrial, and agricultural uses) and hydroelectric facilities (e.g., dams and power generating plants); and,
- urban development and associated infrastructure (e.g., roads, bridges, culverts, impermeable surfaces).

Major wildfires impose unique impacts, but they can affect some watershed controls, stream channels and salmon habitats in ways similar to industrial and domestic works. In response to the recent trend toward frequent, very large and high-severity wildfires, many watershed and salmon habitat recovery methods have been adapted for post-wildfire applications[105]. Potential treatments attempt to mitigate risks and impact pathways and/or recover desired watershed elements. Often their selection requires a series of mechanistic assumptions that distill down to an eventual improvement in salmon habitat. The relationships between actions and outcomes are not always direct or certain. Accordingly, the treatments and strategies offered in this section are not prescriptions that will guarantee success in all circumstances. Instead, they are suggested interventions with utilities in certain circumstances that may benefit the recovery of watershed processes and/or salmon habitat. Owing to the complexity of watershed and habitat forming processes, in most cases their selection and implementation should involve interdisciplinary teams of qualified professionals who are equipped with the appropriate information.

[105] See Beschta et al. 2004, Curran et al. 2006, Napper 2006, Robichaud 2008, Jonas et al. 2019, and Nielson and Nielson 2022

5.1 POST-WILDFIRE RECOVERY TREATMENTS, CONSIDERATIONS AND PRIORITIZATION

5.1.1 PROCESS-BASED AND FORM-BASED POST-WILDFIRE RECOVERY TREATMENTS

Recovery efforts must take the wildfire-imposed risks and impacts to specific elements at risk (e.g., spawning habitat) into consideration. For example, within a burn, the wildfire severity ratings and the risks they impose will often be varied and patchy. Treatment selection and implementation, therefore, must be adjusted to account for differing scales and levels of impacts and risks. Similarly, recovery practitioners must take watershed processes into consideration and select or design treatments and strategies to fit the dynamics of the system, from watershed to site levels, and within the appropriate timeframes. Care must also be taken to minimize the risks to the treatments themselves. Watersheds are dynamic and treatments can be rendered less effective or destroyed by high flow events and/or changes in the stream channel. Further, treatments often come with their own sets of risks and care must be taken to avoid a compounding of impacts.

Two broad categories of treatments are generally recognized: form-based and process-based approaches. Form-based stream restoration promotes the modification of a stream channel to improve conditions through the creation of specific habitat characteristics and features known to benefit salmon. It attempts to improve a stream's condition by *directly* modifying its morphology or architecture. Targeted outcomes can include improved water quality, enhanced fish habitat and abundance, as well as increased bank and channel stability. Very often form-based restoration involves the use of unnatural and/or engineered structures (e.g., an anchored and cabled log jam structure) that emulates and accelerates the attainment of a desired natural feature. Form-based restoration often focuses on the restoration, enhancement and stabilization of stream channel morphology (i.e., where salmon live) and their immediate riparian habitats. Because of this, form-based restoration treatments often align with channel-centric[106] approaches, which do not address upland watershed conditions or processes. The form-based approach is used worldwide and has been the conventional approach to stream restoration, but concerns are sometimes raised regarding the long-term sustainability and value of such interventions.

More recently, practices have evolved to include a greater focus on the restoration of habitat-forming processes and this has come to be known as a process-based approach to watershed restoration.[107] Process-based restoration focuses on restoring the hydrological, geomorphic and ecological processes (or controls) that contribute to the stream's ecological dynamics. Instead of focusing on symptoms, this restoration philosophy emphasizes the need to address the root causes of environmental degradation at appropriate spatial scales. Key processes that can be targeted include erosion and sediment transport, storage and routing of water, plant growth and successional processes, input of nutrients and thermal energy, and nutrient cycling in the aquatic food web. This process-based approach to salmon habitat recovery

[106] Cluer and Powers 2020

[107] Beechie et al. 2010

relates to a similar concept referred to as 'valley-centric' (considering the entire watershed) approaches to restoration, which are undertaken at the appropriate process scale, rather than on a habitat scale. This approach considers all zones of the watershed, including instream/channel, riparian and upslope components and all watershed controls.

The interrelationship between stream and terrestrial habitats underpins many process-based treatments (Photo credit: Ian Redden)

Generalizations and categories, while helpful, can sometimes be problematic. For example, some treatment options may well focus on process (i.e., the proper functioning of a backwater channel), but are considered channel-centric.

Approaches to watershed and habitat restoration that incorporate both channel-centric and valley-centric methods are sometimes referred to as being holistic. For more information on this topic, two video presentations that demonstrate holistic approaches to watershed and salmon habitat restoration are provided in Box 2. Several comprehensive documents that provide guidance and instruction on form-based and channel-centric methods are provided in Box 3. For more information on process-based and valley-centric methods, the reader is directed to the documents in Box 4.

Box 2 **Video presentations demonstrating holistic approaches to watershed and salmon habitat restoration**
Stage 0 River Restoration by Cluer and Powers (2020)
Miller Time: Cheers to Partnerships and PBR by Nielson and Nielson (2022).

Box 3
Key documents that provide Best Management Practices for form-based or channel-centric (within and near-channel works) methods for salmon habitat recovery

Rehabilitation and Enhancement of Aquatic Habitat Guide V. 1.0 by Kavanagh and Hoggarth (not dated)

Fish Habitat Rehabilitation Procedures by Slaney and Zaldokas (1997)

Soil Bioengineering Techniques for Riparian Restoration by Polster (2002)

Restoration & Rehabilitation Component, Aquatic Activity Area by BC MoE (2006)

Fish-Stream Crossing Guidebook (Revised Edition) by BC MoFLNRO, BC MoE and DFO (2012)

Box 4
Key documents that provide Best Management Practices and theory for process-based or valley-centric methods for watershed recovery

An approach to restoring salmonid habitat-forming processes in Pacific Northwest Watersheds by Beechie and Bolton (1999)

Postfire management on forested public lands of the western United States by Beschta et al. (2004)

Gully Control in SAT Watersheds by Pathak et al. (2005)

Large-Scale Erosion and Flooding After Wildfires: Understanding the Soil Conditions by Curran et al. (2006)

Burned Area Emergency Response Treatments Catalogue by Napper (2006)[108]

Post-Wildfire Natural Hazards Risk Analysis in British Columbia by Hope et al. (2015)

Post-fire wood mulch for reducing erosion potential increases tree seedlings with few impacts on understory plants and soil nitrogen by Jonas et al. (2019)

Coupling landscapes and river flows to restore highly modified rivers by Whipple and Viers (2019)

Low-Tech Process-Based Restoration of Riverscapes Design Manual by Wheaton et al. (2019)

5.1.2 THE TIMING OF TREATMENTS

Process-based restoration focuses on correcting disruptions to watershed processes, such that the stream ecosystem can progress along a natural stream evolution trajectory with minimal corrective intervention to instream habitats. Based on this valley-centric perspective of post-wildfire salmon habitat recovery, impacts to habitat-forming processes on the landscape should *typically* be addressed before channel-centric habitat-focused recovery methods are considered. Process-based treatments focus on the restoration of lateral (between the stream and its floodplain) and longitudinal (along the stream) connectivity of a stream,

[108] Napper (2006) and Hope et al. (2015) are comprehensive documents on holistic (channel centric and process-based) watershed and salmon habitat restoration.

while also addressing water and/or sediment movement within the broader watershed area. In addition to physical alterations to restore floodplain connectivity, treatments often focus on upland areas in the watershed with the objectives of improving soil conditions (e.g., water infiltration capacity) and terrain stability (e.g., mass wasting, soil erosion), and accelerating hydrologic recovery (e.g., water storage and reduced runoff rates).

As discussed in Section 3, watersheds are subject to dynamic and interacting controls (e.g., climate, geology and biology) that vary over time. Change imposes risks and, as such, any watershed or salmon habitat management initiative, whether routine or in response to a major disturbance such as a wildfire, should be viewed in the context of risk management. In fact, most post-wildfire recovery treatments and strategies are an attempt to either mitigate risks or increase a system's resiliency to risk. For example, reforestation activities over a broad area can be expected to increase forest cover and mitigate high flows and associated channel altering events (e.g., aggradation). Riparian planting at more localized scales might not mitigate high flows, but the streamside trees and shrubs would increase the channel's resilience to high flows by both dissipating velocities and increasing bank stability. Even the form-based treatments, designed to directly restore habitat conditions, should take risks and treatment sequencing into consideration, otherwise the returns on investments may be low. For example, if watershed scale factors are not addressed first, extreme post-wildfire channel forming events could threaten or destroy in-channel works and set back habitat recovery.

With the process-based model in mind, and depending on the system's hydrology, form-based and channel-centric habitat-based treatments are generally a lower priority in the period immediately after a wildfire. Ideally, they would occur after process-based restoration approaches have addressed more fundamental and watershed-level problems. Such systems would have begun to 'settle down' and be less prone to flashiness and extreme high flows. Despite this general rule, form-based channel treatments can be critical in improving habitat conditions for salmon over various time periods (i.e., repeatedly, including soon after the wildfire as well as later), depending on the risks involved. For example, if a critically important habitat component, such as clean spawning gravels, is limiting a population, investments into risky, short-term and repeated channel-centric treatments may be necessary.

Other exceptions to this generalized sequencing approach exist. Even before process-based and form-based recovery options are considered, emergency works in and around the stream may need to be undertaken to protect fish and fish habitat following a large disturbance such as a wildfire. Conditions that may warrant immediate action include blockages to fish passage (breaks in habitat connectivity) or introduced hazardous materials. Extreme bank erosion can potentially trigger slope failures in high-risk situations and, thus, warrant immediate channel bank stabilization/armouring. In general, impacts that can result in high rates of salmon mortality, significant damage to critical habitats and/or disrupt migrations should be prioritized for immediate actions that are referred to in Figure 15 as 'immediate treatments'. Under this circumstance, while the work will have to be supported by the necessary authorities (agencies and First Nations), it may have to proceed without the benefit of a fully developed planning team or the full array of potential assessments.

Figure 15 graphically illustrates the general sequencing of treatment options for post-wildfire salmon and salmon habitat recovery and how these relate to the content of subsections herein.

IMMEDIATE TREATMENTS (SECTION 5.2.1)	• Treating impacts that have the potential to have immediate and substantial impacts on salmon populations and habitat (e.g., excess mortality, barriers to migration).
PROCESS-BASED TREATMENTS (SECTION 5.2.2)	• Focus on treating habitat-forming processes on the landscape. • Typically done before undertaking in-channel form-based treatments. • Process-based treatments provide on-going treatment and impact mitigation that can reduce the frequency and severity of future disturbance events. For example, if treatments do not first address upslope hydrological recovery, high energy flood flows and debris torrents may persist and can “undo” form-based channel treatments.
FORM-BASED CHANNEL TREATMENTS (SECTION 5.2.3)	• Focus is on treating in-channel habitat values though the creation or enhancement of aquatic habitat features. • Typically done after addressing process-based treatments. • Form-based channel treatments generally result in the creation or restoration of specific habitat features for fish. While channel treatments can be effective for improving habitat quality and availability for fish, they are susceptible to high-energy flows and debris flows that might occur if upland process-based treatments are not completed.

Figure 15. General sequence of treatment options for post-wildfire salmon and salmon habitat recovery.

5.2 TREATMENT OPTIONS

The objective of the remaining portion of this section of the Playbook is to provide guidance on the type and timing of treatments (with references to key documents) and strategies that can be used to hasten the recovery of habitat-forming processes and in-channel habitats following major wildfires. The methods listed in Sections 5.2.1 to 5.2.3 describe various treatment options and their recovery objectives from the perspective of salmon and salmon habitat. A mixture of methods are presented, some of which are commonly used in BC, while others are typically used in other areas of western North America.

Treatment options are organized according to the general priority for implementation post-wildfire:

- immediate treatments;
- process-based treatments; and,
- form-based treatments.

A holistic approach that integrates a variety of process and form-based treatments to address both short-term issues and long-term restoration goals is often most appropriate.

The value of any given treatment will depend on how effectively it mitigates impacts and risks AND the risks imposed by the treatment itself. This document does not provide a detailed description of how to implement the treatments or the inherent risks that can come with them. Rather, it describes the treatments and their intended benefits and provides references for follow-up reading. Qualified professionals should assess impacts and risks (as discussed in Section 4) and consider the potential effectiveness of watershed and site-specific treatment options before prescribing treatments. In some cases, doing nothing can be the most prudent option. For example, several of the treatments identified in this section attempt to intercept sediments, and even large organic debris, before they get to the salmon bearing waters. And yet it is known that in some circumstances these same inputs can be to the benefit of salmon. Restoration is often a matter of clearly identifying the risks and choosing the best mitigative options, while minimizing unintended consequences.

The tables in the following subsections often present specific treatments that are useful for watershed and or/salmon habitat recovery. In practice, several treatments can be used in concert and bundled into strategies, which are integrated into plans and projects. For example, road maintenance, deactivation and rehabilitation are all examples of projects that can employ many different treatments to address a variety of risk factors, such as sediment transport, slope failure and barriers to fish passage. The bundling of different treatments to address multiple values and risks is referred to as a strategy in this document and several common strategy scenarios are discussed in Section 5.3.

5.2.1 IMMEDIATE TREATMENTS

Immediate treatments are those that reduce the risk of imminent and substantial impacts to salmon and/or salmon habitats, including blockages to fish passage. These treatments are not designed to directly improve salmon habitat. In recognition of elevated hazards in post-wildfire settings, they are intended to mitigate immediate risks to salmon and their habitats. Ideally, they should be undertaken on a proactive basis; however, it is recognized that some may also be used on a reactive basis.

The timelines (e.g., operating window) for immediate instream treatments can be influenced by several factors. In the interior regions of BC, these treatments are best completed before winter snow precludes access and before the high flows of spring freshet. Timelines for immediate instream treatments can also be influenced by the presence of salmon and/or their habitat requisites for critical life stages. Under normal circumstances, instream treatments should be completed during the time period of least risk to salmon.

However, in post-wildfire situations, difficult but necessary decisions are often required as teams weigh the risks of ‘timely action’ versus ‘not taking action’ prior to salmon migration or precipitation and freshet events. As previously stated, biological, real-time imperatives such as migration, spawning and rearing may compel reactive and emergency mitigation measures. Such work may not be guided by an established plan (the world cannot always wait) and actions may be needed prior to, or concurrent with, planning processes.

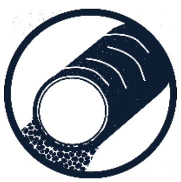
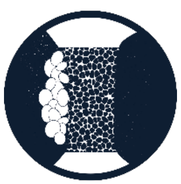
Immediate water and sediment management activities (Photo credit: Jeff Morgan)

A summary of various actions and treatments that can be implemented immediately to protect salmon populations and habitats from threats is presented in Table 9. These treatments are not intended to accelerate watershed recovery. Instead, they are intended to mitigate significant impacts and risks to salmon that present themselves in the immediate aftermath of a wildfire. As discussed, post-wildfire environments often experience higher flows and flood hazards and elevated mass wasting and sediment movement hazards. Accordingly, many of these treatments focus on managing water runoff pathways and mitigating erosion in the vicinity of infrastructure (e.g., road crossings, fire breaks), restoring habitat connectivity (i.e., removing barriers to fish passage), and protecting salmon from hazardous materials. They can also focus on the capture and diversion of high sediment loads and debris flows or the protection of highly erodible banks that could lead to slope failures.

While many of these treatments may be useful immediately after a wildfire, as part of emergency measures, many are useful throughout the restoration process as needs arise. Further, they can be important components of more orderly restoration initiatives such as road deactivation.

Table 9. **Actions and treatments for use after a major wildfire occurs to protect salmon populations from immediate threats.**

Treatment Option	Function	Recovery Objective
Stabilization of hazardous materials[1] 	• Containment of hazardous materials (e.g., industrial facilities, fuels in machinery, cargo trains, brownfields, soils on industrial sites, soils around leaky fuel tanks)	• ↓ hazardous materials transport in channels • Protect against impacts to water and sediment quality • ↓ salmon mortality caused by toxicity
Debris basins[1, 3]  *Specially engineered and constructed emergency basin designed to store runoff and sediment* Provides run-off and sediment control	• ↓ water velocity (energy) • Flood water storage • Groundwater recharge • Settle and trap excess sediment • Settle solids-bound pollutants • Trap woody and other types of large debris (e.g., damaged infrastructure) • ↓ risk of debris jams • ↓ damage to infrastructure • ↓ erosion of channel banks and bottom	• ↓ sediment/debris transport and deposition in channels • ↓ barriers to fish passage (habitat connectivity) • ↓ wash out and burial of critical habitats • ↓ back flooding caused by excess debris • ↓ inundation of near-channel infrastructure (e.g., fuel storage areas, homes) • Protect against impact to water and sediment quality • Hydrologic recovery (↓ high and low flow extremes) • ↓ fish strandings • ↓ salmon mortality caused by toxicity
Debris rack/deflector[3]  *A structure placed across a stream channel to either collect or deflect debris typically before it reaches a culvert or other stream crossing* Provides run-off control	• Trap woody and other types of large debris • ↓ risk of debris jams • ↓ damage to infrastructure • ↓ erosion of channel banks and bottom	• ↓ sediment/debris transport and deposition in channels • ↓ wash out and burial of critical habitats • ↓ back flooding caused by excess debris • ↓ inundation of near-channel infrastructure (e.g., fuel storage areas, homes) • Protect against impacts to water and sediment quality • ↓ barriers to fish passage • ↓ fish strandings

Treatment Option	Function	Recovery Objective
Diversion berm  *Earth berms constructed along a slope to intercept and divert hillslope run-off and direct flows away from disturbed areas and environmentally sensitive areas, and into a stable outlet point or sediment control structure* Provides run-off control	• Focus runoff (establish runoff pathway) • ↓ slope distance • ↓ runoff velocity • ↓ hillslope erosion • ↓ rill and gully formation	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Protect against impacts to water and sediment quality
Culvert/bridge modifications, upgrades and armoring [1, 2, 3, 4]  Provides run-off and erosion control	• ↓ culvert plugging by debris • Focus runoff (re-establish runoff pathway) • ↓ back flooding and water accumulation along road ditch • Protect road materials from saturation and failure • ↓ erosion from road surfaces and embankments • ↓ gully formation	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Protect against impacts to water and sediment quality • ↓ barriers to fish passage • ↓ fish strandings • ↓ erosion below culverts
Armoured low-flow stream crossings (Fording) [1, 2, 3]  *An excavated and armoured crossing of a small stream in lieu of a culvert* Provides run-off and erosion control	• Temporary replacement for culverts/bridges • Protect stream channel from damage by vehicle traffic (channel armouring) • Focus stream flows (clear path for water to follow) • ↓ risk of debris jam • ↓ erosion from road surfaces and embankments • ↓ rill and gully formation • ↓ sediment and soil mobilization at channel crossing	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Protect against impacts to water and sediment quality • ↓ barriers to fish passage

Treatment Option	Function	Recovery Objective
Road rolling dips (with and without overflow structure)[1, 3]  *Rolling dips are constructed to direct run-off water across the surface of roads and trails in a desired direction, in lieu of a culvert* Provides run-off control	• Disperse runoff -or establish a runoff pathway • Armour road embankment (overflow structure) • ↓ slope distance • ↓ runoff velocity • Protect road materials from saturation and failure • ↓ erosion from road surface and embankments • ↓ rill and gully formation	• Control surface runoff • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Protect against impacts to water and sediment quality
Road overside drains[1]  *Openings installed along the edges of roads and trails to remove surface waters from the surface area in a manner that protects nearby fillslopes from erosion* Provides run-off control	• Focus runoff (establish runoff pathway) • Armour road embankment • Protect road materials from saturation and failure • ↓ erosion from road surface and embankments • ↓ rill and gully formation	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Protect against impacts to water and sediment quality

Treatment Option	Function	Recovery Objective
Road out-sloping[1, 3]  *Road or trail surfaces that have been re-contoured to be out-sloping, promoting the dispersal of surface run-off* Provides run-off control	• ↓ slope distance and steepness • ↓ runoff velocity • ↓ erosion from road surface and embankments • ↓ rill and gully formation	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Protect against impacts to water and sediment quality

↓ = decrease

1 Napper 2006

2 BC MoFLNRO, BC MoE and DFO 2012

3 Neary et al. 2005

4 US Fish and Wildlife Service not dated

5.2.2 PROCESS-BASED TREATMENTS

The fundamental aim of process-based treatments is to restore habitat-forming hydrological and geomorphological processes, including the restoration of streams to their wider floodplains, stabilization of upland soils and the establishment of vegetative cover. In many cases, this means understanding and working with ecosystems and accepting that recovery goals must synchronize with, and be shaped by, natural processes. Throughout most of BC, the reforestation of upland areas to restore hydrologic recovery is probably the most effective process-based treatment possible over the long-term. This treatment type can be expected to take five to six decades to achieve full effect, so it will be important to get started as soon as possible! As they grow, young forest stands increasingly contribute to hydrologic recovery and create the added benefits of binding soils and providing shade.

Process-based restoration projects can also focus on restoring valley-wide habitat-forming processes. For example, 'Stage 0' restoration treatments[109] seek to re-establish geomorphic control (i.e., lost due to human alteration such as channelization, large wood removal, beaver extirpation), lower the stream's gradient and allow the resumption of more natural floodplain erosion and depositional processes. This promotes natural stream function, connectivity to the wider floodplain and an increase in instream habitat complexity. For incised, straightened streams, this might also involve treatments like channel infilling and construction of side-channels and over-flow channels that are intended to spread flow across more of the floodplain and improve surface connectivity with the water table. This approach can involve large areas and significant investments in planning and engineering. Alternatively, in smaller systems, low tech solutions, such as beaver dam analogues, can work on the same principle and have similar, though smaller-scale effects.

Boulder placement within a side channel restoration project (Photo Credit: Wayne Salewski)

[109] Powers et al. 2019; Flitcroft et al. 2020

As with any other process-based restoration treatments, Stage 0 restoration treatments should be applied where the re-establishment of a geomorphic control will achieve and sustain the intended benefits. In other cases, incised channels and the absence of a floodplain may exist for entirely natural reasons (e.g., ongoing post-glacial landscape adjustments), and in those sites the implementation of grade control would fall into the category of 'habitat creation' rather than restoration and there could be questions regarding long-term viability of the project. Further, process-based or not, treatments need to address the root causes of habitat degradation. For example, in many cases, streams impacted by wildfire may be aggrading. In such cases, the application of Stage 0 restoration could be detrimental, exacerbating impacts on salmon due to pool infilling and loss of complexity. On the other hand, if prior to wildfire, the channel in question was incised and degraded due to cumulative effects of land use, wildfire-induced aggradation can provide an opportunity to leverage the Stage 0 approach to reverse that legacy impact.[110]

Although the restoration of watershed processes should be considered a high priority in post-wildfire recovery, the timeline for implementing large, complicated restoration projects can sometimes take many years (e.g., greater than five years) and span research, planning, design and permitting phases before they can be implemented. Other smaller process-based treatments may be implemented much sooner, within one to five years, such as the installation of upland run-off and erosion controls, grass seeding and reforestation.

Process-based treatments are not designed to *directly* improve salmon habitat. Instead, they are designed to restore or emulate natural processes that create conditions favorable to habitat recovery. Further, many of these treatments (e.g., fibre rolls) could also have utility as immediate treatments and are placed herein because they may be of value on an ongoing basis. A summary of process-based actions and treatments is provided in Table 10.

[110] Cluer and Thorne 2014; Clark 2024

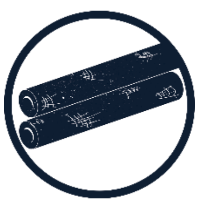
Table 10. Process-based actions and treatments that focus on restoring habitat-forming processes in the watershed.

Treatment Option	Function	Recovery Objective
Stage 0 Restoration[1]  *A novel approach that focuses on raising incised, simplified stream channels and regrading valley floors to restore stream connectivity across the floodplain. Can involve various techniques to achieve this, including channel in-filling, beaver dam analogues, and artificial logjams.* Provides run-off, erosion and sediment control	• Slow water velocity in channel • ↑ retention time of water • Backup water, spreading water over land (increase lateral connectivity recouple channel to riparian and floodplain areas) • Settle excess sediment and debris • ↓ channel incision • Store flood water • Slow release of flood water during basal flow periods • Channel aggradation	• ↓ sediment delivery to channel • ↓ sediment transport • ↓ sediment deposition in certain channel habitats (e.g., pools) • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Dampen riparian soils • Increase habitat diversity and complexity for various species and life stages • Overwintering habitat for fish • Hiding places and refugia for fish • ↑ groundwater recharge • ↓ severity of high and low flow events (runoff attenuation) • Improve water and sediment quality • ↓ vulnerability to wildfires
Beaver dam analogues [10, 11] Beaver Institute[TM, 2]  *Human-made structures installed mid-channel designed to mimic the form and function of a natural beaver dam and associated pond/floodplain habitat*	• Slow water velocity in channel • Backup water, spreading water over land (increase lateral connectivity recouple channel to riparian and floodplain areas) • Settle excess sediment and debris • ↓ channel incision • Store flood water • Groundwater recharge • Slow release of flood water during basal flow periods • ↓ channel erosion • Channel aggradation	• ↓ sediment delivery to channel • ↓ sediment transport and deposition in channel • Recouple channel, riparian habitats and floodplain • Increase habitat diversity and complexity for various species and life stages • Promote growth of riparian vegetation • Dampen riparian soils • Overwintering habitat for fish • Hiding places and refugia for fish • ↑ groundwater recharge • ↓ severity of high and low flow events (runoff attenuation) • Improve water and sediment quality • ↓ vulnerability to wildfires

Treatment Option	Function	Recovery Objective
Upland reforestation  *Planting or aerial seeding of tree species in upland areas to promote reforestation* Provides run-off and erosion control	• Stabilize soils • Add organic components to burned soils • Break up soil hydrophobic layer (roots) • ↓ rain splash • ↑ landscape surface roughness • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation • ↓ invasive weed colonization and spread	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • ↑ nutrient retention on landscape • ↓ overland runoff rates • Hydrologic recovery (↓ high and low flow extremes) • Improve water and sediment quality
Riparian reforestation  *Planting of tree species in riparian areas to promote reforestation and improve riparian function.* Provides run-off and erosion control	• Stabilize soils • Add organic components to burned soils • Break up soil hydrophobic layer (roots) • ↓ rain splash • ↑ landscape surface roughness • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation • ↓ invasive weed colonization and spread • ↑ shading of stream • ↑ leaf litter and insect drop into stream	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • ↑ nutrient retention on landscape • ↓ overland runoff rates • Improve water and sediment quality • Improve bank stability

Treatment Option	Function	Recovery Objective
Seeding to establish grasses and forbs[3, 4, 5, 6, 7]  1 Dry seeding 2 Hydroseeding 3 Helihydroseeding Provides erosion control (weed free mixes)	• Cover exposed soils • Add organic components to burned soils • Break up soil hydrophobic layer (roots) • ↓ rain splash • ↑ landscape surface roughness • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation • ↓ invasive weed colonization and spread	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • ↑ nutrient retention on landscape • overland runoff rates • Hydrologic recovery (↓ high and low flow extremes) • Improve water and sediment quality
Aerial and/or ground mulch [3, 4, 6, 7, 8]  Provides erosion control	• Cover exposed soils • Add organic component to burned soils • ↓ rain splash • ↑ landscape surface roughness • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation • Protect seed bank	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • ↑ nutrient retention on landscape • ↓ overland runoff rates • Hydrologic recovery (↓ high and low flow extremes) • Improve water and sediment quality
Straw mulch [3, 4, 6. 7, 8]  Provides erosion control	• Cover exposed soils • Add organic component to burned soils • ↓ rain splash • ↑ landscape surface roughness • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation • Protect seed bank	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↑ nutrient retention on landscape • ↓ overland runoff rates • Hydrologic recovery (↓ peak flows and flashiness) • Improve water and sediment quality

Treatment Option	Function	Recovery Objective
Slash spreading[3, 6, 7]  Provides erosion control	• Cover exposed soils • Add organic component to burned soils • ↓ rain splash • ↑ landscape surface roughness • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation • Protect seed bank	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • ↑ nutrient retention on landscape • ↓ overland runoff rates • Hydrologic recovery (↓ high and low flow extremes) • Improve water and sediment quality
Scarification[3, 7]  *Hand tools or mechanical equipment are used to break up and loosen topsoil to increase surface roughness* Provides run-off and erosion control (but comes with sediment exposure/transport risks)	• Break up soil hydrophobic layers • Mix remaining organic matter in with mineral soils • ↑ landscape surface roughness • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation • Protect seed bank	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Promote nutrient retention on landscape • ↓ overland runoff rates • Hydrologic recovery (↓ high and low flow extremes) • Improve water and sediment quality

Treatment Option	Function	Recovery Objective
Erosion-control mats[3, 7]  *Synthetic or organic matting that is laid on the ground surface to reduce risk of erosion before vegetative groundcover can be established (preference is to use fully biodegradable organic mats)* Provides erosion control	• Cover exposed soils • ↓ rain splash • ↓ sheet erosion • ↓ rill and gully formation	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Improve water and sediment quality
Contour felled logs [3, 4, 6, 7, 8]  *Logs placed in a shallow trench on the contour of a slope intended to reduce erosion* Provides erosion and sediment control	• ↑ sediment trapping structure on slopes • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • ↑ nutrient retention on landscape • ↓ overland runoff rates • Hydrologic recovery (↓ high and low flow extremes) • Improve water and sediment quality
Fibre rolls and wattles[3, 6, 7, 8]  *Prefabricated rolls of straw, coconut or wood fibres encased in netting placed in shallow trenches on the contour of the slope intended to reduce erosion* Provides erosion and sediment control (but consider impacts of plastic matrix materials)	• ↓ slope distance • ↓ slope gradient • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation	• Promote recovery of landscape soils and vegetation • ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • ↑ nutrient retention on landscape • ↓ overland runoff rates • Hydrologic recovery (↓ high and low flow extremes) • Improve water and sediment quality

Treatment Option	Function	Recovery Objective
Sediment fences[3, 7]  *Temporary, permeable barriers of geo-textile installed in a trench and supported by star pickets or wooden posts to reduce flows and intercept sediment* Provides sediment control, primarily in association with roadways and infrastructure	• ↓ slope distance • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ sheet erosion • ↓ rill and gully formation	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Improve water and sediment quality
Gully Treatments[7, 9]  1 Loose boulder check with shrubs 2 Stabilization with vegetation 3 Loose rock check dam 4 Rock reinforced with wire mesh 5 Loose rock drop structure Provides run-off, erosion and sediment control	• ↓ slope distance • ↓ runoff velocity • ↑ water infiltration • ↑ soil moisture retention • Groundwater recharge • ↓ erosion in gully • ↓ gully size and risk of mass wasting	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Improve water and sediment quality

↓ = decrease; ↑ = increase

1 Cluer and Thorne 2014
2 Pollock et al. 2014
3 Napper 2006
4 Curran et al. 2006
5 Hope et al. 2015
6 Girona-García et al. 2021
7 Neary et al. 2005
8 Robichaud et al. 2010
9 Pathak et al. 2005
10 Fairfax and Whittle 2020
11 USU not dated

5.2.3 FORM-BASED CHANNEL TREATMENTS

While restoration of watershed processes will help restore in-channel structure and habitat features over time, form-based habitat restoration works can hasten the rate at which stream channels and instream salmon habitat recover. These treatments focus on adding human-made habitat features into stream channels to improve instream conditions, particularly for salmonid species. Treatment options include weirs, rock steps, grade-control structures, engineered log jams and woody debris, and bank stabilization, both through bank armouring and bioengineering. These treatments induce immediate changes in a stream, but sometimes can fail to achieve the anticipated effects if degradation is originating at a wider scale. Detractors of form-based approaches argue that ‘forced’ solutions can be out of step with watershed processes and that this can waste effort and resources and, worse, further damage the stream and its habitats. In addition, some form-based treatments, such as bank armoring, are viewed as prioritizing property and infrastructure protection over salmon habitat values. Others argue that well thought-out and well-timed form-based approaches can compliment process-based restoration and accelerate watershed recovery. Treatment selection usually involves a series of mechanistic assumptions and, ultimately, these should distill down to an improvement in salmon habitat.

Bioengineering is one method employed to improve in-channel stability and structure. The concept behind bioengineering is that live structures placed along the banks of impacted stream reaches will protect the stream channel from erosion and trap nutrient-rich fluvial sediment. The live structures are built by planting cuttings of regionally appropriate riparian deciduous species such willows, cottonwood and red-osier dogwood. As the live cuttings grow and other native plants are naturally recruited, their root systems add additional bank stability and other riparian functions. Types of live structures are included in Table 11. Box 2 and Box 3 describe various bioengineering approaches and restoration methodologies used for instream restoration. As well, professionals in riparian restoration[111] can provide direction on bioengineering approaches and restoration methodologies that can be used to restore riparian vegetation and function to the benefit of stream ecosystems.

Live bank protection (Photo credit: Wayne Salewski)

[111] see Polster 2002, Kavanagh and Hoggarth (not dated), and Slaney and Zaldokas 1997

Creating pool riffle habitat (Photo credit: Leo Chira)

Other form-based treatments tend to involve engineered structures, focused on improving specific habitat conditions for salmonid species. These treatments include the engineered installation of features and structures such as boulder clusters, root wads, large woody debris, log jams and Newbury riffles.

Table 11 lists form-based actions and treatments that should generally be considered once habitat-forming processes have been re-established.

Although the installation of form-based treatments will typically be prioritized after process-based treatments, some instream habitat restoration may need to be completed sooner, particularly where process-based treatments are expected to take years/decades to have the desired effect. For example, treatments to stabilize banks can often be implemented quickly, whether through bioengineering or other bank protections, and as such, may get advanced into near-term operations (e.g., within one to five years post-wildfire) when required to prevent ongoing impacts or where a wildfire's impacts on watershed-scale processes have been minimal. Typically, larger instream projects, like the installation of boulder or riffle habitat, are likely to be completed after hydrologic recovery has progressed to the point where peak flows have been moderated and channel scouring events are less likely.

As always, exceptions to any general rule will present themselves. For example, while the construction of habitat features (e.g., spawning substrates, rearing habitats) may be risky in flashy and high energy streams, periodic investments may be necessary to maintain vulnerable salmon populations.

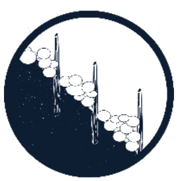
Engineered interventions or treatments can disturb stream channels and banks and create impacts and risks to salmon habitat values and other values, at least in the short-term. Given that riverscapes are dynamic systems, the ecological value of engineered treatments can be lost over time as channels move and natural habitat forming processes occur in the system. The use of engineered structures for potential salmon habitat risk mitigation should be considered carefully. They are often less problematic for the purpose of mitigating impacts (e.g., sediment transport) to streams, and higher risk for in-stream applications. Accordingly, a careful consideration of unintended consequences should accompany any project plan involving form-based interventions.[112]

[112] Tullos et al. 2009

Table 11. Form-based actions and treatments that focus on installation and maintenance of stream channel structures and features.

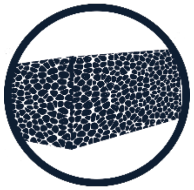
Treatment Option	Function	Recovery Objective
Wattle fences[1]  *Short retaining walls made of live cuttings to stabilize steep slopes by creating terraces and adding root reinforcement*	• ↓ slope distance and steepness on channel bank from a micro-slope perspective • ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle nutrient-rich suspended sediment (channel aggradation) • Protect seed bank • Provide source of live sprouts • ↑ over-channel shading • Seasonal organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improve water and sediment quality • ↓ erodibility of slope
Live bank protection[1]  *Long sections of wattle fences (see above) applied to stabilize stream banks*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle nutrient-rich suspended sediment (channel aggradation) • Protect seed bank • Provide source of live sprouts • ↑ over-channel shading • Seasonal organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improve water and sediment quality
Live palisades[1]  *Cottonwood posts installed in trenches dug along the stream to add root reinforcement*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle nutrient-rich suspended sediment (channel aggradation) • Protect seed bank • Provide source of live sprouts • ↑ over-channel shading • Seasonal organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improve water and sediment quality

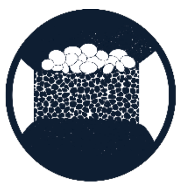
Treatment Option	Function	Recovery Objective
Modified brush layers[1]  *Mattress of interlaced live branches placed and secured on the bank, above typical water level*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle nutrient-rich suspended sediment (channel aggradation) • Protect seed bank • Provide source of live sprouts • ↑ over-channel shading • Seasonal organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improve water and sediment quality
Tree revetments[2]  *Large wood, often entire trees, placed along the streambank, usually parallel to it, with the intention of protecting the banks from erosion*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle nutrient-rich suspended sediment (channel aggradation) • Protect seed bank • Provide source of live sprouts • ↑ over-channel shading • Seasonal organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improve water and sediment quality
Live crib wall[2]  *A box-like structure built out of logs and backfilled with soil and rocks, acting as a retaining wall to prevent bank erosion*	• ↓ slope distance on channel bank • ↓ • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle nutrient-rich suspended sediment (channel aggradation) • Protect seed bank • Provide source of live sprouts • ↑ over-channel shading • Seasonal organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improve water and sediment quality

Treatment Option	Function	Recovery Objective
Brush mattresses[2]  *Compressed layers of branches (5 to 20 cm thick), anchored with twine and wood stakes then sprinkled with soil*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle nutrient-rich suspended sediment (channel aggradation) • Protect seed bank • Provide source of live sprouts • ↑ over-channel shading • Seasonal organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improved water and sediment quality
Fascine bundles[2]  *Bundles of live plant material that are planted in trenches, typically on slope contour, and are meant to prevent erosion*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle nutrient-rich suspended sediment (channel aggradation) • Protect seed bank • Provide source of live sprouts • ↑ over-channel shading • Seasonal organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improve water and sediment quality
Rock and live rock revetments[2]  *Live stakes planted into the soil within the interstitial spaces of a rock (rip rap) blanket to help establish riparian vegetation*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank • Settle suspended sediment (channel aggradation)	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Stabilize channel morphology • Improve water and sediment quality

Treatment Option	Function	Recovery Objective
Root wads[2]  *Structural large wood features using root wads, usually installed perpendicular to flow, to deflect current and prevent bank erosion*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ rill and gully formation on channel bank • Create near-shore velocity variation (depositional and scouring) • ↓ channel incision • Settle nutrient-rich suspended sediment (channel aggradation) • ↑ over-channel shading	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Stabilize channel morphology • Clean spawning substrates (↑ velocity and turbulence) • ↑ habitat complexity • Improve water and sediment quality • Hiding places and refugia for fish
In-channel tree felling[3, 5]  *Streamside trees toppled into the channel to slow down the flow and increase hydraulic complexity*	• ↓ slope distance on channel bank • ↓ runoff velocity on channel bank • ↓ rill and gully formation on channel bank • Create velocity variation (depositional and scouring) • Settle nutrient-rich sediment (channel aggradation) • ↓ channel incision • ↑ over-channel shading • Organics inputs to channel	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Recouple channel, riparian habitats and floodplain • Promote growth of riparian vegetation • Clean spawning substrates (↑ velocity and turbulence increase) • ↑ habitat complexity • Stabilize channel morphology • Regulate water temperature • Improved water and sediment quality • Hiding places and refugia for fish
Live shade[1]  *Placement of cuttings arranged in tripod-like structures to help rapidly establish bank/riparian vegetation*	• Provide source of live sprouts • Provide over-channel shading • Seasonal organics inputs to channel • Localized channel aggradation	• Promote growth of riparian vegetation • ↑ habitat complexity • ↑(organic carbon) for biological production • Hiding places and refugia for fish

Treatment Option	Function	Recovery Objective
Cover log[2]  *A structure made of large wood installed above the water level to provide overhead cover*	• Provide in-channel shading • Localized channel aggradation	• ↑ habitat complexity • Clean spawning substrates (↑ velocity and turbulence) • Hiding places and refugia for fish
Boulder clusters[2]  *Large boulders placed in streams to reduce velocity, increase flow complexity and create scour areas and cover that are beneficial for fish*	• Create velocity variation (depositional and scouring) • Create back eddies and pools • Provide in-channel shading	• ↑ habitat complexity • Clean spawning substrates (↑ velocity and turbulence) • Hiding places and refugia for fish • Create overwintering habitat • Create components of pool-riffle-run channel morphology
Spawning Gravel Cleaning or Augmentation [6, 7, 8, 9, 10, 11]	• Substrate raking or jetting (disturbance to loosen and clean gravel) • Adding structures/deflectors (e.g., boulders) to flush fines • Substrate augmentation (addition of clean gravel)	• ↑ short-term availability and viability of spawning substates
Log jams[4]  *Diverse types of large wood accumulation/assembly that can serve various purposes e.g., bank protection, bar formation or stabilization, and pool creation*	• Create velocity variation (depositional and scouring) • Create back eddies and pools • Provide in-channel and over-channel shading • Settle nutrient-rich suspended sediment (channel aggradation) • Provide organic matter to channel	• ↓ sediment transport in channel • Stabilize channel morphology • Improve water and sediment quality • Regulate of water temperature • ↑ energy (organic carbon) for biological production • Deep pools for overwintering • Hiding places and refugia for fish

Treatment Option	Function	Recovery Objective
Newbury riffle[2]  *Constructed rock riffles, with a mild v-shape to concentrate the flow, and with the upstream slope much steeper and shorter than the downstream slope. This riffle is intended to reduce/break-up the downstream gradient and create backwater conditions to facilitate fish passage*	• ↑ stretches of laminar flow • Create localized erosional areas • Mobilize fine-textured sediments	• Create spawning habitat • Clean spawning substrates (↑ velocity and turbulence) • Create components of pool-riffle-run channel morphology • ↑ habitat complexity • Assist with upstream fish passage at culverts (e.g., hanging culvert outlets)
Live gravel bar staking[1]  *Use of cuttings to initiate the natural successional processes that revegetate the bar surface*	• Channel aggradation • Channel braiding • ↓ gravel bar erosion • Provide source of live sprouts • ↑ over-channel shading • Provide organic matter to channel	• ↓ sediment delivery to channel • ↓ sediment transport and deposition in channel • Stabilize channel morphology • Regulate water temperature • ↑ energy (organic carbon) for biological production • Improve water and sediment quality
Weirs and grade-control structures  *Engineered hydraulic structures intended to reduce gradient and the associated energy/force of the flow*	• Grade control, dissipate energy, concentrate flows at two points within the channel cross section, and create pools • ↓ slope distance • ↓ runoff velocity • Create back eddies and pools • ↓ channel incision	• ↓ sediment transport in channel • Stabilize channel morphology • Deep pools for overwintering • Hiding places and refugia for fish

Treatment Option	Function	Recovery Objective
Log step-pools  *Hydraulic structures made from logs intended to reduce gradient and the associated energy/force of the flow and create pools*	• Grade control, dissipate energy, concentrate flows at two points within the channel cross section, and create pools • ↓ slope distance • ↓ runoff velocity • Create back eddies and pools • ↓ channel incision	• ↓ sediment transport in channel • Stabilize channel morphology • Deep pools for overwintering • Hiding places and refugia for fish
Stream Bank Armoring[5]  *A layer of very coarse material, such as rocks or boulders covering banks or their toe, intended to prevent their erosion. Creates poor quality habitat and has other disadvantages, including potential off-site impacts. Often used to meet infrastructure objectives (e.g., prevent lateral erosion and keep stream in a location).* 1 Gabions 2 Rip rap	• ↓ runoff velocity on channel bank • ↓ sheet erosion on channel bank • ↓ rill and gully formation on channel bank	• ↓ sediment delivery to channels • ↓ sediment transport and deposition in channels • Stabilize channel morphology • Improve water and sediment quality

↓ = decrease; ↑ = increase

Hints:1) When instream wood placement is used to create logjams, installation should avoid the use of cabling. Let the stream do the work to stabilize and secure the material. 2) In-channel tree falling and root wad placement should be managed by qualified professionals for appropriate use in specific habitats (meso-habitat scale) and orientation to the channel morphology.

1 Polster 2002
2 Kavanaugh and Hoggarth (not dated)
3 Napper 2006
4 Slaney and Zaldokas 1997
5 Neary et al. 2005
6 Pulg et al. 2022
7 Pander et al. 2015
8 Pulg et al. 2013
9 Bašić et al. 2017
10 Pedersen et al. 2009
11 Cramer 2012

5.2.4 ADDITIONAL CONSIDERATIONS WHEN PRIORITIZING AND SEQUENCING POST-WILDFIRE RECOVERY TREATMENT OPTIONS

Although the sequencing of recovery options should generally reflect a priority towards addressing immediate risks to salmon and salmon habitat, followed by process-related treatments, the selection and sequencing of treatments, as presented in Section 5.2.1 to 5.2.3, will also be influenced by other factors, such as the relative effectiveness of erosion and sediment controls and the position of the sub-basin or reach within the watershed. It is critical to select and implement the right treatment at the right time and the right place. For example, it is often wise to address and treat sediment sources before choosing to address instream sediment deposition. Similarly, in-channel work within a larger order mainstem may be a safer bet than the same project within a smaller, flashy stream, especially when hydrologic recovery post-wildfire has only just begun.

5.2.4.1 Erosion and Sediment Control Sequencing

Post-wildfire recovery actions should reflect the priority given while managing erosion, sediment delivery and transport. Whenever possible, erosion and sediment management should first prioritize the control of water, followed by erosion, and lastly, hillslope sediment transport. The reasons for this sequencing of actions are related to both treatment effectiveness and treatment cost (e.g., cost to design, install, monitor, and maintain). Controls for water run-off typically have the greatest relative effectiveness with the least amount of cost. The energy of runoff ultimately causes erosion, so if runoff is controlled, the need for controls on erosion and sediment delivery/transport will be reduced.

Within post-wildfire circumstances, *water* control will typically be given highest priority and involve the inspection, maintenance and repair of road and stream crossing infrastructure, which could have been: 1) in a state of disrepair prior to the fire, 2) impacted by fire suppression activities, and 3) not built to the standards that can withstand elevated peak flows. *Erosion* caused by water, including rain splash, sheet, rill, gully and channel erosion, should be addressed next. Most erosion-control efforts focus on the initial stages of the erosion process (i.e., rain splash, sheet and rill) because they are easier to effectively control. *Sediment control* measures are generally undertaken to abate an ongoing risk of sediment transport into streams and other sensitive ecosystems.

In practice, the control of erosion in immediate post-wildfire environments will be difficult because of the extent of the disturbance, the costs of the various treatment options and uncertainty regarding where erosion will actually happen. Depending on budgets, time and resource availability, it will often be necessary to limit erosion control treatments to very high risk and/or readily accessible areas and to address sediment delivery in a more reactive fashion. Sediment controls should be carefully prioritized using risk assessment procedures to identify the habitats that are highly likely to be impacted by excess sediment inputs and where consequences of such impacts would be more deleterious.

Methods for the control of erosion and soil loss from watersheds must consider the factors that affect the rate and amount of erosion, including soil erodibility, distance of overland flow, slope steepness, slope length and vegetation cover. These are factors in erosion and sediment control that may be mitigated. Other contributing factors in erosion and sediment transfer, like precipitation and climate, can not be controlled. These factors and their relationship are described in the Revised Universal Soil Loss Equation (RUSLE), a model commonly used in agricultural settings and sometimes adopted for post-wildfire environments. For further reading an excellent guide entitled *Erosion and Sediment Control* has been jointly prepared and released recently by the College of Applied Biologists, the BC Institute of Agrologists, and EGBC.

5.2.4.2 Watershed Position Considerations

The selection of treatments and their prioritization should consider the position of the recovery area within the broader watershed, its value as salmon habitat, and the watershed processes that can frustrate or enhance recovery initiatives. The location of the recovery area in the watershed plays a significant role in the selection and prioritization in recovery treatments. As described in Section 3.2, watersheds are comprised of: 1) sediment source zones, 2) sediment transport (transfer) zones, and 3) sediment deposition (depositional) zones.

Further, and as discussed previously, wildfires can profoundly change a stream's sediment budget. Channel forming peak flows may increase in both frequency and magnitude and this can change the nature of the reaches themselves. What was once a highly productive rearing channel in a transport zone may become a source zone and lose sediments and complexity. Alternatively, lower gradient reaches may receive sediments and large organic debris that are beneficial. This post-wildfire reality is important for two reasons. First, recovery activities must account for changing values and locations of salmon habitat within a watershed. At a new dynamic equilibrium for sediment movement, the reestablishment of particular habitat types in some reaches may not be possible. Second, treatments must be designed and situated within the watershed to take advantage of existing, or new, opportunities and they must be able to hold up to any changes in the streams flow regime and sediment budget. In the years, even decades, that follow a wildfire, the everchanging hydrologic and geomorphic risks must continuously be re-evaluated to inform the development and implementation of new treatments and strategies.

Steeper headwater reaches are more prone to sediment erosion processes, and their morphologies are often characterized as cascade and step-pool, which offer little spawning opportunity for Pacific salmon. This zone is more likely to be home to resident salmonid species, like Dolly Varden, bull trout and rainbow trout. However, these streams play critical roles in delivering water, sediment, large wood, and other important subsidies, such as nutrients and invertebrates, to the salmon-bearing reaches downstream.[113] Short-term treatments in these steeper upper-watershed areas will typically emphasize run-off and erosion controls and

[113] Gomi et al. 2002; Wipfli et al. 2007; Alexander et al. 2007; MacDonald and Coe 2007

slope stabilization. Longer-term actions could also benefit the productivity of salmon populations downstream by restoring the flow of the above-mentioned subsidies.

Lower gradient, mid-elevation reaches are often associated with sideways, or lateral, erosion. These areas are frequently characterized by riffle-pool and plane-bed[114] stream morphologies and often provide important spawning and rearing habitat for Pacific salmon and resident salmonid species. Treatment options will need to be sensitive to the proximal fisheries values and the dominant erosion and sediment processes. Short-term treatments in these zones will include run-off and erosion controls and slope stabilization, but they can also include riparian treatments that would provide shade and overhead cover and may serve to dissipate flow velocities and manage incising and lateral erosion.

Very low gradient reaches, such as floodplains, are often, though not always, located in the lower elevation areas of the watershed, which have flatter topography that results in increased sediment deposition. Watercourses in these areas are not usually very confined, often having wide floodplains and increased occurrences of stream braiding and meandering. This zone typically has the greatest diversity of fish. Under normal circumstances, the lower gradients typically reduce the risk of erosion and sediment transport but, because of their depositional nature, they are at the highest risk of aggradation. Short-term treatments in these zones will typically include riparian treatments that would serve to dissipate flow velocities and manage lateral erosion. In particular, they can focus on the management of sediments that, when deposited, can be either beneficial or damaging depending on the circumstance. Newly deposited gravels can enhance spawning substates, while, in the short-term at least, sediment can eliminate channel complexity, reduce stream depth and block fish passage.

5.2.5 TREATMENT SELECTION PRINCIPLES

The intent of the recovery treatments and/or strategies and operational guidance should be well reasoned and clearly articulated. The following principles are offered as general guidance.

a) Restoration treatments and/or strategies should be explicitly tied to the impact(s) and risk(s) (i.e., hazard and consequence) they are intended to address.

b) The impacts and risks addressed should be tied to specific elements at risk in specific locations and assessed and identified as factors that are likely to limit the productivity of the salmon population of interest.

c) The mechanism(s) by which the treatment will produce positive results should be clearly articulated (e.g., how will it reduce the likelihood of a given hazard or mitigate its consequence to the element at risk).

[114] Montgomery and Buffington 1997

d) The probability of success and the uncertainties and assumptions associated with a given treatment should be fully considered.

e) The scale of treatments and strategies should be matched to the scale of the risk factors.

f) Cost/benefit analyses should be used to inform treatment/strategy selection and design.

g) The risks to, or imposed by, any treatment or strategy should be clearly identified. This could address the risk to the recovery intervention (e.g., long-term viability) or it could address the risks the intervention itself might impose on the salmon population (e.g., a failed structure could block fish passage) or another value.

h) Clear objectives and standards should be established and/or used to guide operators when undertaking a restoration project. The operator should understand what is desired and why.

i) Develop specific, measurable, achievable, realistic and time-bound (SMART) goals for the treatments and/or strategies.

In summary, treatment options for post-wildfire salmon recovery must be prioritized and selected based on a robust understanding of relevant watershed processes and an evaluation of existing site conditions and constraints, using hierarchical thinking when selecting and planning recovery treatments. This allows one to use the known relationships between salmon and their habitats to accurately translate the recovery actions and watershed changes into the desired salmon habitat and population responses.

5.3 POST-FIRE RESOURCE MANAGEMENT GUIDANCE AND STRATEGIES TO SUPPORT WATERSHED AND HABITAT RECOVERY

In post-wildfire environments, one can expect salmon concerns to compete with economic, safety and other environmental concerns. While numerous post-fire treatments are available to address salmon habitat recovery at the watershed and site level, other resource management activities or treatments should be well managed, as they have the potential to increase risks to salmon and salmon habitat recovery.[115] However, if done to standards and coordinated, they also have the potential to improve some aspects of habitat recovery (e.g., access management and road maintenance). The development of collaborative strategies and/or strategic guidance can be used to coordinate resource management activities for interrelated values and align standing programs with salmon specific projects. Ideally, strategies should be designed to allow for different salmon-oriented treatments to be integrated into the broader suite of resource management activities and post-wildfire recovery initiatives. For example, after the wildfires of 2017, the Chief Forester released timber salvage guidance to promote the expeditious harvest of dead, but merchantable, trees while addressing watershed, ecological and heritage concerns.[116] In other cases, rights holding First Nations may

[115] Beschta et al. 2004

[116] Berg 2023

release their own guidance on the same issues. Such guidance promotes the coordination of multiple activities and values and, in the case of salmon, can relate to such things as salvage harvesting, cattle grazing, resource road operation and maintenance, provincial fire suppression rehabilitation actions, silviculture and hydrologic recovery, and on-site water retention and management.

When developing an overarching approach or strategy for watershed recovery, a recognition of standing programs or existing legal requitements is also important. For example, intensive riparian planting could specifically address habitat values; however, it may be more effective and less costly if integrated with the more extensive, forestry oriented, upland planting. As there are legal requirements and funding sources that pertain to upland planting, salmon habitat restoration goals may be best served by cross-sector collaboration at watershed scales.

Strategies and plans can also tie multiple treatments and activities into a common initiative. For example, an access management plan may address access and maintenance responsibilities, but it can also bundle many different treatments into a cohesive approach to roadway water and sediment management and habitat connectivity.

5.3.1 SALVAGE HARVESTING

Salvage harvest is often undertaken in post-wildfire environments as the provincial government and tenure holders work to extract value from dead, yet still merchantable, stands of timber. Salvage harvest is controversial, because it can exacerbate sediment and mass wasting impacts[117]. However, if well designed and executed, some salvage harvesting can mitigate ecological concerns and play an important role in watershed recovery.[118]

In BC, salvage harvesting obliges the tenure holder to restock harvested sites with trees and this can serve to address hydrologic recovery in a timely manner. It also presents an opportunity to bring in various pieces of equipment and put them to use in recovery treatments, such as roadway and infrastructure maintenance and repair.

On the other hand, if not well managed at the site level, salvage harvest can delay or prevent natural recovery processes by compacting soils, removing organic materials, increasing site susceptibility to erosion and run-off, removing shade structures, and introducing invasive plants. Ancillary road building also poses similar risks and can damage soils, destroy or alter remaining/recovering vegetation, accelerate runoff and erosion, and increase the risk of mass wasting.[119] Salvage harvest can disrupt future woody debris inputs into streams. Similarly, salvage harvest can reduce large organic debris inputs from what could otherwise have shaded microsites in terrestrial environments, maintain moisture levels and enhance the regrowth of vegetation. The cumulative effects of salvage harvest (and ancillary activities) must also be considered at watershed and

[117] Nemens et al. 2019

[118] Leverkus et al. 2021

[119] Nemens et al. 2019; Leverkus et al. 2021

subbasin scales. Watershed analysis can reveal values and risks at these scales and may lead teams to recommend/accept specified salvage harvest activities in some basins, but not others.

The balance between the potential positive and negative consequences of salvage harvest can be addressed with site and wildfire specific direction on when and where salvage should and should not occur and on what practices are acceptable (e.g., harvest systems). Very often, salvage activities are precluded in terrain with: 1) steep slopes, 2) higher potential for sediment exposure and delivery, 3) higher risk of slope failures, and/or 4) in areas requiring salvage-associated, new road building. Salvage harvest can also be precluded or modified in areas where the protection of the surviving green trees is paramount. Further, the watershed and salmon habitats sensitivities may also be addressed by elevating other practices. Examples include requirements for prompt road deactivation and the immediate maintenance and repairs to roads and infrastructure.

In past years, fire-specific direction on salvage in BC has been developed by a regulating agency, licensees and/or the rights holding First Nations. Such guidance can also address other important issues, such as the preservation of cultural heritage and biodiversity.

5.3.2 CATTLE GRAZING AND RANGE MANAGEMENT

Cattle grazing is a common land-use practice on BC's Crown land, particularly through much of BC's southern and central interior. Watersheds and the cattle industry both benefit from recovering grasslands and well managed transitional grazing areas. Targeted grazing programs can be used to reduce fine fuel loads and mitigate wildfire near urban settings. However, cattle grazing also has the potential to negatively impact watershed recovery objectives. Poorly managed grazing can result in elevated erosion and soil compaction and the widening of streams/flattening of banks.[120] Livestock grazing has also been associated with increased stream temperatures, elevated nutrient levels, reduced macroinvertebrate abundance and a reduction in vegetative cover.[121] Wildfire-impacted watersheds will generally be more susceptible to these impacts, because vegetative groundcover is reduced and soil exposure is increased.

A post-wildfire treatment that often emerges as a synergy is 'grass seeding'. From the perspective of the livestock grazer, the value of re-establishing forage is obvious. However, these treatments can also be highly effective in shielding and binding soils and preventing sediment transport. Grass and clover mixes are commonly used to provide early seral ground cover, stabilize the surface of cut and fill slopes along roadways and stream banks and mitigate sediment transport. They can be used over broad areas to serve these purposes and produce forage for wildlife and cattle. In BC, the seed mixes that are readily available typically consist of non-native, agronomic species of grasses and clovers. The selection of seed mixes is often done on a collaborative basis, and often a preference exists for agronomic species that eventually 'fall out' and make way for native grasses and/or later seral stage processes.

[120] Kaufmann and Krueger 1984; Magilligan and McDowell 1997; Knapp and Matthews 1996

[121] Nicholls and Ethier 2018

Grazing in post-wildfire areas may need to be managed and controlled depending on cattle densities and the achievement of recovery objectives, fine fuel management objectives, seasonal climatic conditions and sufficient vegetative regeneration. Management strategies could include grass seeding and tree planting, with grazing in low-risk areas or with restricted or deferred grazing in high-risk areas and/or time periods. This could involve a variety of techniques including fencing, defined drinking stations, grazing rotations/times or combinations thereof to provide grazing opportunities, while re-establishing desired vegetation communities, managing sediments and enhancing stream and wetland function.

5.3.3 RESOURCE ROAD AND ROAD INFRASTRUCTURE OPERATION AND MAINTENANCE

Resource roads, typically gravel roads (and infrastructure) built for industrial purposes to access natural resources in remote areas, and road infrastructure (e.g., bridges, culverts) often present challenges to post-wildfire recovery objectives. These roads are valued assets and an important part of BC's transportation network. However, the issues surrounding resource roads and their potential impacts on salmon and salmon habitat are well documented.[122] Sediment transport from resource roads and skid trails into streams is a particular issue in BC.[123] These effects are often exacerbated in post-wildfire conditions. Hydrophobic soils, loss of vegetation and organic groundcover, and exposed mineral soils can result in the inundation of resource road ditches and culverts with sediment-laden run-off, the introduction of sediments into salmon-bearing streams, and in worst cases, slope failures and landslides.[124] Following wildfires, the increased flows and geomorphic risk factors often test roads and their infrastructure, especially if built to lower standards. To mitigate these post-wildfire impacts and risk factors, immediate and increased assessment and maintenance requirements should be anticipated.

Post-wildfire environments can present opportunities to re-evaluate the existing road networks and develop plans to maintain necessary access, while addressing liabilities associated with old, underbuilt, unnecessary or high-risk road infrastructure. Forest service roads, tenured roads and non-status roads can receive a variety of treatments to minimize risks and impacts. Road surfacing and drainage structures can be designed to minimize sediment delivery into streams and maximize infiltration rates (Table 9). Structures such as bridges, culverts and debris catchment devices can be upgraded, resized or relocated to handle increased flows and minimize the potential for blow-outs and/or avoid overloading unstable terrain with water. Commonly called 'deactivation', ditch lines, cross ditching and culvert armouring can also be improved to handle increased flows, while minimizing erosion and their potential to transport sediments into streams (Table 9). In cases where they are no longer needed, roads can also be rehabilitated, which involves the complete recontouring of the slope to its pre-road condition. This can be an effective means of reducing risks to slope stability, or other environmental values, and increasing groundwater recharge.

[122] Forest Practices Board 2020

[123] Daigle 2010

[124] Hope et al. 2015

Various roads, such as those associated with the Ministry of Transportation, the oil and gas sector, private property (including railway and telecommunications access roads), First Nations and municipalities, may also be connected to the resource road network and can be subjected to increased risks from wildfire (e.g., increased flows and debris flows). Road infrastructure failures of any kind can trigger mass wasting events that threaten salmon and watershed values, other infrastructure, property and human life. Based on their interconnectedness, the complex sets of values they service, and on common risks, coordinated access management can bring all parties together to maintain the value of the road infrastructure, while addressing the impacts and elevated risks that often follow wildfires.

5.3.4 PROVINCIAL FIRE SUPPRESSION REHABILITATION

Following fire control or suppression activities, the BC government, through the BC Wildfire Service, has a responsibility to rehabilitate land damaged by wildfire control activities.[125] One component of rehabilitation focuses on addressing damages resulting from on-the-ground fire control and suppression actions. This type of damage includes machine and hand-built fireguards, fire access roads and trails, breached barriers, stream crossings, staging areas and sumps. Rehabilitation is typically preceded by a fire hazard assessment and a site rehabilitation plan. Under the Wildfire Regulation, site rehabilitation planning must focus on 1) minimizing the fuel hazard created by fire control operations, and 2) maintaining natural drainage patterns to minimize surface soil erosion. Drainage patterns are to be maintained by stabilizing and re-vegetating soils disturbed by heavy equipment, stabilizing stream channels and beds at stream crossings, and stabilizing sump and dam locations that were created as part of fire control. Although the development of a rehabilitation plan is initiated as soon as possible, the regulation allows for the immediate rehabilitation to address high priority locations. Actions may be taken before the fire is completely out, rehabilitating areas that are no longer burning. In these cases, work can be undertaken while fire crews are still present, finding efficiencies and addressing environmental issues early.

These government rehabilitation works provide direct benefits to broader post-wildfire recovery, but they apply only to fire suppression-related damages and focus on fuel hazard, water drainage and soil erosion. Damage caused by wildfire, as opposed to damage caused by fire suppression actions, are not addressed by these rehabilitation programs. The remaining impacts and risks are the responsibility of other land managers, depending on the land ownership status (e.g., provincial parks, municipal watersheds, Indian Reserve lands). As such, from the perspective of the salmon habitat recovery team, the strategic coordination of rehabilitation planning with the applicable land managers, rights holders, landowners and stakeholders is advisable. This helps make sure all parties are well informed of the works being undertaken and restoration works are coordinated.

Fireguards are the most common fire suppression activity that require rehabilitation. A fireguard is a strategically planned barrier that is intended to stop or slow the spread of a wildfire. Heavy equipment, and

[125] Province of British Columbia not dated; Gov. BC 2023

sometimes hand crews, remove vegetation and organic matter until only non-combustible soil remains. Linear fireguards are an effective fire suppression tool; however, they can:

- disrupt or reroute natural drainage patterns by pushing soil, vegetation and debris into streams, draws or other drainage features;
- destabilize soils through the removal of vegetation and exposure of mineral soil that is susceptible to erosion;
- create future fire hazards by pushing large quantities of timber and vegetation aside and into berms, decks, or piles;
- damage/modify infrastructure, such as fences, roads and trails, to provide access and egress to the wildfire;
- increase the risk of invasive species establishment because of soil exposure; and,
- increase the risk of erosion or sediment delivery to water bodies due to vegetation loss and the exposure of soils.

Wildfire suppression rehabilitation, or 'rehab' minimizes the impacts and risks associated with fire suppression activities. Practitioners are responsible for developing and implementing wildfire suppression rehabilitation plans that address the following six objectives:

1. restoring natural drainage patterns;
2. stabilizing soils;
3. minimizing surface erosion;
4. minimizing fire hazards;
5. promoting revegetation while preventing invasive species from inhabiting affected areas; and,
6. repairing damaged infrastructure.

The BC government or its partners can use many different treatments to rehabilitate damages caused by fire suppression activities including:

- removing introduced materials from stream crossings, restore stream profiles as required, stabilize stream banks, and promote revegetation of the riparian area;
- pulling back or recontouring sites with displaced or exposed soils that are no longer stable;
- constructing water management structures or treating soils in a manner that reduces potential for erosion;
- salvaging or disposing of timber and vegetation that has been felled, knocked down, or pushed aside and may pose a fire hazard;
- preparing the soils and seeding, where required, to promote natural vegetation to establish on exposed soils, while reducing the risk of invasive species establishment; and,
- repairing infrastructure, such as fences, damaged by heavy equipment.

In pursuit of its rehabilitation objectives, the BC government collaborates with First Nation communities, especially when it comes to planning and implementing rehabilitation works on Crown land. Additionally, the 'BC Wildfire Risk – Claims Program' is the primary point of contact for fire suppression damages that have occurred on private land. As required, rehabilitation practitioners will coordinate operations with the BC Wildfire Risk – Claims team for rehabilitation activities. Various community groups may also be involved in reviewing plans or providing input if the proposed treatments impact member rights or interests.

More information on the BC Wildfire Management Branch's Rehabilitation Program and its Standard Operating Guidelines can be found online, respectively, at:

1) *Wildfire Suppression Rehabilitation*; and,

2) *BC Wildfire Management Branch Rehabilitation Standard Operating Guidelines*.

The BC Wildfire Service also has an informative website that addresses wildfire suppression rehabilitation, post wildfire natural hazard risk analysis and ecological wildfire recovery. It identifies funding and resources for wildfire prevention and recovery.

5.3.5 SILVICULTURE AND HYDROLOGIC RECOVERY PLANNING

Wildfires seal soils and remove the forest vegetation and this has profound implications for stream flows, sediment delivery and geomorphic risk. The replacement of forest and understory cover and the attainment of 'hydrologic recovery' is the answer; however, this is a complicated and long-term proposition. Even if successfully established, young forests can not be expected to hydrologically recover until they are 50 or more years of age[126].

In BC, forest managers are guided by the concept of equivalent clearcut area (ECA), which is defined as "*an indicator that quantifies the percentage of the forested portion of a watershed that has been altered by harvesting, fires, insects or disease and has not recovered to a state of hydrologically effective green up."*[127] When harvesting forests within any given watershed, forest managers often strive to keep the ECA below 20 to 30%, depending on the risks and values that are present. When one considers that large wildfires commonly increase ECAs within watersheds to well over 50%, the challenge comes into focus.

The pursuit of post-wildfire hydrologic recovery can involve the protection of the remaining green stands (coniferous and deciduous) from harvest, insects and additional wildfires. It also involves the timely reestablishment of forest cover. Depending on the size of the fire, this could be incorporated into a strategic silviculture plan that identifies areas suited to natural regeneration and those that should be restocked, along with objectives for planting timelines and site-appropriate tree species, stock types, stocking densities and

[126] Winkler and Boon 2017; Crampe et al. 2021

[127] BC Timber Sales 2022

treatments (e.g. spacing, thinning). This planning will have to take the objectives for other values into consideration, such as timber productions and wildlife habitat.

Responsibilities for restocking actions can involve many actors, depending on legal obligations, programs and funding sources. Forest companies will be responsible for restocking stands they have harvested. The British Columbia Forest Service will be responsible for restocking areas, such as fire trails, that they have disturbed. Others (e.g., First Nation entities, agencies, companies or non-government organizations) may have access to funding and/or trees to replant in other areas. A well designed Silvicultural/Hydrological Recovery Strategy can weave disparate entities, obligations and funding sources together in pursuit of a variety of objectives, including hydrologic recovery.

Silvicultural planning for hydrologic recovery should also consider landscape or watershed level positioning and downstream values. Forest regrowth and hydrologic recovery is generally most effective in the watershed's mid to higher elevations, which receive higher amounts of precipitation, hold more snow for longer periods, and play an important role in maintaining stream flows in drought. Hydrologists often refer to this as the 'H60', which is the elevational marker/contour above which 60% of the catchment lies.[128] Even within the mid to high elevation areas, recovery efforts can prioritize the geomorphic areas and habitat types that naturally hold or slow down water, such as headwater catchment basins or low gradient wetland habitats. Downstream values add a further critical consideration. Obviously, it will be wise to prioritise the catchments that contain or serve those streams with the high salmon habitat values.

Recent research has shown that heavily stocked, young forests can reduce summer basal stream flows.[129] While they may begin to provide benefits by intercepting heavy precipitation and providing shade, the high densities and rapid growth rates of young stands can intercept too much precipitation and draw excessive water from the soil and then release it, via evapotranspiration, into the atmosphere.

A well-designed hydrologic recovery plan would pursue a variety of site-appropriate stocking prescriptions, across the land base that would maintain desired subsurface flows, while de-synchronizing snow melts over similar slope/aspect/elevation polygons. Further, stocking plans, even at the stand level, could mimic or embrace a diversity of natural regeneration patterns to promote infiltration and the de-synchronization of snow melts while pursuing other objectives, such as biodiversity and resilience to future fires. This could involve a mixture of site appropriate stocking densities and the acceptance of less flammable deciduous trees, such as aspen, that could increase fire resiliency at the stand levels and, if sufficiently dominant, provide fire-break networks at the landscape level.[130] Thus, post-wildfire treatments can be integrated into preventative actions against future wildfires. For additional information on the topic of wildfire resiliency, the reader is directed to the Forest Practices Board's Special Report SR/61, *Forest and Fire Management in BC: Toward Landscape Resilience*.[131]

[128] Gluns 2000

[129] Jones et al. 2022; Segura et al. 2020; Gronsdahl et al. 2019

[130] Hély et al. 2000

[131] Forest Practices Board 2023

Silviculture activities and strategies will also have to consider climate change and what tree species and stock types will survive to maturity in a hotter and drier climate and be more resilient to insects and fire over the coming decades. The northward expansion of the hotter, drier biogeoclimatic zone, such as the Ponderosa Pine and Interior Douglas Fir, in response to climate change within BC has long been predicted. Silviculturists must now take this into consideration when developing stocking plans. Increasingly, attempts to recreate 'what was' may not be possible.

Wildfire risk has already increased calls for a return to historic and Indigenous approaches to ecosystem management and wildfire risk reduction through periodic low intensity burning practices. In BC, these practices often led to mature, low density stands of Douglas-fir and ponderosa pine. Such practices present an opportunity to pursue stand structure and densities that balance evapotranspiration with the need for shade and cooling.

Beyond hydrologic recovery, reforestation can address many other objectives for the watershed. Tree root networks can add stability to unstable or destabilized terrain. They also play fundamental roles in maintaining stream bank stability and flood plain processes, which are especially important where increased flood frequencies and magnitudes are anticipated. As such, riparian planting with fast growing deciduous trees can be an effective and relatively low-cost treatment option that can begin to produce results in the short to mid-term.

The use of shrubs and understory vegetarian to address sediment transport and begin successional pathways has not yet received much attention in BC. However, as growing conditions become more challenging, a reliance on natural and early to mid-seral plants over longer time periods to hold soils and provide shade (and other benefits) is likely to become more common.

5.3.6 WATER INFILTRATION, RETENTION AND MANAGEMENT

Climate change is bringing drier and warmer conditions to BC's southern interior, which is reducing the amount of precipitation received in the form of snowfall and the amount of time that it is stored. This is especially impactful where salmon depend on watersheds that have had 'snow dominated hydrographs', meaning the annual flows are largely influenced by gradual snowmelts that charge the groundwater and maintain stream flows in periods when precipitation alone will not maintain flows. Recent trends in drought conditions across the province have demonstrated that drier summers can deprive even coastal watersheds of the precipitation needed to maintain flows.

Not surprising, salmon productivity within watersheds is often a function of stream flows (which can be strongly correlated to dangerous spikes in water temperature and higher rates of predation). These climate change related phenomena are exacerbated by large wildfires and pre-existing cumulative effects. In the interior of BC, the removal of forest cover can expose the snowpack to the warming rays of the sun earlier in the year, advance the onset of snowmelt and increase the probability of drought conditions in the summer and fall months. In many watersheds, drought will be experienced more often, the frequency of low flows and/or high stream temperatures is likely to increase and, for freshwater salmon life stages, this will limit productivity (i.e., smolt production or average size) or increase die-offs of juveniles and/or adults.

The many droughts that have occurred across BC in the last decade suggest that the time to consider water retention and storage for the sake of salmon is now upon us. Many treatment options designed to help hold back water and regulate flows are not complicated or expensive. 'Stage 0' treatments[132] and beaver dam analogues[133] are specifically designed to hold back and slow the movement of water above *and* below ground. Beavers, if allowed to recolonize, can be expected to create natural structures with the same results. Side channel creation, often used to enhance rearing habitats, can also serve to slow down water and enhance groundwater recharge.

Reservoirs can also have an important role to play for salmon. Impoundments have historically held water back for irrigation, domestic, industrial and environmental purposes. It is probable that our reliance on impoundment structures (i.e., dams and weirs) will increase. In these circumstances, the flow needs for salmon will be an important consideration.

Beyond the apparent 'above ground' water storage, the various treatments and impoundment structures have the potential to encourage infiltration, recharge groundwater and allow for the slower release of water to sustain higher basal flows over low flow periods[134]. This hidden and slow-release storage capacity is often referred to as the watershed's 'sponginess' and this phenomenon is attracting increased attention. In low gradient systems, water storage projects can be conjoined to produce wetland corridors that mete out water more gradually and foster vegetation communities that are less flammable (and thus provide natural firebreaks). Such low gradient habitats with slow moving water can serve as sediment sinks, improve water quality and mitigate risks to salmon at all freshwater life stages.

Water storage and release can also be influenced by road networks within a watershed. Roads often accelerate the delivery of water from slopes to streams by cutting into slopes and diverting groundwater into surface flows. In addition, through their ditching and drainage structures (e.g., culverts), road networks can hasten the flow of surface waters and reduce opportunities for infiltration. Increasingly, road rehabilitation, which involves road removal through recontouring and the return of the slope to its natural state, is being undertaken to restore subsurface flows and thereby assist hydrologic recovery.

Scarification techniques are usually associated with silvicultural practices and the creation of 'plantable spots'; however, infiltration can also be a positive outcome. While consideration must be given to sediment disturbance and transport, in low gradient sites, these risks can be managed and the infiltration of water into the soils can be enhanced. While the trade-offs can be difficult to manage and plan for, this silvicultural practice is one that may be useful in the short term.

[132] Cluer and Thorne 2014

[133] Pollock et al. 2014

[134] Arauz et al. 2022

While water retention and groundwater recharge are just coming to the foreground for salmon conservation in BC, these measures have long been employed to manage or enhance other resource values, including hydroelectric generation, domestic, agricultural and industrial water supplies and waterfowl habitats. While the hydrologic recovery of a forest may take decades, water retention treatments and strategies can quickly follow on the heals of a wildfire. For example, beaver dam analogues and Stage 0 treatments can be low risk and cost-effective approaches that can produce results relatively quickly after the fire. Moreover, by combining many, or all, of the treatments discussed in this section, practitioners can develop basin-wide water infiltration and retention strategies.

With a growing human population and an increasing water demand, competition for water in many parts of BC is already a reality. Domestic, agricultural, and industrial demands often compete with one another, and governments are called upon to balance human use with environmental flow requirements. In the short-term, this tension can place hardships on many salmon populations. In the longer term, many BC communities will have to adapt to a reduction in water supply and manage it effectively. It is hoped that the current reality can move society beyond 'zero sum' competition and toward partnerships that pursue water supply enhancements and couple them with effective water use planning and allocation processes.

5.4 STOCK ENHANCEMENT CONSIDERATIONS

The Salmonid Enhancement Program from DFO describes several stock enhancement methods that can be used, in short or long terms, to bring population numbers up to a level where the population can recover and be self-sustaining[135]. These methods are intended to increase stock production and can involve targeted habitat modifications, or they can involve very direct stock related interventions. They do not involve the introduction of external genetic genotypes. Rather, they use the remaining fish from an at-risk population to re-build the stock over time. An overview of methods is provided in Table 12.

Table 12. Habitat enhancement methods for salmon populations.

Enhancement Method	Description
Fishways	Fishways provide a pathway around barriers to fish passage. They can help up-migrating adults reach spawning grounds and the passage of down migrating juveniles.
Temperature Control	Temperature control, using natural sources of cold water, can mitigate the effects of elevated water temperatures that can occur after major wildfires. For example, this method could involve the diversion of deep water from an upstream lake (i.e., hypolimnetic waters during summer stratification) to a salmon stream.
Flow Control	This method involves flow regulation to mitigate flood events and low-flow events, as can occur after a major wildfire. The method employs the construction of an upstream weir (with a fishway installed) that can be used to hold back flood waters and then to slowly release these waters (to avoid the sudden occurrence of extreme flows). Water that is held behind the weir can be strategically discharged during low-flow events to maintain minimum flows for salmon.

[135] SEP 1977

Enhancement Method	Description
Spawning Channels	These are engineered/created off-channel habitats that provide clean and ideally textured gravels for spawning salmon. Young return to the natural natal stream network after emergence from the artificial spawning beds. Dissolved oxygen concentrations and flows are maintained at optimal levels in the spawning channels. Mechanical methods are used to clean spawning gravels between spawning runs as needed.
Rearing Channels	These are constructed as deep channels for rearing that protect young from predation and permit the addition of feeding supplements as needed.
Incubation Boxes	These are instream layered boxes that create ideal conditions for embryo development. The incubation boxes are similar to those used in hatcheries, but fertilization is done only from adults from the impacted population (i.e., genotypes from external populations are not introduced).
Transplants	Young produced in conservation aquaculture facilities can be transplanted back to affected streams to re-establish at-risk populations.

Source: Table contents from SEP 1977.

Note: Some of the methods in Table 12 can have negative consequences relating to other resident fishes and/or sediment and nutrient pathways. As always, when salmon enhancement methods are being considered, precautions must be taken to avoid negative and unintended consequences.

While adapted fish populations can often recover from wildfires over time, wildfire disturbance (e.g., severe flood events alternating with low-flow events; shifts in water quality including temperature, sediment pulses and deposition; and degradation of physical habitat) can cause a significant decline in fish numbers and, in extreme circumstances, population extirpations[136]. When the number of individuals in a population declines below a critical threshold, the likelihood the population will recover without intervention can be low due to reduced gene flow, genetic drift between neighbouring populations, reduced genetic diversity, reduced fitness caused by inbreeding[137] and reduced encounters between breeding pairs. Populations already having a low number of individuals, especially those that are spatially confined, would be at particularly high risk for extirpation after major watershed disturbances, including those resulting from large and intense wildfires. In such situations, stock enhancement measures can sometimes be considered as a temporary means to 'buy the population enough time' to recover.

Yet, the use of traditional hatchery production to enhance at-risk or genetically distinct salmon populations after watershed disturbances is problematic, from a conservation perspective, because traditional methods can[138]:

1. introduce disease to wild populations;
2. compete with wild populations resulting in lower survival and growth rates in wild populations;
3. select for traits associated with domestication; and,
4. change the genetic profiles (both genotype and phenotype) of wild populations.

[136] Bozek and Young 1994; Brown et al. 2001; Bixby et al. 2015; Rust et al. 2019

[137] Anders 1998 and references therein

[138] Anders 1998 and references therein

In recent decades, 'conservation aquaculture' has emerged to maintain or increase the size of at-risk fish populations while addressing the aforementioned issues. It focuses on breeding programs that conserve the genetic profiles of at-risk populations within facilities that control for disease transmission and natural feeding behaviours[139]. Enhancement techniques that employ the methods of conservation aquaculture use the remaining individuals from an at-risk population to aid in the recovery of the population following population-limiting disturbances and/or long-term limiting factors. Nevertheless, risks can remain and the use of hatcheries, even as a temporary and 'last resort', remains highly controversial. Beyond the tangible risks, some argue that hatcheries are a temptation that can lead authorities away from effective habitat stewardship. Others counter that conservation hatcheries should be viewed as appropriate, time bound, 'stop gaps' that can be dismantled after habitat conditions improve or other limiting factors are addressed.

5.5 SUMMARY OF TREATMENTS AND STRATEGIES

This section has provided a listing of treatments, strategies and implementation advice that can be considered by recovery teams as they grapple with many values (elements at risk), impacts and risks within highly variable operational environments. Treatments were organized into immediate, process-based and form-based categories as a means to place them, and their utility, in the context of watershed processes and real-world challenges. Beyond treatments, 'strategies' were described, which coordinate a variety of different treatments to address common values and elements at risk within the watershed. These strategies are by no means exhaustive, and as we move forward, new treatment groupings and approaches will undoubtedly arise.

The 'art' of watershed recovery involves pairing treatments and strategies to the relevant impacts and risks (as discussed in Section 4) that will, or may, affect the known watershed values and elements at risk at appropriate scales and in a manner that produces the desired benefits. Decision makers will have to contend with many practical considerations including: 1) cost-effectiveness, 2) expected benefits over time, 3) potential risks/impacts that the treatments pose to the watershed and other resources, 4) logistics (e.g., access), and 5) community values. This decision-making process is covered more thoroughly in Section 6.

[139] Anders 1998

6 POST-WILDFIRE RECOVERY PLANNING

Watershed and salmon habitat recovery can be effective when the identified element(s) at risk have been matched with the appropriated treatments and strategies that are: 1) likely to produce the desired results, and 2) can be sustained, operationally and financially, at the scales required. Planning cycle activities described in Section 6 are identified in Figure 16. Guidance on how to characterize the impacts and risks created by wildfire is provided in Section 6.1. Details on decision-making support tools that can be used to select and prioritize the various treatments and strategies are then provided in Section 6.2. While the specific treatment options and recovery strategies will vary for different watersheds and projects, an approach for creating a planning framework is presented in Section 6.3.

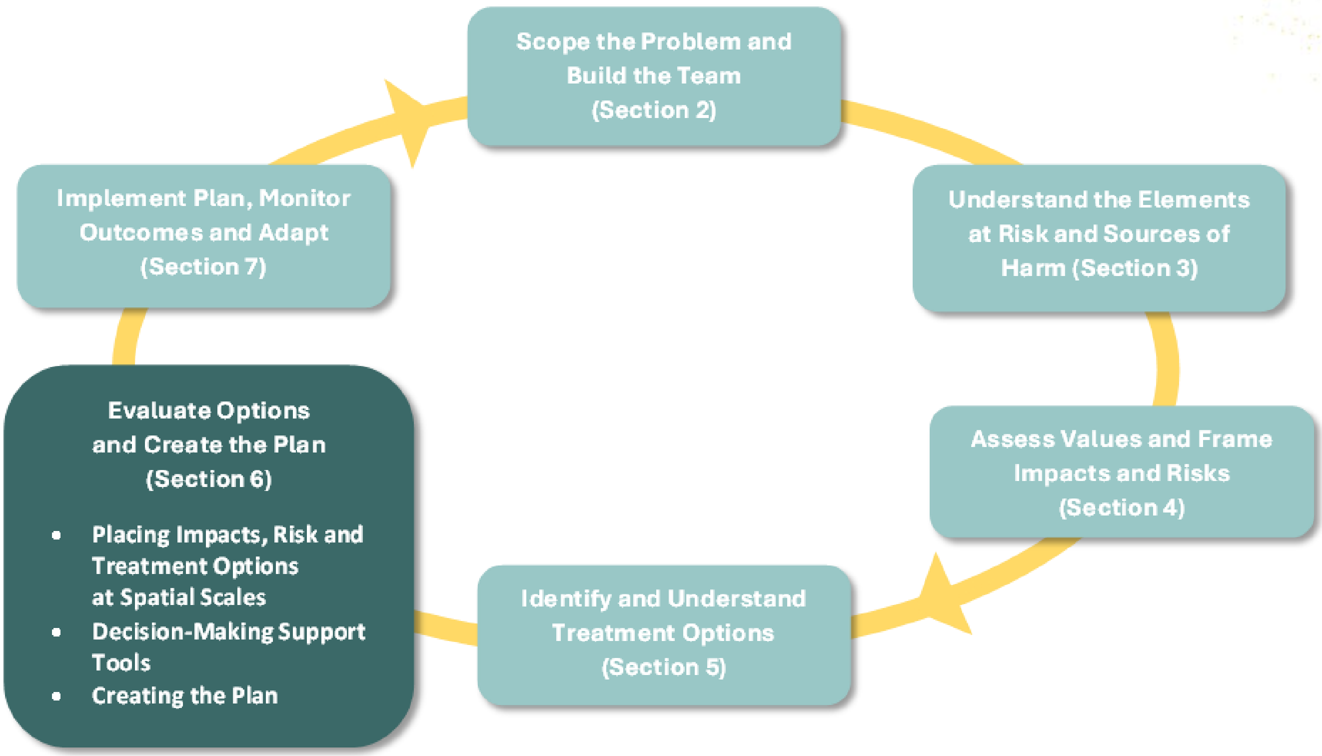


Figure 16. Highlight of Planning Cycle activities addressed in Section 6.

6.1 PLACING IMPACTS, RISKS AND TREATMENT OPTIONS IN SPATIAL CONTEXT

To the extent possible, the watershed information that is gathered and/or generated at the assessment stage (Section 4) should be organized and presented in a manner that identifies and quantifies the spatial relationships between watershed values, elements at risk and the ongoing sources of harm/hazards that have been created by wildfire and other cumulative impacts. In so doing, what 'may happen' can be revealed and a creative, science-based, goal-setting process and action plan can begin to take shape. The synthesis of various sources of information should place the various elements at risk (e.g., coho salmon rearing habitat) in the spatial context of the sources of harm. For example, if forest cover losses could increase flows and negatively impact channel-forming processes, then the spatial relationships between these two factors must be understood. Which basin and sub-basin channels will experience impacts; where and how? At a more localized level, where might sediments be generated, how will they be mobilized and what consequences do they pose to salmon habitats and where? Beyond space, risk assessments can also help to project the time frames and circumstances over which risks can persist and provide insights as to the appropriateness of various treatments over time.

A spatially explicit understanding of watershed processes, wildfire impacts, values and risks is critical in post-wildfire decision making and plan implementation (Section 7). Ideally, the impacts of a given wildfire on a watershed and salmon habitats are best understood by intersecting spatial baseline and post-wildfire data and information (Section 4). This allows for a comparison of pre- and post-wildfire sources of harm/hazards, an identification of the elements at risk and a quantification of consequences and resultant risks. It will be especially important to determine where high value/critical habitats are, or were, located in a watershed (e.g., Chinook spawning habitat), as this may lead to the prioritization of specific restoration works to minimize post-wildfire consequences in these habitats.

In practice, baseline information can be scarce and/or spotty in its availability. This should not deter recovery teams from considering what 'was' and/or 'might be'. In the absence of complete and direct information, various sources of information can be compiled to represent the watershed's status prior to the wildfire. Information on the presence and absence of various fish species, combined with physiographic (e.g., stream depths and widths, gradients, barriers, soils, terrain stability), climate and vegetation information, can be used to reconstruct and infer habitat locations and qualities. Similar and less impacted nearby steams and watersheds can *sometimes* serve as references to help increase confidence in estimates and inferences at various spatial scales. This exercise can also benefit from local knowledge, Indigenous Knowledge, and/or practitioner judgement.

The documentation of applicable information sources, assumptions and estimates is recommended to inform and ground the development of goals and objectives and form a baseline for the subsequent monitoring activities.

6.2 DECISION-MAKING SUPPORT TOOLS

6.2.1 GEOGRAPHIC INFORMATION SYSTEM MAPPING

Geographic information systems are useful because they allow a variety of relevant and interacting geospatial information, commonly referred to as 'layers', to be presented and analyzed together to depict cause and effect relationships. GIS uses spatial datasets, points or layers, to present geographic information for a particular location or 'polygon'. The polygons can be limited by the accuracy of the information that went into their creation; however, they can generally be used at a variety of spatial scales from site level to watershed scales. These layers can come from pre-existing information sources (e.g., the location of spawning habitat) or they can be developed based on assessments undertaken after the wildfire. Accordingly, GIS are useful in depicting the locations and spatial relationships of values and hazards and estimating and depicting the associated risks at various spatial scales. Maps can then be generated to illustrate such things as fish habitat types, quality and locations, the extent and severity of the burn, physical characteristics of the landscape (e.g., aspect, slope, elevation) and hydrology, and where risks are located. Strategies and decision making can then be built upon the understanding and insights this information conveys.

The availability of GIS data layers for stream-level and reach-level applications can be limited. Very often spatial datasets need to be created if existing datasets do not exist, are not at an appropriate scale or have incomplete coverage. Given this, watersheds are often used as the 'assessment unit' for planning post-wildfire responses and parameterizing GIS-based tools.[140] Watershed and channel features and land cover can be digitized from satellite imagery, aerial photos or drone imagery depending on the scale of the assessment unit. Site-specific data (e.g., stream habitat and soils) and information on recent fire suppression related impacts will often need to be collected in the field, post-wildfire, to provide accurate and up-to-date information.

Useful information may exist in non-spatial formats such as reports, interviews, oral histories, Indigenous Knowledge and local knowledge. Non-spatial data can be converted to a spatial data format and linked to a spatial dataset. Alternatively, non-spatial data can be used to inform risk categories, hazard weightings and likelihoods, and consequences (see Section 6.2.2 for an example).

A particularly useful information source that can be collected in pre- or post-wildfire environments is LiDAR (i.e., laser imaging, detection and ranging). It determines the distance (range) between the sensor and an object or a surface and can be used to generate very detailed topographic data that can be useful when characterizing waterbodies, vegetation and terrain. Watershed and hillslope gradients can be determined using LiDAR, which can also be used to identify barriers, such as waterfalls, or monitor geomorphic changes/outcomes, such as hillslope failures and debris flows.

[140] see Carver and Utzig 2000; Lewis et al. 2016

6.2.2 USING GIS INFORMATION TO ESTIMATE RISK

6.2.2.1 Overview

Assessment procedures (discussed in Section 4) often rely on GIS-based tools to estimate risk at strategic or watershed scales and help decision making in response to watershed disturbances. Three assessment procedures are listed in Box 5. These tools can be readily adapted to help with decision making in response to major wildfires in BC.

Box 5
How to Develop a GIS-based Risk Assessment Tool for Watersheds

A GIS-Based Hydrologic Decision-Support Tool for Strategic Planning in the Arrow Forest District Final Report – Revised by Carver and Utzig (2002)

A GIS Indicator-Based Watershed Assessment Procedure for Assessing Cumulative Watershed Effects by Lewis et al. (2016)

Overview Assessment of Potential Hydrologic Response to the Elephant Hill Wildfire (K20637, 2017) in the Bonaparte, Deadman River, and Battle Creek Watersheds by Winkler and Lewis (2020)

Risk estimation involves an understanding of how various factors interact with one another and influence watershed and habitat-forming processes. Each source of harm or hazard can have multiple factors or determinants that influence its likelihood of occurrence and magnitude (e.g., Figure 17). For example, factors that influence hillslope erosion can include precipitation, slope gradient, slope distance, soil texture, soil and vegetation burn severity and land use. Multi-factor (determinant) datasets are effective when assessing risk, because weightings can be applied to account for the influence of each factor on the hazard.[141] Data should also be given confidence or uncertainty scores based on data quality.[142] Temporal scales and seasonality should be incorporated into risk assessments and decision-making tools to account for stochastic weather events and process-related hazards that can cause consequences to vary with time or time periods.

[141] Carver and Utzig 2000

[142] Lewis et al. 2016; Pearsall et al. 2020

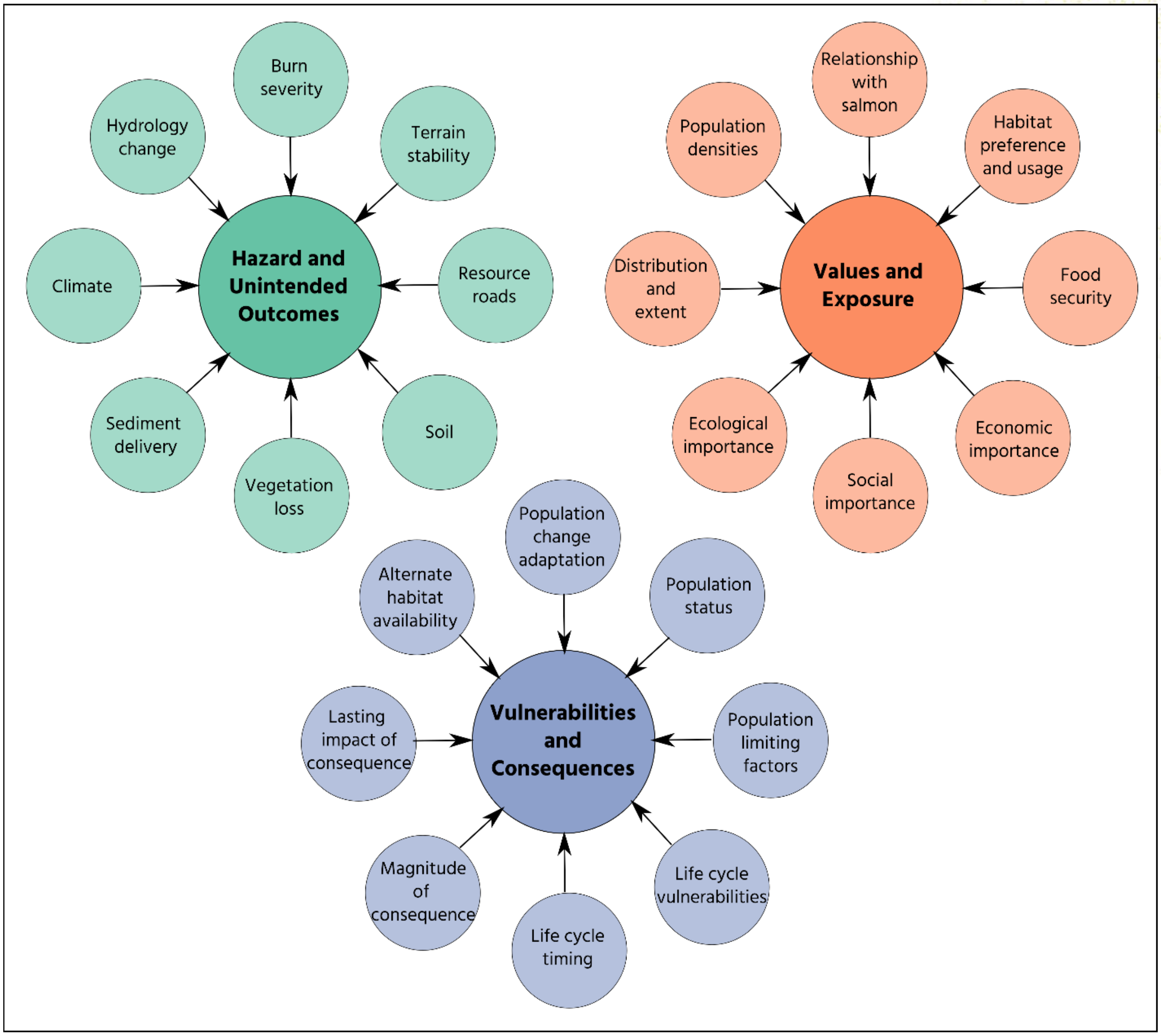


Figure 17. An example of information that could go into an assessment of landslide-imposed risks to salmon habitat.

Note: The consequences of a landslide could include barriers to fish passage, sedimentation of spawning habitats, simplification of channel morphology and a loss of rearing and/or overwintering habitat.

The general steps for developing a GIS-based risk assessment tool are shown in Figure 18.

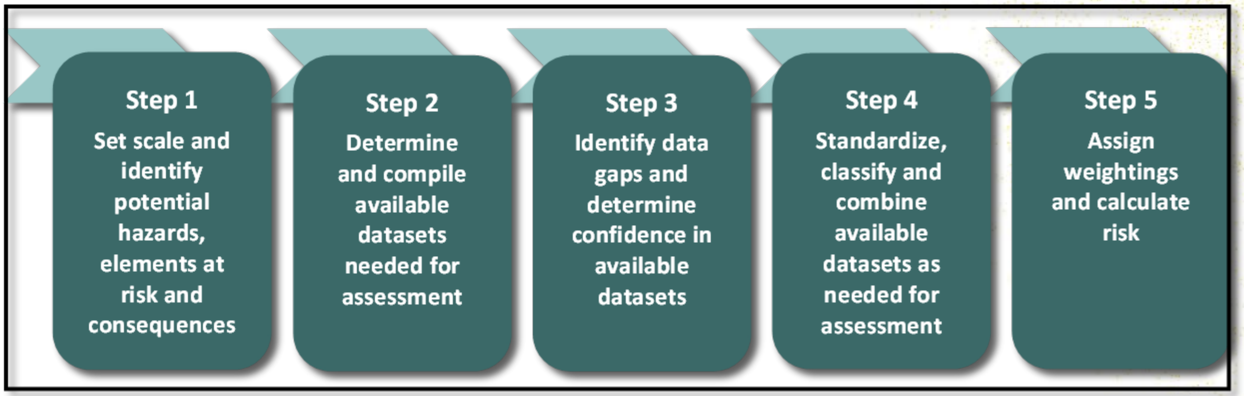


Figure 18. General steps for using GIS information to estimate risk.

Steps 1 though 3 have been covered in Section 4 of this Playbook. Step 4 involves standardizing, classifying and combining available datasets as needed for assessment. This step may be the most important and challenging as it involves selecting and assembling the datasets and sub-assessment outputs that describe values/elements at risk and the sources of harm, vulnerabilities, hazards and possible consequences that are used to calculate and describe risk. Because GIS tools combine and coordinate various and disparate sources of information, it is important to standardize the various data inputs and make sure they relate to the same element at risk and sources of harm and use measurements in a consistent manner. For example, the magnitude of a consequence for an element at risk can be expressed in absolute terms or as a proportion of what exists. The consequence figures can relate to a particular reach, or they can relate to a subbasin or watershed. The classification of datasets is also important. Empirical information and expert knowledge are both used to explicitly define and bin the information into categories (e.g., high, medium, low).

Step 5 is another important and challenging step that informs the expression and comparison of various risks and factors that relate to risk. This step also relies on empirical information and expert knowledge to weigh the relative influence of various factors and potential consequences that go into the tables. For example, low flows may have a far greater impact on an element at risk (e.g., availability of steelhead trout rearing habitat) than channel complexity. Similarly, static factors, such as terrain stability, may well relate to slope failure risk. However, the interacting variable that drives a probability-based risk assessment is likely to be stochastic weather events. As such, the interplay and organization of these variables within the risk assessment is important.

Risk assessments are usually underpinned with specific and numeric information (i.e., measurements); however, these values are usually converted to qualitative scale (e.g., high, moderate, or low) for ease of comparison and communication. Conversions from quantitative measurements to qualitative scales should be informed by consideration of the meaning of each of the terms. For example, sedimentation affecting spawning gravels could result in no mortality, some mortality or complete mortality of eggs, resulting in three consequence bins. Caution should be exercised against simply normalizing quantitative values (i.e., assessment scores) into bins, as it can be difficult to compare values between watersheds or treatment areas. Figure 19 illustrates examples of different five and three class bins used to convert quantitative and qualitative data into three and five class rating bins. The numbers on the left margin in Figure 19, correspond to different steps in the risk assessment process and will be referred to throughout the remainder of this section.

1 **Hazard Rating**

Step						
1A	Hazard Likelihood (Annual Exceedence Probability)	**Very Low** Less than 0.3%	**Low** 0.3 to 1%	**Moderate** 1 to 3%	**High** 3 to 10%	**Very High** More than 10%
1B	Hazard Magnitude (Peak Discharge)	**Very Low** Less than 5 m³/s	**Low** 5 to 25 m³/s	**Moderate** 25 to 100 m³/s	**High** 100 to 500 m³/s	**Very High** More than 500 m³/s

2 **Consequence Rating**

Step						
2A	Likelihood of Hazard Reaching Element at Risk	**Low** Does not reach	**Moderate** Indirect impact	**High** Direct impact		
2B	Likelihood of Element at Risk Being Present at Time of Hazard	**Low** Not present	**Moderate** Temporary presence	**High** Permanent presence		
2C	Estimate of Vulnerability of Element at Risk	**Very Low** Element is not vulnerable	**Low** 10 to 30% loss in productivity	**Moderate** 30 to 50% loss in productivity	**High** 50 to 75% loss in productivity	**Very High** 75 to 100% loss in productivity

Figure 19. Examples of hazard and consequence rating classes.

Note: Step numbers corresponding to the risk assessment example from Figure 20, Figure 21 Figure 22 are shown here as examples.

As will be described in examples to follow, converting the available data to a hazard rating score (e.g., 1A and 1B in Figure 19) and a consequence rating score (e.g., 2A, 2B, and 2C) typically occurs through matrices. Risk ranking matrices are a commonly used qualitative approach to combine the hazard ratings and consequence ratings into a final risk score (e.g., Figure 20).

2 **Consequence Rating**

1 Hazard Rating	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
Very Low	Very Low	Very Low	Low	Moderate	Moderate
Low	Very Low	Low	Low	Moderate	High
Moderate	Low	Low	Moderate	High	High
High	Low	Moderate	Moderate	High	Very High
Very High	Moderate	Moderate	High	Very High	Very High

Figure 20. Example of a risk estimation matrix for five class hazard and consequence ratings.

6.2.2.2 Examples

Two examples of converting hazard and consequence data into ratings and a risk estimation are described in this subsection: one for a single hazard (Figure 21) and one for a varying hazard scenario (Figure 22).

Figure 21 illustrates an example of risk estimation in a single watershed with a single source of harm/hazard, which can then be adapted to multiple elements at risk with differing vulnerabilities. This example is an analogue for when the limiting factors can differ, depending on conditions, between the sedimentation of spawning habitat and the quality of rearing habitat. Because this is a single hazard scenario (post-wildfire landslide) with a common hazard likelihood (occurring within five years of the fire) and magnitude (peak discharge approximately 50 m^3/s), the two aspects can be combined into a five-by-five hazard rating matrix (upper right of Figure 21). Assuming the hazard rating examples shown in Figure 19, this results in a consistent 'High' hazard rating for all spawning habitats (i.e., elements at risk). For the consequence estimation, one simplifying assumption has been made—if the hazard or cascading hazard does not reach a particular element at risk (e.g. fish population B), that element at risk is not carried forward in the risk estimation. The risk estimates in this example are sensitive to the vulnerabilities of each element at risk, given the hazard scenario.

Figure 22 illustrates a second example of a risk estimation for a large watershed. In this example, funding is available to improve rearing habitat resiliency against future flood damages. Based on the understanding of limiting factors—that most damage to rearing habitats occurs during high flow events (e.g., blowouts, bank erosion)—a hazard scenario is selected that would result in this undesired outcome: sustained atmospheric river within 50 years following the fire results in significant flooding and sediment transport. This example is an analogue for a risk prioritization across a large watershed area, where multiple hazards at various scales can result in risks. The 'assessment unit' is defined to be stream reaches of approximately equal size. The watersheds contributing to these stream reaches generate differing hazard magnitudes, based on differing flows in response to the storm, but the hazard likelihood remains the same (approximately 1-in-50, or 2% annual exceedance probability).

For the consequence estimation, some complexities are introduced in this second example. Rather than asking if the hazard could reach the element at risk (defined as square metres of rearing habitat) and if the element at risk is vulnerable at the time of the hazard, the number of square metres of rearing habitat in each assessment unit/reach is estimated. This provides a better approximation of the magnitude of the total consequence. To estimate vulnerability of each element at risk from the flushing flows, information about the hazard magnitude is used to answer this question. For example, a peak discharge of 50 m^3/s may generate only floods and little geomorphic change in one stream reach, but in another stream reach, this same magnitude could result in catastrophic bank erosion and vertical channel erosion. In this example, peak discharge increases along the stream channel (flowing from right to left), with significant peak discharge spikes downstream of burned tributary watersheds. Further, the terrain and bank characteristic of the reaches differs and influences habitat availability. The increasing peak discharge magnitude also results in differing vulnerabilities as more habitat is expected to be disturbed with increasing flows.

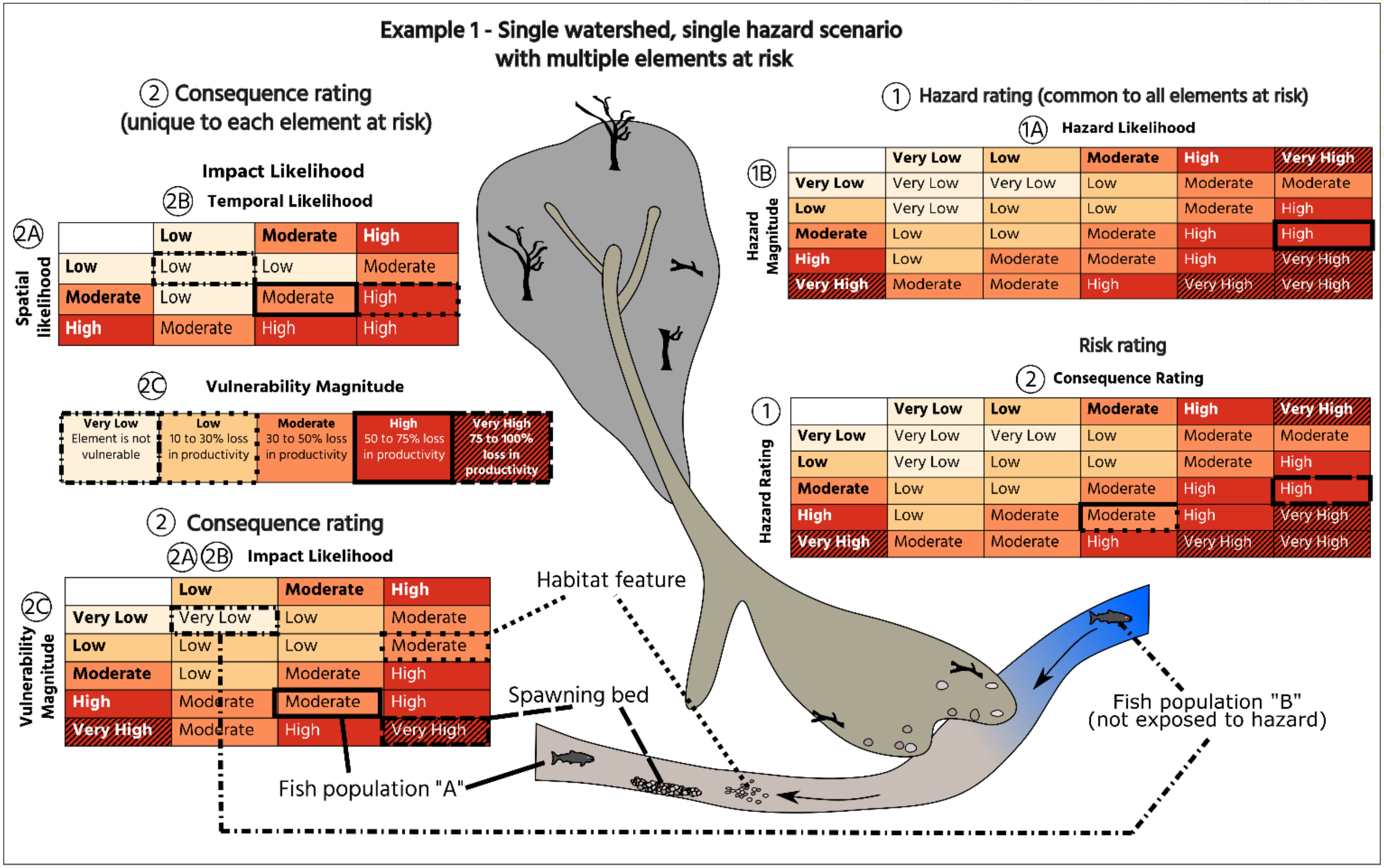
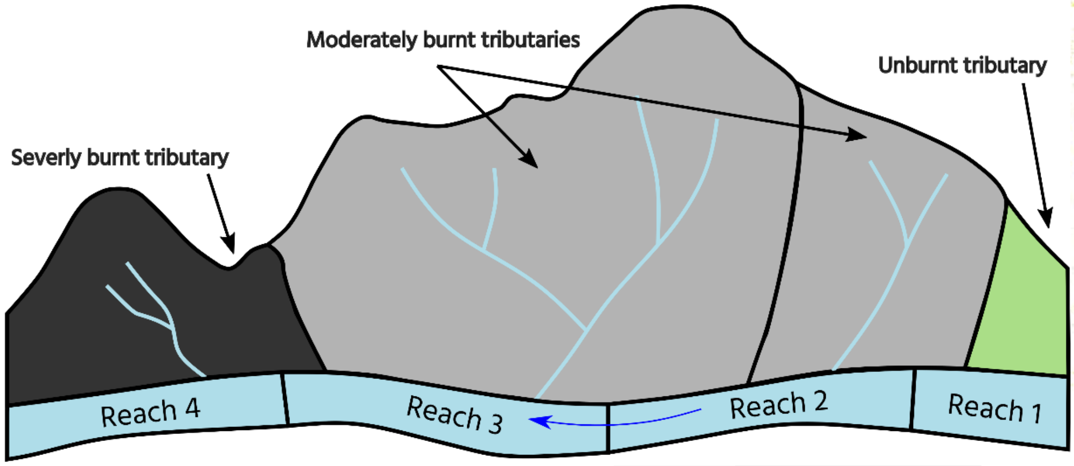


Figure 21. Example 1 – Single watershed, single hazard scenario with multiple elements at risk.

1A Hazard Likelihood (Annual Exceedence Probability)

Very Low	Low	Moderate	High	Very High
Less than 0.3%	0.3 to 1%	1 to 3%	3 to 10%	More than 10%



1B Hazard Magnitude (Peak Discharge)

Very Low	Low	Moderate	High	Very High
Less than 5 m³/s	5 to 25 m³/s	25 to 100 m³/s	100 to 500 m³/s	More than 500 m³/s
		Reach 1 and 2	Reach 3	Reach 4

1 Hazard rating (unique to each stream reach)

1A Hazard Likelihood

1B Hazard Magnitude	Very Low	Low	Moderate	High	Very High
Very Low	Very Low	Very Low	Low	Moderate	Moderate
Low	Very Low	Low	Low	Moderate	High
Moderate	Low	Low	Moderate 1,2	High	High
High	Low	Moderate	Moderate 3	High	Very High
Very High	Moderate	Moderate	High 4	Very High	Very High

2A 2B Estimate of Consequence (square metres of habitat per reach

Low	Moderate	High
Less than 100	100 to 1000	More than 1000
Reach 2 and 3	Reach 1 and 4	

2C Estimate of Vulnerability of Element at Risk

Very Low	Low	Moderate	High	Very High
Element is not vulnerable	10 to 30% loss in productivity	30 to 50% loss in productivity	50 to 75% loss in productivity	75 to 100% loss in productivity
	Reach 1	Reach 2	Reach 3	Reach 4

2 Consequence rating (unique to each rearing habitat)

2A 2B Consequence Estimation

2C Vulnerability Magnitude	Low	Moderate	High
Very Low	Very Low	Low	Moderate
Low	Low	Low	Moderate
Moderate	Low 2	Moderate 1	High
High	Moderate 3	Moderate	High
Very High	Moderate	High 4	Very High

Risk rating (unique to each reach/rearing habitat)

2 Consequence Rating

1 Hazard Rating	Very Low	Low	Moderate	High	Very High
Very Low	Very Low	Very Low	Low	Moderate	Moderate
Low	Very Low	Low	Low	Moderate	High
Moderate	Low	Low 2	Moderate 1	High	High
High	Low	Moderate	Moderate 3	High 4	Very High
Very High	Moderate	Moderate	High	Very High	Very High

Figure 22. Example 2 – Multiple assessment units, single hazard scenario with common elements at risk.

Risk factors, elements at risk and risk assessments should be verified and refined through field ground truthing[143] before on-the-ground treatments are developed and prescribed. This is why the watershed assessments described in Section 4.2.4 often include Tier 1 (GIS) and Tier 2 (Field) assessments. Field verification often adds new information and precision, which can improve risk maps and tools and then modify weightings and scores.

6.2.2.3 Spatial Representation of Risk and Decision Support

As previously discussed, a GIS allows spatial datasets (or 'layers' as described in Section 6.2.1) of the distribution, type and vulnerability of elements at risk to be depicted spatially. Maps showing variations in risk ratings can then be created through the combination of spatial datasets that represent: 1) the elements at risk (i.e., values of concern that are at risk), 2) the presence and likelihood of various scenarios and sources of harm/hazard, and 3) the consequence, or impact, should the hazard occur. To accomplish this, several layers of information are overlain, and this produces a variety of intersecting polygons that explicitly generate products of hazard likelihood x consequences to create a risk map that shows spatial variability in ratings (e.g., from very low risk to very high risk; Figure 23).

This spatial representation of risk is valuable in determining where and how hazards and impacts may be mitigated through various treatments. The predictive capabilities of this information will depend on the accuracy and precision of the information layers and the robustness of the understanding of cause-and-effect relationships. Very often, spatial data are used to identify risk categories polygons that flag where site visits should occur to increase precision and knowledge and inform recovery planning. This approach allows planning teams to focus on the most consequential of hazards and it 'narrows down' the amount of field work required. Companies now specialize in developing standardized GIS-based approaches to use various sources of information to understand risks and inform treatment selection.

The risk management framework, discussed in Section 4 and in this section, has focused on biophysical information that would go into the assessment of salmon population-related elements at risk, hazards and consequences. A similar approach could be used to assess wildfire risk on salmon-related socioeconomic elements at risk, including indices of food security and human health, traditional and ceremonial practices, family and community gatherings, recreational opportunities, careers and employment, and economic diversity and stability.

[143] Lewis et al. 2016

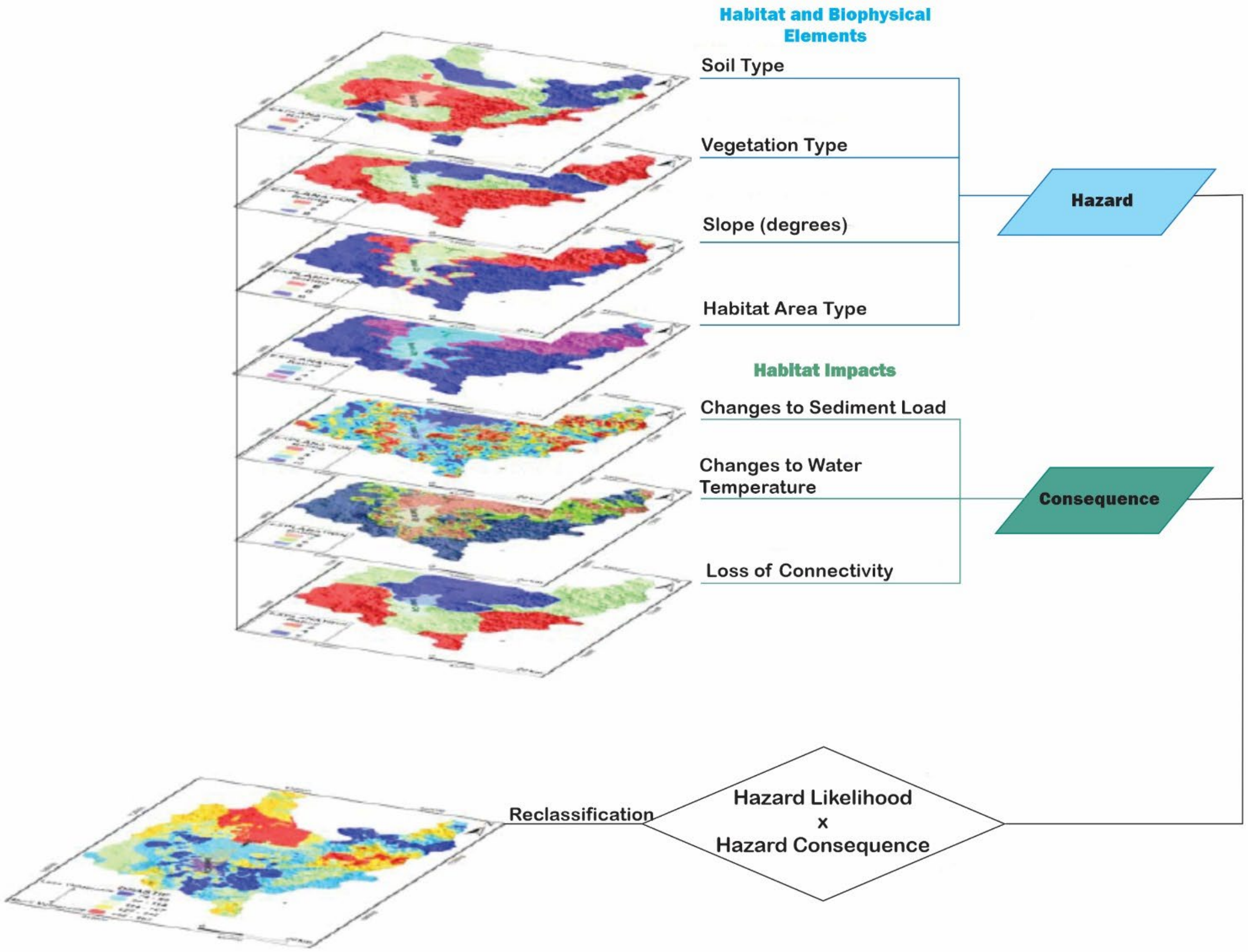


Figure 23. Conceptualization of combining spatial data (GIS) on hazards and consequences to visualize wildfire risk on a single 2-dimensional wildfire "risk map".

Note: figure adapted from Alwathaf and Mansouri (2011).

The consistency and portability of GIS data sets has created opportunities for professionals to move towards well documented, reproducible, open-source programming workflows using scripting languages. This allows for a consistent approach by which GIS information packages are used and combined to provide useful information and decision support to planning teams and decision makers. It also allows for cost savings through the leveraging of each other's work. However, this programming would still need to be innovated, improved and tailored to suit specific watersheds. For example, a scripting program could automatically call up information on geohazard risks that could be overlaid with additional geological and hydrological information and fish habitat information to identify risk factors such as sediment deposits in particular sections of a given stream associated with specific elements at risk. While the use of some scripts could become standardized to promote collaboration and efficiency, this would not come at the expense of innovation and analyses that are unique to individual watersheds.

Instead of each professional doing their own analysis on custom datasets with many ad-hoc workflows, professionals could move towards open-source programming workflows using scripting languages like 'R' or 'Python'. A BC example of a tool for reproducible workflows is bcdata[144], which is a package that allows the user to access data from the BC Data Catalogue. This package can be used to build a mirror of government data that is used in projects. Because the loading of data to a Postgres database is done automatically and the names of the data schemas and tables are equivalent to those served out by the province, GIS analysis is portable and analysis can be rerun with fresh data over time. This facilitates collaboration and reproducibility on a level that is not achievable without much more effort and skill than is required when not using a tool such as this. Other key tools include fwapg[145] and bcfishpass[146], among others.

In addition to these open-source tools, commercial interests are offering data platforms and decision support tools that readily accommodate new or different data sets and can be tailored to suit unique data sets and challenges associated with individual watersheds. An example of this is Terrainworks, which is a company that has pre-organized data sets and decision support tools on a platform known as NetMap. As required, Terrainworks can add data sets and then provide more detailed and customizable inquiries and decision support. For smaller organizations, reliance on other organizations with professionals specializing in GIS analysis and decision support may be more cost effective.

Consistent and well documented approaches to the identification of risks and restoration methods will provide opportunities for collaboration and the advancement of knowledge. With approaches/scripts/programs, and their assumptions, being documented, the restoration community would be in a position to compare these and make improvements.

The GIS environment is well suited to the incorporation of 'Artificial Intelligence' and 'Machine Learning'. "*Put in context, artificial intelligence refers to the general ability of computers to emulate human thought and perform tasks in real-world environments, while machine learning refers to the technologies and algorithms that enable systems to identify patterns, make decisions, and improve themselves through experience and data.*"[147] Society will continue grapple with bigger questions regarding the use of such technologies; however, the burgeoning fields of data capture (e.g., LiDAR, Environmental DNA Sampling), GIS and AI are likely to become increasingly fused as technology advances and, increasingly, this may prove to be an asset to the pursuit of watershed recovery.

6.2.3 DECISION-MAKING MATRIX

Once assessment results and recovery options and strategies have been reviewed, decisions on the prioritization of management actions, project and activity sequencing, and implementation must then be made. To guide this process, a decision-making matrix can be used to summarize the relevant sources of

[144] Norris 2024a

[145] Norris 2024b

[146] Norris 2024c

[147] Columbia Engineering 2024

information (including costs of options) and help establish priorities, in light of cost considerations. Table 13 provides *an example* of such a decision-making matrix. The examples in Table 13 incorporate the numerical risk-based values (i.e., likelihood and consequence) as inputs to the decision-making matrix. Those could be the only values used by the decision makers, or they could be combined with other rating metrics, such as cost. The additional elements in the decision matrix may be used to produce a priority ranking system (e.g., low, medium, high). This semi-quantitative approach offers decision makers a combination of defined physical criteria with the flexibility of policy elements, such as budgetary constraints. In turn, this allows the tool to assist with prioritizing competing recovery treatments, strategies or operational plans.

Budgets often constrain what can be accomplished and, as such, it is usually necessary to choose between or develop priorities for recovery treatments and strategies. In these cases, choices can be informed by cost/benefit analyses and, for some options, it may be determined that the costs and risks are too great compared to the potential benefits. The following are some general concepts related to comparing costs, adapted from *Watershed Restoration Planning and Priority Setting – An Emphasis on Fish Habitat*[148]:

- Comparing costs allows for a systematic ranking of various recovery options.
- As seen with past forest practices, a complete and balanced mix of options are often needed to effectively rehabilitate an area. As a result, it may be most effective to allocate a certain amount of funds to the recovery of the entire area, based on consideration of the total cost of the recovery options required for that area.
- Costs associated with implementing options to reduce, not necessarily eliminate, the risk of a certain hazard can also be considered.
- Costs need to be included for follow-up monitoring, particularly when restoration techniques are based on adaptive management.

Table 13 provides generic examples of how the numerical risk calculations could be combined with the qualitative categories, such as a budget constraint. Table 13 includes legends for the risk and priority matrices, to illustrate how the rankings combine to support the final outcome in the decision-making tool, where the costs have been rated by the decision-making body specific to their management objectives or available resources.

Decision matrices are one method to organize information and to structure a consistent and defensible decision-making process. Another support process is referred to as structured decision-making. This process offers decision-making matrices/models that can explicitly incorporate values (e.g., preferences) in addition to risks and costs into the table.[149]

[148] WRP 2004

[149] Gregory et al. 2012

Table 13. Example of a Decision-making Matrix for use in recovery planning.

Legend for the decision-making table

Risk Rating Matrix				
Hazard Likelihood Rating	**High**	Moderate	High	High
	Moderate	Low	Moderate	High
	Low	Low	Low	Moderate
		Low	**Moderate**	**High**
	Consequence Rating			

Priority for Implementation Matrix				
Risk Rating	**High**	High	High	Moderate
	Moderate	High	Moderate	Moderate
	Low	Moderate	Moderate	Low
		Low	**Moderate**	**High**
	Cost			

Note: 1 The definitions for the Priority Matrix should be reviewed and adjusted by each watershed recovery team to their specific situation.
2 The matrix could be expanded to also consider the treatment effectiveness.

Location	Post-wildfire Hazard	Hazard Likelihood Rating	Consequence Rating	Risk Rating[1]	Recovery Option[2]	Cost[3] ($)	Priority for Implementation[4]
Watershed X	Soil sealing	High	High	High	Scarification	10,000 (Moderate)	High
	Losses of landscape vegetation	High	Low	Moderate	Seeding	5,000 (Low)	High
Watershed Y	Pollutant losses from burned contaminated sites	Low	High	Moderate	Containment Remediation	5,000 (Low)	High
	Significantly reduced forest cover	High	Low	Moderate	Upland Reforestation	50,000 (Moderate)	Moderate
	Infrastructure (e.g., road grade or culvert erosion) collapse	Low	Moderate	Low	Re-construction Road grade and culverts Erosion control mats Straw wattles	>100,000 (High)	Low

Note: Example table developed from the concept of Table 5 in WRP 2004.
1 The Risk Ratings are a function of the Hazard Likelihood Rating and the Consequence Rating as explained in the Legend: Risk Rating Matrix.
2 See Section 5 for a discussion on various treatment options.
3 Values are hypothetical and for demonstration purposes only.
4 The Priority for Implementation ratings are a function of the Risk Rating and the Cost Rating as explained in the Legend: Priority for Implementation Matrix.

6.3 CREATING THE PLAN

Planning processes and resultant plans for post-wildfire watershed recovery will be highly varied and could range between site-level project plans and land-use plans with supporting legal objectives or regulations. These plans could be multi-layered and connected (e.g., a project plan within a sub-basin plan), complimentary (e.g., one plan may address watershed and habitat processes, while another may address water supply) or singular.

The preparation of the restoration plan will draw together and roll up the information (e.g., risk assessments), and decisions generated through the various planning stages. Despite the anticipated variability in planning processes and plans, common content could include the following:

1. **Rationale or Purpose Statement** that briefly describes the goals of the plan, why the plan is required (i.e., the relevance of the plan) and how results will be achieved.
2. **Description of the Planning Process** that describes teams, committees, sub-committees, authorities, decision-making processes, plan approval process and meeting frequencies (which may be captured in a terms of reference, project charter or project plan).
3. **Description of the Plan's Scope** that describes:
    a. the values/risk elements (e.g., coho habitat), components (e.g., spawning habitat, rearing habitat) and limiting factors (e.g., flows, gravels, channel structure) that the plan will address;
    b. the area/scale the plan will address (e.g., watershed, sub-basin, reach and site);
    c. known timelines for project completion or the plan's longevity and relevance;
    d. the nature or type of plan (e.g., site-level project plan, land or water use plan with legal direction, influence model, priority setting advice); and,
    e. relationships with: i) other relevant resource values (e.g., water, archaeology), ii) influences and accountabilities (e.g., other programs and affiliated or non-affiliated plans), obligations (e.g., statutes, orders, treaties, agreements), and iii) all associated authorities and rights.
4. **Outline of the Foundational Information** used to guide decisions and the plan's development, which could include:
    a. the baseline information, assessment information and Indigenous Knowledge that was used to quantify and qualify impacts and/or risks to the resource values of concern;
    b. a Risk Management Framework (identifying elements at risk, sources of harm/hazards and consequences);
    c. an understanding and identification of the limiting factors that relate to the values of concern (e.g., risk assessment methodology for salmon);
    d. understanding of treatment options and how they were matched to impacts and risks (e.g., their cost effectiveness/return on investment); and,
    e. decision models (e.g., decision-making matrix, structured decision-making) and processes that were used.

5. **Plan Guidance,** which could include direction on:
    a. overarching goals or targets for recovery;
    b. priorities for recovery (what should be done for what values/risk elements and where):
    c. strategies and treatments to be used for recovery (e.g., specific strategies or treatments that address specific risks or impacts);
    d. objectives for recovery strategy and treatment implementation;
    e. monitoring activities and measures for success relating to goals, targets, strategies or objectives:
        i. compliance monitoring (i.e., operational conformity to the plan from site to watershed levels);
        ii. effectiveness monitoring and routine effectiveness monitoring (i.e., the effectiveness of treatments, strategies or management regimes in producing the desired results):
            - to address watershed, habitat, fish population and behaviour responses to treatments, strategies or management regimes;
        iii. Long term ecological monitoring/assessment:
            - to monitor changes in watershed values and levels of risk.
6. **Direction on the Plan's Implementation,** which could include:
    a. specific description of roles, responsibilities and processes including:
        i. authorities (referrals and approvals);
        ii. accountabilities (how are other values looked after);
        iii. responsibilities (who does what);
        iv. meeting structures, participants, and frequencies;
    b. guidance on implementing the plan, which could address:
        i. schedule of activities or works with budgets;
        ii. direction on the coordination and interaction of various activities, referral processes, and permit requirements;
        iii. monitoring activities (including measurements), techniques, periodicity and reporting;
        iv. communications and reporting (internal and external); and,
        v. the process for adapting or renewing the plan;
            - comparing monitoring results against established objectives; and,
            - identifying the process for adapting or renewing the plan, including any known timelines or triggers for plan renewal. This could include adaptations to the plan itself and to associated risk management frameworks, implementation plans and monitoring plans.

6.4 SUMMARY OF POST-WILDFIRE RECOVERY PLANNING

Post-wildfire recovery plans must recognize the watershed values and potential elements at risk and set goals and objectives for their protection or recovery. Coordination with the management of other resource values must be done in a manner that recognizes the rights, authorities and interests of others and pre-existing legal obligations, policy, agreements and plans.

Beyond human-centered challenges, the planning process should take advantage of decision supports that place impacts, risks, values and elements at risk within a spatial context to support decision making and, ultimately, develop a plan or series of plans with spatially explicit objectives. This section has built upon the guidance provided in all previous sections and sets the stage to the implementation and monitoring processes that should follow (see Section 7).

To the greatest extent possible, plans must clearly articulate a vision and a plan for implementation. This vision may be expressed in many forms, but a road map for the continuance of the planning cycle and a willingness to continually monitor outcomes and adapt (as required) are key. Above all, the planning process should be flexible and prepared to absorb change. While recovering from one wildfire may be the immediate task at hand, between the fire and a true recovery, other disturbances will likely occur. Thus, most plans should have the ability to adjust to, or tackle, new impacts, challenges and processes.

7 IMPLEMENT AND MONITOR

This section provides information on the implementation of watershed recovery plans and operational planning relating to permitting and referral processes, and monitoring (Figure 24).

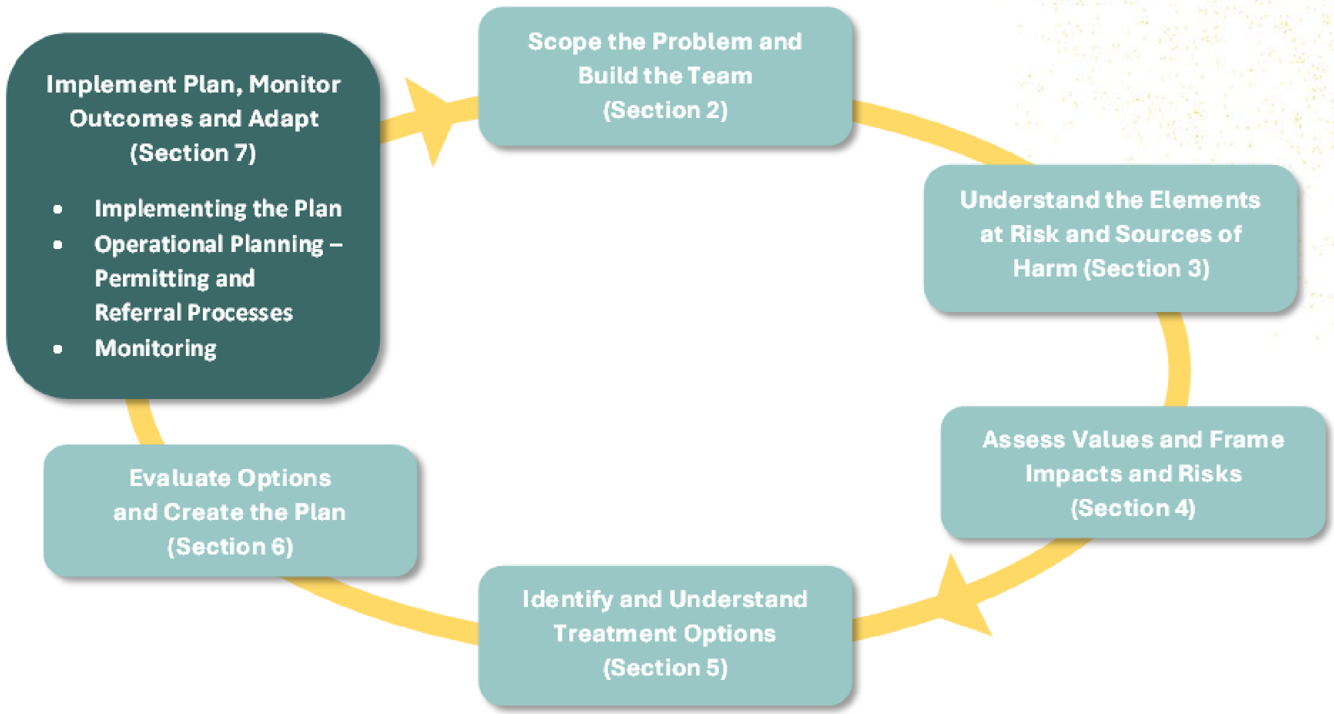


Figure 24. Highlight of Planning Cycle activities addressed in Section 7.

7.1 IMPLEMENTING THE PLAN

Efforts to accelerate the recovery of salmon habitats in wildfire damaged watersheds will often require collaboration and integrated approaches over long time periods. As indicated in Section 6, watershed restoration plans, and even project plans, should provide instructions and lay out a process for plan implementation. These instructions will vary depending on the scope and complexity of the plan. However, all plans have one thing in common—ultimately, their success depends on effective implementation and an adaptive process. The roles and responsibilities of all participants should be clearly articulated and placed in the context of important planning phases and activities such as operations/execution, resourcing, reporting, meetings and communications, monitoring and adaptations.

The responsibilities associated with the implementation of a project plan may be straightforward and involve the actions of a proponent, after feedback and approvals have been received from agency and First Nations referral processes. Alternatively, the delivery of an ongoing watershed level plan may involve authorities, accountabilities and responsibilities that are linked to: 1) government agencies and First Nations, 2) standing programs, 3) internal and external planning committees, and 4) other partnerships.

More complex plans are often well served by effective communication, outreach and reporting, which keep planning participants, external participants, partners and the public informed of the plan's intentions, progress, status and outcomes. This will promote additional input, cooperation and resource alignments and help to avoid unintended consequences.

Most watershed and salmon habitat recovery activities will occur within operationalized landscapes in which various entities will be pursuing their own objectives. Forest companies may be harvesting/salvaging timber, ranching interests may be re-establishing fence lines and grazing cattle, government agencies may be addressing infrastructure and First Nations may be assessing impacts and risks to heritage values and developing watershed recovery strategies. If such activities are not coordinated and aligned, they have the potential to negatively impact other values or interfere with other activities. Conversely, if they are coordinated, there may well be opportunities to cooperate in the pursuit of common goals (e.g., reforestation-hydrologic recovery). Some activities may be coordinated directly through a planning process, or they may be more loosely coordinated through agency approval processes and/or First Nations referral processes. As such, in the implementation phase, all entities should observe the established protocols for communications, referrals and approvals, and seek out opportunities to improve communications, collaboration and integrate management actions.

Watershed recovery will usually be a long process that unfolds over decades. As such, plan implementation and monitoring activities may span careers and involve many different players over time. As well, resources and participation in the process may dwindle over time—especially when one considers the extended timelines that could be involved in plan implementation and monitoring. The plan should account for this by clearly expressing timelines, goals and objectives and confirming the authorities and resources required to implement the plan over lengthy time periods. Communications and funding strategies can be a key component to maintaining plan longevity and effectiveness.

7.2 OPERATIONAL PLANNING – PERMITTING AND REFERRAL PROCESSES

Initiatives relating to watershed and salmon habitat restoration can involve many layers of activities that require support from First Nations via referral processes and statutory approvals from various government agencies. These processes must be understood, well managed and completed (e.g., permit issued, approvals from rights holding First Nations in place) before on-the-ground activities can commence. In some cases, the restoration proponent will be required to prepare an operational plan that has the consent of the rights holding First Nation(s) and is approved by a statutory decision maker. In other cases, the proponent may also be required to apply for, and receive, a particular permit. Depending on the nature of the work, several plans and/or permit approvals may be required.

Operational plans and permit applications must recognize all pre-existing and relevant direction. This will include the direction provided by statutes, and any attendant guidelines, but it may also include legal objectives established through a planning process and/or via an 'order' under a statute (e.g., Government Actions Regulation), or an agreement with a First Nations (e.g., Treaty). It will also be necessary to consider direction that may not have a legal underpinning, but is generated or supported by various authorities. This could include the advice received from agencies and First Nations and direction found within non-legal plans.

Salmon habitat restoration initiatives will often require a permit for what the *Water Sustainability Act*, and the Water Sustainability Regulation, term a 'change(s) in and about a stream'. These are directly relevant to habitat-related, post-wildfire restoration works, because a change in and about a stream is associated with work or activities that:

- *"occur within the stream channel, meaning bed of the stream and its banks, both above and below the natural boundary;*
- *regardless of location, are likely to modify the stream or stream channel over time; or*
- *occur at, or are planned under, the bed of the stream and are likely to influence the bed of the stream over time"*[150].

The first two documents listed in Box 6, recently published in 2022, provide comprehensive step-by-step guidance on how to apply for in-stream works, including habitat restoration works, under the *Water Sustainability Act* and Water Sustainability Regulation.

Box 6

Documents Providing Guidance for *Water Sustainability Act* Approvals for Instream Fish Habitat Restoration

A User's Guide for Changes In and About a Stream in British Columbia: Understanding Your Obligations under the Water Sustainability Act and Water Sustainability Regulation (Version 2022.01) by Government of BC (2022a)

Requirements and Best Management Practices for Making Changes In and About a Stream in British Columbia: Understanding Your Obligations Under the Water Sustainability Act and Water Sustainability Regulation (Version 2022.01) by Government of BC (2022b)

Forest Investment Account (FIA) Activity Standards Document by BC MoE (2006)

Fish-Stream Crossing Guidebook (Revised Edition) by BC MoFLNRO, BC MoE and DFO (2012)

Permitting and operational planning processes can also depend on the location of the activity and the pre-existing tenures and licences that may be in place. For example, if an activity is proposed on private land, then permitting may be required under a certain statute (e.g., the *Water Sustainability Act*). Alternatively, if the same activity is proposed by a forest tenure holder, then a permit or approval may be granted under a different statute (e.g., the *Forest and Range Practices Act*). Table 14 describes various relevant permits and operation plans and the circumstances around which they are authorized.

Protocols for the sequencing of activities in post-wildfire environments are often in place prior to the wildfire. For example, for millennia First Nations communities and individuals travelled widely over the land base in

[150] Government of BC 2022a

pursuit of food and other resources and appropriate settlements and camp locations. Areas that provided ready access corridors and food (e.g., waterbodies and valley bottoms) are often considered to be likely sites of past habitation. Accordingly, proposed restoration activities that have the potential to disturb artifacts and areas of occupation will usually require archaeological overview assessments and/ or archaeological impact assessments. These assessment requirements and procedures are described on the BC Government's Archeology Branch website. These assessments will normally precede activities that have high rates of disturbance; such assessments can take time and extend a project's timelines and costs (depending on the nature of the activity).

In other circumstances, activities must be sequenced in a manner that most effectively supports the many objectives and activities that must follow. For example, while the rehabilitation of a particular section of road may ultimately be the best option to manage mass wasting risks, in the short term the road may be needed to provide access and maintain cost effective opportunities to reforest, fence, salvage harvest or access habitat restoration sites. If this is the case, temporary treatments to address mass wasting and roadway sediments, while maintaining access, may be in order. Once again, the recognition of management authorities and the activities of others is required if salmon values are to be effectively integrated into post-wildfire plans and operations. Investments in understanding the various requirements and communicating with others will help to avoid frustrations, while helping to build teams and partnerships.

The realities of permit application and referral processes, which are designed to protect other values, rights, and interests, must be recognized and regarded. These processes take time and usually require the proponent to commit resources and acquire professional expertise. Accordingly, associated steps and resources should figure into the relevant project management plans.

Note: Table 14 provides several examples of permits/authorizations that are commonly required to conduct recovery tasks following wildfires. This is not an exhaustive list of examples, so proponents and practitioners must thoroughly understand what permits are required and obtain these permits/authorizations before commencing work.

Table 14. Permits and operational plans required for various restoration activities.

The Name of the Permit and the Statute	Approving Agency	Activities Authorized, Circumstances and Relationships to Other Permits or Planning Requirements
Special Use Permit – *Forest and Range Practices Act* (FRPA)	Ministry of Forests	The proponent requires a Special Use Permit to temporarily occupy public land and a FRPA 52(1)(b) authorization to plant and/or cut incidental trees. Project site plans/prescriptions including silviculture treatments, wildlife enhancement and restoration activities are typically included in the permit application, along with requests for any other required authorizations.
Road Use Permit and Road Use Agreement – FRPA *Forest Act* s117, *Ecological reserve Act, s5.1*	Ministry of Forest and tenure or Road Use Permit holder (e.g., forest licensee)	Required when heavy equipment needs to be transported on or used on Forest Service or Road Permit Roads. Examples of activities that require a Road Use Permit or Road Use Agreement include road construction and maintenance including the installations and removal of culverts in fish bearing waters and site preparation. For forest service roads, a *Forest Act* s117 Road Use Permit is required. For Road Permit roads, a Road Use Agreement is required.
Cutting Incidental Trees (~10 interior or 5 coast) for purpose of silviculture treatment (includes Habitat enhancement) FRPA s. 52 Authorization (FRPA 52(1)(b) & FRPA 52.1)	Ministry of Forests	Authority to cut incidental timber to carry out silviculture, stand tending, forest health, fire hazard abatement or another purpose such as habitat rehabilitation.
Scientific Collection Permit – Angling and Scientific Collection Regulation *Wildlife Act* Section 18	Ministry of Water, Land and Resource Stewardship	A Fish Collection Permit is a document that authorizes an organization or individuals to capture and/or collect fish specimens for scientific and other non-recreational purposes.
Scientific Collection Permit – *Wildlife Act*	Ministry of Water, Land and Resource Stewardship	Amphibian salvage may be required prior to the construction of some recovery projects. A detailed Amphibian Salvage Permit Application will need to be developed to obtain approval.
Change Approval *Water Sustainability Act* - Section 11	Ministry of Water, Land and Resource Stewardship	Change Approvals for changes in and about a stream are granted with terms and conditions. The terms and conditions may relate to the time of year in which you may do the work, and/or other measures that protect the aquatic ecosystem, the hydraulic integrity of the stream channel and the rights of water users and landowners downstream.
Authorized Change *Water Sustainability Act* - Regulations Section 39(1) (a) to (v)	Ministry of Water, Land and Resource Stewardship	Authorized Changes (notifications) are used for specified low risk changes in and about a stream that have minimal impact on the environment or third parties. The work must meet the requirements of the Water Sustainability Regulation and comply with any conditions set out by a habitat officer in response to a notification.

The Name of the Permit and the Statute	Approving Agency	Activities Authorized, Circumstances and Relationships to Other Permits or Planning Requirements
Park Use Permit or Ecological Reserve Permit (section 20 of the *Park Act*)	BC Parks within Ministry of Environment and Climate Change Strategy (BC Parks for activities in Parks and Protected Areas. BC Recreation and Trails for works in Recreation Sites or along Trails under the control of MoECCS)	Land Use Occupancy Permits may be required when restoration works occur within BC Parks and Protected Areas, Recreation site or along Trails under the control of MoECCS. In general, the restoration works will be required to conform to the existing conservation or recreation objectives for such areas or features.
Heritage Conservation Act – Archaeology	Ministry of Forests - Heritage Branch	All archaeological sites in BC are protected under the *Heritage Conservation Act* and may not be altered or changed in any manner without a permit.
Fisheries Act	Fisheries and Oceans Canada	This Act focuses on managing and protecting Canada's fisheries resource. Proponents are responsible for determining whether projects near water will comply with the *Fisheries Act*. There is no requirement to request permission for work that a Qualified Environmental Professional determines will not result in harmful alteration, disruption or destruction of fish habitat (HADD) or death of fish.
HADD Authorization *Fisheries Act* Sections 34.4(1), 35(1) and paragraphs under 34.4(2)(b) and 35(2)(b)	Fisheries and Oceans Canada	Per subsections 34.4(1) and 35(1), works, undertakings or activities other than fishing that result in the death of fish or HADD are prohibited. However, under paragraphs 34.4(2)(b) and 35(2)(b) of the *Fisheries Act*, the Minister of Fisheries and Oceans (the Minister) may issue an authorization with terms and conditions in relation to a proposed work, undertaking or activity that may result in the HADD. Habitat compensation is a requirement of an Authorization.
Emergency Measures - HADD Authorization *Fisheries Act*	Fisheries and Oceans Canada	Under emergency conditions, DFO may allow for the assessment of HADD, death of fish, and design and consultation of offsetting projects to occur after the work is completed. Some works pertinent to wildfire recovery, such as changes to road-stream crossings, would potentially qualify as an emergency work. However, proponents should contact DFO Regulatory staff if they are uncertain as to how to proceed with a project.
Scientific Collection Licence	Fisheries and Oceans Canada	This federal licence is required to fish for scientific, experimental or educational purposes—where Pacific salmon reside.

Appendix D contains an excellent summary document of many internal MoF permit issuance procedures: *Administration Guidelines for Externally Funded 2 Billion Trees Projects on Public Lands in British Columbia Advice for District Staff Administering and Authorizing Externally Funded Natural Resource Canada 2 Billion Trees Reforestation Projects and Associated Activities on Public Land in British Columbia*.

7.3 MONITORING

Monitoring is a critical, yet often overlooked, component of the planning cycle used to continuously assess the status of a watershed or salmon population and make decisions on future actions. In smaller 'project scale' plans, monitoring (or reporting) requirements may be minimal and merely confirm the project was completed to standards. Larger and longer-term planning processes should account for uncertainty, and this often involves a process for adapting the plan in response to monitoring results and other sources of new information.

Monitoring applies to values and risks (Photo credit: Pacific Salmon Foundation)

The four broad types of monitoring relevant to post-wildfire recovery planning are compliance monitoring, trend monitoring, routine effectiveness monitoring and effectiveness monitoring.[151] The design for monitoring, including the parameters measured and the location of monitoring sites, should reflect the post-wildfire impacts, ongoing sources of harm, elements at risk, and risks that were previously identified

[151] Machmer and Steeger 2002; Lindenmayer and Likens 2010; Gov. BC 2024

and assessed (see Sections 4 and 6). Many of the initial assessment procedures should be used consistently over time to document changes in a standardized manner.

Compliance monitoring is used to confirm whether an action or treatment is consistent with the direction provided (e.g., within a prescription, plan, contract or standard). This form of monitoring can play an important role in confirming the quality of watershed recovery treatments and initiatives that have been implemented. It also allows for the standardization and/or description of treatment methodologies, which then allows for effectiveness monitoring. It is simply not possible to understand the effectiveness of a given treatment unless one can accurately describe what was done in the first place.

Trend or ecological monitoring is used to document a watershed's recovery, which helps planning teams to predict recovery timelines. By undertaking consistent measurements periodically and understanding trends, the interrelationships between watershed processes and salmon habitat quality can be understood and predicted. This information can then be used to inform decisions on the scheduling and sequencing of restoration activities. For example, if certain in-channel works require more stabilized flows, then monitoring and predicting hydrologic recovery trends can inform when such work can/should occur. Alternatively, if a desired trend is not manifesting (i.e., a problem is persisting) then this may direct additional inquiries/assessments as to "why". Whenever possible, the trend monitoring of salmon populations should be assessed and interpreted in the context of baseline and newly acquired data. This can help teams to attribute any detected trends to the recovery of freshwater habitats versus other changes to independent variable (e.g., marine survival).

Routine effectiveness monitoring (i.e., policy and plan monitoring) is used to monitor the effectiveness of policies or plans in producing on-the-ground results and is an important part of the resource management planning process. It is an ongoing activity to assess how well the operational activities under the guidance of a plan or management regime are working. While it does not undertake a scientific approach to address cause-and-effect relationships between particular treatments and outcomes, it does monitor watershed or habitat conditions and changes to them that occur under overarching direction.

Effectiveness monitoring is a more rigorous approach to monitoring that addresses the question of how successful a treatment, methodology or strategy is at restoring the ecosystem or its component parts. Very often this involves an experimental design and monitoring timelines that allow for a statistically valid comparison of treatments against controls. This form of monitoring allows for the assessment of restoration outcomes in relation to treatment prescriptions and the associated objectives. For example, effectiveness monitoring could be used to measure the effectiveness of terrestrial sediment capture treatments in mitigating the delivery of sediments into streams. Such information can them be used to consider cost effectiveness and guide decisions on future treatment methodologies. Alternatively, it could be used to modify or adapt the design of the original treatment.

All monitoring activities are an important part of the planning cycle, which allows management direction and actions to be evaluated against desired and stated outcomes. This allows planning teams to understand whether the desired outcomes are being achieved, what is working and what is not. Importantly, it allows the teams to modify/adapt plans and treatment strategies in accordance with the learning that comes from 'doing'. This is often referred to as 'adaptive management', which can be highly scientific and rigorous (e.g., be supported with effectiveness monitoring) or more flexible and retrospective (see Box 7). Adaptive Management has been defined broadly as a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Wildfire science and concerted wildfire recovery initiatives are both relatively new. Thus, it will be important to learn from successes…and mistakes.

Box 7
Adaptive Management

Adaptive Management of Forests in British Columbia by Kremsater (1997)

Assessing the Effectiveness of Fish Habitat Compensation Activities in Canada: Monitoring, Design and Metrics by the Canadian Science Advisory Secretariat (2012)

Effectiveness Monitoring Guidelines for Ecosystem Restoration by Machmer and Steeger (2002)

An informative monitoring plan may be the most vital part of any watershed recovery initiative. The following set of recommendations is intended to provide consideration for the development of a monitoring plan:

- Have a clear and strategic purpose for monitoring by developing a monitoring plan that is consistent with the recovery initiative's objectives. This purpose could be articulated in a project plan, a recovery plan (e.g., goals, objectives) and/or any risk management framework that may have been established. If a risk management framework has been developed, it will be key for the monitoring plan to address the post-wildfire impacts (conditions at Ground 0), elements at risk, the ongoing sources of harm (i.e., hazards), risks that have been identified and assessed (see Section 4) and treatments or operational guidance (see Sections 5 and 6).
- Clearly identify what will be monitored and how and where it will be monitored and measured.
- Be systematic and have a consistent approach. Clearly articulate what kinds of monitoring (e.g., trend, routine effectiveness, and effectiveness monitoring) and what monitoring procedures will be used to monitor what values and interrelationships, and why.
- Depending on the intent of the monitoring, begin monitoring as quickly as possible and make sure the monitoring plan accounts for the timing of important events over the year (e.g., freshet) and has monitoring take place over a period long enough to address the phenomenon in question (e.g., hydrologic recovery).
- Integrate monitoring activities with those that are already ongoing (e.g., Water Survey of Canada).
- Articulate how the various monitoring activities will compliment one another to reveal biophysical interrelationships and management-related cause-and-effect relationships.
- Identify all reporting requirements and how the monitoring plan fits into the general planning cycle—especially the plan adaptation.

- Identify all monitoring and reporting responsibilities.
- Identify equipment and training requirements.

At its core, watershed monitoring will build an understanding of recovery trends and/or cause-and-effect relationships. Very often it will, and should, involve techniques, methodologies and interpretations that are founded in western science. As well, monitoring will need to consider Indigenous Knowledge, worldviews and 'ways of knowing'. For example, within First Nations communities, knowledge keepers have place-based information, handed down over generations. Monitoring activities are an excellent opportunity to begin a longer-term process for collaboration in both land use planning and for knowledge building, which will require communications with various First Nations individuals (e.g., Elders) and entities (e.g., rights holding First Nations, corporations). On an ever-increasing basis, First Nations entities are taking on elevated roles in monitoring programs through a variety of program types, including fisheries management programs and guardian programs. Knowledge transfer, communications and monitoring within partnerships provide opportunities to reconfirm watershed values and consider the tracking of important variables and their interconnectedness through time.

7.4 SUMMARY OF PLAN IMPLEMENTATION AND MONITORING

The planning for post-wildfire recovery should set the foundation for implementation and monitoring. For larger plans, much of the challenge in implementation involves the commitment and support for the implementation phases. An implementation process, as described in Section 6, should be an integral component to of the plan itself. More practically, implementation will require the timely permitting of treatments, and the planning team should invest in understanding all authorization and referral processes and relevant laws, policies, and competing plans/agreements. Continuous adaptive management, particularly for larger plans with longer timelines, that relies on careful management actions and continuous monitoring will help to generate the learning opportunities to improve upon the design of treatments, strategies, monitoring methodologies and their implementation.

8 CONCLUSIONS AND MOVING FORWARD

Over the last two decades, wildfire size and area burned annually have increased to unprecedented levels across much of western North America, including BC. This trend is expected to compound and amplify the many pre-existing conditions, natural and human caused, that impact salmon populations. These impacts will be felt most acutely in drought-prone and/or snowpack-dominated watersheds, which are critical rearing habitats for many salmon populations, including the majority of those that are listed as ‘at risk’ by COSEWIC.

This unfolding reality is altering watershed processes at fundamental levels and impacting many economic, social and cultural values that are tied to Pacific salmon. Beyond salmon, many other valued ecological goods and services, such as biodiversity, water quality and quantity and community safety, are also a function of watershed health. In BC, these assets and processes have long been managed by four levels of government (First Nations, federal, provincial, and local) and further influenced by stakeholders, and non-government organizations. Accordingly, if the stewardship of salmon populations and their watersheds is desired, the many different, yet interlocking, authorities and influences must work effectively and cooperatively in the development and implementation of watershed management plans and habitat recovery projects.

Unique combinations of watershed characteristics, wildfire impacts, salmon populations and habitat values, authorities, rights holders and interests will emerge within post-wildfire settings, and highly varied circumstances will lead to differing recovery processes and solutions. With this diversity in mind, this Playbook provides an overarching watershed recovery framework to support the following phases: 1) scoping the problem and team building, 2) understanding the elements at risk and sources of harm, 3) assessing values and framing impacts and risks, 4) identifying and understanding treatment options, 5) evaluating options and creating the plan, and 6) implementing the plan, monitoring outcomes and adapting.

It is hoped that, in its totality, this work will facilitate the integration of salmon habitat recovery efforts into post-wildfire planning and operational activities, empower all participants and advance the concept of a ‘watershed recovery community’. If ever a call for unity and action for the sake of Pacific salmon and their natal streams was needed, it is now.

Chinook coming home (Photo credit: Pacific Salmon Foundation)

GLOSSARY

The definitions found with this glossary explain the intended meaning of words or terms that have been used by the Playbook.

Word or Term	Definition (as used in the Playbook)
Aboriginal Rights	Rights that are affirmed by Section 35 of the *Canadian Constitution Act* (1982), which states that "*The existing aboriginal and treaty rights of the aboriginal peoples of Canada are hereby recognized and affirmed*". Aboriginal rights, which can apply to title, resources and resource use practices, are inherent, collective rights that Aboriginal peoples have practiced since before European contact.
Aggradation [1]	The raising of a land surface by deposition (vertical accretion) of sediment, as on a beach, dune, mudflat, marsh, coastal plain or delta.
Avulsions	Often accompanied by high flows, aggradation and lateral erosion in low gradient stream stages, avulsions are the formation of new stream channels.
Base or basal flow [1]	Sustained, low or fair-weather flow of a stream, often largely derived from groundwater flow.
Bioengineering [1]	The use of any form of vegetation as an engineering material as, for example, in soil conservation or riverbank erosion control.
Channel [1]	The bed and banks that confine the surface flow of a stream.
Channelization [1]	Straightening or deepening of a natural channel by artificial cut-offs, grading, flow-control measures or diversion of flow into a human-made channel.
Channel centric treatments	Treatments that focus on the stream channel or near channel (e.g., bank, flood plain) restoration. They often employ form-based approaches; however, they can also employ process-based approaches.
Climate change	Changes to the Earth's climates, at local, regional or global scales, which can be attributed to non-anthropogenic and anthropogenic causes, such as the burning of fossil fuels (and other greenhouse gas emissions) and land use practice, which results in a net release of carbon dioxide (CO_2)
Consequence	Estimate of the realized loss for element(s) at risk, considering both their exposure and vulnerability.
Conservation Unit	Conservation Units are the fundamental units of biological diversity that are managed and conserved under Canada's Policy for the Conservation of Wild Pacific Salmon. They may be comprised of one salmon population or they may be made up of as many as 170 separate salmon populations.
Decision matrix	A decision matrix is a listing of options that includes information that is relevant to them. In the context of wildfire recovery, it is a decision-making tool that allows for the evaluation and prioritization of competing treatments, strategies or operational plans
Debris flow [1]	A mixture of fine material (sand, silt and clay), coarse material (gravel and boulders), with a variable quantity of water, that forms a muddy slurry, which moves downslope.
Designated Unit [3]	A unit of Canadian biodiversity that is discrete and evolutionarily significant, where discrete means that there is currently very little transmission of heritable (cultural or genetic) information from other such units, and evolutionarily significant means that the unit harbours heritable adaptive traits or an evolutionary history not found elsewhere in Canada. Used as a basis for SARA, COSEWIC assessments, categorizations and listing.
Ecological wildfire recovery [4]	The suite of actions undertaken to assess, recuperate, restore, reclaim and/or salvage landscape values that have been disturbed by a wildfire.

Word or Term	Definition (as used in the Playbook)
Element at Risk	Specific things of value (e.g., known spawning habitats for a specific salmon population) that could potentially suffer damage or loss due to a hazard.
Evapotranspiration	A process within the Earth’s water cycle that transfers water from the land to the atmosphere by evaporation and by plant transpiration.
Exposure	A measure of how much the element(s) at risk is exposed, in time and space to a hazard, such as the size, quality and quantity of spawning reaches that are impacted by a hazard at the time of spawning.
First Nation	The term used to describe one of three Aboriginal peoples of Canada whose Aboriginal Rights are recognised by Section 35 of the *Canadian Constitution Act* (1982). First Nations along with Métis and Inuit peoples make up the Aboriginal and Indigenous peoples of Canada.
Form-based treatments	Restoration treatments that promote the modification of a stream channel to improve conditions through the creation of specific habitat characteristics and features known to benefit salmon. It attempts to improve the condition of a stream by directly modifying its morphology or architecture.
Fluvial [1]	Pertaining to rivers
Fluvial geomorphology	A field of study that addresses the removal, transfer and deposition materials on the Earth's surface through riverine processes.
Geomorphology [2]	The science of landforms with emphasis on their origin, evolution, form and distribution across the physical landscape.
Gully [1]	A small hollow or channel incised into sediments or unconsolidated rock by running water.
Hazard	Processes, with varying magnitudes and likelihoods, that are a source of harm in a post wildfire landscape.
Hereditary Chief governance structure	A leadership structure within some First Nations in Canada that involves house or clan level governance structures.
Holocene epoch	The Holocene is the current geological epoch that began with the Holocene glacial retreat approximately 11,700 years ago.
Hydrograph	The measurement of flow versus time at a specific point in a river or stream.
Hydrology [2]	The science that deals with the waters above and below the land surfaces of the Earth; their occurrence, circulation and distribution, both in time and space; their biological, chemical, and physical properties; and their interaction with their environment.
Hydrologic recovery [2]	Hydrologic recovery can refer to stand or watershed-scale interactions between forests and hydrologic processes, and means the extent to which regenerating forests compare to a reference stand (typically a pre-disturbance stand) with respect to characteristics affecting streamflow response (rainfall interception, snowpack development and ablation behaviour).
Incising	A process by which stream flows cause down-cutting erosion of the channel and bed-level lowering.
Indigenous (or cultural) burning practices	Burning practices that are done, or have been done, with the intent to manage natural resources and ecosystems to produce desired outcomes.
Indigenous Knowledge	Knowledge that reflects the unique cultures, languages, values, histories, governance and legal systems of Indigenous Peoples. It is place-based, cumulative and dynamic. Indigenous Knowledge systems involve living well with, and being in relationship with, the natural world.
Laminar flow [1]	Overland water flow in which the lines of flow are essentially constant and in which flow direction at all sites remains nearly unchanged through time.
Lateral erosion	Sideways erosion that acts on a riverbank and often causes a widening of the channel.

Word or Term	Definition (as used in the Playbook)
Landslide [1]	A generic term describing those downward movements of slope forming material as a result of shear failure occurring along a well-defined shear plane.
Likelihood [2]	The chance of something happening. Likelihood is expressed as the chance of occurrence over a given time period, often using relative terms such as very low to very high or very unlikely to almost certain. Probability is a mathematical expression of likelihood.
Mass wasting [1]	The failure and movement by gravity of a volume of soil, alluvium or rock to a downslope site.
Mitigate [2]	To take measures in advance to offset or reduce the likelihood of negative effects. e.g., distributing harvest areas with regard to aspect, elevation zone or other factors to reduce the likelihood that peak flow increases will occur; or to reduce the possible magnitude of peak flow increases; or to establish standard operating procedures for road construction to reduce the potential for instability or drainage problems.
Overland flow [1]	The part of precipitation or snowmelt that moves over the land surface before becoming concentrated within a channel of a rill, gully or stream.
Planning objectives and goals	A goal is an aspirational yet achievable outcome that is usually large in scope, both in time and space, while objectives tend to define measurable actions over a period of time required to achieve the overall goal.
Process-based treatments	Treatments that focus on restoring the hydrological, geomorphic and ecological processes (or controls) that contribute to the ecological dynamics of a stream. Instead of focusing on symptoms, this restoration philosophy emphasizes the need to address the root causes of environmental degradation at appropriate spatial scales.
Raindrop impact, splash and wash [1]	A term expressing the effect that individual raindrops have on erosion processes. The dislodging of soil particles that are then susceptible to entrainment by water moving downslope.
Recovery	Used in a manner that is synonymous with some definitions of 'ecological restoration', which are the management actions that accelerate the recovery of a watershed that has been degraded, damaged or destroyed. It does not imply a return to a previous state, but rather a return to ecological controls and processes more favourable to salmon and salmon habitats.
Remediate [2]	To take measures to fix effects after they have occurred, e.g., deactivating old, unstable roads or implementing sediment control measures on active roads.
Rill [1]	A very small incision eroded into soil or soft rock as a response to runoff.
Risk	Where an element at risk may be exposed to an undesired outcome that will have negative consequences. Risk ratings are the probability that a particular negative consequence will occur within the planning cycle or some other predefined period of time.
Risk analysis/analyses [2]	The systematic use of information to comprehend the nature of risk and estimate the level of risk.
Risk assessment [2]	The overall process of risk identification, risk analysis, and risk evaluation.
Risk evaluation [2]	The process of comparing the results of risk analysis with risk tolerance criteria to determine if the risk is acceptable, tolerable or unacceptable; weighs the estimated level of risk against the expected benefits.
Risk identification [2]	The process of finding, recognizing, and describing Risks; involves identifying the values, the sources of risk (sources of potential harm), their causes, and the potential consequences.
Risk management [2]	Coordinated activities to control risks.
Risk Management Framework	A written document or model that provides the context/conditions, scope and standards/risk tolerance criteria for managing watershed risks.

Word or Term	Definition (as used in the Playbook)
Risk tolerance criteria [2]	References against which the significance of a risk is evaluated. Generally, these are associated with defined qualitative or quantitative risk levels.
Salmon	Chinook, coho, sockeye, chum and pink salmon and steelhead trout, which belong to the genus *Oncorhynchus.*
Salmon alevin	A young salmon hatched from its egg that retains its yok sack and has not emerged from the spawning gravels.
Salmon fry	Young salmon that have consumed all of their yolk sac and have grown in size and emerged from spawning gravels to begin feeding in freshwaters.
Salmon parr	Young salmon that are actively feeding in freshwater and between the fry and smolt stages. Typically, this term is applied to those species that rear in freshwater.
Salmon smolt	A stage in the development of salmon that involves smoltification, a process by which they undergo the physiological process that allows them to migrate and adapt to estuarine and marine environments.
Sediment budget [1]	The identification and quantification of the individual components of a sediment-transfer system.
Seral stage	An intermediate plant community stage that is found in a post disturbance ecosystem as it moves toward an older, sometimes 'climax' community. Most successional pathways involve several seral stages that transition through time toward the final plant community.
Stakeholders	An umbrella term meant to include NGOs, industry and user groups.
Stochastic	A descriptor for natural phenomena/events that occur somewhat randomly or unpredictably. While they can often be described statistically, they cannot be predicted with precision.
Strategy	A variety of treatments that are coordinated in space and/or time toward the reestablishment of processes, function or structure within a watershed.
Stream order [1]	The position that a stream-channel segment has within the hierarchy of channels of a drainage network.
Treatment	A management action that is directed toward the reestablishment of processes, function or structure within a watershed.
Undesired outcome	A hazard scenario that an element at risk could be exposed to and that could have a negative consequence.
Valley centric treatments	Treatments that consider the entire watershed when devising approaches to restoration. They are undertaken at the appropriate process scale, rather than on a habitat scale.
Value(s) [2]	The specific or collective set of natural resources and human developments in a watershed that have measurable or intrinsic worth. Within the Playbook, values are typically used to describe salmon or salmon habitat in a particular state.
Vulnerability	Negative outcomes that are tied to a specific element at risk and are influenced by the magnitude, intensity, duration and timing of the hazard (e.g., direct fish mortality or a loss of habitat type that limits a specific salmon population of value).
Watershed controls	The geological, climatological and ecological factors that shape watershed processes.
Watershed assessment [2]	Identification and analysis of hydrologic and geomorphic processes in a watershed or portion of a watershed.
Watershed recovery [2]	The recovery of the ecological, hydrologic and geomorphic conditions that influence watershed processes and salmon habitat conditions.
Wildfire	A wildfire is an unplanned fire that typically burns over a natural area such as a forest or grassland; however, they can also involve areas of human habitation.

Word or Term	Definition (as used in the Playbook)
Wildfire suppression rehabilitation [4]	A form of deactivation, specific to fire suppression activities that: 1) restore natural drainage patterns; 2) stabilize soils; 3) minimize surface erosion; 4) minimize fire hazards, 5) promote revegetation while preventing invasive species from inhabiting affected areas, and 6) repair damaged infrastructure.
Worldview	A particular philosophy of life, or conception of the world and how they are shaped and influenced by various factors.

1 Quoted or derived from the *Alphabetical Glossary of Geomorphology*; International Association of Geomorphologists (IAG) Association Internationale des Géomorphologues. 2014. *Alphabetical Glossary of Geomorphology* Version 1.0. Prepared for the IAG by Andrew Goudie, July 2014.

2 Quoted or derived from *Watershed Assessment and the Management of Hydrologic and Geomorphic Risk in the Forest Sector* by EGBC and ABCFP (2020)

3 Quoted from COSEWIC 2024

4 Quoted or derived from Gov. BC 2024

Note: additional sources of definitions included online references, such as Wikipedia, and professional experience.

APPENDICES

APPENDIX A RECOVERY COMMUNITY: ROLES AND RESPONSIBILITIES

This appendix is intended to familiarize the reader with the common authorities and players that have mandates, rights, interests and roles to play in the recovery of watersheds and salmon habitats following wildfires. Those involved in watershed restoration should see themselves as fitting into a community that, when working together, is far greater than the sum of its parts. As such, understanding all entities/groups and how they fit into watershed recovery is an important competency for those involved in watershed restoration.

Much of the following information has been gleaned from various sources, including service plans and mandate letters.

Ministry of Forests (MOF) – Provincial

The Ministry of Forests (MOF) is the provincial agency responsible for the management of forests, lands and range, and integrated decision making for water, fish and wildlife, archaeology permits and authorizations, and natural resource compliance and enforcement. The MOF is also responsible for making sure the province is well positioned to address natural hazards, including wildfire and flood management. It also works to address climate change by enhancing the role of forests and forest products as carbon sinks or opportunities to reduce emissions, and by preparing for and responding to the impacts of climate change already underway. The MOF oversees policy development, operational management and implementation, and administers relevant statutes and associated regulations. It is accountable for the *Forest and Range Management Act*, *The Forest Act*, the *Wildfire Protection Act* and the *Lands Act*. Accordingly, the MOF is directly responsible for the operational, land-use planning and decision making (including licensing and permitting) of almost all operational activities tied to watershed recovery planning within lands classified as Crown land.

As laid out in the *BC Wildfire Management Branch Rehabilitation Standard Operating Guidelines*[152], MOF has immediate post-wildfire responsibilities regarding fire suppression, damage rehabilitation planning and actions (machine and hand guards, fire access roads and trails, breached barriers, stream crossings, staging areas and sumps). MOF is also the Ministry responsible for access control on Crown lands and leads assessment work to understand risk to the public, infrastructure and resources. The MOF has other key responsibilities that relate to watershed restoration including:

- the reduction of risk and increased community resilience through implementation of the *Government's Action Plan: Responding to Wildfire and Flood Risks* in response to Addressing the New Normal: 21st Century Disaster Management in British Columbia;
- the delivery of funding through the Community Resiliency Investment program to support work in treating the wildland-urban interface through delivery of FireSmart activities, and strengthen capacity of local emergency authorities and Indigenous communities to prepare and respond to wildfire events;

[152] Government of British Columbia 2015

- the development of a provincial risk reduction strategy to reduce wildfire risk through targeted wildfire management activities in high wildfire risk landscapes;
- the development and implementation of a Wildfire Recovery Program, as well as a Flood Recovery Program, in conjunction with the BC Flood Strategy, to improve natural hazard management and governance, and in collaboration with Indigenous Peoples, partners and interested parties;
- the development of drought management strategies in collaboration with other ministries, interested parties, and Indigenous Peoples that will help British Columbians better prepare for future drought and climate change impacts;
- the implementation of the United Nations Declaration on the Rights of Indigenous Peoples through application of the *Declaration Act* in alignment with the Ministry of Indigenous Relations and Reconciliation;
- the advancement of opportunities to include Indigenous Peoples as full and active partners in the forest sector and support economic development of Indigenous communities;
- the creation of land-use objectives through modernized land-use planning and making sure sustainable natural resource management reflects shared social, cultural, economic and environmental values, while collaborating with the new Ministry of Water, Land and Resource Stewardship and partnering with Indigenous governments and engaging interested parties and communities; and,
- the application of new and existing management tools and practices to recover priority species at risk that reflect Indigenous values and provide certainty to affected natural resource users.

Ministry of Water, Land and Resource Stewardship (WLRS) – Provincial

The Ministry of Water, Land and Resource Stewardship (WLRS) works with other natural resource sector ministries to achieve BC's goals of reconciliation with Indigenous Peoples, economic recovery, and environmental sustainability. It is responsible for the effective development of land and marine use policy and planning, biodiversity and ecosystem health, including species at risk policy and program management. The WLRS is also responsible for developing a new vision for land and resource management with First Nations that will embrace shared decision making on the land base as part of reconciliation with Indigenous Peoples in BC. It is accountable for all or key parts of the *Environment and Land Use Act*, *Forest and Range Practices Act, Land Act*, *Ministry of Environment Act*, *Ministry of Forests and Range Act*, *Muskwa-Kechika Management Area Act*, *Water Sustainability Act*, and the *Wildlife Act*. The Ministry directs work across natural resource ministries to develop solutions to sector-wide challenges and advance dedicated sector-wide policy, including managing for cumulative effects, improving permitting and authorizations, as well as providing dedicated secretariat support for effective governance of the natural resource sector. Salmon and watershed-specific tasks include the advancement of the Watershed Security, Coastal Marine and Wild Salmon Strategies.

Under the *Water Sustainability Act*, the WLRS is the ministry responsible for water sustainability planning to resolve water use conflicts and/or risks to water quality or aquatic ecosystem health. In addition, WLRS has recently been assigned authorities under the *Water Sustainability Act* and is also responsible for water-related permitting functions and the development of drought management strategies.

Other WLRS key responsibilities that relate to watershed restoration include:

- building a vision for co-management on the land base that embraces shared decision making and builds an approach for co-management of land and natural resources;
- developing a long-term collaborative approach with Indigenous partners to manage cumulative effects on the land base to balance economic opportunities and protect environmental and cultural values;
- modernizing land-use planning, undertaken with First Nations, to help identify areas where environmental values are affirmed through protection and sustainable economic opportunities;
- collaborating with partners to develop and improve relationships, agreements, and strategies that enhance wildlife management and biodiversity (including species at risk);
- connecting systems, tools and people to the transformative work taking place across the natural resource sector and increasing the province's ability to manage cumulative effects through integrated, science-based land, aquatic, resource, and geographic data;
- land-use planning that sets the strategic direction to guide sustainable resource stewardship and management of provincial public land and waters and meets economic, environmental, social, and cultural objectives. Modernized land-use planning is led by the BC government in partnership with Indigenous governments and includes engagement of communities, local governments, industry and other stakeholders;
- developing and implementing a provincial approach to establish Water Sustainability Plans;
- developing BC's first Coastal Marine Strategy to better protect coastal habitat while building strong coastal economies and developing a Watershed Security Strategy and Fund to help heal the land and restoring wetlands and riparian areas using nature-based solutions to sustain rivers and provide access for salmon to return home to spawn; and,
- working with the federal government, First Nations leadership, and stakeholders to develop strategies for wild salmon recovery and revitalization in BC.

Many of the above responsibilities are becoming tangibly manifest in the Intentions Paper for a *Watershed Security Strategy and Fund*[153], which has been jointly released by WLRS and the BC-First Nations Water Table. The stated policy intentions are to:

- enable new approaches to watershed governance through inclusion, capacity building and collaboration;

[153] WLRS and BC-First Nations Water Table 2023

- pursue legislative change, policy development and alignment of laws and policy to be consistent with the UN Declaration;
- build a strong foundation of watershed science and knowledge that is accessible for use by Indigenous Peoples, local governments and communities;
- apply holistic approaches to watershed management and ecosystem protection; and,
- balance water supply and demand (quality and quantity) at the watershed scale to address the needs of people, the environment and the economy.

A final Watershed Security Strategy is under development. The Watershed Security Strategy and Fund Intentions Paper can be found at https://engage.gov.bc.ca/app/uploads/sites/722/2023/03/WSSF-Intentions-Paper-March2023.pdf. It is expected that the Playbook will align with many of the approaches and principles identified in the Watershed Security Strategy.

Ministry of Environment and Climate Change Strategy (ECCS) – Provincial

The BC Ministry of Environment and Climate Change Strategy (ECCS):

- administers the province's parks and protected areas, recreation sites and trails;
- monitors and enforces compliance with environmental laws and regulations;
- manages discharges to the environment from human activities;
- mitigates and manages the risks and consequences from climate change, including developing plans to meet carbon pollution reduction targets;
- responds to the impacts of climate change; and,
- oversees provincial environmental assessment through the Environmental Assessment Office.

Key pieces of environmental legislation that will relate to watershed recovery activities are the *Park Act and the Ecological Reserve Act,* which contains provisions for the protection and management of environmental resources including timber. Some permitting for activities, such as the cutting or disposal of timber, will often be administered under other legislation and authorities (e.g., MoF); however, watershed recovery activities within a BC Park or Protected Area would have to be approved by BC Parks/ECCS before permitting can proceed. More importantly, watershed recovery planning that impacts the province's parks and protected areas should involve BC Parks, which has authorities to oversee the management of these areas and many of the resources within them. Similarly, if the recovery has the potential to impact a Recreation Site or Trail, then permitting should be secured through BC Recreation Sites and Trails (which operates separately from BC Parks).

Ministry of Emergency Management and Climate Readiness (EMCR) – Provincial

The Ministry of Emergency Management and Climate Readiness (EMCR) is the primary coordinating agency for reducing climate risk impacts and responding to provincial-level emergencies and disasters in BC. "*The mission of the Ministry is to lead provincial emergency and disaster risk management, build and foster collaborative relationships and partnerships, advance meaningful and lasting reconciliation with Indigenous*

Peoples, and support all people in British Columbia to reduce climate and disaster risk. The Ministry works to advance the vision of a disaster resilient British Columbia."[154]

"*The Ministry is responsible for providing cross-ministry coordination to enhance British Columbia's readiness and resilience towards climate and disaster risks and working towards a comprehensive and interconnected approach to achieving climate and disaster risk reduction. The Ministry leads provincial emergency management through the four-phased approach of mitigation, preparedness, response, and recovery in close collaboration with First Nations, local authorities, other provinces and territories, federal departments, industry, nongovernmental organizations, and volunteers. Delivery of the Ministry's mandate is supported by the Emergency and Disaster Management Act*."[155]

Fisheries and Oceans Canada (DFO) – Federal

Fisheries and Oceans Canada (DFO) is responsible for the management of Pacific salmon in BC. It has committed to leading a coordinated response to address the multiple drivers of Pacific salmon stock declines and is making strategic investments to provide the greatest chance of mitigating these declines in the long term.

DFO implements the *Fisheries Act* by applying the prohibitions against the destruction of fish and fish habitat. DFO's Fish and Fish Habitat Protection Program oversees an online public registry, provides guidance for the regulatory reviews of proposed development projects near water, and promotes integrated planning. DFO will continue to manage fisheries consistently with the fish stock provisions under the *Fisheries Act* by maintaining healthy fish stocks at levels necessary to promote sustainability and by developing and implementing rebuilding plans for depleted stocks.

Activities such as forestry are regulated by provincial statutes, yet they have the potential to impact fish habitats. However, provincial statutes do not override the federal *Fisheries Act,* which prohibits activities that could result in the death of fish or harmful alteration, disruption or destruction of fish habitat. If an activity is proposed that does not comply, DFO may issue an authorization with terms and conditions that need to be met before the activity can proceed.

In recent decades, DFO has had fewer resources to dedicate to higher level planning initiatives and has focused its habitat-oriented efforts on transactional processes (e.g., permitting). This is changing and in BC, DFO has established an integrated planning unit and an expanded habitat restoration program. DFO is now able to provide expertise to planning processes and focus considerable resources on watershed restoration planning and operations.

[154] Gov. BC 2024

[155] Gov. BC 2024

Environment and Climate Change Canada (ECCC) – Federal

Under its core responsibility of 'Conserving Nature', Environment and Climate Change Canada (ECCC) has responsibilities and authorities that relate to the recovery of watersheds containing salmon. This responsibility is described as: "*Protect and recover species at risk and their critical habitat; conserve and protect healthy populations of migratory birds; engage and enable provinces and territories, Indigenous Peoples, stakeholders, and the public to increase protected areas and contribute to conservation and stewardship activities; expand and manage the Department's protected areas; and collaborate with domestic and international partners to advance the conservation of biodiversity and sustainable development*."[156]

The most direct influence that ECCC is likely to have on salmon habitat restoration will be in listing, and potential recovery planning for, salmon that may be listed as 'at risk' (e.g., endangered, threatened, special concern) by the federal government under the *Species at Risk Act* (SARA). When it comes to salmon, responsibilities at the federal level are shared with DFO. The various assessment and planning processes (e.g., recovery plans, recovery potential assessments) used in the protection of 'species at risk' involve First Nations, the provincial governments and various impacted stakeholder groups.

Key programs and funding under the Conserving Nature responsibility that can be applied to watershed and salmon habitat recovery include: 1) the Land Conservation Program (The Government of Canada has committed to conserving 25% of Canada's land and oceans by 2025), 2) Nature Agreements, 3) Nature Smart Climate Solutions Fund and 4) Conserving species at risk, which includes the delivery of SARA. The SARA contains key provisions regarding the listing and management of species at risk in Canada.

Under another core responsibility entitled 'Taking Action On Clean Growth and Climate Change', ECCC has responsibilities and authorities that relate to the recovery of salmon watersheds. Under this responsibility, the Nature-based Climate Solutions Program will deliver the Natural Climate Solutions Fund, which will be applied in conjunction with the other initiatives and programs already described under the 'Conserving Nature' responsibility.

Parks Canada – Federal

Lands and waters within National Parks fall under the authority of the federal government. While Parks Canada often cooperates with provincial agencies and other entities in pursuit of environmental objectives, it maintains its own permitting system for land-use activities. Importantly, Parks Canada maintains its own Conservation and Restoration Program, which prioritizes projects that address restoration actions for ecosystems that are in poor or fair condition and projects that address species at risk issues.

[156] ECCC 2020

Local Governments

With respect to watershed and salmon habitat restoration in BC, local governments (e.g., municipal governments and regional districts) can have several important roles. They can function as a stakeholder with an interest in watershed health or in the health of the salmon populations. Community watersheds and drinking water sources can be impacted by wildfire through the same pathways, and water quality and quantity objectives relate strongly to salmon habitat objectives. In most cases the objectives for clean and stable supply of water will align with salmon habitat objectives. That said, water use objectives can conflict with salmon habitat objectives, and this often requires management attention. Beyond water related objectives, the tourism sector, within many communities, benefits from the presence of salmon and will have a vested interest in the recovery of habitat values.

Local governments in southern BC also have an important role as 'regulator' and are required to cooperate with the province in the permitting of developments that are adjacent to riparian habitat. The Riparian Areas Protection Regulations define riparian areas and lay out provisions for their protection within local government permitting processes.

First Nations and Government to Government Processes

In BC, Pacific salmon have been integral to the way of life of Indigenous Peoples for millennia. Historically, salmon have provided most Indigenous Peoples in BC with food security in the form of delicious, high-quality protein, oils and essential nutrients. Salmon are deeply embedded in Indigenous cultural and ceremonial practices; the intergenerational transfer of knowledge; mental, emotional, spiritual and physical health; family structures; community cohesion and gatherings; and giving, sharing and trading practices. As such, healthy populations of Pacific salmon contribute significantly to the food security, self-determination and overall well-being of BC's Indigenous Peoples. In recent decades, many of BC's salmon populations have been in rapid decline and this decline represents a cultural crisis for BC's Indigenous Peoples. Indigenous societies feel an inherent responsibility to make sure that healthy salmon populations will be available for future generations, and this aligns directly with post-wildfire watershed recovery actions.

Beyond the inherent connectedness of First Nations and salmon populations throughout most of BC, new social and political realities have emerged and are resulting in profoundly different relationships, collaborations and governance structures among the federal, provincial and local levels of government and rights holding First Nations. Since the patriation of the Canadian Constitution (*Constitution Act* 1982, Sec. 35 [1]) and through subsequent legal decisions, Aboriginal rights at the community and individual levels have been affirmed and clarified. In addition, a comprehensive and global vision for Indigenous human rights and control over cultural and land-use decisions and economic opportunity was articulated and advanced by the United Nations in 2007 when it developed and released its *Declaration on the Rights of Indigenous Peoples (UNDRIP)*. Article 32 is one of the more impactful articles of this document and its three parts read:

> *"1. Indigenous Peoples have the right to determine and develop priorities and strategies for the development or use of their lands or territories and other resources.*

2. States shall consult and cooperate in good faith with the Indigenous Peoples concerned through their own representative institutions to obtain their free and informed consent prior to the approval of any project affecting their lands or territories and other resources, particularly in connection with the development, utilization or exploitation of mineral, water or other resources.

3. States shall provide effective mechanisms for just and fair redress for any such activities, and appropriate measures shall be taken to mitigate adverse environmental, economic, social, cultural or spiritual impact."

Both Canada and BC have adopted the UNDRIP and created separate pieces of legislation that, among other things, attempt to reconcile the interpretation, application and/or redrafting of statues in a manner that is consistent with the 46 articles under the BC *Declaration on the Rights of Indigenous Peoples Act* and the Canadian *United Nations Declaration on the Rights of Indigenous Peoples Act*.

First Nations in BC are now integral to land-use planning and management from strategic to operational levels. This has accelerated the expansion of natural resource management departments within First Nations Band offices and the proliferation of non-rights holding umbrella First Nations organizations that assist resource management processes. Within the last 40 years the social and legal landscapes have changed dramatically and this is bringing new information (e.g., Indigenous Knowledge), sensibilities, values, resources and expertise to environmental management and land-use decision making processes.

In today's lexicon, the legitimacy and necessity of First Nations governance is embodied by the term 'government to government' (G2G), which is applied to relationships and collaborations between two or more levels of government. Salmon and salmon habitats in BC are best served if effectively co-managed by state ministries (i.e., federal and provincial governments) and First Nations.

This 'new state of being' can result in very high-level negotiations between various levels of government that can result in land-use plans over broad areas (e.g., Great Bear Rainforest) and/or decision-making agreements (e.g., Lake Babine Nation Foundation Agreement). At the same time, it influences the day-to-day transactional approval processes such that First Nation referral teams usually review and provide input into provincial and federal government approval/permitting processes at more local scales. Post-wildfire watershed recovery planning will fall between these extremes and a standard process is yet to emerge. Furthermore, G2G relationships and processes are highly varied depending on the Nation involved and its particular customs, values, and governance structures and leaders.

Understanding the roles of the various First Nation entities will be critical to success in any land-based management endeavour. 'Rights holding' First Nations have rights within their traditional territories that are protected under the Canadian *Constitution Act*. Very often these are the Indian Bands (with a Chief and Council governance structures) that were set up under the authority of the *Indian Act* and that have asserted traditional territories. In most cases, it is the rights holding First Nations that will engage directly in post-wildfire planning. In some parts of BC, however, another rights-holding layer of governance exists in the form of the 'Hereditary Chief' structure, which is usually aligned with a First Nation and traditional territories, but locates power and authority across the land base in a more dispersed manner and according to Nation protocols. These two separate governance entities may or may not have established and agreed upon their respective levels of authority for resource management issues.

Some First Nations have entered into Treaty Agreements with the federal government (or more recently with the federal and provincial governments). These agreements can provide specificity on rights and authorities in relation to natural resources and are paramount to the provincial and federal resource management statutes. As such, resource management provisions under treaties must be regarded as the prevailing law of the land. Information on treaties and treaty processes can be found at the BC Treaty Commission website.

Multi-band organizations are another form of First Nations governance exercised not through rights, but through expertise, access to resources, and leadership and relationships that can be established with the rights-holding First Nations, G2G processes and agencies. Very often, cooperating Indian Bands choose to gain efficiencies by organizing and supporting entities, such as Tribal Councils and Fisheries Commissions, that deliver services across larger scales.

It is also important to understand that with respect to the more than 200 First Nations in BC (see Box A-1), many will have overlapping traditional territories. As such, land-based collaboration can involve two, three or more rights holding First Nations.

Box A-1

Information on the territory boundaries, office locations, history, mandates and contact information for each of BC's First Nations, and their associated councils

The territory boundaries, office locations, history, mandates and contact information for each of BC's nearly 200 distinct First Nations, and their associated councils, are provided on these websites:

First Nations in BC Interactive Map by British Columbia Assembly of First Nations (accessed July 18, 2022)

First Nations A–Z Listing by Government of BC (accessed July 18, 2022). See also *BC First Nations and Indigenous People* (accessed July 18, 2022)

Contacts for First Nation Consultation Areas by Government of BC (accessed July 18, 2022)

First Peoples' Map of BC by First Peoples' Cultural Council (accessed July 18, 2022)

It can be challenging to understand the distribution of power/authority, expertise and capacity within a broad First Nations community, but this is a vital step in relationship building and planning and presents an opportunity to align interests, benefit from knowledge and expertise, and create synergies. Many government and industry representatives and First Nations entities themselves have knowledge and experience and can be helpful in mapping out the authorities and representatives. The MOF, which has its own First Nations Engagement Advisors within its district offices, can also be a wealth of knowledge.

While the G2G landscape in BC would seem to have been resolved at legal and policy levels, the 'on the ground' realities associated with wildfires and land use decision making can be very different. Agency structures and programs are still ramping up to address UNDRIP and the associated provincial and federal statutes. In addition, by its very nature, wildfire compels timely actions that must be undertaken, while new G2G structures and processes are under development. As one might expect, successes and frustrations are being experienced in this period of change. Information on First Nations perspectives regarding land management activities associated with the Elephant Hill Fire is provided in Box A-2.

Box A-2
Select First Nations Perspectives Regarding Post-Wildfire Land Management and Engagement

Indigenous Leadership in Wildfire Recovery and Restoration: Lessons Learned from Elephant Hill and Secwepemcúl'ecw by John, Kane and Dickson-Hoyle (2022) – no link available; see Appendix C for case study information on this topic.

Elephant Hill: Secwépemc Leadership and Lessons Learned from the Collective Story of Wildfire Recovery and Summary and Recommendations by Dickson-Hoyle and John (2021)

Stakeholders and Industry

Salmon have also shaped the culture and economy of BC. These fish species are cherished and pursued by recreational fishers in both marine and freshwater environments and renowned as table fare at home and in restaurants. The increasingly non-consumptive viewing of salmon and their predators (e.g., killer whales) is contributing to BC's tourism economy. These economies, in turn, have often shaped patterns of development and demonstrated the interdependence of lifestyle and ecological health.

At the same time, the potential for industrial and urban development to negatively impact salmon and/or salmon habitat, is recognized and addressed through various regulations. These necessary constraints influence various industries that must attend to operations while observing environmental objectives and restrictions. In all cases, considerations and the possible engagement of stakeholders will stimulate 'buy in', creativity and collaboration.

The province has identified that "...*in a land-use planning context, stakeholder engagement is the process of involving groups of citizens who are affiliated by geographic proximity, interest, or sector/industry to address issues affecting their well-being, values and interests…*" (in *Modernized Land Use Planning: A Guide to Effective Stakeholder Engagement*). The document also stated that "*Interested stakeholders can include, but are not limited to:*

- *Local governments (municipalities, regional districts, incl. the Islands Trust and improvement districts); Natural resource industries (forestry, mining, and oil and gas interests); Conservation and environmental protection advocates (environmental NGO);*
- *Individual tourism operators and tourism associations; Commercial fishing industry, aquaculture; Hunters and trappers; Farmers and ranchers; and Recreational users of public lands*".

When engaging stakeholders, therefore, the emerging planning team must first ask 'who stands to be impacted by our planning process or its outcomes?' and then begin to reach out accordingly. Stakeholder engagement and contributions will often vary depending on the stakeholder's interest in the scope of the planning process. Some stakeholders may not want to be engaged, others may want updates only, and still others may become key leaders in the process.

Increasingly, non-government organizations (NGOs) are invited to assume roles of elevated importance when it comes to the delivery of important environmental initiatives. This is demonstrated by the proliferation of federal and provincial grant programs, which make funds available to NGOs that assume responsibility for the delivery of important projects and programs aligning with government objectives. Enhancement Societies can become important players in watershed restoration by harnessing the expertise, capacity and enthusiasm within communities and the resources offered up by governments and other entities and then directing them to habitat recovery projects. They can also recognize and respond to a diversity of public needs including educational programming that can further foster community goodwill and possibly draw additional resources to the challenge of watershed recovery.

Many NGOs can be found in BC with different areas of specific expertise regarding watersheds, salmon and salmon habitat that could potentially contribute to the planning and implementation phases of post-wildfire responses. The NGOs are highly varied and can play diverse roles including:

- the operational delivery of stewardship programs and projects;
- the provision of strategic linkages to broader land-based initiatives and coordination functions;
- the provision of resources; and,
- the dissemination of scientific/technical advice.

Tenure and license holders (often within the forestry, grazing and agricultural sectors) will commonly have vested interests in the recovery of forest ecosystems following major wildfires and often have the resources, expertise, and finances to help with recovery efforts. For example, the recovery of forests will help restore the hydrologic impacts of major wildfires. Increasingly, professionals, such as Registered Professional Foresters, are expected to assume greater responsibilities in the delivery and safeguarding of resource management standards. This means that land management professionals will play an important role in both representing their employers and providing a skill set to watershed recovery initiatives. While industry, stakeholders and the various governments have a variety of potentially conflicting objectives, post-wildfire watershed recovery initiatives will be enhanced through collaboration.

In post-wildfire environments, forest licensees will have an interest in reforestation. Cattle grazers will have an interest in the reestablishment of ground cover (grasses) and water storage, both above ground and in aquifers. A stable and well-designed road system to facilitate access and recovery actions is appreciated by all. When it comes to salmon streams and watersheds, obvious partnerships are in the making. In addition to the sharing of financial resources to achieve common objectives, there is also the sharing of expertise and knowledge, access (e.g., through private lands) and the presence of resource managers and machinery on the land base. Watershed recovery initiatives will be well served by processes and relationships that seek to align common interests.

Consultants and Academia

As grants become increasingly available for conservation-related activities, the use of specialized talent as part of the Watershed Recovery Team is becoming common. The ability of consultants and academia to bring specific expertise to watershed restoration challenges cannot be overstated. Watershed restoration requires expertise and capacity within highly specialized fields such as geomorphology, hydrology, fish and fish habitat, ecology, agrology, forestry, water management, land-use planning, G2G processes, process facilitation, archaeology and others. Academia can also bring specialized talent and cutting-edge research (sciences and humanities) to the challenge of post-wildfire watershed restoration. This offers innovation and cross discipline solutions, can help solve immediate problems and consolidate learnings for future processes and people.

APPENDIX B SOURCES OF PRE-WILDFIRE (BASELINE) ASSESSMENT INFORMATION

Watershed (Landscape) Baselines

Vegetation Baseline

Baseline data on vegetation coverage for watersheds are available from the BC Forest Service's Biogeoclimatic Ecosystem Classification (BEC) Program website and from the associated BEC GIS data layers. Baseline vegetation coverage for watersheds can also be accessed from BC's Vegetation Resource Inventory (VRI) through iMapBC, VRI GIS data layers, and BC Forest Cover Reserve (Results). These sources include data and information on dominant and sub-dominant vegetation types, stand composition including age, and disturbance (e.g., harvest or wildfire) occurrences. Currently, no provincial databases provide descriptions of understory communities, but industry (e.g., forestry licensees and mine developers) are required to collect baseline vegetation and soil data before operations are initiated. For forestry, these data are archived within provincial and licensee databases (e.g., *RESULTS* and *Phoenix*). Baseline vegetation coverage can be used to make decisions regarding the species considered for any post-wildfire planting and where planting should focus on the burned landscape. Appendix Table B-1 lists information and data sources that can be used to establish landscape vegetation baselines in BC.

Appendix Table B-1. Information and data sources that can be used to help establish watershed vegetation baselines (pre-wildfire) in BC.

Source	Information/Data Format	Information Type
BC Harvested Areas (Consolidated Cutblocks)	GIS data layers	Cut block boundaries and year of harvest (helpful for estimating baseline equivalent clearcut area [ECA]).
BC Wildfire Perimeters (Current)	GIS data layers	Wildfire perimeters for the current wildfire season (active and inactive wildfires).
BC Wildfire Perimeters (Historical)	GIS data layers	Wildfire perimeters for wildfire seasons prior to the current wildfire season.
Biogeoclimatic Ecosystem Classification Coverages	GIS data layers	Data layers for vegetation coverage and geographic and climatic features, natural disturbance types, broad ecosystem zones, and select seed-seed planning zones. Can be used for Predictive Ecosystem Mapping and Protected Areas Strategy.
Biogeoclimatic Ecosystem Classification Program	General website	Information on vegetation coverage and geographic and climatic features.
Forest Cover Reserve (Results)	GIS data layers	Forest retention reserves that are associated with a silvicultural system. Reserves are forest patches or individual trees retained during harvesting to provide habitat, scenic, biodiversity, and other values. Reserve types include riparian and wildlife tree patches.
Vegetation Resource Inventory	GIS data layers	Vegetation coverages across the Province of BC. Includes areas impacted by wildfires and associated timber mortality, forest harvesting, silviculture and reforestation activities.
USGS EarthExplorer	GIS data layers	Landsat 8 imagery for pre-wildfire and post-wildfire periods.

Soils Baseline

An easily accessible source for baseline soils data is the online tool BC Soil Information Finder Tool (SIFT). This interactive tool shows soil survey mapping polygons for the entire province. Polygons in SIFT often provide information on soil texture, percent of coarse fragments, soil drainage characteristics, topographic gradients, thermal factors, and elevation. Additional baseline data on soils texture, composition, chemistry, consolidation, stratigraphy, mineralogy, thickness, and parent materials is available through *BC Digital Geology*, *BC Surficial Mapping*, and *BC Soil Mapping Data Packages*. Baseline information on watershed soils can inform on the areas of the watershed most vulnerable to soil sealing by wildfires (e.g., areas with high organics content) and where restoration actions (e.g., breaking up post-wildfire hydrophobic layers, mulching and planting) should be focused (see Section 5). Baseline soils information can also inform on where it might be advisable to avoid or limit post-wildfire timber salvaging (i.e., areas where soils are vulnerable to erosion and compaction). Appendix Table B-2 lists information and data sources that can be used to establish landscape soils baselines in BC.

Appendix Table B-2. Information/data sources that can be used to help establish soils, geologic and landform baselines (pre-wildfire) in BC.

Source	Information/Data Format	Information Type
Digital Geology, Surficial Mapping, and Soil Mapping Data Packages	Searchable database and GIS data layers	Soils texture, composition, chemistry, consolidation, stratigraphy, mineralogy, thickness and parent material.
LiDAR (Light Detection and Ranging)	GIS data layers	GIS datasets that can be used to assess baseline ground structures and post-wildfire erosion and mass wasting.
Open LiDAR Data Portal	GIS data layers	GIS datasets that can be used to assess baseline ground structures and post-wildfire erosion and mass wasting.
Soil Information Finder Tool (SIFT)	Searchable database and GIS data layers	Soil texture, percent of coarse fragments, soil drainage characteristics, topographic gradients, thermal factors, and elevation. SIFT has links to a library of soil survey data, reports and maps and to two GIS data layers: *Soil Project Boundaries* and *Soil Survey Polygons*.

In-Channel (Salmon Habitat) Baselines

Hydrologic Baseline

Long-term (quality assurance/quality control verified) historical hydrometric data for gauged streams, rivers and lakes (stage) can be used to assess pre-wildfire runoff patterns in wildfire-affected watersheds. Long-term hydrometric data for gauged watersheds are available from Water Survey of Canada's (WSC) Historical Hydrometric Data Search. Real-time (unverified) hydrometric data (as might be needed after wildfire occurrences to assess immediate hydrologic hazards) for gauged watersheds can be downloaded from WSC's Real-Time Hydrometric Data Text Search.

Baseline hydrology can also be inferred from the output of hydrologic models. Mechanistic hydrologic models are usually spatially semi or fully distributed. This means that hydrometric calculations are based on spatial representations, either established as a matrix of cells or lumped into hydrological response units (HRU), also known as grouped response units. Each HRU cell/unit possesses a known area in which every effective process needs to be calculated or estimated. The HRUs aggregate together all adjacent areas with similar land uses, soils and slopes within a sub-basin. This gives a uniform response to events and reduces the computing power necessary to run the model. Semi-distributed hydrologic models are practical because they require little data and can use coarse spatial data. Soil & Water Assessment Tool (SWAT[157]) and Hydrologiska Byråns Vattenbalansavdelning-Environment Canada (HBV-EC[158]) are examples of semi-distributed models. The SWAT and HBV-EC can be parameterized to account for changes in the landscape caused by disturbance. Historically, SWAT has mostly been used to investigate water quality and erosion issues caused by land management practices and climate change; however, there has been an increase in its use to solve questions regarding wildfire impacts.[159] The SWAT has an ArcGIS module available for download here .

Hydrologic models that can be fully distributed, such as Topography Based Hydrological Model and Watershed Erosion Prediction Project Model, necessitate calculations for every raster cell, each possessing a 3-D coordinate and equal area. Many similar topographic and GIS-based models use a form of flow accumulation mapping, where the amount of water flowing from one cell to the next downslope cell depends on the flow generation characteristics of the cell as well as its flow inputs from upslope cells.[160] The GIS-based models are especially relevant to management applications, because they are also used in risk analysis[161] and input data for parameterization are often already available and regularly updated. Fully distributed hydrologic models are more data intensive and complex to set up than semi-distributed models. Therefore, fully distributed hydrologic models have not been widely used to support post-wildfire remediation efforts.[162] Many hydrologic models and their derivatives have been optimized and are capable of reasonably calculating the hydrological effects of wildfires.[163]

[157] Neitsch et al. 2011

[158] Hamilton et al. 2000

[159] Loiselle et al. 2020

[160] Beven et al. 2021

[161] Lewis et al. 2016

[162] Miller et al. 2016

[163] Renschler 2003; Frankenberger et al. 2011; Chen et al. 2013; Kinoshita et al. 2014; Wang et al. 2019

Box B-1
Key Documents Providing Techniques, Methodologies and Best Practices for Hydrological Models

Soil & Water Assessment Tool (SWAT): see Arnold and Fohrer (2005), Neitsch et al. (2011), Devia et al. (2015), Havel et al. (2018), Hernandez et al. (2018), Loiselle et al. (2020)

Hydrologiska Byråns Vattenbalansavdelning-Environment Canada (HBV-EC): see Bergstrom (2015), Lidström et al. (1997), Siebert (1997, 1999, 2000), Siebert et al. (2010), Devia et al. (2015), Mahat et al. (2015)

Topography Based Hydrological Model (TOPMODEL): see Beven and Freer (2001), Devia et al. (2015), Beven et al. (2021)

Watershed Erosion Prediction Project Model (WEPP): see Nearing et al. (1989), Lane and Nearing (1989), Renschler (2003), Flanagan et al. (2007), Mao et al. (2010), Frankenberger et al. (2011), Gould et al. (2016), Fernandez and Vega (2018)

Habitat Connectivity, Structural Habitat, and Water and Sediment Quality Baselines

For some streams, historical data and information are available for habitat connectivity, water and sediment quality (physical and chemical variables) and fish habitat attributes. Datasets on fish habitat attributes (e.g., channel structure, cover and other features) for many salmon-bearing watersheds were compiled during inventories funded by Forest Renewal BC and Fisheries Renewal BC, the Watershed Restoration Program and through industry-related baseline studies (e.g., Fish Stream Identification). Appendix Table B-3 compiles information and data sources that can be used to establish in-channel habitat baselines for BC watersheds.

The Fish Habitat Assessment Procedures (FHAP) developed for the BC Watershed Restoration Program in the 1990s have been used in many watersheds throughout the province over the past three decades. The standardized data collected, and the reports produced are invaluable in helping establish a baseline for both in-channel (salmon habitat) and ecosystem (salmon and foodweb) baselines. "*The assessment procedure consists of four steps:*

1. *identification of fish species at risk in the watershed,*
2. *a quantitative description of fish and fish habitat conditions,*
3. *evaluation of fish habitat conditions, and*
4. *identification of opportunities for effective fish habitat rehabilitation.*" [164]

[164] Johnstone and Slaney 1996

Appendix Table B-3. **Information/data sources that can be used to help establish in-channel (habitat) baselines (pre-wildfire) for BC streams and rivers.**

Source	Information/Data Format	Information Type
Drinking Water Sources Points of Diversion	GIS data layers	Drinking water source points of diversion and water licences (element at risk by wildfires).
EcoCat: The Ecological Reports Catalogue	Searchable database	A catalogue of technical reports, data reports, and field assessments on fish habitat attributes.
Environmental Monitoring System	Searchable database	Water and sediment quality (physical and chemical variables) datasets for streams, rivers and lakes. In many cases, federal and provincial data have been combined in the Environmental Monitoring System.
Environmental Remediation Sites	GIS data layers	Properties that are known to be impacted by contamination/pollutants (potential for habitat contamination after major wildfires).
Field Data Information System (FDIS)	Searchable database	Used to view and work with habitat inventory data (Fish Renewal BC program) over the period 1997-present (NOTE: many versions of FDIS are in use).
Fish & Fish Habitat Data & Information	Searchable database and GIS data layers	Fish habitat data and information.
Fisheries Information Summary System (FISS)	Searchable database	Spatially represented summary-level fish habitat data.
Fisheries Inventory Data Queries (FIDQ)	Searchable database	Fish habitat data (lakes, streams, and rivers).
Freshwater Atlas	GIS data layers	Hydrologic features, watershed boundaries, stream, lake and wetland connectivity, stream order and size, drainage density.
Habitat Wizard	Searchable database	Data and information on fish habitat assessments.
Historical Hydrometric Data Search	Searchable database	WSC collects suspended sediment concentration data at some of their river/stream gauging sites.
LiDAR (Light Detection and Ranging)	GIS data layers	GIS datasets that can be used to assess baseline ground structures and post-wildfire erosion and mass wasting.
Open LiDAR Data Portal	GIS data layers	GIS datasets that can be used to assess baseline ground structures and post-wildfire erosion and mass wasting.
Real-Time Hydrometric Data Text Search	Searchable database	WSC collects real-time suspended sediment concentration data at some of their river/stream gauging sites. Real-time data are subject to quality assurance/quality control verification).

Source	Information/Data Format	Information Type
Obstacles to Fish Passage	GIS data layers	Known barriers to fish passage. Includes records from FISS, Fish Habitat Inventory & Information Program (FHIIP[165]), Fish & Fish Habitat Data & Information, Field Data Information System (FDIS), and Resource Analysis Branch (RAB) inventory studies. Source acknowledges that not all obstacles have been identified.
West Coast Water Authorization Station Discharge	Searchable database and GIS data layers	Hydrometric data for flow gauging stations that are maintained by west coast water authorizations.

Ecosystem (Salmon and Foodweb) Baselines

Extensive fish inventory databases (including for juvenile Pacific salmon) for BC watersheds were developed during the 1990s and early 2000s in conjunction with the Forest Renewal BC and Fisheries Renewal BC programs. Fish inventories, using standard methods, are still regularly undertaken as part of industrial baseline investigations, impact assessments and for research purposes. Fish inventories often include data and information on species presence/absence, fish abundance (e.g., three-pass removals and mark-recapture), fish distributions, fish lengths and weights, fish condition factor and observations on ecosystem components that support juvenile salmon and other salmonids (e.g., periphyton, general water quality [e.g., water temperature, pH, and specific conductivity] and benthic macroinvertebrates). Fish inventory databases can be used to assess the status of stream ecosystems prior to a wildfire occurrence. Comparisons of pre-wildfire ecosystem status (using fish inventory databases) versus post-wildfire ecosystem status (post-wildfire assessments) can help with decisions regarding desired ecosystem recovery end points (outcomes). Appendix Table B-4 compiles available information and data sources to establish salmon and ecosystem baselines for BC streams.

Appendix Table B-4. Information/data sources to establish salmon and aquatic ecosystem baselines (pre-wildfire) for BC streams and rivers.

Source	Information/Data Format	Information Type
EcoCat: The Ecological Reports Catalogue	Searchable database	A catalogue of technical reports, data reports, field assessments and other information on fish distributions.
Environmental Monitoring System	Searchable database	Some datasets include the chemistry of biological tissues (e.g., periphyton, phytoplankton, zooplankton, and fish).
Field Data Information System (FDIS)	Searchable database	Used to view and work with habitat inventory data (Fish Renewal BC program) over the period 1997-present. Note: many versions of FDIS are in use.

[165] Rauhe and Reid (1986)

Source	Information/Data Format	Information Type
Fish & Fish Habitat Data & Information	Searchable database and GIS data layers	Fish data and associated information.
Fish Observations and Distributions	GIS data layers	Fish observances (updated regularly), identification of fish-bearing streams, lakes and wetlands. Incorporates data from Fisheries Information Summary System (FISS), Fisheries Inventory Data Queries (FIDQ).
Fisheries Information Summary System (FISS)	Searchable database	Spatially represented summary-level fish inventory data.
Fisheries Inventory Data Queries (FIDQ)	Searchable database	Fish data for lakes, rivers, and streams. Fish stocking records.
Habitat Wizard	Searchable database	Data and information related to fish inventory assessments.
Salmon Explorer	Searchable database	Data and information related to fish inventory assessments.
SARA Critical Habitat of Species at Risk	GIS data layers	Critical habitat for species categorized as being endangered or threatened under the *Species at Risk Act* (SARA).

First Nations people, including Elders, might be able to share valuable Traditional Ecological Knowledge on salmon and aquatic ecosystem baselines. Many BC First Nations have natural resources agencies that are actively involved in habitat recovery initiatives, stock assessment, and aquatic ecosystem assessment and monitoring, including fish research. These agencies are a source of valuable baseline data and information that can be used to assess the impacts of wildfire on salmon and stream ecosystems.

Due to the traditional, cultural and economic importance of salmon and freshwater ecosystems in BC, virtually all universities in the province support fish and aquatics research. Several federal research institutes[166]) are also involved in fish and aquatics research in the province. Results on fish and fish habitat studies that are undertaken by university and federal government researchers are often published in the scientific literature. Scientific literature can be searched using easy-to-use databases and search engines (Appendix Table B-5). Baseline information and data can be searched by typing stream name (e.g., Willow River, Bowron River, Tabor Creek) into the subject field and all related published studies will download. Databases for searching scientific literature can be accessed in most university libraries.

[166] e.g., Pacific Biological Station, Cultus Lake Laboratory and Institute of Ocean Sciences

Appendix Table B-5. **Databases and internet search engines used to get baseline (pre-wildfire) data and information on fish (including salmon) and freshwater ecosystems.**

Database/Search Engine	Core Collection or Relevant Subject Coverage
Clarivate Web of Science	Science Citation Index Expanded (SCIE) Social Sciences Citation Index (SSCI) Arts & Humanities Citation Index (AHCI) Emerging Sources Citation Index (ESCI) Book Citation Index (BKCI) Conference Proceedings Citation Index (CPCI)
Google Scholar	Uses Search Engine Optimization to search using keywords for all online peer-reviewed journals, books, conference papers, theses and dissertations and technical reports
Agricultural Online Access (AGRICOLA)	Agriculture, botany, chemistry conservation, forestry, human ecology, hydrology, plant sciences, pollution, public health rural sociology, soil science, water quality, weather and climate, wildlife, and zoology
ScienceDirect	Health sciences, life sciences, physical sciences and engineering, and social sciences and humanities

Other Sources of Information:

The Province of BC has significant capacity, activities and publications on watersheds, water, fish-forestry interactions, and fish and habitat within the Ministry of Forests research program, the WLRS (Aquatic Ecosystems Branch, Water Protection and Sustainability Branch, and elsewhere). Published literature is available on the BC government website and through Knowledge Management Branch.

APPENDIX C CASE STUDIES

Case Study #1: The Secwepemcùl'ecw Restoration and Stewardship Society Project to Restore the Riparian Ecosystem at Elephant Hill after the Wildfire.

Contact Information: https://www.srssociety.com/

Introduction

The Secwepemcùl'ecw Restoration and Stewardship Society has taken a broad landscape approach to restore and monitor the health of the riparian areas impacted by the 2017 Elephant Hill Wildfire. The Elephant Hill Wildfire burned for 75 days and covered approximately 192,725 ha. Through preliminary monitoring conducted by Skeetchestn technicians and the University of BC - Faculty of Forestry, researchers identified: 1) a lack of tree and shrub regeneration;2) indications of the intensity of the fire to demolish the existing canopy and understory vegetation; and 3) the fire had burned off the available natural seedbanks for regeneration.

The Elephant Hill Wildfire directly affected the traditional territories of 8 of the 17 Secwépemc Communities within the Secwepemc Nation. The eight communities have joined together and partnered with the provincial government and established the Elephant Hill Joint Leadership Council to jointly lead wildfire recovery across the affected territory.

Approach

Taking a holistic and landscape scale approach, this project addresses riparian restoration requirements, while also assessing the need and potential for riverbank stabilization, in-stream enhancements, and upslope restoration aligned with existing land management objectives and plans. The information from the field surveys and the engagement is being used to develop a comprehensive restoration plan.

Based on needs identified through in-field assessments, restoration activities on this project include:

(i) stabilizing riverbanks;

(ii) tree planting; and,

(iii) in-stream fish habitat restoration.

These restoration efforts work to mitigate the large changes to the hydrograph resulting from denuded forests and riparian areas post-fire. Restoring headwater areas is necessary to maintain the overall health of fish and fish habitats by enhancing water quality, providing buffered water temperatures and increasing the potential for water retention.

Activities

1. Stakeholder Engagement:

The Stakeholder Engagement process aimed to develop shared goals and engage stakeholders in active participation in the restoration and management of riparian areas.

Deliverables:

1. Identify Stakeholders and create a database, internal (eight communities) and external (e.g., landowners, government, ministries, industry).
2. Internal and external interviews.
3. Documentation of stakeholders.
4. Communication and contact with stakeholders through various methods (working groups, tech meeting reports, community interviews, project information packages, websites, referrals, newsletters, informal and formal emails).

Outcomes:

a. Database.

b. Collaborative Partnerships.

c. Working Groups.

d. Technical Table.

2. Planning, Prescription, and Surveys:

Deliverables:

1. Develop a triage map for all streams.
2. Collect survey data and prioritize streams.
3. Develop teams to carry out the fieldwork.
4. Map and GPS stream reaches.
5. Apply for permits (special-use permits….).
6. Order and secure seedling.
7. Identify planting methods.

3. Riparian Restoration:

Deliverables:

1. Allocate the appropriate mix of seedlings to each site.
2. Harvest suitable cuttings if staking is prescribed.
3. Start thawing seedlings 2 weeks prior to planting.
4. Transport seedlings to sites.
5. Microsite plant the seedlings in each site.
6. Survey the sites to make sure the seedlings are planted properly and with the correct number per hectare.

Outcomes:

a. Sites with the appropriate mix of seedlings and stakes are established.
b. The next forest is started.

4. Monitoring Before and After Treatment:

Deliverables:

1. Prior to reforestation, survey the sites to make sure:
   i. the site has few to no seedlings;
   ii. the site has been burned; and,
   iii. no signs are found of other activities like timber harvesting plans.
2. After the treatment, survey the sites after 1 or 2 years to:
   i. monitor the seedling survival;
   ii. determine the cause of success or failure; and,
   iii. recommend changes to improve future reforestation efforts.

5. Highlight and Success:

1. Most sites now have seedlings established.
2. Finding sites, getting approvals, growing/finding seedlings, and planting the seedlings in a short time frame was a big success.

3. Microsite planting is an appropriate process when planting.

6. Lessons Learned:

1. The weather has a huge impact on the seedling success.
   i. Drought of 2021 drastically affected the seedling survival from 2021.
2. Staking is expensive and time-consuming.
   i. Stake survival is poor on poor sites (i.e., rocky, dry sites) and much better on good sites (i.e., where the stakes hit the water table, and where soils are fine and stakes can go deep).
3. Start early and give yourself time.
   i. Year 1: find and layout the areas to treat.
   ii. Year 2: grow the seedlings, finalize the prescriptions, and apply for the permits.
   iii. Year 3: plant the seedlings.
   iv. Year 4 and/or 5: complete survival surveys.
4. Larger plugs and seedlings should be better than smaller seedlings especially in the drier sites like the IDFxh2, and other IDF blocks.

Case Study #2: The Shovel Lake and Island Lake Post-Wildfire Planning

Contact Information: https://sernbc.ca/

1. Situation:

Shovel and Island Lake Wildfires burned extensive areas of BC's central interior in 2018. An ecosystem restoration plan (ERP), initiated in the fall of 2018, focused on long-term restoration to values, with strong linkages to the values identified and processes developed in the Environmental Stewardship Initiative (ESI). The ecosystem restoration plans were intended, in part, to demonstrate a delivery mechanism for ESI objectives.

The ESI is a provincial and First Nations government initiative intended to foster reconciliation and involvement in forest management. Work so far includes developing trusted data, assessing risks to identified values and designing immediate measures to manage impacts to values.

2. Tasks:

A Request for Proposal was developed and delivered by a team from the Society for Ecosystem Restoration in Northern BC, government and Nations. A consultant was hired to lead the planning process. The consultant brought the data, people, and plans together over a relatively short period of time through a series of workshops. A draft plan was completed in three months, with fine tuning of plan details happening over another six months.

The ERP collaborative process among the Society for Ecosystem Restoration in Northern BC, government and affected First Nations identified priority values to maintain and restore within the burned areas, including ESI values (forest biodiversity, moose, water and fish), species at risk (grizzly bears, goshawk), additional cultural values (berries, medicinal plants, cultural areas), economic values (timber, range, mushrooms, furbearers) and climate change values (carbon, resilience, connectivity).

Four zones were delineated to support priority values and build resilience: wildland urban interface, fireguards, timber restoration zone, and special restoration zone (SRZ, similar to special management zone). In the first three zones, the intent is to manage fuels, rehabilitate wildfire suppression impacts, sequestrate carbon and provide for short-, mid-, and long-term timber supply.

The SRZ includes areas with the highest potential to maintain and restore ecological and cultural values; in these zones, the intent is to focus on what to leave. The SRZ is anchored by existing legal designations (parks, old growth management areas, ungulate winter range, scenic areas, riparian management areas, Lakes North Sustainable Resource Management Plan, forest ecosystem networks, wildlife habitat areas). Candidate areas were developed by the Omineca ESI project team. This core area was expanded in workshops to include culturally important areas, and connectivity corridors designed to increase resilience and speed recovery.

An implementation manager was hired, who helped develop an implementation governance structure and Terms of Reference. Yun Ghunli (Dakelh for Stewards of the Land) was created and continues to steer implementation.

3. Actions:

Working with Yun Ghunli, the implementation manager has created protocols for managing aspects of the ERP that differ from traditional recovery approaches and considers the broader objectives contained in the ERP.

The ERP developed a treatment option matrix and suggested rehabilitation, harvesting, planting, seeding and access treatments to maintain and restore the values within each zone. Harvesting treatments aim to maintain legacies and manage fuel. Planting treatments aim to restore landscape diversity and resilience. Options include traditional practices promoting timber supply, and planting deciduous tree species, shrubs and berries to improve habitat and cultural values. Access treatments promote timber values, remove hydrological impacts and restore predator-prey dynamics.

4. Results:

The forested area within the Shovel Lake Wildfire (excluding lakes and non-forested) covers 83,702 ha. The SRZ zone incorporates legally designated areas (9,742 ha), Omineca ESI non-legal designations (18,226 ha), and culturally important areas and connectivity corridors (10,025 ha). The timber resiliency and wildland urban interface zones comprise the remaining 45,709 ha.

The forested area within the Island Lake Wildfire is 20,221 ha. The Island Lake SRZ zone incorporates park (5,697 ha), Omineca ESI non-legal designations (3,470 ha) and culturally important areas and connectivity corridors (1,882 ha). The timber resiliency zone comprises the remaining 9,172 ha.

Zonal objectives are being managed at a high level by Yun Ghunli and implementation is through existing licensee obligations and forest regeneration activities of the provincial government. New protocols for implementation are being explored and implemented, such as planting with gaps and road rehabilitation. Recovery related research and monitoring is being delivered. Collaborative implementation is being maintained.

5. Tricky Pieces, Lessons Learned, and Future Things to Think About:

Incorporating the views of the Office of the Chief Forester (OCF): there is a potential, or perhaps likely, impact to timber supply when you start to manage for other values. This is less of a concern when you are working in fire-impacted areas because the timber supply has already been impacted by the fire, but long-term, timber supply flows will likely change. Depending on your co-collaborators in the planning initiative, and the degree and type of interest by the OCF, planning teams will need to consider how to balance these views and interests. The OCF involvement will provide more legitimacy to the process, but may reduce the opportunities for flexibility due to timber supply pressures.

Implementation: implementation is long and slow, but if you have capacity, has tremendous opportunity for relationship building and learning from many perspectives. Setting up some governance structures to assist with year-to-year implementation. Including Nations, government, industry, practitioners and academia will really help sustain momentum. Consider hiring an implementation manager that can bring people together, chair meetings, set agendas, scope funding, or program deliveries that can be adjusted to, for example, communicate plans, build operational protocols that help interpret plans to on-the-ground results, and network with other recovery planning tables to share information.

Connect planning to Forest Landscape Plan processes: this planning is being developed and delivered in the non-legal realm, because of the lack of landscape plans to direct recovery. However, these plans are being worked on and can be informed by learnings from these recovery plans.

APPENDIX D ADMINISTRATION GUIDELINES FOR EXTERNALLY FUNDED 2 BILLION TREES PROJECTS ON PUBLIC LANDS IN BRITISH COLUMBIA

Source: British Columbia Ministry of Forests

Administration Guidelines for Externally Funded 2 Billion Trees Projects on Public Lands in British Columbia

Advice for District Staff Administering and Authorizing Externally Funded Natural Resource Canada 2 Billion Trees Reforestation Projects and Associated Activities on Public Land in British Columbia

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I. Background

As part of the Natural Climate Solutions Fund, the Government of Canada has committed to planting two billion trees by 2031. This is outlined in both the Minister of Natural Resource's mandate letter and the 2020 Speech from the Throne. The 2 Billion Trees Program (2BT) has been established by Natural Resources Canada (NRCan) in order to achieve this goal.

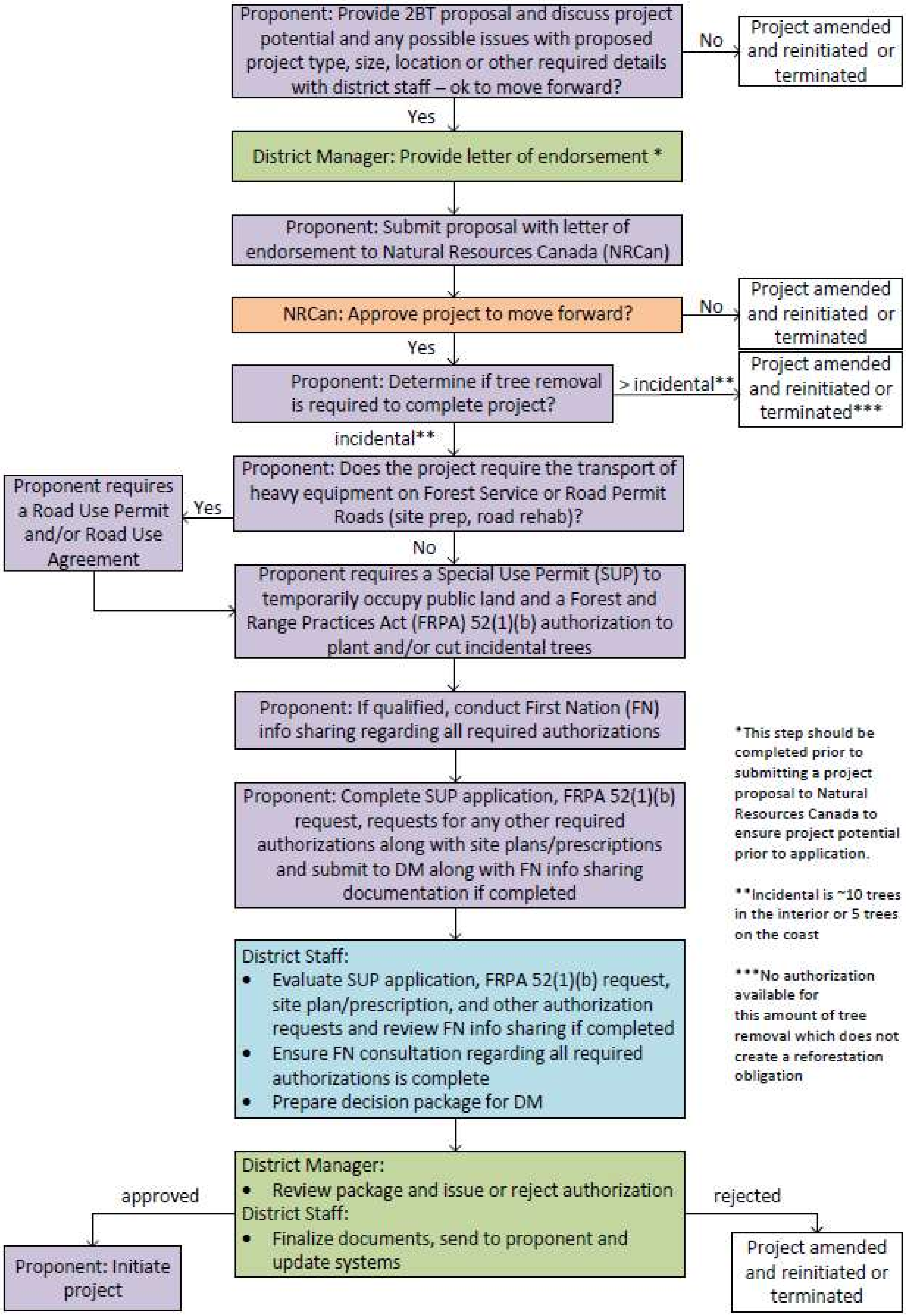
British Columbia (BC) has a 2BT agreement with NRCan to deliver reforestation activities. Proponents external to the BC government may apply for cost recovery agreements directly with NRCan for projects not funded or led by the BC Ministry of Forests (FOR).

This document is intended to assist district staff in the review, administration and/or authorization of these externally funded NRCan 2BT projects proposed on public land in British Columbia.

II. Process Overview

Figure 1 provides an overview of the approval and authorization process appropriate for most types of externally funded reforestation projects located on public land.

Figure 1: Authorization Procedures for Externally Funded 2 Billion Trees (2BT) Reforestation Projects on Public Land



*This step should be completed prior to submitting a project proposal to Natural Resources Canada to ensure project potential prior to application.

**Incidental is ~10 trees in the interior or 5 trees on the coast

***No authorization available for this amount of tree removal which does not create a reforestation obligation

Step 1) District Endorsement: Assessment on whether externally funded reforestation projects should move ahead on public land

District review and endorsement involves the assessment and evaluation of externally funded NRCan 2BT proposals located on publicly managed land. Project proponents requiring the temporary access to, and use of, public land for these projects should contact district managers (DM) and their staff, who should review and provide their support for the project proposals prior to submission to NRCan.

This preliminary review significantly increases the possibility that a project will be authorized to move forward if it is approved for funding by NRCan. However, it does not guarantee future authorization. For example, First Nations consultation, and other land and resource use decisions could affect the results of those applications.
Upon completion of the district staff review, the district manager will make the decision to:

- endorse the project,
- endorse the project with modifications/conditions, or
- not endorse the project.

Upon receipt of a 2BT proposal from a proponent, district staff should review and confirm:

- **Access to and availability of appropriate trees for the proposed areas**: In BC, this involves a multi-year process, with sowing requests for the correct stock based on surveys occurring in year one.
- **Access to publicly managed land**: District staff should request georeferenced maps and/or GIS locations of project areas in order to conduct status and clearance reviews and identify any encumbrances that may prevent the future authorization of the proposed project or use of public lands e.g. conflicting land uses, overlapping existing reforestation projects or obligations, and existing tenures or authorizations.
- **Reforestation capacity and experience of the proponents**: District staff should request and review documentation of proponent-related work experience and history, including a list of previously awarded work, staff qualification, and contact information. District staff should be satisfied the proponent has demonstrated they have the experience and capacity to deliver complex multi-year tree planting projects, they have an understanding of reforestation treatments and practices that meet the project and legislative requirements, and that they have accreditations such as Registered Professional Forester status as required. This includes experience and capacity to complete activities including, but not limited to, surveys, sowing, access management, planting implementation, monitoring tree survival, and reporting into RESULTS for the entire term and breadth of the proposed project.

The 2BT project proposal endorsement options to return to the proponent are:

- **Endorsement:** The district manager will only endorse projects which, upon completion of the review, demonstrate an ability to achieve/meet government goals and objectives and are consistent with land use objectives. Only projects with written endorsement should then be submitted by the proponent to NRCan for project approval. This endorsement only covers work being proposed at the time of endorsement and does not cover any recommendations, conditions, or changes required by NRCan or otherwise. This written endorsement should be provided to NRCan to supplement the proposal and inform their review and decision process. Endorsement does not guarantee that a proposal will be approved by NRCan or authorized by FOR; however, it greatly increases the chances that it will be.

  Proposed projects may be endorsed if they meet the following criteria:

  - They are consistent with provincial government goals and objectives, land use designations (e.g., WHA, UWR, VQO, OGMAs, and WUI), and legislation.
  - Appropriate seed and seedlings are available
  - They have demonstrated competency and experience of proponent and partners
  - They do not conflict with other tenure holders plans and obligations or work already included in a provincially funded program
  - The project location is suitable for reforestation (i.e., not wetlands, agricultural lands or natural grass lands) and not in areas already encumbered by a non-complementary use.
  - The project area is where planting is not already required under an existing obligation.
- **Endorsement with modifications/conditions:** Identified issues or concerns should be documented and discussed with the proponent during the review. For projects with potential, it is recommended that an opportunity be given to the proponent to address issues noted, through an endorsement with modifications/conditions approach. Where modifications are required, identify the issues/concerns to be addressed, and state that the project is not endorsed until an updated proposal is resubmitted and the DM is satisfied that the identified issues/concerns have been addressed. An endorsement with conditions must include any conditions required as part of the project being conducted. As above upon receipt of endorsement or endorsement with conditions, the proponent can then submit the updated project proposal with endorsement to NRCan and this endorsement does not endorse conditions or changes required by NRCan, if applicable.
- **Not endorsed:** District staff should promptly notify the proponent if a project is not endorsed. If the proponent decides to submit their proposal to NRCan without endorsement, and NRCan provides the proposal to FOR for review after submission, this information should then be provided to NRCan for their consideration. NRCan should be made aware that there is lack of DM endorsement, reasons for this, and that there is a low

likelihood for authorization of the proposal activities on public lands. It is recommended that proponents do not submit proposals to NRCan without district endorsement.

Step 2) NRCan Project Approval

NRCan should receive DM endorsement and a summary of comments or conditions (if applicable) for each project prior to approving project proposals and allocating funding. NRCan has indicated that they will provide the Forest Investment and Reporting Branch (FIRB) with a list of proposals for projects located on publicly managed lands in BC prior to NRCan approval. FIRB will bring the proposed projects to the attention of the DM for their input and advice. All input and advice received from the DMs regarding proposals will be provided to NRCan for their consideration prior to the approval of projects and allocation of funds. In the case that projects have not been endorsed, this will be the check prior to NRCan approval of a project.

Step 3) Authorization of 2BT Reforestation Projects on Public Land

For projects subsequently approved for funding by NRCan, the next step required is for proponents to work with FOR District staff on finalizing project details, conducting First Nations consultation, and then submitting applications/requests for authorizations to complete the proposed project. See **Figure 1** for decisions points regarding various authorizations that may be required for different activities.

<u>Note:</u> DMs are responsible for issuing authorizations for use and occupation of public lands. These authorizations are discretionary. The DM is not obligated to issue authorizations, especially if a project is not consistent with legislation, reforestation requirement criteria, and government land use objectives and designations regardless of project proposal approval by NRCan.

Upon receipt of a NRCan approved 2BT project, district staff should determine the specific authorizations required and if First Nation information sharing conducted by the proponent meets government consultation requirements. Non-tenures/authorization staff should discuss projects with tenures/authorization staff to confirm all authorizations required for the approved project.

Table 1 indicates an overview of authorization requirements for potential 2BT reforestation project activities. District staff should complete final status and clearance reviews to determine appropriate authorizations and finalize First Nations consultation as required as part of the authorization process. If the DM is satisfied that all issues have been addressed, First Nations consultation is complete and there is no unjustifiable infringement of Aboriginal rights and title or conflict with government goals and objectives, and there are no conflicts with licensee/BCTS reforestation obligations, they may issue the appropriate authorization(s).

Table 1: Authorizations Required for Non-Obligation Reforestation Projects and Associated activities on Public Land

Eligible Project Activities	Authorization Required	First Nations Consultation Requirements	Comments	Required For: Externally Funded Projects	Required For: Externally Funded Projects on Area-Based Licences	Required For: Contracts with BC Government funded under a vote
Surveys, layout, danger/ wildlife tree assessments etc.	• Land Use Policy Permissions	Discretionary based on district requirements and local agreements with Nations	• No separate authorization or consent required for these activities on most provincial forest lands • See Land Use Permissions Policy for exempted activities	Permitted by policy	Permitted by policy	Permitted by policy
Tree planting	• Provincial Forest Use Regulation Section 9 - Special Use Permit (SUP) • Forest and Range Practices Act (FRPA) 52(1)(b) for silviculture treatments	Required, but can be done in conjunction with other authorizations if conducted by the same proponent for the same area	• SUP's provide authority for non-tenure holders to occupy public land • No long-term or exclusive rights associated with this authorization • FRPA 52(1)(b) authorization provides authority to conduct reforestation projects on public land where authority of occupation has been granted	Both an SUP for silviculture treatments or wildlife habitat enhancements and a FRPA 52(1)(b) for tree planting are required	FRPA 52(1)(b) is required and if activity is NOT conducted by or on behalf of Licence holder, an SUP will also be required	Neither required; First Nations consultation may be required; discretionary based on district requirements

Eligible Project Activities	Authorization Required	First Nations Consultation Requirements	Comments	Required For: Externally Funded Projects	Required For: Externally Funded Projects on Area-Based Licences	Required For: Contracts with BC Government funded under a vote
Moving heavy equipment on forestry roads for site prep or road rehab works	• For Forest Service Roads a Forest Act s 117 Road Use Permit (RUP) is required • For Road Permit (RP)roads a Road Use Agreement (RUA) is required	Discretionary based on district requirements	• Activities funded cannot be associated with legal requirements of road construction, maintenance, or deactivation	RUP and/or RUA required as applicable	RUP required if applicable; RUA required for RP roads not held by licence holder	Not required
Road Rehab Road Work (not including reforestation activities)	• Same as for tree planting	Required	• Activities funded cannot be associated with legal requirements of road construction, maintenance or deactivation • Activities cannot be conducted on a Forest Service Road or road held under a RP holder	See Tree Planting	See Tree Planting	See Tree Planting

Eligible Project Activities	Authorization Required	First Nations Consultation Requirements	Comments	Required For: Externally Funded Projects	Externally Funded Projects on Area-Based Licences	Contracts with BC Government funded under a vote
Cutting incidental trees (~10 interior or 5 coast) for purpose of silviculture treatment	• FRPA s. 52 Authorization (FRPA 52(1)(b) & FRPA 52.1) (both are included in the FRPA 52(1)(b) planting template)	Required, but can be done in conjunction with other authorizations if conducted by the same proponent for the same area	• Authority to cut incidental timber to carry out silviculture, stand tending, forest health, fire hazard abatement or another purpose such as habitat rehabilitation • Separate authority such as an SUP required to occupy land • Provincial government retains rights to the timber • Decked timber can be auctioned or government must complete fire hazard abatement.	FRPA 52(1)(b) in conjunction with an SUP are required	FRPA 52(1)(b) is required and if activity is not conducted by or on behalf of Licence holder, a SUP will be required first	None are required as long as this activity is included in the government contract
Cutting greater volumes than only incidental trees for the purpose of reforestation	• Licence to Cut Regulation Section 4	Required	• Authority to harvest greater volumes than only incidental tree removal if required as part of a site preparation treatment for reforestation • No SUP is required; however, a competitively awarded government contract for reforestation must be in place	Not Applicable – all options available result in reforestation obligations	Not Applicable – all options available result in reforestation obligations	Yes, required

III. Authorization Overview

The following section describes authorization related requirements for various types of 2BT activities. **Appendix 1** provides links to further guidance as well as required templates for the authorizations described.

A. First Nations Consultation:

Following NRCan approval, as a first step in the authorization process, the proponent must proceed with First Nations information sharing regarding all required authorizations, if district staff deems them qualified to do so. If the proponent is not qualified, district or region First Nations Advisors will manage consultation through their own referral process.

Proponents are expected to contact district or region staff prior to initiating the information sharing process for district specific requirements and direction. District or region First Nations Advisors should provide guidance to the proponent on the required level of information sharing and other information relative to the process in their area. Districts or regions may conduct the entire consultation process depending on local policy.

Consultation is required for all authorizations prior to issuance. If the project is being conducted by, or on behalf of an area-based licensee or a First Nation, information sharing/consultation is still required. This information sharing/consultation should be conducted simultaneously for all authorizations required by the proponent for the same area. Authorizations to occupy public land and commence activities must not be provided to a proponent until information sharing is deemed adequate and consultation by the DM or their designate has been completed.

B. Land Use Permissions Policy

The Land Use Permissions Policy allows externally funded proponents to enter public land to conduct surveys with no further authorization or documentation required. These activities however should not be initiated prior to DM endorsement to ensure there is no conflict with existing reforestation projects, tenures, or authorizations. It should be noted that the policy only allows for surveys and that future activities such as site preparation and tree planting do require authorizations.

C. Special Use Permits (SUP)

Special Use Permits (SUP's) are required for use and occupation of public lands by externally funded proponents for the purposes of:

- silviculture treatments
- wildlife enhancement activities
- associated facilities including camps and waste disposal sites if required to conduct the above activities

SUP's however do NOT provide authorization to conduct these activities. They only authorize a person to use or occupy the land.

If a project is conducted by or on behalf of an area-based license holder within their license area, an SUP is not required as the licensee has authorization for use and occupation via the area-based tenure. However, any activity on an area-based tenure not conducted as part of the tenure agreement or obligation requirements will require a Forest and Range Practices Act (FRPA) Section 52(1)(b) authorization. Forest Stewardship Plans do not apply to areas outside of cutting permit areas or net areas to be reforested.

D. Forest and Range Practices Act (FRPA) Section 52(1)(b) Authorization

FRPA 52(1)(b) authorizations are required by externally funded proponents to conduct silviculture activities such as tree planting and cutting of incidental trees to accommodate planting activities on publicly managed lands. These activities cannot be associated with legal obligations. A FRPA 52(1)(b) authorization does NOT provide authority for non-tenure holders to occupy public land. Therefore, an SUP is required prior to or in conjunction with this authorization. No long-term or exclusive rights are associated with either of these authorizations. If a proponent already has the authority to occupy or use the land through another form of tenure, they only require a FRPA 52(1)(b) authorization.

If more than incidental tree cutting/removal is required to complete a reforestation activity, refer to the Licence to Cut Administration Manual and the Guidance on the Use of Forest Act 52 or FRPA 52. These types of projects however, when conducted by externally funded proponents, create reforestation obligations which cannot be legally funded by the 2 Billion Trees Program as per FRPA 120.

The FRPA 52(1)(b) template for planting specifies options and standards for associated activities, as well as requirements for reporting in FOR RESULTS system for tracking and inventory updating purposes. As specified in the RESULTS Information Submission Specifications for Government Funded Silviculture Activities, Individuals, First Nations and agencies who receive direct funding from the Federal Government to conduct forestry activities on public land must use the "FED" Funding Source Code for reporting.

The proponent must comply with WorkSafeBC requirements at all times. Safety standards however do not need to be specified within tenure agreements.

Appendix B of the FRPA 52(1)(b) planting template includes a site plan or planting prescription section. This should be required as part of the application for reforestation and must be signed by a BC Registered Professional Forester. The site plan or planting prescription should state clearly at what point the project proponents will cease to be responsible for the management/maintenance of the trees, and when responsibility reverts to the district. This will allow the district time to schedule and budget future activities as necessary. In preparing the site plan or planting prescription, the prescribing forester should consult with district staff regarding local guidance in silviculture and/or forest landscape strategies, as well as forest health, and other risks to establishment that should be incorporated into the prescription.

Seed and seedlings used must meet the Chief Forester's Standards for Seed Use and is a requirement of the FRPA 52(1)(b) authorization. Stocking standards including species, inter-tree spacing, and densities must be provided as part of the FRPA 52(1)(b) planting template. For projects inside the timber harvesting land base, the standard should, at minimum, be consistent with district default approved stocking standards or those in an approved Forest Stewardship Plan. Higher densities are generally encouraged.

Stocking standards, species selection, stock type, seed source, planting density, and planting season should be consistent with the biogeoclimatic classification system, the Reference Guide for Forest Development Plan Stocking Standards, and climate change adaptation tools to inform seed, genetic material use, and species/seed selection in a changing climate. Deviations should be reviewed and approved by district staff for appropriateness to achieve the desired objectives given expected climate change impacts. For projects with objectives such as riparian restoration, cultural purposes, or wildlife habitat rehabilitation, alternative stocking standards may be specified with supporting rationale.

Depending on the project, the FRPA 52(1)(b) approval decision should be based on forest management decisions including survey methodology, species choice, seed use and sowing, site preparation, danger tree assessments and post treatment follow up activities. Refer to the Stand Establishment and Treatment Standards and the Forest Carbon Information Note on Reforestation for more information on reforestation projects on public land. Under FRPA 52(1)(b), the statutory decision maker can impose pre-conditions or conditions that are considered necessary or desirable including, but not limited to, requiring that the proponent provide security.

E. Road Authorizations

Externally funded road rehabilitation activities cannot be applied to, Road Permits (RP) roads or Forest Service Roads (FSR) which have legally required obligations including road construction, maintenance, or deactivation. The DM may require that a project proposal be amended and resubmitted if it includes these activities on RP roads or FSR's.

If site preparation using heavy equipment is required prior to planting, and access is required to transport heavy equipment on RP roads or FSR's, externally funded proponents are required to attain the following authorizations prior to moving/transporting heavy equipment on forest roads:

- Road Use Permit (RUP) from the DM for use of FSR's
- Road Use Agreement (RUA) from RP holder for use of RP roads

Road rehabilitation, including tearing up roads and deactivation work conducted by externally funded proponents require the following authorizations for roads not under the status of FSR or RP road:

- SUP and FRPA 52(1)(b) as with other site prep and tree planting activities (Note: roads not under the status of FSR or RP are not treated as roads and do not require RUP's or RUA's)
- Status check and consultation with stakeholders and First Nations

If road maintenance on status roads is required, then the following is required:

- Road Work Exemption letter – FRPA 79.1

F. Other Considerations for District Staff When Reviewing Project Proposals and Authorization Requests

District staff should also consider the following when reviewing externally funded project proposals and authorization requests:

- Ensure there are clear project objectives and project types (e.g., wildfire reforestation, riparian objectives, road rehab, etc.) to consider suitability for the location.
- Determine whether the project really needs to be conducted or if the site is regenerating naturally or has a high natural regeneration probability.
- Ensure mid- and long-term maintenance of the planting is considered and included. The 2BT program ends in 2031 and long-term funding for this type of work beyond that date is uncertain.
- Ensure requirements for road rehabilitation to provide access have been considered and stakeholders have been consulted.
- Ensure there is no overlap with existing tenures/authorizations with legislated rights and obligations such as free growing.
- Ensure there is acceptable and available access to complete the work.
- Confirm known hazards or risks will not be exacerbated by the project (e.g., environmental, wildfire, forest health).
- Confirm there is no potential for infringement of proven Aboriginal rights and title.

Appendix 1: Reference Links to Further Guidance and Templates for Authorizations Required for Externally Funded Reforestation Projects on Public Land

Authorization/Activity	Reference (Link)
Land Use Policy Permissions	SECTION 3 (gov.bc.ca)
Special Use Permit (SUP): Provincial Forest Use Regulation Section 9	Forestry SUP website: Special Use Permits Special Use Permit Administration Guide, Templates and Application Forms: FOR-FTA - Special Use Permit - All Documents (sharepoint.com) Memo specific to reforestation SUP: Provincial Forest Use Regulation and Forest Practices and Planning Regulation Amendments
Forest and Range Practices Act (FRPA) s. 52 Authorization: FRPA 52(1)(b) (silviculture) & FRPA 52.1 (cutting incidental trees) - both are included in the FRPA 52(1)(b) planting template	Guidance on the Use of Forest Act 52 or FRPA 52: MRL Letter Template (sharepoint.com) FRPA 52(1)(b) authorization template for planting: FOR-FTA - Forest Act 52 & FRPA 52 - All Documents (sharepoint.com) Stand establishment and treatment standards: Stand Establishment and Treatment Standards - Province of British Columbia (gov.bc.ca) Forest Carbon Information Note on Reforestation: module_3_reforestation_web.pdf (gov.bc.ca) RESULTS Information Submission Specifications for Government Funded Activities: RESULTS Business and Policy Documentation - Province of British Columbia (gov.bc.ca) Chief Forester's Standards for Seed Use: Chief Forester's Standards for Seed Use - Province of British Columbia (gov.bc.ca) Reference Guide for Forest Development Plan Stocking Standards: Stocking Standards - Province of British Columbia (gov.bc.ca)

Authorization/Activity	Reference (Link)
Road Work/Authorizations	Forest Carbon Information Note on Road Rehabilitation: module_4_road_rehabilitation_web.pdf (gov.bc.ca) Criteria for Road Rehabilitation Projects: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nrs-climate-change/mitigation/forest-carbon-initiative/appendix_1_-_road_rehabilitation_project_criteria.pdf Engineering Standards for Road Rehabilitation Projects: FOREST CARBON INITIATIVE (gov.bc.ca)
Licence to Cut Regulation Section 4	License to Cut Administration Manual: Admin Manual (gov.bc.ca)
Further Applicable Guidance Provided Regarding Similar Externally Funded Projects	Authorizations available for projects funded by the Forest Enhancement Society of BC: Authorizations Available for Projects Funded by the Forest Enhancement Society of BC

Appendix 2: List of Acronyms Used in Document

BC Ministry of Forests	**FOR**
2 Billion Trees Program	**2BT**
Natural Resources Canada	**NRCan**
Special Use Permits	**SUP**
Forest and Range Practices Act	**FRPA**
District manager	**DM**
Road Use Permit	**RUP**
Road Use Authorization	**RUA**
Forest Service Roads	**FSR**
Road Permit	**RP**