PACIFIC FISHERIES RESOURCE CONSERVATION COUNCIL
Conseil pour la conservation des ressources halieutiques du pacifique

HELPING PACIFIC SALMON SURVIVE THE IMPACT OF CLIMATE CHANGE ON FRESHWATER HABITATS

Pursuing Proactive and Reactive Adaptation Strategies

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EXECUTIVE SUMMARY

For many generations in western Canada, five species of Pacific salmon have provided a defining role to native and non-native peoples. As a reflection of this cultural importance, there has been a long-standing tradition of communities and governments taking action to help salmon cope with both natural and human pressures on their survival. Recently, the Intergovernmental Panel on Climate Change has clearly indicated that humans, by burning fossil fuels and changing the landscape, are responsible for unnatural changes in the world's climate. In turn, these changes are leading to significant effects on our continents, in our oceans, and in freshwater streams and lakes. Pacific salmon have always responded to past changes in climate and are vulnerable to the types of changes in freshwater streams and lakes being discussed today. Thus emerges another challenge threatening salmon survival which once again requires action by local communities and governments.

Recognizing that Pacific salmon face significant hurdles in the future and that society can take action to help them survive, this report presents an approach and research around key elements to help government decision makers and local communities decide upon appropriate actions. This approach involves four steps:

STEP 1: Identify **Issues** of Concern

STEP 2: Assess **Vulnerability**

STEP 3: Summarize **Assets**

STEP 4: Describe **Adaptation Strategies**

The first step involves clarifying the local setting within which governments or communities are pursuing actions to help salmon. What is the region, watershed, or stream of interest? Are there competing resource uses—among salmon, freshwater supplies, and hydropower generation, for instance? Who are the decision makers? Although the general issues of interest discussed in this report relate to changes in freshwater flows and water temperatures, we recognize that local issues of concern may be more varied. A companion report, "*Helping Pacific salmon survive the impacts of climate change on freshwater habitats: Case study perspectives from the Okanagan, Nicola, Quesnel, Cowichan, Nass, and Englishman River watersheds*"[1], presents a sample of issues in a local context of geography, people, and salmon at three interior and three coastal basins in British Columbia.

The second step requires describing the sensitivity of Pacific salmon to expected changes in their freshwater habitats. Across the globe, the effects of a warming climate are consistently predicted to change freshwater flows, especially in snow-dominated regions. In British Columbia, a variety of measurable changes in air temperatures, precipitation, snow pack, streamflows, and water temperatures are expected. For instance, in the Okanagan, predictions suggest noticeable increases in winter air temperatures (from 1.5 to 4.0˚C) and precipitation (5–20%) by the 2050s, as well as decreases in summer precipitation (by 20%). By the 2050s in the Georgia Basin, climate models predict general warming (1.5–2.0˚C), a reduction in snowpack (by 50%), and a possible increase in December runoff (by 60%). On the coast, these predictions mean little change in the total amount of water flowing through our watersheds, though increases in the number and size of floods are likely.

For Pacific salmon, the effect of such changes in freshwater flows and temperatures are fundamentally linked to their survival. Warming of Fraser River water temperatures can delay sockeye salmon migration and reduce en-route survival. Low water flows in the late summer can block access to spawning grounds. Winter flooding can wash eggs out of the gravels. Parts of B.C. are also uniquely vulnerable. Although incomplete, this report identifies

[1] Nelitz, M., C.A.D. Alexander, and K. Wieckowski. 2007. Helping Pacific salmon survive the impacts of climate change on freshwater habitats: Case study perspectives from the Okanagan, Quesnel, Nicola, Cowichan, Nass, and Englishman River watersheds. Final report prepared by ESSA Technologies Ltd., Vancouver, B.C. for Pacific Fisheries Resource Conservation Council, Vancouver, B.C.

thirty-two areas that have warm water temperatures or low / high freshwater flows that currently affect salmon survival. These areas are centered in the Southwestern, Southern Interior, and Central Interior of the province.

Management agencies and local communities have a wealth of knowledge about salmon watersheds and experience working with local partners. This knowledge and experience is an asset because it can be used to help plan and implement feasible actions most likely to be successful in the future. The third step of the approach requires accounting for existing assets. Several planning efforts are currently being developed that could help identify freshwater streams and lakes most vulnerable to climate change. These efforts include identifying the status of salmon populations under Fisheries and Oceans Canada's Wild Salmon Policy, designating "Fisheries Sensitive Watersheds" and "Temperature Sensitive Streams" by the BC Ministry of Environment, as well as developing tools to help governmental and non-governmental agencies prioritize areas for conservation and restoration. There is also a long history of taking action to help a variety of fish species and their habitats, including salmon. In British Columbia, *Public awareness and education*, *Instream restoration / enhancement*, and *Fish culture activities* (e.g., release of hatchery raised young salmon) have been the most common. Fish projects are most numerous in the Vancouver Island, Lower Mainland, and Skeena regions.

The final step describes strategies or actions that could be implemented in the short or long-term to help reduce Pacific salmon's vulnerability to climate change. A first group of actions includes "*hard infrastructure*" strategies; engineering or technology-focused innovations that can be implemented on-the-ground to either help salmon adapt to climatic changes, mitigate the effect of changes in habitats, compensate for climate-induced losses to salmon, or restore habitats affected by past deterioration in habitats. Strategies can be aligned with four types of actions: (i) flow-focused, (ii) temperature-focused, (iii) fish-focused, and (iv) fish habitat-focused.

Flow-focused actions are likely the most effective to help salmon in the context of anticipated climate-driven changes in precipitation and snowpack. Maintaining sufficient instream flow at appropriate times of year can protect natural river-forming processes, enable upstream migration of adult salmon, improve availability of spawning and rearing habitats, reduce vulnerability of salmon to disease, and help downstream passage of juvenile salmon outmigrating to the ocean. Water use efficiency can be implemented today to increase the amount of water available for instream needs. For instance, drip irrigation technology has the potential to double agricultural crop yield per unit of water. Water use efficiencies and recycling are also possible in other industries (e.g., pulp and paper, mining, etc.).

Building additional storage capacity (e.g., new dams and reservoirs) is a controversial, but potentially invaluable solution in the context of climate change. Storage provides decision makers with the ability to store water at times of the year when water resources are plentiful and release it when water supplies are limited. Dams can, however, have significant impacts by posing barrier to salmon passage (both adults and out migrating juveniles), and impose unnatural flow patterns which change river processes. Thus, to be effective, operating rules for storage facilities must explicitly recognize ecosystem rights to water and entrenchment of this principle in water management. It is not enough to provide token recognition that water supplies are managed for salmon needs, because too often human needs over-ride ecological needs. There are challenges in developing appropriate operating rules given that it is not always clear what 'environmental flow regime' will optimize flow releases across all necessary fish species and ecological values. Analytical and participatory methods are available to help resolve such problems.

Salmon survival, reproduction, and growth are fundamentally linked to water temperatures in freshwater environments. In some locations, infrastructure can be used to maintain cool or reduce warm water temperatures. Water storage facilities can draw deep cold water for surface water release. Protecting groundwater supplies can help maintain cool temperatures in summer and warm temperatures in winter at locations where groundwater has a direct influence on stream temperature. Riparian vegetation provides shade to tributaries and mainstem habitats, which helps maintain cool stream temperatures. Thus, actions to maintain or restore streamside vegetation can also benefit water temperatures and salmon.

Some scientists, however, believe actions to protect water temperatures cannot be applied across a large enough geographic scale to mitigate against the effects of climate change. Ranges of salmon distribution have changed over their evolution responding to changes in habitat conditions, such as water temperatures. Therefore, shifts in their distribution may be unavoidable, resulting in the loss of salmon in some areas where habitat conditions are close to tolerable limits. While such losses may have grave consequences in some areas, salmon populations in British Columbia inhabit central latitudes in the north Pacific. British Columbia may provide an important stronghold for salmon and thermally suitable habitats in the context of climate change.

Managers can also directly manipulate salmon distribution, abundance, and diversity. Range expansion has been tried with some success in British Columbia (e.g., upper Adams River). Re-introductions are also being considered in other areas such as the Coquitlam and upper Columbia Rivers. Through hatcheries and harvest management, there may be opportunities to experimentally develop stocks with traits that are less vulnerable to the effects of climate change (e.g., temperature tolerance). Use of hatcheries, however, is not without controversy and scientific uncertainties. Release of hatcheries-raised salmon may have adverse effects on genetic diversity and overall population fitness in the long-term.

Manipulations of physical habitats have historically received a lot of attention in fisheries management. Such fish habitat manipulations have included: (i) adding large woody debris or boulders to increase the channel complexity and quality of rearing habitat; (ii) restoring connectivity among habitats blocked by past development activities; or (iii) restoring connectivity between the floodplain and river channel by removing channel armouring structures. These options can be effective in the short term if they respond to historic degradation in habitats, but they do not represent appropriate long-term solutions for managing salmon, in part because of criticisms that monitoring and evaluation of restoration actions has not been sufficient to help managers understand what actions are working and which are not. Although not directly affecting water temperature or water flows, the intention of using these strategies would be to improve other habitat conditions limiting salmon so as to offset additional mortality imposed by climate-induced changes in freshwater habitats.

The complete list of flow, temperature, fish, and fish habitat focused strategies includes:

- Transplanting stocks or species
- Reintroducing salmon to extirpated areas
- Introducing salmon to new areas
- Conserving pristine habitats
- Implementing low impact irrigation practices
- Recycling water in industry
- Installing water meters
- Building additional storage capacity
- Diverting water from other locations
- Decreasing surface water runoff
- Managing water storage
- Releasing cold water
- Manipulating surface water / groundwater interactions
- Transporting fish manually
- Improving fish passage
- Implementing low impact forestry practices
- Implementing low impact grazing practices
- Engineering streams
- Enhancing instream habitat
- Enriching streams / lakes with nutrients
- Enhancing production with hatcheries
- Creating off-channel habitat
- Creating deep pools
- Cleaning gravels
- Restoring connectivity
- Restoring slope stability
- Restoring riparian ecosystems
- Moving dykes back from rivers

A second group of actions to help salmon are termed "s*oft infrastructure*" strategies—those changes in local governance, regulations, policy, or agency management approaches that might encourage innovation and more efficient / effective use of society's hard infrastructure. The intention of using such levers would be to encourage positive human behaviour, innovation, and technological changes to help mitigate the effect of human and climate-induced disturbances on salmon and their freshwater habitats.

One example includes "*Requiring effective operating licenses*". Operating licences can help ensure sustainable use of natural resources, such as water. In B.C., however, there are several weaknesses in the way water use rights are apportioned through water licenses under the *Water Act*. Licenses for conservation of water for fish and wildlife have lower precedence than licenses for other purposes—e.g., domestic, waterworks, mineral trading, irrigation, mining, industrial, power, hydraulicking, and storage uses. Even though the provincial *Water Act* explicitly recognizes that "*the minister may consider concerns related to fish, fish habitat, and other environmental matters*", fish are not formally recognized as rights holders and do not have their beneficial uses legally entrenched. Orders can be issued under a water license requiring development of Water Management Plans, but there is neither a formal recognition of instream flow values nor consideration of the amount of water needed to maintain ecological health prior to applications being received and licenses granted. To be effective water licenses and water allocations should be based on a formal assessment of water supplies and water demands within a watershed. Such an assessment would help reduce the potential for oversubscription of water licenses. These considerations will be increasingly important in the context of climate change and expected changes in freshwater supplies.

Another major weakness with B.C.'s *Water Act* and its use of water licenses is that there are no regulations controlling siting and quantities of groundwater extraction within ecologically sustainable limits. Groundwater is inextricably linked to the hydrological cycle and salmon. Reductions in groundwater supplies resulting from human pressures, climate change, and natural variation in the frequency and magnitude of floods and droughts can have a direct influence on surface water flows. In particular, groundwater withdrawals can exacerbate low base flows. In spite of its ecological importance, groundwater takings are almost entirely unassessed and unregulated in B.C., and groundwater management rarely considers effects on Pacific salmon. British Columbia is the only jurisdiction in the Canada that does not have licensing requirements for use of groundwater above defined thresholds.

A second example includes, "*Adjusting fisheries management practices*" which can enable salmon to better cope with changing freshwater and ocean environments by better protecting natural genetic diversity. Inherent in maintaining stock diversity is a need to allow sufficient number of salmon escaping fisheries (i.e., escapement) across strong and weak stocks. In a world of variable marine and freshwater conditions the ability to set and achieve adequate escapement targets across individual stocks is difficult because contributions of en-route and pre-spawning mortality cannot be measured until after most harvesting occurs. Current trends suggest that environmental conditions, including increased water temperatures, extreme flows, and increased rates of disease, are becoming more unfavourable for salmon survival, particularly at the southern end of their range. Harvesting or climate-induced variation in salmon returns can also affect productivity of nursery lakes, further complicating our understanding of juvenile production. Therefore, sustaining viable salmon populations in the future may require decreases in harvest (e.g., subsistence, recreational, and commercial fisheries) or changes in the management approaches used to set locations, timing, and quantities of harvest. The degree of success in how alternative approaches protect diversity and abundance across stocks ultimately depends on how well each sets and meets in-season escapement goals.

"*Entrenching ecosystem rights to water*" is another example where legislative changes could benefit salmon. Freshwater and riparian ecosystems are entitled to water, as are people. Thus, a portion of the available water supplies should be allocated to freshwater ecosystems, including salmon. Entrenchment of these rights can then allow for water licenses to be bought from existing owners to help ensure water availability for salmon. In the U.S., the Nature Conservancy has purchased water rights to protect environmental flows. Taking a more extreme view, water rights could even be expropriated, though this option is generally viewed as unlikely. Entrenchment of ecosystem rights can also help ensure that water gains resulting from water conservation and use efficiency are allocated to instream needs instead of enabling increases in human demands on water. Currently, federal and provincial water policies don't explicitly acknowledge ecosystem rights or allow for assurances in ecosystem protection. South Africa's national *Water Act* guarantees water for basic needs—drinking, cooking and sanitation—as well as for the ecosystem.

A complete list of the identified "*soft infrastructure*" strategies includes:

- Compensating for unavoidable / non-mitigated impacts
- Requiring effective operating licenses
- Using demand-side management tools and pricing signals
- Providing financial incentives
- Providing financial disincentives
- Implementing results-based management
- Implementing prescription-based management
- Designating environmental aspects for special management consideration
- Coordinating / implementing planning frameworks
- Ensuring protection of critical habitats
- Encouraging partnerships for water / habitat stewardship
- Developing a water budget
- Entrenching ecosystem rights to water
- Recognizing Aboriginal rights to water and salmon
- Adjusting fisheries management practices

While implementing the hard and soft infrastructure actions mentioned above, seven fundamental principles should also be considered. Following these principles will help ensure strategies are effective in achieving their intended outcome.

Consider social values implied by adaptation strategies: No strategies to help salmon will be free of human values. Strategies discussed above need to be considered in the context of society's willingness to help salmon because it would not be fruitful to pursue one action if local watershed users or political decision makers do not value salmon enough to motivate change. Soft and hard infrastructure solutions lie along a continuum of values. If society values salmon very highly we would be willing to make any necessary sacrifices, and to take any and all actions to help salmon. If valued highly, the range of options available would be much greater and the list different than if society values salmon very little.

Embrace an ecosystem approach to managing water resources: The ultimate goal of reforming water governance should be to ensure sustainable use of water for all users, not just people. Inherent in developing a comprehensive approach is the need to deal with the difficult challenge of balancing ecological and human interests. Existing regulatory frameworks are not well structured to deal with the complexity, uncertainty, and increasing vulnerability of both natural and human systems. To help address some of these limitations, integrated water resources management is widely touted as a process to better coordinate development and management of water. Implementation of such a process would improve management of water allocations for environmental needs within limits of ecological availability. A more holistic approach would also work towards a desired state of the ecosystem, rather than simply managing individual components to benefit people. Inherent in this type of approach should be requirements to prioritize, establish, and enforce conservation objectives that are binding through legislation, bilateral agreements, land / watershed plans, and municipal bylaws.

Align energy policies with fish and water management objectives: In British Columbia the goal of becoming energy independent and interest in developing energy sources with low carbon emissions has lead to a situation where Independent Power Producers are pursuing a large number of projects that could potentially affect salmon. Concerns about carbon emissions and climate change are increasing attention on clean energy, energy conservation, energy efficiency, co-generation, as well as small and large hydroelectric developments. For salmon dealing with a heightened vulnerability from climate change, an increased focus on hydro options suggests that B.C.'s energy policy (and specific development options) should have greater consideration of energy impacts on

Pacific salmon. For instance, small hydro projects may not necessarily be free from incremental and cumulative impacts on salmon and their habitats.

Implement proactive strategies before reactive strategies: Priorities for taking action should focus on proactive strategies before reactive ones. In the context of climate change, proactive strategies represent those actions considering a long-term perspective to help avoid impacts on salmon before they limit productivity (e.g., conserving high quality habitats before they are degraded), while reactive strategies represent those being taken to respond to immediate impacts on salmon survival (e.g., restore degraded riparian zones or stabilize exposed slopes). A focus on proactive strategies is based on the notion that environmental and financial costs associated with managing an ecosystem are minimized in the long-run. There are two reasons for believing that proactive strategies will reduce total costs. First, the past cycle of watershed degradation and restoration has been an expensive endeavour with a questionable record of effectiveness. Second, decision makers often underestimate the true value of natural resources, or economic benefits of conservation. Given Pacific salmon's vulnerability to climate change and their inherent value to society, we cannot rely on the past approach of reactive management.

Learn from others: Given the complexities and challenges facing Pacific salmon, managers in British Columbia and the Yukon must learn from the successes and failures in other jurisdictions. Other areas of the world (e.g., California, Australia, or South Africa) are more advanced by having a greater vulnerability to increases in water temperatures and reductions in water supplies, greater population pressures, greater demands on water resources, and/or more advanced technologies / institutional frameworks for resolving human-water conflicts. In the continental U.S., over one-third of rivers are already listed as impaired or polluted, and many salmon populations are listed under the Endangered Species Act. Not all insights will be transferable to B.C., but it is certainly sensible to take lessons from other regions.

Implement adaptive management: Implementing adaptive management implies both: (i) a recognition of uncertainties, and (ii) a commitment to learning. The use of models to improve management decisions and monitoring of population abundance and habitat status are key considerations. Models can be a cost-effective way to help decision makers understand the implications of alternative strategies without investing in actions that aren't effective on-the-ground. Models can also integrate best available information, recognize uncertainties, test likelihood of implementation success, and help ensure that decision-making is transparent and objective. Monitoring is an essential component to adaptive management that helps "close the loop" between what is happening in the environment and how decision makers respond to that information. Baseline and effectiveness monitoring of both policy options and technological innovations will be important.

Consider both ecosystem features and functions: Ideally, restoration and conservation strategies need to take a holistic view of the ecosystem by considering both the functional processes being targeted by restoration and the relevance of restored habitat features in addressing limitations to salmon productivity. Typically restoration managers tend to focus on restoring habitat features, not ecosystem functioning. Such a focus is a failure of ecosystem restoration because it does not recognize that if habitat forming processes are not functioning properly, a restored habitat feature will have a limited life-span or will have to be periodically maintained.

As highlighted by the long list of adaptation strategies described above, governments and local communities are not limited by creative approaches to helping Pacific salmon in freshwater habitats. Instead, barriers to helping salmon may be centred on a lack of political will at a regional level or a lack of appropriate planning and implementation at a local level. Helping salmon survive the impacts of climate change on freshwater habitats will require smart assessment, design, implementation, and evaluation of alternative strategies to identify successes in the short and long-term.

LIST OF ACRONYMS

AFS	Aboriginal Fisheries Strategy
BCWWA	British Columbia Water and Waste Association
CCME	Canadian Council of Ministers of the Environment
CDP	Community Development Program
CEAA	Canadian Environmental Assessment Act
CH	Chinook salmon
CM	Chum salmon
CO	Coho salmon
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CU	Conservation Unit
DFO	Fisheries and Oceans Canada
DPI	Designated Public Involvement Program
FRAP	Fraser River Action Plan
FREMP	Fraser River Estuary Management Program
FSW	Fisheries Sensitive Watershed
GAR	Government Action Regulation
GCM	Global Climate Model
HADD	Harmful Alteration, Disruption or Destruction
HVT	Hoopa Valley Tribe
IPP	Independent Power Producer
ITQ	Individual Transferable Quotas
IUCN	The World Conservation Union
IWRM	Integrated Water Resource Management
MOE	Ministry of Environment
MW	Megawatt
NAFTA	North American Free Trade Agreement
NCC	Nature Conservancy Canada
NFCP	Nechako Fisheries Conservation Program
NNL	No Net Loss
NOAA	National Oceanic and Atmospheric Administration
OPRD	Oregon Parks and Recreation Department
OPS	Major hatcheries
ORRI	Okanagan River Restoration Initiative
PIP	Minor Public Involvement Programs
PK	Pink salmon
PSF	Pacific Salmon Foundation
ROD	Record of Decision
RSER	River specific exclusive ownership rights
SARA	Species at Risk Act
SK	Sockeye salmon
TAC	Total Allowable Catch
TMDL	Total Maximum Daily Load
TRRP	Trinity River Restoration Program
TSS	Temperature Sensitive Stream
UNBC	University of Northern British Columbia
USBR	US Bureau of Reclamation
USFWS	US Fish and Wildlife Service
UVic	University of Victoria
WLAP	Ministry of Water, Land and Air Protection
WUP	Water Use Plan

1. INTRODUCTION

For many generations, five species of Pacific salmon on the west coast have provided cultural and economic benefits to native and non-native peoples. As a reflection of this cultural significance, there has been a long-standing tradition of communities and governments pursuing actions to help salmon overcome challenges—natural and human-induced stressors—affecting their survival in freshwater and marine environments. Prior to European contact, First Nations fisheries selectively harvested salmon recognizing the potential consequences of their actions on upstream communities and future generations. Since the late 19th century hatcheries have released billions of salmon to help re-build weak stocks or provide fishing opportunities. For 25 years, thousands of children have gained an appreciation for the salmon life cycle by incubating salmon in classrooms. Federal and provincial government restoration initiatives, such as the British Columbia Watershed Restoration Program of the 1990s, have allocated millions of dollars to restore salmon habitats resulting from past degradation. Although their effectiveness has been questioned, these actions reflect society's inherent value of salmon and desire in sustaining abundance for future generations.

Awareness about climate change has recently heightened in the public consciousness even though it is not a new issue in the minds of scientists and resource managers in the Pacific region. The fourth in a series of assessment reports by the Intergovernmental Panel on Climate Change has powerfully communicated that the weight of evidence clearly indicates that human actions, through greenhouse gas emissions, are responsible for unnatural changes in the world's climate[2], and that these changes are leading to significant adverse effects on terrestrial, freshwater, and marine environments[3]. Pacific salmon have always responded to past climate-induced changes in the environment—changes in freshwater supplies or sea surface temperatures, for instance—and are vulnerable to the human-induced climatic changes discussed today. Thus emerges another challenge threatening salmon survival which once again requires action by local communities and governments.

Prior to pursuing actions to help salmon survive the effects of climate change, managers need to strategically think about and intelligently plan for feasible and effective solutions. As a first step, federal and provincial government agencies have recognized the threat of climate change on salmon survival. In 2005 with the release of the Wild Salmon Policy, Fisheries and Oceans Canada explicitly recognized the need to integrate climate change considerations into management[4]. In a report, *"Indictors of Climate Change for British Columbia 2002"*[5], the Government of British Columbia used Fraser River water temperatures / flows and the associated stresses on in-river migration of Pacific salmon as one measure of British Columbia's vulnerability to climate change. Next steps require focused attention on developing and implementing adaptation strategies to help salmon survive into the next century. However, using history as a guide, the pace of environmental policy changes is slow[6]. Time is an unaffordable luxury given that climatic changes are occurring faster than originally predicted. Smart decision-making and smart decisions should not be sacrificed for the sake of expediency. Public and political commitments around the environment and the cultural importance of Pacific salmon emphasize that the time to take concerted action is here.

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[2] Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: The Physical Science Basis–Summary for Policymakers. Available at: www.ipcc.ch/

[3] Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability–Summary for Policymakers. Available at: www.ipcc.ch/

[4] Fisheries and Oceans Canada. 2005. Canada's policy for conservation of wild Pacific salmon. Available at: http://www-comm.pac.dfo-mpo.gc.ca/publications/wsp/default_e.htm

[5] Ministry of Water, Land, and Air Protection. 2002. Indicators of Climate Change for British Columbia, 2002. Available at: www.env.gov.bc.ca/air/climate/indicat/pdf/indcc.pdf

[6] Scheffer, M., F. Westley, and W. Brock. 2003. Slow responses of societies to new problems: causes and costs. Ecosystems 6: 493-502.

The overall purpose of this report is to facilitate development of feasible actions to help salmon by proposing a framework for developing adaptation strategies and summarizing preliminary research around its four steps. Section *2. Framework for pursuing adaptation strategies,* briefly summarizes the framework and its four steps.

STEP 1: Identify **Issues** of concern. This report focuses on issues related to climate change impacts on freshwater habitats (e.g., water temperature and flows) even though climate-induced changes in the ocean and estuaries will also critically affect salmon.

STEP 2: Assess **Vulnerability** (e.g., sensitivity, adaptive capacity) of salmon to climate change. Section *3. Issues and vulnerabilities,* summarizes the broad range of issues facing salmon, biological and physical mechanisms of vulnerability, as well as some regions of concern in British Columbia.

STEP 3: Summarize **Assets** (e.g., existing infrastructure) that could be used as a basis upon which to develop strategies to help salmon adapt to climate change. Section *4. Assets,* summarizes some management and restoration strategies that have already been implemented in British Columbia or will be developed in the near future that could be leveraged to help salmon.

STEP 4: Describe **Adaptation Strategies** that could be implemented in the short or long-term to help reduce Pacific salmon's vulnerability to climate change. A list of potential hard infrastructure (i.e., engineering or technology-focused changes) and soft infrastructure (i.e., regulatory changes, policies, management approaches) strategies are summarized in Section *5. Adaptation strategies.*

This work and the proposed framework could be supported by DFO's Wild Salmon Policy, specifically "Action Step 3.2 Integrate climate and ocean information into annual salmon management processes", which suggests that "A more comprehensive view of salmon production and its determinants, from egg to spawning adult, is necessary to direct management actions more accurately and effectively conserve Pacific salmon resources in an uncertain future." Salmon in the Pacific region face a variety of freshwater habitat conditions and management approaches across their distribution. No single strategy or set of management actions will necessarily be appropriate across all situations. Thus, future stages of work should evaluate the effectiveness and feasibility of implementing adaptation strategies in specific regional or local contexts. This report provides a first step to more detailed evaluations by summarizing the range of potential issues and approaches that could be implemented.

This report is intended for a technical audience as it provides a review and synthesis of technical concepts to help salmon in the context of climate change. It does not provide a comprehensive scientific or policy review that would satisfy research scientists or policy analysts. Thus, this report is intended for informed stakeholders, First Nations, fish and fish habitat managers, and to a certain extent policy makers. A companion document, "*Helping Pacific salmon survive the impacts of climate change on freshwater habitats: Case study perspectives from the Okanagan, Nicola, Quesnel, Cowichan, Nass, and Englishman River watersheds*"[7], integrates the general ideas (not the framework) from this one into a local context of geography, people, and salmon at six locations across British Columbia: three interior and three coastal basins.

[7] Nelitz, M., C.A.D. Alexander, and K. Wieckowski. 2007. Helping Pacific salmon survive the impacts of climate change on freshwater habitats: Case study perspectives from the Okanagan, Quesnel, Nicola, Cowichan, Nass, and Englishman River watersheds. Final report prepared by ESSA Technologies Ltd., Vancouver, B.C. for Pacific Fisheries Resource Conservation Council, Vancouver, B.C.

2. FRAMEWORK FOR PURSUING ADAPTATION STRATEGIES

Spittlehouse and Stewart (2003) developed a framework to help forest managers adapt to climate change. This framework has been slightly modified here to facilitate design, planning, and implementation of strategies that could help Pacific salmon. Table 1 provides a sample of how information from each step could be summarized.

STEP 1: Identify Issues: The first step involves clarifying the specific context within which decision makers are trying to develop adaptation strategies. What is the location of interest? What are the multiple resource management objectives (e.g., related to water resources, other fish species, economic activities, etc.) within the region, watershed, or stream of interest? Who are the relevant management agencies, decision makers, and/or stakeholders? What are the physical habitat conditions affected by climate change? What are the salmon species and life stages that will likely be affected? The main issues of interest in this report relate to changes in freshwater habitat conditions (e.g., water temperature and flows). Section 3.1 briefly summarizes some of the physical drivers of vulnerability.

STEP 2: Assess Vulnerability: The second step requires describing the sensitivity of relevant salmon species and life stages to expected changes in habitats. Section 3.1 and Figure 1 provide a brief summary of salmon vulnerabilities. Section 3.2 provides a preliminary list of regions of vulnerability where current observations of water temperatures and flows may be constraining salmon production. An assessment of vulnerability may also consider the flexibility of management systems to respond to future changes. For example, management systems that are informed by limited data or sampling at few locations may have a limited capacity to respond to climate-induced changes in habitats and population responses. This step may also consider how climate vulnerability is either exacerbated or mitigated by other factors affecting salmon survival (e.g., pollution, invasive species).

STEP 3: Summarize Assets: Management agencies and local communities have a wealth of experience working with local partners and knowledge about salmon watersheds. This experience and knowledge is an asset because it can be used to help inform managers about which adaptation strategies are likely to be the most successful. Individuals involved in developing adaptation strategies at the local or regional level will also have existing resources at their disposal, which can be leveraged to help salmon (e.g., existing network of volunteers, funding sources). Thus, the third step requires accounting for existing assets with the goal of implementing the most feasible adaptation strategies. At a broad-level, Section 4 summarizes some assets available to salmon managers in British Columbia.

STEP 4: Develop Adaptation Strategies: Given the information gathered in the preceding steps, decision makers can then look to develop relevant, effective, and feasible adaptation strategies that will help reduce salmon's vulnerability to climate change. Such planning should look to take action in both the short and long-term recognizing that the future will hold many uncertainties about how climate, habitats, and salmon will respond to change. A monitoring and evaluation program with high statistical power to detect biologically meaningful changes should accompany implementation of adaptation strategies so managers can best learn from successes and failures. Section 5 provides a relatively comprehensive, though not exhaustive, list of potential adaptation strategies—hard infrastructure (i.e., engineering or technology-focused changes) and soft infrastructure (i.e., regulatory changes, policies, management approaches) strategies.

TABLE 1. Example of how the proposed framework could be used to identify appropriate and feasible adaptation strategies to help Pacific salmon survive the impacts of climate change on freshwater habitats.

Step 1: Identify Issues	Effect of reduced summer base flows on chinook salmon migration, spawning, and / or rearing in watershed X	Effect of increased late summer / early fall water temperatures on coho salmon migration, spawning, and / or rearing in stream Y
Step 2: Assess Vulnerability	Blocked access to upstream spawning habitats Stranding of juveniles in mainstem rearing habitats Limited natural capacity for water storage (i.e., snowmelt, glaciers, lakes, groundwater)	Increased vulnerability to temperature-dependent diseases Increased growth rates of juveniles Thermally-induced stress and mortality of juveniles and adults Changes in egg hatch date
Step 3: Summarize Assets	Existing storage capacity on Lake Z Abundant precipitation over the year	Local watershed volunteers engaged in riparian planting Existing and functional riparian zone protected within Provincial Park Agricultural operators actively engaged in watershed stewardship activities Hydrogeology allows for strong influence of groundwater on stream temperatures
Step 4: Describe Adaptation Strategies	Increase height of dam / weir on existing reservoir Adjust operating rules for water storage facility, prioritize water management for releases during salmon migration, spawning, and rearing	Restore riparian zone to maintain shading along affected reaches Recharge groundwater aquifers near stream reaches important to salmon

3. ISSUES AND VULNERABILITIES

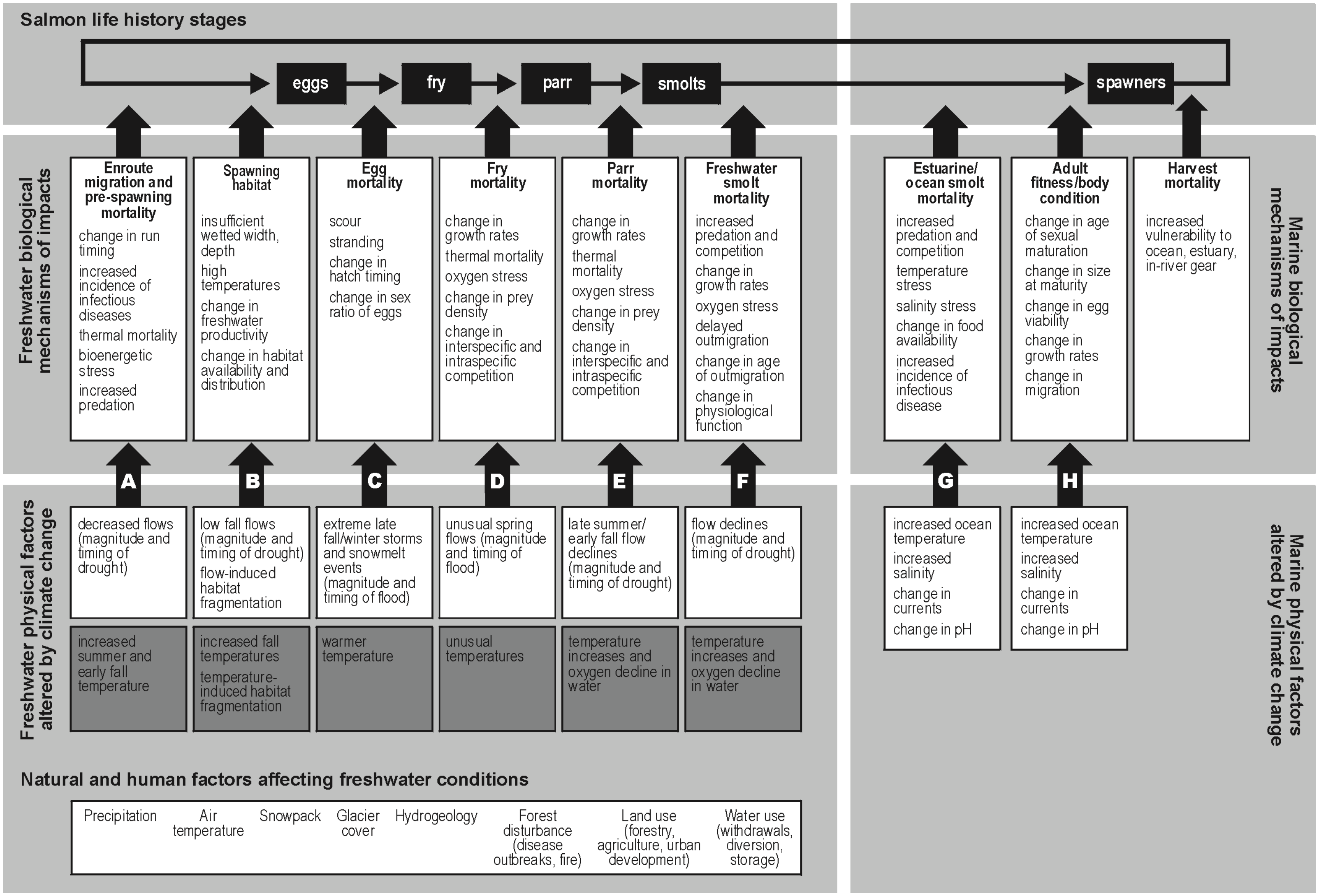
3.1 PHYSICAL AND BIOLOGICAL MECHANISMS OF VULNERABILITY

At a global-scale, effects of a warming climate are consistently predicted to lead to changes in the timing and magnitude of flows (Milly *et al.* 2005), especially in snow-dominated regions which are expected to see less winter accumulations of snow and earlier melting of snowpacks (Barnett *et al.* 2005). Predictions of such potential broad-scale changes in future climate are obtained from global climate models (GCMs). Application of these models at large spatial scales can be "downscaled" to regional scales which are necessary to provide better regional forecasts of changes in climate. Uncertainties are inherent in such regional-scale predictions. For instance, local patterns of precipitation and changes in hydrology are much more difficult to predict than changes in air temperatures (Paul Whitfield, Environment Canada; Dan Moore, University of British Columbia, pers. comm.). Regardless, regional-scale trends in climate are clear.

In British Columbia, it is expected that changes in global and regional climate patterns will lead to a variety of measurable changes in air temperatures, precipitation, snow pack, streamflows, and water temperatures. For instance, in the Okanagan Basin, available models predict an increase in winter temperatures of 1.5–4.0°C and precipitation increase of 5–20% by the 2050s (Merritt *et al.* 2006). Likewise, several GCM scenarios suggest a 20% decrease in summer precipitation. In the Georgia Basin, climate predictions suggest warming of 1.5–2.0°C by the 2050s and little change in total annual run-off, though other hydrologic changes are expected—a 50% reduction in snowpack and a possible 60% increase in volume of December runoff (Leung and Qian 2003). These regional predictions are supported by relationships developed between past climate and hydrological observations (Jakob *et al.* 2003; Leith and Whitfield 1998; Mote 2003; Walker and Pellatt 2003; Wang *et al.* 2006; Whitfield and Cannon 2000). In general, local hydrological predictions suggest an earlier onset of spring snowmelt and peak flows, a tendency towards more rainfall dominated hydrographs and considerable reductions in annual snowpack and run-off volumes by 2050 in modelled interior watersheds (Merritt *et al.* 2006; Merritt and Alila 2004). Watersheds that are currently rainfall dominated are predicted to show an increase in overall flood magnitude and frequency (Whitfield *et al.* 2003). Given the demonstrated and known linkage between air and water temperatures (Caissie *et al.* 2001; Cluis 1972; Foreman *et al.* 2001; Nelitz *et al.* 2007a; Poole and Berman 2001; Stefan and Preud'homme 1993), a warming of stream environments would also be expected.

For Pacific salmon, changes in timing and magnitude of flows and thermal regimes are fundamentally linked to behavioural and physiological responses at each life stage, which ultimately lead to population-level effects. These types of effects are well documented (select references provided in Appendices A and B). Figure 1 illustrates the linkages between freshwater habitat drivers and mechanisms of salmon survival for generalized life stages (pathways A-F).

FIGURE 1. Conceptual diagram illustrating linkages among freshwater physical habitat factors altered by climate change (e.g., water flows and temperatures), freshwater biological mechanisms affecting survival, and life stages.



Each life stage can potentially be affected by changes in water flows and temperatures. For instance, timing of salmon migration (Figure 1, pathway A) has been linked to in-river water temperatures so adults can avoid conditions that are bioenergetically demanding or favourable for diseases (Goniea *et al.* 2006; Hodgson and Quinn 2002; Hyatt *et al.* 2003; Macdonald *et al.* 2000a; Naughton *et al.* 2005; Rand *et al.* 2006). In the Fraser River, elevated water temperatures is one hypothesis that may explain recent behavioural shifts in timing of peak migration for late-run sockeye salmon and associated increases in enroute and pre-spawning mortality (Cooke *et al.* 2004; Lapointe *et al.* 2003). Once adults have reached their spawning grounds (Figure 1, pathway B), elevated water temperatures or reduced water levels can increase rates of holding, delay spawning, or block access to suitable habitats. During egg incubation (Figure 1, pathway C) elevated fall-winter water temperatures can reduce egg survival rates or shift emergence timing (a potential benefit or detriment depending on ecological requirements). Low late-summer and winter base flows can lead to stranding of eggs in the spawning gravels. Elevated flows in coastal streams during the winter, or movement of anchor ice in interior streams can lead to scouring of redds, thereby increasing egg mortality. During juvenile rearing (Figure 1, pathways D and E) water temperatures are an important driver of growth rates, macroinvertebrate production, dissolved oxygen content, and disease transmission rates. Finally, during smoltification elevated water temperature can affect predation rates (Petersen and Kitchell 2001) and peak flushing flows assist with juvenile outmigration. Across all life stages, the above relationships are supported by a variety of empirical studies that relate salmon survival indices to various measures of freshwater flow and temperature conditions (e.g., Anderson and Hinrichsen 1996; Crozier and Zabel 2006; Jager *et al.* 1997; Lawson *et al.* 2004).

Beyond the general salmon life stage-specific responses summarized above, each species will have different vulnerabilities based on their specific uses of freshwater habitats. For example, pink and chum salmon only use freshwater environments for a limited portion of their life cycle (spawning and incubation) and will therefore only be vulnerable to freshwater habitat changes during these life stages. Sockeye salmon can rear for up to several years in freshwater lakes and will be most vulnerable to climate-induced changes in lacustrine habitats. Stocks that migrate in freshwater during the summer months will be more vulnerable to exposures to extreme water temperatures and low flows than those species and stocks migrating at other times of year. In consideration of such differences, Table 2 reorganizes the potential vulnerabilities in Figure 1 by species and life-stage responses.

Figure 1 also accounts for climate-induced changes in the physical marine environment and associated salmon responses (pathways G-H). Although not the focus of this report, marine-induced effects on salmon populations are important to recognize because they have the potential to confound or distort understanding of the effects of changes in freshwater environments. For instance, increased ocean temperatures can lead to changes in ocean productivity (i.e., food availability) which can result in changes of size at maturity. Under such conditions, smaller sized salmon returning to spawn may not have sufficient energy reserves to endure upstream migration in harsh freshwater conditions (e.g., increased temperatures). Moreover, smaller adult salmon are not as fecund as larger salmon, producing fewer and smaller eggs, which could ultimately affect egg survival in the freshwater environment. Therefore, survival at any life one stage is dependent and linked to the stages preceding it, including transitions from marine to freshwater environments.

TABLE 2. Species and life stage-specific summary of *potential* biological vulnerabilities to climate-induced changes in water flows and temperatures.
Linkages among climate drivers, physical changes in freshwater habitats, and biological mechanisms of response are summarized in Figure 1.

	Eggs	Fry	Parr	Smolts	Spawners
Chinook	• scour • stranding • change in hatch timing • change in sex ratio of eggs	• change in growth rates • thermal mortality • oxygen stress • change in prey density • change in competition	• change in growth rates • thermal mortality • oxygen stress • change in prey density • change in competition	• increased predation and competition • change in growth rates • oxygen stress • delayed outmigration • change in age of outmigration • change in physiological function	• change in run timing • increased incidence of disease • thermal mortality • bioenergetic stress • increased predation
Chum	• scour • stranding • change in hatch timing • change in sex ratio of eggs				• change in run timing • increased incidence of disease • thermal mortality • bioenergetic stress • increased predation
Coho	• scour • stranding • change in hatch timing • change in sex ratio of eggs	• change in growth rates • thermal mortality • oxygen stress • change in prey density • change in competition	• change in growth rates • thermal mortality • oxygen stress • change in prey density • change in competition	• increased predation and competition • change in growth rates • oxygen stress • delayed outmigration • change in age of outmigration • change in physiological function	• change in run timing • increased incidence of disease • thermal mortality • bioenergetic stress • increased predation
Pink	• scour • stranding • change in hatch timing • change in sex ratio of eggs				• change in run timing • increased incidence of disease • thermal mortality • bioenergetic stress • increased predation
Sockeye	• scour • stranding • change in hatch timing • change in sex ratio of eggs	• change in growth rates • thermal mortality • oxygen stress • change in prey density • change in competition	• change in growth rates • thermal mortality • oxygen stress • change in prey density • change in competition	• increased predation and competition • change in growth rates • oxygen stress • delayed outmigration • change in age of outmigration • change in physiological function	• change in run timing • increased incidence of disease • thermal mortality • bioenergetic stress • increased predation

In addition to life stage and species-specific responses, changes in habitat conditions can also affect population-level abundance and distribution (e.g., Dunham *et al.* 2001). In the past, genetic diversity has allowed for evolutionary adaptations (Benhke 2002). Some predictions under future climate regimes predict losses in salmon habitats (Eaton and Scheller 1996; O'Neal 2002). Recent observations of salmon at the limits of their distribution suggest adaptations and changes are happening. In the south, there is evidence that chinook in the Klamath River, California and steelhead in southern California are tolerating warmer temperatures (Nina Hemphill, Trinity River Restoration Program, pers. comm.). In the Arctic, salmon have been colonizing new habitats and are expected to continue expanding their range (Al von Finster, Fisheries and Oceans Canada, pers. comm.). All five Pacific salmon species have now been documented in the Mackenzie River, Northwest Territories (Mcleod and O'Neil 1983; Babaluk *et al.* 2000). Expansion into new habitats in British Columbia (e.g., Chilko River) and the Yukon (e.g., Alsek River) could also be expected as glaciers melt, thereby affecting existing flows and temperatures so they are more favourable for salmon production (Timber Whitehouse and Al von Finster, Fisheries and Oceans Canada, pers. comm.). For instance, if the Tweedsmuir glacier melts, exposing an accessible river channel in the upper Alsek River, ~ 16,000 km^2 of lake and river habitats suitable for sockeye, chinook, and coho could become available (Al von Finster, Fisheries and Oceans Canada, pers. comm.).

3.2 REGIONS OF VULNERABILITY

There is no doubt climate-induced changes in flows and temperatures will affect salmon habitats across the Pacific Region. The effect and significance of these future changes on salmon will be driven, in part, by the current status of freshwater habitats. For instance, watersheds where thermal regimes are currently close to upper tolerable limits for salmon migration and spawning will likely be the most vulnerable to future changes and adverse effects on salmon. Similarly, areas with low late-summer / winter base flows or high winter flooding flows today will likely experience increased egg / juvenile mortality and reduced population-level production given future climate conditions. In other habitats where water temperatures are sub-optimal for growth, conditions may improve for juvenile rearing.

Several previous efforts have been completed to identify or rank watersheds with management concerns (Angelo 2006; FRAP 2000; Lill 2002; Precision 1998). These efforts, however, were completed for a variety of purposes. They were not intended to identify areas of vulnerability to climate-induced changes in freshwater habitats. They consider a limited geographic area (e.g., Fraser River Basin, Georgia Basin), a wide variety of effects on habitats (e.g., forestry activities, urban development, mining activities, pollution, etc.), and more watershed values than just salmon (e.g., steelhead). Based on a review of available reports and expert knowledge, Table 3 represents a partial list of watersheds where current hydrologic (low late-summer / winter, or high winter floods) and thermal conditions (elevated temperatures) are known to adversely affect salmon and may therefore be most vulnerable to the effects of climate change.

Table 3 identifies thirty-two areas where water flow or temperature related concerns have been identified. These areas are centered in three regions of British Columbia: Southwestern (Figure 2), Southern Interior (Figure 3), and Central Interior (Figure 4). These areas are consistent with areas where future climate-induced changes in salmon habitats are expected: west coast of Vancouver Island, Georgia basin (including east coast of Vancouver Island and Lower Mainland), and southern interior (Kim Hyatt and Heather Stalberg, Fisheries and Oceans Canada, pers. comm.). This list does not sufficiently represent areas where temperature and flow data are limited, however (e.g., Central or North Coast). Anecdotal observations of low summer flows and temperature concerns during salmon migration in these areas have also been documented (Tom Pendray, Fisheries and Oceans Canada, and Misty MacDuffee, Raincoast Conservation Society, pers. comm.).

TABLE 3. List of areas with currently observed habitat concerns (i.e., high water temperatures, low base flows, and/or high winter flows) in British Columbia.
See Table 4 for definitions of conservation units and Table 5 for a list of conservation units with the greatest habitat concerns (dark shaded cells).
See Figure 2, Figure 3, and Figure 4 for locations of watersheds. CH—chinook, CM—chum, CO—coho, PK—pink, SK—sockeye.

Regions of concern	Relevant Conservation Units[8]					Habitat concern	References	Comment
	CH	CM	CO	PK	SK			
Adams River	06		04	Odd 01	Lake 005 Lake 019 Lake 030	high water temperatures	Dave Patterson, Fisheries and Oceans Canada, pers. comm.	Upper Adams sockeye faces some of the warmest average migration corridor temperatures (including the Adams River) of any Fraser River population.
Bessette Creek	07		04		Lake 038	low summer flows high water temperatures	Swain 1991 Stacy Webb, Pacific Salmon Foundation, pers. comm.	Bessette Creek and most of its tributaries have regulated flow regimes. The creeks in the watershed are heavily used for domestic and agricultural purposes. For example consumptive water uses in Bessette Creek are 6.8 m^3/d for domestic consumption and 1162 m^3 per year for irrigation. Seven-day low flows have ranged from 0.28 m^3/s to 1.07 m^3/s in Bessette Creek near its mouth. Seven-day low flows have ranged from 0.0 m^3/s to 2.02 m^3/s in Duteau Creek, a tributary of Bessette.
Bonaparte River	08		05	Odd 01		high water temperatures	FRAP 2000 Swain 1986 Timber Whitehouse, Fisheries and Oceans Canada, pers. comm. Dean Watts, Fisheries and Oceans Canada, pers. comm.	The Fraser River Action Plan highlights the Bonaparte River as one of many rivers that exceeds temperatures of 21C. In addition, agricultural water use is intense along the reaches of the Bonaparte river and may put additional stress on migrating salmon if water levels fall below a minimum requirement for upstream passage. Water storage facilities have been built in to the river system at Bonaparte Lake and are used to manage flows for the benefit of salmon. Fishways are also present to facilitate passage.
Capilano River	No conservation units listed					low summer base flows	Angelo 2006 FRAP 1999 Lill 2002 Precision Identification Biological Consultants 1997	Capilano River was ranked #1 (tie with Cheakamus, Coquihalla, Englishman, Puntledge, and Seymour Rivers) by Outdoor Recreation Council of BC in 2006, as part of Georgia Basin steelhead streams. Rationale behind ranking includes historically low steelhead stocks, habitat loss through urbanization, water extraction, water contamination, destabilization of steep banks, low summer flows, high water temperatures. Listed as endangered by Precision 1997 in part due to diversions of >50% of stream discharge.

[8] Fisheries and Oceans Canada, Wild Salmon Policy Conservation Units List with Stream Names. Available at: www.pac.dfo-mpo.gc.ca/species/salmon/wsp/CU/CU27Sept06.htm.

Regions of concern	Relevant Conservation Units[8]					Habitat concern	References	Comment
	CH	CM	CO	PK	SK			
Coldwater River	08		05			excessive water extraction low summer flows (highly variable) high water temperatures	Angelo 2006 FRAP 2000 Nelson *et al*. 2001 Stacy Webb, Pacific Salmon Foundation, pers. comm. Dean Watts, Fisheries and Oceans Canada, pers. comm..	Ranked #5 by Outdoor Recreation Council of BC in 2006 due to excessive water extraction, consistently low summer flows, and high water temperatures. The Fraser River Action Plan also highlights the Coldwater as one of many rivers that exceeds temperatures of 21˚C. Nelson *et al*. 2001 note that there is enough water for both human and ecosystem needs in most years, yet significant water shortages occur at least 2–3 times per 10 years. Water shortages for fish are exacerbated by diversion of water in these low-flow years.
Coquihalla River		02	07	Odd 01	Ocean 02	potential for flooding due to significant amount of dyking and rain on snow events	Angelo 2006 FRAP 1999 Lill 2002 Precision Identification Biological Consultants 1997	Ranked #1 (tie) by Outdoor Recreation Council of BC in 2006, as part of Georgia Basin steelhead streams, for the same reasons outlined for the Capilano River. The Coquihalla river was also listed as endangered by Precision 1997 due to a variety impacts on habitats.
Cowichan River	16	03	10			low summer flows high water temperatures	Lill 2002 Westland Resource Group Inc. 2005 Tom Rutherford, Fisheries and Oceans Canada, pers. comm. Leroy Hop Wo, Fisheries and Oceans Canada, pers. comm.	The Cowichan River Basin supports a wide range of resource interests including urban/agricultural water users, resident and anadromous fisheries, First Nations interests, recreation, flood protection, real-estate expansion around Cowichan Lake, municipal waste dilution, and water requirements for Catalyst Paper's operations. These interests compete for water, a challenge further exacerbated by drought, climate change, and population growth in the Basin. Natural water flow from Cowichan Lake into Cowichan River is controlled by a weir, installed more than 50 years ago to supply water to the Crofton Pulp Mill. The late summer/fall dry period often requires difficult choices regarding how to allocate limited water supplies to facilitate fish passage and support industrial requirements. This conflict is illustrated when low water levels in Cowichan Lake threaten both in-river fisheries and jobs at the mill if a temporary closure is required to help salmon passage. A Water Management Plan for the Basin has recently been completed offering recommendations to help manage water supplies and trade-offs among resource users (Westland 2007). Chinook have had challenges entering the river August through September during periods of to low flows. Flow management at the dam is required to ensure pulses of water are sent down river at the right time to maximize upstream migration. Such planning requires coordination across resource interests.
Cultus Lake (Sweltzer Creek)					Lake 031	high water temperatures	Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	Elevated water temperatures during sockeye migration. Effects on Cultus salmon are exacerbated by observed shift to earlier entry timing for late run Fraser sockeye, thereby resulting in greater conflicts among migration, spawning, and water temperatures.

Regions of concern	Relevant Conservation Units[8]					Habitat concern	References	Comment
	CH	CM	CO	PK	SK			
Deadman River	08		05	Odd 01	Ocean 01	high water temperatures	FRAP 2000 Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	The Fraser River Action Plan highlights the Deadman River as one of many rivers that exceeds temperatures of 21˚C. The Deadman River is also a hotspot for agricultural use of water which may affect salmon by altering flows.
Englishman River	16	03	10	Even 02 Odd 02	Ocean 04	water extraction low summer flows extreme winter flows	Angelo 2006 Bocking and Gaboury 2001 Lill 2002 Rosenau and Angelo 2003	Ranked #1 (tie) by Outdoor Recreation Council of BC in 2006, as part of Georgia Basin steelhead streams, for the same reasons mentioned for the Capilano River. Conflicts between human uses of water and salmon needs during summer periods are common. Flows in this system were low even prior to human development pressures and water extraction. In low water years some tributary streams are dry. Coastal watershed hydrology poses flooding risks to incubating salmon and flushing of juveniles.
Fortune Creek			04			low summer flows high water temperatures	Stacy Webb, Pacific Salmon Foundation, pers. comm.	Fortune Creek has run dry during the summer for the past six years. This has resulted in a loss of juvenile fish habitat due to dewatering, in addition low flows have prevented adults from returning to spawn. The City of Armstrong is the main water license holder and uses the majority of water for domestic purposes. Currently, PSF is funding a surface water study to investigate these concerns.
Fraser River (1–Yale to 2–Bridge River rapids)	Multiple conservation units use this migration corridor					high water temperatures	Angelo 2006 Cooke *et al.* 2004 Lapointe *et al.* 2003 Macdonald *et al.* 2000b Morrison *et al.* 2002 Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	Lower Fraser and other points along the river experience high summer water temperatures and reduced / elevated flows in some years—both of which can affect energy expenditures during migration. Late run stocks have shifted timing of migration since 1995, resulting in higher en-route and pre-spawning mortality. Although not fully understood, several hypotheses explain why salmon are experiencing higher rates of in-river mortality, including shifts in behaviour as a result of changing in-river conditions. Ranked #3 by Outdoor Recreation Council of BC in 2006.
Fulton River	26		23	Even 07 Odd 07	Lake 216	high water temperatures low water flows	Traxler *et al.* 1998 Dave Peacock, Fisheries and Oceans Canada, pers. comm.	Water temperature concerns associated with disease outbreak in 1994 and 1995 which resulted in high pre-spawning mortalities of sockeye in spawning channels.
Gates Creek	O4		02	Even 01 Odd 01	Lake 006	high water temperatures	Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	Elevated water temperatures during migration and spawning of sockeye salmon.

Regions of concern	Relevant Conservation Units[8]					Habitat concern	References	Comment
	CH	CM	CO	PK	SK			
Horsefly River	03		02		Lake 025	high water temperatures	Cooper 1973 Roos 1991 Williams 1973 Williams *et al.* 1977 Dave Patterson, Fisheries and Oceans Canada, pers. comm. Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	High water temperatures above 20°C on mainstem and tributaries (McKinley Creek). This concern is further aggravated by intense logging in some areas of the watershed which has led to the destruction of riparian zones and increased sediment runoff endangering spawning beds.
Johnston Creek (in Rivers Inlet)		07	15	Even 06	Ocean 08	low summer flows	Misty MacDuffee, Raincoast Conservation Society	Creek walkers and Central Coast biologists have observed low water levels on pink and chum salmon spawning grounds. Not located on maps that follow.
Little Campbell River	13	03	08			dewatering during the summer	Pamela Zevit, The Como Watershed Group, pers. comm. Precision Identification Biological Consultants 1997 FRAP 1999 Lill 2002	River has run dry the past couple of summers and everything has dewatered due to use of water resources for agriculture, recreation, and domestic purposes. Listed as endangered by Precision 1997 due to a variety of impacts on habitats.
Nadina River					Lake 010	high water temperatures	Timber Whitehouse, Fisheries and Oceans Canada, pers. comm. Eric Parkinson, Ministry of Environment, pers. comm.	
Nechako River	04				Ocean 01	high water temperatures	Angelo 2006 FRAP 2000 Mitchell *et al.* 1995 NFCP 2005 Roos 1991	Lack of a water use plan and has concerns about high water temperatures and effects on downstream chinook and sockeye salmon. Fraser River Action Plan highlights the Nechako river as one of many rivers that exceeds temperatures of 21C, as well as being heavily impacted by urban developments around Prince George). Summer Temperature Management Program has been established by the Nechako Fisheries Conservation Program which has been effective in maintaining temperature targets on the lower River. Construction of a cold water release facility is currently being considered. Current water temperature targets would not change while operating this facility. Purpose of the facility would be to shift water releases to different times of year to restore a more natural hydrograph, benefiting salmon and other species.

Regions of concern	Relevant Conservation Units[8]					Habitat concern	References	Comment
	CH	CM	CO	PK	SK			
Nicola River	08		05	Odd 01		water withdrawals high water temperatures	FRAP 2000 Kosakoski and Hamilton 1982 Rosenau and Angelo 2003 Walthers and Nener 1997 Walthers and Nener 1998 Stacy Webb, Pacific Salmon Foundation, pers. comm. Angus MacKay, Pacific Salmon Commission, pers. comm. Timber Whitehouse, Fisheries and Oceans Canada, pers. comm. Heather Stalberg, Fisheries and Oceans Canada, pers. comm.	In 2003/04, the Outdoor Recreation Council identified the Nicola as the most endangered river in BC—due to recent trends of critical low flow and lethal stream temperatures. The Fraser River Action Plan also highlights the Nicola as a river that exceeds temperatures of 21˚C. Historically, agriculture, industry, and urban/domestic sectors have been the main users of surface and groundwater sources, but new development proposals with associated water needs are on the rise.
North Thompson River tributaries (Lemieux, Louis, Dunn, and Buffalo Creeks)	05	01	03	Odd 01	Lake 012	high water temperatures	FRAP 2000 Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	The Fraser River Action Plan highlights the North Thompson River as a river that exceeds temperatures of 21˚C. Urban, industrial, and agricultural water use from the North Thompson and its tributaries is substantial which further may provides additional stress to salmon by decreasing river flows. Intense logging in some areas of the watershed has also led to the destruction of riparian zones and increased sediment runoff destroying spawning beds.
Okanagan River	01				Lake 001	water extraction high water temperatures	Angelo 2006 Hyatt *et al.* 2003 Kim Hyatt, Fisheries and Oceans Canada, pers. comm.	High water temperatures in the mainstem river result in sockeye migration delays. Migration into the Canadian portion of the Okanagan River is complicated by the need to pass beyond numerous lower Columbia River dams. River ranked #8 by Outdoor Recreation Council of BC in 2006 due to channelization, water extraction, urban encroachment, riparian habitat loss and the building of dams and weirs.
Pinkut Creek	26		23	Even 07 Odd 07	Lake 216	high water temperatures low water flows	Traxler *et al.* 1998 Dave Peacock, Fisheries and Oceans Canada, pers. comm.	Water temperature concerns associated with disease outbreak in 1994 and 1995 which resulted in high pre-spawning mortalities of sockeye salmon in spawning channels.

Regions of concern	Relevant Conservation Units[8]					Habitat concern	References	Comment
	CH	CM	CO	PK	SK			
Puntledge (Courtenay) River	16	03	10	Even 02 Odd 02	Ocean 04	low summer base flows high water temperatures	Angelo 2006 Lill 2002	Long-standing BC Hydro project in watershed, chronic problems with low summer flows and high temperatures partially addressed by Interim Flow Order from Water Comptroller effectively doubling the base flow from 2.8 to 5.7 cms starting in 1998. It remains in effect until completion of current Water Use Plan (Lill 2002). Water Use Plan has since been initiated. Ranked #1 (tie) by Outdoor Recreation Council of BC in 2006, as part of Georgia Basin steelhead streams, due to historically low steelhead stocks, habitat loss through urbanization, water extraction, water contamination, destabilization of steep banks, low summer flows, high water temperatures.
Salmon (Deleeuw) River (near Fort Langley)		02	07			flash floods falling water tables high water temperatures	Angelo 2006 FRAP 1999 Lill 2002 Precision Identification Biological Consultants 1997	Ranked #10 (tie) by Outdoor Recreation Council of BC in 2006 due to declining fish stocks, agricultural pollution, flash floods, falling water tables, urbanization. Listed as endangered by Precision 1997 due to a variety of impacts on habitats.
Salmon River (near Salmon Arm)	06		04		Lake 019 Lake 042	summer low flows high water temperatures water extraction	FRAP 1999 FRAP 2000 Quadra Planning Consultants Ltd. 1995 Regnier 1999 Murray Ross, Secwepemc Fisheries Commission, pers. comm. Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	Summer low flows continue to be a critical problem in the Salmon River. Water temperature in the Salmon River during summer low flow periods are a major threat to fish survival. In addition, the Fraser River Action Plan highlights the Nechako river as one of many rivers that exceeds temperatures of 21˚C. Lack of water and high temperatures exerts tremendous pressure on salmon populations attempting to spawn and rear in the Salmon River watershed. The peak irrigation season coincides with critical low flow period. The Salmon River was ranked as the #1 priority area within their territory by the Secwepemc Fisheries Commission.

Regions of concern	Relevant Conservation Units[8]					Habitat concern	References	Comment
	CH	CM	CO	PK	SK			
Shuswap River (lower river and tributaries—Ashton, Blurton, Johnson, and Trinity Creeks)	06		04	Odd 01	Lake 039	low summer flows high water temperatures	Carlson 2006 Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	Ashton and Blurton Creek have been experiencing significant annual fish kills and Johnson and Trinity Creeks significant dewatering of rearing and cold water refuge habitat because of the recent trend of summer drought like conditions and associated increased irrigation demands. Each of identified streams has two agricultural water licensees who consume the majority of the summer low flows with intakes. Migration corridor through the lower Shuswap River mainstem (Mara Lake to Mabel Lake) is also an area with high temperature and low flow concerns, which affect migration and spawning. Mainstem of lower Shuswap River (i.e., Mara to Mabel Lakes) also has high water temperatures and low flow which directly affect spawning habitats in the river and indirectly affect upstream habitats given use of this corridor for upstream migration.
Shuswap Lake tributaries	Multiple conservation units use these habitats.					low flows high water temperatures	Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	Shuswap Lake tributaries are used by early summer runs of sockeye salmon. Low summer flows and elevated water temperatures affect this group by creating flow and thermal barriers restricting access to upstream areas.
South Thompson River (1–Kamloops to 2–Chase)	Multiple conservation units use this migration corridor.					warm water temperatures	Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	Corridor with elevated water temperatures during spawning migration, exacerbated by periods of extended droughts and high summer air temperatures in the Thompson region.
Somass River	17	04	12	Even 03 Odd 03	Lake 049	water withdrawal and water use	Leroy Hop Wo, Fisheries and Oceans Canada, pers. comm. Don Hall, Fisheries Manager, Nuu-chah-nulth Tribal Council, pers. comm.	There have been a couple of low flow years over the last few years, which has resulted in blocked upstream passage to spawning areas.
Stuart River (including Tachie and Middle Rivers)	04				Ocean 01	high water temperatures	Foreman *et al.* 2001 FRAP 2000 Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	The Fraser River Action Plan highlights that the Stuart River, as well as the Tachie and Middle River, is known to exceed temperatures of 21°C. Foreman *et al.* 2001 predict the most adverse effects can be expected for the Early Stuart run as they have to travel the farthest (beyond the Stuart River) and are in the river during the warmest temperatures.
Thompson River (1–Lytton to 2–Savona)	Multiple conservation units use this migration corridor.					high water temperatures	Timber Whitehouse, Fisheries and Oceans Canada, pers. comm.	Corridor with elevated water temperatures during salmon migration. Effects on salmon are exacerbated by periods of drought and elevated air temperatures within the region.

TABLE 4. Definition of Conservation Units listed in Table 3.

	Chinook	Chum	Coho	Pink	Sockeye
Conservation Unit Codes	01-Okanagan 03-Middle Fraser-summer 04-Middle Fraser-spring 05-North Thompson-spring 06-South Thompson-ocean 07-South Thompson-summer 08-Lower Thompson-spring 13-Boundary Bay-ocean 14-South Coast 16-E Vancouver Island 17-W Vancouver Island 26-Middle Skeena	01-Interior Fraser 02-Lower Fraser 03-Georgia Strait 04-W Vancouver Island 07-Hecate Strait-QC Sound	02-Middle Fraser 03-North Thompson 04-South Thompson 05-Lower Thompson 07-Lower Fraser 08-Boundary Bay 09-South Coast 10-SE Vancouver Island 12-W Vancouver Island 15-Rivers-Smith 23-Middle Skeena	Even Year 01-Fraser River Even Year 02-Georgia Strait Even Year 03-W Vancouver Island Even Year 06-Hecate Strait-QC Sound Even Year 07-Nass/Skeena Estuary Odd Year 01-Fraser River Odd Year 02-Georgia Strait Odd Year 03-W Vancouver Island Odd Year 07-Nass/Skeena Estuary	Lake 001-Okanagan-OKANAGAN Lake 005-Fraser-ES-ADAMS Lake 006-Fraser-ES-ANDERSON / SETON Lake 010-Fraser-ES-FRANCOIS Lake 012-Fraser-ES-KAMLOOPS Lake 019-Fraser-ES-SHUSWAP Lake 025-Fraser-S-QUESNEL Lake 030-Fraser-L-ADAMS Lake 031-Fraser-L-CULTUS Lake 038-Fraser-L-MABEL Lake 039-Fraser-L-MARA Lake 042-Fraser-S-SHUSWAP Lake 049-SW Vancouver Island-GREAT CENTRAL/SPROAT Lake 216-Skeena-BABINE Ocean 01-Interior Fraser Ocean 02-Lower Fraser Ocean 04-Georgia Strait Ocean 08-Hecate Strait-QC Sound

TABLE 5. Conservation Units with the greatest number of watersheds with flow and/or temperature related concerns (see Table 3).

Conservation Unit	Number of watersheds with habitat concerns	Total number of watersheds within Conservation Unit	Percentage of watersheds with habitat concerns
Chinook (08) Lower Thompson–spring	4	7	57%
Chum (03) Georgia Strait	4	144	3%
Coho (04) South Thompson	5	43	12%
Pink-Odd Year (01) Fraser River	8	86	9%
Sockeye-Ocean (01) Interior Fraser	3	18	17%

FIGURE 2. Map of the *Southwestern* British Columbia showing watersheds with water flow and/or temperature related habitat concerns as identified in Table 3.

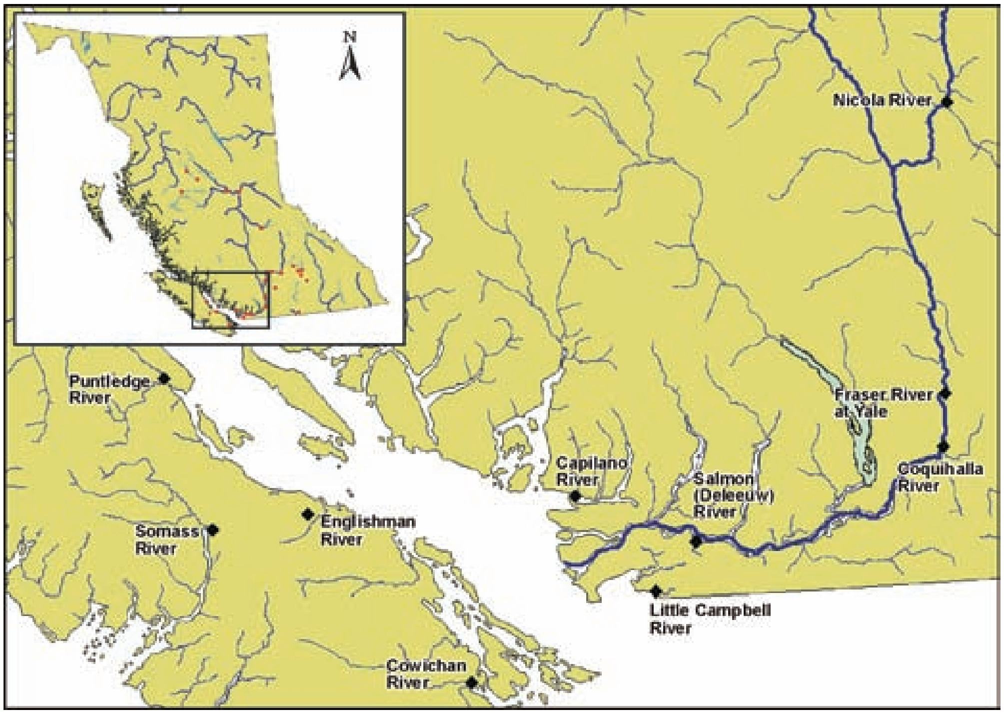


FIGURE 3. Map of *Southern Interior* of British Columbia showing watersheds with flow and/or temperature related habitat concerns as identified in Table 3.
See Table 3 for locations with number references on the Fraser, Thompson, and South Thompson Rivers.

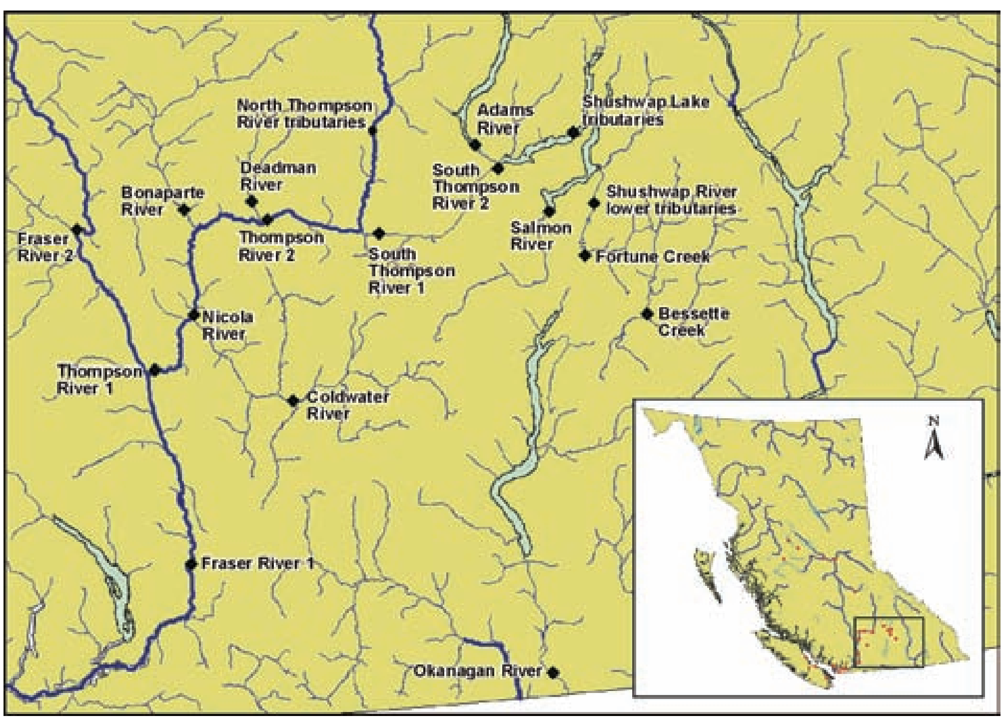
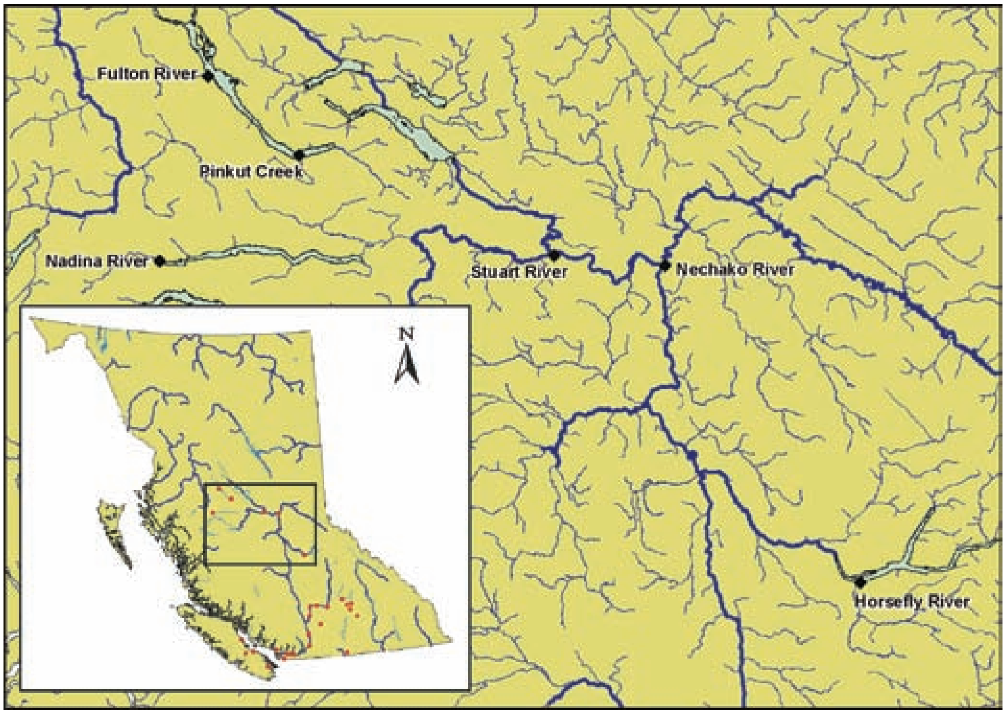


FIGURE 4. Map of *Central Interior* of BC showing watersheds with flow and/or temperature related habitat concerns as identified in Table 3.



Developing a list of areas as presented in Table 3 is helpful for identifying areas most vulnerable to climate change and highest priority areas requiring management action. However, it is important to recognize that salmon distribution changes over time. Presence within an individual watershed may change over time, but not singly affect overall population status. Thus, a more informative and robust approach would be to consider habitat status across all watersheds occupied by a distinct population—by using DFO's Conservation Units (DFO 2005) or NOAA's Evolutionary Significant Units (Waples 1991), for instance. Conservation Unit (CU) designations for British Columbia are available (Table 4), though currently under review (DFO 2007). Using Conservation Units as the currency for identifying regions of vulnerability, the following CUs have the greatest number of areas with habitat concerns (Table 5): Chinook (08)—Lower Thompson spring (57% of watersheds), Chum (03)—Georgia Strait (3% of watersheds), Coho (04)—South Thompson (12% of watersheds), Pink odd year (01)—Fraser River (9% of watersheds), and Sockeye ocean (01)—Interior Fraser (17% of watersheds).

There are, however, several critical limitations in identifying regions of vulnerability using the approach applied here. For instance, this list:

- was not developed using an objective analysis of all watersheds in the Pacific Region (i.e., British Columbia and Yukon) to identify areas with flow and temperature related concerns for salmon;
- does not consider salmon status, trends, or productive capacity of those watersheds, which would affect management importance;
- combines information from a variety of objective and subjective sources that have used different criteria to identify watersheds of concern;
- does not account for differences in intensity of monitoring across the province, implying that some areas may be over-represented simply because they are more well studied than others;

- does not include systems (i.e., lakes and rivers) where flow or temperature changes might lead to positive effects on salmon; and
- does not explicitly consider interaction of flow-temperature related concerns with other stressors on habitats (e.g., sedimentation, pollutants).

Therefore, Table 3 does not represent a comprehensive evaluation of areas of vulnerability across the entire distribution of salmon in western Canada and should not be used on its own to prioritize management action.

To develop a credible list for management purposes, a more defensible analysis would need to consider the following minimum information:

- current observations and future predictions of air temperatures (and thermal regimes where available);
- classification of watersheds into distinct hydrological types (e.g., Wade *et al.* 2001);
- general predictions of flow related changes (e.g., timing and magnitude) for these watershed types (such predictions would be highly uncertain given that detailed hydrological predictions are not possible at a broad-scale due, in part, to the geographic diversity across BC, high variation in land use activities, and poor ability to predict future changes in precipitation);
- expert-driven rules for describing how existing and predicted future flow and temperature related changes would affect salmon;
- status and trends of Conservation Units at greatest risk (e.g., Slaney *et al.* 1996); and
- natural and human disturbance pressures on habitats (e.g., human population growth and demands on water).

Another limitation is that the above list does not acknowledge climate change impacts on Pacific salmon habitats beyond British Columbia. Yukon and the north face four unique responses to climate change. First, reductions in flow, particularly in tributaries, are a concern in southwestern Yukon. A recent study in northern B.C. and southwestern Yukon (Fleming and Clarke 2003) found that glacier fed rivers grew larger and snowpack-driven streams progressively smaller over the study period under a regional warming trend. Such changes may be a concern to salmon because reductions in flows can cause juvenile chinook rearing streams in the north to dry during the winter (Bradford *et al.* 2001; von Finster 2006). Second, a recent assessment of post-fire growth and succession in southwestern Yukon found a shift from white spruce to aspen parkland forest ecosystems (Hogg and Wein 2005). These types of changes will likely be associated with hydrological alterations due to changes in forest cover and changes to forest species (e.g., aspen) that use more water than spruce (Al von Finster, Fisheries and Oceans Canada, pers. comm.). As well, the abundance of beavers and beaver dams has been increasing with the increasing dominance of aspen in the forest community, thus affecting fish passage in tributary streams (Al von Finster, Fisheries and Oceans Canada, pers. comm.). Third, as the permafrost melts, nutrient contributions to streams are increasing significantly (Al von Finster, Fisheries and Oceans Canada, pers. comm.). Premafrost melting coupled with increasing incidence of forest fires / hot weather events is triggering more slope failures (e.g., detachments between upper soil layers and underlying frozen materials (van Everdingen 1998 as cited in Lipovsky *et al.* 2006)). The long-term effects of permafrost melting and associated changes on salmon are not yet clear. Fourth, stream temperatures are hypothesized to be increasing in large rivers like the Yukon due to the 24 hours of daylight and high turbidity (affecting absorption of solar radiation). Although long-term temperature data sets are not available for the Yukon River, values of 18°C have been measured for extended periods (Al von Finster, Fisheries and Oceans Canada, pers. comm.). Warm temperatures are not currently a concern in smaller streams.

4. ASSETS

4.1 MANAGEMENT STRATEGIES

Broad-scale planning tools currently being developed by governmental and non-governmental organizations in British Columbia are assets to decision making because they can help decision makers identify freshwater areas vulnerable to climate change. These efforts include (summarized in Table 6):

- prioritization of Conservation Units and development of habitat indicators under the Wild Salmon Policy by Fisheries and Oceans Canada;
- designation of Temperature Sensitive Streams and Fisheries Sensitive Watersheds by the BC Ministry of Environment;
- development of a Watershed Decision Support tool through a multi-agency partnership under the Living Rivers Program (Fisheries and Oceans Canada, BC Ministry of Environment, Nature Conservancy Canada, Pacific Salmon Foundation, and the Fraser Basin Council); and
- assessment of Eco-Regional Units within the Central Interior by Nature Conservancy Canada.

Although not designed for the specific purpose of identifying regions of vulnerability, these efforts represent the leading decision support technologies being developed to identify known / emerging areas of concern for fish and water resource management in BC. Information sources from these efforts could be leveraged to help salmon in the context of climate change.

In identifying areas of management interest, it is also important to consider how this information will be used (i.e., what objectives guide management actions in identified watersheds?). Depending on the intended purpose, different watersheds could be identified. For instance, will the information be used to identify areas where managers should focus *restoration* (restore areas that are currently degraded) or *conservation* (protect critical areas to maintain diversity)? Table 3 is focused on identifying areas where current hydrologic and thermal regimes may be constraining salmon production. Given the large expenditures on river restoration, limited ability to determine biological effectiveness of these actions (e.g., Bernhardt *et al.* 2005), and continued declines of wild salmon, some have advocated for conservation-oriented approaches to helping salmon (e.g., Rahr and Augerot 2006).

Existing federal, provincial, municipal, and private protected areas are other assets that may benefit Pacific salmon. In British Columbia more than 12% of the provincial land base is dedicated to protected areas (WLAP 2002). It is uncertain how these areas overlap with salmon habitats. For instance, a review by Raincoast Conservation Society found that 20% of salmon watersheds on the North and Central Coast will be protected under the Great Bear Rainforest[9]. Protection of individual watersheds ranged from 0 to 100%. Maintaining and expanding protected area assets for Pacific salmon could help conserve genetic diversity. Such an approach is consistent with the principles around managing Conservation Units under the Wild Salmon Policy (DFO 2005). Recent evidence suggests that salmon stocks may cycle through strong and weak periods (Hilborn *et al.* 2003), underlying the importance of protecting diversity in supporting long-term viability of salmon populations. Maintaining genetic resilience through conservation is also more proactive than restoration because it provides salmon with the evolutionary tools to adapt to a changing climate. Changes in salmon distribution in the Yukon and Northwest

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[9] Raincoast Conservation Society. 2006. News release: "*Less than 20% of salmon watersheds to receive full protection on the central and north coast under Great Bear Rainforest deal*" http://www.raincoast.org/publications/news/salmonGBR20060831.shtml

Territories, as well as shifts in migration timing of Fraser River sockeye suggest that salmon may already be adapting to environmental changes.

4.2 RESTORATION STRATEGIES

Local watershed stewards and government agencies have a history of experience implementing a variety of strategies to improve productivity of salmon habitats in the Pacific region. This experience represents an additional asset that can be leveraged to help develop future adaptation strategies. Table 7 summarizes projects from the federal-provincial Fisheries Project Registry that have been implemented for the benefit of all fish species and habitats across British Columbia. Among the types of project listed, "*Public awareness and education*" are the most numerous (17%), followed by "*Instream restoration / enhancement*" (13%), and "*Fish culture activities*" (11%). Vancouver Island (28%), Lower Mainland (22%), and Skeena (10%) are the regions with the greatest number of projects. The dominant action also varies across regions. "*Riparian restoration / enhancement*" is the dominant action in the Okanagan (14%), while "*Restoring fish passage / barrier modification / obstruction*" actions are dominant in the Thompson-Nicola (14%). Given the range of hard infrastructure strategies discussed in Section *5 Adaptation Strategies*, it is likely these priorities will also benefit salmon in the context of climate change. The emphasis on "*Public awareness and education*" in several regions (e.g., Vancouver Island, Mower mainland, and Cariboo) will not likely mitigate climate-induced impacts on freshwater habitats as directly. In the Skeena region, "*Fish culture activities*", have received the greatest attention among actions.

Fish culture / enhancement activities have been an important management tool for salmon in British Columbia. In Table 7, these activities represent the third most common strategy across the province (11% of all projects). As well, government and local hatchery programs have released billions of salmon since the 1950s (Figure 5). In 2006, 181 million sockeye, 107 million chum, 40 million chinook, 20 million pink, and 10.8 million coho were released through all hatchery programs (Figure 5). DFO's major hatchery programs have provided the bulk of releases for each species, with less significant contributions from community development and other release programs.

Previous investments in hatchery infrastructure may be an asset that can be leveraged to help salmon in the context of climate change. The focus and implementation of hatchery efforts would likely be different, however. The primary purpose of existing hatchery programs has been to augment fishing opportunities and supplement wild stocks for conservation reasons (MacKinlay *et al.* 2004). Given future changes in freshwater habitats, there may be a greater emphasis on using hatchery releases to assist in reintroduction of salmon to extirpated areas, introduction to new areas, or transplantation of temperature-tolerant stocks to watersheds with thermally vulnerable habitats, for instance (discussed further in Section 5 and Appendix C). A critical pre-cursor to using this management tool, though, is to have a better scientific understanding of physical attributes (i.e., genotype and phenotype) of existing salmon stocks (Tony Farrell, University of British Columbia, pers. comm.). Currently, the research hasn't been completed to reliably use this strategy as a tool to help salmon adapt to changes in freshwater habitats in the future.

TABLE 6. List of potentially relevant prioritization initiatives in B.C.

Prioritization initiative	Description	References	Contact person(s)
Prioritization of Habitat and Population Status under the Wild Salmon Policy	In 2005 the Wild Salmon Policy set forth clear principles, goals, objectives, and strategies to help conserve Pacific salmon. As part of this policy three strategies are relevant to identifying salmon watershed and habitats that might be adversely affected by climate change: Strategy (1) Standardizing monitoring of wild salmon status, Strategy (2) Assessment of habitat status, and Strategy (3) Inclusion of ecosystem values and monitoring. Strategy (1), Action Step 1.1 requires identification of salmon conservation units (CUs), which are currently under public review, and Action Step 1.2 requires a characterization of the biological status of those CUs. The resultant "red-amber-green" zone ranking of spawning abundance and distribution of CUs would provide a baseline understanding of salmon stocks requiring special management considerations. Strategy (2), Action Steps 2.1, 2.2, and 2.3 would be helpful at identifying flow and temperature indicators relevant to salmon, and characterizing habitat characteristics by CUs. Consideration of Strategy (3), Action Step 3.2 Integration of climate information into annual salmon management processes, would provide the additional filter necessary to identify those conservation units most at risk from climate-induced changes in freshwater habitats. To better understand watershed and population priorities, DFO is working with Compass Resource Management to develop a watershed prioritization system that integrates criteria and indicators for areas of interest to ultimately rank watersheds for decision making (see Watershed Prioritization System, http://www.compassrm.com/wps).	Fisheries and Oceans Canada. 2005; 2007	Heather Stalberg, Senior Habitat Management Biologist, Fisheries and Oceans Canada
Designation of Temperature Sensitive Streams (TSS)	As set forth under the Forest and Range Practices Act (FRPA), specifically the Government Actions Regulation (Sec 14) and Forest Practices and Planning Regulation (Sec 8), the BC Ministry of Environment is responsible for designating Temperature Sensitive Streams (TSS). By order from the Minister, a portion of a fish stream may be designated as temperature sensitive if: (a) trees are required adjacent to the stream to manage the temperature of the designated portion for the protection of fish, and (b) management of the temperature of the designated portion is not otherwise provided. Designations would primarily affect forest activities in riparian areas of crown lands. Currently no streams are designated as Temperature Sensitive as the process for these designation is under development. However, the intention is to identify streams that are both physically sensitive to riparian disturbances and where fish species (e.g., salmon) would be sensitive to increases in water temperatures.	Ministry of Environment 2007a; Marmorek and Alexander 2003; Nelitz *et al.* 2007a	Ted Down and Eric Parkinson, Ministry of Environment
Designation of Fisheries Sensitive Watersheds (FSW)	As set forth under FRPA, specifically the Government Actions Regulation (Sec 14) and Forest Practices and Planning Regulation (Sec 8), the BC Ministry of Environment is responsible for designating Fisheries Sensitive Watersheds (FSW). To qualify as an FSW, watershed must be have high fisheries values (e.g., productive salmon habitats) and high sensitivity to disturbance from forestry activities. Once designated licensees will be required to set objectives in their Forest Stewardship Plans that ensure forestry activities conserve: (a) natural stream bed dynamics; (b) stream channel integrity; (c) quality, quantity and timing of water flow; and (d) natural, watershed level, hydrological conditions and integrity.	Ministry of Environment 2006; 2007b; Marmorek and Alexander 2003	Ted Down, Lars Reese-Hansen, and Eric Parkinson, Ministry of Environment

Prioritization initiative	Description	References	Contact person(s)
Watershed Decision Support Tool	Funded through the provincial Living Rivers Program, Nature Conservancy Canada (NCC) is working with the Ministry of Environment, Fisheries and Oceans Canada, the Fraser Basin Council, and the Pacific Salmon Foundation to develop a watershed decision support tool for British Columbia. This analytical tool will use the provincial Watershed Atlas as the framework upon which to build a tool to help decision makers understand current watershed conditions (including salmon values) and evaluate threats associated with future conditions (e.g., water use, climate change, and population growth).	Nature Conservancy Canada 2006	Pierre Iachetti, Director of Conservation Science and Planning, Nature Conservancy Canada
Central Interior Ecoregional Assessment	NCC uses a four-step process to conserve habitats. The first step in this process is to conduct an ecoregional assessment, of which BC is separated into several ecoregions (e.g., Central Interior, Southern Interior (Okanagan), Kootenays, Georgia Basin). Currently, NCC is in the initial stages of an ecoregional assessment of both terrestrial and freshwater habitats in the Central Interior. This work is being completed in partnership with the Ministry of Forests and Range, and the Ministry of Agriculture and Lands. For freshwater conservation in the Central Interior, this analysis will use the most up-to-date spatial information to identify representative third order basins. The assessment is based on the provincial Watershed Atlas and will apply a newly developed freshwater classification system (similar to the terrestrial biogeoclimatic ecosystem classification (BEC) system) to group basins with similar freshwater characteristics. These layers of information will also be overlaid with fish species information (including salmon), measures of human development (available through MOE's Watershed Statistics database), and climate change scenarios (developed in conjunction with UVic and UNBC) to prioritize areas for conservation across a range or representative areas.	Nature Conservancy Canada 2007a; 2007b; 2007c	Pierre Iachetti, Director of Conservation Science and Planning, Nature Conservancy Canada

TABLE 7. Projects in British Columbia's Fisheries Project Registry[10] from 1955 to 2006.

Projects are summarized by Ministry of Environment region and type of action. Only those types of projects deemed most likely to affect fish habitats were summarized here. Activity types not summarized include fisheries economic development, research, stock assessment, and "other" categories. Shaded cells identify the dominant action within a region (centre cells of table), the region with the greatest number of projects (bottom row), and the dominant type of action being implemented across the province (last column on the right).

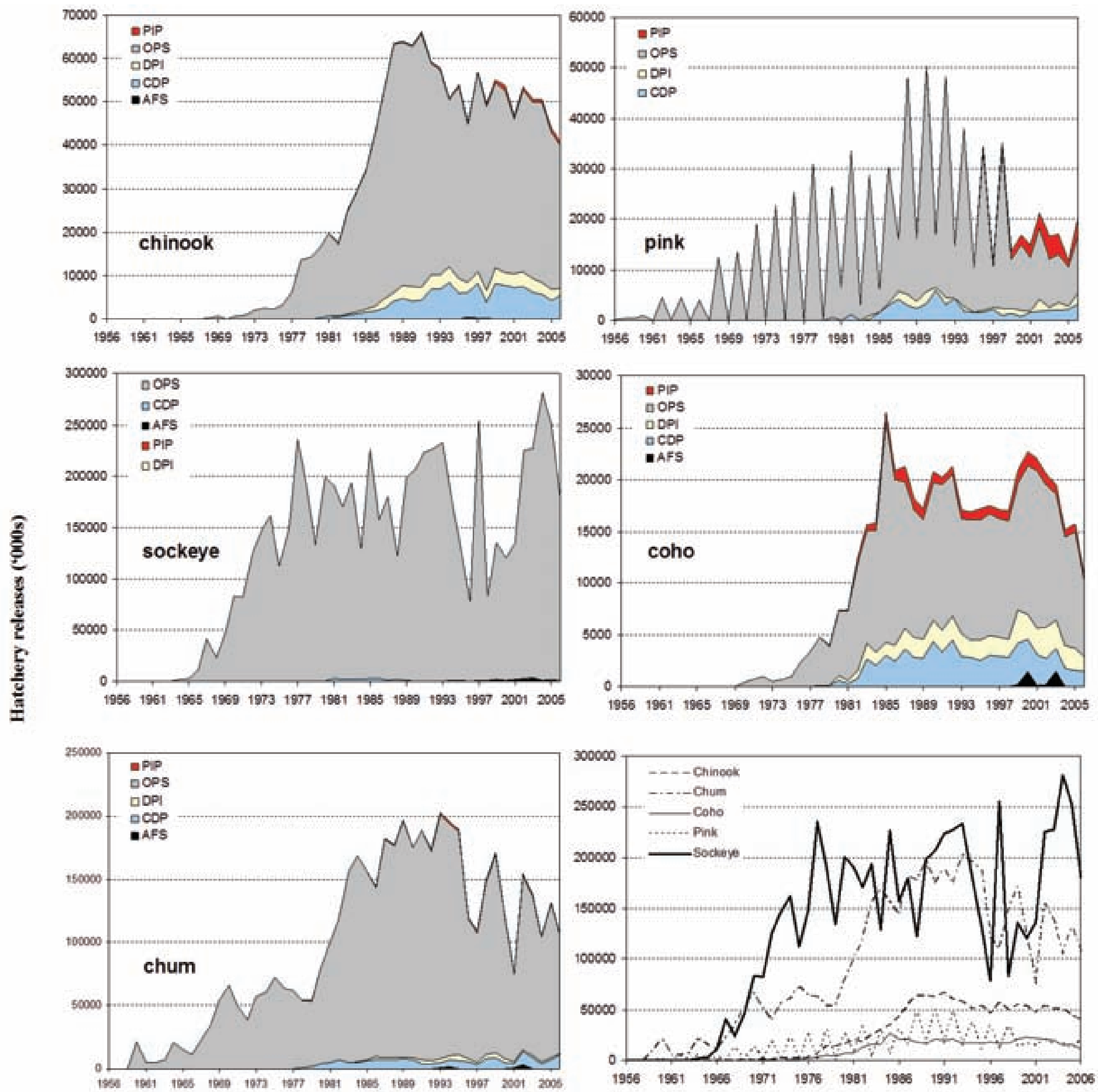
Category	Type of Action	Region									Total
		Vancouver Island	Lower Mainland	Thompson-Nicola	Kootenay	Cariboo	Skeena	Omineca	Okanagan	Peace	
Water Quality	Aeration	13	3	23	5	12	0	0	18	7	81
	Fertilisation	83	33	1	6	0	0	10	0	0	133
	Flow	83	52	53	87	13	30	14	54	4	390
	Other	146	104	69	159	26	43	27	41	0	615
Restoration	Watershed based fish sustainability planning	12	2	4	3	5	9	0	4	1	40
	Lake wetland or estuary restoration / enhancement	36	36	13	23	17	7	3	19	7	161
	Water use planning	37	41	46	23	5	10	9	18	4	193
	Effectiveness monitoring and evaluation	123	128	50	20	40	71	45	29	11	517
	Restore fish passage/ barrier modification / obstruction removal	169	117	135	81	115	125	31	82	29	884
	Upslope restoration	169	184	114	175	71	116	37	47	16	929
	Riparian restoration / enhancement	267	242	112	38	72	52	28	95	16	922
	Spawning habitat or off-channel restoration / enhancement	278	270	113	64	73	60	22	56	5	941

[10] Fisheries Project Registry available at: www.canbcfpr.pac.dfo-mpo.gc.ca/fpr/Qf_Welcome.asp

Category	Type of Action	Region									Total
		Vancouver Island	Lower Mainland	Thompson-Nicola	Kootenay	Cariboo	Skeena	Omineca	Okanagan	Peace	
	Instream restoration / enhancement	454	275	87	81	83	127	53	91	18	1,269
	Other	30	21	8	5	3	13	4	10	0	94
Enhancement	Fish culture activities	362	267	66	14	76	218	68	28	44	1,143
Stewardship	Public awareness and education	540	430	94	97	134	192	135	91	24	1,737
Total		2,802	2,205	988	881	745	1,073	486	683	186	10,049

FIGURE 5. Summary of hatchery releases (in thousands of individuals) across B.C. by year, salmon species, and type of release program.

Note differences in range of values along axes for each graph. Program types include: AFS=Aboriginal Fisheries Strategy; CDP=Community Development Program; DPI=Designated Public Involvement Programs; OPS=major hatcheries; PIP= minor Public Involvement Programs. Data provided by Don MacKinlay, Fisheries and Oceans Canada.



5. ADAPTATION STRATEGIES

Clearly, human actions have a direct influence on salmon and their habitats. Changing government regulations, policies, environmental guidelines, and restoration actions by stewardship groups can either exacerbate climate-induced changes in habitats, or help mitigate the effects of hydrologic and thermal alterations. Based on interviews with a variety of habitat managers, scientists, First Nations, and watershed stewards from across western North America, as well as a review of available literature, this section synthesizes ideas around two types of actions: *hard infrastructure* and *soft infrastructure* alternatives. Changes to hard infrastructure relate to engineering / technology focused actions that can be implemented to either help salmon adapt to climatic changes, mitigate the effect of changes in habitats, compensate for climate-induced losses to salmon, or restore habitats with reduced productive capacity due to past degradation. Soft infrastructure strategies include targeting shifts in governance, regulations, policy, or management approaches. In other words, hard infrastructure strategies describe the direct actions we can take to change salmon's natural environment, while soft infrastructure strategies relate to direct actions we can take to change our social environment.

The purpose of presenting the alternatives below is to be solutions-oriented—to present a breadth of options that could be used to help salmon in the context of climate change. The intention is not to describe these alternatives in depth. Citations and examples have been provided where interested audiences can explore these options further. Also, the intention is not to advocate for one approach over another. Local challenges for building on-the-ground infrastructure or regulatory barriers to seeing changes in legislation / policy will ultimately govern implementation success. Strategies must be implemented effectively to ensure success—a good strategy, implemented poorly, will not necessarily lead to good outcomes.

5.1 HARD INFRASTRUCTURE STRATEGIES

> *"The image of a broken chain helps explain how so much money could be spent on salmon restoration over the past couple of decades with such little result. Restoration programs have been fixing individual links in the life history chain. Little attention has been given to the restoration of whole life histories. A life history-habitat chain is a living system. It must be 100% complete—all the links habitable—or the system dies." Jim Lichatowich, 2002*

This section describes engineering or technology-based solutions, such as transplanting stocks, managing water releases, or restoring instream habitats (see Figure 6 and Table 8). Successful implementation is driven, in part, by the policy-oriented levers discussed in Section 5.2 which would ideally encourage on-the-ground innovation and change. Appendix C provides examples where strategies have been applied, a scientific basis for recommending actions, and considerations for implementation. Actions are organized into four categories: (i) adaptation / avoidance, (ii) mitigation, (iii) compensation, and (iv) restoration. Strategies have also been aligned with their anticipated effect on water flows, temperatures, individual fish, or physical habitats (Figure 6). Many actions relate to how we can mitigate for climate-induced changes in freshwater habitats by increasing water storage, reducing water consumption, or managing timing, volume, and temperature of water releases. Other actions can directly affect salmon by manipulating genetic diversity / abundance or indirectly affect salmon by enhancing productive capacity of habitats. While these other actions do not relate directly to climate-induced change in freshwater environments they can be effective by offsetting associated increases in mortality (Ward *et al.* 2006).

FIGURE 6. Summary of hard infrastructure strategies (i.e., engineering / technology oriented approaches) to help salmon in the context of climate change

Strategy	Category	Action	Flow	Temp.	Fish	Habitat
Adaptation/ avoidance	Genetic	Transplant stocks or species		✓	✓	
	Range extension	Reintroduce salmon to extirpated areas			✓	
		Introduce salmon to new areas			✓	
	Habitat conservation	Conserve pristine habitats				✓
Mitigation	Water conservation	Implement low impact irrigation practices	✓			
		Recycle water in industry	✓			
		Install water meters	✓			
	Water management	Build additional storage capacity	✓		✓	✓
		Divert water from other locations	✓			
		Decrease surface water runoff	✓			
		Manage water storage	✓			
		Release cold water		✓		
		Manipulate surface water/groundwater interactions	✓	✓		
	Fish passage	Transport fish manually	✓		✓	
		Improve fish passage			✓	
	Habitat	Implement low impact forestry practices	✓	✓		✓
		Implement low impact grazing practices		✓		✓
Compensation	Habitat	Engineer streams				✓
		Enhance instream habitat				✓
		Enrich streams and lakes with nutrients				✓
	Enhancement	Enhance production with hatcheries			✓	
Restoration	Habitat	Create off channel habitat				✓
		Create deep pools		✓		
		Clean gravel				✓
		Restore connectivity				✓
		Restore slope stability				✓
		Restore riparian ecosystems	✓	✓		✓
		Move dykes back from rivers				✓

TABLE 8. Description of hard infrastructure strategies (i.e., engineering / technology oriented approaches) summarized in Figure 6.

Strategy	Description
Transplant stocks or species	Transplant stocks or species to take advantage of differences in physiological characteristics (e.g., temperature tolerance).
Reintroduce salmon to extirpated areas	Reintroduce salmon to areas where they have been extirpated (e.g., due to barriers to fish passage).
Introduce salmon to new areas	Introduce salmon into regions where they were previously unable to survive, but with changing climate may be suitable (e.g., streams that were previously too cold or were not accessible)
Conserve pristine habitats	Conserve habitats that currently support or could support salmon.
Implement low impact irrigation practices	Implement irrigation practices that minimize water loss and direct impacts on fish due to entrainment.
Recycle water in industry	Implement technologies to increase industrial water use efficiency.
Install water meters	Measure individual water consumption.
Build additional storage capacity	Build storage capacity, thereby providing a greater ability to manipulate instream flows (e.g., timing, volume, temperature).
Divert water from other locations	Diversions across or within basins can be used to enhance water flows and decrease water temperatures at a recipient location. This action could be associated with decreased water flows and possible increases in temperature at the donor location.
Decrease surface water runoff	Forest harvesting and changes in the amount of impervious surfaces due to urban development increase surface water runoff / water yields, which can adversely affect hydrologic regimes for salmon.
Manage water storage	Manage the timing and volume of water releases to meet salmon habitat requirements (i.e., establish environmental flow regimes).
Release cold water	Use cold water releases from lakes or reservoirs to reduce water temperatures.
Manipulate surface water / groundwater interactions	Use groundwater injection to cool surface waters, thereby moderating temperatures and providing flows in rearing channels.
Transport fish manually	In locations where flows are excessively low, spawners can be captured and trucked to upstream spawning areas.
Improve fish passage	Fish passage devices can improve survival of adults migrating upstream to spawning areas, and juveniles outmigrating to the ocean.
Implement low impact forestry practices	Use forestry practices that minimize impacts on watersheds.
Implement low impact grazing practices	Use cattle grazing practices that minimize impacts on rivers and riparian zones.
Engineer streams	Engineer streams to create artificial habitats that replace lost or degraded rearing habitats.
Enhance instream habitat	Use large woody debris (LWD), boulders, or gravel to improve fish habitat and compensate for the loss of habitat complexity.
Enrich streams / lakes with nutrients	Add nitrogen and phosphorous to freshwater environments using salmon carcasses.

Strategy	Description
Enhance production with hatcheries	Use hatcheries to aid conservation of depressed salmon stocks or enhance catch for fisheries.
Create off-channel habitat	Create side channel spawning and rearing habitats.
Create deep pools	Dig deep pools for adult holding, or juvenile rearing, thereby providing thermal refuges.
Clean gravels	Remove silt and sand from spawning gravels, both of which reduce egg survival.
Restore connectivity	Restore connectivity to high-quality fish habitats by removing perched culverts or other artificial obstructions.
Restore slope stability	Restore slope stability to prevent slides, erosion, and/or sediment deposition in streams.
Restore riparian ecosystems	Restore riparian zones that contribute sources of large woody debris and help maintain cool stream temperatures.
Move dykes back from rivers	Setting dykes back allows rivers to meander naturally, restoring connectivity of the river channel to the flood plain.

5.1.1 FLOW-RELATED ACTIONS

Increasing instream flow is probably one of the most effective actions to help salmon. Increased flow maintains natural alluvial processes, enables upstream migration of adults, increases area of spawning and rearing habitats, reduces vulnerabilities to disease, and aids downstream passage of smolts. So how do we increase river flows while we face changes in patterns of precipitation combined with reduced water storage through changes in snowpacks? Postel (2000) recommends increasing water use efficiency and changing policies to enhance water productivity. Efficiency improvements can occur immediately without government regulations. As well, policy considerations are important to ensure renewable water sources are equitably shared among environmental, agricultural, industrial, and residential needs.

Excluding power generation, agriculture, industry / mining, and residential are the top three water users in British Columbia. In each sector, water use efficiencies can be implemented today to increase productivity of our water supplies. For instance, drip irrigation technology has the potential to double crop yield per unit of water (Postel 2000). A pilot project on the Nicola River at Quilchena uses a number of mini-irrigation monitoring stations that track soil moisture and weather conditions, thus providing an innovative way of conserving water (Angus MacKay, Pacific Salmon Commission, pers. comm.). Water use efficiencies and recycling are also possible in other industries (e.g., pulp and paper, mining, etc. Lens *et al*. 2002).

Building additional storage capacity is another way to ensure sufficient water is available throughout the year for instream needs. Building new dams is a controversial though potentially invaluable solution in the context of climate change. Storage provides water and salmon managers with the ability to store water at times of the year when water resources are abundant and release it when water supplies are limited. Obviously, dams can have significant costs on fish, however; they can pose barrier to fish passage (both adults and out migrating smolts), and impose unnatural hydrographs which change fluvial geomorphology processes.

In places where there is sufficient water storage, it is important to manage the timing and volume of releases so as to match fish needs as much as possible (Martin 2003; Connor *et al*. 2003). BC hydro applies this approach through their Water Use Planning (WUP) process. With varying degrees of success, other rivers in the western U.S. also work to manage water supplies in a similar way (e.g., the Columbia, Snake, Trinity, and Sacramento Rivers).

To ensure that new and existing storage capacity meet salmon needs in the future, operating rules for storage facilities must be governed by recognition of ecosystem rights to water and entrenchment of this principle in water management (see Section 5.2). It is not enough to provide token recognition that water supplies are managed for salmon needs, because too often human needs over-ride ecological needs. There are challenges in developing appropriate operating rules, however, given that it is not always clear what 'environmental flow regime' will optimize flow releases across all necessary fish species and ecological values. Though analytical and participatory methods are available to help resolve such problems (e.g., Richter *et al.* 2003; Pahl-Wostl 2007).

Reducing surface water run-off can also increase natural water storage capacity within a watershed. In urban areas such an approach could include building green roofs, installing porous pavement, and significantly increasing proportion of vegetative cover in a watershed. In wilderness areas this approach could include implementation of low impact forestry practices, such as more selective logging and development that minimizes runoff and soil disturbance on steep slopes (Chamberlain *et al.* 1991).

5.1.2 TEMPERATURE-RELATED ACTIONS

Salmon survival, reproduction, and growth are fundamentally linked to the thermal regime of freshwater habitats. In rivers that are thermally vulnerable, infrastructure could be installed to maintain or reduce water temperatures. However, some scientists believe actions to protect / maintain water temperatures cannot be applied across a large enough geographic scale to mitigate against the effects of climate change. Ranges of salmon distribution have changed over their evolution responding to changes in habitat conditions, such as water temperatures. Shifts in distribution may be unavoidable, resulting in the loss of salmon in some areas where habitat conditions are close to tolerable thresholds (Dave Levy, consultant; Mike Bradford, Fisheries and Oceans Canada; Nina Hemphill, Trinity River Restoration Program, pers. comm.). While such losses may be a concern in some areas, salmon populations in British Columbia inhabit central latitudes in the north Pacific. Distribution of sockeye, chum, and pink salmon extend into Washington and northern Oregon, while chinook, coho, and steelhead survive as far south as California (Behnke 2002). British Columbia may provide an important stronghold for salmon and thermally suitable habitats in the context of climate change.

Water storage facilities can also be used as a source of cold water, particularly in snow dominated watersheds. Cold-water releases are used extensively in California where they are considered a success (Zedonis 2007; Nina Hemphill, Trinity River Restoration Program, pers. comm.); while in British Columbia (e.g., Horsefly) cold water releases have been tried and are viewed as having questionable effectiveness. When managing flow releases, another consideration is that higher flows can reduce travel time of water, leading to less stream heating from atmospheric exchanges (e.g., Skins Lake Spillway on the Nechako River). Groundwater can also be used to moderates water temperatures in rearing channels, maintain cool temperatures in summer and warm temperatures in winter. Groundwater fed side-channels are less prone to winter scouring of eggs / juveniles, and can maintain water supply throughout the summer. Locally, groundwater is being used as inflow to side-channel habitats in the Pundledge, Nicola, Coldwater, Englishman, Clearwater and Cowichan Rivers (Howie Wright, Okanagan Nation Alliance; Angus McKay, Pacific Salmon Commission; Tom Rutherford, Fisheries and Oceans Canada, pers. comm.).

Riparian vegetation provides shade to tributaries and mainstem habitats, which helps maintain cool stream temperatures. Thus, actions to maintain or restore streamside vegetation—maintenance of riparian buffers or exclusion fencing for grazing animals—can also benefit water temperatures and salmon. Riparian re-vegetation is critical in areas that have already been affected by development activities. Restoring riparian shading and function is generally considered an important and effective strategy (Roni *et al.* 2002; USFWS and HVT 1999; Pamela Zevitt, The Como Watershed Group; Dave Patterson, Fisheries and Oceans Canada; Jeff Jung, Fisheries and Oceans

Canada, Howie Wright, Okanagan Nation Alliance; Craig Orr, Watershed Watch Salmon Society; Nina Hemphill, Trinity River Restoration Program, pers. comm.). To maintain cool temperatures, some believe riparian planting should occur in tributaries where riparian shading is a critical driver (i.e., the influence of shading on large rivers is relatively minimal). Riparian restoration should also consider the level of connectivity among the riparian zone, river, and floodplain because meandering channels can inundate and scour recently replanted riparian areas.

Two other relatively unique temperature-related strategies have been applied in California, a region struggling to maintain habitats that are thermally suitable for salmon (Nina Hemphill, Trinity River Restoration Program, pers. comm.). First, the Yurok Tribe is restoring access to high elevation tributaries to help endangered coho in the Trinity River. Higher elevation habitats are being targeted because they provide cool refuges during times of the year when water is warmer at lower elevations in the mainstem. Second, the San Joaquin River Restoration Program has implemented a strategy to dig deep pools, providing cool water holding areas for adults.

5.1.3 FISH-RELATED ACTIONS

In addition to the above categories of actions, managers can directly manipulate salmon distribution, abundance, and diversity. Range expansion has been tried with some success in British Columbia. Reintroduction attempts of sockeye to the upper Adams River have persisted in spite of many failed efforts, while chinook populations into the same area have proven successful (Doug Lofthouse, Fisheries and Oceans Canada, pers. comm.). Re-introductions are also being considered in other areas such as the Coquitlam (Perrin *et al*. 2006) and upper Columbia Rivers (Nelitz *et al*. 2007c). Beyond B.C., Pacific salmon have been successfully introduced—New Zealand, Chile, and the Great Lakes (Behnke 2002). Through hatcheries and harvest management, there may be opportunities to experimentally develop stocks with physiologically preferable traits (Tyedmers and Ward 2001). For instance, stocks selected on the basis of a preferred run-timing or tolerance to temperatures. In the past, fisheries managers in B.C. were able to shift the timing of lower Fraser River chum stocks by 3–4 weeks within several generations (Doug Lofthouse, Fisheries and Oceans Canada, pers. comm.). Use of hatcheries is not without controversy and scientific uncertainties, however. Although there are benefits associated with enhancing fisheries in the short-term, there may be adverse effects on genetic diversity and overall population fitness in the long-term (e.g., ISRP and ISAB 2005).

5.1.4 FISH HABITAT-RELATED ACTIONS

Manipulations of physical habitats have historically received a lot of attention in fisheries management. For instance, in the 1990s the Watershed Restoration Program invested heavily in restoring fish habitats across British Columbia (Slaney and Zaldokas 1997; Slaney and Martin 1997). Such fish habitat manipulations have included: (i) adding large woody debris or boulders to increase the channel complexity and quality of rearing habitat; (ii) restoring connectivity among habitats blocked by past development activities; or (iii) restoring connectivity between the floodplain and river channel by removing channel armouring structures. These options can be effective in the short term if they respond to historic degradation in habitats, but they do not represent appropriate long-term solutions (Roni *et al.* 2002). There has also been some criticism that monitoring and evaluation of restoration actions has not been sufficient to help managers understand what actions are most successful (e.g., Bernhardt *et al.* 2005). Although not directly affecting water temperature or water flows, the intention of using these strategies in the context of climate change would be to improve other habitat conditions so as to offset climate-induced mortality on various salmon life stages.

5.2 SOFT INFRASTRUCTURE STRATEGIES

"The choice between more government and less government is a false choice. What Canada really needs is better governance, which will probably require more government intervention (including, though not necessarily limited to, more regulation) to achieve superior environmental protection." David Boyd, 2003

"Whiskey is for drinking, water is for fighting over." Mark Twain

This section summarizes the legal, regulatory, policy, and/or management-oriented levers (e.g., providing financial incentives / disincentives, using pricing signals and demand-side management, implementing results-based or prescription-based management procedures) that are available to policy makers (Table 9). The intention of applying these levers would be to encourage positive human behaviour, innovation, and technological change to help mitigate the effect of human and climate-induced disturbances on freshwater habitats. These categories of approaches represent a broad range of resource management options being implemented in different jurisdictions around the world. These categories have been developed, in part, on the basis of an evaluation of the strengths / opportunities and weaknesses of federal-provincial legislation in Canada (see Appendix E), which focused on the federal *Fisheries Act* and provincial *Water Act*.

It is also important to recognize that strategies in Table 9 are not independent. Multiple strategies could be used in combination to design effective water / fish habitat legislation, regulation, policy, or management approaches. For instance, the Australian state of Victoria's $300 million Victorian Water Trust[11] uses multiple strategies for restoring ecological capacity of streams: water licence transfers, reallocation of water rights, more conditional licences, water metering, and allocating water based on highest value uses (Jon O'Riordan, Pacific Salmon Forum, pers. comm.). The State is buying back water licences at market value, and is taking aggressive action to put water back into streams. Rivers have been given a legal share of water for the first time under a new Environmental Water Reserve. Water that is set aside is legally protected through legislation. Moreover, the State is applying a holistic approach to watershed management through Catchment Management Authorities and the development of Catchment Management Plans and Stream Flow Management Plans.

[11] State of Victoria. Department of Sustainability and Environment. Victorian Water Trust. See: www.dse.vic.gov.au/DSE/wcmn202.nsf/LinkView/F2FC43C535683C3FCA256FFE00091C20F8BDECC858787AFCCA257003001BFFE1

TABLE 9. Description of soft infrastructure strategies (i.e., legal, regulatory, policy, or management oriented approaches) to help salmon in the context of climate change.

Strategy	Description
Compensate for unavoidable / non-mitigated impacts	Implement policies to ensure protection, restoration, or compensation for losses to habitats due to development activities, or other climate-induced changes in habitats. Examples include: (i) Habitat compensation as specified by No Net Loss requirement under DFO Policy for the Management of Fish Habitat; (ii) No Net Loss of Wetlands as applied to US Army Corps of Engineer projects; (iii) Mitigation / compensation banking.
Require effective operating licenses	Require operating licenses that specify best management practices, rates of resource use, or desired environmental outcomes associated with resource use activities. Examples include: (i) Water licenses that specify practices / outcomes for surface water users; (ii) Stream flow protection licenses for community-based organizations; (iii) Habitat-related license surcharges; (iv) Water licenses regulating groundwater extraction, research, and monitoring as applied in Ontario.
Use demand-side management tools and pricing signals	Ensure resource consumption better reflects true costs by accounting for environmental externalities. Examples include: (i) Water use fees (e.g., water metering and pricing); (ii) removal of water subsidies, (iii) Water cap and trade system (e.g., groundwater pumping credits for trading such as the system for the Edwards Aquifer in Texas) ; (iv) Remove energy subsidies.
Provide financial incentives	Encourage good behaviour by providing financial incentives supporting actions that benefit salmon habitats. Examples include: (i) Conservation bonuses (e.g., covenants / easements) for protection of land and salmon habitats; (ii) Differential tax rates; (iii) Recognizing good public behaviour dependent on level of protection of ecosystem values.
Provide financial disincentives	Discourage actions having impacts on salmon habitats by imposing financial penalties to individuals pursuing destructive behaviour. Examples include: (i) Fines associated with unauthorized Harmful Alteration, Disruption, or Destruction of fish habitats as specified in the Fisheries Act, (ii) Fines associated with impacts on species or critical habitats under the Species at Risk Act, (iii) Collection of municipal taxes for water management initiatives (e.g., Okanagan Basin Water Board is legally constituted to tax for water management initiatives agreed upon by the 3 Regional Districts), (iv) Fines for damage to fish and fish habitat under the Private Managed Forest Land Act, (v) Tax penalties for ecologically-destructive forms of land use.
Implement results-based management	Specify desirable management targets or environmental standards which must be met when undertaking development having impacts on salmon and their habitats. Examples include: (i) Water quality guidelines for temperature (e.g., British Columbia or Canadian Council of Ministers of the Environment standards);(ii) Hard caps on the number of water licenses or rate of water extraction; (iii) Requirement for Forest Stewardship Plans under the Forest and Range Practices Act; (iv) Description of indicators and benchmarks for habitats and conservation units under the Wild Salmon Policy; (v) Loads based water quality standards as applied by the US Environmental Protection Agency.
Implement prescription-based management	Establish Best Management Practices or Codes of Practice associated with development having impacts on salmon and their habitats. Examples include: (i) Operational Statements for regulatory review of low-risk activities as part of DFO's habitat modernization process and development of a risk management framework, (ii) Instream flow guidelines (e.g., assessment methods; instream flow thresholds) for Independent Power Producer projects as required by the Fisheries Act / Water Act; (iii) Standards and Best Practices for Instream Works; (iv) Guidance on preparing agricultural drainage management plans through the Agricultural and Rural Development Subsidiary Agreement; (v) Municipal by-laws regarding riparian set-backs as provided under the Fish Protection Act and associated Riparian Areas Regulation.

Strategy	Description
Designate environmental aspects for special management considerations	Designate environmental aspects (e.g., species / habitats) requiring special management considerations. Special management considerations could then include application of prescription or results based management procedures discussed above. Examples include: (i) Species / habitat listings as specified by Committee on the Status of Endangered Wildlife in Canada and enforced by the Species at Risk Act; (ii) Designation of Fisheries Sensitive Watersheds or Temperature Sensitive Streams in B.C. (iii) Local bylaws protecting riparian areas under the Riparian Area Regulations of the provincial Fish Protection Act.
Coordinate / implement planning frameworks	Salmon and habitat management are increasingly multi-disciplinary in nature. Thus, coordination among stakeholders, communities, government agencies, and non-governmental organizations is essential to effectively managing limited resources. Examples include: (i) Water Management Plans as specified under Part 4 of the BC Water Act; (ii) BC Water Stewardship Policy/ Action Plan; (iii) Integrated Watershed Management Plans developed by regional planning authorities (e.g., Capital Regional District); (iii) Forest Stewardship Plans as required under the Forest and Range Practices Act; (iv) Water allocation plans.
Ensure protection of critical habitats	Protect instream flows from excessive water withdrawals and physical habitats from development pressures. Examples include: (i) orders by DFO to maintain instream flows for fish (e.g., Bridge and Nechako Rivers), (iii) Oregon's Instream Water Rights Act to protect flows for fish.
Encourage partnerships for water / habitat stewardship	Similar to above, salmon and habitat management are increasingly multi-disciplinary in nature. Thus, there is a need to strengthen the feeling of stewardship or sense of responsibility in those individuals impacting salmon and their habitats. Examples include: (i) BCWWA's Water Bucket Program and other Water Sustainability Committee initiatives as described under the Water Sustainability Action Plan for British Columbia; (ii) Living Rivers Trust Fund, a multi-stakeholder trust fund initiative funded by the provincial & federal governments; (iii) Levies on hunting/fishing/trapping licences as applied through the Habitat Conservation Trust Fund in B.C.; (iv) Framework for cooperation with provinces/territories regarding conservation, development and use of water; (v) Oregon's Put a Salmon on Your Plate fees are used to fund habitat enhancement initiatives.
Develop a water budget	Water is a finite resource with a limited amount of year-to-year and long-term renewal. Water use needs to fit within constraints of annual and long-term yields within a watershed. If water managers make decisions with a sense of certainty about the abundance of water resources, they need to be informed by quantitative water budgeting exercises. Examples include: (i) Accounting for surface water—groundwater interactions to identify availability of water supplies for groundwater withdrawal.
Entrench ecosystem rights to water	A clear recognition of ecosystem rights to water in government policies is fundamental to ensuring healthy communities and freshwater ecosystems (salmon and other freshwater reliant species) into the future. Examples include: (i) South Africa's national Water Act guaranteeing basic human and ecosystem needs for water.
Recognize Aboriginal rights to water and salmon	Court actions by First Nations in Canada and Tribes in the U.S. have lead to the recognition of Aboriginal rights to water and salmon. In some cases these actions have helped address some historic impacts on salmon and their habitats. Examples include: (i) Restoration of instream flows for salmon and other fish species (e.g., Trinity River, California).
Adjust fisheries management practices	Adjust management procedures / harvest rates which have direct effects on salmon mortality. Examples include: (i) River specific exclusive ownership rights, with cooperative ownership on the Fraser; (ii) Individual Transferable Quotas with harvesters allocated a fixed share of allowable catch.

5.2.1 COMPENSATE FOR UNAVOIDABLE / NON-MITIGATED IMPACTS

Given the potential for increases in salmon mortality imposed by climate change impacts on freshwater habitats, it will be important to ensure that human development activities contribute as little additional mortality as possible. Thus, to ensure no net loss of fish habitat in the face of development activities, one strategy is to create new habitats to offset expected losses. Across Canada, habitat compensation initiatives are designed to offset habitat losses authorized by DFO (i.e., under a HADD authorization). Compensation is guided by DFO's habitat policy and the goal of ensuring "No Net Loss" (NLL) of productive capacity. This approach, however, has been insufficient and ineffective, largely because of inadequate enforcement and monitoring (Auditor General's assessment, as cited in Young and Werring 2006). A weakness is the difficulty in determining how to measure productive capacity and determine whether replacement habitats have sufficiently compensated for what was lost. In many cases footprint area of losses is the only measure used to evaluate whether new areas are sufficient replacements for lost productive capacity. Such a measure is limited because it does not describe biological effectiveness or how well the habitat functions at supporting salmon productivity. As well, evaluating success of compensation habitats should be considered over a longer time frame than is currently the case. Beyond a compliance period as set forth in the HADD authorization, proponents are not responsible for successful maintenance of habitat structures.

Ideally replacement habitats should demonstrate proper ecological function before affected habitats are lost. To achieve this outcome, in some cases, proponents can purchase "credits" from other developers of privately or publicly owned land who have restored or created habitats for compensation purposes (Environmental Law Institute 1993). Mitigation / compensation banks have seen fairly limited use in B.C. and Canada, yet are recognized as being effective in ensuring no net loss of functional ecosystem values at regional scales. The North Fraser Port Authority, in collaboration with the Fraser River Environmental Management Program (FREMP), has been a leader in applying this strategy in B.C. (Dale Desrochers, Fisheries and Oceans Canada, pers. comm.). In the U.S., a mitigation banking program within Section 404 of the *Clean Water Act* has the intention of promoting wetland restoration, enhancement, creation and preservation. In 2005, 450 approved mitigation banks were open in the U.S. including ones in California, Washington and Oregon. Another 198 banks were in the proposal stage (US Environmental Protection Agency 2006). In Bend, Oregon, the Deschutes Resources Conservancy operates the innovative Deschutes Water Exchange Groundwater Mitigation Bank (IUCN 2004).

A comprehensive policy for wetlands with a goal of "no loss of wetlands" and a "net gain in the productive capacity of wetlands" is required in B.C. (Nowlan and Jeffries 1996). Such a policy could reduce vulnerability of salmon habitats to climate change by maintaining natural storage capacity in watersheds, thereby moderating the effects of flooding events that could become more prevalent. These twin goals could help to address the cumulative effect of many losses of small wetlands. A cumulative erosion of wetland habitats has been observed in the U.S. and Washington State in spite of a "no net loss" of wetlands policy for some activities. Thus, a formal wetland policy for B.C. must be accompanied by appropriate legal reforms. For example, ensuring the *Fish Protection Act* provides a statutory basis supporting a goal of "no loss of wetlands", and requiring that this goal be given priority in decisions made under the *Land Act, Local Government Act*, *Environmental Assessment Act* and the *Water Act*.

5.2.2 REQUIRE EFFECTIVE OPERATING LICENSES

Operating licences can be effective at ensuring resource users adhere to sustainable use of natural resources, such as water. In B.C., however, there are several weaknesses in the way water use rights are apportioned through water licenses under the *Water Act*. Although section 62 (2) of the provincial *Water Act* explicitly recognizes that "*the minister may consider concerns related to fish, fish habitat, and other environmental matters*", fish are not formally recognized as rights holders and do not have their beneficial uses legally entrenched. Orders can be issued under a water license requiring development of Water Management Plans, but there is neither a formal recognition of instream flow values nor consideration of the amount of water needed to maintain ecological health prior to applications being received and licenses granted (Dean Watts, Fisheries and Oceans, pers. comm.; Cohen and Neale 2003; Nowlan and Jeffries 1996; Christensen 2007). Under the B.C. *Water Act*, licenses for conservation of water for fish and wildlife have lower precedence than licenses for other purposes—e.g., domestic, waterworks, mineral trading, irrigation, mining, industrial, power, hydraulicking, and storage uses. When reviewing new water licence applications, and when existing permits are up for renewal, water managers should give greater attention to protecting instream flow requirements and defining the minimum amount of water needed to maintain ecological health. These considerations will be increasingly important in the context of climate change and anticipated changes to hydrologic regimes (Tydemers and Ward 2001).

Another major weakness with B.C.'s *Water Act* and its use of water licenses is that there are no regulations controlling siting and quantities of groundwater extraction within ecologically sustainable limits. Groundwater is inextricably linked to the hydrological cycle and salmon (e.g., Douglas 2006). Reductions in groundwater supplies resulting from human pressures, climate change, and natural variation in the frequency and magnitude of floods and droughts can have a direct influence on surface water flows. In particular, groundwater extraction can exacerbate low base flows. In spite of its ecological importance, groundwater takings are almost entirely unassessed and unregulated in BC (Christensen 2007), and groundwater management rarely considers effects on Pacific salmon (Douglas 2006). British Columbia is the only jurisdiction in the Canada that does not have licensing requirements for use of groundwater above defined thresholds (Nowlan 2005).

In the context of the *BC Environmental Assessment Act*, the Ministry of Environment has identified that groundwater extraction can have the following impacts on fish and fish habitats (as cited in Christensen 2007):

- reductions in streamflow and surface water availability, including adverse effects on low flows, lakes, springs, and streams especially spawning habitats;
- interception of groundwater flow is critical for forest and grasslands habitats, wetlands, and fish habitats, specifically spawning areas;
- sea water intrusion in coastal areas can result in water quality degradation and impacts on fish habitat; and
- non-sustainable extraction or aquifer mining where rates of extraction exceed rates of replenishment, thereby reducing water availability for other users of groundwater supplies (e.g., fish).

Such impacts are only considered for the few relevant projects that trigger reviews by the Environmental Assessment Office. While the necessary regulations do not currently exist, B.C.'s *Water Act* could be expanded to include licensing for groundwater[12]:

"BC remains the sole jurisdiction in Canada that has no general licensing requirement for groundwater extraction above a defined threshold level. The BC Water Act contains licensing provisions which could apply to all or designated areas of BC, but they will apply only if and when cabinet makes such a designation. In 2004, a Groundwater Protection Regulation was introduced, but it does not mandate licensing, instead focusing on standards for well construction and groundwater quality protection." (Nowlan 2005)

Without modifications, extension of the current water licensing system to groundwater is not advisable given that existing legislation does not sufficiently protect environment users of water and does not encourage sustainable / efficient use of water (Christensen 2007). New groundwater regulations and licensing requirements must ensure

[12] B.C.'s 2004 *Groundwater Protection Regulation,* promulgated under the *Water Act,* focuses on well construction standards and groundwater quality protection only. A proposed 3rd phase will focus on implementing water management plans in designated areas and other protection for aquifers (Christensen 2007).

that sustainable use of groundwater supplies protect instream flows requirements (Young and Werring 2006). A groundwater regulatory framework should provide mechanisms for addressing habitat-related concerns, such as:

- potential effect of groundwater usage on aquatic ecosystems, the environment, and the long-term use of the aquifer;
- hydrologic relationship between groundwater sources and aquatic systems;
- salt water intrusion in coastal areas; and
- changes to groundwater quality and quantity due to siting. (Christensen 2007).

At a municipal level, regulation of groundwater can be strengthened using by-laws that restrict development activities affecting groundwater water quantity (e.g., size and location of subdivisions, restrictions on amounts of impervious surfaces, designation of groundwater recharge areas as environmentally sensitive) (Nowlan 2005).

To be effective water licenses and water allocations should be based on a formal assessment of the water supplies available to support water demands within a watershed. Such an assessment would help reduce the potential for oversubscription of water licenses. Following completion of a Water Management Plan, Alberta has decided to no longer accept water license applications for the Bow, Oldman and South Saskatchewan Rivers (Fekete 2006). The province, however, retains the right to allocate water, through Crown reserves, for specific purposes such as storage of peak flows and water conservation objectives. Alberta Environment is suggesting that companies purchase water license rights from industrial or municipal users. The community based watershed management process in the Nicola has proposed a cap and trade mechanism as a way of managing water supplies (Dean Watts, Fisheries and Oceans Canada, pers. comm.). Such an approach would recognize a total cap on the amount of water available for human demands. While water licence buy-backs are common in such places as Australia, South Africa, Nevada and California, their effectiveness may be limited because many streams are already overallocated, and rates of water extraction are not monitored closely enough.

5.2.3 USE DEMAND-SIDE MANAGEMENT TOOLS AND PRICING SIGNALS

A strong and effective strategy for changing water consumption patterns is to ensure that the markets better reflect the value of water and value of the ecological services this resource provides. In British Columbia, water rental fees vary according to the purpose of the water use, and are charged for water licenses under the *Water Act* (Christensen 2007). However, water license consumption is generally not metered meaning that fees are based on user estimates not licensed quantities. For example, small run-of-river generating facilities (<20 MW) pay a minimal $5,000 while larger facilities are capped at $10,000. Water rental fees for generating electricity do not reflect anywhere near the value of the energy generated from that resource (Dobbin 2006).

Implementation of universal water metering and charges for water use (i.e., consumption based pricing) can lead to significant reductions in water consumption when compared to flat rate pricing (Environment Canada 2007a). Experience from larger communities, like Kelowna, suggest that a reduction of 20 to 30% in domestic water use is reasonable when water meters and a usage based price are implemented. In 1999, Kelowna's residential customers began paying for water using volume-based rates. Since that time average per capita July water consumption has decreased by 23% (Neal Klassen, pers. comm. as cited in Cohen and Neale 2003). In British Columbia, water rental fees for surface water use help offset costs borne by provincial water agencies (Christensen and Magwood 2005). In Seattle, Washington seasonal pricing has been implemented where water is priced higher during peak periods from mid-May to mid-September[13]. Water pricing is also widely applied in California, South Africa, Israel and Australia. Water pricing has an additional benefit of encouraging water conservation and use

[13] Seattle Public Utilities. Commercial Water Rates. See www.seattle.gov/util/Services/Water/Rates/COMMERCIAL_200312020910213.asp

efficiency. Revenues can then be used to fund water and/or habitat conservation initiatives (Wilkie 2005). In spite of the clear benefits there are concerns around using water-pricing strategies. Some argue they may constrain economic growth, be difficult to implement (e.g., How to decide upon appropriate rates for different water users?), or open the door to water being traded as a resource under NAFTA by assigning a monetary value.

In arid areas it is common practice to sell / transfer portions of annual water allocations to other users (i.e., trade water rights, Nowlan 2005). British Columbia currently allows water licences to be transferred from one party to another (e.g., South East Kelowna Irrigation District). In Alberta, the only province that allows for the sale of water licences through a transfer scheme, has introduced this strategy in only one area—the South Saskatchewan Basin—and the Basin Management Plan does not apply to groundwater (Nowlan 2005). Water trading is also practiced in Australia (e.g., Murray-Darling Basin), California (Water to Water program), and South Africa (Wilkie 2005). While water trading may provide an incentive to encourage conservation and water use efficiency, total water use can still increase. Moreover, there is currently no marketplace supporting the sale and trade of water allocations (Wilkie 2005).

5.2.4 PROVIDE FINANCIAL INCENTIVES

Positive measures, such as tax breaks, credits, grants, low-interest loans, and conservation-based pricing, are designed to encourage good behaviour and protection of the environment. Such tools are increasingly recognized as being effective mechanisms to protect fish habitats. Typically, such measures are easier to implement than pricing instruments (both practically and politically), and they are often perceived more positively than pricing (Wilkie 2005). Funding financial incentive programs with public funds, however, may be problematic.

In Oregon, the Conserved Water Program[14] provides incentives to water rights holders to conserve and use water more efficiently. The Program allows water users who voluntarily conserve water to retain control over a portion of the saved water. Water users have several options for reallocating 75% of conserved water supplies, including irrigation of additional lands, lease or sale of the water, or allocation to instream uses. In exchange for granting water users the right to reallocate a portion of conserved water supplies, 25% is allocated by law as an instream water right. As another example, the "*Cash for Grass*" programs in many US states where water supplies are limited (e.g., California, New Mexico) encourage xeriscapic landscaping.

5.2.5 PROVIDE FINANCIAL DISINCENTIVES

Section 35(1) of the *Fisheries Act* provides a good example of how this strategy has been applied in Canada. This section has a requirement that "*no person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction (HADD) of fish habitat*". Violations can result in fines to responsible individual(s). HADD's under Section 35 of the *Fisheries Act* are often difficult to prove, however, and even harder to enforce. For instance, Fisheries Officers often use Section 32 (fish kills) instead of Section 35(1) HADDs because fish mortality is easier to link to an offender (Dean Watts, Fisheries and Oceans Canada, pers. comm.). A concern with this strategy, as demonstrated by the *Fisheries Act*, is that enforcement can become increasingly difficult with reductions in enforcement personnel.

5.2.6 IMPLEMENT RESULTS-BASED MANAGEMENT

Implementation of results-based management requires setting clear targets / thresholds for resource users without specifying the methods needed to achieve the target / remain below a threshold. The *Forest and Range Practices Act* is an example of how the Government of British Columbia is using a results-based approach to environmental management. Another example is the use of loads-based water quality standards in the U.S., Under

[14] Oregon Water Trust. Improving Streamflow - The Tools We Use. See: www.owt.org/solutions.html

the U.S. *Clean Water Act* (sections 303 and 404) provides for development a Total Maximum Daily Loads (TMDL) program and association regulations. Designed to protect water quality, the TMDL program can be applied to stream temperatures (as it is, for example, on the Columbia and Snake Rivers). In Washington State, lands subject to the *Forest Practices Act* require TMDL strategies implemented through the Forest Practices Program.

In considering implementation of TMDLs in B.C., a constraining factor may be the need for monitoring, given current trends towards reduced monitoring capacity by government agencies. Another consideration is whether TMDLs are appropriate given interest in moving towards ecosystem-based management approaches. For example, it may be preferable to consider nutrients, water temperature, and flow conditions, because lower flows and higher temperatures can lead to a greater risk of eutrophication. Given these kinds of interactions and linkages among water quality parameters, it may be worthwhile to review water quality objectives in B.C. if results-based strategies are considered appropriate strategies to help salmon in the context of climate change.

One difficulty associated with results-based management is that it is not always possible to determine when / if desired results are achieved. A results-based framework must be accompanied by a monitoring program that is capable of detecting biologically meaningful changes in the environment with a sufficient level of statistical power (e.g., Sit and Taylor 1998). Some regulatory initiatives (e.g., the *Private Managed Forest Land Act*) include both results-based initiatives and provide for mitigation requirements and/or fines if damage to fish and/or fish habitat occurs.

5.2.7 IMPLEMENT PRESCRIPTION-BASED MANAGEMENT

Prescription-based approaches to management would describe the best management practices or guidelines for operating in a particular environment. A weakness with many of these strategies is that they are unenforceable (i.e., voluntary) and will only be effective if truly implemented. Therefore, a solution may be to marry requirements for best management practices with enforceable legislation. As well, financial incentives can often encourage adoption of best management practices (e.g., irrigation practices). These mechanisms are often difficult to sustain, however, even when there are long-term economic benefits of doing so.

5.2.8 DESIGNATE ENVIRONMENTAL ASPECTS FOR SPECIAL MANAGEMENT CONSIDERATION

A number of federal and provincial instruments already allow for designation of environmental aspects for special management considerations (e.g., species or critical habitat designations under the federal *Species at Risk Act*, designation of Fisheries Sensitive Watersheds / Temperature Sensitive Streams by provincial Government Actions Regulation). Such tools can be effective if accompanied by a scientifically defensible basis for designation, strong political will, and strong measures to protect environmental aspects. For instance, the U.S. Endangered Species Act is widely acknowledged as one of the strongest environmental laws in the world, while failure of the Canadian *Species at Risk Act* to list Sakinaw and Cultus Lake sockeye salmon populations has been cited as a lost opportunity for protection (Temple 2005; Ashley 2006; Dean Watts, Fisheries and Oceans Canada, pers. comm.).

5.2.9 COORDINATE / IMPLEMENT PLANNING FRAMEWORKS

The B.C. *Water Act* and water licenses allow for development of Water Management Plans to better manage water resources. Consequently, numerous multi-stakeholder water management planning frameworks have been implemented in the province. BC Hydro's Water Use Planning process has been the most comprehensive, consistent, and broadly applied example to-date[15]. A non-trivial challenge in coordinating such planning frameworks is (i) acquiring funding to complete and implement the planning framework, and (ii) developing

[15] BC Hydro. Water Use Planning. See: http://www.bchydro.com/environment/wateruse/wateruse1775.html

management outcomes that satisfy many potentially competing objectives among resource users (e.g., Samp-Somass water use planning process[16]).

5.2.10 ENSURE PROTECTION OF CRITICAL HABITATS

Existing legislation can be used to protect salmon habitats. In the context of water management, protection of critical habitats implies protections of instream flows. Under Section 22(3), the *Fisheries Act* has been used as the basis to issue flow orders to water users on the Nechako, Bridge, and Columbia River below Keenleyside Dam. In Oregon, instream flows were legally recognized in 1987 as being a beneficial use of water, with passage of the *Instream Water Rights Act*. The Act provides two ways to ensuring instream rights are recognized. First, instream water rights with junior priority dates (relative to other users) can be created by (i) converting minimum perennial streamflows adopted under the 1955 Act, or (ii) allowing select state agencies apply for new instream water rights. Second, the Oregon Water Trust (see Section 5.2.11), allows private parties to purchase, lease, or accept donations of existing water rights for conversion to instream rights with the same priority date as the original right holder. Of these options, acquiring instream rights with older priority dates is the only way to effectively restore instream flows. The Trust uses a process of *Converting Existing Out-of-Stream Water Rights to Instream Flows* under the *Instream Water Rights Act*, which involves negotiating a private agreement with a water right holder and then applying to Oregon Water Resources Department for approval of water right transfer.

Another consideration here is that physical habitats can be protected by creating network of salmon sanctuaries that protect habitats from spawning grounds to the ocean. For selected stocks and populations, land and water license ownership could be transferred to non-profit publicly accountable salmon societies (Rahr and Augerot 2006).

5.2.11 ENCOURAGE PARTNERSHIPS FOR WATER / HABITAT STEWARDSHIP

The Living Rivers Trust Fund, established by the Province of British Columbia in 2002, represents a governmental and non-governmental initiative that seeks to improve quality of water and life in B.C. by supporting river and watershed research, encouraging sustainable use of water supplies, and helping undo past damage. The Trust Fund builds on existing partnerships across the province that fund projects related to watershed protection and restoration, increased public awareness of the conservation and sustainable use of water, management and restoration of river flows in systems susceptible to periodic droughts, and implementation of recovery plans to restore priority fish populations (e.g., steelhead in the Georgia Basin). With a current endowment of $21 million, the Trust is administered by the Vancouver Foundation, a philanthropic, non-government community foundation. The Fraser Basin Initiative (one of the main Living Rivers projects) involves a $20 million partnership between the Government of B.C. and Government of Canada (split evenly between cash and in-kind contributions) to support four key areas of work: (i) improved science for decision making; (ii) stewardship and habitat; (iii) fisheries management; and (iv) collaboration and relationship building.

B.C.'s Habitat Conservation Trust Fund[17] was created in 1996 through an amendment to the *Wildlife Act* and is funded through hunting, angling, trapping and guiding license surcharges. Among many activities, collected monies are used, in part, to acquire ranches with significant water licenses, and support fish habitat enhancement projects.

Oregon has also developed a "Put a Salmon on Your Plate" program, whereby vehicle owners can pay a small surcharge when obtaining/registering vehicle license plates. Since its creation, the Oregon Parks and Recreation

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[16] Times Colonist. Saving Salmon from the Weather. See: http://www.canada.com/victoriatimescolonist/news/sports/story.html?id=316c2c5d-9830-4b39-b527-0216a9ad18d1

[17] Habitat Conservation Trust Fund. See www.hctf.ca

Department (OPRD) has received more than $2.5 million in revenue from plate sales (about $650,000 in the last fiscal year). OPRD has invested tens of thousands of dollars each year in park projects in each management area to improve salmon habitat, even though the guiding legislation does not require the department to earmark these funds for salmon restoration. Supported projects include efforts to restore salmon-friendly stream flows and increase public awareness about what is being done and what needs to be done to improve salmon runs. The salmon plate purchases also provide funds to the Oregon Watershed Enhancement Board grant program which supports projects that remedy road-related impacts on fish and wildlife, including salmon. Past projects have included road improvements to reduce sediment delivery to nearby waterways, replacement of culverts blocking upstream migration, and bridge construction to improve fish passage[18].

The Oregon Water Trust's[19] mission is to restore surface water flows for healthier streams in Oregon by using cooperative, free-market solutions (e.g., income from marginally productive areas, replacement feed for lost production, funding for irrigation efficiency projects, tax breaks for permanent donations of water rights, and flexibility in managing water rights). Founded in 1993 by a group with diverse water interests, it was the first water trust in the US. With its transactional approach, it focuses on streams where small amounts of water provide significant ecological benefits. The Trust restores streamflow by compensating willing landowners to leave all or a portion of their water right instream in lieu of using it for out-of-stream purposes. The Trust can also receive donations of water rights. These measures can range from short-term to permanent transactions. It focuses on water rights with early priority dates and uses existing laws to put water back into Oregon's rivers and streams.

5.2.12 DEVELOP A WATER BUDGET

Given that water resources are finite and its abundance in the context of climate change is uncertain, a water budget can help ensure that water demands are set within natural limits of supply. Water budgeting estimates all water inputs (e.g., precipitation, subsurface contributions, storage) and outputs (e.g., irrigation, diversions, discharge, evapotranspiration, evaporation, run-off, groundwater recharge). This information can then be used to guide decision making around human water withdrawals (e.g., magnitude and timing of availability) and how human uses can best fit within ecological constraints of the system.

5.2.13 ENTRENCH ECOSYSTEM RIGHTS TO WATER

To be effective, many of the soft infrastructure strategies discussed here require that ecosystem rights to water be entrenched in legislation. Freshwater and riparian ecosystems are entitled to water as are humans, suggesting that a portion of the mean annual water yield should be apportioned to freshwater ecosystems. Entrenchment of these rights can then allow for more effective implementation of a number of adaptation strategies—e.g., water rights could be purchased from existing owners to help ensure water availability for salmon[20]. In the U.S. the Nature Conservancy has purchased water rights to protect environmental flows (Christensen and Lintner 2007). Taking a more extreme view, water rights could even be expropriated, though this option is generally viewed as unlikely (Christensen and Lintner 2007). Entrenchment of these rights can also help ensure that water gains resulting from water conservation and use efficiency are allocated to instream needs instead of accommodating for increases in human demands on water. Currently, federal and provincial water policies don't explicitly acknowledge these rights or allow for assurances in protection. South Africa's national *Water Act* guarantees water for basic needs—drinking, cooking and sanitation—as well as for the ecosystem.

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[18] Oregon Plan for Salmon and Watersheds. See www.oregon-plan.org/OPSW/

[19] Oregon Water Trust. Cooperative Solutions, Healthy Streams. See: www.owt.org

[20] To a certain extent, purchasing water rights also implies there is some way of controlling water storage / use so as to allow releases for use by fish at critical times of year (i.e., regulated through operations of dams / reservoirs).

5.2.14 RECOGNIZE ABORIGINAL RIGHTS TO WATER AND SALMON

The Canadian constitution and court actions have recognized Aboriginal rights to natural resources. For instance, *"In 1990, the Supreme Court of Canada released its landmark decision in R. v. Sparrow which held that, after conservation and other 'valid legislative objectives', Aboriginal rights to fish for food, social and ceremonial purposes have priority over all other uses of the fishery. The Court also held that infringements of Aboriginal rights must be justified and that part of the justification analysis involves an assessment of whether adequate consultation has occurred."*[21] Similarly, U.S. courts have implied tribal access to water in association with reserve lands (WSTB & BEST 2004). Trust responsibilities of the U.S. government obligate them to provide services that protect and enhance Indian lands and resources, which includes the need to maintain harvestable stocks of anadromous fish and claims to water. Given this legal context, recognition of Aboriginal rights can benefit First Nations, water resources, and Pacific salmon.

5.2.15 ADJUST FISHERIES MANAGEMENT PRACTICES

A fundamental way of enabling salmon to better cope with changing freshwater and ocean environments is to protect their natural genetic diversity (Mantua and Francis 2004). Inherent in maintaining stock diversity is a need to allow sufficient escapement across strong and weak stocks. In a world of variable marine and freshwater conditions, however, the ability to set and achieve adequate escapement targets across individual stocks is difficult given that contributions of enroute and pre-spawning mortality cannot be measured until after most harvesting occurs. Current trends suggest that environmental conditions, including increased water temperatures, extreme flows, and increased rates of disease, are becoming more unfavourable for salmon survival, particularly in the southern end of their range (Rand *et al.* 2006; Tops *et al.* 2006). Harvesting or climate-induced variation in salmon returns can also affect productivity of nursery lakes, further complicating our understanding of juvenile production (Finney *et al*. 2000). Therefore, sustaining viable salmon populations in the future may require decreases in harvest (e.g., subsistence, recreational, and commercial fisheries) because adjusting harvest management practices is one of the most effective strategies for protecting individual stocks diversity in freshwater habitats. Below we consider the pros and cons of three harvesting alternatives and their ability to maintain stock diversity (Table 10).

The degree of success in how these approaches protect diversity and abundance across stocks ultimately depends on how well each sets and meets in-season escapement goals. To meet these goals, active adaptive management needs to be integrated into harvest management so managers can sensibly respond to changing environmental conditions (Levy 1992; Healey 1990; Mantua and Francis 2004). Management decisions need to consider implementation uncertainty (i.e., the difference between realized escapement and target escapement goals resulting from imperfect control of harvesting outcomes, Holt and Peterman 2006) and changes in freshwater conditions / marine productivity. Management adjustment models are being developed for Fraser River sockeye which consider changes in environmental uncertainty (e.g., in-river temperatures). Currently adjustments to escapement targets focus on abundance of dominant stocks, thereby increasing vulnerability of weaker stocks to overharvesting pressures; though adjustments to harvest levels of dominant stocks can be used to better protect weak stocks (e.g., harvest of sockeye salmon in the Skeena River). Moving towards smaller management units, as done with delineation of Conservation Units, under the Wild Salmon Policy may also help in maintaining diversity and abundance in the context of climate change and future salmon fisheries in the Pacific region.

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[21] Fisheries and Oceans Canada. Food, Social and Ceremonial (FSC). See: www.pac.dfo-mpo.gc.ca/tapd/fsc_e.htm

TABLE 10. An evaluation of three alternative harvesting regimes and their ability to maintain genetic diversity.

Approach	Status Quo	River specific exclusive ownership rights (RSER)	Individual Transferable Quota Scheme (ITQ)
Description	Under this framework salmon harvest is dominated by the commercial sector (with Aboriginal and recreational fishing opportunities) in which vessel licenses are assigned to a management area with separate licenses required for each area coupled with restrictions on gear type per license. Each geographic area is allocated a total allowable catch (TAC) and harvesters try to maximise their catch within their respective areas.	Under this system the right to catch all salmon entering a river would be allocated / leased for a period of 'x' years to a single owner. The use of a 'single owner' does not preclude corporate ownership with multiple stakeholders.	Under this system harvest quotas could be allocated to Aboriginal, recreational, or commercial fisheries in the ocean or in-river. Harvesters within a designated area would be allocated a share of the allowable catch that is proportional to their quota holdings prior to the start of the fishing season.
Pros	Reduction in aboriginal, recreational, and commercial catch can minimize impacts on vulnerable stocks. Limited entry access allows managers a greater control over the fleet based on in-season updates on run-timing and abundance	Rights holders have a vested interest in seeing high returns in subsequent years, thus helping ensure adequate escapement reach the spawning grounds. Fishing within individual rivers allows runs to be managed for abundance and diversity at the local population level removing the pressure on weaker and less productive small stocks exerted by the mixed stock fisheries. Will benefit weaker stocks and facilitate closures for severely depressed systems.	More selective fishery providing the ability to catch fish at the time that best suits harvester, rather than a limited entry to acquire share of TAC (i.e., reduced vulnerability on weaker stocks). No incentive to overinvest in vessels and gear to increase share of total harvest. Can allow for transfer of licenses from high to low cost harvesters, thus reducing excess capacity and increasing net returns from the fishery. Can be used to shift harvest to different sectors (e.g., commercial, recreational, Aboriginal fisheries).
Cons	Maintaining stock diversity made more difficult because it is a multi-stock fishery that includes smaller, more vulnerable stocks as well as dominant stocks. Smaller stocks co-migrate with large healthy stocks potentially leading to overexploitation and possibility of being driven to extinction at harvest rates that larger stock can sustain. Reductions in catch impact the fishery economically. Conflict under the current management regimes between maintaining biodiversity and the economic pressures to maximize profits.	Degree to which RSER will be effective dependent on individual rights holders allowing for sufficient escapement as well as ensuring the scale at which rivers are leased and managed is compatible with the stock level. Quality considerations would invariably lead to some offshore harvesting defeating the point of terminal fishing (Schwindt *et al.* 2003). RSER framework is not likely to be effective for salmon conservation on the Fraser River because politically infeasible to sell the rights to the Fraser to a single owner (Schwindt *et al.* 2003). Multiple stocks migrate up main stem of the Fraser on route to distant spawning grounds. Harvesting salmon at the terminals of the Fraser's tributaries would decrease the quality of fish making it an unappealing option for commercial fisheries.	ITQ management regime can also result in a mixed stock fishery that is unable to exclusively target dominant stocks. ITQs in the salmon fishery may be inappropriate due to the nature of salmon biology and the composition of the fleet (Grafton and Lane 1998). Salmon migration to spawning grounds focuses management on ensuring optimal escapement rather than taking a sustainable portion of the biomass (Schwindt *et al.* 2003). Run size highly variable, therefore managers constantly having to update allowable catch estimates in season to ensure escapement targets are met. Fishermen not guaranteed access to the resource despite holding an ITQ if total number of returning spawners is not higher than escapement target.

5.3 PRINCIPLES OF IMPLEMENTATION

Below we present a set of fundamental principles that should be considered when implementing the hard and soft infrastructure actions described above. Following these principles will help ensure strategies are effective in achieving intended outcomes.

1. Consider social values implied by adaptation strategies;
2. Embrace an ecosystem approach to managing water resources;
3. Align energy policies with fish and water management objectives;
4. Implement proactive strategies before reactive strategies;
5. Learn from others;
6. Implement adaptive management; and
7. Consider both ecosystem features and functions.

5.3.1 CONSIDER SOCIAL VALUES IMPLIED BY ADAPTATION STRATEGIES

One of the most fundamental principles of implementation is that strategies to help salmon will not be free of social values (e.g., Lackey 1999). Thus, strategies discussed above need to be considered in the context of society's willingness to help salmon because it would not be fruitful to pursue one action if local watershed users or political decision makers do not value salmon enough to motivate change.

Soft and hard infrastructure solutions lie along a continuum of values (Figure 7), where the value of salmon to society defines the alternative ends of the spectrum. If society values salmon very highly we would be willing to make any necessary sacrifices, and to take any and all actions to help salmon. If valued highly, the range of options available would be much greater and the list different than if society values salmon very little. Different perspectives will line up differently along this continuum. For instance, some First Nations may be more willing to pursue any and all actions necessary to maintain salmon given their cultural, spiritual, and economic importance. Most feasible actions, however, will likely reflect values near the middle of the spectrum, where a fine balance among trade-offs is necessary. This concept is not to intended to suggest that strategies to help salmon are pitted against human development. Some will provide win-win outcomes that benefit both salmon and people—e.g., improvements in water use efficiency / water conservation can benefit both salmon and people.

FIGURE 7. Conceptual representation of how actions that affect salmon lie along a continuum of human values. *Actions can tend to favour human interests or salmon interests. This representation is an over-simplification of reality, however, because it does not consider how actions may affect other interests (e.g., other species, natural resources uses, etc.)*

5.3.2 EMBRACE AN ECOSYSTEM APPROACH TO MANAGING WATER RESOURCES

The ultimate goal of reforming water governance should be to ensure sustainable use of water for all users, not just people. Governments must therefore adopt a "*comprehensive regulatory approach that integrates the political, economic, administrative and social processes and institutions by which public authorities, communities and the private sector take decisions on how best to develop and manage water resources*" (Christensen 2007). Inherent in developing a comprehensive approach is the need to deal with the difficult challenge of balancing ecological and human interests.

Although the Wild Salmon Policy embraces an ecosystem-based approach to management, most legislation in Canada is still sectoral (Jon O'Riordan, Pacific Salmon Forum, pers. comm.). Consequently, existing regulatory frameworks are not well structured to deal with the complexity, uncertainty, and increasing vulnerability of both natural and human systems (Christensen 2007). To help address some of these limitations, integrated water resources management is widely touted as "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*"[22]. Implementation of such a process would improve management of water allocations for environmental needs within limits of ecological availability (Christensen 2007). A more holistic approach would also work towards a desired state of the ecosystem, rather than simply managing individual components to benefit people. Inherent in this type of approach should be requirements to prioritize, establish, and enforce conservation objectives that are binding through legislation, bilateral agreements, land / watershed plans, and municipal bylaws (Young and Werring 2006).

In some instances, watershed management authorities are being tasked with managing ecosystems as a whole. Integrated water resources management, mostly focussed on watershed-level planning and management, is underway in B.C. (e.g., Nicola Water Use Management Plan developed by the Nicola Watershed Community Round Table; BC Hydro's Water Use Planning process; Okanagan Similkameen Boundary Fisheries Partnership; community watershed round tables), although there is currently no consistent approach for managing watersheds proactively and holistically. In Ontario, conservation authorities have regional government responsibilities to manage freshwater systems. Since 1993, the Ontario Ministries of Environment and Natural Resources have been fostering the use of an ecosystem/ watershed basis for local and regional land use planning. In the European Union, adoption of the Water Framework Directive requires that river basins are the management unit as opposed to political or other administrative boundaries (Christensen 2007).

5.3.3 ALIGN ENERGY POLICIES WITH FISH AND WATER MANAGEMENT OBJECTIVES

In British Columbia the goal of becoming energy independent and interest in developing energy sources with low carbon emissions has lead to a situation where Independent Power Producers (IPPs) are pursuing a large number of projects that could potentially affect salmon. Concerns about carbon emissions and climate change are increasing attention on clean energy, energy conservation, energy efficiency, co-generation, as well as small and large hydroelectric developments. For salmon dealing with a heightened vulnerability from climate change, an increased focus on hydro options suggests that B.C.'s energy policy (and specific development options) should have greater consideration of energy impacts on Pacific salmon—the fate of salmon are inextricably linked to human development and choices around energy options (e.g., Ashley 2006).

[22] Global Water Partnership. Why & How IWRM. Definition available at: http://www.gwptoolbox.org/index.cfm/site/465EBFAD-C0A3-9DDA-589E7C3A28B5B62E/pageid/46F480C6-9E54-8194-64583214C91B3114/index.cfm

Micro-hydro projects may not necessarily be free from impacts on salmon habitats. For instance, water temperatures downstream of micro-hydro projects may increase because of a reduction in water quantity. Minimum water levels and water fluctuations in the tailrace and reaches being bypassed can be a concern for salmon, instream habitats, and riparian zones. In general, BC Hydro's Green Criteria (BC Hydro 2003) consider these concerns. First, the criteria state that a micro-hydro facility must preserve the ability of anadromous fish to migrate. In practice facilities will usually be located above gradient barriers to anadromous fish. Second, these criteria state that facilities must preserve resident fish communities, and adhere to DFO's goal of "No Net Loss" in productive capacity of fish and fish habitats. Third, flows in bypassed reaches and downstream of the tailrace must conserve freshwater habitats and riparian communities as they were prior to development. Fourth, a minimum wetted channel perimeter must be maintained at all control structures with a constant in-river flow throughout the year. Fifth, facilities will avoid designated "sensitive streams", and will not threaten / harm habitats of species of conservation concern (i.e., threatened, endangered, or of regional concern). Finally, written statements by 'reputable scientists or regulatory agencies' are required to comply with these conditions.

A concern with these criteria, however, is that impacts on fish and fish habitat may not be sufficiently monitored. There are no standards or guidelines for defining "minimal impacts" on water quality, what minimum flows are needed in bypassed reaches, or how to monitor impacts on fish communities and their habitats. Written statements of compliance will discuss the nature / degree of impacts and describe how conservation measures are adequate, but they will not be prepared in a way that allows for comparisons to objective standards. A compliance assessment by regulatory agencies could address this concern, but such follow-ups may not necessarily occur.

Regional and provincial strategies for IPP projects must be developed so areas with high ecological values are adequately protected and cumulative effects avoided (Douglas 2005). Regional considerations of development will also be more important in the future as DFO shifts towards management of salmon Conservation Units (CUs). Currently, there is a lack of planning to identify optimum locations and numbers of run-of-river IPP projects from the perspective of minimizing impacts. If regional strategies are developed they should consider the cumulative effect of IPP projects in the context of other development activities such as roads, transmission lines, and other development. There is only one provision for Low Impact Hydroelectric Facilities in BC Hydro's Green Criteria that potentially addresses cumulative effects. This provision requires that "*facility operations are coordinated, to the extent commercially reasonable, with any other hydroelectric facility on the same stream to reduce impacts and protect indigenous species and habitats*". As well, this provision is voluntary and does not address cumulative effects of roads, transmission lines, penstocks, and other industrial activity on salmon and their habitats.

5.3.4 IMPLEMENT PROACTIVE STRATEGIES BEFORE REACTIVE STRATEGIES

Priorities for taking action should focus on proactive strategies before reactive ones (Roni *et al.* 2002). In the context of climate change, proactive strategies represent those actions considering a long-term perspective to help avoid impacts on salmon before they limit productivity (e.g., conserving high quality habitats before they are degraded), while reactive strategies represent those being taken to respond to immediate impacts on salmon survival (e.g., restore degraded riparian zones or stabilize exposed slopes).

A focus on proactive strategies is based on the notion that environmental and financial costs associated with managing an ecosystem are minimized in the long-run. There are two reasons for believing that proactive strategies will reduce total costs in the long-run. First, the past cycle of watershed degradation and restoration is an expensive endeavour with a questionable record of effectiveness (e.g., Bernhardt *et al.* 2005). Second, decision makers often underestimate the true value of natural resources, or economic benefits of conservation (Kroeger and Manalo 2006). Given Pacific salmon's vulnerability to climate change and their inherent value to society, we cannot rely on the past approach of crisis (i.e., reactive) management.

5.3.5 LEARN FROM OTHERS

Given the complexities and challenges facing salmon, managers in British Columbia and the Yukon must learn from the successes and failures in other jurisdictions. Other areas of the world (e.g., California, Australia, or South Africa) are more advanced by having greater vulnerabilities to increases in temperatures and reduced water supplies[23], greater population pressures[24], greater demands on water resources, and/or more advanced technologies / institutional frameworks for resolving human-water conflicts. In the continental U.S., over one-third of rivers are already listed as impaired or polluted (Bernhardt *et al.* 2005), and many salmon populations are listed under the Endangered Species Act (Behnke 2002). Not all insights will be transferable to B.C., but it is certainly sensible and proactive to take lessons from experiences elsewhere in the world.

California is a place where conflicts between water users and the environment have been taking on a high profile for many years. In 1964 the majority (~75%) of flows on the Trinity River were diverted to California's central valley (USFS and HVT 1999). After 16 years of study, the United States Secretary of Interior signed a Record of Decision in 2000 to restore about 50% of the water to the Trinity River (ROD 2000). The San Joaquin River is a river that once had runs of up to 2 million spawning chinook salmon (Behnke 2002). Since 1940, the majority of its water had been diverted to California farmers and cities leaving a 96 kilometre section of the river completely dry during the summer. Recently, a settlement was reached in the fall of 2006 marking an end to an 18-year legal dispute, and a beginning to a massive restoration program (USBR 2006). California restoration managers also have an abundance of experience designing and implementing technologies to mitigate the impact of reduced flows and increased temperatures. For instance, groundwater banking (i.e., injection and direct recharge) is one strategy being used to help maintain subsurface aquifers and reduce threats of saline intrusion[25].

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[23] Salmon in watersheds at southern latitudes are exposed to warmer environments and less natural storage capacity due to differences in snowpack. For example, average maximum august temperature in Vancouver, B.C. is 21.9°C (Environment Canada 2007b), and 33.4°C in Sacramento, CA (National Weather Service 2007).

[24] Despite having almost half the size, California has almost nine times the population of British Columbia. California's total area is 423,999.2 km^2 while British Columbia's is 947,800 km^2. The population of British Columbia is approximately 4.3 million people, 85% of which live in a few urban centers (Statistics Canada 2006), while California has a population of 36.1 million (US Census 2005).

[25] San Joaquin County Groundwater Banking Authority. See: http://www.gbawater.org/index.html

5.3.6 IMPLEMENT ADAPTIVE MANAGEMENT

> *"AM is a rigorous approach for learning through deliberately designing and applying management actions as experiments. First developed in the 1970s (Holling 1978), it has since been applied to a wide range of resource and ecosystem management problems (ESSA 1982; MacDonald et al. 1997; Bouris 1998). AM is a problem-solving environmental management approach, not a recipe. It involves synthesizing existing knowledge, exploring alternative actions, making explicit predictions of their outcomes, selecting one or more actions to implement, monitoring to determine whether outcomes match those predicted, and using these results to adjust future plans (Walters 1986; Taylor et al. 1997). In reality, these conceptual steps may not occur in this neat order (e.g., baseline monitoring may continue while initial evaluations and adjustments are made), but breaking the approach into discrete sequential steps increases the level of rigor in management discussions. Of cardinal importance is the circular nature of the AM approach—evaluation and adjustment ("closing the loop") are integral parts of a systematically designed learning process.—excerpt from Murray and Marmorek, 2003*

Among other considerations, implementing adaptive management implies both: (i) a recognition of uncertainties, and (ii) a commitment to learning. The following suggestions can help decision makers with these elements.

Use Models to Improve Management Decisions

Adaptation strategies can be assessed using science-based approaches that test their likelihood of implementation success, and evaluated in a way that recognizes uncertainties. Models can be a cost-effective way to help decision makers understand the implications of alternative strategies without investing in actions that aren't effective on-the-ground. Models can also integrate best available information, thereby helping ensure that decision-making is transparent and objective. The Okanagan Fish / Water Management Tool (Alexander *et al*. 2006), discussed in the Okanagan River case study (Nelitz *et al*. 2007b) is a success story demonstrating how modeling tools can be used to improve the quality of information available to decision makers when managing water resources for both fish and people.

Monitor Population Abundance and Habitat Status

Monitoring is an essential component to adaptive management that helps "close the loop" between what is happening in the environment and how decision makers respond to that information. Baseline and effectiveness monitoring of both policy options (Ferraro and Pattanayak 2006) and technological innovations will be important.

In the context of climate change, baseline monitoring of salmon escapement and habitat status will be vital to providing decision makers with the ability to proactively detect environmental changes, while effectiveness monitoring will be important to evaluate success rates for current and future projects. Strategies 1 and 2 of the Wild Salmon Policy (DFO 2005) are focused on monitoring population and habitat status. In pristine watersheds, collection of good quality baseline data can help managers understand how salmon and their habitats are changing. Early detection of changes can help managers identify appropriate policy actions and technologies. The Salmonid Rivers Observatory Network project[26] is attempting to provide good quality baseline data for a number of pristine watersheds including the Taku, Skeena, and Kitlope Rivers in B.C., the Kol and Utkholok Rivers in Russia, and the Kwethluk in Alaska. Information on species and stock specific environmental thresholds will also be critical to helping managers distinguish among adaptation strategies. For instance, scientists need to understand the temperature requirements for particular species and stocks if transplantation or fish culture activities are going to be effective.

[26] University of Montana. Salmonid Rivers Observatory Network. See: http://www.umt.edu/flbs/Research/SaRON.htm

5.3.7 CONSIDER BOTH ECOSYSTEM FEATURES AND FUNCTIONS

Ideally, restoration and conservation strategies need to take a holistic view of the ecosystem by considering both the functional processes being targeted by restoration and the relevance of restored habitat features in addressing limitations to species productivity (Roni *et al.* 2002). Typically restoration managers tend to focus on restoring habitat features, not ecosystem functioning. Such a focus is a failure of ecosystem restoration because it does not recognize that if habitat forming processes are not functioning, a restored habitat feature will have a limited life-span or will have to be periodically maintained (Roni *et al.* 2002; Orr *et al.* 2006).

Hydrological and geomorphological processes governing flooding and droughts, sediment and nutrient transport, riparian functioning, channel morphology, and water storage are all interconnected. On some large rivers recruitment of riparian vegetation is dependent on periodic flooding, inundation, and scouring of the floodplain to enable recruitment of seedlings. Peak flows are also important by moving channel substrates and eroding channel banks. Bank erosion leads to recruitment of riparian vegetation into stream channels, thereby contributing to channel complexity and formation of large woody debris cover for rearing juvenile salmon. Thus riparian re-vegetation can be an important adaptation strategy where riparian vegetation is lacking, but only if accompanied by strategies to maintain / restore instream flows and lateral channel movement (e.g., maintain a natural hydrograph, set dykes back from stream banks, avoid channel armouring, etc). The Okanagan River Restoration Program (ORRP) and the Trinity River Restoration Program (TRRP) are examples of restoration programs attempting to restore such ecological functioning (USFS and HVT 1999; Howie Wright, Okanagan Nation Alliance, pers. comm.).

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APPENDIX A. SUMMARY OF LITERATURE REVIEW

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Anderson & Hinrichsen 1996	All	Climate change	• changes in outmigration timing • thermal mortality and/or stress	Pacific Northwest	Regional		X					X	X		Demonstrated that cool / wet conditions were associated with high survival and catch. Smolt-adult survival correlated with arrival into the estuary.
Arkoosh *et al.* 2003	Smolts	Climate change	• infectious disease	Pacific Northwest	Regional								X		
Barnett *et al.* 2005	Not applicable	Flow	Not applicable		Global		X	X	X	X	X	X			Warmer climate will lead to less winter precipitation, earlier timing of peak run-off in snow dominated regions.
Beechie *et al.* 2006	All	Flow	• changes in reproduction / development • changes in outmigration timing • changes in run timing	Puget Sound, Washington	Local	• water storage / release	X					X			Restoration of salmon to habitats above dams may allow greater life history expression. Effects of climate change on flow regimes may affect life history expression. By association conservation efforts may be adversely affected if they target populations with distinct life history types.
Beer & Anderson 2001	Fry	Flow and temp	• changes in reproduction / development • changes in growth rates	Methow River, Washington	Local		X		X	X					Time of spawning and fry emergence are strongly linked which have adapted to local river conditions (i.e. to avoid high water temperatures and scouring flows).
Blackbourn 1993	Eggs	Temp	• effect of sea surface temperature on eggs	Pacific Ocean	Regional				X					X	Study suggesting that sea surface temperature affects the viability of eggs in fresh water.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Bradford & Irvine 2000	Adults / Spawners	Climate change	• ocean mortality	Thompson River, BC	Local	• water withdrawal • road density • over fishing • land development		X					X	X	Attributes declines in coho spawner abundance to changes in ocean conditions (i.e. climate change), fresh water habitat alteration, and over fishing.
Bradford & Cook 2004	Not applicable	Temp	• habitat alteration and/or fragmentation • changes in physiological function • changes in behaviour	Atlantic Provinces	Local			X	X	X	X				
Breau 2004	Fry	Temp	• changes in biotic interactions	Little Southwest Miramichi River, New Brunswick	Local					X					
Caissie 2000	Not applicable	Temp	Not applicable				X	X	X	X	X	X			Summary of role of temperature in shaping freshwater ecosystems, processes controlling temperature variability, modelling approaches, and human influences on thermal regimes.
Caissie & Satish 2001	Eggs	Temp	• changes in growth rate	Catamaran Brook, New Brunswick, Canada	Local				X						Links increases in ground water from climate change with increase in temperature in riverbed gravel.
Cannon & Whitfield 2002	Not applicable	Flow	Not applicable	British Columbia	Regional		X	X	X	X	X	X			Developed an approach to predict 5-day average streamflow for 21 watersheds in the province. Model predictions were consistent with recently observed conditions.
Connor *et al.* 2003a	Eggs	Temp	• changes in reproduction / development	Snake River, Idaho	Local		X	X	X						Describes how water temperatures affect incubation, emergence timing, and spawner distribution.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Connor *et al.* 2003b	Smolts	Flow and temp	• low water velocity • delayed reservoir passage • increased predation • dam mortality • lethal levels of dissolved gases	Snake River Basin	Local	• water storage / release			X	X					Discusses the efficacy of summer flow augmentation. Concluded that flow augmentation increased survival of juvenile chinook salmon due, in part, to decreased water temperatures.
Cooke *et al.* 2004	Adults / Spawners	Temp	• changes in run timing	Fraser River, BC	Local		X								Discuss competing hypotheses explaining changes in behaviour of spawning migrations of sockeye salmon and associated increases in en route / pre-spawn mortality.
Cox & Hinch 1997	Adults / Spawners	Temp	• changes in growth rates	Fraser River, BC	Local									X	Demonstrated declines in size at maturity over the past 42 years in sockeye salmon. Observations of declines in size at maturity differed between males and females.
Cragg-Hine *et al.* 2006	Smolts	Flow and temp	• changes in outmigration timing	River Dee, Wales, United Kingdon	Local	• water storage / release				X					Observed significant increases in the proportion of 1+ year smolts from the period from 1949–2002.
Craig *et al.* 1996	Eggs	Temp	• changes in reproduction / development	Takla Lake, BC	Local				X						Interesting results concerning changes in sex ratio of sockeye as a result of increased temperature.
Crossin *et al.* 2004	Adults / Spawners	Flow and temp	• bioenergetic stress • temperature mortality and / or stress • flow related stress	Fraser River, BC	Local		X								Ocean productivity was linked to level of somatic energy in adult sockeye salmon. Low somatic energy levels are likely to contribute to prespawning and en route mortality in Fraser sockeye in years with energetically demanding river conditions (e.g., high temperatures and flows).

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Crozier & Zabel 2006	Smolts	Flow and temp	• thermal mortality and/or stress • habitat alteration and/or fragmentation	Salmon River, Idaho	Local						X	X			Parr-smolt survival indices were linked to summer temperatures and minimum fall stream flows.
Deriso *et al.* 2001	All	Flow	• dam mortality • ocean mortality	Columbia River and Snake River	Local	• water storage / release	X						X	X	Developed models to predict instantaneous mortality of chinook salmon stocks from two different parts of the Columbia (upriver and down river). Best models predicting instantaneous mortality included common-year effects. Year-effects were not correlated with climate or water travel time through the Columbia River.
Douglas 2006	All	Flow and temp	• habitat alteration and/or fragmentation • decreased carrying capacity	British Columbia	Regional	• water withdrawal	X	X	X	X	X				Discusses effects of groundwater usage with respect to human withdrawals and resultant alterations in temperatures, flows, and salmon habitats.
Dunham *et al.* 2001	All	Temp	• increased predation • habitat alteration and/or fragmentation • changes in prey density • changes in biotic interactions • changes in physiological function	Columbia Basin	Regional		X	X	X	X	X	X			Summary paper discussing the effects of temperature on salmonid populations, mainly as affecting distribution of salmonids in the Pacific Northwest.
Eaton & Scheller 1996	Not applicable	Temp	• thermal mortality and/or stress • habitat alteration and/or fragmentation`	USA	National		X	X	X	X	X	X			Predicts continental-scale changes in water temperatures due to climate induced increases in air temperatures. Infers how these changes to water temperatures may result in fish habitat losses and changes in fish distribution. Salmon are included in their analysis of effects on a variety of fish species.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Edmundson & Mazumder 2001	Smolts	Temp	• changes in growth rate	Alaska	Regional						X	X			
Finney *et al.* 2000	All	Climate change	• decrease in lake nutrients	Bristol Bay, Alaska	Local		X	X						X	Used lake sediment records to reconstruct sockeye salmon abundance over the last 300 years. Observed shifts in population abundance which appeared to be related to climatic changes.
Foreman *et al.* 1996	Adults / Spawners	Flow and temp	• thermal mortality and/or stress	Fraser and Thompson River	Local	• water storage / release	X								Developed flow and temperature models to predict temperatures and flows as relevant for salmon migrating through the Fraser River basin.
Foreman *et al.* 2001	Smolts	Flow and temp	• thermal mortality and/or stress	Fraser River, BC	Local		X								Developed flow and temperature models to predict temperatures and flows as relevant for salmon migrating through the Fraser River basin.
Goniea *et al.* 2006	Adults / Spawners	Temp	• changes in run timing • changes in migration patterns • thermal mortality and/or stress	Columbia River, Washington	Local		X								Demonstrated that warming of the Columbia River has been associated with shifts in the run timing of fall chinook salmon.
Greene *et al.* 2005	All	Flow and temp	• habitat alteration and/or fragmentation • effects of floods on egg incubation	Skagit River, Washington	Local		X	X	X	X	X	X			Developed a model to predict return rates of chinook salmon. Environmental conditions (magnitude of floods during incubation) in freshwater environment helped explain greatest among of the variation in return rates.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Hauer *et al.* 1997	Not applicable	Flow and temp	• habitat alteration and/or fragmentation • changes in reproduction / development • changes in biotic interactions	Rocky Mountains	Regional	• introduction of invasives • land development • water withdrawal • forestry	X	X	X	X	X	X			General overview of the effects of climate change on rocky mountain freshwater ecosystems.
Heggberget & Wallace 1984	Eggs	Temp	• changes in reproduction / development	Lab					X						
Henderson *et al.* 1992	All	Temp	• thermal mortality and / or stress • changes in feeding patterns • changes in biotic interactions	Adams River, BC	Local		X			X	X				Discusses the potential impacts of climate change on lake residence of juveniles and spawning adults given the influence of water temperatures on physiology, growth, and survival of sockeye salmon. Conclude that global warming will likely reduce the freshwater production of Adams River sockeye salmon.
Henderson *et al.* 1995	Fry	Temp	• changes in reproduction / development	Fraser River, BC	Local				X	X					Evaluated the effect of water temperature on timing of pink salmon fry emigration and fry size.
Hengeveld 1990	Not applicable	Flow	Not applicable		National		X	X	X	X	X	X			Discusses the anticipated effects of climate change on air temperatures and water temperatures, including implications of these changes to freshwater habitats.
Hinch *et al.* 1995	Adults / Spawners	Climate change	• changes in body size	Fraser River, BC	Regional									X	Developed a bioenergetics model to predict ocean weight of Fraser River sockeye salmon using sea-surface temperature as a predictor variable. Effects of climate change were estimated using assumptions of future increases in sea surface temperature.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Hodgson & Quinn 2002	Adults / Spawners	Temp	• changes in run timing	Pacific Northwest	Regional		X								Used data on the timing of migration and spawning to evaluate the effect of freshwater temperatures influences. Observed that timing of migration was related to temperature regimes during spawning and migration.
Hyatt *et al.* 2003	Adults / Spawners	Temp	• changes in run timing	Okanagan River, BC	Local		X								Developed a migration run timing model to predict migration delays of sockeye salmon due to elevated water temperatures. Authors then used this model in a retrospective analysis to evaluate the effects of past climate on migration.
Jager 1997	Smolts	Flow and temp	• redd mortality • juvenile mortality • habitat alteration and/or fragmentation • changes in outmigration timing	Tuolumne River, California	Local	• water storage / release		X	X	X					Evaluated the effect of instream release from upstream reservoirs on smolt production for fall chinook.
Jain *et al.* 2005	Not applicable	Flow	Not applicable		National		X	X	X	X	X	X			Documented an emerging trend among large rivers in western North America (Fraser, Columbia, Sacramento-San Joaquin, Upper Colorado) that suggests greater year-to-year variation in streamflow, and increase in the synchronicity of flows (simultaneous high or low flows).
Jakob *et al.* 2003	Not applicable	Flow	Not applicable	Vancouver, BC	Local				X	X	X	X			Demonstrated increasing trend in high intensity rainfall events in the Vancouver area.
Jensen 2004	All	Temp	• thermal mortality and/or stress • changes in reproduction / development	Puntledge River, BC	Local		X	X	X						

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Johnson *et al.* 2003.	Smolts	Flow	• mortality due to jet flows at dam outfalls	Washington	Local	• water storage / release			X	X					Explored the relationship between mortality / injury of juvenile salmon and jet velocities near high flow outfalls.
Keleher & Rahel 1996	Not applicable	Temp	• habitat alteration and/or fragmentation • thermal mortality and/or stress	Rocky Mountains, Wyoming	Regional		X	X	X	X	X	X			Investigated distribution of salmonids as predicted by summer air temperatures. Used these results to then estimate the resulting loss in available habitats due to climate induced increases in air temperature.
Lapointe *et al.* 2003	Adults / Spawners	Temp	• shifts in migration timing • enroute / pre-spawn mortality	Georgia Basin, BC	Local		X								Abnormal migration may be due to involving physiology, environmental conditions, contaminants, parasites, and predators. Cause is uncertain, but high enroute and pre-spawning mortality is becoming more common.
Lawson *et al.* 2004	Smolts	Flow and temp	• ocean mortality • increased predation • habitat alteration and/or fragmentation • changes in reproduction / development	Oregon and Washington	Regional	• forestry • land development • water withdrawal	X	X	X	X	X	X			Annual air temperatures, winter flows, date of first fall freshet, and flow during smolt outmigration were highly correlated with smolt production. Also demonstrated that freshwater conditions are typically associated with good marine conditions.
Leavesley *et al.* 1997	Not applicable	Climate change	Not applicable		National		X	X	X	X	X	X			Defined eight regional boundaries for North America that could be used to help understand the effects of climate change on freshwater ecosystems.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Lee *et al.* 2003	Adults / Spawners	Temp	• thermal mortality and/or stress • bioenergetic stress	Fraser River, BC	Local		X								Examined the effects of temperature on swimming performance and metabolic rates of sockeye and coho salmon.
Leith & Whitfield 1998	Not applicable	Flow	Not applicable	South-central, BC	Regional		X	X	X	X	X	X			By analyzing hydrological records from south-central BC, identified general trends of earlier spring run-off, lower late summer-early fall flows, and higher winter flows with warmer climate.
Leung & Qian 2003	Not applicable	Flow	Not applicable	Georgia Basin, BC	Regional		X	X	X	X	X	X			Simulated the effects of changes in air temperatures on snowpack and run-off under a variety of climate changes scenarios. Predicted that small watersheds have a greater chance of increased winter flooding, and a reduced streamflow in early summer.
Levy 1992	All	Flow and temp	• shifts in migration timing • enroute / pre-spawn mortality • premature emergence, reduced egg survival • oxygen depletion and related stress / mortality • thermal stress / mortality • invasion of exotics / altered fish distribution	Fraser River, BC	Local		X	X	X	X	X	X			Summarizes climate change science and the potential effects on salmon species / life stages. Also discusses some management options to adapt to the effects of climate change.
Macdonald *et al.* 2000	Adults / Spawners	Flow and temp	• shifts in migration timing • enroute / pre-spawn mortality	Fraser River, BC	Regional		X								Using behavioural observations of sockeye migration in 1997, the authors evaluated the usefulness of in-river decision support models.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Mangel 1994	All	Flow and temp	• changes in growth rates • changes in run timing • changes in feeding patterns • changes in outmigration		National		X	X	X	X	X	X			
Mantua & Francis 2004	All	Climate change		Pacific Northwest	Regional		X	X	X	X	X	X			Considers salmon fisheries management policies in the context of climate change and provides recommendations to change management practices in freshwater and marine environments to ensure viable salmon populations.
Mantua *et al.* 1997	Adults / Spawners	Climate change		Alaska	Regional		X						X	X	Uses Alaskan pink and sockeye salmon commercial fisheries data to relate salmon production to Pacific (inter) Decadal Oscillation.
Marine & Cech Jr 2004	Smolts	Temp	• habitat alteration and/or fragmentation • changes in growth rates • increased predation	Sacramento River, California	Local					X	X				Investigated the thermal tolerances of salmon to elevated water temperatures, mainly by looking at effects on growth and smoltification of chinook salmon.
Materna 2001	All	Temp	• infectious disease • bioenergetic stress • changes in turbidity • changes in chemical tolerance	USA	National		X	X	X	X	X	X			This issue paper reviews biological, physical, and chemical properties related to temperature within salmonid ecosystems.
McCormick *et al.* 1999	Smolts	Temp	• changes in physiological function	Connecticut River, New Hampshire	Local							X			Study documents the loss of smolt characteristics (i.e. ability to tolerate increasing salinity) in those fish that have delayed outmigration in warmer waters.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
McCullough 1999	All	Flow and temp	• habitat alteration and/or fragmentation • dam mortality • thermal mortality and/or stress • infectious diseases • changes in run timing • changes in reproduction / development	Columbia Basin	Regional	• water storage / release	X	X	X	X	X	X			Comprehensive review of the effects of water temperatures on different life stages. Focus is on chinook salmon.
McCullough *et al.* 2001	All	Temp	• thermal mortality and/or stress • changes in reproduction / development • changes in growth rates • bioenergetic stress	USA	National		X	X	X	X	X	X			Comprehensive review of the effects of water temperatures on different life stages.
Merritt *et al.* 2006	Not applicable	Flow	Not applicable	Okanagan, BC	Regional		X	X	X	X	X	X			Used downscaled climate models and the University of BC watershed model to predict hydrological responses under various climate change scenarios. All scenarios predicted an earlier onset of spring snowmelt, a more rainfall dominated hydrograph, and reductions in the annual and spring volumes.
Milly *et al.* 2005	Not applicable	Flow	Not applicable		Global		X	X	X	X	X	X			Predicts global patterns of streamflow and water availability, with mid-latitude North America experiencing reduced runoff.
Ministry of Water, Land, & Air Protection 2002	Adults / Spawners	Flow and temp	• shifts in migration timing • enroute / pre-spawn mortality	British Columbia	Regional		X								Uses salmon spawning migration success as an indicator of climate change for British Columbia.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Minns *et al.* 1995	Smolts	Flow and temp	• thermal mortality and/or stress • changes in growth rates • habitat alteration and/or fragmentation	Eastern Canada	Regional						X	X			Estimate the area of potentially lost habitats through changes in wetted width and discharge due to climate change, and then related these changes to potential changes in growth rates and age of smoltification.
Moore 2006	Not applicable	Temp	Not applicable	British Columbia	Regional		X	X	X	X	X	X			Developed an empirical model to predict stream temperature patterns using landscape-level and climate variables.
Morrison *et al.* 2002	Not applicable	Flow and temp	Not applicable	Fraser River, BC	Regional		X	X	X	X	X	X			Authors analyzed historic flow and water temperatures in the Fraser River to use these findings to evaluate the effects of future climate changes on in-river conditions. Projections suggest earlier timing of peak flows and ~2 degree increases in water temperatures.
Moscrip & Montgomery 1997	Adults / Spawners	Flow	• flow related stress	Puget Sound, Washington	Local	• water withdrawals • riparian / channel management	X								Study provides evidence that urbanization and resulting increases in flood frequency or associated habitat alterations have reduced salmon productivity in affected watersheds.
Mote 2003	Not applicable	Flow	Not applicable	Georgia Basin	Regional		X	X	X	X	X	X			Paper evaluates climate trends in the Georgia Basin, discovering that mountain snowpack during the spring and at low elevations has declined since the1950s.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Mueter *et al.* 2002	All				Regional		X						X	X	Estimated the effect of sea surface temperatures on survival of three salmon species. Found that warm anomalies in coastal temperatures were associated with increased survival rates for stocks in Alaska and decreased survival rates in Washington and British Columbia.
Naughton *et al.* 2005	Adults / Spawners	Flow and temp	• thermal mortality and/or stress • changes in migration patterns	Columbia River, Washington	Local	• water storage / release	X								Evaluated migration success and migration behaviours were affected in the Columbia River.
Nichols *et al.* 2007	Smolts	Temp	• infectious diseases	Klamath River, California	Local							X			Investigated the incidence of infection by two parasites during spring out-migration.
Nislow *et al.* 2004	Fry	Flow and temp	• changes in growth rates	Connecticut River, New Hampshire	Local					X	X				Evaluated the relationship between summer flow / water temperatures and growth of juvenile salmon.
O'Neal 2002	All	Temp	• habitat alteration and/or fragmentation • thermal mortality and/or stress • increased predation • changes in biotic interaction	USA	National	• water storage / release • water diversion • pollution • land development	X	X	X	X	X	X			Paper presents results from a simulation study investigating the effects of climate induced change on salmon habitats throughout the U.S.
Petersen & Kitchell 2001	Smolts	Temp	• bioenergetic stress • increased predation	Columbia River, Washington	Local						X	X	X		Investigated how climatic regime shifts may affect predation rates on juvenile salmon in the Columbia River.
Poole *et al.* 2001a	All	Temp		Pacific Northwest	Regional	• land development	X	X	X	X	X	X			Summary paper describing the natural physical processes and human activities that can affect thermal regimes.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Poole *et al.* 2001b	Not applicable	Temp	Not applicable	Pacific Northwest	Regional		X	X	X	X	X	X			Summary paper describing the scientific issues related to effects of temperature on salmon and setting appropriate temperature criteria.
Poole & Berman 2001	Not applicable	Temp	Not applicable	Pacific Northwest	Regional		X	X	X	X	X	X			Summary paper describing the physical basis for spatial and temporal variations in stream temperature.
Pyper *et al.* 2001	All				Regional		X						X	X	Found positive covariation in survival among nearby stocks, and no covariation among distant stocks. Propose that regional covariation is due to regional similarities in marine processes.
Quinn & Adams 1996	Adults / Spawners	Flow and temp	• changes in run timing • changes in migration patterns	Columbia River, Washington	Local	• water storage / release	X								Evaluate the effect of flow and temperature changes on the Columbia River on migration timing of sockeye salmon and American shad.
Rand *et al.* 2006	Adults / Spawners	Flow and temp	• bioenergetic stress • thermal mortality and/or stress • flow related stress	Fraser River, BC	Local		X								Authors evaluate the effect of past and future changes in Fraser River temperatures and discharge on sockeye salmon migration performance.
Reiger & Meisner 1990	Not applicable	Flow and temp	Not applicable						X	X	X				Authors integrate physical and biological linkages to water temperatures and flow to develop a framework for assessing the effects of climate change on production of salmonids.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Richter & Kolmes 2005	All	Temp	• changes in reproduction / development • changes in run timing • infectious diseases • changes in chemical tolerance • changes in migration patterns • thermal mortality and/or stress	Pacific Northwest	Regional	• land development	X	X	X	X	X				Provides an overview of the physiological or population-level influences of temperature in terms of the decline of wild salmon. In addition an evaluation of numeric temperature criteria and their potential in salmon recovery planning is undertaken.
Rosenau & Angelo 2003	All	Flow	• habitat alteration and/or fragmentation • delayed or prevented upstream—migration • stranding	Nicola and Englishman Rivers, BC	Regional	• water storage / release • water withdrawal	X	X	X	X	X	X			Report summarizes the conflicts between human uses and fish uses of water with a special emphasis on activities in the Nicola and Englishman River watersheds.
Salinger & Anderson 2006	Adults / Spawners	Flow and temp	• thermal mortality and/or stress • changes in run timing • flow related stress	Columbia River, Washington	Local		X								Evaluates the effect of temperature and flow on migration of chinook salmon. Migration delays were related to temperatures, though flows were not significant in predicting migration behaviour.
Sauter *et al.* 2001	All	Temp	• changes in biotic interactions • bioenergetic stress • changes in feeding patterns	Pacific Northwest	Regional	• water withdrawal • water storage / release	X	X	X	X	X				Summary paper describing the behavioural changes related to changes in water temperatures.
Scheuerell & Williams 2005	Adults / Spawners	Climate change	• ocean mortality	Snake River, BC	Regional		X						X	X	Used indices of coastal upwelling to predict changes in ocean survival of Snake River chinook salmon.
Schindler 1997	Not applicable	Flow and temp	• changes in water quality	USA	Regional										Summarizes the broad range of expected changes in freshwater communities resulting from climate change.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Schindler 2001	Not applicable	Flow and temp	• changes in water quality • changes in migration patterns	Canada	Regional	• water storage / release • water withdrawal • over fishing • non-native species • land development									Summarizes the broad range of expected changes in freshwater communities resulting from climate change.
Schindler & Donahue 2006	Not applicable	Flow	Not applicable	Western Canada	Regional	• human development activities									Illustrates how trends in air temperatures, precipitation, and river flows are leading to stresses on freshwater lakes and rivers.
Shirvell 1994	Smolts	Flow	• flow related stress	British Columbia	Regional						X				Describes microhabitat use by coho and chinook salmon in relation to variations in streamflow.
Sommer *et al.* 2001	Parr	Temp	• changes in feeding patterns • thermal mortality and/or stress	Sacramento River, California	Local						X				Despite higher temperatures, demonstrated increased growth rates of parr in floodplain waters (as compared to in-river habitats) resulting from increased availability of prey.
Stohlgren *et al.* 1998	Not applicable	Temp	Not applicable	Colorado	Regional	• water withdrawals • water storage / release									Provides qualitative evidence that land use activities affects water temperature.
Sullivan *et al.* 2000	Smolts	Temp	• infectious disease • changes in physiological function • changes in growth rates • thermal mortality and/or stress	Pacific Northwest	Regional				X	X	X				Paper develops a risk-based approach to analyze summertime temperature effects on juvenile salmon species.
Taylor, E. 2004	Not applicable	Climate change		Fraser River delta	Regional								X		Discusses climate change impacts on Fraser River delta water quality and quantity.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Tops *et al.* 2006	Adults / Spawners	Temp	• infectious disease		Global										Discusses the relationship between prevalences of a salmonid disease and water temperatures, which will have anticipated linkages given effects of climatic change.
Torgersen *et al.* 1999	Adults / Spawners	Temp	• habitat alteration and/or fragmentation	John Day River Basin, Oregon	Local	• land development	X								Observations of thermal refugia and their use by chinook salmon reveal that thermal patchiness in streams also should be recognized for its biological potential to provide habitat for species existing at the margin of their environmental tolerances, even though heterogeneity in the longitudinal stream temperature profile may be viewed as an ecological warning sign.
Traxler *et al.* 1998	Adults / Spawners	Temp	• infectious disease	Skeena River, BC	Local		X								Documents disease outbreaks in sockeye salmon during the 1994 and 1995 spawning seasons in the Skeena River watershed.
Wade *et al.* 2001	Not applicable	Flow	Not applicable	Georgia Basin, BC	Regional		X	X	X	X	X	X			Summarizes following hydrological and climatic zonations. (1) Coastal Areas. Summer: low stream discharge and low amounts of rain. Winter: high discharge and heavy rainfall. (2) Interior Areas Summer: high discharge and snowmelt. Winter: low discharge and snowpack accumulation.
Walters & Ward 1998	Smolts	Climate change	• UV exposure • ocean mortality	British Columbia	Regional						X	X	X		Hypothesize that UV exposure in freshwater environments leads to increased ocean mortality.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Wang *et al.* 2006	Not applicable	Flow	Not applicable	British Columbia and Yukon	Regional		X	X	X	X	X	X			Relate low-flow response of rivers in BC and the Yukon to Pacific Decadal Oscillation (PDO) and El Nino / Southern Oscillation events. Low flows in coastal BC rivers were responsive to PDO changes, though the interior of BC and were not in the Yukon.
Welsh *et al.* 2001	Smolts	Temp	• thermal mortality and/or stress	Mattole River, California	Local				X	X	X				Examined the relationship between presence of coho salmon and summer temperatures. Water temperature was an important variable that helped predict distribution.
Weston *et al.* 2003	Not applicable	Flow	Not applicable	Englishman River, BC	Local		X	X	X	X	X	X			Investigated changes in flood frequency and magnitude on the Englishman River. Authors predict significant increases in the frequency and magnitude of peak flows due to climate change.
Whitfield 2003	Not applicable	Flow	Not applicable	Georgia Basin, BC	Regional		X	X	X	X	X	X			Separate watersheds within the region using three categories: rainfall driven, snowmelt driven, and hybrid (mixed rainfall and snowfall). Future predictions of hydrologic changes suggest changes in magnitude and frequency of flooding and low flow events will vary across these watershed types.

Citation	Life Stage	Habitat Driver	Salmon Mortality / Biophysical Consequences	Location	Spatial Scale	Human Action	Relevant Pathway (see Figure 1)								Summary Notes
							A	B	C	D	E	F	G	H	
Whitfield *et al.* 2003	Not applicable	Flow	• flow related stress	Georgia Basin, BC	Regional		X	X	X	X	X	X			In snowmelt driven streams magnitude and duration of summer flood increases; whereas in rainfall driven streams frequency of flood increases but not magnitude. Low flows in rainfall driven streams maintain same frequency and number but over greater period of time; whereas low flow in snowmelt driven streams low flow events occur less often.

APPENDIX B. REFERENCES CITED IN APPENDIX A

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APPENDIX C. DETAILED DESCRIPTIONS OF HARD INFRASTRUCTURE ACTIONS

Action	Description	Evidence, examples and considerations for implementation
Transplant stocks or species	Transplant stocks or species to take advantage of differences in physiological characteristics (e.g., temperature tolerance).	There is evidence that the optimum temperature for maximum oxygen consumption differs among Fraser sockeye stocks (Lee *et al* 2003). Additionally there is evidence of differences in temperature tolerance among different salmon species (Lee *et al*. 2003; MacNutt *et al*. 2006). This suggests that a possible strategy given increasing stream temperatures is to transplant temperature tolerant stocks or species to warmer streams. Another possible strategy is to manipulate the run-timing to avoid peak temperatures. There are examples of fisheries managers altering the run timing of stocks. For example, they moved the peak of return for lower Fraser chum by 3–4 weeks in a couple of generations (Doug Lofthouse, Fisheries and Oceans Canada, pers. comm.). This strategy could be controversial as it risks maintaining unique stocks and could result in a decrease in biodiversity. Experience with transplanting stocks for enhancement has had limited success, so this strategy may be difficult to implement. Information on species & stock specific environmental thresholds, ranges and ecology is critical to informing management actions. If we are to try and manage temperature, flow and habitat we need to understand how these actions affect different species and stocks (Tony Farrell, University of British Columbia, pers. comm.). For example pink salmon may have a wider temperature tolerance range than sockeye (MacNutt *et al*. 2006).
Reintroduce salmon to extirpated areas	Reintroduce salmon to areas where they have been extirpated (e.g., due to barriers to fish passage).	The re-introduction of sockeye to the Upper Adams River, BC appeared successful in 2000 with returns of 70,000 sockeye (DFO 2001) after having no sockeye from 1913–1953. However, the run declined to 3,000–5,000 spawners in 2004 as a result of high temperatures in the Fraser River (Doug Lofthouse, Fisheries and Oceans Canada, pers. comm.). Although there is optimism the population will become self-sufficient again. Chinook have also been introduced to the Upper Adams River (Lofthouse 2002), although in smaller numbers (~100–200 spawners). These salmon appear to be self-sustaining; no enhancement has occurred since 1993 (Doug Lofthouse, Fisheries and Oceans Canada, pers. comm.). Ocean and stream type Chinook were successfully reintroduced in the Clearwater River, Idaho, although it took many more attempts to establish the Fall Chinook run (Narum *et al*. 2007). There are several re-introduction projects currently being considered in BC including re-establishment of sockeye to Skaha Lake (Wright and Smith 2003) and restoring anadromous salmon to the Canadian Reaches of the Upper Columbia River (Nelitz *et al*. 2007). In the US re-introduction projects are being considered for chinook and steelhead in the Sacramento-SanJoaquin basin (Lindley *et al*. 2007) and coho in the Yakima River (Bosch *et al*. 2007). Re-introduction is costly and many efforts have failed (Withler 1982). Things to consider: • potential interactions with other species (e.g., Kokanee) • engineering logistics of allowing fish passage • choice of source stocks for recolonization • introducing multiple life histories can be beneficial to successful colonization (Burger *et al*. 2000) • focus on areas that are expected to remain suitable habitat given climate change (Lindley *et al*. 2007)

Action	Description	Evidence, examples and considerations for implementation
Introduce salmon to new areas	Introduce salmon into regions where they were previously unable to survive, but with changing climate may be suitable (e.g., streams that were previously too cold or were not accessible).	Pacific Salmon have been successfully introduced in a number of areas outside their native range (Behnke 2002). Chinook transplanted from California have been successfully established in New Zealand (Quinn *et al.* 1996). Coho may have established a few self sustaining runs in Chile (Ginetz 2002). Chinook salmon introduced to Lake Superior derived from stocks that spawned in November or December were able to survive an additional 6 months to spawn in May when the water warmed sufficiently (Behnke 2002). Tyedmers and Ward (2000) suggest that experimental options should be pursued that attempt to accommodate likely shifts in ranges and abundance due to climate change. For example, the recession of the Tweedsmuir glacier may open up access to ~16,000 km^2 of habitat in southwestern Yukon via the Alsek River (Al von Finster, Fisheries and Oceans Canada, pers. comm.), if this happens should we allow colonization to happen naturally or should we try to accelerate it?
Conserve pristine habitats	Conserve habitats that currently support or could support salmon.	Conserving habitat may be less expensive and more effective than restoring habitat once it has been destroyed. We are very fortunate in BC that we still have substantial areas where there are relatively few human impacts, 85% of our ~4.3 million people live in a few urban centers (MacKinlay 2004). This provides us with the opportunity to proactively protect remaining habitat, unlike the continental U.S. where over one-third of rivers are listed as impaired or polluted and a conservative estimate of the average cost of river restoration is 1 billion dollars per year (Bernhardt *et al.* 2005). Things to consider: • Location: do we focus on protecting areas that are likely to be most affected by climate change, or do we protect areas that we expect to be good habitat for salmon in spite of or because of climate change impacts? • It is important to conserve the watershed function (Roni *et al.* 2002; USFWS and HVT 1999; Pamela Zevitt, The Como Watershed Group, Dave Patterson, Fisheries and Oceans Canada; Jeff Jung, Fisheries and Oceans Canada; Al von Finster, Fisheries and Oceans Canada, pers. comm.) • Floodplains are key habitat and key to allowing river function to occur, they should be treated as part of the river and they should not be allowed to be owned or developed. Once we develop floodplains we inevitably end up constraining the river (Al von Finster, Fisheries and Oceans Canada, pers. comm.)
Implement low impact irrigation practices	Implement irrigation practices that minimize water loss and direct impacts on fish due to entrainment.	Optimal timing: Manage the daily timing of irrigation to minimize evaporation during warm periods and waste during rain. A pilot project on the Nicola at Kilchena where they installed a number of mini irrigation monitoring stations that track soil moisture and weather conditions. They link the monitoring station to the farmer's phone so they know when the fields need to be irrigated and when they have had enough. This is an innovative way of conserving water and farmers seem to like it (Angus MacKay, Pacific Salmon Commission, pers. comm.). Drip irrigation: Drip irrigation technology has the potential to at least double the crop yield per unit of water (Postel 2000). A number of Indian research institutes have found drip irrigation leads to water use reductions of 30–60% and typical yield increases of 20–50% (Postel 2000). David Hill, Executive Director, Alberta Irrigation Projects Association pointed out in a 2004 interview that the types of crops grown and the scale of the agriculture will impact the suitability of drip irrigation. Replace ditches with polyvinyl chloride pipes: Use of polyvinyl chloride pipes rather than ditches for irrigation in Oregon resulted in a reduction of water loss to the soil and so more water for agriculture & river. May be suitable in some urban areas where we have short ditches (Jenkins 2006). Irrigation screens: Ensure farmers and ranchers to properly screen their intake pipes so fish aren't pulled into the irrigation system. All water intakes must be properly screened as stipulated in Section 30 of the Fisheries Act and the DFO "Fish Screening Directive". Additional information regarding screening requirements is provided by the DFO Freshwater Intake End-of-Pipe Fish Screen Guideline.

Action	Description	Evidence, examples and considerations for implementation
Recycle water in industry	Implement technologies to increase industrial water use efficiency.	Water scarcity is already a problem around the world and is expected to become more of an issue in BC and Canada due to the effects of climate change. Postel (2000) recommends working towards a goal of doubling water productivity. Technology exists today for industry and others to reduce their consumption of water, for example: • recycling process and cooling water (Postel 2000) • treating and recycling waste water for non-drinking water use • rainwater can be harvested and used for a variety of non-drinking water uses • wastewater can be recycled for irrigation use • water efficiencies and re-use are possible in many different industries, including: textile, pulp and paper, mining and horticulture (Lens *et al*. 2002)
Install water meters	Measure individual water consumption.	The Ministry of Environment, Canada found that metered households generally saw reductions in water use and that water use was 70% higher when users pay flat rates rather than volume based rates.
Build additional storage capacity	Build storage capacity, thereby providing a greater ability to manipulate instream flows (e.g., timing, volume, temperature).	Damming rivers for conservation purposes is a controversial concept. In places like California where dams are numerous, the dams were part of the problem, but they are also part of the solution (Nina Hemphill, Trinity River Restoration Program, pers. comm.). They may provide managers with the ability to store water and manage river flows (timing, volume, temperature) to best suit the needs of salmon. here are many arguments against building more dams including: the barrier to fish passage (both adults and out-migrating smolts), the impact on species besides salmon, the impacts on the geomorphology of the river, plus it implies we know how to manage the system better than nature (what temperature/flow to target at what time of year for what species). As previously mentioned climate change is expected to affect the timing and volume of precipitation (Stahl 2007; Milly *et al.* 2005; Barnett *et al.* 2005) and one consequence of this may be that areas which currently support salmon will not have adequate water storage in the future. In watersheds without sufficient water storage (natural or not), damming rivers may be an idea worth discussing.

Action	Description	Evidence, examples and considerations for implementation
Divert water from other locations	Diversions across or within basins can be used to enhance water flows and decrease water temperatures at a recipient location. This action could be associated with decreased water flows and possible increases in temperature at the donor location.	Like dams, diversions are very controversial. Taking water from one area and moving it to another is something that should only be done with extreme caution. Like dams, diversions may provide managers with the ability to store water and manage river flows (timing, volume, temperature) to best suit the needs of salmon. However there are major impacts to both the area where the water is removed and the area where the water is diverted to. Examples of diversions: Nechako River, BC: Water from the 92,000 hectare reservoir created by the Kenney Dam on the Nechako flows the opposite direction and is now sent to Alcan's Kemano power plant via a 16km underground tunnel. In the case of Nechako River, large areas of First Nations territory were flooded with little warning and the flow to the Nechako River and Fraser River were diminished. "The Nechako River in the Lakes Forest District once boasted one of the strongest salmon runs in British Columbia. Since the building of the Kenney Dam, stocks in the Nechako have been in decline, in part due to an insufficient and inconsistent amount of water released annually from the dam into the river", drawn from http://www.britishcolumbia.com/rivers/?ID=113. "The Cheslatta T'en are Carrier people from north-central British Columbia whose way of life was altered drastically by flood waters from Alcan's Kemano hydroelectric project, built on the Fraser River watershed in the early 1950s", drawn from Indian and Northern Affairs Canada, http://www.ainc-inac.gc.ca/ch/rcap/sg/sg40_e.html. Trinity River, CA: up to 90% of the river's water was diverted from the Trinity River and sent through multiple power plants and then to the California central valley for agricultural use. Impacts to the Trinity River include: loss of habitat above the dam, loss of channel shaping flood events, loss of coarse sediment supply, accumulation of fine sediment and inadequate flows/temperatures for salmon (USFS and HVT 1999). San Joaquin River, CA: The San Joaquin River which may once have had runs of up to 2 million spawning chinook salmon (Behnke 2002) has had the majority of its water diverted to California farmers and cities. Now a 60 mile stretch of the river completely dries up during the summer. Conflicts over water led to this outcome, but a settlement was filed in the fall of 2006 to end an 18-year legal dispute over water flows on the San Joaquin and a massive restoration program is beginning (USBR 2006).
Decrease surface water runoff	Forest harvesting and changes in the amount of impervious surfaces due to urban development increase surface water runoff / water yields, which can adversely affect hydrologic regimes for salmon.	Urban areas are less able to store water, due to the large area of pavement or buildings, where precipitation runs directly into the storm drains and out to the ocean instead of being absorbed into the soil, plants and trees which are able to store the water locally. Climate change is expected to result in more frequent storms with more rain in the winter and less in the summer. This makes it even more important to store the rainwater locally rather than have it immediately run off into the storm drains. Increasing development and population pressures also make it important to improve storm water management (Jeff Jung, Fisheries and Oceans Canada, pers. comm.). In wilderness areas this generally means implementing low impact forestry practices that minimize runoff such as: minimizing soil disturbance particularly on steep slopes and thinning rather than clearcutting (Chamberlain *et al.* 1991). There are many technologies available to minimize surface water runoff in cities. Examples include: • Green roofs, which retain rainwater to be slowly released and filter any runoff that does occur. They reduce the amount and timing of the runoff and as a result moderate temperature mitigating the urban heat island effect (www.greenroofs.net/index.php?option=com_content&task=view&id=26&Itemid=40). • Porous pavement, which allows rain to pass through the surface into a stone reservoir below where the water can slowly be absorbed into the soil • Tiled or green driveways, which may or may not have grass growing amount the tiles but do not completely cover the driveway allowing rain to absorb between the tiles into the soil • Planting trees to maximize the water stored in the local system and minimizing the amount of paved land

Action	Description	Evidence, examples and considerations for implementation
Manage water storage	Manage the timing and volume of water releases to meet salmon habitat requirements (i.e., establish environmental flow regimes).	Simply increasing flow to rivers is probably the most effective action we can take (Craig Orr, Watershed Watch Salmon Society, pers. comm.). Increased flow should restore the natural alluvial processes (USFWS and HVT 1999) enable fish passage, increase area of spawning and rearing habitat, dilute effects of disease, move smolts downstream more quickly (Nina Hemphill, Trinity River Restoration Program, pers. comm.). However, we need to be careful not to drain the water table in order to obtain more water (Tom Rutherford, Fisheries and Oceans Canada; Angus MacKay, Pacific Salmon Commission, pers. comm.). Operating water storage facilities in a 'fish friendly' manner, by changing the storage and release patterns to account for fish needs is a successful strategy that is being widely used for Pacific Salmon. This concept is being applied to all BC hydro facilities through the Water Use Plan (WUP) process as well as many rivers in the Western US including: Columbia River, Snake River, Trinity River and Sacramento River (Martin 2003; Tom Rutherford, Fisheries and Oceans Canada; Angus MacKay, Pacific Salmon Commission; Nina Hemphill, Trinity River Restoration Program, pers. comm.). Altered flood control operations, plus earlier reservoir refill, creates a more natural peaking flow regime that is more harmonious with the salmon's life cycle (Martin 2003). Pulses of water released from weirs on Cowichan Lake over 36 to 72 hour period attract Chinook from downstream into spawning habitat upstream (Tom Rutherford, Fisheries and Oceans Canada, pers. comm.). Things to consider: • Important to provide Coho juveniles with wetted habitat in the summer (Tom Rutherford, Fisheries and Oceans Canada, pers. comm.) • Need sufficient flow and low enough temperatures for spawners of various species and life history strategies, which return at different times of the year • Can use dam releases to make out-migration conditions more favourable (Connor *et al* 2003) • Increased flows can scour eggs and juveniles • Timing of increased flows also is important for both establishing and scouring riparian vegetation as well as driving geomorphological processes

Action	Description	Evidence, examples and considerations for implementation
Release cold water	Use cold water releases from lakes or reservoirs to reduce water temperatures.	Using cold water pools to maintain cooler river temperatures is a strategy that is used extensively in California and has been tried with varying degrees of success in BC. California: In California the Trinity and Sacramento River temperatures are managed quite effectively by using large cold water reservoirs (Trinity and Shasta Reservoirs) to supply the rivers (Zedonis 2007; Nina Hemphill, Trinity River Restoration Program, pers. comm.). They plan to use this strategy in the restoration of the SanJoaquin River, CA as well (Nina Hemphill Trinity River Restoration Program, pers. comm.). Temperature control curtains are a tool to enable the withdrawal of cooler water from a reservoir with thermal stratification and are being used in the Trinity River Reservoir, CA. and may be a cost effective way of selectively withdrawing cooler water from a reservoir with thermal stratification (Vermeyen 1997). Cameron lake, BC: A computer system monitors river temperature and releases water from the weir on the lake as needed during critical spawning times. This has successfully resulted in summer water temperatures that are more tolerable to salmon (Angus MacKay, Pacific Salmon Commission, pers. comm.). Seton Lake, BC: Is an example where the temperature was decreased unintentionally as a result of cold water releases at a dam, but in this case fish migration and production was impacted in a negative way (Dave Patterson, Fisheries and Oceans Canada, pers. comm.; Bridge-Coastal Fish & Wildlife Restoration Program available at: www.bchydro.com/bcrp/about/docs/ch10_final.pdf). Kenney Dam on the Nechako River, BC: Is being considered for a retrofit to allow cold water release from the base of the dam (Dave Levy, consultant; Dave Patterson, Fisheries and Oceans Canada, pers. comm.). The Nechako is one of the two largest sources of warming for the Fraser (Foreman *et al*. 1996). Stuart Lake, BC: A modeling exercise suggests that cold water releases from deep in Stuart Lake would reduce the temperatures in the Stuart River and Nechako but would have limited effect once the Nechako meets the Fraser River (Foreman *et al*. 1996). Things to consider: • There may only be a local effect on temperature • Effect on the ecosystem, colder is not always better • Engineering challenges & costs of maintaining and accessing cold water source • Temperature control curtains may be a cost effective way of selectively withdrawing cooler water from a reservoir with thermal stratification (Vermeyen 1997) • Climate change is expected to result in ecosystems shifting from glacierized or snow dominated to snow or rain dominated (Stahl 2007). These changes (i.e. less snow melt and more rain) will affect the cold water source and the methods used to maintain a cold water supply. For example, a reduction of snowmelt in the Trinity River watershed would mean that greater carryover storage (minimum water level in the reservoir) would be necessary as lowering the level too far warms the reservoir (Deas 1997).

Action	Description	Evidence, examples and considerations for implementation
Manipulate surface water / groundwater interactions	Use groundwater injection to cool surface waters, thereby moderating temperatures and providing flows in rearing channels.	Groundwater fed side channels are a strategy being used in the Pundledge, Nicola, Coldwater, Englishman, Clearwater and Cowichan Rivers in BC (Howie Wright, Okanagan Nation Alliance; Angus McKay, Pacific Salmon Commission; Tom Rutherford, Fisheries and Oceans Canada, pers. comm.). Groundwater moderates the temperature of rearing channels maintaining cool temperatures in summer and warm temperatures in winter. Groundwater fed side channels are less prone to winter scouring of eggs and juveniles and have a water supply through the summer. There are a number of criteria to build a groundwater fed side channel that is going to work: • Groundwater source • Sufficient space and the right slope • Substrate (gravel; clay, sand, silt do not work) • GROUNDWATER channels are self fed and therefore self sustaining if setup properly
Transport fish manually	In locations where flows are excessively low, spawners can be captured and trucked to upstream spawning areas.	This strategy ensures that at least a limited number of fish get into the spawning ground, in years where few can get there by themselves. In Cowichan River, BC 2006, only 200 of 11,000 chinook were able to reach the spawning grounds due to low flows, they were able to truck an additional 900 fish up to the spawning grounds (Tom Rutherford, Fisheries and Oceans Canada, pers. comm.).
Improve fish passage	Fish passage devices can improve survival of adults migrating upstream to spawning areas, and juveniles outmigrating to the ocean.	There is a large body of evidence describing how fish passage over hydropower devices can be improved. The Electrical Power Research Institute has written a Manual of Upstream and Downstream Fish Passage and Protection Technologies for Hydroelectric Application (http://www.epri.com/Portfolio/product.aspx?id=1167). The fish passage center in Oregon provides recommendations and analysis of fish passage data (http://www.fpc.org/about_fpc.html). Examples of downstream fish passage technology: CANMET Energy Technology Centre Natural Resources Canada—Currently working to develop a fish-friendly but efficient turbine. (http://www.nrcan.gc.ca/es/etb/cetc/cetc01/TandI/pdf/Fish-friendly%20Presentation%20Hydrovision2006.pdf). Pacific Northwest National Laboratory scientists—turbine design studies to provide the biological criteria for fish to survive turbine passage (http://hydropower.id.doe.gov/turbines/pdfs/pnnl-biospec.pdf) Advanced Hydropower Turbine Project (sponsored by the U.S. Department of Energy (DOE))—have designed a new turbine that should allow safe passage of fish through the runner, while achieving a competitive hydraulic power efficiency (Cook *et al.* 2000; http://www.aldenlab.com/index.cfm/Services/Hydroelectric_Turbine_Design). Alstom Power Hydro—designed the "vortex turbine" to reduce injury to fish passing through the turbine (http://www.hydro.power.alstom.com/home/technology_centers/turbine_technology_center/fish_friendly_turbines/7220.EN.php?languageId=EN&dir=/home/technology_centers/turbine_technology_center/fish_friendly_turbines/). Examples of upstream fish passage technology include (http://wdfw.wa.gov/hab/ahg/fishguid.pdf): (i) Fish ladders, (ii) Improved culvert design, (iii) Pool and W\wr, (iv) Vertical slot, (v) Roughened channels, (vi) Hybrid fishways, and (vii) Mechanical fishways.

Action	Description	Evidence, examples and considerations for implementation
Implement low impact forestry practices	Use forestry practices that minimize impacts on watersheds.	Poor forestry management (insufficient riparian buffers) has resulted in changes to the tributaries that affect the entire watershed. Increased runoff and fine sediment supply from tributaries to the mainstem creates habitat concerns. Decreased shade in the tributaries can lead to heating in mainstems and a reduction in supply of large woody debris. Many references discuss best management practices that minimize impacts on freshwater ecosystems (e.g., Slaney and Zaldokas 1997; Solari no date; Meehan 1991). Examples include: • Maintaining riparian buffers • Avoiding steep slopes • Minimizing the use of chemicals Logging Road Management: • Design to minimize sediment input • Use crushed rock reduces surface erosion (Roni *et al.* 2002) • Install adequate drainage structures and stream crossings • Deactivate old logging roads thus restoring land to its original condition
Implement low impact grazing practices	Use cattle grazing practices that minimize impacts on rivers and riparian zones.	Domestic grazing animals can adversely affect rivers and the riparian zone. Maintaining riparian vegetation is particularly important to help maintain cool stream temperatures. In locations where ranchers restrict access to streams and river banks, slope failure can be prevented leading to re-establishment of riparian zones (Angus MacKay, Pacific Salmon Commission, pers. comm.). The California Cattlemen's Association recognized 9 different ranches which have taken innovative measures to protect the rivers and riparian areas in the booklet, Grazing for Change (Macon no date). Low impact grazing techniques can include: • Riparian fencing • Rotational grazing • Offstream water development (prevents cattle from needing to directly access the river) • Brush and woody vegetation control/removal • Rangeland Water Quality Management Plan • Riparian restoration • Controlled burning • Native perennial grass restoration
Engineer streams	Engineer streams to create artificial habitats that replace lost or degraded rearing habitats.	Engineered streams are constructed as natural type channels that meander over a location to maximise functional stream surface area, with variable stream widths that contain the natural components of salmon rearing habitat (pools, riffles, runs, deep ponds). Spawning channels for sockeye, chum, and pinks have been successful in providing spawning habitat and increasing productivity (e.g., Weaver Creek Channel in the Harrison Lake Basin, BC). A pilot engineered stream on the Dungeness River has had production efficiencies as high as 10 fingerlings per square meter, representing more than 70% survival of eggs (Brannon 2006). Engineered streams cost from $10,000 to $50,000 per km and require ongoing maintenance.

Action	Description	Evidence, examples and considerations for implementation
Enhance instream habitat	Use large woody debris (LWD), boulders, or gravel to improve fish habitat and compensate for the loss of habitat complexity.	Increasing quality of freshwater habitat and hence increasing survival to offset increased mortality due to climate change is one strategy to help salmon survive climate change (Ward *et al.* 2006, Nina Hemphill, Trinity River Restoration Program, pers. comm.). There is evidence that instream habitat enhancement may be effective for increasing freshwater productivity for some species (Roni *et al* 2002; Lacey *et al.* 2004; Ward *et al.* 2006). However they tend to have limited persistence and they should be employed only where short term enhancement is needed (Roni *et al.* 2002). A more holistic approach is needed in the long term, restoring ecological function so that the instream enhancements are unnecessary. For example, planting riparian vegetation to provide a long term source for woody debris and ensuring adequate flows to ensure the natural hydrological processes occur to maintain sediment budgets and channel complexity (USFWS and HVT 1999).
Enrich streams / lakes with nutrients	Add inorganic nitrogen and phosphorous to freshwater environments by using artificial fertilizers or hatchery salmon carcasses.	In BC, surveys indicated large decreases of nutrients in watersheds where populations have not been enhanced by hatchery supplementation, fertilization, construction of spawning channels, or other mitigating action (Larkin and Slaney 1997 as cited in Roni *et al.* 2002). Late summer weights of coho salmon and steelhead fry in the Keough River, British Columbia, were 1.4–2.0-fold greater and smolt yield doubled during years when N and P were added to the river (Johnston *et al.* 1990 and Ward 1996 as cited in Roni *et al.* 2002). The addition of N and P during the growing season resulted in increased primary, secondary and tertiary productivity in a number of sockeye lakes (Stockner and Hyatt 1984; Hume *et al.* 1996; Bradford *et al.* 2000 all as cited in Hume *et al.* 2003). Things to consider: • Nutrient concentrations at point of application and downstream • Influence of urban areas where nutrient loadings may already artificially high • Application of hatchery carcasses to a site several times through the spawning season rather than all at once • Consider reductions in harvest prior to artificial enhancement of nutrients
Enhance production with hatcheries	Use hatcheries to aid conservation of depressed salmon stocks or enhance catch for fisheries.	Hatcheries are generally thought to be a threat to wild salmon as they can cause major evolutionary shifts and reduce biodiversity due to the inflated success of a few hatchery raised genotypes (Nina Hemphill, Trinity River Restoration Program, pers. comm.). However, despite the potential harm to wild salmon, hatcheries are here to stay. They provide compensation for the reduction in wild salmon due to river degradation from dams and urbanization. If we want salmon populations large enough to sustain viable recreational and commercial fishery we need to have enhancement (Curtis and Lovell 2006). Hatchery practices can be managed to minimize the impact on wild salmon by mimicking natural mate selection (Hankin 2007), using local broodstock, mating procedures that maintain genetic diversity, obtain eggs from throughout the spawning period and releasing smolts at similar weights and time as wild smolts (MacKinlay *et al.* 2004). Tyedmers and Ward (2001) suggest that a possible management response to climate change is to re-evaluate the role of hatcheries and consider shifting the focus from maintaining the fishery to the conservation of threatened species and the possible experimental outplanting of fish into environments outside their current range. Outplanting hatchery raised fertilized eggs or juveniles into a new environment for the purpose of enhancing the wild stocks has been tried many times in BC, but most programs have been cancelled due to the lack of success (Roos 1991; Marc Conner, Taku River Tlingits First Nation pers. comm.). In the Taku River watershed, recent attempts to stock Tatsamenie Lake with Sockeye were unsuccessful (Hyatt *et al.* 2005; Marc Conner, Taku River Tlingits First Nation, pers. comm.). However, corresponding attempts in the Tahtlan Lake of the nearby Stikine watershed were considered successful with the survival rate for hatchery fry being three times that of wild fry (Hyatt *et al.* 2005).

Action	Description	Evidence, examples and considerations for implementation
Create off-channel habitat	Create side channel spawning and rearing habitats.	Increasing the amount of freshwater habitat to offset increased mortality due to climate change is one strategy (Ward *et al.* 2006). As stream flows increase in fall and winter, juvenile coho salmon and certain other salmonids seek refuge in off-channel habitats (Peterson 1982 and Tschaplinski and Hartman 1983 as cited in Roni *et al.* 2002). Overwinter survival and growth of coho salmon are higher in off-channel ponds and low-gradient ephemeral tributaries than in main-stem habitats (Swales and Levings 1989 as cited in Roni *et al.* 2002). The Yurok tribe in California is working to provide tributary habitat, particularly high elevation habitat as a strategy to help endangered coho in the Trinity River. Higher elevation habitat should be cooler later in the year (Nina Hemphill, Trinity River Restoration Program, pers. comm.). Things to consider: • Sufficient woody debris and other sources of instream cover • Ensure entrance doesn't run dry • Optimal pond size and depth • High elevation habitats may be particularly important given climate change
Create deep pools	Dig deep pools for adult holding, or juvenile rearing, thereby providing thermal refuges.	One tactic they may use in an attempt to restore the San Joaquin River, CA where they don't have as much snow is to dig deeper pools in the river for fish to hold in (Nina Hemphill, Trinity River Restoration Program, pers. comm.). These deeper holes will not warm up as quickly. They may occur naturally, but often get filled in due to an excess of fine sediment. So fine sediment management is another part of this solution as the holes may have to be dug out periodically.
Clean gravels	Remove silt and sand from spawning gravels, both of which reduce egg survival.	Ideally spawning gravel is free of silt and sand so water can percolate through the redds bringing oxygen to the eggs. Spawning gravel can be cleaned, but is expensive and fresh sediment may be deposited with later high flows. This strategy has been tried with limited success in BC in the Horsefly and Nadina Rivers.
Restore connectivity	Restore connectivity to high-quality fish habitats by removing perched culverts or other artificial obstructions.	Increasing the amount of freshwater habitat to offset increased mortality due to climate change is one strategy (Ward *et al.* 2006). One way to increase amount of freshwater habitats is by removing barriers (e.g., culverts) to allow access to previously utilized areas as well as to areas that may not have had salmon previously. This strategy is used throughout the Pacific Northwest and in California where individual projects are tracked by a FishXing project team (see www.stream.fs.fed.us/fishxing/case.html). (Nina Hemphill, Trinity River Restoration Program, pers. comm.) Culvert removal or redesign: • Culverts need to be designed to allow passage of both adults and juveniles. Culverts designed for adult passage often create water velocities that exceed juvenile salmon swimming abilities and prevent juvenile fish from reaching important rearing areas (Furniss *et al.* 1991). Smooth culverts lacking roughness or baffles normally impair juvenile fish passage except at very low slopes. (Robison 1999 as cited in Roni *et al.* 2002) • Culverts may affect coho in particular because they tend to use smaller streams where there is not as much flow (Roni *et al.* 2002) • Culverts affect the movement of nutrients up and downstream (Roni *et al.* 2002)
Restore slope stability	Restore slope stability to prevent slides, erosion, and/or sediment deposition in streams.	Restore slope stability to prevent slides, erosion, fine sediment deposition before starting habitat improvements in the main channel (Hartman *et al.* 1996).

Action	Description	Evidence, examples and considerations for implementation
Restore riparian ecosystems	Restore riparian zones that contribute sources of large woody debris and help maintain cool stream temperatures.	The riparian ecosystem is particularly important given climate change, since riparian vegetation provides shade which helps to cool tributaries. In addition riparian vegetation provides a source of large woody debris which improves the quality of rearing habitat and provides habitat for a number of other wildlife species. This strategy is in effect throughout the Pacific Northwest and California. Things to consider: Restoring ecosystem function: • Riparian restoration works really well is in less developed settings, because the river is not constrained and can shift, change and flood (Stacey Webb, Pacific Salmon Foundation, pers. comm.) • In some areas it is hard to get riparian vegetation to establish. There is some question as to whether we improve things by planting or if vegetation would grow just as well without any help (Howie Wright, Okanagan Nation Alliance, pers. comm.). • Re-establishing successional processes for pioneer species would require channel meandering with formation of new alluvial surfaces and flow regimes that mimic the natural frequency and timing (Orr *et al.* 2006). • Riparian restoration without ecosystem function restored may require periodic intervention as well as expensive actions such as floodplain grading (Orr *et al.* 2006) Choice of Species: • Plant conifers in riparian zones after disturbances, conifers provide better long term source of woody debris (Roni *et al.* 2002). • There may be tradeoffs between species in terms of the shade they provide and the water they require (Bill Green, Columbia River Inter-tribal Fisheries Commission, pers. comm.). • Detailed understanding of the timing of seed dispersal and recruitment requirements is needed in order to best determine which plants are most suitable and how to manage the flows most effectively. Where? The focus for riparian planting should be in the tributaries (Nina Hemphill, Trinity River Restoration Program, pers. comm.). The impact of shading on large rivers is minimal (Al von Finster, Fisheries and Oceans Canada, pers. comm.). Tributaries will remain cooler with sufficient shading and this will flow into the mainstem providing cold water refuges in the mainstem. These are used by adult migrating fish as holding areas and they can move between these in order to find an appropriate spawning area (Nina Hemphill, Trinity River Restoration Program, pers. comm.). Timing: It takes 15–20 years to see habitat effects of riparian planting.
Move dykes back from rivers	Setting dykes back allows rivers to meander naturally, restoring connectivity of the river channel to the flood plain.	Constraints such as dykes prevent natural alluvial processes including meandering, scouring, flooding and sediment transport and create channelized simple rivers including the Okanagan River and the Trinity River (Howie Wright, Okanagan Nation Alliance, pers. comm.; USFWS and HVT 1999). They are setting dykes back in the Okanagan River, BC and removing dykes and buying up floodplain land in the Trinity River, CA in order to allow the natural alluvial processes to occur (Howie Wright, Okanagan Nation Alliance, pers comm.; USFWS and HVT 1999). Complex river channels have significantly more habitat for a range of species and are necessary to maintain ecosystem function. This strategy is much easier in less developed regions, where the floodplain land is not owned by private owners and there are fewer concerns with flooding. In the Trinity River, a great deal of money and effort is being spent to purchase critical floodplain habitat from home owners. Conserving floodplains along with rivers in the first place would be much cheaper.

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APPENDIX E. REVIEW OF FEDERAL-PROVINCIAL LEGAL, REGULATORY, AND POLICY LEVERS

Relevant legislation, regulations, or policies	Strengths and opportunities	Weaknesses
Fisheries Act S. 35(1): prohibits works/undertakings that result in HADD of fish habitat (includes enforcement/fines, habitat compensation) Operational Statements for S. 35(1) regulatory review of low-risk activities S. 30: installation & maintenance of fish guards/screens on water intakes or diversions where the Minister deems it necessary S. 32: prohibits the destruction of fish by means other than fishing unless authorized by the Minister or GIC S. 22: requires sufficient flow of water for the descent of fish past obstructions, for the free movement of migratory fish during construction and for the safety of fish and fish eggs downstream, where the Minister deems it necessary. S. 22(3): Flow orders d/s of dams	• Under S. 22(3), Act can be used to protect flows (e.g., cancellation of Alcan's Kemano Dam project on the Nechako; Young, pers. comm.). This is very political. DFO has ordered BC Hydro to release water for the safety of fish and eggs (Watts, pers. comm.). • Re. Fish habitat (HADD) compensation / remedial measures: (1) Criteria for success of compensation structures should be considered over a longer time frame. Require that proponents are responsible for the successful maintenance of habitat structures. If a natural disturbance destroys a habitat structure, the proponent needs to rebuild it. (2) Biological effectiveness should also be required when evaluating success of compensation structures. Currently footprint area is the focus of evaluating / designing compensation projects. • Re. S. 35(1) HADD enforcement/ fines: Fisheries Officers often use S. 32 (fish kills) instead of S. 35(1) as it is easier to tie to an owner/user than is a HADD (Watts, pers. comm.).	• DFO's regulatory powers mainly deal with retroactive damage and are not well suited to forward planning (Pendray, pers. comm.). • DFO's influence is mainly either "indirect" (i.e., DFO doesn't control a particular activity (e.g., forestry), but can provide comments, scientific advice, etc.) or is fairly localized (i.e., review and application of Fisheries Act requirements at discrete sites only) (Pendray, pers. comm.). • S. 35 HADD is difficult to prove, even though case law states water is habitat. First must deal with the water as habitat issue, then must prove the harm (e.g., extraction). S. 35 doesn't address cumulative issues of water use—question of where the harm was and who did it (e.g., on the Nicola there are 200+ users). It is especially difficult to prove a HADD if it's due to groundwater extraction (of particular relevance on southern Vancouver Island & in the BC Interior, where critical stream flow in summer depends on groundwater (Watts, pers. comm.; Christensen 2007). • Compensation initiatives designed to offset approved habitat losses have been insufficient and ineffective, largely because of inadequate enforcement & monitoring (cited in Young and Werring 2006). • Lack of enforcement, reductions in enforcement personnel compounded by reduced enforcement personnel at provincial level.
Proposed new Fisheries Act (Bill C-41)	• Distinguishes between large scale & small scale projects, ensures that actual harm to fish & fish habitat take precedent over process, and removes overlap and duplication between federal & provincial processes. • Includes more "meat" on key sections (e.g., right now if an authorization is given for a HADD, there is no recourse if habitat compensation is not done). Practitioners were keen on ticketing provisions, but likely won't fly (Watts, pers. comm.).	

Relevant legislation, regulations, or policies	Strengths and opportunities	Weaknesses
Species at Risk Act (2002)	• Provides opportunities for species & habitat protection, as critical habitat can be designated for protection. • The US Endangered Species Act has been a powerful tool for conservation of salmon and their habitat in the PNW. SARA could be used in a similar fashion, should the political will and appropriate science be available.	• Salmon harvesting allowed even if species are listed; listing entire species vs. distinct populations (Lackey *et al*. 2006). • Failure to list Sakinaw and Cultus Lake sockeye, populations that were listed as endangered in 2002 by the COSEWIC. If the Interior Fraser coho had been listed, recovery planning strategies would have focused on water flow and temperatures as these are key limiting factors (Temple 2005; Watts, pers. comm.)—non-listing of species may be due to economic & political pressures (Ashley 2006) and/or difficulties in defining critical habitat.
Policy for the Management of Fish Habitat (No Net Loss (NNL) policy) (DFO 1986)—Advocates net gain of habitat for fisheries resources, & is based on NNL of productive capacity of habitat (Rosenau and Angelo 2005). The first and preferred approach is prevention of habitat loss. DFO policy also stipulates that where a harmful alteration of habitat is authorized by the Minister, losses shall be compensated by habitat replacement.	• A more effective approach to achieve NNL must assess the importance of habitat on an ecosystem basis, and balance the degree and type of impact with the most effective remedy. In evolving to a more integrated approach, DFO must make greater use of indicators to assess and monitor the health of habitat. • To achieve the NNL objective, wide ranging and specific conservation objectives, tied to quantifiable performance measures, should be established (Young and Werring 2006).	• Strategies for achieving "NNL" have focused primarily on project-by-project review. • As Auditor General has repeatedly noted, limited effectiveness (continued loss of habitat) due to overall lack of enforcement (because of deregulation, poor funding & staffing, and poor definition of responsibilities), ineffective policy and poor management (Young and Werring 2006). Poorly protects smaller streams. Two significant shortcomings are (1) application is not mandatory, and (2) it is aimed primarily at the protection of "habitat that produces a fisheries resource"—in other words, protection of habitat for salmon stocks that are commercially harvested. This discretionary approach contributes to an inconsistent application of the policy and leads to inevitable loss of salmon habitat. Habitat protection efforts don't focus on full range of habitats required to protect abundance and diversity of salmon (Young and Werring 2006).

Relevant legislation, regulations, or policies	Strengths and opportunities	Weaknesses
Policy Framework for the Conservation of Wild Pacific Salmon (Wild Salmon Policy) (DFO 2005)	• Based on conservation units which take genetic diversity into account. There are clear steps to outline performance measures and conservation goals for the various conservation units. Although they haven't implemented these things yet, the pieces are in place to conserve and monitor status / trends in the near future. A new focus on the salmon habitat that is most productive, limiting, or at risk in a CU will clarify decision-making and better link habitat management strategies to harvest and salmon assessment (Strategy 4). Low risk activities, where measures to avoid or mitigate impacts are well understood, will be dealt with through other mechanisms such as guidelines and standards. • Recognizes importance of managing salmon diversity and, in doing so, disavows actions/ concepts that don't adequately protect/recognize salmon diversity (e.g., managing development projects in isolation) (Young and Werring 2006). • Recognizes the need to incorporate ecosystem values into salmon management (but does not commit to doing so); while vague on details of how to do this, it is nonetheless important in introducing the concept of ecosystem-based management (Young and Werring 2006).	• Does not commit DFO to continue to protect habitat when a specific stock is in decline or reaches critical levels (Young and Werring 2006).
Canada Water Act (1970)	• Provides framework for cooperation with provinces & territories in the comprehensive conservation, development, and utilization of Canada's water resources and related ecosystem initiatives.	• Limited application to date—Part II dealing with water quality has never been used.
Canadian Environmental Assessment Act (1995)	• Focus is on precautionary principle, provides for mitigations to address HADDs.	• Fewer proposed projects are requiring assessment under CEAA because of Fisheries Act authorization triggers due to DFO's Risk Management Framework ("low-risk" projects won't require an authorization, and thus won't trigger CEAA). • Increased use of class screenings removes focus on individual project impacts; all measures & conditions taken to avoid a HADD will be non-project specific.
Navigable Waters Protection Act	• Fundamental tool used in conservation and habitat protection, because of its role as "law list" trigger for Environmental Assessments under CEAA.	
Indian Act	• Limited provisions regarding the types of water bylaws that bands can pass on reserve land (Nowlan 2005).	

Relevant legislation, regulations, or policies	Strengths and opportunities	Weaknesses
CCME Environmental Quality Guidelines and provincial BC Water Temperature Guidelines—see http://www.env.gov.bc.ca/wat/wq/BCguidelines/temptech/index.html#TopOfPage	• Contain water quality guidelines (including water temperature, turbidity, suspended sediments) for the protection of aquatic life. • CCME (through National Water Research Institute) supports importance of science in policy initiatives—potential opportunity for highlighting science to policy makers.	• Unenforceable.
Water Act (S. 9) and Water Regulation (Part 7)—deal with the use / diversion of water & specify requirements that assure work being done in & about a stream doesn't compromise water quality, fish & wildlife habitat and the rights of other water users.—see http://www.env.gov.bc.ca/wsd/water_rights/cabinet/wrconsolidation.pdf Water licences Part 4 relates to Water Management Plans	• Government can restrict changes in and about streams using the power vested in it in the Act. • When reviewing new license applications & when existing licenses are up for renewal, explicit consideration could be given to the protection of instream flows (e.g., minimum monthly flow requirements) and the amount of water that is needed to maintain ecological health (e.g., potential for reduced summer flows in many rivers/streams due to climate change and resulting pressures on fish populations) (Tyedmers and Ward 2001). • S. 3 states the Lieutenant Governor in Council may develop regulations to apply the Act to groundwater, however this has not occurred. • Specification of purposes for which water will be used supports the concept of beneficial use. Section 23(2)(a) of the Water Act allows a water license to be suspended or revoked if the licensee does not make beneficial use of the water as outlined in the terms of the license. Beneficial use is not defined in the Act; however, s. 39 (1)(c) gives "engineers and officers" employed by the government the power to determine what constitutes beneficial use (Cohen and Neale 2003).	• No mention of fish—under the Act fish are not users of water and therefore do not have any beneficial rights to water. Neither recognition of instream flow values nor consideration of the amount of water needed to maintain ecological health prior to applications being received and licenses granted (Watts, pers. comm.; Cohen *et al* 2003; Nowlan and Jeffries 1996; Christensen 2007). • Applies only to surface waters; no attention given to groundwater in the Act. (Watts, pers. comm.) • Attitude that water is plentiful & cheap is reinforced by the Act (O'Riordan, pers. comm.). • Potential for oversubscription of licences (no formal assessment of the capacity of the water source to support the water use) (Christensen 2007); licences are allocated too long-term; monitoring and enforcement of licences needs to improve; costs of licences don't reflect value of water; there are no incentives for water use efficiencies. • Water rights issued with a license are perpetual; they don't expire or require renewal (exception is newer licenses, however they have strong rights of renewal) (Christensen 2007). Licenses are transferred or divided when the land or undertaking to which they are appurtenant is sold, subdivided or otherwise transferred. The date of precedence does not change with transfer or division of a water license therefore the priority of the water license on the source remains constant (Cohen and Neale 2003). • The Ministry does not monitor actual consumption or beneficial use on a regular basis, however it may take these into consideration when evaluating new license applications (Cohen and Neale 2003). • "No loss of wetlands" is not given priority in water licensing and approval decisions under the Act. Definition of "stream" is narrow, and excludes other types of wetlands. (Nowlan and Jeffries 1996) • Part 4 provisions relating to Water Management Plans (which can be used to protect instream flows for fish & fish habitat)

Relevant legislation, regulations, or policies	Strengths and opportunities	Weaknesses
		haven't been implemented (although one is currently under preparation in Langley) (O'Riordan, pers. comm.; Christensen 2007). • Has a "use it or lose it" feature whereby rights may be forfeited for non-use. While this is positive in that water can be reallocated to other uses, it may act as a disincentive to conservation by promoting water use when not needed (to maintain a legal use right) (Christensen 2007). • No public rights to be notified of license applications (only riparian owners and others with water licenses for the same water source) (Christensen 2007).
Water Stewardship Policy / Action Plan	• Under development; this policy is needed and must be approved before Water Act is revised (Watts, pers. comm.). • Two of three issues have relevance to salmon: (1) wise use of water (i.e., demand-side management tools to encourage conservation—metering, pricing), and (2) watershed stewardship.	• Wasn't referred to in the Throne Speech.
Water Use Planning	• Developed through multi-stakeholder consultative process in an effort to find the balance between competing uses of water such as domestic water supply, fish and wildlife, recreation, heritage and electrical power needs; reviewed under BC's Water Act. • Proactive ecosystems-based approach to planning allows for management according to flow timing needs of downstream users (including salmon) (Tyedmers and Ward 2001). • Not limited by legislation (Young, pers. comm.). • Very effective (O'Riordan, pers. comm.), but requires significant funding ($20 million/year) for power offsets—paid for by rate-payer). Also requires will, priority-setting, and recognition of opportunities for habitat protection.	• WUP that allocates minimum flows for fish may be in conflict with the Water Act. (Young, pers. comm.) • Water Use Plans don't currently consider water temperature requirements; need to develop downstream "fish friendly" thermal regime targets (Tyedmers and Ward 2001).

Relevant legislation, regulations, or policies	Strengths and opportunities	Weaknesses
Instream Flow Guidelines—see www.env.gov.bc.ca/wld/BMP/ instreamflow_wkgdrft.html Provides a unified set of guidelines (coarse filter method) for IPP proponents with respect to fish flow issues, potentially addressing conflicts between the *Water Act* & the *Fisheries Act* (i.e., if flow changes constitute a HADD) & encouraging consistency across projects when addressing flow issues	• Developed collaboratively with DFO. • Good for encouraging hydrological studies/research (Watts, pers. comm.). • Have applicability to assessing impacts of any water extraction, not just hydro. • Encourages IPPs to mimic natural flow variability (based on historic flow information); aligned with NCC paradigm (Watts, pers. comm.).	• No regulatory teeth on their own. • Limited application; many proponents going directly to detailed studies as the guidelines are too conservative (Watts, pers.com.).
Fish Protection Act and related Streamside Protection, Sensitive Streams Designation, Licensing Regulations—This enabling legislation allows municipalities to enact by-laws and take other steps to control residential, commercial and industrial activities in proximity to streams and rivers within their municipal boundaries (e.g., prohibits bank-to-bank dams on provincially significant rivers).—see http://www.qp.gov.bc.ca/statreg/reg/F/FishProtect/89_2000.htm See below for discussion of related *Riparian Areas Regulation*.	• Provides for fish habitat compensation; establishes special rules in relation to water licences on "sensitive streams" where fish habitat is at risk (15 designated to date, O'Riordan, pers. comm.). • S. 7 allows for recovery plans to be developed for "sensitive streams," to implement measures to recover flows needed for sensitive fish populations (O'Riordan, pers. com; Rosenau and Angelo 2005). • Allows stream flow protection licenses to be issued to community-based organizations in an effort to ensure adequate flows for fish (assuming there is adequate information/ data around it) (Rosenau and Angelo 2005; Watts, pers. comm.). • Temporary reduction in water use rights during periods of drought when the sustainability of fish is threatened can be authorized by regional water manager (but must have the information needed to make the decision). By using the powers vested in them in the Act, municipal governments can dramatically restrict logging on private lands or on Crown lands within the district or municipality.	• Some portions of the Act critical to protecting habitat values are currently not in force (Rosenau and Angelo 2005). • Inadequate application of "sensitive streams" designation. Few streams determined by DFO & the province to have inadequate water flows have been designated (only 4% in 2002; T. Buck Suzuki Foundation, no date). • Vague, not much substance (Watts, pers. comm.). • Nothing specific relating to temperature. (Watts, pers. comm.) • Doesn't provide a statutory basis for "no loss of wetlands" (Nowlan and Jeffries 1996). • S. 5 (which provides for consideration of fish and fish habitat concerns in water licensing decisions and allows for measures requiring reductions in water used pursuant to surface water licenses (where a water management plan is created under the Water Act)) can't be invoked to protect fish/fish habitat from impacts of groundwater extraction because licenses are only required for surface water extraction.
Forest and Range Practices Act & related Range & Forest Planning & Practices Regulations (GAR instruments listed separately below—see http://www.for.gov.bc.ca/tasb/legsregs/frpa/frparegs/govact/gar.htm)	• Unlike the Forest Practices Code, which was prescription-based, the FRPA is results-based (e.g., maintenance of vegetative integrity).	• Difficulty in determining when/if results are achieved (are there standards, monitoring of stream temperatures?). • Requires more monitoring capacity.

Relevant legislation, regulations, or policies	Strengths and opportunities	Weaknesses
Fisheries Sensitive Watersheds (*GAR* S. 14 and Forest Practices and Planning Regulation S. 8)—see http://www.env.gov.bc.ca/wld/frpa/fsw/ index.html	• To qualify, watershed must have significant fisheries values and watershed sensitivity. Once a watershed is designated (3 to date), FRPA agreement holders must set out objectives in their Forest Stewardship Plans that identify management actions that conserve important watershed level attributes protecting fisheries values (www.env.gov.bc.ca/wld/frpa/fsw/index.html). • Recognizes integral linkages between upland conditions and their influence on maintaining aquatic conditions (including flow & temperature) necessary to sustain healthy fish populations.	
Temperature Sensitive Streams (GAR S. 15)—see http://www.env.gov.bc.ca/wld/frpa/tss/ index.html	• Designation may occur if trees are required adjacent to stream to manage temperature for protection of fish and if management of the temperature is not otherwise provided. • Theoretically effective in maintaining watercourse shading to ensure mainstem and tributary temperatures (e.g., Nicola) (Watts, pers. comm.).	• No streams designated yet under FRPA however TSS designations under FPC still apply (O'Riordan, pers.com).
Riparian Areas Regulation (2004) enacted under S. 12 of the *Fish Protection Act*	• Calls on local governments to protect riparian areas during residential, commercial, & industrial development by ensuring that proposed activities are subject to a science based assessment conducted by a Qualified Environmental Professional. • Provides, in theory, for the protection of the features, functions & conditions that are vital in the natural maintenance of stream health & productivity. These vital features, functions and streamside area conditions are numerous and varied and include such things as sources of large organic debris (fallen trees and tree roots), areas for stream channel migration, vegetative cover to help moderate water temperature, provision of food, nutrients and organic matter to the stream, stream bank stabilization and buffers for streams from excessive silt and surface runoff pollution. • Doesn't explicitly deal with stream shading and flow (Young, pers. comm.).	• Applies only to local governments located on the east side of Vancouver Island, the Lower Mainland and the Southern Interior, as these are the parts of BC experiencing the most rapid urban growth. This includes the following regional districts and all municipalities within them: Capital, Central Okanagan, Columbia-Shuswap, Comox-Strathcona, Cowichan Valley, Fraser Valley, Greater Vancouver (except the City of Vancouver), Nanaimo, North Okanagan, Okanagan-Similkameen, Powell River, Squamish-Lillooet, Sunshine Coast, Thompson-Nicola and the trust area under the Islands Trust Act. • The regulation does not apply to agriculture, mining or forestry-related land uses. Riparian protection for these activities are provided by other initiatives.

Relevant legislation, regulations, or policies	Strengths and opportunities	Weaknesses
Agricultural and Rural Development Subsidiary Agreement (ARDSA) (Ministry of Agriculture, Food and Fisheries)	• Funding mechanism (federal-provincial-municipal) and criteria for agricultural drainage. • Guidance on how to prepare Agricultural Drainage Management Plans.	• Agricultural ditches (used for drainage and/or irrigation purposes) may affect fish habitat (e.g., through maintenance activities; nutrient leaching may cause vegetation growth, increasing stream temperatures). ARDSA objectives specify that drainage channels have a 1.2 metre freeboard in outlet ditches. Drainage systems constructed to these specifications cause damage to aquatic wetland ecosystems adjacent to streams, channelized waterways or drainage ditches through drying and desiccation, as well as disrupting the hydrology (rate of flow). When these criteria are implemented they can also act as a barrier to juvenile fish passage into adjacent wetland habitats.
Mountain Pine Beetle Action Plan (see http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/actionplan/2006/Beetle_Action_Plan.pdf)	• One action relates to habitat: Examine opportunities & costs, including possible funding sources, for techniques to restore non-timber values (e.g., wildlife habitat, hydrological function).	• Minimal reference to habitat; no regulatory teeth on its own. Salvage logging likely to result in temperature & flow impacts.
Environmental Assessment Act and Reviewable Project Regulation	• Groundwater extraction projects with an extraction capacity > 75L/s trigger an assessment. Also proposed groundwater extraction where it is part of a larger project triggering an assessment (Christensen 2007).	• Doesn't apply to forestry.
Land & Resource Management Plan (LRMP) Process		• Riparian habitat/watershed protection; candidate protection areas (CPAs); ecosystem-based management approach.
Private Managed Forest Land Act and Regulation	• Sets objectives for water quality & fish habitat; provides for mitigation/fines for damage to fish and fish habitat.	
Wildlife Act	• Provides for designation of endangered species.	
Water Protection Act		• Very indirect link to project, as focus is on use of groundwater as drinking water. Relates to temperature because increased temps mean increases in bacteria levels.
Local Government Act (formerly *Municipal Act)*	• Provides enhanced powers for municipalities to protect wetlands through designation of environmentally sensitive areas, zoning and subdivision procedures, etc., and for the collection of taxes.	
Land Act (s. 16)	• Watershed reserves (allows for Integrated Resource Management; may include logging). • Policy of "no net loss" of wetlands could be given priority in land use decisions involving wetlands on Crown land.	

APPENDIX F. REFERENCES CITED IN APPENDIX E

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