Breaking Down Barriers:

A Practitioners' Guide to Watershed Connectivity Remediation Planning

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Introduction

Connectivity is a critical component of freshwater ecosystems that encompasses a variety of factors related to ecosystem structure and function, such as the ability of aquatic organisms to disperse or migrate, the transportation of energy and matter (e.g., nutrient cycling and sediment flows), and temperature regulation (see Seliger and Zeiringer 2018 for a thorough review of freshwater connectivity). Though each of these factors are important when considering watershed health, for the purposes of this guide, the term "connectivity" is defined as the degree to which aquatic organisms can disperse or migrate freely through freshwater systems. Within this context, connectivity is primarily constrained by barriers, which can include manmade infrastructure such as dams, weirs, and stream crossings, as well as natural features such as waterfalls and debris flows. The ability to assess, quantify, and improve connectivity through the remediation of barriers is vital, because fragmentation of freshwater systems due to anthropogenic barriers affects the integrity of ecological communities, including their productivity, species and genetic diversity, and population viability (e.g., Díaz et al. 2021; Fullerton et al. 2010; Jungwirth, Muhar, and Schmutz 2000).

Remediating barriers is both time and labour intensive, and as such, scarce remediation resources must be allocated strategically to maximize the ecological return on investment. This guide aims to assist teams in addressing barriers strategically, by providing a framework for watershed-based connectivity planning. Watershed Connectivity Remediation Plans (WCRPs) are long-term, actionable plans that blend local stakeholder and rightsholder knowledge with innovative GIS analyses to identify where remediation efforts will have the greatest benefit for freshwater target species. Plan development is a collaborative process that relies on strong partnerships. As such, building team cohesion and a shared understanding of the current watershed context is critical to the success of a WCRP.

There are a myriad of interconnected and cumulative threats that affect freshwater ecosystems and WRCPs should not be developed in a vacuum. WCRPs focus specifically on the direct remediation and prevention of localized, physical barriers (e.g., dams), rather than broad and chronic land-use issues (e.g., thermal change and sedimentation caused by deforestation); however, the aim is not to allocate limited conservation funding to pursue barrier remediation at the expense of addressing other important threats. Instead, WCRPs help to identify reasonable and achievable connectivity goals, recognizing that fragmentation may never be fully eliminated and that other conservation priorities likely exist. WCRPs are not intended to replace the need for watershed-scale conservation plans or fish habitat restoration plans; instead, they are intended to be nested within these initiatives to strategically address specific barriers to connectivity. As such, WCRPs can be developed as either standalone plans, or as modules of broader watershed-scale conservation or restoration planning initiatives.

Section 1: Conceptualizing a WCRP

There are three interconnected core concepts that WCRP coordinators must consider starting. These are, (1) the watershed for which the WCRP will be developed, (2) a preliminary list of the species that connectivity is being conserved or restored for in the watershed, and (3) a preliminary assessment of the dimensions of connectivity that the WCRP will aim to address, and the barrier types associated with those dimensions. The following sections provide an overview of each of these core concepts.

1.1 Defining the Watershed

The first step in conceptualizing a WCRP is to select the watershed that the plan will be developed for and to clearly define its boundary (i.e., the primary geographic scope - see Section 3.3). The choice of watershed underpins each subsequent step in the planning process, including the identification of potential stakeholders and rightsholders (see Section 2.2). There is no consistent definition of the term "watershed"; WCRP coordinators must ultimately decide on the planning scale that best fits their desired outcomes. If starting from scratch, consider using a provincial or national watershed classification system as a starting point (e.g., the National Hydrographic Network (NHN) Work Unit system; see Appendix A for a list of watershed classification systems by province) and refine your selection by considering your organizational mandate, potential partner priorities, or funding eligibility requirements. Alternatively, a watershed prioritization framework can be applied to strategically identify which watersheds will most likely benefit from connectivity remediation efforts (e.g., NAACC: Prioritize HUC12s for Road-Stream Crossing Surveys, Mazany-Wright et al. 2021b). Prioritization criteria may include population status (e.g., Species at Risk), species richness, barrier density or degree of fragmentation, magnitude of cumulative anthropogenic threats, number of engaged local partners, data availability, and accessibility of the watershed, among others. Though it may be tempting to select large watersheds for efficiency in coordinating connectivity remediation efforts across a broad spatial scale (Neeson et al. 2015), developing the WCRP becomes more difficult as scale increases (i.e., increased number of partners to engage with and greater amounts of knowledge and data to manage). As such, WCRP coordinators should carefully consider the trade-offs between coordination efficiency and the realities of managing the WCRP planning process. To achieve this balance, it is recommended that watersheds not exceed the scale of a NHN work unit or a Hydrologic Unit Code 8, otherwise the planning process risks becoming less tractable.

1.2 Species of Connectivity Concern

Once the watershed boundary is defined, the next step is to consider the species (or in some cases, specific populations of a species) that are affected by fragmentation within the watershed. At this stage, the aim is not to finalize the list of focal species; this choice must ultimately be made by the planning team once workshops begin (i.e., "target species" - see Section 3.2). Identifying a preliminarily list of species will help initiate this discussion. In some cases, the species that the WCRP aims to benefit may be restricted by project funding criteria (e.g., a grant focused exclusively on aquatic Species at Risk) and will therefore need be identified before partner engagement begins. Once the preliminary list of species is identified, clearly define the life history characteristics of each species (see Table 1). If you choose to target all species in the watershed, or many species, it may make sense to group them together into target species guilds. Target species will be revisited when evaluating habitat modelling and connectivity assessment methods (see Section 4.3) and will inform the final step of conceptualizing a WCRP: defining the dimensions of connectivity and associated barrier types.

Table 1. Typical life history characteristics of freshwater species.

Life history	Description
Diadromous	Species that migrate between the ocean and freshwater to complete their life cycles. These include species that spawn in freshwater and migrate to the ocean (anadromous) and vice versa (catadromous; Gross, Coleman, and McDowall 1988).
Adfluvial	Species that migrate between lakes or reservoirs and rivers (Watry and Scarnecchia 2008).
Fluvial	Species that migrate between mainstem rivers and tributaries (Schmetterling 2001).
Resident	Species that typically spend their entire life cycle near where they hatched, though may occasionally disperse (Narum et al. 2008).

1.3 Connectivity Dimensions and Barrier Types

The final conceptualization step is to define which of the four structural dimensions of freshwater connectivity can be addressed by the WCRP (see Table 2; Figure 1) and to draft a list of barrier types that are associated with those dimensions. As with the other conceptualization steps, the purpose of this exercise is not to pre-empt the planning team in deciding which connectivity dimensions and barrier types the WCRP *will* address (see Sections 3.3 and 3.4), but to identify which connectivity dimensions and barrier types the WCRP *could* address if chosen by the planning team. For example, funding eligibility requirements may be limited to certain connectivity dimensions or barrier types. This must be understood by the WCRP coordinators prior to engaging with partners so as to manage expectations. Even if no external constraints exist, WCRP coordinators should understand the four dimensions of connectivity and critically assess which may be included in the WCRP.

Table 2. The four structural dimensions of freshwater connectivity.

Connectivity Dimension	Description
Longitudinal	Connectivity of a stream along the upstream-downstream plane (Figure 1), including access to tributaries and spawning and rearing habitat. Longitudinal connectivity can be fragmented by physical barriers (e.g., anthropogenic or natural structures) or by physiological limits of distribution for species (e.g., stream gradient, temperature, or flow requirements).
Lateral	Connectivity of a stream bed to adjacent riparian wetlands and floodplains (Figure 1), including access to rearing and overwintering habitat. Lateral connectivity can be fragmented by physical barriers, channelization, armouring of the stream bed, or artificial flow regulation.
Vertical	Connectivity of a stream bed to groundwater/hyporheic zone (Figure 1), including access to oxygen-rich temperature refugia. Vertical connectivity can be fragmented by water withdrawals and anthropogenically induced changes to the hydrological, thermal, and sediment regimes of the watershed.
Temporal	Connectivity variability in any of the three spatial dimensions based on temporal changes in the natural flow regime. Variation in temporal connectivity occurs naturally; however, fragmentation can be exacerbated through anthropogenically induced changes to the hydrological, thermal, and sediment regimes of the watershed.

As noted, WCRPs are intended to focus on the direct remediation and prevention of localized, physical barriers rather than broad land-use patterns that are causing chronic connectivity issues, and it is this distinction that differentiates a WCRP from traditional watershed or fish habitat restoration plans. As such, the dimensions of connectivity that WCRPs will typically focus on are longitudinal and lateral, because field assessment, remediation planning, and barrier prioritization methods are further developed for these (McKay et al. 2020). For this reason, this guide does not explicitly address the remediation of vertical or temporal barriers (although WCRP coordinators are free to include these dimensions if they wish to do so). Nonetheless, it is recommended that vertical and temporal connectivity still be accounted for when developing a WCRP focused on longitudinal or lateral barriers, because vertical and temporal factors can influence the success of remediation actions. For example:

- Longitudinal and lateral barriers may be passable to fish at certain times of the year, but alignment of passability timing with the needs of each life history stage must be considered when prioritizing barriers for remediation (e.g., juvenile migration to rearing habitat; Zeiringer et al. 2018).

- Vertical connectivity issues may need to be addressed in conjunction with remediating longitudinal or lateral barriers (e.g., installing beaver dam analogues in conjunction with dyke breaching to expand the area of groundwater influence and cold water refugia; Weber et al. 2017).

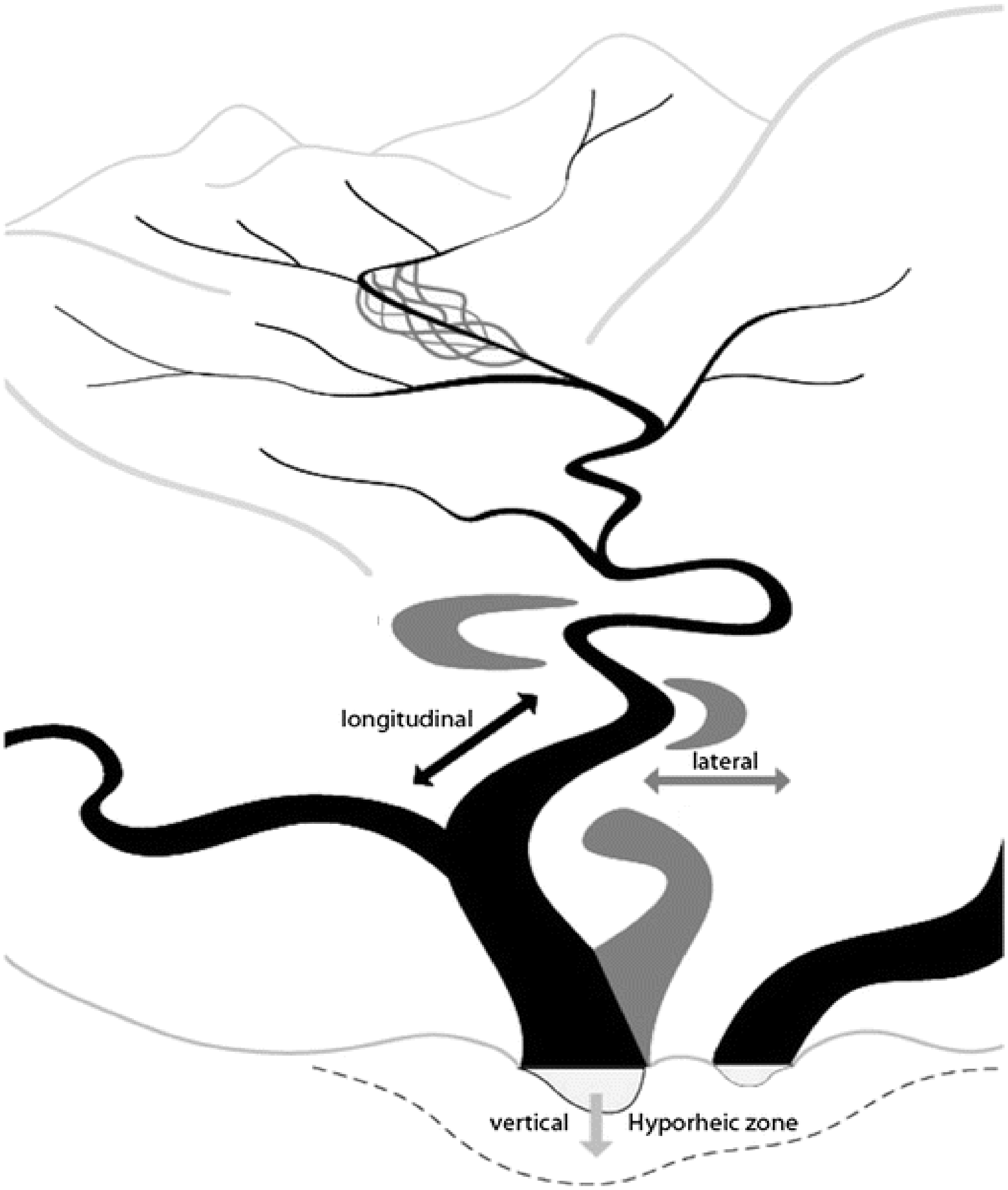

Figure 1. An illustration of the three spatial dimensions of freshwater connectivity. Adapted from Seliger and Zeiringer 2018 (CC BY 4.0).

Once initial connectivity dimensions are defined, the next step is to list the barrier types that can be addressed in the WCRP (see Table 3). For example, even if longitudinal connectivity is one of the dimensions to be included in the WCRP, there may be specific longitudinal barriers that the WCRP coordinators choose not to prioritize for remediation in the WCRP (e.g., waterfalls).

Table 3. A non-exhaustive list of barrier classes, barrier types, and their respective connectivity dimensions.

Barrier Class	Barrier Types	Spatial Connectivity Dimensions
Water-control structures	Dams	Longitudinal
	Weirs	Longitudinal
	Water-withdrawal structures	Vertical
Flood-mitigation infrastructure	Tide gates, aboiteaux	Longitudinal/lateral
	Pump stations	Vertical
Stream crossings	Road-stream crossings	Longitudinal
	Rail-stream crossings	Longitudinal
	Trail-stream crossings	Longitudinal
Lateral	Dykes, levees	Lateral
	Roads, rail lines	Longitudinal/lateral
	Berms, embankments	Lateral
Natural	Waterfalls	Longitudinal
	Debris jams (e.g., rocks, logs)	Longitudinal
	Sediment wedges	Longitudinal/lateral

Barrier Class	Barrier Types	Spatial Connectivity Dimensions
Physiological	Gradient	Longitudinal
	Flow	Vertical
	Temperature	Vertical/longitudinal
	Water quality	Vertical

Section 2: Partner Engagement

Once the WCRP is conceptualized and funding is secured, the next step is to develop an effective process for engaging stakeholders and rightsholders. The term “stakeholder” refers to any individual or group that has an interest in freshwater connectivity within the projects’ primary geographic scope. Examples may include federal, provincial, or local governments, non-governmental organizations, academics, natural resource companies, and local environmental groups, among others. The term “rightsholder” refers to Indigenous peoples with traditional territory that coincides with the primary geographic scope. Indigenous peoples have an internationally recognized right to support or oppose activities that occur within their traditional territory, and as such, distinguishing between stakeholders and rightsholders is critically important to avoid conflating the distinct rights of Indigenous peoples with the interests of other groups. Meaningful engagement with stakeholders and rightsholders (hereafter called “partner engagement”) is essential when undertaking a partner-based strategic planning process such as a WCRP, given that success is ultimately dependent on building relationships, fostering collaboration, and maintaining strong team cohesion throughout the lifespan of the plan. To achieve this requires two-way communication and knowledge sharing, as well as a sincere desire to understand and integrate the spectrum of stakeholder and rightsholder views, interests, and values into the WCRP.

2.1 Planning for Partner Engagement

Partner engagement provides an opportunity for all stakeholders and rightsholders to be informed and involved throughout the strategic planning process, while also providing important contributions toward the development of the WCRP. It allows those who may affect, be affected by, or have an interest in the outcomes of a WCRP to collectively pool knowledge, experience, and expertise to co-create solutions to important connectivity challenges in the watershed. Partner engagement can help build productive and collaborative relationships and improve communication channels. Listening to multiple perspectives throughout the planning process enables organizations to better address criticisms and concerns, effectively solve problems, and ultimately ensure that there is clarity of purpose and a shared vision for the future.

Engagement can also help to determine the level of interest and support that exists for developing a WCRP in the watershed. Partners often have firsthand information about current or past conservation work in the watershed and the types of knowledge and data needed for development of the WCRP. Upon completion of the WCRP, some partners in the watershed may choose to take ownership of the plan or contribute to specific components of the plan’s implementation. Overall, engagement should help to align the WCRP with the conservation goals and priorities of the local communities in the watershed.

2.1.1 Defining the purpose of initial engagement

Before any engagement occurs, first identify what you aim to achieve during initial partner engagement, such as an introduction to the coordinating organization, requesting permission to work in a specific geographic area, gauging the level of familiarity and support for the proposed work, providing information about the planning process, or requesting participation in developing the WCRP. Regardless of the aim, initial engagement should begin early so that WCRP coordinators can flag any potential issues that may affect the planning process. Some important questions to consider when defining the purpose of initial engagement are:

- Is the potential partner familiar with my organization or the WCRP process?
- What do I want to learn about this potential partner?
- What are the key freshwater conservation issues to be discussed during this conversation?
- Are potential partners being asked to contribute time or other resources?
- Are resources available to support their involvement in the WCRP process?
- Does the potential partner have past experience working with conservation organizations? If so, were those experiences positive or negative?
- Are there important timeframes to consider for initial engagement?
- Are there legal obligations to consider for engagement?

2.1.2 Core values for participation

The core values for participation are guiding principles that influence how partners will participate in various stages of the WCRP process. Developing a set of core values like those presented in Table 4 will not only help strengthen the engagement process, but also help communicate expectations on how the WCRP process will unfold over time.

Table 4. Core values for partner participation.

Core Value	Description
Committing to include partners in conservation decisions.	Partners have a voice when decisions about conservation actions could affect their interests, cultures, or livelihoods.
Ensuring contributions from all partners are considered.	The coordinating organization has clarified that participation from partners means that all contributions made throughout the planning process will be collectively discussed and considered for inclusion in the final WCRP.
Promoting a transparent decision-making framework.	When the needs and interests of all partners are recognized and communicated openly and transparently, decisions can be sustained over the long term throughout the planning process.
Allowing partners to determine how they participate.	Partners are responsible for determining both how they participate and their level of involvement throughout the process of creating and implementing a WCRP.
Sharing information in a meaningful way.	Information that is needed to participate in the planning process is provided to partners.
Communicating how partners have influenced the final WCRP.	Communicate how contributions from partners have influenced the stages of the planning process and the final WCRP. This may be done through regular updates, meetings, workshops, or other forms of communication.

2.2 Identifying Partners

2.2.1 Developing a partner register

Identifying and creating a register of potential partners is the next step in the engagement process. The register should comprise a preliminary list of all partners with interest, activities, or traditional territory in the watershed. It should identify key individuals and their role within their respective group or organization, contact details, and any additional information that may be relevant to the engagement process. Once engagement commences, the register can be used to track contact attempts, including date(s) and method(s) of engagement. When working with numerous partners, this can help streamline the engagement process and provide a basis to gauge if or when subsequent engagement attempts should be made. The register should also be updated as partners identify other groups and organizations to engage in the WCRP process over time. An example of a partner register is available in Appendix B.

2.2.2 Level of partner participation

There are multiple ways a partner can contribute to the development of a WCRP, which are often limited by their interests or capacity (both financial and time; see Table 5). This information can be captured in the register and updated over time if applicable.

Table 5. Levels of potential partner involvement influenced by interest and capacity.

Levels of Participation	Description
No further participation	The goals and scope do not align with the partners' goals and scope of work.
Receive updates	Partners are interested in learning about the initiative and remaining apprised on project progress and results.
Contribute	There is an interest and capacity from partners to participate in the planning or implementation of the WCRP. This may involve more frequent and direct engagement throughout plan development or taking responsibility for certain actions during implementation. The organization or other lead group(s) have planning and implementation responsibilities.
Lead	There is an interest and capacity from partners to lead or co-lead the development or implementation of the WCRP. This may involve one or more groups leading all or most of the process, including partner engagement, plan development, implementation, and reporting.
Coordinate	There is an organization with the resources and expertise to coordinate the development or implementation of the WCRP. The coordinating organization may also play the leading role, but this is not always the case (e.g., a national organization instigating a local planning process and seeking local coordination, but the lead partner is ultimately responsible for the project's implementation).

2.3 Engaging with Partners

2.3.1 Methods of engagement

The methods of engagement should be tailored to meet the needs of local partners, and may include one or more of the following:

- Individual or group telephone or videoconference calls
- Email
- In-person meetings with individual partners or groups of partners

If the primary geographic scope of a WCRP covers a large area, any in-person meetings should be held in a central location or across several different locations to ensure that as many partners as possible have an opportunity to attend. There may also be temporal considerations when engaging with partners; telephone calls and virtual meetings should account for the different time zones in which partners may be located. Engagement methods may change over time, both in response to seasonal changes, such as when partners are busy with field work during in-stream work windows, or during unforeseen circumstances, such as the onset of COVID-19. Remain flexible and accommodate the needs of each partner.

2.3.2 Partner profiles

Creating a profile for each partner provides an opportunity to document any important information about their potential involvement in the WCRP, as well as to track any key issues, concerns, or questions that are raised by the partner. Having an internal system for following up on important items that were raised is critical to provide clarity, build trust, and streamline communication during future engagement. Profiles provide a detailed summary for partners who agreed to actively participate in the planning process. Profiles should be updated throughout the planning process as new information becomes available over time. A partner profile template is available in Appendix C.

2.3.3 Building trust

Building trust is an essential prerequisite for meaningful partner engagement, as is a commitment to deepening that level of trust. Investing time to understand the motivations and concerns of partners can lead to strong, open, and receptive relationships where misunderstandings are reduced. Leading with empathy and striving to find solutions that benefit all partners are both key to building trust and team cohesion. Being transparent about the status of the planning process and development of the WCRP, and keeping partners apprised of progress, setbacks, and shifting timelines and priorities, is also key to building a culture of trust. This should include directly communicating any issues or concerns that are brought forward and asking partners for help and advice when needed. When building trust, only make commitments if they can be fulfilled.

2.3.4 Obstacles to engagement

Recognizing and addressing obstacles to partner engagement can help to achieve equitable participation when developing the WCRP. Obstacles to engagement may vary depending on a variety of socioeconomic factors (see Table 6). Developing solutions that work toward reducing these barriers will help to increase engagement in the WCRP.

Table 6. Obstacles and solutions for partner engagement.

Obstacle	Solution
The partner is located in a remote area with limited telephone or internet access.	Allow the partner to convey their preferred method and frequency of engagement.
The partner cannot engage or participate without funding.	Determine if your organization can provide or help obtain funding prior to engagement.
There is limited time or staff capacity that can be invested in the planning process.	Provide flexibility and allow the partner to determine how much time they invest in the planning process.
The partner has other projects and priorities to focus on.	Provide information and benefits of the WCRP to the partner, allowing them to determine if this project should be added to their list of priorities.
Staff changes within a partner's organization.	Introduce yourself, the organization, and the WCRP planning process to new staff and offer support and background materials on the project.
Mistrust has been created from past conservation initiatives, including concerns that the planning process will not translate to direct conservation action.	Identify key concerns and focus on building trust. If there is skepticism as to whether the WCRP planning process will translate into action, acknowledge that this often happens with planning initiatives and describe the steps that will be taken to ensure the WCRP is implemented.
There is real or perceived overlap with existing work or duplication of effort.	Identify the related aquatic conservation planning that has occurred in the watershed and clearly communicate how the WCRP is either distinct from this existing work or will build upon the existing work and add value.

2.3.5 Frequency of engagement and techniques

WCRP coordinators should proactively determine the frequency of engagement based on the level of participation of each partner's choosing. For example, partners may prefer longer intervals between communications, regular engagement, or a single multi-day workshop. Partners that are leading or contributing should be engaged regularly and included in all important communications, whereas those that wish to receive updates may prefer to be contacted when important milestones have been reached. Effective engagement may require several separate events using a variety of techniques at different points throughout the planning process (see Table 7).

Table 7. Coordination techniques for engaging with stakeholders and rightsholders.

Technique	Description
Hosting a Partner Engagement Meeting (PEM)	A PEM is an opportunity to listen and have an open discussion with partners early in the relationship-building process to learn more about the watershed, local conservation priorities, introduce the scope, aims, and steps involved in creating a WCRP, and identify potential opportunities for collaboration.
Establishing a formal Working Group	A formal Working Group is established for the partners desiring a higher level of participation in the planning process.
Hosting a series of workshops	Workshops provide opportunities to: (1) communicate planning outcomes, data summaries, responses to previous questions, and other information needed to inform decision-making; (2) make collective decisions; and (3) allow partners to express their views.
Knowledge and data validation	Having local partners validate and contribute data captures on-the-ground knowledge.
Awareness and outreach	Sharing highlights and success stories with the public through web and social media posts can help generate support for the work being done.

2.3.6 Core principles for effective engagement

Developing and following a set of core principles (see Table 8) for effective engagement with partners should be a continuous process. Effective engagement is essential to ensure the successful development and implementation of a WCRP because the planning process necessitates that local partners actively contribute to establishing goals to improve the connectivity status of the watershed and identifying strategies and actions that will be undertaken locally to achieve on-the-ground gains in connectivity (see Section 3.7). Additionally, a significant component of WCRP implementation requires field work to assess barriers, confirm habitat, and remediate barriers and will occur on the traditional territory of Indigenous groups or privately owned land in the watershed. Ensuring that partner engagement is undertaken respectfully and effectively will help to facilitate the necessary collaborations and permissions that are required to undertake this field work. A good set of core principles should be flexible to incorporate feedback from partners and adapt to shifting needs and priorities.

Table 8. Core principles for effective partner engagement.

Principle	Description
Two-way communication	Both sides can exchange views and information, and have their questions and concerns addressed.
Transparent information	Available information and analysis are transparent and contextualized to provide partners with a holistic image of the planning process.
Inclusive representation	All partners are provided an opportunity to engage regardless of gender, race, age, class, sexual orientation, education, or religion
Equitable representation	Partners that belong to minority groups or have less power and influence in the watershed have equal opportunity to contribute to the planning process (Volger, Macey, and Sigouin 2017).
Engagement is continual	Engagement is ongoing and iterative and will start as early as possible in the planning process. Partners will not feel abandoned by the WCRP coordinators.
Engagement is culturally sensitive	The organization is aware that the outcomes of a WCRP may affect groups differently. These may include social, cultural, and spiritual effects.
Indigenous Traditional Knowledge is respected	The organization shares Indigenous knowledge in an appropriate or accepted way. This may involve following the OCAP® (Ownership, Control, Access and Possession) principles and negotiating knowledge and data-sharing agreements (see Section 4.1.3).
Recognize trade-offs	Recognizing trade-offs acknowledges that partners might not achieve all their desired outcomes from a WCRP.
Local goalsetting	Conservation goals usually define tradeoffs between ecological and socioeconomic priorities. They are not objective, or quantitatively derived. As such, they must be made by local stakeholders and rightsholders who live with the outcomes of such tradeoffs.

Section 3: Developing the WCRP

The WCRP process follows a modified version of the Conservation Standards (CS; CMP, 2020), which is conservation planning framework designed to systematically plan, implement, and monitor conservation actions. Planning teams work through the various CS planning steps, ideally with the assistance of a professional CS facilitator (or "Conservation Coach"), which helps to ensure that limited time is budgeted appropriately for each planning step and that discussions stay on topic. The WCRP process described here includes several modifications to traditional CS terminology and the order of the planning steps, to better reflect the sole thematic focus on freshwater connectivity and the iterative nature of the underlying GIS analyses used to support decision making (see Section 4). These modifications are described in each of the sections below where applicable. Though partner engagement is treated as a separate section in this document (Section 2), engagement is ongoing throughout the development of WCRPs and is critical to the success of both the planning effort and subsequent implementation.

3.1 Establish the Team, Workplan, and Project Purpose

Based on feedback and survey responses from stakeholders and rightsholders following preliminary partner engagement (see Section 2.3), you should now have a clear understanding of who is on the planning team. Next, develop a simple but comprehensive team charter that, at minimum, details each participant's name, the organization or group that they represent (if applicable), their role in developing the plan (e.g., coordinator, facilitator, core team member, or advisor), and the specific skills or expertise that they bring to the project. Given that participant turnover will likely occur over the lifetime of the plan, by maintaining an updated team charter, you will be able to track any gaps in roles, skills, and expertise if team members leave and new members are sought after to replace them.

A clear workplan lets team members know what time commitment to expect. To create one, first consider the number and length of workshops required to complete the planning process. There are several variables that will influence how long a planning process will take, such as the number of team members, the number of target species selected (see Section 3.2), whether certain planning steps will be accomplished outside of a workshop setting, and whether workshops will be held in person, over videoconference, or a combination of the two. If hosting videoconference workshops, a starting point is to plan for two-hour workshops (or multiple sessions of a maximum of two hours each) scheduled at two- to three-week intervals. If in-person planning is preferred, a single two-day workshop may suffice, and videoconference workshops can be scheduled, if necessary, to complete any remaining work. Be flexible and prepared for uncertainty; workshop scheduling is an iterative process, and the number, length, and discussion topics of workshops will likely change from the original workplan as you begin to better understand the dynamics and priorities of the planning team.

At the beginning, review the project purpose and approach as initially introduced during preliminary partner engagement (see Section 2.3). This not only helps to reinforce the big picture of what the project is working to achieve, but also allows participants to ask additional clarifying questions. A best practice is to craft a purpose statement that captures the overall intent of the planning process in 1-3 sentences, which can be referred back to throughout the planning process. This is best accomplished by presenting a draft purpose statement and allowing the team to provide feedback and suggest edits until the team is comfortable with the result. Though a purpose statement can be crafted prior to a workshop if time is a concern, allowing participants to discuss and formulate the purpose statement together is preferred, because this helps to foster a shared understanding of the project purpose and contributes to strengthening team cohesion.

3.2 Define Target Species and Conduct Connectivity Status Assessments

Target species (or "Targets" in CS language) represent the species or groups of species that connectivity is being conserved or restored for in the watershed. In most cases, it is assumed that target species will typically be either specific fish species (e.g., Chinook Salmon; *Oncorhynchus tshawytscha*) or species groups (e.g., Pacific salmonids), although non-fish target species could also be included if desired (e.g., Signal Crayfish; *Pacifastacus leniusculus*). The choice of which target species to select will depend on several factors, such as funding source priorities, the availability of species-distribution data to inform the spatial analyses, and the ecological and cultural priorities of the team. Within a workshop setting, a best practice is to (1) present the team with an initial list of species that are known to be affected by fragmentation in the watershed, (2) brainstorm whether any additional species should be included, and (3) go through a grouping exercise to combine species into groups where appropriate. Though there are no rules on how best to combine species into groups, factors such as life history (e.g., anadromous or resident) and distribution in the watershed (significant overlap or distinctly separate?) can be helpful starting points for discussion. Even if the planning team wishes to include all species, combining them into groups that may require different conservation approaches will help keep the plan strategic and focused. All else held equal, fewer target species will make the planning process easier and more time efficient. As such, it is recommended to task the group with identifying as few, meaningful target species as is appropriate.

Once target species are selected, the next step is to assess the connectivity status of each target species ("Target Viability" in CS language). In doing so, the planning team will establish an initial condition against which progress will be measured over the course of implementing the plan (see goals - Section 3.7). This process involves selecting, (1) a minimum of one Key Ecological Attribute (KEA), (2) an indicator that will be used to measure the KEA, and (3) definitions of four ratings that represent what a hypothetical connectivity status of Poor, Fair, Good and Very Good mean in relation to the indicator. In most cases, habitat-based KEAs that use linear- or area-based indicators to quantify the degree of habitat fragmentation in the watershed are recommended over species-specific responses to fragmentation (e.g., genetic exchange or population responses). The latter forms of data are rarely if ever available to confidently track the progress of WCRPs, and the time and resources that would be required for project teams to undertake initial studies and subsequent monitoring activities is likely to be impracticable for the majority of WCRP initiatives. Species-specific responses to fragmentation are also likely to be moderated by other factors external to the scope of the WCRP, including harvest, climate change, and other habitat influences. For more information on how to select and quantify habitat-based connectivity KEAs and indicators, see Section 4.3.2. Initially, defining indicator ratings for habitat-based KEAs will likely boil down to subjective decisions representing the best judgment of the planning team, and the aim should be to choose ratings that the planning team feels comfortable with rather than trying to establish values that are objectively correct. Indicator ratings can be revised later, as knowledge of the system increases.

Connectivity status assessments are thus created for target species by identifying KEAs and associated indicators and status ratings, and subsequently assessing the current status relative to these indicators. As a starting point, it can be helpful to present a draft connectivity status assessment for the team to discuss and edit (see Table 9). Depending on the target species selected and the spatial data available, teams may decide to refine the assessment by developing several KEAs and indicators for each target species, such as metrics for different habitat types (e.g., spawning habitat, rearing habitat, overwintering habitat). Though a wish list of indicators and associated datasets will inevitably be identified, focus discussion on assessing connectivity status based on the best available information. Ideally, the best available information will be comprehensive GIS datasets on the distribution of the target species and their respective habitats throughout the watershed, but this will rarely be the case. When less-than-ideal data are the only option, move forward with these data as a starting point, record their limitations and any assumptions about how the data will be interpreted, and, if warranted, identify the information needed to improve the assessment as a knowledge gap[1] (see Section 3.7). Once the team establishes KEAs, indicators, and indicator rating definitions for each target species, the current connectivity status can then be calculated within a GIS (see Section 4.3.1).

Table 9. An example connectivity status assessment for an anadromous fish species.

			Indicator Ratings			
Target Species	KEA	Indicator	Poor	Fair	Good	Very Good
Atlantic Salmon	Available spawning habitat	% of total linear spawning habitat accessible	<50%	51 - 75%	76 – 90%	>90%
Current status:					**84%**	

[1] A Knowledge Gap describes what needs to occur to generate new knowledge and information that will be used to better inform planning and implementation.

3.3 Determine the Project Scope

Defining the scope of a WCRP can be a complex process that will likely be multi-step and iterative in practice, though is treated as a single step in this guide for the sake of clarity. The target species that are selected can have a significant influence on the scope of a WCRP. As such, it is recommended to introduce scope *after* defining the target species of interest. WCRPs have both a geographic and thematic scope, which are further divided into primary and secondary definitions.

The primary geographic scope of a WCRP represents the watershed boundary, which in most cases will have been identified in the early stages of the project prior to establishing the planning team (see Section 1.1). However, the secondary geographic scope requires refining the watershed boundary to identify only those portions of the watershed for which the barrier prioritization and remediation will be conducted, and subsequent remediation efforts will take place (i.e., watershed exclusion areas – see Section 4.2.5). Particular areas might be excluded from a WCRP because of the presence of invasive species for which barrier remediation would expand their range and pose a threat to native species, a known absence of suitable habitat for the target species, or other potential threats that could negate the benefit of opening up additional habitat (e.g., toxic pollutants or increased temperatures that render habitat inhospitable). These considerations should all be discussed with the planning team, and a combination of existing data (if available) and local knowledge should be used to spatially identify affected areas (see Section 4.2.5). Once the team has identified the areas to be excluded, these can be delineated in GIS and used to create the secondary geographic scope map for the WCRP.

In addition to geographic scope, WCRPs also have a primary thematic scope, which is freshwater connectivity. Though this may seem obvious, it should not be assumed that all planning team members have a shared understanding of freshwater connectivity concepts, and these must be defined and clarified early in the process to avoid confusion and scope creep. Once the team gains a shared, conceptual understanding of freshwater connectivity, the secondary thematic scope can be introduced, which represents the specific dimensions of freshwater connectivity that the WCRP intends to address. As discussed in Section 1.3, there are many types of freshwater connectivity issues and it may not be possible to address all of these. Decisions will depend on a variety of potential factors, such as funder expectations and the expertise of planning team members. There can be considerable nuance on how various connectivity issues interact in a watershed, and adequate time should be dedicated to discussing this nuance with the planning team.

3.4 Identify and Rate Barrier Types

Barriers are defined as anything that is obstructing passage by target species or fragmenting their habitat (equivalent to “Threats" or "Pressures” in CS language). Based on the preliminary GIS analyses (see Section 1.3) and thematic scope discussions with the planning team, you should now have a good understanding of the types of barriers that will be included in the remediation plan. The next step is to explicitly list those barrier types and determine their relative effects on the target species using a modified version of the CS Threat Rating Assessment tool (see Appendix D for the Barrier-Type-Rating Assessment). This tool allows teams to consistently assess each barrier type based on its "Extent" (i.e., the proportion of target species habitat that is affected by the barrier type), "Severity" (i.e., the proportion of the barrier type occurrences that are blocking passage to the target species), and "Irreversibility" (i.e., the degree to which the effects of a barrier type can be reversed, and connectivity restored). Wherever possible, extent and severity assessments should be informed using relevant GIS data, however, in the absence of these data, the assessments can be still be completed using local knowledge, even if this is a best guess by the planning team. This also holds true for the irreversibility assessment, which is inherently more subjective in nature. Regardless of how the assessments are completed, it should be clearly communicated to the planning team that the results are never final, and that they can be updated if better information becomes available. The barrier-type-rating assessment will give the planning team a shared understanding of the relative effect (rated as Low, Medium, High, or Very High) of each barrier type on the target species (see Table 10). Ask the planning team whether the final barrier ratings make sense and, if necessary, revisit the assessment until everyone is satisfied with the results.

Table 10. An example barrier-type-rating assessment.

Barrier Types	Extent	Severity	Irreversibility	Overall Threat Rating
Large dams (>3m height)	Low	Very High	High	Low
Small dams (<3m height)	Low	Very High	Medium	Low
Road-stream crossings	High	Very High	Medium	High
Rail-stream crossings	High	High	Medium	High
Trail-stream crossings	Medium	Medium	Low	Low
Lateral barriers	Medium	Very High	Medium	Medium
Natural barriers	Medium	High	Medium	Medium

3.5 Conduct a Situation Analysis

A situation analysis is a process for establishing a shared understanding of the broader project context. Within the context of a WCRP, this involves, (1) describing the complexity of underlying social, economic, cultural, or political factors that contribute to connectivity issues in the watershed, and (2) using the results to identify potential actions to address these connectivity issues (see Section 3.6). To begin a situation analysis, the planning team must decide which barrier types to focus on, and this will depend on the amount of time available, the number of barrier types identified, and the barrier effect ratings (e.g., if there are many barrier types, teams may decide to only develop a situation analysis for barrier types rated as High or Very High). Barrier effects ratings are not meant to dictate which barrier types to include in a situation analysis, but merely to inform this decision.

Once the barrier types are chosen, present a draft situation analysis to the planning team (such as from an existing WCRP) to stimulate discussion (see Appendix E). When presenting a draft situation analysis, give the team the opportunity to verify, edit, or remove each of the contributing factors included in the draft. Ask questions about each factor's relevance to the watershed and whether phrasing can be improved to reflect the specific watershed context. This will likely stimulate ideas about additional contributing factors as well, which should be included in the analysis. Discussion should focus on factors that are within the project scope, because there are diminishing returns in discussing factors beyond those that can realistically be addressed by the team (e.g., human population growth, capitalism). Once all contributing factors have been identified, time should also be set aside to explicitly focus on identifying potential actions, though these might also be suggested while identifying contributing factors. The situation analysis can be considered complete when the team has exhausted all new ideas. The facilitator's role is to capture all the information generated by participants during the exercise, but also to ask probing questions to clarify uncertainty and ambiguity, uncover potential biases, and challenge assumptions. The project scope can be referred to when deciding whether to include tangential ideas that arise. This is to ensure that the team is building a realistic model of the watershed context, which is essential for identifying meaningful actions.

3.6 Craft a Vision Statement

A vision statement is a concise (1-3 sentences) yet aspirational description of the ultimate condition that the project is working to achieve. Although establishing a vision statement is often conducted as one of the first steps in the CS planning process, for the purposes of a WCRP, it is recommended to do so after completing the situation analysis so that team members can craft a collective vision for the future based on a shared understanding of the connectivity context of the watershed. When conducting a visioning exercise, present a draft statement for participants to review and modify rather than generating a vision statement from scratch. Similar to the purpose statement (see Section 3.1), the vision statement can also be developed outside of a workshop setting if time is a concern; however, there are several benefits to conducting visioning exercises in a group setting, such as building team cohesion and fostering a shared sense of motivation to achieve the collective vision for the future.

3.7 Define Connectivity Goals

In the context of a WCRP, goals are defined as formal statements of the desired future status of the target species' Key Ecological Attributes (see Section 3.2). Each target species should have a minimum of one goal, which involves, (1) reviewing the status assessment for the target species, (2) selecting a KEA and indicator to be represented as a goal, (3) writing the draft goal that defines the desired future connectivity status, and (4) applying the five criteria of a SMART Goal:

- **S**pecific: Each goal should be directly linked to the target species and phrased so that team members have a shared understanding of the goal's intent.
- **M**easurable: Definable in relation to a specific unit of measurement (e.g., the connectivity status indicator).
- **A**chievable: Can be accomplished by the planning team within realistic constraints (e.g., financial, time, ethical).
- **R**esults-oriented: Represents the change necessary to improve the connectivity status.
- **T**ime-bound: Framed within a specific period of time.

In some cases, a lack of baseline data may make it impossible for a goal to meet all five SMART criteria (e.g., a goal is drafted to increase access to an important habitat type, but that habitat type has not yet been mapped in the watershed, so the current connectivity status is unknown). In these cases, draft goals to meet as many of the five SMART criteria as possible, and identify the limiting factor(s) as a knowledge gap. Though goals should be informed by the best-available information, the goal-setting process is both subjective and iterative, and the aim should be to develop goals that the planning team feels comfortable with rather than trying to establish goals that are objectively correct. In all likelihood, the initial goals will require updating over time as new information becomes available, such as when information is collected to better inform the connectivity status assessments (e.g., refinements to the GIS analyses as described in Section 4), and as the team gains a better understanding of what can realistically be accomplished.

3.8 Define Actions and Strategies

Once goals are established, refine the list of potential actions generated through the situation analysis. This is achieved by, (1) reviewing each action to ensure that the phrasing is clear and that the planning team has a shared understanding of its intended outcome, and (2) rating the effectiveness of each action using a modified version of the CS Effectiveness Rating tool (see Appendix F). This tool allows teams to consistently assess each action based on its Feasibility (i.e., the degree to which the planning team can implement the action within realistic constraints) and Impact (i.e., the degree to which the action is likely to contribute to achieving one or more of the project goals). Because the feasibility and impact rating definitions are inherently subjective, ratings should be selected by team consensus after discussion. Once complete, the planning team will have gained a shared understanding of the relative effectiveness of each action (i.e., Low, Medium, High, or Very High). At this point, ask the planning team whether the final effectiveness ratings make sense and, if necessary, revisit the assessments until everyone is satisfied with the results.

A secondary review can then be conducted for all actions with a final rating of “Needs More Information” or “Not Effective”, to determine whether it makes sense to pursue their implementation. The choice to keep or remove an action should be by consensus once participants have had an opportunity to discuss the various pros and cons. This discussion can be facilitated by asking whether the project goals can be achieved without the action, and what the conceptual costs and benefits of its implementation are. The overall aim is to remove actions that will not contribute to achieving the project goals so that limited time and resources are invested strategically. If the team decides not to pursue implementation of one or more actions, these should still remain in the situation analysis for posterity, because they may become relevant in the future if the watershed context changes.

Once the final list of actions is selected, they can be grouped into overarching strategies, which are defined as one or more actions with a common focus that work together to achieve a specific outcome. Though there are no rules for determining how best to group actions together into strategies, a minimum of two strategies are recommended as a starting point for discussion: Barrier Remediation and Barrier Prevention. The team can then begin to categorize each action based on intended outcome. Depending on the suite of actions, the team may decide to explore other potential strategies as well, such as splitting remediation or prevention strategies by barrier type (e.g., Lateral Barrier Remediation), or to capture one or more actions with a distinct theme. The exercise is complete once each action has been assigned to a relevant strategy.

3.9 Develop Theories of Change and Objectives

Once strategies are developed, create a Theory of Change ("Results Chains" in CS language) for each. Within a WCRP, a theory of change depicts the causal (if-then) progression of assumptions of how the actions within a strategy work together to achieve project goals. For some, the process of developing theories of change can be conceptually challenging, so consider presenting a draft as a starting point (see Appendix G). Give the team opportunities to verify, edit, or remove each of the assumptions in the draft by asking questions about the relevance of each assumption and whether phrasing can be improved to reflect the specific watershed context. This may stimulate ideas about additional assumptions, which should be captured.

A theory of change is considered complete when the team has exhausted all assumptions that link each action together and to the beneficial outcome for the target species. Once complete, review the theory of change with the team using causal language to connect each assumption, which not only reinforces the team's understanding of how the actions relate to one another, but also helps to identify illogical or tenuous connections that may need further refinement. Also similar to situation analyses, the facilitator should not accept every suggestion at face value but instead, ask probing questions to challenge potential biases and uncover tenuous connections. This helps to ensure that the team develops a realistic roadmap to achieving project goals.

Once theories of change are developed for each strategy, the next step is to develop objectives, which, in the context of a WCRP, are defined as formal statements of the desired future outcomes of strategies. By developing objectives, the team will be able to test assumptions identified in the theory of change and, in doing so, track whether the project is achieving its desired outcomes. Developing objectives is an iterative process that requires discussion about the types of information that are important for the planning team to collect (e.g., will this information help improve implementation?), how that information can be collected, and whether the associated indicators are both efficient and affordable to measure. Though ideally, each action would have at least one (1) objective so the team can understand which parts of the plan are working, depending on the number of actions and their implementation complexity, this may not be feasible. At a minimum, WCRPs should include one (1) objective for each barrier type included in the theory of change that reflects the number of barriers to be remediated to achieve the project goals. For example, if a goal is to provide access to 100 km of habitat for migratory salmon, several objectives will be required to track the number barriers of each type that, collectively, will achieve that goal if remediated (e.g., gaining access to 100 km of habitat requires remediating 3 dams, 9 road-stream crossings, and 1 lateral barrier). Like goals, these objectives should be SMART (see Section 3.6), and the same objective may be included multiple times with different timeframes to verify progress (e.g., By 2025, a minimum of 4 road-stream crossing barriers will be remediated; By 2030, a minimum of 9 road-stream crossing barriers will be remediated). When developing objectives with the team, present a suite of draft objectives for review and feedback rather than designing them from scratch, particularly if the theories of change are complex or there are known constraints on what can be monitored.

3.10 Develop Progress Tracking and Implementation Plans

The next stage of the WCRP process involves compiling information already generated into a progress-tracking plan ("Monitoring Plan" in CS language) and implementation plan. In both cases, present the information to the planning team in table format and allow team members to review and provide feedback. Though this can be achieved outside of workshops, if there are areas of uncertainty in either plan, it can be helpful to discuss these with the planning team in a workshop setting. To develop the progress-tracking plan, list each of the goals and objectives and, for each one, include details on, (1) the indicator that will be used to assess the goal or objective, (2) the specific method that will be applied to measure the indicator value, (3) how often the indicator value will be measured (e.g., annually or every 5 years), (4) who is responsible for taking the measurements, and (5) any additional clarifying details (e.g., a URL link to detailed methods). When filling this in, be as specific as possible so that both current and future team members have a clear understanding of how and when to conduct progress-tracking activities in a consistent manner.

To develop the implementation plan, list each of the strategies and associated actions (including the progress tracking plan) and, for each action, include details on, (1) who is responsible for leading implementation, (2) the timeframe in which implementation will take place, taking into account whether there are actions that need to be implemented in chronological order, and (3) budgetary information, which, at minimum, should include the total estimated cost of implementation. Depending on the complexity of the project or internal planning and budgeting processes, you may wish to include additional information as well, such as other participants or funding sources. Regardless of what information you include, be as specific as possible so that both current and future team members have a clear understanding of when actions need to be implemented, who is responsible, and cost. When complete, the costs of all actions can be summed for each strategy and for the entire plan as a useful point for discussion of whether the total cost and timeline are realistic. If not, refine the plan. It can also be useful to include a table listing potential funding sources. At minimum, this table should include details on, (1) the name of the funding source, (2) the estimated proportion (%) of the total plan cost that the funding source will cover, and (3) any clarifying details on spending restrictions or other considerations.

3.11 Create the final WCRP

The last step in developing a WCRP is to compile the information into a single document. In addition to presenting each of the planning results identified throughout sections 3.1 – 3.10, the final WCRP should include several additional sections, including:

- Introductory paragraphs on the project background and approach.
- A list of key actors representing individuals or organizations that were identified as being critical to the successful implementation of the plan.
- A reference list capturing any information sources cited in the plan.
- Appendices for any additional information used to inform the plan.

The sequence of information presented in the plan will likely not match the sequence of how that information was generated with the planning team, and this is typical of most planning initiatives. When developing the final document, a best practice is to minimize narratives where possible; a plan is not a literature review, and large, complicated planning documents tend to collect proverbial dust. A short and succinct plan should focus on actions rather than summarizing information. Though not essential for a successful WCRP, it is also recommended to have the document professionally designed and edited. Professional, aesthetically pleasing plans are more likely to keep readers engaged, which not only includes planning team members, but also external funders and supporters. Wherever possible, allow the team to contribute ideas for graphic design and to submit images that reinforce the team's vision for the future. These are simple but meaningful gestures that can have an outsized effect on building team cohesion and project buy-in, both of which are critical to the success of a WCRP.

3.12 Budget for WCRP Development

The allocation of financial and human resources is an important consideration when planning and implementing conservation projects. The majority of resources should support direct conservation action, but a reasonable investment in planning is needed to ensure strategic and efficient implementation. To help WCRP coordinators estimate budget requirements for the planning process, we provide an overview of the roles and estimated human resource costs for development of a WCRP (see Table 11). A successful WCRP can be developed with more limited resources; however, a core project team is needed to undertake partner engagement, WCRP development, data management, and spatial analysis. Costs may increase depending on data-compilation needs, modeling detail, and time spent on situation analyses and action planning. Each role does not necessarily represent unique staff required for the project; individuals may fill multiple roles given appropriate skillsets.

Table 11. A generalized estimate of roles and human resource costs for the development of a WCRP.

Role	Time
Conservation coach/facilitator	60 hours
Project manager	0.125 Full-time employee (FTE)
Partner engagement coordinator	0.1 FTE
Biologist	0.05 FTE
Spatial analyst	150 hours
GIS technician	0.15 FTE
Compensation for partner participation in workshops and data validation and sharing	$5,000
Total	**$50,000**

Section 4: Supporting Spatial Analyses

There is an extensive body of literature on how to quantify the connectivity of freshwater systems (e.g., Cote et al. 2009; Grill et al. 2019; Diebel et al. 2015), as well as on methods to prioritize barriers for remediation (e.g., Martin 2019; Kemp and O'Hanley 2010; King and O'Hanley 2016; McKay et al. 2017, Moody et al. 2017). This section of the guide largely builds on the strategic approach developed by the B.C. Fish Passage Technical Working Group, to account for the considerable logistic and socioeconomic factors that influence connectivity remediation decision making (Fox, Magilligan, and Sneddon 2016), and to link the results of the spatial analyses to on-the-ground implementation of remediation actions.

Spatial analyses are one of the fundamental underpinnings of the WCRP process, used to update the connectivity context of the watershed, to forecast where best to take action to efficiently achieve the WCRP goals, and to track progress. Several important data inputs are required for WCRP spatial models, such as those used to quantify the current connectivity status or prioritize barriers for remediation. There are a variety of options for conducting spatial analyses to achieve these outcomes, and all rely on the best-available information to support data-driven decision making throughout the development of the WCRP. This is supported by the compilation of existing spatial datasets and supplemented with local knowledge and Indigenous Knowledge.

The intricacies of compiling and analyzing relevant spatial data will be unique to each WCRP depending on existing data availability, the number of local partners involved, and the technical and resource capacity of the planning team. As such, there is no single method for conducting WCRP spatial analyses, and for this reason, the aim of this section is not to specify step-by-step methods, but rather to provide conceptual guidance by outlining the key spatial components and considerations for each step in the planning process (see Section 3). This guide is designed to be applicable using any GIS software. The authors hope that this guidance provides you with enough information to successfully conduct the spatial analyses for your WCRP, but the Canadian Wildlife Federation may be available to support planning teams with developing WCRP spatial models if assistance is needed. Regardless of the degree of GIS sophistication that you choose to deploy, the aim of every WCRP spatial model remains the same — to support decision making around the strategic allocation of limited barrier-remediation resources by prioritizing those barriers that will provide the greatest ecological return-on-investment, thus providing an alternative to the predominant (until recent years) opportunistic approach to barrier remediation (McKay et al. 2017).

4.1 Spatial Data and Knowledge – Sources and Management

4.1.1 Spatial data sources

The search for relevant data can begin once the watershed is selected (see Section 1.1), and simple internet searches can be an excellent starting point if you are unaware of existing data repositories for your watershed. Begin by listing all potential data that may be relevant to the

WCRP, then refine this list over time as project scoping decisions are made and more is learned about the watershed context, data quality, and local partner priorities. Data availability (or lack thereof) can significantly influence project scoping decisions, and as you begin to compile relevant data, you may find that more data are available for certain barrier types or species than others. Though WCRPs should always be based on the best-available information, a lack of spatial data should not prevent planning teams from evaluating species or barrier types that have been deemed as a high priority by the planning team. In these cases, the best-available information may be local or Indigenous knowledge, and incorporating this knowledge into the spatial model is critically important to not only strengthen the model results, but also to avoid planning paralysis (Lenz and Lyles 1985). Regardless of whether you are using existing spatial data or generating new data based on local or Indigenous knowledge, the datasets should cover the entire geographic area of the watershed wherever possible to ensure consistency of model results. In many cases, existing datasets will be at significantly larger scales than the watershed scale (e.g., provincial or national scale) and, as a result, may not be at an appropriate resolution to support local decision-making. In these cases, local data and knowledge will be invaluable to help refine model inputs (Lin et al. 2019). As discussed in Section 2, building trusting relationships with Indigenous and other partners is paramount for exploring opportunities to collaborate and share local knowledge. For additional information on the different types of data that can be applied within WCRP spatial analyses, see Appendix H.

4.1.2 Spatial data management

The strategic compilation and management of spatial data, regardless of source, is fundamental to the success of the WCRP planning process. As such, it is best to establish an explicit data-management framework early on, though adjustments will likely be required as potential data sources are explored in more detail. This guide promotes the implementation of open data, licenses, and tool development practices; however, it is recognized that this is not always feasible, and there may be some proprietary factors that need to be accounted for. Key considerations to help define the data-management framework include:

- What is the geographic scope of the WCRP?
- Who will be responsible for compiling and managing spatial data? What resources and capacity do those group(s) have at their disposal?
- Will multiple groups or organizations require access to the raw spatial data for analysis or review?
- Will data processing and spatial analyses be manually performed each time an update is required, or will models be developed to automate connectivity analysis processes?
- What are the feature types and key attributes required for each data type (see Sections 4.2.1 - 4.2.5)?
- How will spatial data be shared outside of the planning team? Will raw data be made available or just derivative data products?

- Are there data sources that require the establishment of a data-sharing agreement? If so, what are the limitations imposed by data and knowledge providers and how does this affect sharing the data and its derivatives with other partners?

Establishing the answers to these questions with the planning team will allow the key components of the data-management framework to be defined, including the spatial data management system, data access, spatial analysis methods, the need for data-sharing agreements, and documentation.

4.1.3 Indigenous Knowledge

Wherever possible, planning teams should aim to incorporate Indigenous Knowledge into the planning process when and where it is appropriate to do so. The knowledge passed down through generations of Indigenous peoples often includes information of direct relevance to WCRPs, including changes in the geography, animals, plants, climate, and seasonal fluctuations that occur in Indigenous peoples' traditional territories. It is critical to recognize Indigenous peoples' inherent jurisdictional right to govern their knowledge, that Indigenous Knowledge comes in many forms, and that it is sacred and proprietary in nature such that some knowledge cannot be shared outside of a community. The OCAP® principles[2] (Ownership, Control, Access, and Possession) are an excellent framework to help build respectful relationships and ensure that appropriate knowledge governance principles are applied (see Table 12). Planning teams should work with local Indigenous organizations to establish appropriate standards for how and where Indigenous Knowledge and derived data are collected, protected, used, and shared. It is best practice to establish data-sharing and confidentiality agreements in partnership with individual Indigenous communities to ensure that any unique needs or concerns are addressed. Though some Indigenous groups may have existing data-sharing agreement templates, others may need to be developed from scratch. The Alberta First Nations Information Governance Centre provides an excellent guide to developing data-sharing agreements. In this way, Indigenous partners will be able to exert their right to control why, how, and by whom information is collected and used.

A fundamental component of the OCAP® principles is establishing the sharing relationship to be reciprocal and mutually beneficial, wherever possible. This includes working with Indigenous groups to ensure that any data, reports, or other products derived from their knowledge are shared back with the community in a format of their desire. Providing access to, and control of, resulting products develops trusting and meaningful relationships, and ensures both the WCRP process and Indigenous groups will benefit from the exchange of knowledge. WCRP coordinators can also work with Indigenous groups to develop data-management capacity and expertise to support them in using derivative products to their benefit in the future.

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[2] OCAP® is a registered trademark of the First Nations Information Governance Centre (FNIGC). For more information, please visit www.FNIGC.ca/OCAP

Table 12. The four OCAP Principles and their definitions. The principles were developed focusing on information governance for First Nations; however, the framework and principles can be adapted to meet the needs of other Indigenous groups, including Inuit and Métis. This should be discussed and agreed upon at the start of the engagement process.

OCAP® Principle	Description
Ownership	Refers to the relationship of First Nations to their cultural knowledge, data, and information. This principle states that a community or group owns information collectively in the same way that an individual owns his or her personal information.
Control	Affirms that First Nations, their communities, and representative bodies are within their rights in seeking to control over all aspects of research and information-management processes that affect them. First Nations control of research can include all stages of a particular research project from start to finish. The principle extends to the control of resources and review processes, the planning process, management of the information and so on.
Access	First Nations must have access to information and data about themselves and their communities regardless of where it is held. The principle of access also refers to the right of First Nations' communities and organizations to manage and make decisions regarding access to their collective information. This may be achieved, in practice, through standardized, formal protocols.
Possession	Though ownership identifies the relationship between a people and their information in principle, possession or stewardship is more concrete: it refers to the physical control of data. Possession is the mechanism by which ownership can be asserted and protected.

In addition to Indigenous Knowledge, planning teams can work with Indigenous partners to ensure that Indigenous worldviews, ways of knowing, and cultural values are incorporated throughout the development of the WCRP. Indigenous cultures have an inherent connection to the land, water, plants, and animals that occur within their traditional territories, resulting in a harmonious and inseparable relationship to the natural world. As such, establishing meaningful partnerships with local Indigenous communities is critical to the success of WCRPs. There is no one size fits all approach to working with Indigenous communities, and each partner should establish the method of engagement and degree of contribution that works best for them. Building trusting and meaningful relationships with Indigenous partners requires that WCRP coordinators listen, engage in good faith, and communicate transparently, early, and often.

4.2 WCRP Model Inputs

Once you begin to build the list of available data and knowledge sources that could potentially inform the WCRP, begin identifying which of these sources can be used to inform the five fundamental WCRP model inputs: (1) a dendritic hydrographic network, (2) species-distribution data, (3) species-habitat data, (4) barrier data, and (5) watershed exclusion areas. The specific datasets used to capture these inputs will differ for each WCRP depending on the watershed location, species of interest, and established dimensions of connectivity and barrier types. The following section provides an overview of considerations for data compilation, preparation, and analysis for each of the five model inputs.

4.2.1 Hydro networks

Dendritic hydrographic networks (hereafter called "hydro networks") are spatial models that represent the hydrographic features of a particular watershed (i.e., rivers, streams, and lakes). The hydro network is the foundation for all WCRP spatial analyses, because all other model inputs are assessed in relation to their location along the hydro network, such as the amount of useable habitat for species of interest and the amount of habitat being blocked by barriers (see Section 3.4). Hydro networks are made up of "edges" (i.e., linear features that represent flowing streams and rivers, called "flowpaths"), "nodes" (i.e., point features that represent confluences), and polygons (i.e., area-based features such as lakes), and consist of a mainstem and branches that hierarchically increase in number and decrease in size when tracing upstream through the network (Grant, Lowe, and Fagan 2007). Both the mainstem and branches of a hydro network represent dispersal pathways for aquatic biota to access suitable habitat, while also acting as potential habitat in and of themselves. As such, quantifying connectivity within a hydro network requires determining the spatial relationships between the various hydro network features (Cote et al. 2009). To do so, quality assurance and quality control (QA/QC) edits to the hydro network should be performed to remove any topological errors (i.e., spatial relationship errors) or geometric errors (i.e., structural errors), including:

- Disconnected flowpaths (i.e., branches that do not connect with the mainstem).
- Dangling nodes (i.e., flowpaths that overshoot or undershoot the node with which they are intended to coincide).
- Loops or duplicate node IDs (i.e., loops in the stream flowpaths that direct back into themselves).
- Redundant skeleton flow paths (i.e., an excessive number of flowpaths exist within polygonal waterbodies due to the convergence of multiple tributaries).
- Erroneous or conflicting flow directions (i.e., flowpath direction is incorrectly assigned).
- Anastomosing or braided networks, bifurcation errors, or misidentified "primary" flowpaths (i.e., multiple flowpaths flowing away from the same node or where the network splits into divergent flowpaths so that the primary flow path cannot be identified).

Though hydro network errors can be identified and fixed manually, this can be time consuming. Tools explicitly designed to identify network errors can be used (see Table 13). Errors identified by these tools can be fixed using the tools themselves, or manually corrected using the Editor toolbar and Set Flow Direction tool in ArcGIS or the Advanced Digitizing toolbar in QGIS.

Table 13. Tools to identify hydrographic network errors and their respective GIS platforms.

Tool	GIS Platform
Utility Network Analyst	ArcGIS
Topology Checker/Geometry Checker	QGIS
CHyF tools (Natural Resources Canada and Canadian Wildlife Federation)	Stand-alone tool
FIPEX (Greig Oldford and Fisheries and Oceans Canada)	ArcGIS
BAT (The Nature Conservancy)	ArcGIS

The hydro network will also be the basis for identifying potentially accessible and currently accessible stream segments (i.e., distinct sections of the stream network defined between two nodes). In the context of a WCRP, "potentially accessible" stream segments are defined as flowpaths within the hydrographic network that the target species should be able to access in the absence of anthropogenic barriers and are delineated at the upstream end by (1) waterfalls or other permanent natural barriers, (2) gradient or other physiological barriers, and (3) watershed exclusion areas (see Section 4.3.1). "Currently accessible" stream segments are only used to analyze connectivity for anadromous or adfluvial species, and are defined as flowpaths downstream of all modelled or known anthropogenic barriers and represent parts of the network that the target species can currently traverse without obstruction (based on the best-available data and knowledge). Potentially accessible and currently accessible stream segments are used throughout the connectivity modelling process, including to refine the geographic scope of the project, limit the identification of species habitat types, and assess the current connectivity status.

Though the attributes contained in a hydro network dataset will vary depending on the source of the data (See Appendix A for national and provincial hydro network sources), Table 14 details several attributes that should be calculated for each stream segment within the WCRP hydro network, where possible.

Table 14. Recommended hydrographic network segment attributes.

Attribute	Notes
Waterbody name	Name of the river, stream, or lake.
Stream order	Hack or Strahler stream order; some hydrographic networks will come with this field pre-populated.
Stream gradient	The average gradient calculated along the length of the stream segment.
Upstream network length	The sum of the lengths of all upstream stream segments and skeleton flowpaths.
Upstream catchment area	The sum of the area of all upstream sub-catchments (calculation only possible when using hierarchical watershed classification systems).
Number of downstream barriers	Identifies the presence or IDs of downstream barriers; this can be broken into multiple attributes for various barrier types (e.g., anthropogenic, natural, gradient).
Potential accessibility	Identifies a stream segment as potentially accessible based on the presence of (1) waterfalls or other permanent natural barriers, (2) gradient or other physiological barriers, and (3) watershed exclusion areas (see Section 4.3.1).
Habitat type	Identifies a stream segment as a particular habitat type; this can be split into multiple attributes by species and habitat type (e.g., spawning and rearing).
Affected by a lateral barrier	Identifies the stream segment extent that is affected by a lateral barrier.

4.2.2 Species-distribution data

Species-distribution data refers to data sources that can be used to map the current or historic extent of target species in the watershed. Though there may be overlap between species-distribution data and species-habitat data (Section 4.2.3), this is not always the case, and the two should therefore be treated separately. Species-distribution data are used in combination with barrier data to refine the secondary geographic scope of the WCRP (see Section 3.3) and to assist with identifying stream segments that are potentially accessible.

Species-distribution data can be represented by several different formats, all of which are useful, including points (e.g., species observation points), lines (e.g., stream segments known to be used by the species), or polygons (e.g., explicit distribution or population extent boundaries). Distribution data can be prone to errors and limitations and should be evaluated and subjected to QA/QC review prior to including in the analysis. Species-observation data are inherently limited by the level of collection effort. Point and line data are often the most accurate but can be biased by where sampling occurred and may include misidentification errors. Polygons delineating species distributional ranges are less likely to include identification errors, but generally cover broader areas than are actually occupied by the species. The finalized extents of species distribution should be reviewed by the planning team and updated based on local knowledge, where necessary. Once compiled, the various species-distribution data sources should be encoded as attributes in the hydro network using an overlay or intersect tool. By directly linking the species distribution extents to the specific stream segments within the hydro network, it is possible to split stream segments at the bounds of focal species distribution. These stream segments can then be used as the starting point to trace the network upstream until natural barriers are encountered, thereby delineating stream segments that are potentially accessible to that species. Though the attributes contained in species-distribution datasets will vary depending on the source of the data (e.g., biodiversity observation inventories, Critical Habitat mapping, or surveys and scientific reports), Table 15 details several species-distribution attributes that should be calculated for each stream segment within the WCRP hydro network, where possible.

Table 15. Recommended species-distribution attributes.

Attribute	Notes
Species name	Name of species to which the distribution data applies.
Source	Source of the observation or distribution data; can link to relevant reports or other documents.
Date	The date the information was created, collected, or compiled.

4.2.3 Species-habitat data

Species-habitat data refers to data sources that can be used to distinguish between different habitat types that are required for target species to carry out their life processes (e.g., spawning, rearing). Habitat data, often combined with habitat modelling, are used to identify stream segments or lateral polygons that will be included in subsequent connectivity analyses to quantify the connectivity status and prioritize barriers (i.e., stream segments or lateral polygons that are not identified as habitat will not be counted in these calculations). Similar to species-distribution data, species-habitat data can be represented in a variety of formats, such as points, lines, and polygons. Overlay or intersection analyses can be run to assign a specific habitat type to each hydro network segment that coincides with the habitat data. In many watersheds, habitat data will not exist or will be limited or patchy in their spatial coverage, and in these cases, local and Indigenous knowledge can be particularly useful for mapping different habitat types. Depending on available resources and capacity, habitat models can also be developed to approximate the locations and distributions of different habitat types.

Unless comprehensive habitat mapping already exists for the watershed, some form of habitat modelling should be used, such as Intrinsic Potential (IP) habitat modelling (see Sheer et al. 2009 for an excellent synthesis of the IP modelling framework). The IP framework identifies stream segments that have the potential to be habitat for species of interest based on, (1) stream gradient, (2) stream channel width or discharge, and (3) stream channel confinement (i.e., the ratio of channel width to valley width; see Mazany-Wright et al. 2021a for an example of IP modelling implementation for a WCRP). However, in the complete absence of available habitat data or lack of capacity to develop habitat models, the simplest means of quantifying habitat is to assume that all hydro network segments downstream of watershed exclusion areas (see Section 4.2.5) are potential habitat to the target species, and the need for better habitat data can be identified as a knowledge gap within the plan.

The attributes contained in species-habitat datasets will vary depending on data source (e.g., local and Indigenous knowledge, watershed reports, and existing habitat models and surveys). Table 16 details several species-habitat attributes that should be calculated for each stream segment within the WCRP hydro network, where possible.

Table 16. Recommended species-habitat attributes.

Attribute	Notes
Species name	Name of species to which the habitat data applies.
Habitat type	The specific type of habitat (e.g., spawning or rearing) that is being identified.
Habitat quantity	The amount of habitat either as a linear or areal measure.
Waterbody name	Name of the river, stream, or lake. For polygonal lateral habitat, assign the waterbody name from the source data or from its spatial relationship with stream network.
Source	Source of the habitat data; can link to relevant reports, databases, or other documents.
Date	The date the information was created, collected, or compiled.

Though most WCRPs will map habitat as linear features that align with the hydro network, many freshwater species also use lateral habitats (e.g., side- and off-channel wetland habitat) that cannot be quantified using linear measures. The inclusion of lateral habitats in connectivity analyses is not well documented in existing literature; however, the areal extent of specific lateral habitats could be defined and should still be aligned with the hydro network to ensure the spatial relationship is enforced.

4.2.4 Barrier data

Barrier data refers to a wide range of data sources that map the natural, anthropogenic, and physiological barriers to connectivity in the watershed. The data available in each watershed and the barrier types selected as being in scope for the WCRP (see Section 3.3) will influence how the current connectivity status of the watershed is assessed and how barriers are prioritized for remediation. Barrier data contribute to each stage of the spatial analysis and planning process, and how the barrier data are used in the WCRP spatial model depends on the barrier type (see Table 17).

Table 17. Example barrier types and how the associated data for each type are used.

Use	Barrier Types
Quantify current connectivity status of the watershed and prioritize barriers for remediation	• Dams, weirs, flood gates, aboiteaux • Stream crossings (road, rail, and trail) • Lateral (dykes, levees, road and rail lines, berms, and embankments) • Natural (debris jams and sediment deposits)
Refine focal species distribution and geographic scope	• Waterfalls • Physiological (gradient, flow, temperature)

Barrier data can be represented in a variety of formats, such as points, lines, and polygons; however, barriers that affect connectivity in the longitudinal plane should be compiled, digitized, and mapped as point features that can be snapped to the hydro network. The barrier points can then be used to split the network into segments (i.e., create new node end points). In this way, the amount of habitat upstream or downstream of an individual barrier or the effect each barrier has on the connectivity score can be calculated (see Section 4.3.2). Though lateral barriers can be mapped as point features using the method described above, they can also be mapped and analyzed as linear features (e.g., a road running along a river that disconnects a river channel from its floodplain). The simplest way to do this is to encode the extent of these linear lateral barriers directly into the stream network attributes.

In the absence of comprehensive barrier inventories, several barrier types can be modelled - namely gradient barriers and road-, rail-, and trail-stream crossings (collectively referred to as "stream crossings"). Where possible, barrier modelling should be conducted using simple spatial analyses (see Table 18) to help refine the extent of potential barrier fragmentation more accurately in the watershed. However, not all modelled crossings and gradient barriers will actually block passage for target species, and as such, it is recommended that modelled barrier data be verified by field assessments and local partner knowledge wherever possible (Januchowski-Hartley et al. 2013, FPTWG 2014). Where barrier assessments have not yet been completed, modelled crossings should be treated as Potential Barriers that require further assessment once the preliminary barrier prioritization results are produced (see Section 4.3.3). To prevent duplicate barriers from disrupting the connectivity analysis, linkages between assessed barrier points and modelled barrier points can be made using several approaches, such as applying a search threshold to identify all points within a certain distance of each other (e.g., 100 m) and distinguishing true duplicates through manual review. Attributes from the assessed barrier point can then be applied to the modelled barrier point.

Table 18. Methods for modelling stream crossings and gradient barriers.

Barrier type	Model methods
Stream crossings	Intersect road, rail, and trail spatial networks with the hydrographic network. Intersection points represent potential stream crossings.
Gradient barriers	A gradient barrier for a given threshold (e.g., 15% based on target species' swimming abilities) can be created by starting at the mouth of the network and iterating through each node of the stream flowpath, calculating the gradient between the given node and the next node at least 100 m upstream. Any segment of stream with a gradient exceeding the threshold is identified as a potential gradient barrier (See Norris and Mount 2016).

Though the attributes contained in barrier datasets will vary depending on data source (e.g., existing barrier inventories, road and rail network datasets, and modelled stream crossings), Table 19 details several attributes that should be included for each barrier, where possible.

Table 19. Recommended barrier attributes.

Attribute	Notes
Unique identifier	Barriers should be assigned a unique and stable code (usually numeric) to ensure that individual barriers can be identified upon subsequent iterations of the analysis.
Barrier source	The data source of the barrier point, usually "Modelled" or the name of the data source.
Barrier type	The type of barrier represented by the feature (e.g., dam, road-stream crossing, or gradient barrier).

Attribute	Notes
Barrier status	The passability status of the barrier, generally Passable, Potential Barrier (modelled barriers), Partial Barrier, Barrier, or Unknown.
Barrier owner	The owner of the barrier, where known.
Waterbody name	Assign the waterbody name from the source data or from its spatial relationship with the stream network.
Number of downstream barriers	Identifies the presence or unique identifier of downstream barriers; this can be broken into multiple attributes for various barrier types (e.g., anthropogenic, natural, or gradient). Allows the barriers that do not have any downstream barriers to be identified. This field can also be used to identify sets of barriers during the prioritization process (see Section 4.3.3).
Potential accessibility	Indicates whether the barrier is located on a potentially accessible stream segment, defined as stream segment downstream of (1) waterfalls or other permanent natural barriers, (2) gradient or other physiological barriers, and (3) watershed exclusion areas (see Section 4.3.1).
Upstream network length	The total length of stream segments upstream of the barrier.
Upstream habitat (linear)	The amount of calculated habitat upstream of the barrier; this can be broken into multiple attributes by species and habitat type (e.g., spawning or rearing).
Lateral habitat (areal)	The amount of lateral habitat associated with the barrier.
Upstream catchment area	The sum of the area of all sub-catchments upstream of the barrier (calculation only possible when using hierarchical watershed classification systems).
Date	The date the information was created, collected, or compiled.

4.2.5 Watershed exclusion areas

Watershed exclusion areas refer to datasets that can help inform where barrier prioritization and subsequent remediation efforts should not take place within the watershed. These areas are excluded from the WCRP. As discussed in Section 3.3, there are numerous reasons why a certain area may be excluded from a WCRP, and the spatial delineation of these areas helps to refine the secondary geographic scope. In the unique case of aquatic invasive species, these data can also be used to identify barriers that should remain in place to prevent their dispersal (Rahel and McLaughlin 2018). Though it is highly recommended that exclusion areas are explored with the planning team before any exclusion decisions are made, developing an initial list of potential data sources that could inform delineation of exclusion areas is a useful starting point for discussion. Watershed exclusion area data can be represented in a variety of formats, such as points (e.g., known instances of point-source pollution), lines (e.g., stream segments known to exceed temperature thresholds for the species of interest or those upstream of natural gradient barriers [Mount et al. 2011]), or polygons (e.g., areas of the watershed that have been heavily deforested causing extreme sedimentation). When the final list of exclusion area datasets has been identified and verified with the planning team, these should be transformed to points located at the furthest downstream extent of the exclusion area and then snapped to the hydro network. All segments upstream of these points can be removed from the WCRP analysis.

The attributes contained in the various datasets used to identify watershed exclusion areas will vary depending on the source of the data (e.g., local and Indigenous knowledge, existing threat maps, watershed reports and scientific studies). Table 20 details several attributes that should be included for stream segments upstream of exclusion area points, where possible.

Table 20. Recommended watershed exclusion areas attributes.

Attribute	Notes
Exclusion type	Identifies the justification for the exclusion (e.g., water-quality issues, land cover alteration, invasive species).
Source	Source of the exclusion data; can link to relevant reports or other documents.
Date	The date the information was created, collected, or compiled.

4.3 Establish Watershed Context and Refine Geographic Scope (supports Section 3.3)

Once data compilation and preparation are complete, the five fundamental WCRP model inputs can be used to refine the secondary geographic scope and establish an assessment of the current connectivity context in the watershed. In addition to spatial modelling, this requires significant engagement with local partners to identify local concerns, priorities, and shared values (see Section 2.3). Refining the geographic scope of the project requires identifying potentially accessible stream segments for each species of interest using species-distribution data, certain barrier types (see Table 17), and watershed exclusion area data. These stream segments are bounded by "exclusionary points", which are, (1) waterfalls or other permanent natural barriers of a size that the target species cannot pass, (2) gradient or other physiological barriers, and (3) watershed exclusion areas. If a target species is diadromous, stream segments upstream of exclusionary points are omitted from further analysis (see Table 21 for an example), whereas for non-diadromous species, the presence of an exclusionary point does not necessarily preclude the existence of a population occurring upstream of that point. In these cases, species-distribution data can be used to override the points if the non-diadromous target species is known to exist upstream of the barrier. Exclusionary points are only used to define the bounds of potentially accessible stream segments and are not included in the calculation of the connectivity status.

Table 21. Example of exclusionary point parameters for Chinook Salmon.

Definite barrier type	Value
Waterfall	Height > 5m
Gradient	Gradient >15%
Exclusion Area #1	Intermittent streams
Exclusion Area #2	Temperature >20° C
Exclusion Area #3	Risk of invasive species dispersal past barrier

Exclusionary points should be stored as point features and used to split the stream segments at the appropriate locations, allowing flowpaths downstream of these points to be appropriately encoded as potentially accessible in the hydro network attribute table. Exclusionary points and their locations should be validated with local partners, which can be achieved by presenting the results of the potentially accessible stream segments map using GIS software in real time or reviewing printed maps, when technology access is limited. Any suggested changes to the potentially accessible stream segments should be recorded and updated in the respective spatial datasets before moving on to the next stage of the process. The refined geographic scope, limited to potentially accessible stream segments, forms the foundation for all subsequent analyses and planning steps, including mapping or modelling useable habitat types, quantifying the current connectivity status, and planning other remediation actions.

4.4 Assess Connectivity Status (supports Section 3.2)

With potentially accessible stream segments finalized, assess the current connectivity status for the target species using the habitat-based KEAs and indicators selected (see Section 3.2). The selection of KEAs will determine the spatial analyses required to assess the current connectivity status of target species habitat, and vice versa (i.e., the KEA selection may be influenced by data availability). The KEAs should be based on the extent of accessible habitat type(s) for each target species, but the exact indicator will likely depend on the life history of the species of interest (see Table 22).

Table 22. Life-history strategies and related connectivity status assessment considerations.

Life history	Connectivity assessment considerations	Example KEA and Indicator
Diadromous	Requires migratory access to and from the ocean. Habitat connectivity can be quantified based on the amount or proportion of habitat that is currently accessible.	KEA: Accessible Spawning Habitat Indicator: % of total linear spawning habitat currently accessible
Adfluvial	Requires migratory access to and from a lake or reservoir. Habitat connectivity can be quantified based on the amount or proportion of habitat that is currently accessible.	KEA: Accessible Rearing Habitat Indicator: Area (m^2) of rearing habitat currently accessible
Fluvial	Requires migratory access between mainstem and tributaries; however, there can be populations upstream and downstream of specific barriers. As such, the connectivity status needs to be assessed using a connectivity index, metric, or score.	KEA: Spawning Habitat Connectivity Indicator: Dendritic Connectivity Index for spawning stream segments (range 0-1)
Resident	Species tend to remain within tributary systems where they spawn. Populations may persist upstream and downstream of specific barriers. As such, the connectivity status needs to be assessed using a connectivity index, metric, or score.	KEA: Stream network Connectivity Indicator: Longest Fragment Index based on all stream segments (range 0-1)

Once useable habitat types associated with the project KEAs have been mapped or modelled (see Section 4.2.3) and barrier data overlaid, an appropriate connectivity indicator should be selected to quantify the current connectivity status based on how existing barriers affect the connectivity of each habitat type (see Table 23). See Malvadkar, Scatena, and Leon (2015) for a detailed review of potential connectivity indicators and metrics. Connectivity analyses that rely on modelled stream crossings will result in a preliminary connectivity indicator status based on the assumption that all modelled barriers are potential barriers. As such, the current connectivity status of the watershed may change drastically based on the results of field assessments, even prior to the remediation of any barriers. This should not deter the planning team from using the preliminary connectivity status assessment results to inform subsequent steps of the plan (e.g., goal setting) – WCRP development is intended to be an iterative process based on the best-available information at each step (See Section 3).

Table 23. Example indicators that can be used to assess the current connectivity status.

Connectivity Indicator	Description
Dendritic Connectivity Indicator (DCI; Cote et al. 2009)	The DCI is a measure of connectivity based on the concept of "coincidence probability", i.e., the probability that fish can move (without encountering a barrier) between two randomly chosen points in a stream network. The DCI has multiple derivatives including a measure for diadromous and adfluvial species (DCI_D) and one for fluvial and resident species (DCI_P), allowing for a direct comparison of connectivity scores across disparate life histories.
Connectivity Status Index (CSI; Grill et al. 2019)	The CSI was developed at the global scale to assess freshwater connectivity across all four dimensions. The CSI represents a weighted score based on six pressure indicators: degree of fragmentation, degree of regulation, sediment trapping index, consumptive water use, road density, and urban development.
Novel Connectivity Metric (C; Diebel et al. 2015)	C builds on the DCI_P metric for fluvial and resident species by incorporating variables that represent habitat type and quality and the effect of dispersal distance on potential species movements.
Longest Fragment (LF; Díaz et al. 2021)	LF is the ratio between the longest connected section of the stream network and the total length of the network. This is applicable to fluvial and resident species.

The approaches described in Table 23 are limited to assessing longitudinal connectivity, because frameworks for quantifying the status of lateral connectivity within a watershed are lacking. If lateral habitat is a priority, a simple estimate of the proportion of lateral habitat that is currently inaccessible to species of interest is a useful starting point. In this case, lateral habitat will need to be mapped throughout the watershed, which can be accomplished through manual delineation using existing imagery sources, and later improved through field verification. If there is a lack of capacity to undertake manual delineation in the short-term, this can be identified as a Knowledge Gap within the plan.

4.5 Rate Effects of Each Barrier Type (supports Section 3.4)

With habitat types quantified and barriers located, the amount of habitat upstream and downstream of each barrier (to the subsequent barrier on the system; in either the upstream or downstream direction) can be calculated using network analysis tools in GIS (see Table 13). This also allows two key metrics to be calculated for each type of barrier to inform the barrier-type ranking exercise (see Section 3.4):

1. **Barrier type extent** – The proportion (%) of habitat that is affected (fully or partially blocked or fragmented) by each barrier type.
2. **Barrier type severity** – The proportion (%) of assessed barriers within each barrier type that have been designated as a Barrier or Potential Barrier to fish passage. This is based on data compiled from any existing barrier assessments or based on local knowledge and review.

4.6 Undertake Iterative Barrier Prioritization (supports Section 3.10)

The barrier prioritization decision-support tool accounts for inherent uncertainty in the modelling process and allows for the iterative updating of input datasets and prioritization results. Existing literature on this topic features desktop prioritization exercises focusing on longitudinal connectivity, with only theoretical considerations for implementing on-the-ground barrier remediation efforts and little to no analytical methods for prioritizing lateral barriers for remediation. This section provides guidance on developing a prioritization tool designed to achieve WCRP aims.

The need to develop an explicit implementation approach stems from the inevitable lack of knowledge of barriers, their passability status within the watershed, and the quality of associated habitats. Additionally, there is a need to account for the considerable social, economic, and logistic factors that could derail a potential remediation project (Fox, Magilligan, and Sneddon 2016). The planning team has no way of knowing if a prioritized barrier is in fact a good candidate for remediation without such information. As such, a preliminary list of prioritized barriers provides an intermediate guide to inform which barriers to assess in the field and consider further, rather than a final list of barriers to remediate. The prioritization analysis should be re-run whenever input datasets are updated, or at minimum at the end of every field season to incorporate barrier assessment and habitat confirmation results. The implementation approach summarized here builds on the Province of British Columbia's Fish Passage Technical Working Group (FPTWG) strategic approach and presents an iterative approach to identifying candidate barriers, undertaking field assessments, and implementing barrier remediation projects.

4.6.1 Select a prioritization approach

The aim of any WCRP barrier prioritization is to identify a suite of barriers that need to be remediated to meet the WCRP goals (see Section 3.7). Each planning team will need to evaluate which methods work best for their unique context. An overview of common prioritization methods is summarized in Table 24. See McKay et al. (2020) for a thorough review of each approach.

Table 24. Example barrier prioritization methods (adapted from McKay et al. 2020).

Method	Description
Optimization	Derive the mathematically optimal suite of barriers to remediate based on a specific set of user-defined objectives. The optimal suite comprises the set of barriers that, if **all** remediated in conjunction with each other, would maximize the connectivity gain for a given financial investment.
Hybrid	A hybrid approach between optimization and scoring and ranking, the number of additional barriers downstream or upstream of each individual barrier is calculated to identify opportunities for maximizing the connectivity gain by remediating sets of barriers on the same system in concert with each other (usually sets of less than 5 barriers). Gains from remediating sets of barriers are compared to gains from remediating an equivalent number of individual barriers. This is not a full optimization in that all possible barrier combinations are not assessed.
Scoring and ranking	Rank barriers based on metric(s) that quantify the amount of connectivity gain (e.g., amount of upstream habitat). Barriers are prioritized individually based on their rank.
Local knowledge	Identify a suite of barriers for remediation through engagement with local partners to qualitatively inform ecological, engineering, and social priorities.

Though a mathematically optimized set of barriers is the ideal approach in principle, it is virtually impossible to achieve in practice. This is because each barrier in the optimal suite is prioritized on the assumption that all other barriers in the suite will also be remediated and that the passability status of every single barrier in the watershed is known (King et al. 2017). Given that it is rarely feasible for planning teams to assess every potential barrier in the watershed prior to implementing barrier remediation efforts, optimization may be a less favorable approach. Even in the rare cases where the passability of every barrier is known, if any barrier on the optimized list is not remediated (e.g., due to socioeconomic considerations) then the solution set is no longer optimal, and the strategic benefit of this approach is lost. In contrast, ranking approaches based solely on individual barriers may fail to identify efficient multi-barrier solutions. Hybrid approaches allow greater flexibility and are generally recommended.

4.6.2 Iteratively run barrier prioritization model

The following is a simple hybrid barrier prioritization workflow that can be adapted to facilitate the development of any WCRP (see Appendix I for a diagram of the complete process). The workflow assumes that the habitat type(s) for which barriers are being prioritized is explicitly identified by the KEA(s) in the plan. This approach can easily be adapted to the other prioritization methods summarized in Table 24.

I. If prioritizing for diadromous or adfluvial species, rank individual barriers by the amount of habitat blocked (i.e., habitat upstream of the barrier in question but downstream of subsequent upstream barriers). Amount may be calculated by length or area, and may include all habitat upstream of the barrier, usable habitat, or high-quality habitat. Calculate the number of downstream barriers for each barrier on the list. If prioritizing for fluvial or resident species, individual barriers can be ranked by the combined amount of habitat upstream and downstream of the barrier (i.e., the total amount of habitat that would be reconnected if the barrier were to be remediated).

II. Review the preliminary list of ranked barriers (or a set of high-ranked barriers if there are too many to review overall) with the planning team to identify any obvious errors.

III. Re-run ranking exercise, if necessary, based on any updates stemming from step II.

IV. Working down the updated ranked list, identify the subset of highly ranked barriers that warrant further consideration (the "intermediate barriers list"). In most cases, the intermediate barrier list should include more barriers than are needed to achieve goals. It is likely that some barriers will be passable, others will not be associated with usable habitat, and others may not be feasible to remediate because of logistic considerations. Only a subset of highly ranked and field-assessed barriers are likely to ultimately be remediated to achieve WCRP goals.

Highly ranked barriers that would require the remediation of downstream barriers to realize actual habitat gains can be prioritized by accounting for barrier "sets" (i.e., two or more barriers for which remediation can be planned in concert). Sets of barriers may be selected if their combined removal provides more connectivity gain than barriers that individually block or disconnect more habitat, even if one barrier in the set only blocks a small amount of habitat (see Figure 1). Generally, barrier sets should be limited to less than five barriers due to the diminishing returns as the size of the set increases. It is rare that large sets of barriers would offer more significant gains than combinations of individual barriers or smaller sets. As such, for diadromous and adfluvial prioritizations, highly ranked barriers with many downstream barriers can be excluded from further consideration.

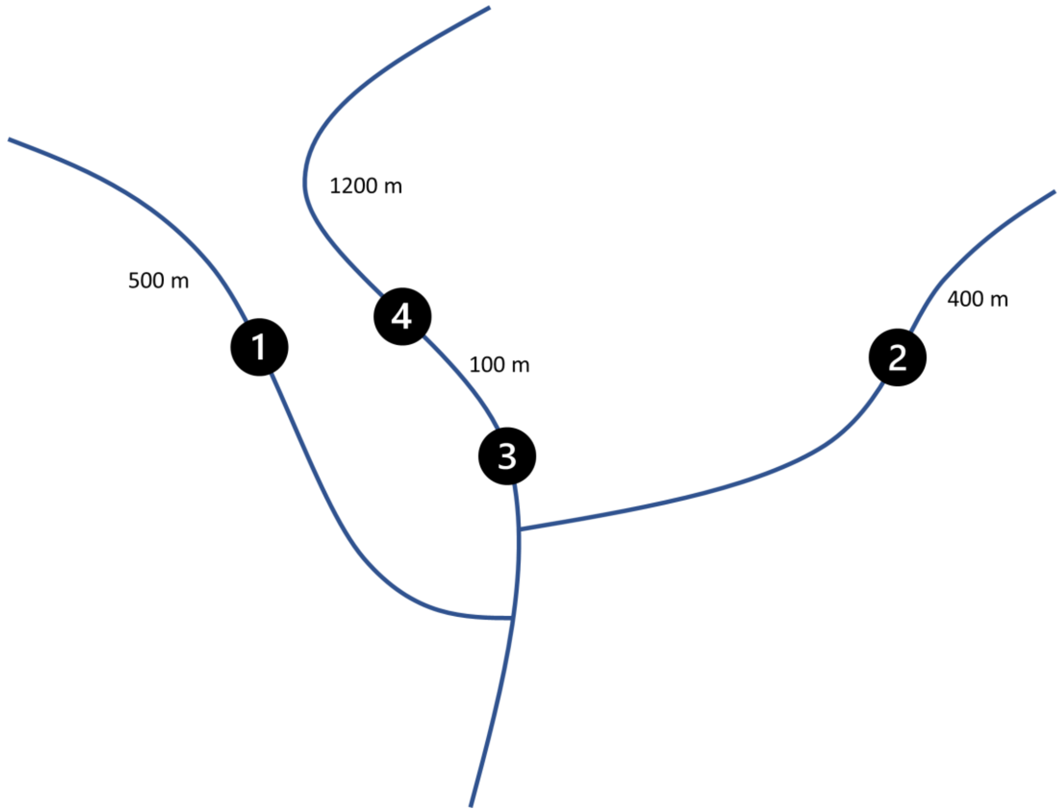

Figure 2. Schematic demonstrating how sets of barriers can be evaluated during prioritization. Barrier 3 would not rank highly, but its remediation is necessary to achieve gains through the remediation of barrier 4. In this case, the set of barriers 3 and 4 would be prioritized above the combination of barrier 1 and 2 as individual barriers.

Except in rare cases, it is assumed that modelled barriers and assessed barriers without confirmed habitat will be included in this ranking process. Some of the modelled barriers on the intermediate barrier list will not exist (e.g., the road was previously decommissioned), be found to be passable to target species, or not be associated with suitable habitat. As such, the intermediate barrier list is meant to help target further field assessments. Assessment results will be used to iteratively refine the prioritization analysis to identify a "priority barrier list", consisting of the barriers that will undergo further evaluation based on additional socioeconomic and logistic considerations (see Sections 4.6.3-4.6). This list represents the suite of barriers that, based on the current knowledge at any given stage in the prioritization process, will meet the connectivity goals. The priority barrier list will be iteratively updated at each subsequent step to ensure that the connectivity gains associated with any barriers that are removed from consideration are replaced by remaining barriers from the intermediate list (in some cases this may require replacing a single barrier with multiple barriers).

If lateral habitat and associated barriers are a priority, once mapped, a similar prioritization approach can be applied. However, prioritizing between longitudinal and lateral barriers is challenging due to the potentially different units of measurement used to assess the amount of habitat that is blocked (linear versus areal).

4.6.3 Perform barrier assessments and habitat confirmations

Depending on the data sources available, the intermediate barrier list will include barriers at one of three possible stages, (1) modelled barriers, (2) barriers that have been assessed and determined to be Barriers or Partial Barriers, and (3) barriers for which associated habitat suitability has been confirmed. Field assessments may be needed to close any gaps:

I. Modelled barriers will need to undergo "barrier assessments", whereby expert practitioners conduct standardized field assessments of structures to determine the passability status for the species of interest. If a structure is assessed as Passable or if there is an obvious lack of habitat value, it should be removed from the intermediate barrier list. Depending on the planning team's preference, semi-passable barriers may be considered passable, as full barriers, or given intermediate weighting (e.g., Partial Barrier).

II. Modelled barriers that have been assessed and confirmed as Barriers or Partial Barriers will need a "habitat confirmation", whereby expert practitioners evaluate the quantity and suitability of habitat to be gained through remediation of a particular structure. This is achieved through a combination of reviewing existing reports and performing field assessments using standardized habitat assessment protocols for the species of interest. A key component of this process is confirming whether any previously unidentified barriers exist upstream or downstream of the barrier in question. These could be natural or anthropogenic and could reduce or eliminate expected gains if the target barrier were remediated. If habitat quantity and suitability are confirmed to be sufficient and worthwhile for remediation, the barrier continues to be considered for the priority barrier list.

III. Barriers for which assessments and habitat confirmations were previously completed should be reviewed and, if necessary, reassessed. Considerations when reviewing existing assessments include the age of the assessment, and whether the data collected provide adequate information to assess passability and habitat suitability for target species.

4.6.4 Consider additional factors

Field data on barrier status and habitat suitability can be combined with other considerations to further refine the priority barrier list. Potential Barriers deemed to be passable or not associated with suitable habitat for target species may be removed from the list (see Section 4.6.6). The remaining list of barriers should be reviewed with the planning team to identify additional cultural and socioeconomic considerations when selecting barriers for remediation, including but not limited to:

- Species value – if multiple target species are grouped for the KEA(s), is there a particular species for which gains should be assured?

- Habitat quality – should barriers that would provide access to a large amount of medium-value habitat be prioritized over barriers that provide access to smaller amounts of high-value habitat?
- Cultural value – would remediation of the barrier provide connectivity to culturally important sites (e.g., historic Indigenous traditional use sites)?
- Barrier ownership, type, and cost – is it a barrier that would require the planning team to raise funds to remediate? Is there a barrier owner that can take responsibility for remediating the barrier? Do regulatory mechanisms exist that can be applied to require the remediation of the barrier?
- Logistics – is the site accessible to remediation equipment? Do the characteristics of the site require a remediation design that would be prohibitively expensive?

Evaluating barriers with the planning team ensures that identified barriers are appropriate and make sense based on local complexities, watershed context, priorities, and threats. This also provides an opportunity for other barriers of local importance to be added to priority barrier list, ensuring that all remediation projects that break ground within the watershed have the support of local stakeholders and rightsholders. Use these considerations to further refine the priority barrier list to achieve project goals. This may mean eliminating some of the barriers that were highly ranked based on the amount of modelled habitat, and replacing them with barriers from the intermediate list.

4.6.5 Commission engineering designs

Most barrier remediation projects require detailed engineering designs for infrastructure components, geomorphological designs for in-stream components, or both. These must be supported by field surveys of stream and infrastructure benchmarks, and may involve consideration of a series of preliminary designs before final designs are commissioned. This process can cost <$10,000 for simple forestry road culverts, or >$100,000 for situations with complex infrastructure components, especially in urban areas. Given costs, designs should only be commissioned for barriers that have passed through the filters above; however, this too is iterative. In some cases, the financial costs or logistical infeasibility of a remediation solution will only become known once designs are commissioned.

Designs allow for more exact cost estimates that account for site-specific requirements. In turn, cost estimates can be incorporated as an additional consideration alongside the other ecological and logistic factors. This may allow for further prioritization based on cost-effectiveness or ecological return on investment. In this case the amount of connectivity gain relative to cost for each barrier or set would be an even better metric for establishing priorities than amount of habitat alone.

4.6.6 Iteratively update barrier priorities and WCRP components

After each field season of barrier assessments and habitat confirmations, update the barrier datasets, habitat mapping, and barrier prioritization model and reevaluate other relevant WCRP components. Barriers that were found to not exist, assessed to be passable, or were not associated with suitable habitat should be updated accordingly in the input barrier datasets. Re-run the barrier prioritization model and update the intermediate and priority barriers lists.

Update the current connectivity status for each KEA. The amount of currently accessible habitat or the connectivity indicator score will increase based on modelled barriers being assessed as passable. The amount potentially accessible habitat will be reduced if stream segments previously modeled as habitat were found to be unsuitable for target species. Subsequently, update the priority barrier list taking into consideration habitat quality, cultural and logistic factors, and costs and return on investment. Ensure that remediation of the barriers on this list would achieve WCRP goals. This essentially identifies the team's estimate of the most efficient solution, all factors considered.

Once these updates are made, it is worthwhile to revisit the WCRP goals with the planning team to evaluate whether the updated connectivity status or the challenge of addressing all barriers on the priority barrier list warrant changes to the WCRP goals or the associated timeline. Reinforcing the iterative nature of WCRP development, the strategies, actions, objectives, and progress tracking and implementation plans should all be revisited and updated as necessary.

Recognize that the priority barrier list will never be final, at least until remediation projects are underway for all barriers on the list. It will continue to be refined as additional field and logistic information are obtained and incorporated into the process. Despite this, it remains a powerful tool for communication with partners, guiding and prioritizing assessment and planning work, and confirming that goals are appropriate and achievable. Early in the process, when field-data availability is limited, the priority barrier list is likely to be a coarse estimate that will undergo significant revision. Even so, it helps in understanding the current situation and the path ahead.

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Appendix A: Canadian Watershed Classification Systems

Global scale: HydroSHEDS (World Wildlife Fund)

Hydrographic network:

- HydroRIVERS – vectorized lines network
- HydroLAKES – shoreline polygons

Watershed classification:

- HydroBASINS – watershed boundaries and sub-basin delineation

National scale: National Hydrographic Network (NHN)

Hydrographic network and watershed classification:

- NHN Single Line Watercourse and Network Linear Flow
- NHN Waterbodies
- NHN Work Units (watersheds)

Provincial and territorial scale:

Alberta

Hydrographic network:

- Base Hydrography for Alberta
  - Single Line Network
  - Waterbody Polygons
- Alberta ArcHydro dataset (digital-elevation-model derived)

Watershed classification:

- Watersheds of Alberta
  - Water Survey of Canada Regions
  - Major Subwatersheds
  - Watersheds
  - Water (Ministerial) Regulation Major River Basins
  - Major Basins
  - Subcontinental Drainage Basins
  - Continental Drainage Basins

- Hydrologic Unit Code (HUC) Watersheds of Alberta
    - HUC 2 (coarsest level), 4, 6, 8, and 10 (finest level)

British Columbia

Hydrographic network:

- Freshwater Atlas:
    - Stream Network
    - Lakes

Watershed classification:

- Freshwater Atlas:
    - Watershed Groups (coarsest level)
    - Assessment Watersheds
    - Fundamental Watersheds (finest level)

New Brunswick

Hydrographic network and watershed classification:

- New Brunswick Hydrographic Network (includes stream network and watershed boundaries)

Nova Scotia

Hydrographic network:

- Nova Scotia Hydrographic Network

Watershed classification

- Primary (coarsest level), secondary, tertiary, sub-tertiary (finest level)

Ontario

Hydrographic Network:

- Ontario Hydro Network
    - Watercourse
    - Waterbody

Watershed classification:

- Ontario Watershed Boundaries
    - Main (coarsest level), primary, secondary, tertiary, quaternary (finest level)

Prince Edward Island

Hydrographic network:

- PEI Hydro Network

Watershed classification:

- PEI Watershed Boundaries

Quebec

Hydrographic network and watershed classification:

- Quebec Hydrographic Network
    - Geometric stream network
    - Hydrographic Division Units

Yukon

Hydrographic network:

- Yukon Watercourses and Waterbodies (1:1,000,000) (coarsest level)
- Yukon Watercourses and Waterbodies (1:250,000)
- Yukon Watercourses and Waterbodies (1:50,000) (finest level)

Watershed classification:

- Yukon Watersheds

Saskatchewan, Manitoba, Newfoundland and Labrador, Northwest Territories, and Nunavut

The authors are not aware of any distinct hydrographic network or watershed classification system data products for these provinces and territories. The National Hydrographic Network does, however, provide full coverage of these regions.

Appendix B: Partner Register Example

Organization Name	Organization Type	Contact Name	Contact Title	Email	Phone	Website	Contact Date	Contact Method	Notes

Appendix C: Partner Profile Template

Partner profile – [Insert organization name]

- Group type: [Insert type here (e.g., First Nation, NGO, or government)]
- Primary point of contact: [Insert name and role here; and which aspects of project they should be contacted about]
- Other points of contact: [Insert name and roles here; and which aspects of project they should be contacted about]
- Partner participation survey – answer sheet
    - Date:
    - Name of contact:
    - Participation preferences (place a X in each cell that applies):

Preference	Data sharing	Planning	Field assessment	Implementatio n
No further participation				
Receive updates				
Contribute				
Lead				
Coordinate				

- Who is the appropriate person within your organization or community to speak with about knowledge and data sharing?
- Are there any other considerations or concerns that you would like to share?

Optional questions, if partner raised the issue of resources and capacity:

- Is funding required for your organization to participate?
- Is your organization willing and able to seek funding?
- Is your organization willing and able to share data and knowledge to contribute to plan development?
- Other call summary notes.

Appendix D: Barrier-Type-Rating Assessment

As part of the WCRP process, barrier types are prioritized based on their effects on target species to concentrate subsequent planning and remediation efforts where they are needed most. To do so, first determine the extent, severity, and irreversibility of each barrier type using the definitions below:

Extent: Within the project scope, the proportion of the target species' habitat extent that is affected by the barrier type.

Very High	The barrier type affects the target species across all or most (71-100%) of its habitat extent in the watershed.
High	The barrier type affects the target species across much (31-70%) of its habitat extent in the watershed.
Medium	The barrier type affects the target species across some (11-30%) of its habitat extent in the watershed.
Low	The barrier type affects the target species across a small proportion (1-10%) of its habitat extent in the watershed.

Severity: Within the project scope, the proportion of barrier type occurrences that are restricting passage to the target species.

Very High	All or most of the barrier type occurrences are blocking passage to the target species (71-100% of occurrences).
High	Many of the barrier type occurrences are blocking passage to the target species (impassable 31-70% of occurrences).
Medium	Some of the barrier type occurrences are blocking passage to the target species (impassable 11-30% of occurrences).
Low	A few of the barrier type occurrences are blocking passage to the target species (impassable 1-10% of occurrences).

Irreversibility: Within the project scope, the degree to which the effects of a barrier type can be reversed, and connectivity restored.

Very High	The effects of the barrier type cannot be reversed.
High	The effects of the barrier type can technically be reversed, but it is not practically affordable.
Medium	The effects of the barrier type can be reversed with a reasonable commitment of resources.
Low	The effects of the barrier type are easily reversible at a relatively low cost.

Once complete, the extent and severity ratings are combined to give the overall magnitude of each barrier type using the matrix below:

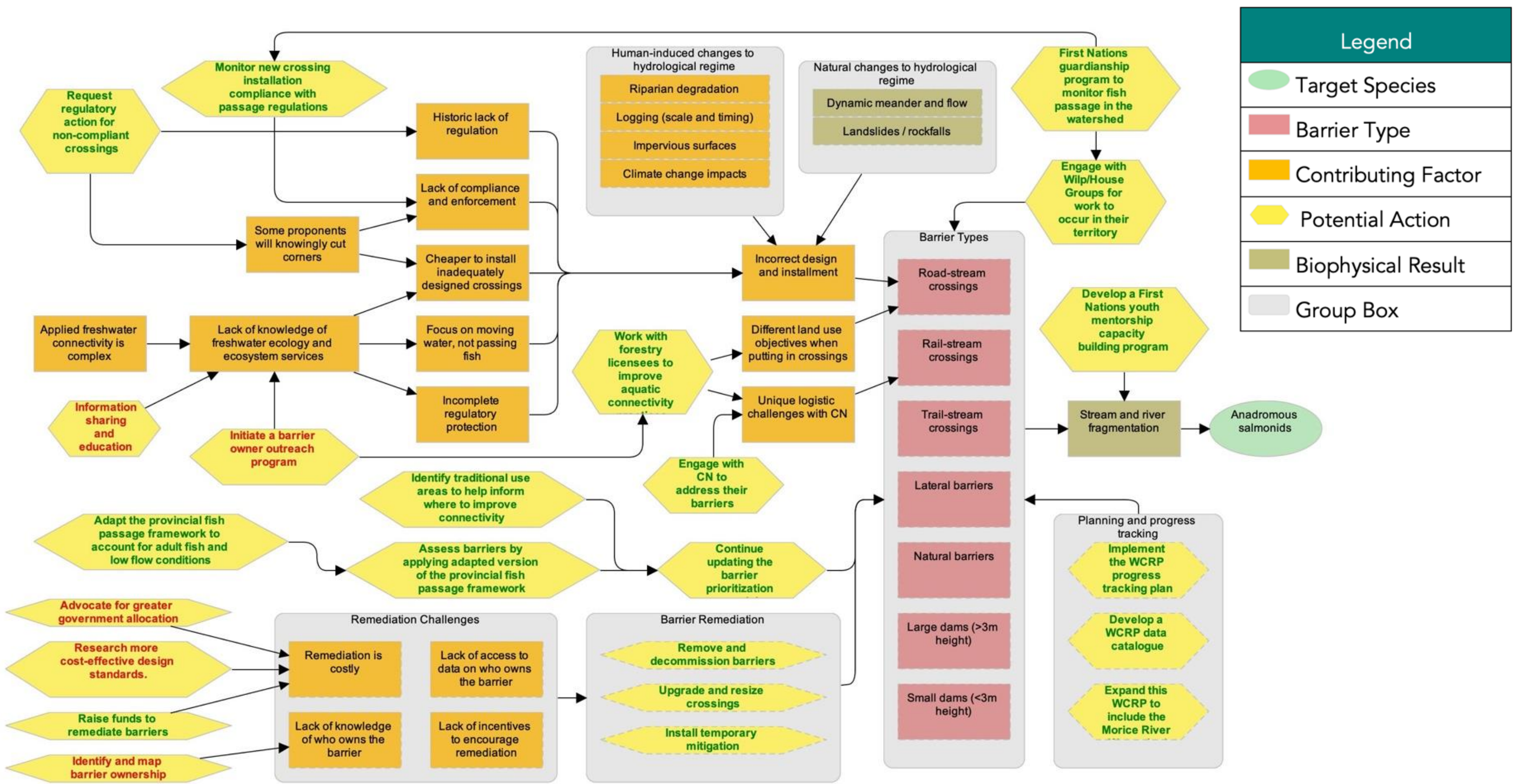
		Extent			
		Very High	High	Medium	Low
Severity	Very High	Very High	High	Medium	Low
	High	High	High	Medium	Low
	Medium	Medium	Medium	Medium	Low
	Low	Low	Low	Low	Low

Finally, the magnitude and irreversibility ratings are combined to give the overall pressure rating of each barrier type using the matrix below:

		Irreversibility			
		Very High	High	Medium	Low
Magnitude	Very High	Very High	Very High	Very High	High
	High	Very High	High	High	Medium
	Medium	High	Medium	Medium	Low
	Low	Medium	Low	Low	Low

Appendix E: Example Situation Analysis

A situation analysis is a graphical representation of the project context. The purpose of this analysis is to ensure that the project team has a shared understanding of the project complexity, including the contributing factors, which are the social, economic, cultural, and political factors that directly or indirectly affect fragmentation in the watershed. Situation analyses also provide opportunities for the project team to brainstorm potential actions to improve connectivity in the watershed. As shown in the example below, these actions can later be colour coded to reflect those that the team will implement (actions with green text) and those that the team will not implement (actions with red text).



Appendix F: Action Effectiveness Assessment

As part of the WCRP process, prioritize actions with the greatest potential to contribute to achieving the WCRP goals. To do so, first determine the feasibility and impact of each potential action using the definitions below:

Feasibility: Within the project scope, the degree to which the planning team can implement the action within realistic constraints (financial, time, ethical).

Very High	The action is ethically, technically, and financially feasible.
High	The action is ethically and technically feasible but may require some additional financial resources.
Medium	The action is ethically feasible, but either technically or financially difficult without substantial additional resources.
Low	The action is not ethically, technically, or financially feasible.

Impact: Within the project scope, the degree to which the action is likely to contribute to achieving one or more project goals.

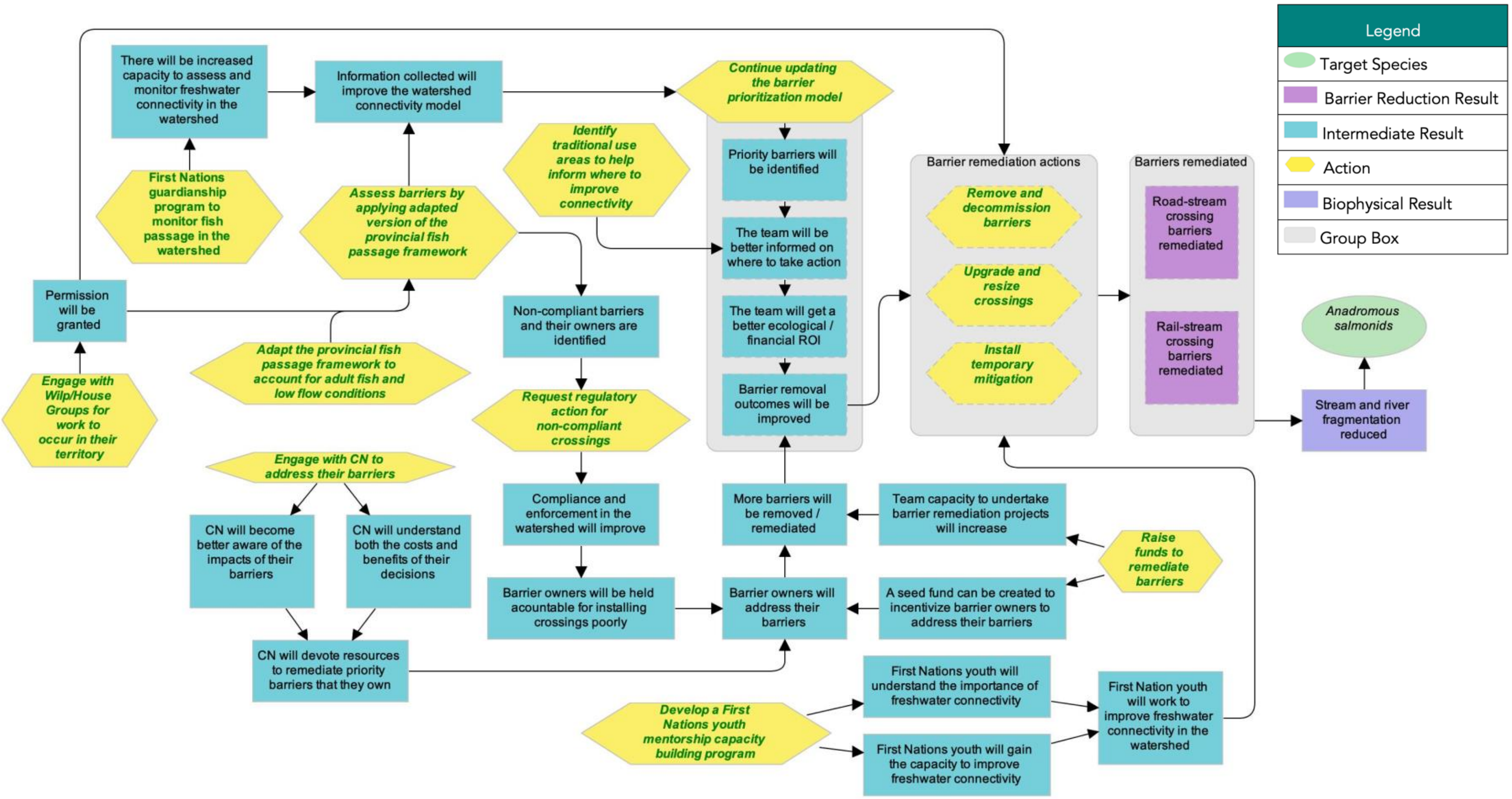
Very High	The action is very likely to contribute to achieving one or more project goals.
High	The action is likely to contribute to achieving one or more project goals but would require detailed monitoring to ensure it is effective.
Medium	The action could possibly contribute to achieving one or more project goals but would require pilot testing to be sure.
Low	The action is unlikely to contribute to achieving one or more project goals.

Once complete, the feasibility and impact ratings are combined to give the overall effectiveness of each potential action using the matrix below:

		Feasibility			
		Very High	High	Medium	Low
Impact	Very High	Very Effective	Effective	Needs More Info	Not Effective
	High	Effective	Effective	Needs More Info	Not Effective
	Medium	Needs More Info	Needs More Info	Needs More Info	Not Effective
	Low	Not Effective	Not Effective	Not Effective	Not Effective

Appendix G: Example Theory of Change

Theories of change are graphical representations of how the project team expects a strategy to achieve its desired outcome. Theories of change help to ensure that the project team has a shared understanding of the intermediate results, which are the assumptions of how each action within a strategy contributes to achieving the WCRP goals.



Appendix H. WCRP Data Types, Formats, and Recommendations

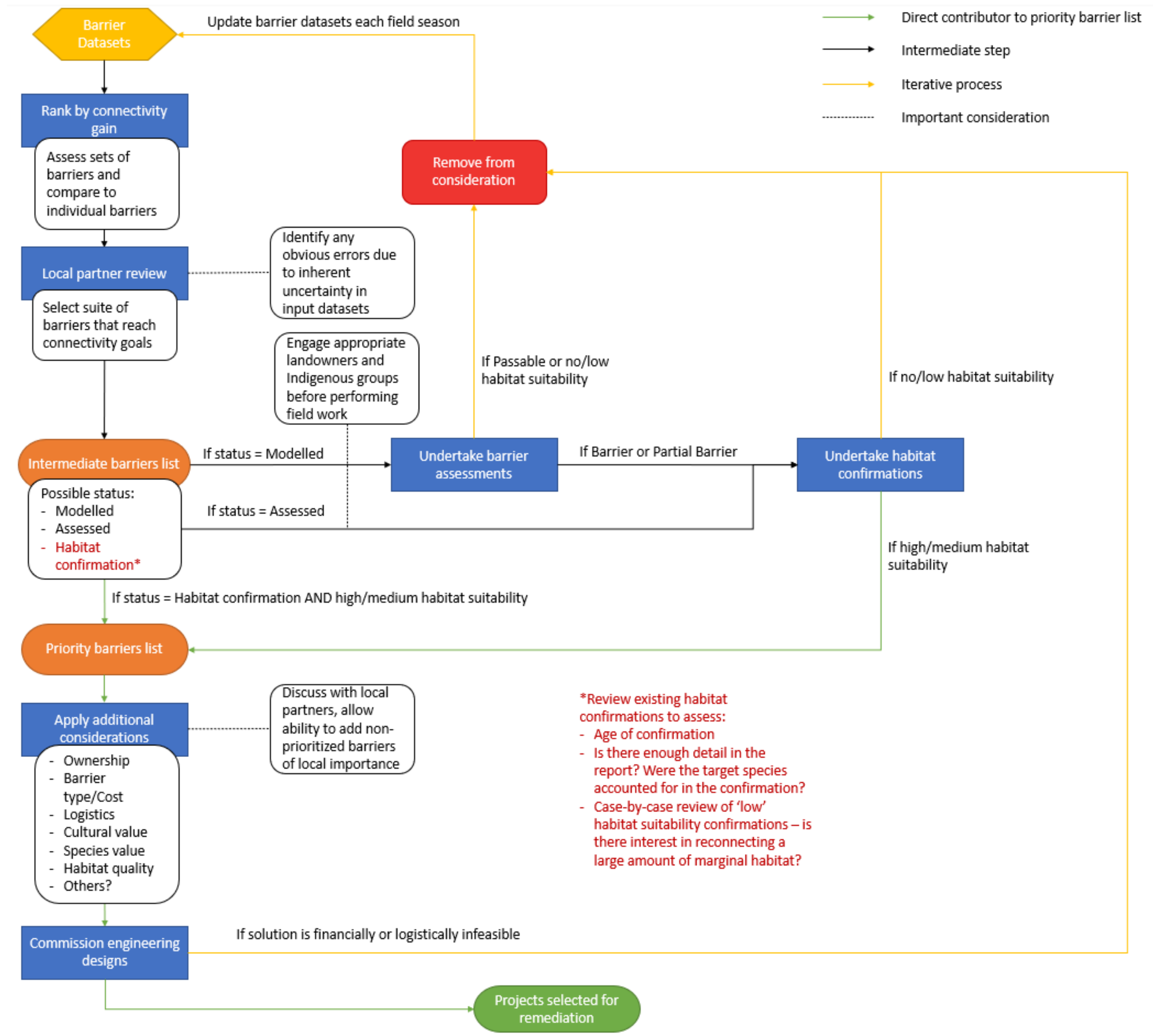
Data types	Example formats	Transform to spatially explicit data	Further reading
Spatial datasets	▪ Vector data (e.g., shapefiles, geopackages, or KML files) ▪ Raster data (e.g., Imagine, GeoTIFF) ▪ Spatial databases (e.g., Microsoft SQL Server, PostGIS)	N/A	GIS data management Data types (ArcGIS) Spatial types in databases (ArcGIS) Exploring data formats and fields (QGIS) PostGIS layers (QGIS)
Tabular data	▪ Spreadsheets (e.g., Excel files, CSV) ▪ Database tables (e.g., Microsoft Access, MySQL, PostgreSQL)	Each entry (row) in a data table will need to be assigned to a spatial feature (point, line, or polygon). This can be done by creating or editing features and their attributes (ArcGIS/QGIS) using built-in tools in the GIS software.	Work with Microsoft Excel files in ArcGIS Common table and attribute tasks (ArcGIS) Databases and ArcGIS Delimited text files (QGIS) Database concepts with PostgreSQL (QGIS)

Table continued on next page.

Data types	Example formats	Transform to spatially explicit data	Further reading
Reports	▪ Scientific literature ▪ Habitat studies ▪ Watershed reports	Relevant data, tables, maps can be converted to spatial data via digitization (creating or editing features) in GIS software. In contrast to tabular data, an attribute table may need to be developed using information contained in the report.	Create datasets in a geodatabase (ArcGIS) Creating layers (QGIS) Creating a new vector dataset (QGIS)
Local knowledge and Indigenous Knowledge	▪ Oral ▪ Written	Local knowledge and Indigenous Knowledge can be transformed into spatial data through relationship building and Participatory Mapping exercises where appropriate to do so, see Section 4.1.3.	Good practices in participatory mapping (International Fund for Agricultural Development) Participatory mapping (Cochrane and Corbett 2018) Producing an Indigenous Knowledge web GIS for arctic Alaska communities: challenges, successes, and lessons learned (Eisner et al. 2012)

Appendix I. Iterative Hybrid Barrier Prioritization Workflow Diagram

This workflow diagram represents the iterative barrier prioritization approach described in Section 4.6. Using the best-available data as a starting point the five key steps of the process and associated considerations are represented: 1) rank barriers by potential gains in connectivity, including evaluating sets of barriers whose combined removal provides more habitat access than would be provided by removing individual barriers; 2) select a suite of barriers or sets of barriers that exceed the requirements to meet the established connectivity goals to create the intermediate barrier list; 3) undertake barrier assessments and habitat confirmations as required and iteratively update the barrier datasets and prioritization model results based on field verification; 4) refine the suite of barriers to those that will meet the connectivity goals to create the priority barrier list and consider additional logistic, social, and economic factors to select which barriers to pursue for remediation; and 5) commission engineering designs for remediation solutions and, if necessary, remove barriers from consideration where financial costs or logistical infeasibility of remediation is prohibitive.


Barrier Datasets
Update barrier datasets each field season
Direct contributor to priority barrier list
Intermediate step
Iterative process
Important consideration
Rank by connectivity gain
Assess sets of barriers and compare to individual barriers
Remove from consideration
Local partner review
Identify any obvious errors due to inherent uncertainty in input datasets
Select suite of barriers that reach connectivity goals
Engage appropriate landowners and Indigenous groups before performing field work
If Passable or no/low habitat suitability
If no/low habitat suitability
Intermediate barriers list
If status = Modelled
Undertake barrier assessments
If Barrier or Partial Barrier
Undertake habitat confirmations
Possible status:
- Modelled
- Assessed
- Habitat confirmation*
If status = Assessed
If high/medium habitat suitability
If status = Habitat confirmation AND high/medium habitat suitability
Priority barriers list
Apply additional considerations
Discuss with local partners, allow ability to add non-prioritized barriers of local importance
*Review existing habitat confirmations to assess:
- Age of confirmation
- Is there enough detail in the report? Were the target species accounted for in the confirmation?
- Case-by-case review of 'low' habitat suitability confirmations – is there interest in reconnecting a large amount of marginal habitat?
- Ownership
- Barrier type/Cost
- Logistics
- Cultural value
- Species value
- Habitat quality
- Others?
Commission engineering designs
If solution is financially or logistically infeasible
Projects selected for remediation