WaterShade

Policy for the protection and enhancement of cold-water refuges in New Brunswick

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1. Context

Climate change and human activities have resulted in dramatic changes across all ecosystems that Atlantic salmon populations inhabit, causing drastic population declines. Changes in river temperature dynamics (e.g., daily variability, frequency, and duration of summer maximum, warmer thermal regimes) is one of the main concerns as it impacts growth rates, reproductive success, abundance of prey, timing of migration, and survival. During low flows and warmer conditions, thermal heterogeneity becomes essential to the resilience and survival of Atlantic salmon.

The past decade has produced scientific advances in thermal regime understanding and more specifically cold-water refuges (CWRs) as key components of thermal heterogeneity, but policy development has not kept pace. The dynamic nature of CWRs makes identification, measurement, protection and management challenging and requires an interdisciplinary and collaborative approach between scientists, managers, stakeholders, land-use planners and policymakers that will : (1) include CWRs explicitly as a primary consideration for effective management, (2) implement dynamic spatial and temporal management practices, (3) leverage existing and new policies, and (4) improve coordination across jurisdictions as done for other ecosystem units.

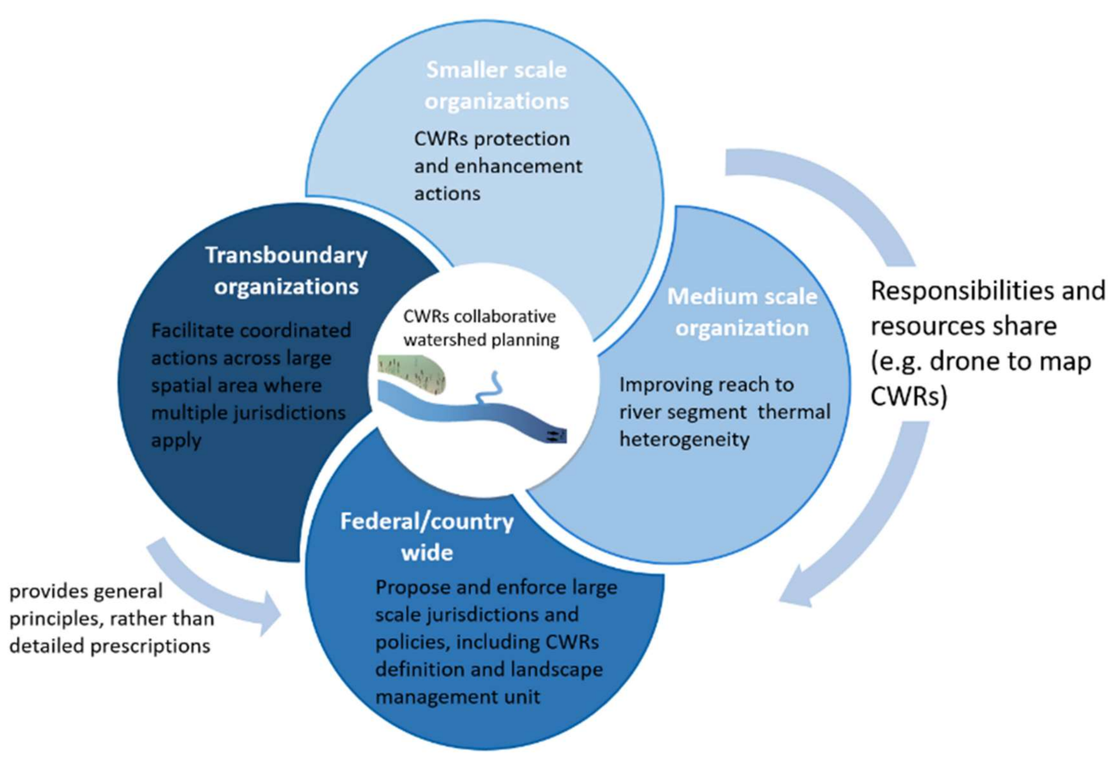

Figure 1: Scales of organization with corresponding management prioritization of cold-water refuges (source: Mejia et al., 2023)

2. The WaterShade project

The WaterShade project consists in developing a long-term and watershed-scale strategy for the management of CWRs in New Brunswick, targeting the headwater streams, ensuring that the riparian zones are adequately restored and protected in the long term while defining the maximum acceptable land use in the sub-watersheds. WaterShade would therefore become our preferred approach for the protection of CRWs in the face of climate change.

WaterShade has two components:

1) A general policy including a methodological framework for the selection, protection and enhancement of CWRs at the watershed scale
2) An implementation plan for the protection and enhancement of specific CWRs on the Restigouche River watershed

The main partners in this project are:

- Working team
  - Gespe'gewa'gi Institute of Natural Understanding (GINU, formerly Gespe'gewaq Mi'gmaq Resource Council – GMRC)
  - Restigouche River Watershed Management Council (RRWMC)
  - LeBlanc MultiRessources
- Funding
  - Department of Fisheries and Ocean Canada (DFO) through the Aquatic Ecosystem Restoration Fund
  - The Atlantic Salmon Conservation Foundation
- Scientific support
  - University of New Brunswick
  - Institut National de Recherche Scientifique, centre Eau, Terre et Environnement (INRS-ETE)
- Governmental collaboration
  - Department of Natural Resources and Energy Development of New Brunswick (DNRED)
- Inter-provincial intra-watershed collaboration
  - Organisme de Bassin Versant Matapédia-Restigouche (OBVMR)
- Potential partners for future application
  - Licensees Owners on the Restigouche River watershed
  - Nepisiguit Salmon Association
  - Northeast Fisheries Science Center
  - Listuguj First Nation
  - Pabineau First Nation
  - Eel River Bar First Nation
  - Chaleur Bay Watershed

3. WaterShade policy objectives

The objectives of this policy are to provide concerted guidelines for:

1. **Protection of CWRs and maintenance of their function.** To manage human activity near CWRs and in their drainage areas in a manner that will achieve no loss of CWR function.
2. **Creation or enhancement of CWRs.** To improve CWRs efficiency where thermal anomalies exist but are not, or poorly, used by salmon during high temperature events.
3. **Securement, stewardship, education and awareness.** To promote and facilitate the development of CWR stewardship, education and awareness through government initiatives and cooperative relationships with local citizens, private sector stakeholders, and municipal, provincial, and federal governments.
4. **Further research for thermal regime understanding.** To promote, develop and coordinate scientific research to better understand thermal heterogeneity of New Brunswick river systems, the impacts of human activities and the way to protect CWRs.

WaterShade aims to be an adaptive management approach. As a part of it, this policy is an evolving document. This first version of the policy is proposed as an integrative tool and a reference baseline for further discussion with stakeholders and other partners and for implementation on pilot sites on the Restigouche River watershed (see WaterShade Implementation plan). It should be regularly updated to account for lessons learned from implementation, research advancement, changes in guidelines and regulations, as well as spatial and temporal variability of CWR, following a three-loop approach as depicted on Figure 3. Each loop involves re-evaluating assumptions to decide whether to alter the decision-making framework.

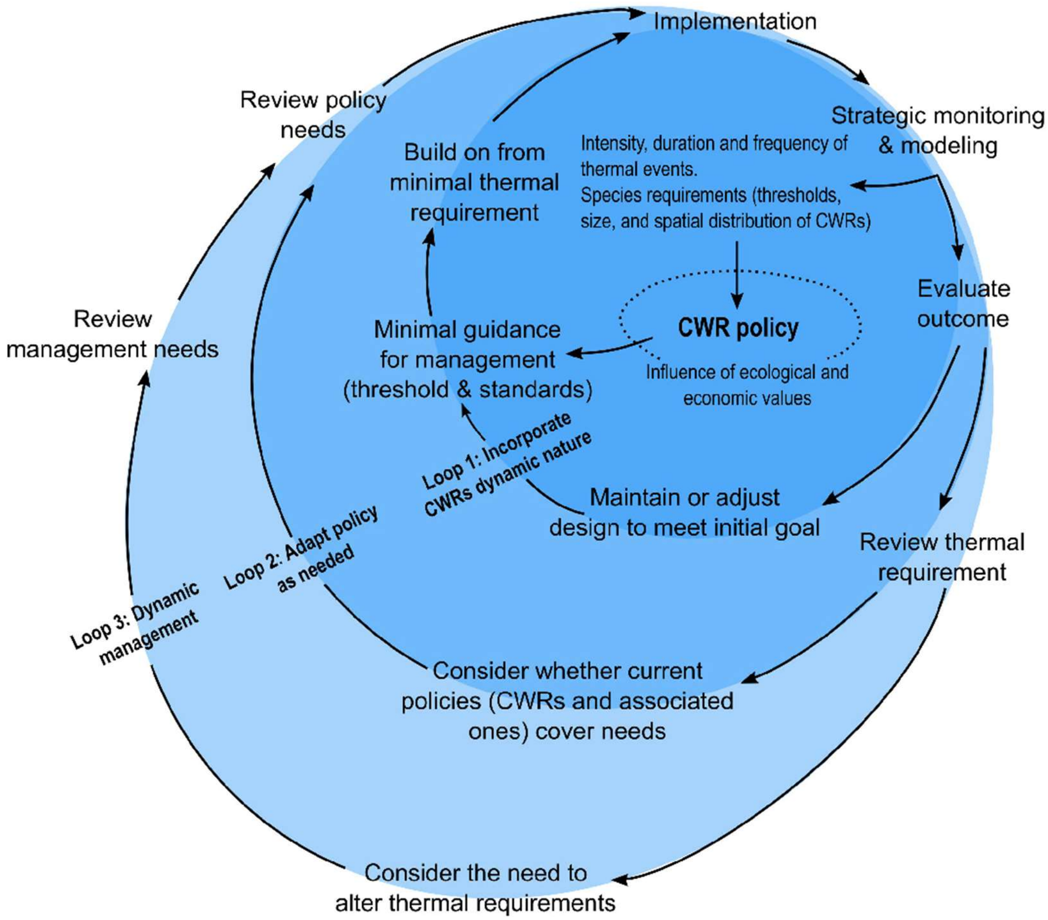

Figure 2: Triple-loop learning adaptive management approach showing the different pathways and outcomes of cold-water refuge (CWR) policies (source: Mejia et al., 2023)

4. Background

The following information is a summary of current regulation and knowledge regarding CWRs and their management. A detailed literature review will be given in the two papers that are in preparation for publication in international journals about (i) the general approach of CWR selection, protection and management, and (ii) best practices for cold-water refuge enhancement (Gillis et al., in preparation).

4.1. Cold-water refuges

When water temperatures reach 20-23 °C, thermal stress occurs and salmon exhibit behavioral thermoregulation to avoid warmer areas by accessing CWR (e.g., upstream shaded areas, tributaries, groundwater upwelling zones). This ability to thermoregulate becomes limited as thermal heterogeneity decreases, and CWRs become less available. The distribution, abundance, and persistence of these CWRs are critical to the resilience of catchments to sustain wild Atlantic salmon populations. See *Definitions* section for CWR typology.

4.2. Buffer zones

The buffer zone (or buffer strip or riparian buffer) of a watercourse (or a wetland) provides a progressive transition between the stream and the surrounding area (forest, agriculture) which influences some characteristics of the river ecosystem such as water and air temperature, physical and chemical processes in the ground litter, as well as habitat of semi-aquatic and hydrophilic species. The trees and shrubs in the buffer zone help maintain the microclimate around the watercourse or the wetland by providing shade and acting as an insulator against the extremes of temperature and humidity found in open areas.

The removal of buffer zones has a significant impact on the thermal regime by reducing shading and increasing solar radiation on water. These impacts include:

- A faster increase of temperature in early summer
- An increase of mean and maximum water temperature during summer

4.3. Headwaters

Headwaters perform ecological functions (i.e., biological, geochemical, and physical processes that occur within an ecosystem) that are critical for ecosystem services throughout their drainage basins. They play an important role in the thermal regime of a river system and its response to land use and forest harvesting: (i) they are highly sensitive to surface and subsurface processes, and the smallest streams often experience the greatest increase in stream temperature following forest harvesting; (ii) the warming of water in these small streams has a downstream effect on larger streams and rivers, which may mitigate the efficiency of buffer zone protection for these larger watercourses, especially in early summer.

4.4. Land use in drainage areas

Landscape scale characteristics can control the local, reach scale habitats driving the location and characteristics of CWR. More specifically, the removal of forest cover, or the cultivation of crops with low vegetation cover such as potato in agricultural lands, increases insulation of exposed ground, reduction of transpiration and thermal exchanges at soil level, especially solar radiation, which contributes to the warming of soil as well as runoff water and groundwater before they reach streams. This effect applies at large watershed scale but also at the scale of smaller drainage areas where the slopes are higher and flow is essentially underground in summer.

4.5. Urban stormwater runoff

Urbanization leads to extensive increases in impervious surfaces such as roads, roofs, parking lots and pavements, that absorb and retain more heat from solar radiation during summer months than during the rest of the year. These aspects can directly or indirectly lead to the thermal pollution of stormwater runoff and downstream surface waters.

4.6. Other threats to cold water refuges

The integrity of groundwater-sourced thermal refugia is subject to a number of human factors that may warm or reduce discrete groundwater discharge to streams and rivers, including aggregate extraction (*e.g*., sand and gravel pits), groundwater extraction, flow manipulations, and atmospheric climate change.

4.7. Current approach in the management of water thermal regime in New Brunswick

Protection of surface water thermal regime in New Brunswick relies currently on the following components. No specific regulation exists regarding freshwater temperature.

The Clean Water Act

According to the *Clean Water Act* (S.N.B. 1989, ch. c-6.1) and the *Watercourse and Wetland Alteration Regulation* (NB Reg. 90-80), any project that is likely to alter a watercourse or a wetland, including any disturbance of the ground within 30 m of the bank, requires any alteration in or within 30 metres of a watercourse or a wetland requires a Watercourse and Wetland Alteration (WAWA) permit.

Forest management on New Brunswick Crown Lands

The protection of thermal quality in streams and rivers of New Brunswick Crown Lands is mainly managed by the protection of buffer zones, as defined in the *Forest Management manual for New Brunswick Crown Lands* (FMM).

- 30 m from a natural watercourse with continuous flow or with a discernible channel wider than 0.5 m, and from wetlands of more than 1 ha or associated with a natural watercourse that meets the previous criteria. Partial harvesting is permitted beyond 7 m from the watercourse.
- 7 m from a natural watercourse without continuous flow and less than 0.5 m wide, and from wetlands of less than 1 ha that are not connected with a permanent watercourse. All merchantable trees can be harvested within the 7 m buffer zone.
- No buffer zone is required along forested wetlands.

Specific buffer zones are also defined to protect special features including “cold-water inputs and refuge” (as defined by DNRED), with a 30 m buffer without any timber harvesting.

Timber harvesting may occur within appropriate buffer zones as long as “*the partial harvest treatment maintains buffer zone function over time*” and as “*mineral soil exposed through forestry operations with the potential to enter a natural watercourse will be stabilized immediately*”.

Licensees are responsible to delimitate and respect these buffers on the field while DNRED has the responsibility to control the application of the FMM by licensees.

Cut areas are limited to 75 ha in sectors sensitive to natural perturbations (“GAP”) and to 200 ha elsewhere in Crown Lands (“STAND”).

Protected natural areas

Since 2003 and the Protected Natural Areas Act (O.C. 2003-54), the government of New Brunswick has defined 208 Protected Natural Areas (PNA) for a total area of 2 738 km² of lands and watercourses. These PNA have been selected as high value forest ecosystems, including old forests and forests with rare geological and ecological characteristics. Class I PNA are denied access while class II PNA allow some recreational and traditional activities. Forest harvesting, agriculture and industrial activities are forbidden in all PNA, which allows to see the ecosystem regeneration and its effects on freshwater.

Between 2021 and 2023, in the context of the Natural Legacy Initiative, the government of New Brunswick defined 552 new protected areas (for 3 848 km²), which enabled reaching the target of 10% of provincial lands. These new protected areas have been defined to protect more specifically watercourses, lakes and wetlands, with larger buffer zones along some salmon rivers such as Restigouche, Patapedia, Kedgwick and Upsalquitch rivers.

Private woodlots owners (including J.D. Irving)

Private woodlots owners must abide by federal and provincial laws regarding freshwater protection, including the New Brunswick *Watercourse and Wetland Alteration Regulation*. The applications of other best management practices such as buffer zones along the streams is recommended, although not mandatory.

Agricultural lands

Several best management practices enable to reduce runoff, sediment transport but also soil and water temperature warming, such as buffer zones along streams and ditches or intercropping. The adoption of such practices by farmers is voluntary and supported by the Environmental Farm Plan (EFP) which is funded by the Canadian Agricultural Partnership.

Warm water protocol

A warm water protocol has been implemented in the main salmon rivers of New Brunswick (Miramichi, Restigouche). It is used as a tool for conservation of the Atlantic salmon during environmentally stressful conditions (i.e. warm water episodes during summer). It is activated when certain predetermined temperature thresholds are reached. Restrictions may include reducing the number of fishing hours allowed or complete closure of recreational fishing in a river or sections of a river. When environmental conditions improve, restrictions are lifted according to the conditions set out in the protocol.

4.8. Comparison with cold-water refuges management in Quebec

No specific policy or guidelines exist in Quebec for the protection or enhancement of CWRs. The main differences with New Brunswick are described below and summarized on Table 1.

- Water temperature standards

Surface water temperature standards are defined in Quebec as follow:

> Every decrease or increase in water temperature should not:

- modify water temperature on a whole river section or a portion of a lake resulting in the predictable movement or the modification of present or potential aquatic populations;

- alter certain sensitive and localize, such as a spawning area;

- kill the organisms living in the vicinity of a discharge.

Moreover, the environment should not suffer any sudden change in water temperature triggered by, for example, a sudden end of a thermal discharge during the cold season.

- Fishing restrictions

Angling in cold-water refuge can be forbidden by local river management groups. For instance, this is the case in the Matane River where a part of a pool known as an important cold-water refuge is closed to angling in August each year.

Warm water protocols are also applied in two rivers of the Saguenay-Lac-St-Jean region in the context of an experimental project.

- Specific buffer zones upstream CWRs on public land

According to the *Règlement sur l'Aménagement durable des Forêts* (RADF), a 60 m buffer zone is applied along the rivers designated as "salmon rivers". This applies only to the river and not to its tributaries. No specific adding buffer is defined for cold-water sources and refuges.

- Legal protection of CWR drainage area on public lands through regional regulation

In some Quebec regions, drainage areas of selected CWRs are in the process to be legally protected through their inclusion in *Plan régional des milieux humides et hydriques* (PRMHH) of regional county municipalities (RCM). These plans aim to integrate the conservation of wetlands and bodies of water into land use planning, by promoting sustainable and structuring development. This is the case for PRMHH of Avignon and Matapedia RMCs. These PRMHHs are currently in the final process to be approved by the ministry.

Some groups work for the recognition of CWRs as "wildlife interest sites" which would be protected in Quebec legislation.

- Voluntary-based protection of selected CWRs drainage area on private lands

Voluntary-based protection plan which focused on information, awareness and involvement of landowners in the CWRs drainage areas. Such a plan has been implemented in 2020 in the Matapedia River watershed by OBVMR. This process led to the signing of voluntary conservation agreements by land owners.

Table 1: Comparison of the main components of water temperature and cold-water refuges management in New Brunswick and Quebec

Province	New Brunswick	Quebec
Water temperature standards	No	Yes
Fishing restriction in CWRs	No	In some rivers and for specific CWRs (ex: Matane River)
Warm water protocol	Restigouche, Miramichi and Nepisiguit rivers	Petit-Saguenay and Saint-Jean du Saguenay rivers (experimental)
Specific buffer zone upstream cold-water inputs on public land	Yes (30 m buffer with total protection as opposed to 30 m with partial harvest elsewhere)	No (but 60 m buffer with total protection along salmon rivers)
Legal protection of CWRs drainage area on public lands	No	In some regions through PRMHHs
Voluntary base protection programs on private lands	No	In some regions (ex: Matapedia River watershed)

Education, awareness and research efforts to better understand and protect CWRs in Quebec are being done by several organisms such as the *Fédération Québécoise du Saumon Atlantique* (FQSA), the *Centre Interuniversitaire de recherche sur le saumon atlantique* (CIRSA), INRS-ETE and watershed organizations.

4.9. Principles of thermal quality management at the watershed scale

According to literature, the best way to protect the thermal regime of a river for salmon and other native cold-water fauna is to combine:

- The protection of the coldest portions of the river network (i.e., the most important existing cwr)
- The preservation of shading buffer zones along streams and rivers
- The preservation of groundwater connectivity and hyporheic exchange (aquifer recharge/discharge, storage, wetland and floodplain management)
- The protection of headwaters forested drainage areas from intensive logging, especially from clearcutting
- The management and limitation of bare soil surfaces in agricultural lands
- The management and limitation of surface and groundwater withdrawals for drinking and irrigation
- The management of urban stormwater runoff through harvesting and infiltration facilities

4.10. Principles of cold-water refuge enhancement

Existing thermal anomalies may not function as effective refugia for target species because of physical or chemical conditions, including limited temperature difference from the ambient river temperature, insufficient cover or inadequate dissolved oxygen levels. The objective of CWR enhancement is to augment thermal anomalies to improve performance as refugia or to create new thermal refugia in uniformly warm river reaches.

Confluence plumes are the most suitable class of CWRs that can be enhanced. Enhancement uses solutions that can be:

- Passive solutions, such as (i) creating pools or installing deflectors upstream of confluence plumes in order to enlarge them, (ii) creating or increasing riparian shading, or (iii) install cooling drainage field in a meander of the river
- Active solutions, such as pumping cold groundwater into the river

Numerous CWRs enhancement projects have been done in Canada, following a trial-and-error approach. CWR enhancement needs guidelines to avoid the “free for all” approach.

5. Objective 1: Management and protection of cold-water refuges

The following proposed actions for a better management and protection of CWRs are summarized in Table 1.

5.1. Identification and classification of thermal anomalies

The methodological approach to identify thermal anomalies in a river is usually based on thermal infrared imagery, complemented by local knowledge. The analysis of thermal enables to classify cold-water anomalies according to the typology presented in section 9.

5.2. Update governmental inventory of cold-water inputs and refuges

The streams located upstream of cold-water inputs and refuges, which are defined by DNRED in the Forest management manual, are supposed to be protected by a 30 m buffer without any harvesting. However, these cold-water inputs and refuges are currently often based on old and/or partial data.

- All CWRs in New Brunswick salmon rivers will be listed and mapped according to existing data. This information will be available to government, stakeholders, and Crown Land licensees subject to confidentiality agreement, but no to the public (see section 5.2). When data is not available, CWR inventory research programs will be performed (see objective 3, section 7).
- Buffer zones for cold-water inputs and refuges in Crown Lands, as defined in the FMM, will be updated accordingly.

5.3. Gather cold-water refuge data in a shared platform

Investing in platforms that bring together data about CWR (including localization, physical, geomorphological and biological characteristics) is needed to streamline access to data and build the evidence base for CWR collaboratively. Such platforms already exist, for example on the Quebec part of the Restigouche River watershed, where GINU, with the financial support of DFO, has built a web platform (GeoNode) to visualize and get access to data regarding CWRs as well as their drainage areas. This platform could be first expanded to the New Brunswick part of the Restigouche River watershed, before being applied to other watersheds.

However, it is of high importance that CWR localization data do not become publicly available since during hot summer periods, CWR become sanctuaries where a lot of salmon gather and therefore become vulnerable to eventual poaching. The issue is to share the information between partners and stakeholders while ensuring its confidentiality. Data sharing may also be subject to the signature of a non-disclosure agreement (NDA).

5.4. Protect cold-water refuges from human activities

Once the CWRs are identified and mapped, potential human activities that could have an impact on their integrity or on fishes, such as poaching, should be identified by discussion with local people (fishing camp users, first nations, landowners). If such an issue is identified, outreach activities should be promoted (see objective 3, section 6) and a watching crew should be deployed on the site during summer.

5.5. Adopt land use management strategies in CWR drainage areas

The specific protection of freshwater thermal heterogeneity should include:

- Identification of the processes that generate CWRs (e.g. Direct or indirect groundwater discharge)
- Prioritization of CWRs to protect through hydrological analysis, thermal monitoring and spatial distribution
- Identification and mapping of target headwater drainage areas in the watershed according to geomorphological features (e.g. Soil, slope, orientation, presence of wetlands, hydrogeology)
- Adaptation of forest cutting plans in target areas to limit clearcutting and bare soil areas
- Restoration and protection of vegetated buffer zones along streams and rivers
- Limitation of land use change, groundwater pumping and aggregate extraction in target areas
- Monitoring of water temperature to assess the efficiency of protection measures

A general framework for the selection of CWRs and thermally sensitive sites to be protected is given in Appendix A (section A.1), together with an action plan for protection of selected CWRs (section A.2).

Such an approach is being applied on the Restigouche River watershed as a pilot project (see WaterShade Implementation plan).

5.6. Improve the application of legislation regarding buffer zones in Crown Lands

It is of crucial importance for CWR protection to:

- Ensure that buffer zones of permanent streams and wetlands are well protected
- Ensure that the hydrological status (intermittent/permanent) of small stream is adequately determined on the field
- Ensure that the partial treatments (harvesting of merchantable trees) in the 7 m buffer zone of intermittent streams and small wetlands preserve the shading function of riparian vegetation, as required in the Forest Management Manual

This could be done by:

- Improving education and awareness of licensees, workers, and government representatives
- Increasing inspections on the field by DNRED
- Highlighting and rewarding the licensees' initiatives that protect more buffer zones than minimum legal requirements set forth by the province of New Brunswick

5.7. Improve legislation regarding forest management in Crown Lands

The current Forest management manual was released in 2014 and, since then, some gaps have been identified regarding the protection of river systems, including temperature heterogeneity. The most important one is probably the lack of limitation regarding cut areas, especially clearcut areas, at the watershed scale. In an improvement process, the next version should include:

- The implementation and calculation of equivalent cut areas calculations at the watershed scale in licences forest management plan. It is recommended that the delimitation of elementary watersheds for such an implementation is based on streams with a Strahler's order of 3.
- The identification of sensitive elementary watersheds regarding streamflow, siltation and water temperature issues in potential or confirmed salmon habitats, based on field observations and available data.
- The limitation of equivalent cut area at 30% in sensitive watersheds, 50% elsewhere.
- Evaluate the possibility to adopt a total protection (e.g. without harvesting of merchantable trees) in the 7 m buffer zone along intermittent streams and small wetlands located in CWRs catchments.

5.8. Create new protected areas targeting CWRs

In the continuity of the Natural Legacy Initiative which defined protected areas around watercourses, lakes and wetlands of high importance for fish habitat, the future creation of protected areas should target specifically the drainage areas of highly sensitive CWRs. It could be through an eventual new round of protected natural areas in the Natural Legacy Initiative or through the Indigenous Protected and Conserved Area (IPCA) program.

5.9. Establish water temperature standards and guidelines

Temperature standards and guidelines are critical components of the assessment of water quality or ecological status for many countries and Canadian provinces. They enable them to directly manage and regulate water temperature, CWRs, and the fish that use them. Such standards do not exist in New Brunswick.

With a view to coordination with the province of Quebec, the adoption of such standards in New Brunswick could be based on the Quebec ones (see section 4.8). Water temperature standards should also include a CWR definition that is specific, clear, implementable, and recognizes their dynamic nature.

5.10. Promote best management practices on private woodlots

On private lands, the protection of buffer zones and headwaters drainage areas is not mandatory. Thus, a better protection of CWR and thermal regime will be achieved by information, awareness, and involvement of private landowners (see objective 3, section 7) regarding the same issues as on Crown Lands (i.e., buffer zones, drainage areas).

This should include:

- The prioritization of CWRs to protect
- The characterization of CWR drainage areas and determination of sensitive areas to protect (headwaters, wetlands, etc.)
- Discussions with land owners
- The signing of voluntary conservation agreements

5.11. Promote best management practices in agricultural lands

The restoration, enhancement and protection of buffer zones along ditches, streams and wetlands should be promoted on agricultural lands (see objective 3, section 7). The riparian vegetation should include shrubs and trees in order to provide shading to water flow.

This should include:

- The prioritization of CWRs to protect
- The characterization of CWR drainage areas and determination of sensitive areas to protect (buffer zones)
- Discussions with farmers
- The signing of voluntary conservation agreements

5.12. Promote the control of runoff water in urban areas

The control of runoff water in urban areas has many advantages and enables to limit urban stormwater runoff temperature, but also river peak flow, erosion and siltation and water pollution. This should be promoted at the municipal level and with land owners (see objective 3, section 7), using a “slow it, spread it and sink it” approach including the following examples:

- gutters and downspouts
- drip-line protection
- roof rainwater collection system
- outlet protection
- rain gardens
- swales in landscape management
- infiltration structures
- mulch basins
- pervious hardscapes for patios and driveways
- ground covers
- erosion control blankets
- living roofs
- cross drains
- retaining walls and terracing

5.13. Integrate cold-water refuges protection in municipal plans and policies

In the same way as wetlands, CWRs should be legally protected at all levels of government, including municipalities. This will be achieved by (i) information and awareness activities among municipal actors (mayor, city council; see objective 3, section 7), and (ii) integration of selected CWRs in municipal regulations, plans and policies.

5.14. Ensure coordination with other jurisdictions at the watershed scale

For rivers that cross boundaries (Quebec province or United-States) it is necessary to align, as far as possible, consistent protection strategies guided by common socio-economic values.

6. Objective 2: Enhancement of cold-water refuges and river thermal regime

Every CWR enhancement (or creation) project in any river system of New Brunswick should be based on a multidisciplinary approach, including biology, geomorphology, hydrology, hydrogeology and engineering, and on the following principles and steps.

6.1. The principles of ecological restoration

The International principles and standards for the practice of ecological restoration (Gann *et al*., 2019) **"***Provide a guide to practitioners, operational personnel, students, planners, managers, regulators, policymakers, funders, and implementing agencies involved in restoring degraded ecosystems across the world—whether terrestrial, freshwater, coastal, or marine. They place ecological restoration into a global context, including its role in recovering biodiversity and improving human wellbeing in times of rapid global change*"**.** It includes eight principles that underpin ecological restoration (figure 2).

Figure 3: Eight principles for ecological restoration (source: Gann et al., 2019)

6.2. Reserve CWR enhancement projects to professionals

CWR enhancement projects should be performed by professionals from universities, watershed groups or governments.

6.3. Selection of CWRs to enhance, restore or create

The selection and choice of the CWRs to enhance, restore or to create should:

- Be based on an informed decision-making process to determine possible success of restoration (remote sensing, LiDAR, FLiR, drone, feasibility). This should include important criteria including, but not limited to, First nations acceptability, machinery access and proximity of other CWRs.
- Be done in collaboration with, or at least approved by, multiple partners (communities, watershed organizations, First nations, consultants, farmers, landowners, government organizations).
- Be integrated in a watershed scale approach by taking into account drainage area characteristics (gradient, land use, shading along streams and rivers, runoff, beaver activity, etc.) and ensuring that the root causes of a potential water warming are addressed before considering CWR enhancement.
- Integrate Indigenous and Local Knowledge. In alignment with Canada's National Adaptation Strategy, the creation or enhancement of CWRs should "Respect jurisdictions and uphold Indigenous rights" and "Advance equity and environmental justice." It should be inspired by the "Two-Eyed Seeing" approach to develop solutions that match local needs.

A detailed framework for the selection of CWRs to enhance, restore and create is given in Appendix A (section A.3).

6.4. Selection of enhancement method

Appropriate light, passive and long-term methods should be selected in priority. It includes deflectors and tree cover restoration (see section 6.8).

When engineering solutions are used to improve a CWR, it should:

- Work with the river and not against it
- Be based on multidisciplinary up-to-date science (biology, hydrology, engineering)
- Take into account the effects on hydrological and ecological issues regarding fish behaviour
- Be designed by an experimented professional or consultant
- Be designed, as far as possible, in a way to discourage eventual poaching effort (*i.e.* Fishes not easily spotted and nets not easily swept)
- Be approved by project partners
- Be approved by a governmental permit according to the provincial regulation

Active solutions such as groundwater pumping should be used with caution and be preceded by local hydrogeological analyses to avoid potential issues regarding groundwater pattern and to maximize the ecological function of the created thermal anomalies.

6.5. Monitoring, maintenance and feedback

Every enhancement project should include a long-term monitoring before (baseline) and after the works regarding:

- Daily water temperature

- Fish behaviour and CWR usage by fish
- Impacts on multiple trophic levels
- State, evolution and efficiency of the structure (e.g. deflectors)

A regular and long-term maintenance of the structure should be performed if needed to maintain the project's targets over its lifetime.

6.6. Communication

Each CWR enhancement project should include a communication component to inform partners, members of the scientific community, community members and public through outreach (see Objective 4, section 6).

A community of practice regarding CWR enhancement issues would gather all groups and people involved in CWR enhancement (called community members) and create opportunities to work together rather than a patchwork of CWR enhancement projects. This would enable to:

- Provide a forum for community members to help each other with work needs
- Develop and disseminate best practices, guidelines, and strategies for their members' use
- Organize, manage, and steward a body of knowledge from which community members can draw
- Create breakthrough ideas, new knowledge, and new practices
- Move towards the setting and continuous improvement of standards and targets

The leading and organization of this community should be done by an experienced and dedicated group or professionals.

6.7. Tree cover restoration in riparian areas

The restoration or creation of a riparian woodland can be costly and logistically challenging. Any project should first:

- Identify and map streams and rivers in the watershed that are not protected by any substantial tree cover and with low potential for natural recovery
- Prioritise areas where replanting can have greatest benefits for river temperature, specifically, where rivers are (i) warm, (ii) sensitive to climate change, and (iii) can be effectively cooled by riparian woodland, which can be broadly characterised by river order
- Prioritise the most southerly bank of channels
- Prioritise indigenous tree and shrub species, adapted to forecasted future climate

7. Objective 3: Securement, stewardship, education and awareness

This objective is a cross-cutting one and include the following components:

- Use a variety of strategies to conserve and protect CWRs, which may include restrictive covenants, conservation easements, stewardship agreements, ecologically sensitive land gifts and acquisition.
- Participate in cooperative projects to manage CWRs through agreements.
- Promote and assist in the development of CWR education programs that target the general public, public schools, landowners and other private sector stakeholders.
- Support and encourage the development of cooperative educational programs with private sector stakeholders.
- Encourage the exchange of information and expertise among government departments regarding CWRs.
- Encourage all other government departments, municipalities, planning commissions, and local service districts to ensure that all policies and programs are consistent with and, where appropriate, supportive of the CWR conservation objectives of this policy.
- Strengthen capacity for management, protection and enhancement of CWRs. This would include equipping key professional groups (e.g., planners, asset managers, engineers, landscape architects) with training tools and resources that would support the protection and enhancement of CWRs and involve people and community-based organizations (e.g., watershed groups, municipal champions, advocacy groups, citizen science) in the decision-making process.
- Inform, aware and involve private landowners to protect CWRs on a voluntary basis.

8. Objective 4: Applied research

A better understanding of CWRs is essential to their protection. Bottom-up driven research enhances the likeliness of developing effective and useful tools for end users. Here are some research topics to develop.

8.1. Inventory, monitoring and characterization of CWRs

Identification of the spatial distribution of CWR can be done using several methods including thermal surveys with a distributed array of temperature loggers, fiber optic distributed temperature surveys, thermal profile method or manned aerial infrared surveys. A standardization of these methods is needed to facilitate their implementation and the homogeneity of data and results.

Since these methods are time and money consuming, further research is also needed to develop methods based on GIS and geomorphological analysis of river systems focusing on indicators such as lake and wetland density, forest type and riparian vegetation, catchment slope, river sinuosity, channel curvature and confinement.

8.2. Assess the effect of protected natural areas on thermal regime

Long term studies should be initiated to assess the influence of preservation activities such as protected natural areas on the thermal diversity of selected stream and river reaches in comparison to nearby reaches that have not been targeted for thermal diversity preservation. This will enable us to better understand and quantify the effects of land use on water temperature, as well as the factors to take into account in land use management in the context of CWR protection.

8.3. Assess the long-term viability and impact of CWR enhancement solutions

The different solutions, either active and passive, that have been applied in different places for augmenting existing thermal anomalies or creating new refugia via groundwater pumping and focused discharge would have to be monitored to verify their efficiency on the long term and their potential impact on salmon and the whole river ecosystem.

8.4. Characterize processes driving thermal anomalies

The interactions between hydrological, hydrogeological, physical, atmospheric and geomorphological processes that affect CWRs and the adjacent landscape are highly complex and multifactorial.

Groundwater dynamics plays a key role in thermal heterogeneity of surface water. Subsurface discharge in streams and rivers can be either discrete (thermal patchiness) or diffuse (radiator effect). A better understanding of groundwater dynamics, how it contributes to thermal heterogeneity and its sensitivity to climate change will enable it to better identify where thermal refuges are needed, how to create/enhance them and to develop effective thermal refugia management strategies.

Further work is also required to better understand the links between watershed hydromorphology and the distribution of thermal refuges, as well as their effect size (i.e., length, volume, area), spatial configuration and temporal occurrence.

This knowledge would enable to develop a methodology to identify thermally sensitive drainage areas at the watershed scale that should be prioritized for protection.

8.5. Modelling thermal regime

The application and use of water temperature models at the watershed scale can be of great use to water resource managers to: (i) better identify and understand the processes driving river temperatures, and (ii) do simulations of land use scenarios, assessing their effect on thermal regime. For instance, the application of such a model on a small, forested watershed upstream of a sensitive CWR, integrating the effect of riparian buffers and forest practices, could be used to simulate the effect of different forest management scenarios on water temperature. This would constitute an efficient tool for stakeholders and foresters in the preparation of forest management plans.

A wide range of water temperature models already exist, that can be either process-based models or statistical ones, but further work is needed to develop more accurate river temperature projections in space and time.

8.6. Assess the impact of urban water uses on CWRs during dry periods

In urban areas, thermal and flow regimes may be affected by water withdrawal (from surface water or groundwater) and wastewater discharge.

8.7. Strengthen the use of economic valuation of CWRs

Economics is a powerful driver of decision making. There is a need to assess the financial value of the benefits of CWRs to better engage decision-makers. Making the economic benefits of investing in CWRs more visible on balance sheets and in regulatory and funding decisions is a key avenue for moving forward.

9. Definitions

Cold-water refuge

The typology around cold-water refuges is now well defined: a **cold-water patch** is a physical notion usually defined as a discrete area of water temperatures cooler (2–10°C) than ambient streamflow immediately upstream" while a **cold-water refuge** has a biological dimension and is defined as a "cold-water patch that is used by poikilotherm avoiding higher temperatures" (Sullivan *et al.*, 2021). A **thermal refuge** can be a cold-water or a warm water refuge.

CWR can be classified in seven well defined hydrological types, as depicted on figure 1:

- Tributary confluence plume: the confluence area and the lower section of a cold-water tributary that discharges into the warmer main river channel.
- Lateral spring or seep: elongated bankside filament of cold-water created by the diffuse or local inflow of cold groundwater on the riverbank of steep valleys or terraces.
- Springbrook: cold-water channel that flows from springs, marshlands, or depressions adjacent to the main channel. Often associated with abandoned channels.
- Side channel: small channel that branches from a main channel of a braided river. Side channels can form, disappear or become main channels over time.
- Alcove: inflow of cold groundwater in backwater at the downstream edge of a bar. Alcoves are disconnected from upstream channels at summer low flow but can maintain a downstream flow that is entirely fed by groundwater.
- Wall-base channel: groundwater fed channel formed on terraces and flowing down into the main channel.
- Hyporheic upwelling: inflow of cold groundwater in the riverbed, including river water that submerges into the gravels and then re-emerges colder than the river.

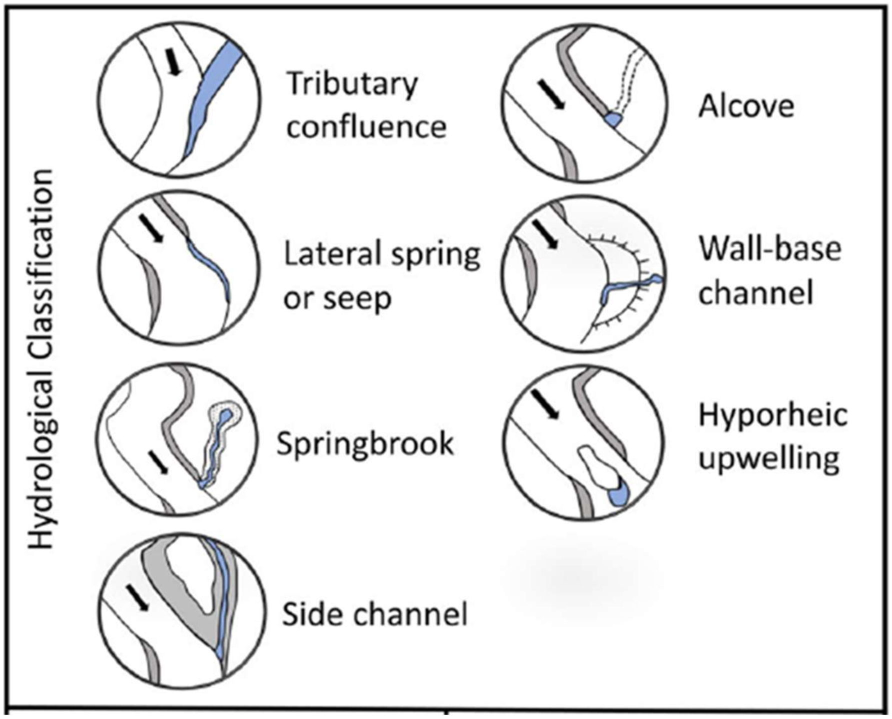

Figure 4: Common types of cold-water refuges (from Dugdale et al., 2013; Sullivan et al., 2021)

Community of practice

A community of practice (CoP) is a group of people who share a common concern, a set of problems, or an interest in a topic and who come together to fulfill both individual and group goals.

Communities of practice often focus on sharing best practices and creating new knowledge to advance a domain of professional practice. Interaction on an ongoing basis is an important part of this.

Many communities of practice rely on face-to-face meetings as well as web-based collaborative environments to communicate, connect and conduct community activities.

Headwaters

Headwaters include wetlands outside of floodplains, small stream tributaries with permanent flow, tributaries with intermittent flow (e.g., periodic or seasonal flows supported by groundwater or precipitation), or tributaries or areas of the landscape with ephemeral flows.

Private sector stakeholders

Includes, but not limited to, individuals, non-government organizations, groups, associations, educational institutions, researchers, businesses, not for profit organizations, landowners.

Thermal heterogeneity

Spatial and temporal thermal diversity in rivers due to several factors such as fluvial geomorphic features, landscape topographies and riparian vegetation (figure 3)

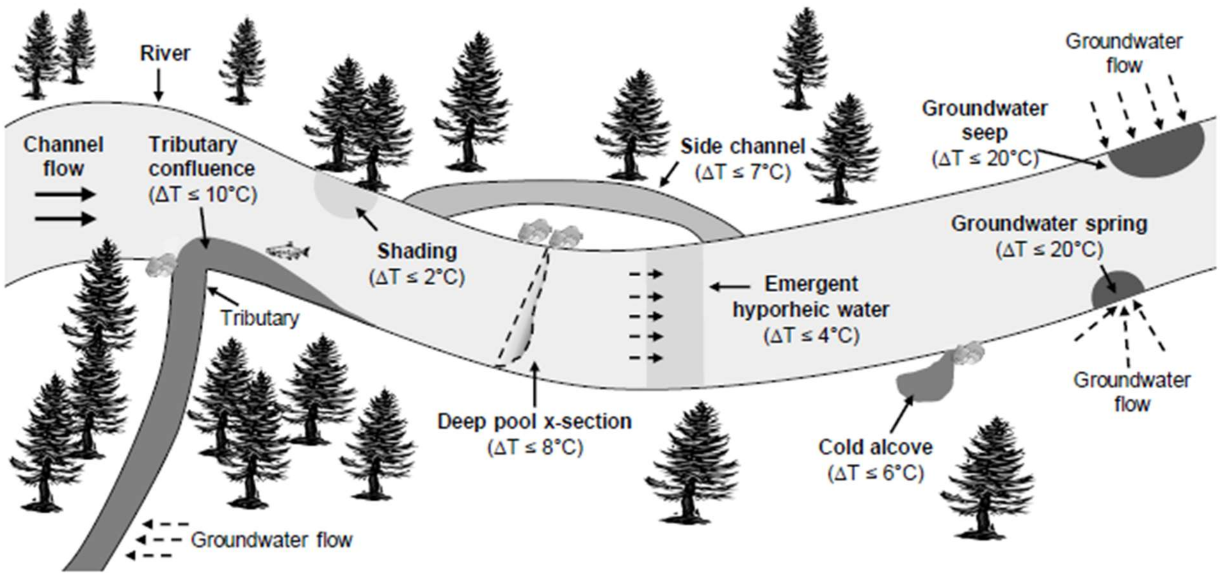

Figure 5: A conceptual overview of mechanisms that induce thermal diversity in rivers and create suitable cold-water refuge (from Kurylyk et al., 2015)

References

Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., Hallett, J.G., Eisenberg, C., Guariguata, M.R., Liu, J., Hua, F., Echeverría, C., Gonzales, E., Shaw, N., Decleer, K. & Dixon, K. (2019). International principles and standards for the practice of ecological restoration. Restoration Ecology, 27(S1), S1-S46.

Kurylyk, B. L., MacQuarrie, K. T., Linnansaari, T., Cunjak, R. A., & Curry, R. A. (2015). Preserving, augmenting, and creating cold-water thermal refugia in rivers: Concepts derived from research on the Miramichi River, New Brunswick (Canada). *Ecohydrology*, *8*(6), 1095-1108.

Mejia, F.H., Ouellet, V., Briggs, M.A., Carlson, S.M., Casas-Mulet, R., Chapman, M., Collins, M.J., Dugdale, S.J., Ebersole, J.L., Frechette, D.M., Fullerton, A.H., Gillis, C-A., Johnson, Z.C., Kelleher, C., Kurylyk, B.L., Lave, R., Letcher, B.H., Myrvold, K.M., Nadeau, T.-L., Neville, H., Piégay, H., Smith, K.A., Tonolla, D. & Torgersen, C.E. (2023). Closing the gap between science and management of cold-water refuges in rivers and streams. Global Change Biology. https://doi.org/10.1111/gcb.16844.

Dugdale, S.J., Bergeron, N.E. & St-Hilaire, A. (2013). Temporal variability of thermal refuges and water temperature patterns in an Atlantic salmon river. *Remote Sensing of Environment*, *136*, 358-373.

Sullivan, C.J., Vokoun, J.C., Helton, A.M., Briggs, M.A. & Kurylyk, B.L. (2021). An ecohydrological typology for thermal refuges in streams and rivers. Ecohydrology, 14(5), e2295.

Appendix A. Methodological framework for the protection and enhancement of cold-water refuges at the watershed scale

A.1. Selection of cold-water refuges for protection and enhancement

The following framework enables to select cold-water refuges for protection and enhancement, and to target areas to protect or restore in their drainage areas (Figure B.1). This framework is inspired by the ones proposed by Torgersen et al. (2012) and Kurylyk et al. (2015).

Once the CWR identification and classification process is done (step 1), a pre-selection of thermal refuges that could be potentially protected or enhanced is done based on existing available data regarding water temperature (including aerial thermal imagery survey) and geographical information (step 2). A second selection requires further analysis of optical and thermal imagery and, if possible, a field visit of pre-selected sites (step 3). Retained sites should meet the following major criteria:

- is located in a warm river with high density of juveniles, if possible near major holding pools or spawning areas
- is much cooler than the mainstem in summer (at least 3°C difference)
- has large area and volume of cool water
- for confluence plumes, the tributary should have a Strahler's order higher than 3

The potential for protection will be determined by:

- the geomorphology and land use in the drainage area (or tributary catchment for a confluence plume)
- the mechanisms that generate the thermal anomaly (e.g. groundwater)

Once a CWR has been selected as an important site to be protected, a specific characterization of its drainage area (or tributary catchment) has to be done based on available information (step 4). This catchment snapshot may discuss watershed features and temperature trends, opportunities to cool the tributaries, current protection and/or restoration efforts, and enables to target the main issues, the most sensitive areas and the actions to focus on to protect and restore thermal anomalies. This has to be complemented by a field visit (step 5) to verify the actual state of streams, soil and vegetation and the needs and opportunities for eventual restoration (replanting).

The potential for enhancement will be determined by:

- the effective utilization of the CWR by cold-water fish
- the geomorphological configuration of the site
- the accessibility for vehicles and machinery

This whole process should be iterative to adapt to the geomorphological evolution of rivers, streams and CWRs.

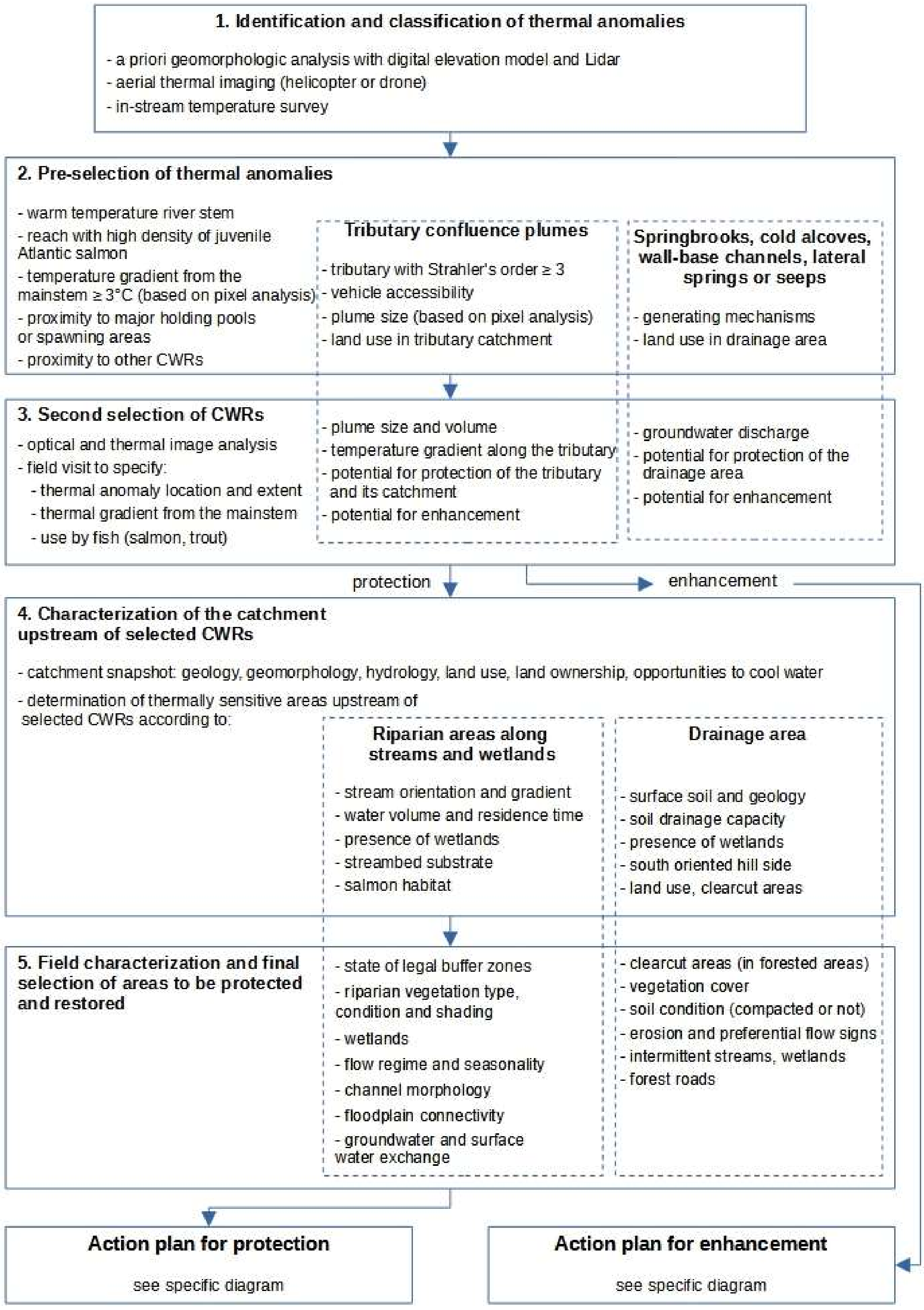

Figure A.1: Framework for the selection of cold-water refuges

A.2. Action plan for the protection of cold-water refuges

Once the CWRs that need protection and the specific sites in their drainage area that shall be protected (or restored) have been identified, an action plan has to be prepared, following the proposed diagram on Figure B.2.

The first step is to elaborate a monitoring plan to verify and quantify the effects of protection actions on the CWR. As far as possible, a long-term monitoring of water temperature with thermographs located upstream the CWR, in the cold-water patch (or plume) and in the surrounding mainstem, should be envisioned. In the case of tributary confluence plumes, the monitoring of nearby similar streams with unprotected catchment (control site) is also recommended to be able to compare and assess the specific effects of protection actions independently of meteorological or hydrological factors that may vary from year to year.

The protection approach has then to be adapted depending on land use and land ownership (step 2). On private lands (urban areas, woodlots, farmed lands), protection actions mainly lie in information and sensibilization of landowners, leading to conservation or restoration voluntary agreements. In some cases, regulatory obligations may be implemented. On Crown Lands, discussions with DNR and licensees should aim to include, when possible, targeted areas in natural protected areas, and to improve harvesting practices and regulation application. Actions may include:

- protect and restore riparian shade and stream functions to maintain cool river temperatures
- protect and restore drainage areas of headwater streams
- protect sources of groundwater
- protect wetlands for their hydrological buffer role and their contribution to surface flow in summer
- restore natural channel complexity, reconnect the river with its floodplain, and restore groundwater interactions
- implement on-farm best management practices to restore continuous flow in summer, which will help to cool river temperatures and expand CWR volume
- encourage private landowners and farmers to enter riparian buffer protection programs
- support education and outreach about the role of riparian buffers on privately-owned properties to maintain cool water temperatures
- promote the control of runoff water in urban areas by adopting a “slow it, spread it and sink it” approach

In targeted areas that have been recently deforested or with unvegetated riparian zones, and where vegetation may provide shading for surface water or shallow groundwater, replanting may be envisioned (step 3), provided that these areas will be protected on the long term (natural protected areas of conservation agreements).

The effects of these actions will be assessed through the long-term monitoring (step 4).

Communication (step 5) before, during and after protection actions is an essential component of the strategy to improve the chances of success. It concerns the actors that are directly concerned by protection actions (e.g. landowners, licensees) but also the stakeholders, the scientific community and the public to ensure a learning from experience.

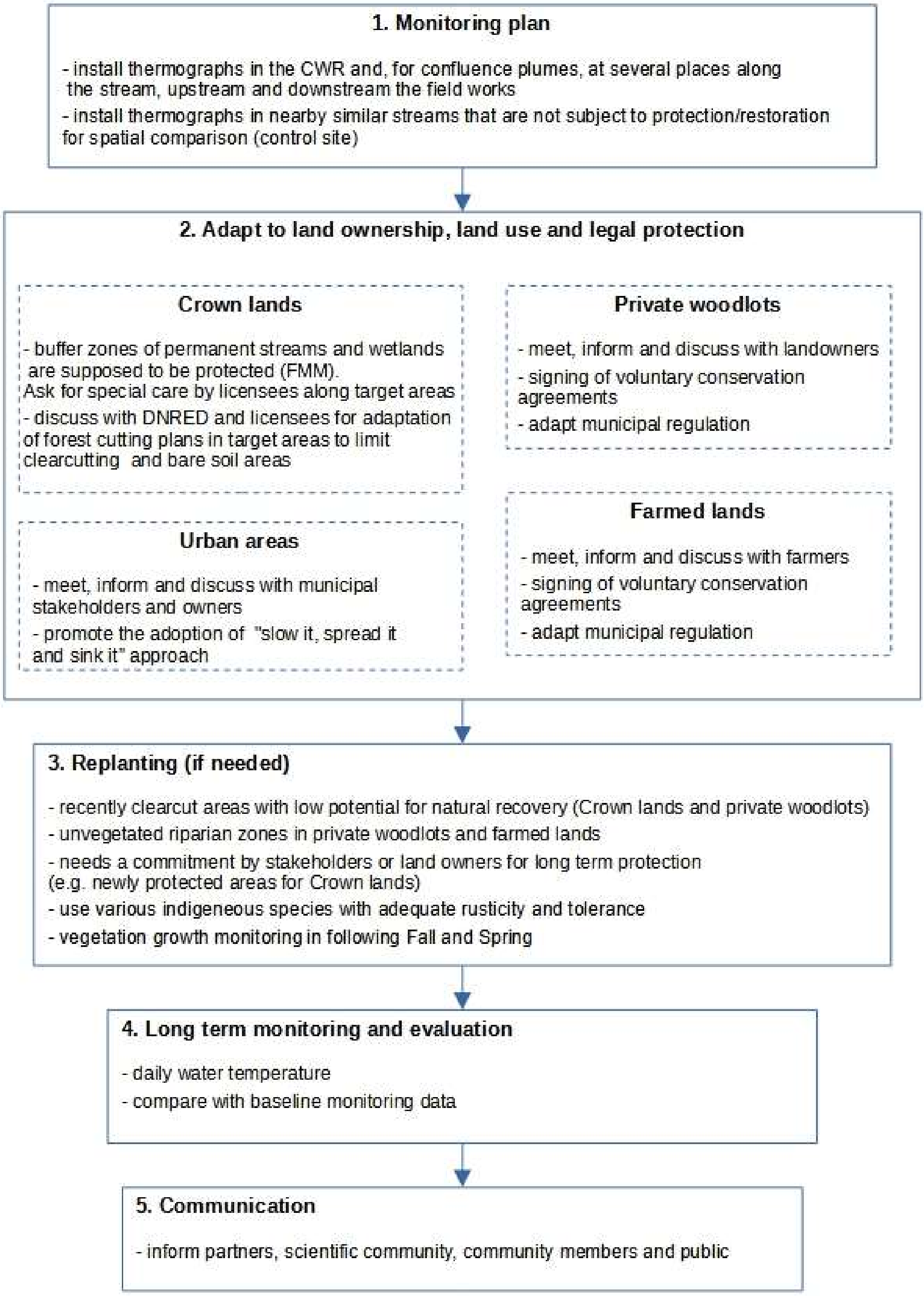

Figure A.2: Action plan for protection of cold-water refuges

A.3. Action plan for the enhancement or creation of CWRs

Once a site has been identified as having a potential for enhancement (for an existing CWR) or creation of a new CWR, the following action plan may be followed (Figure B.3) to ensure that the enhancement project is pertinent and legitimate.

Additional criteria that are specific for enhancement should be considered, such as the accessibility for vehicle and machinery. It is also of crucial importance to understand why the thermal anomaly is nor or poorly used by cold-water fish, to make sure that enhancement will respond to fish needs. This could be done by considering the historical, social and hydrogeomorphological context of the site. The analysis of historical maps and images may provide a reference condition for assessing the influence of current human activities on stream temperature and illustrate areas where CWRs have been lost and potentially could be restored. In some cases, the restoration of geomorphological channel structures, sediment dynamics, and flow regimes in the tributary may be needed for the reestablishment of historical temperature regimes, prior to the implementation of instream engineering methods at the confluence. Moreover, CWR enhancement should be envisioned only if broader protection/restoration actions at the catchment scale have been done or are planned. Finally, social acceptability by local people and First Nations should be verified.

The selection of the enhancement method (step 2) should be done by a multidisciplinary team. The choice of a passive method should be considered in priority. Replanting may be a good solution in some places where vegetation has been removed but is a long-term process since it takes several years for shading to occur. Instream engineering methods are particularly suited for confluence plumes due to the typically greater flow rates of cold water compared to groundwater derived thermal refuges. Groundwater pumping only enables to drop the surface water temperature a few degrees and should be used cautiously and only during low-flow and warm-temperature conditions in the target river to minimize the impact on natural groundwater flow.

The technical design of the enhancement method (step 3), especially interim engineering ones, should consider local characteristics such as potential ice damage and be delegated to specialized consultant firms. A permit should be obtained, if necessary, before doing the work (step 4).

Once the enhancement method has been put in place, a rigorous monitoring should be performed to evaluate the impacts of the project (step 5), including:

- daily water temperature
- fish behaviour and CWR usage by fish
- impacts on multiple trophic levels
- state, evolution and efficiency of the structure (e.g. deflectors)

Finally, a communication program (step 6) has to be applied all along the project and long-term maintenance should be scheduled to ensure that the benefits of the project for cold-water fish maintains over the years (step 7).

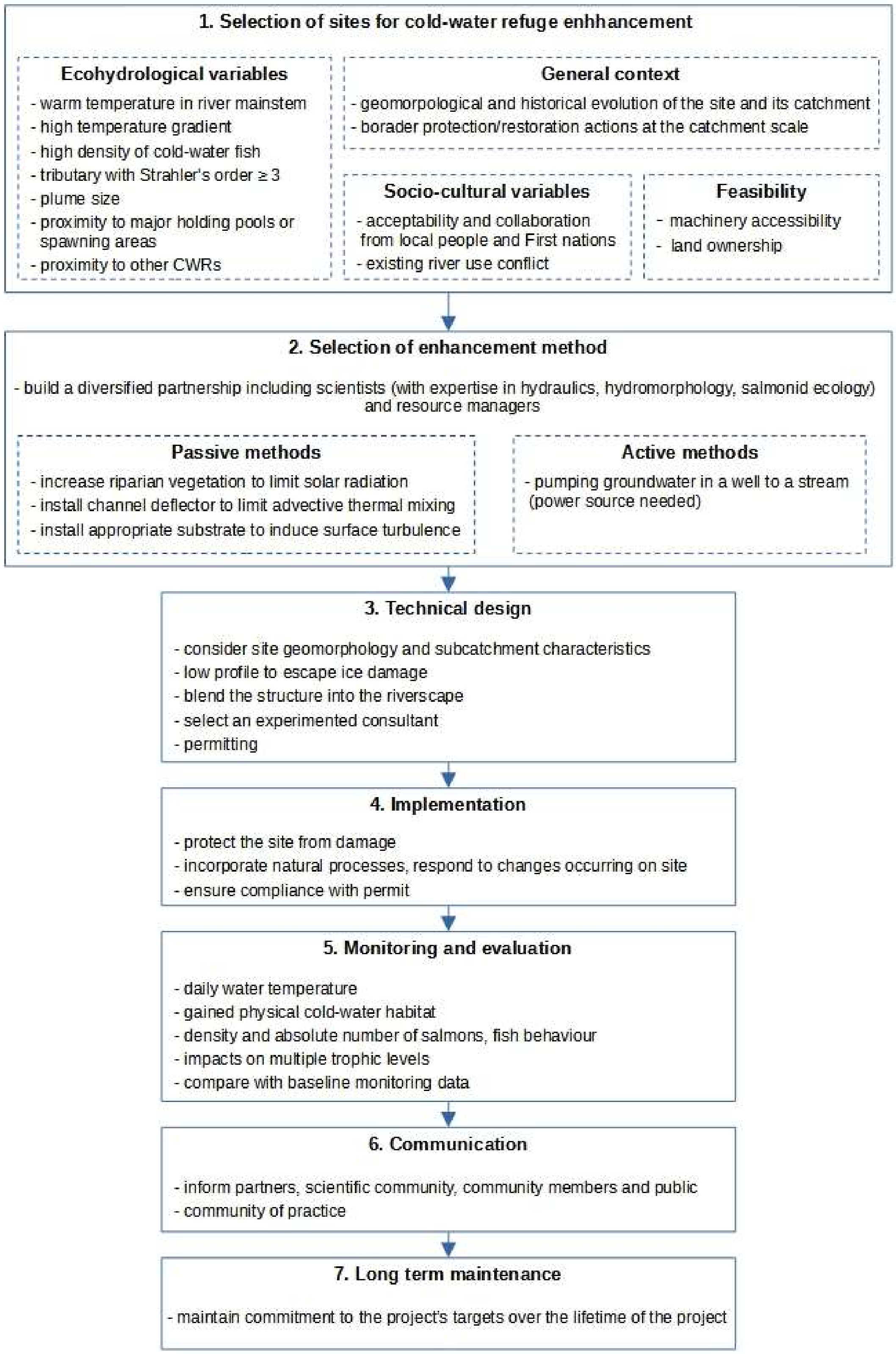

Figure A.3: Action plan for the enhancement of cold-water refuges