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: CASE STUDIES

Perspectives from the Okanagan, Quesnel, Nicola, Cowichan, Nass, and Englishman River Watersheds

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Our intention with this report is to present a range of local stories illustrating unique interactions among people, salmon, freshwater habitats, and climate across British Columbia. These case study perspectives draw upon a literature review and discussions with a limited set of people familiar with these watersheds. We are extremely grateful to these people for their time and contributions:

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Any errors of omission or oversight in presenting these case studies are our own. Given our limited ability to engage local interests, we also apologize in advance to any groups / individuals who did not have an opportunity to provide input. Our hope is that these case study perspectives facilitate a broader understanding about the challenges facing freshwater habitat managers and local communities in the context of an uncertain climate future, not to contradict, ignore, or impede progress towards helping salmon in these watersheds. Many thanks to the Pacific Fisheries Resource Conservation Council for initiating this interesting work.

LIST OF ACRONYMS

AAC	Annual Allowable Cut
BC MOF	British Columbia Ministry of Forests
BCWWA	BC Water and Waste Association
CCLUP	Cariboo-Chilcotin Land Use Plan
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Fisheries and Oceans Canada
ENSO	El Nino / Southern Oscillation
ESA	Endangered Species Act
FWMT	Okanagan Fish/Water Management Tools
IJC	International Joint Commission
MELP	Ministry of Environment, Land and Parks
MPB	Mountain Pine Beetle
OBA	Okanagan Basin Agreement
OBWB	Okanagan Basin Water Board
ONA	Okanagan Nation Alliance
ORRI	Okanagan River Restoration Initiative
PDO	Pacific Decadal Oscillation
PSC	Pacific Salmon Commission
SARA	Species at Risk Act
TAC	Total Allowable Catch
TSA	Timber Supply Area
WUMP	Water Use Management 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[1], and that these changes are leading to significant adverse effects on terrestrial, freshwater, and marine environments[2]. 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 equally 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[3]. In a report, *"Indicators of Climate Change for British Columbia 2002"*[4], 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[5]. Time, though, 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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[1] Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: The Physical Science Basis–Summary for Policymakers. Available at: www.ipcc.ch/

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

[3] 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

[4] 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

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

The purpose of this report and companion document, "*Helping Pacific salmon survive the impact of climate change on freshwater habitats: Pursuing proactive and reactive adaptation strategies*"[6] is to facilitate thinking and planning around feasible options that could be implemented. In general, this report integrates ideas from the other one into a local context of geography, people, and salmon at six locations across British Columbia: three interior basins (Okanagan, Quesnel, and Nicola Rivers) and three coastal areas (Cowichan, Nass, and Englishman Rivers). Individual case studies are structured in a way that consider four questions commonly used in State of Environment (SOE) reporting[7]. The intention is not to summarize available information to provide definitive answers in a particular watershed; instead this case study report is intended to communicate a single and diverse story about the range of climate change issues facing salmon in a variety of locations across the province.

1. **What is happening?** A summary of the biophysical features of the watershed, some basic information on salmon and water resources, natural and human factors that limit salmon production, and status / trends of salmon populations.
2. **Why is it happening?** A discussion concerning the state of knowledge about cause-effect linkages, including linkages between climate change-salmon habitats, and to a limited extent confounding factors (see Figure 1).
3. **Why is it significant?** A consideration of the human dimensions to what is happening in the watershed—the human values defining the importance of what is happening to the biophysical environment. For instance, the economic importance (e.g., cost—salmon fishery, water uses), social-regulatory relevance (e.g., Species at Risk Act listings), or ecological / biological significance (e.g., genetically unique) may be underlying drivers defining action in a watershed.
4. **What can we do about it?** A discussion about the solutions-oriented strategies that have been implemented in the past, are currently being pursued, or could be implemented in the future to help Pacific salmon. These considerations relate to the hard and soft infrastructure adaptation strategies described in a companion report, *"Helping Pacific salmon survive the impact of climate change on freshwater habitats: Pursuing proactive and reactive adaptation strategies"*. Summaries of these strategies are provided in Figure 2, Table 1, and Table 2. We recognize there are many issues related to the technical, ecological, and social feasibility of these strategies when applied in a local context. The purpose of this report is not to explore feasibility of implementation.

This report is intended for a more technical audience as it provides technical information and concepts about Pacific salmon in the context of climate change. Case study perspectives do not provide a comprehensive summary of the "state of the science" or policy analysis for a particular basin that would satisfy research scientists or policy analysts. Like the companion report, this one is intended for informed stakeholders, First Nations, fish and fish habitat managers, and to a certain extent policy makers.

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[6] Nelitz, M., K. Wieckowski, D. Pickard, K. Pawley, and D.R. Marmorek. 2007. Helping Pacific salmon survive the impacts of climate change on freshwater habitats: Pursuing proactive and reactive adaptation strategies. Final report prepared by ESSA Technologies Ltd., Vancouver, B.C. for Pacific Fisheries Resource Conservation Council, Vancouver, BC

[7] Examples of State of Environment reports include:

Government of Canada, Province of British Columbia, UBC Fisheries Centre, and University of Victoria. 2006. Alive and Inseparable: British Columbia's Coastal Environment 2006. Available at: www.env.gov.bc.ca/soe/bcce/

Government of Canada. 1991. The State of Canada's Environment. Ottawa, ON.

Province of British Columbia, Ministry of Environment, Lands and Parks, and Environment Canada. 1993. State of the Environment Report for British Columbia.

FIGURE 1. Conceptual diagram illustrating the linkages among freshwater physical habitat factors altered by climate change (e.g., water flows and temperatures), the freshwater biological mechanisms affecting survival, and life stages.
Conceptual diagram described further in Nelitz et al. 2007.

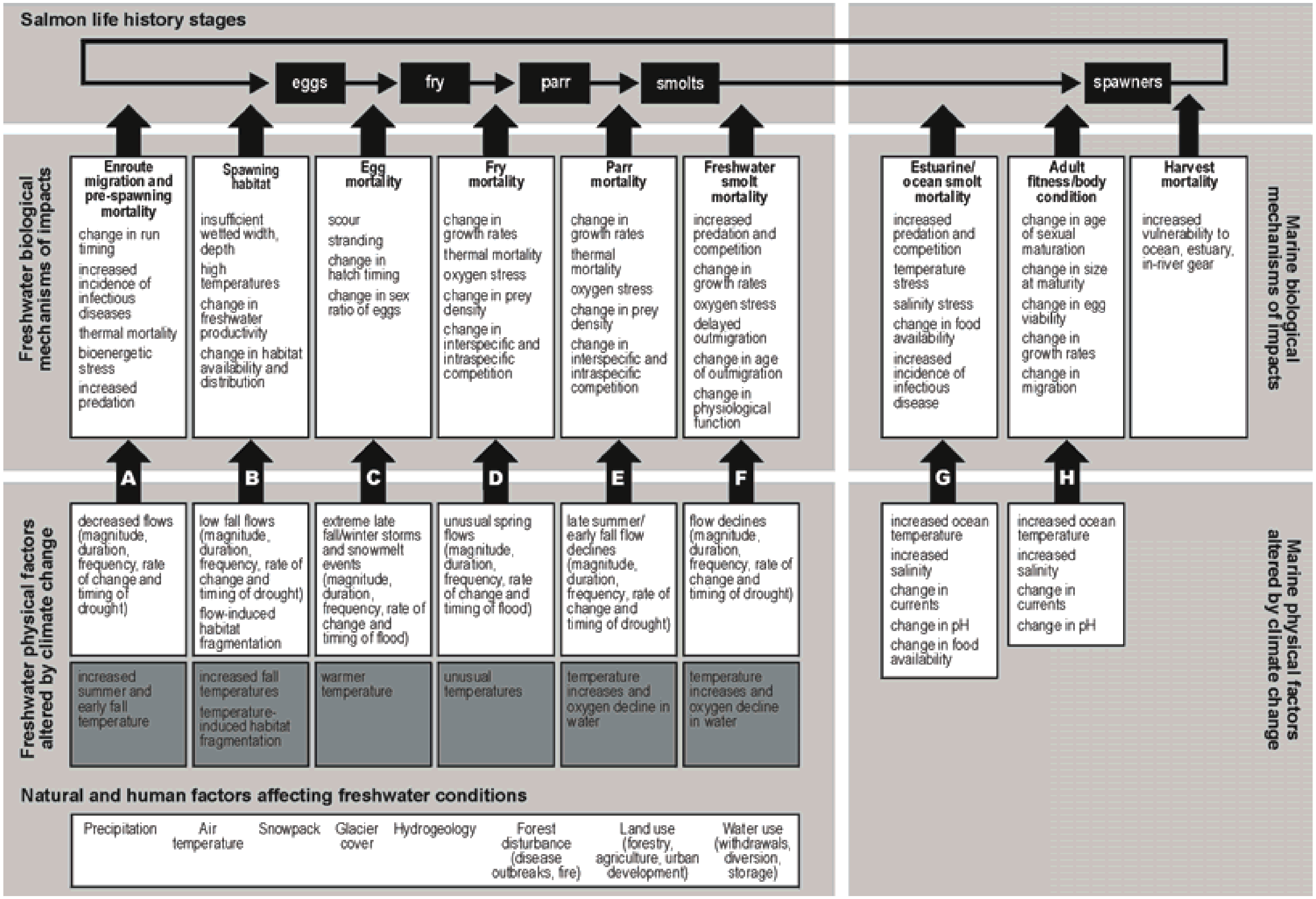
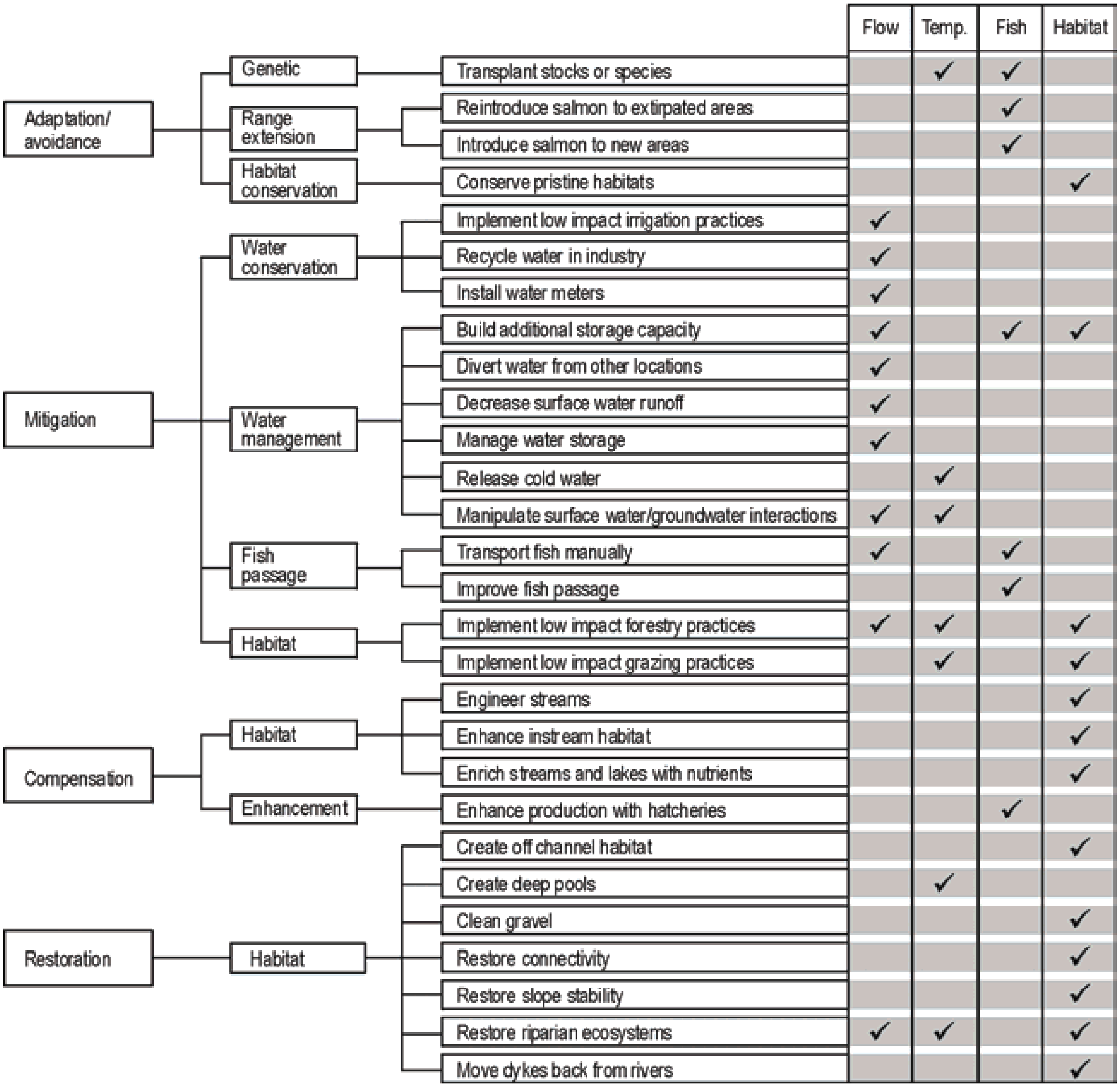


FIGURE 2. Summary of hard infrastructure strategies (i.e., engineering / technology oriented approaches) to help salmon in the context of climate change.
Strategies described further in Nelitz et al. 2007.



			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 1. Description of hard infrastructure strategies (i.e., engineering / technology oriented approaches) summarized in Figure 2.

Strategies are described in more detail in Nelitz et al. 2007.

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.

TABLE 2. Description of soft infrastructure strategies (i.e., legal, regulatory, policy, or management oriented approaches).

Strategies are described in more detail in Nelitz et al. 2007.

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.

2. WATER, FISH, AND PEOPLE IN THE OKANAGAN BASIN: A FUTURE FORESEEN WITHOUT PREPARATION?

WHAT IS HAPPENING?

Casting ourselves to the year 2050, the foreseeable facts for the Okanagan basin are:

- Greenhouse gases will continue to change regional climate such that average winter temperatures in the semi-arid, hydrologically snow-dominated Okanagan are 3˚C to 4˚C warmer[8], winter snow packs decline, and overall mean annual inflows fall by at least 25% (Merritt *et al.* 2006).
- Valley-wide population will easily grow to over 600,000 (Neale 2005).
- The length of the growing season will increase 20% to 35% from present (Cohen and Neale 2003; Neilsen *et al.* 2004), significantly increasing both evapotranspiration and crop water demand.
- Integrating these supply side reductions and demand side increases, *average* net cumulative inflows to Okanagan Lake will fall at least 40% (Figure 3).
- 'Enabled' by the changed climate, major landscape-level disturbances already underway like mountain pine beetle infestations and big fires will impart substantial *one-way* conversions of land cover from forests to grasslands, compounding hydrologic changes.
- Surface run-off patterns will change, with an increase in winter rainfall, higher peak spring flows with earlier average timing and less inflow later in the season when demands are higher.
- And at the bottom of the valley, all of these factors will mean water flows in Okanagan River for endangered salmon and other aquatic and riparian species will become ever more squeezed in an attempt to meet our lascivious demand.

Given this information about *future* climate, how are the region's salmon species doing *today*? Okanagan River sockeye constitute the last persistent population of more than a dozen now extirpated salmon stocks that originated in Canadian portions of the Columbia River and its tributaries prior to its intensive development to meet hydroelectric power and irrigation needs (Hyatt *et al.* 2003). Historically, chinook, coho, chum and steelhead were also indigenous salmon species in the Okanagan basin, but today they are either extinct or found in very low numbers. Okanagan sockeye, like many salmon populations located at the southern end of their range, exhibit a trend of declining numbers over the past 50 years (Hyatt *et al.* 2003). Recently, the annual return of Okanagan sockeye adult spawners has varied between a low of 2048 (in 1998) and a high of 34,490 (in 2001). In the 1900s, the adult spawning abundance for this population is reputed to have frequently been in excess of 100,000.

The only Columbia basin origin population to enter Canada, it is estimated that there are less than 50 chinook salmon adults that return yearly to the Okanagan River, and very little is known about them. Debate remains over whether this is a unique population, separate from the Okanogan chinook population in Washington State. The Canadian federal government until recently has considered chinook in the Okanagan basin to have long ago been extirpated, and because of this, no resources have been devoted to studying this stock. In 2005, following preliminary studies and requests made by the Okanagan Nation Alliance (ONA), the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) recommended that the Minister of Environment emergency list Okanagan River chinook as endangered under Canada's fledgling *Species at Risk Act* (SARA). A recent development

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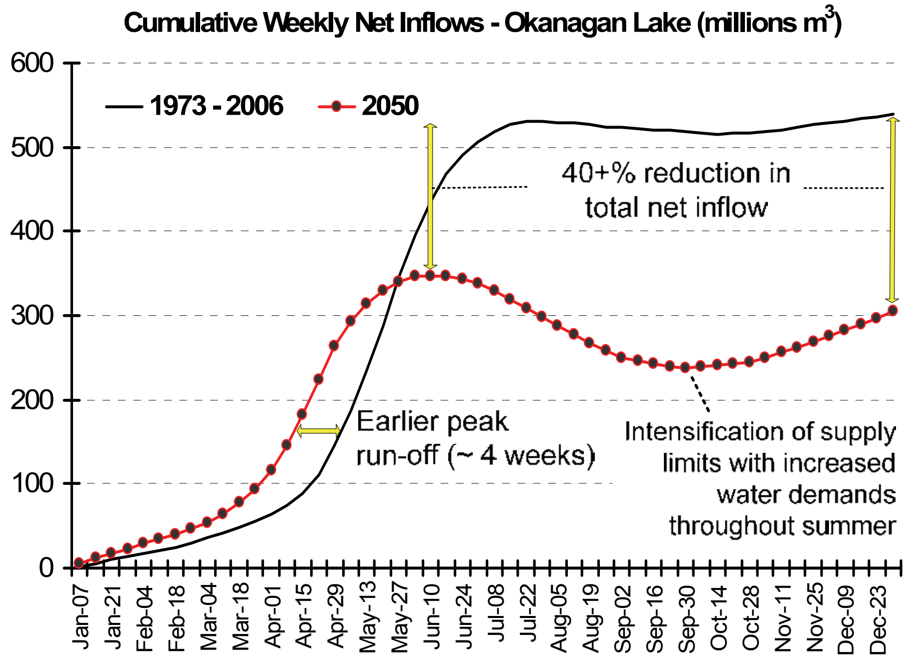
[8] See: Pacific Climate Impacts Consortium; http://www.pacificclimate.org/tools/

is the decision of ONA and Fisheries and Oceans Canada to partner on the development of a Recovery Potential Assessment to inform the Minister's decision. The SARA decision on Okanagan River chinook is expected to be made in 2007.

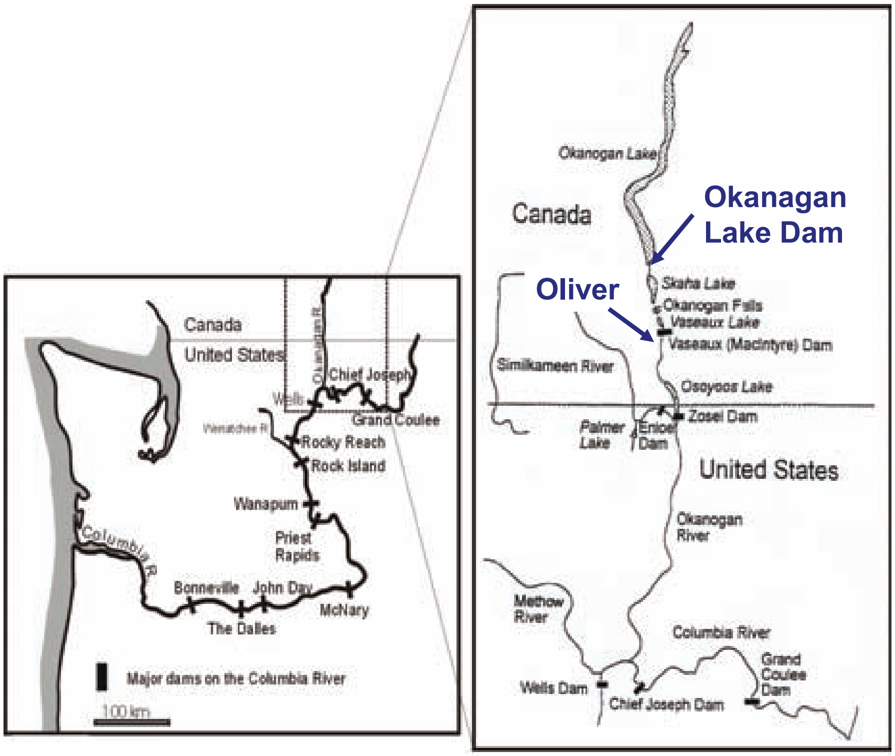
FIGURE 3. Average cumulative net inflows to Okanagan Lake, 1973–2006 vs. year 2050 (2041–2070).
The 2050 hydrology is based on the Hadley Centre's Global Circulation Model A2 emissions scenario outputs (HadCM3-A2), downscaled and used by the UBC Watershed Model (Merritt et al. 2006). Other water budget components are based on an array of datasets, with major demand side elements provided by Langsdale (2007) and Neale (2005). The aggregate water demand scenario used in the FWMT 2050 climate study includes a number of demand management components based on modest population growth. Hence, 2050 net inflows represent a moderate outcome. Source: Okanagan Fish/Water Management Tools (FWMT) climate study, in progress.



WHY IS IT HAPPENING?

In the case of salmon population declines in the Okanagan basin, humans are the major actors. Beginning more than seventy years ago, the Columbia River and its tributaries experienced sweeping hydroelectric development leading to construction of more than 30 dams. Salmon returning to the Okanagan River in Canada must pass through 9 of these dams, with their northward migration ultimately limited by (the much smaller) McIntyre Dam, located on the Okanagan River between Osoyoos and Vaseux Lakes (Figure 4). This dam prevents access by the population to historic rearing lakes upstream, including Skaha and Okanagan Lake. Presently, the majority of indigenous sockeye spawning occurs within a 6–7 km stretch of Okanagan River that remains in a semi-natural state while the remaining portions of the river (~63 km) have been dramatically simplified by channelization and damming in the 1950s. Despite these passage and habitat limitation challenges, this unique sockeye population has managed to persist.

FIGURE 4. Columbia River, showing a portion of the basin's major dams, emphasizing the migration corridor for Okanagan River sockeye salmon (upper limit is McIntyre Dam).



The story of climate change and salmon in the Okanagan comes full circle when we consider water supplies and water temperatures. Many studies have identified the importance of changes to annual and seasonal variations in water temperature and flows in controlling migration, spawning, incubation and rearing success of various life history stages of salmon under regulated conditions found in the Okanagan and Columbia (as cited in Hyatt *et al.* 2003). The assumed optimum water temperature for migrating sockeye adults (physiological and swimming performance) is 15˚C (e.g., Lee *et al.* 2003). Lethal temperatures are considered to be those > 24˚C. Adult sockeye returning to spawn have been observed to temporarily stop migrating and drop back downstream and hold in cooler refuges when they encounter water temperatures > 21˚C (Hyatt *et al.* 2003). These temperature thresholds are important, given the required movements of Okanagan sockeye spawners from the larger and considerably cooler Columbia River to the smaller warmer Okanagan River. Prolonged migratory delays use up finite energy reserves, thereby increasing bioenergetic stress and susceptibility to disease, reducing efficiency of energy used during spawning, and reducing the viability of gametes—all factors that ultimately reduce the abundance of deposited eggs (MacDonald *et al.* 2000).

High water temperatures and low oxygen levels in Osoyoos Lake during August-October are also known to limit sockeye production by contributing to occasionally severe density-independent mortality during rearing. The development of high temperatures (> 17˚C) in the epilimnion and of hypoxia in the hypolimnion (< 4 ppb O_2) during the late summer to fall interval have a major negative influence on the quantity and quality of limnetic habitat that is suitable for rearing by juvenile sockeye (Figure 5). Under these conditions, field observations have demonstrated that both the south and central basins of Osoyoos Lake become unsuitable for occupation by juvenile sockeye through most of the late spring through fall growing season (Hyatt *et al.* 2007). Thus, as suggested in Figure 6, ongoing future warming and our ability to manage for it will be an increasingly important determinant of success in salmon population management and restoration in the Okanagan.

FIGURE 5. Temperature-oxygen "squeeze" that commonly develops in Osoyoos Lake between August and October. *"Useable Volume" represents the portion of water column that can be physiologically tolerated by rearing sockeye salmon smolts without dramatic increases in rates of mortality. Source: Hyatt et al. (2007).*

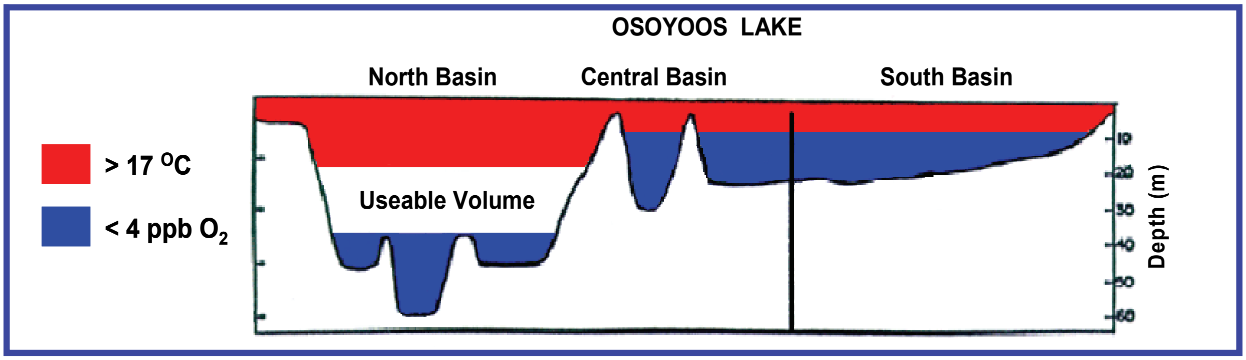
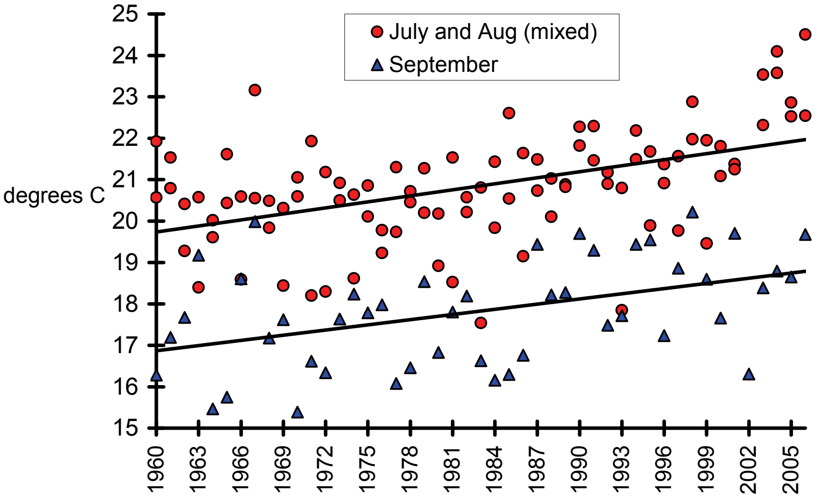


FIGURE 6. Average summer water temperatures in the Okanagan River near Oliver, BC. *Data prior to 2002 are based on air-to-water reconstructions (see Alexander and Hyatt 2007).*



Flow releases from Okanagan Lake dam (combined with unregulated tributary inflows) that exceed 30 $m^3.sec^{-1}$ during sockeye egg incubation (October–April) progressively lead to increasing redd scour mortality and premature flushing of fry out of the gravel (Summit 2002). Likewise, the probability of sockeye egg losses due to desiccation rise rapidly when Okanagan River flows at Oliver fall below 5.5 $m^3.sec^{-1}$ (Summit 2002). Given the hydrologic changes projected under climate change (earlier, more rapid peak flows and lower fall/winter base flows), susceptibility to these mortality processes will increase, putting a further spotlight on flow management at Okanagan Lake dam.

There are also factors which confound local management efforts, such as Columbia River passage mortalities and related delayed mortality impacts associated with downstream migrations, ocean harvest rates, predation, as well as competition with introduced species in Osoyoos Lake (large mouth bass, small mouth bass, mysis shrimp) and related nutrient / food web dynamics.

WHY IS IT SIGNIFICANT?

Water is a determining factor not only for salmon survival, but our own. The looming water crisis is entirely foreseeable and its impact on the quality of life in the Okanagan will depend on our efforts to intelligently plan for and adapt to the changes ahead. Casting ourselves to the year 2050 and running projected hydrology minus total demands through the established Okanagan Lake and River 'operating rules' embedded within the Okanagan Fish/Water Management Tool (Alexander *et al.* 2006), we discover that we fail to meet numerous management objectives (e.g., maintaining lake levels for navigation, or maintaining sufficient volumes of flow for domestic or agricultural intake)[9]. Without more aggressive planning and adaptation actions the significance of such outcomes is clear:

- Okanagan Lake levels will not meet historical elevation targets in summer and fall, particularly during periods where year over year water supplies are low.
- Reduced lake levels will: (1) significantly impact recreational opportunities, as marinas become unusable, requiring some to be re-located to deeper water or major access channels dredged; and (2) impact lakeside aesthetics to residents and tourists seeking beaches.
- Agricultural and domestic intakes in Okanagan River will need to be 'sunk' to have more reliable access to low river flows.
- Endangered sockeye in Okanagan River will face increasing rates of mortality due to more frequent de-watering events.
- Low Okanagan River flows will dramatically reduce or eliminate opportunities to mitigate the temperature-oxygen squeeze in Osoyoos Lake (Figure 5)—mitigation which is hypothesized to require in the neighbourhood of 120 to 170 million m^3 of summer water. The reduced opportunity for flow mitigation is a particularly worrying given trends in Figure 6.

Given these pressures, a number of biologists have begun to quietly muse: *"perhaps we should write certain streams and stocks off, and focus our restoration and management efforts on more pristine, robust watersheds in less climate sensitive regions"*. This kind of thinking is not based on a disregard for species diversity but on evolutionary first principles: fish (and other animals) do not adapt to temperature and hydrologic changes as fast as plants. Given the speed of projected climatic changes relative to evolutionary adjustments, these biologists are simply asking whether it is possible for populations like Okanagan River sockeye and chinook salmon to keep up?

The question about whether Okanagan sockeye and chinook will persist is fortunately an *open* one. The question of whether it is a good idea to re-focus restoration and management elsewhere is less the subject of 'facts', and more one of people's intrinsic values and priorities. Certainly, Okanagan First Nations people who have aspirations to revitalize subsistence fishing opportunities and reinforce their traditional culture will emphatically pursue continued restoration and priority management for these species. For them, protecting sockeye and chinook is much more than an academic exercise or a "cost optimization" problem on how best to spend 'limited restoration dollars'. Still others are emphatic about the importance of maintaining all unique genetic populations to safeguard the resilience of the species as a whole. Others want to preserve the simple pleasure of showing their children the wonder of a spawning salmon run.

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[9] Research is funded as part of a larger Canadian Climate Impacts and Adaptation Research grant to Dr. Kim Hyatt, Principal Investigator, Pacific Biological Station, Hammond Bay Road, Nanaimo, BC V9R 5K6.

WHAT CAN WE DO ABOUT IT?

If we want the Okanagan basin to remain a prosperous life-sustaining place in the future, there are a number of things we must do. The Okanagan Basin Water Board (OBWB)[10] pursues coordinated water management throughout the basin, and is the best suited organization to facilitate improvements to water management. The following adaptation strategies expand upon ideas summarized in Figure 2, Table 1, and Table 2. In the context of the *foreseeable* changes described above these ideas are not radical. Though it should go without saying, to do the things listed in a *meaningful* way there needs to be more public funds allocated towards water stewardship and environmental management. Implementing the following solutions in the Okanagan would likely cost millions. While the true costs are more palatable when viewed over a 20-year planning horizon with full cost accounting principles, in the end, "you can't get something for nothing."

SOFT INFRASTRUCTURE STRATEGIES

Develop water budget / entrench ecosystem rights to water: Establish environmental water accounts and entrench ecosystem "rights" to water, as done in jurisdictions like South Africa, Washington State, and California. With water set aside for ecosystem needs, a more realistic and honest estimate of surplus water available for future growth can be defined and appropriate planning decisions thus informed. This water would therefore be *removed* from the supply that is available for new water allocation. Such an approach is different in that it assumes needs for water can be defined later, based on vague notions of "societal choices" "if and when necessary". Recognizing ecological water needs implies there are mechanisms of controlling water storage/use so as to provide water for a representative set of focal species[11] needs at critical times of year (e.g., dams/reservoirs). Environmental accounts would need to be established at the appropriate scale, recognizing the valued ecosystem components that exist whether by individual stream, sub-basin, or overall watershed.

Require effective operating licenses: Western water law in North America was developed in a time when our population and economies' ability to use the water granted was a small fraction of what was available. A tenet that emerged from this bygone era of abundance still with us is: "first in time is first in right". Such an approach has led to a proliferation of "vested rights" to water that has paralyzed government water managers. Many streams in the Okanagan are already fully or over-allocated. Indeed, many past water licensing decisions were made in a vacuum, with limited or no understanding of sub-basin and basin-wide water budgets and seasonal and inter-annual hydrologic variation. This kind of decision making has included licensing in a upstream areas, without taking into account cumulative downstream consequences. This legal framework also maintains the notion of "beneficial" use of the water license on that appurtenant land. Traditionally, water left flowing in a river for purposes of ecological benefits like fish survival was not originally defined as a "beneficial" use in Western water law, whereas growing alfalfa in deserts were deemed "beneficial". This limited interpretation of beneficial use has in some situations created a perverse incentive to waste water in a licensee's effort to protect their overall water right.

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[10] Okanagan Basin Water Board. http://www.obwb.ca/

[11] An ecosystem based perspective should not be restricted to one or two fish species.

Reforming water licensing in British Columbia (and Canada) is the first critical step towards reconciling future climate and growing human populations with a life-sustaining environment. This requires a combination of legal reforms and exercise of government powers that accomplish the following:

- adding restrictions and conditions of use to both new and existing water licenses;
- water license buy-backs;
- regulating ground water in the same fashion as surface water, recognizing their obvious interconnection;
- where necessary, outright expropriation of water licenses with compensation; and
- expanding monitoring and enforcement tools.

Clearly, wherever possible negotiated voluntary arrangements are in everyone's best interest. In this context, such negotiations will be more successful if the re-acquisition or water-use efficiency restrictions can be demonstrated to not simply be a re-allocation to future growth or otherwise be given to a direct "water competitor". Hence, a defensible proportion of the water budget must be set aside in an 'ecological reserve' and as a 'drought buffer' while anticipating some planned future population and water-use efficiency level.

On some waterways, transboundary flow orders, as issued by the International Joint Commission (IJC), can add another layer of governance affecting water management in British Columbia. In drought years Osoyoos Lake is a case where lake levels are operated so as to maintain high water throughout the summer for irrigation and instream fish needs in the fall when water is scarce—a seemingly good purpose. However, maintaining a high lake level is associated with an increased risk of shoreline erosion, which is a concern for shoreline property owners. There are also concerns the criteria for designating drought years may not be appropriate as half of the years since Zosel Dam was completed in 1988 have been designated as having drought conditions (Glenfir Resources 2006). These criteria consider the amount of water in Okanagan Lake, expected summer inflow to Okanagan Lake, and the expected inflow to Similkameen River. They do not, however, consider the severity of a drought. In the context of climate change others (e.g., Glenfir Resources 2006) have recommended studies be conducted to understand how anticipated changes in local hydrology will affect these criteria and the related effects on lake levels and timing of lake adjustments. Future studies should also consider not only hydrologic change, but also its impacts of resultant flow management practices with regards to endangered steelhead populations and threatened chinook populations below Zosel dam. Such insights will be essential to informing changes to IJC's "Orders of Approval" for Lake Osoyoos which currently terminate in 2013. Water management decisions today must be based on good science and allow the next generation of decision makers some flexibility to cope with an uncertain future. The upcoming Osoyoos Lake Science Forum (fall 2007) will provide an excellent opportunity to gather agency staff and managers to review lake level management, which ought to include looking forward to climate change adaptations.

Designate environmental aspects for special management considerations: Specifically, strengthening of endangered species legislation in British Columbia and Canada would mean much tougher legislation than SARA; tougher than the well-intentioned and purportedly strong but marginally effective US *Endangered Species Act* (ESA). As critics of the US ESA argue, such legislation must not be designed to drive species down to their theoretically computed "minimum viable population" levels and keep them there. Rather, such law needs to directly protect ecosystems to begin with, and be based on sound science rather than lobby and special-interests. It must also have tough sanctions for violator's rather than fines that can be easily absorbed and built into the "cost of doing business." This rather tough sounding top-down recommendation does not mean creative ideas for voluntary incentives should not be vigorously pursued. Balancing the number of 'stick' and 'carrot' measures is always important. But with respect to endangered species, it is very hard to imagine a series of voluntary measures that in practice could come close to achieving the same standard of protection.

Use demand-side management tools and pricing signals: Universal water metering and stronger regional and municipal programs targeting water use efficiency could be improved. Despite having the lowest per capita water supply in Canada and using twice the national per capita average, the Okanagan does not have universal metering. To avoid fears of privatization, future metering and related fee collection, schemes should remain firmly in the hands of local governments. Whenever feasible, roll some of the funds from the metering back into other water use efficiency programs. Municipalities should pass zoning rules that more aggressively insist on increased housing densities, moving the Okanagan away from an urban sprawl future. Require new homes and provide incentives for owners of older homes to use more water efficient technologies, low flush toilets, rain and grey-water capture and separation, climate appropriate landscaping, etc. In all cases, meaningful cash and tax incentives for these things should be funded. On the agricultural side that uses 70% of the valley's water, provide further incentives, tax breaks, etc. for technologies like real-time soil moisture monitoring and efficient water delivery systems, and selection of high value (lower-water) crop types.

Encourage partnerships for water / habitat stewardship: Better coordination among existing environmental 'initiatives' to reduce stress on the limited supply of professionals and funds is required to achieve more real-world impact. More and more often new environmental initiatives, stewardship groups etc. have overlapping mandates that offer only slight variations on a theme (instead of competition that improves quality or performance). These initiatives routinely demand time from the same core groups of individuals (and funding pools). This dilutes the effectiveness of both the professionals in these groups and what they can actually achieve 'on the ground'. So while they may 'feel' like there are lots of committees, task forces, partnership initiatives, roundtables, workshops, conferences, newspaper articles, TV and radio reports, speeches and announcements—there is a disproportionately low amount of tangible results (with exceptions of course). A related recommendation is to ensure that funds given to different initiatives or projects focus more on *products* and a little less on process (e.g., more $ for real-world tools and actions rather than discussions, meetings and paper reports). Multi-disciplinary cooperation and coordination is definitely a good thing so long as environmental practitioners divide and conquer the tough problems they face rather than dividing and diluting themselves.

HARD INFRASTRUCTURE STRATEGIES

Where soft infrastructure strategies discussed above are *meaningfully* implemented, the flexibility for resource managers to solidify and extend existing programs and test new creative solutions would grow dramatically. In the case of Okanagan salmon population management and recovery in the face of a changing climate, there are three hard infrastructure strategies that resource managers could pursue:

Manage water storage: Whether called "in-stream flows", "fish flows", "environmental flows", "base flows"—a key adaptation strategy is to define what they are in a broad sense by using a range of representative species, and working to define, evaluate and refine them. It is well established that there is a close correlation between streamflows and water temperatures. Likewise, there is a close correlation between streamflows themselves and specific mortality processes on fish (e.g., if water is too high or too low). In many places in the world, scientists also look to define flows that trigger and maintain desired fluvial geomorphic processes that benefit the habitats of the aquatic and riparian species of interest so that repeated physical interventions are not required or required less frequently.

For example, research by Dr. Peter Dill at UBC Okanagan, suggests that the only effective means to reduce water temperature impacts on Mission Creek kokanee is to increase flows during August and September. Likewise, a comprehensive 25 year retrospective analysis performed using the Okanagan Fish/Water Management Tool suggested better flow management could improve average sockeye smolt production gains from Osoyoos Lake by 55% without adversely impacting flooding and economic interests (Hyatt and Alexander 2005). Such flow criteria vary by species (and fluvial geomorphic process targeted), water year, and season.

In the context of significant reductions in net flows, despite the tainted reputation of dams and fish, flow management will likely be one of the most effective freshwater adaptation tools for fish. This depends on our ability to define, evaluate and refine our ecological flow criteria and not use all of the stored water for our immediate needs alone. It also depends on design and construction of dams that as much as possible, take into account fish passage needs.

Re-introduce salmon to extirpated areas / introduce salmon to new areas: Re-introduction and range expansion aims to restore access of endangered species to suitable habitats that are larger and more resilient to future climate change impacts. For instance, in the Okanagan, an experimental re-introduction and monitoring program is underway for sockeye salmon, with fry being raised in a hatchery environment, and released into Skaha Lake. The purpose of this program is to evaluate trophic and species interactions in Skaha Lake (which cannot be accessed at the present time) to determine if the re-introduction can be safely extended to Okanagan Lake without adversely affecting resident kokanee. Given the marginal fall rearing conditions available in Osoyoos Lake for Okanagan River sockeye, and the likely future intensification of temperature-oxygen squeeze events, this kind of range expansion is a very worthwhile adaptation strategy to understand. Okanagan Lake is many times larger than Osoyoos and Skaha Lakes, and thus affords a vastly superior thermal refuge capable of withstanding future climate change.

With regard to rearing conditions for sockeye salmon in the Okanagan basin, three lakes are available: Osoyoos Lake, Skaha Lake and Okanagan Lake. Only one of these lakes, Osoyoos, is presently naturally accessible by the Okanagan River sockeye stock. Skaha Lake is presently being stocked with fry via hatchery outplants as part of a 12 year experimental re-introduction led by the Okanagan Nation Alliance, with funding from Grant and Chelan Public Utility Districts (Washington State). Okanagan Lake (as with Skaha Lake) is currently not naturally accessible to this population due to 3 small dams on the mainstem river. Early data from field monitoring associated with the Skaha Lake project does indicate that it has better physical conditions for rearing (i.e., does not develop hypolimnetic oxygen deficiency) relative to Osoyoos Lake. However, other aspects of the Skaha Lake rearing environment, including density dependent food competition with resident kokanee and mysid shrimp and/or predation by bass and northern pikeminnows are the subjects of active investigations inside the re-introduction project. Okanagan Lake is considered by expert limnologists to be an entirely different ecosystem from Skaha and Osoyoos Lakes given its much larger size and depth and other properties.

Restore riparian ecosystems: Riparian restoration attempts to increase habitat quality and quantity through one-time physical activities. This includes actions such as rip-rap removal, setting back dykes, re-meandering stream channels, augmenting spawning gravels, re-establishing pools and riffles, re-connecting channels with their floodplains and enabling riparian forests to shade streams without over-armouring stream banks. This type of activity is typically paired with ecological flow releases (e.g., periodic moderate “flushing” and “channel maintenance” flows) to enable the fluvial geomorphic processes critical to perpetuating the beneficial attributes of the restored habitat (e.g., desired percent sand in spawning gravels). This is the general approach taken by the Okanagan River Restoration Initiative (ORRI). These types of projects can sometimes improve spawning, juvenile and rearing survival for aquatic and riparian species. This depends on their design being of sufficient scale and framing them within an adaptive model. To avoid the need for repeated human interventions, the best riparian restoration efforts allow for natural flow driven processes to evolve the original planform design thereby continuing to sustain the quality of the restored habitat.

Conserve pristine habitats: An ‘insurance’ strategy for dealing with salmon and climate change is to enable adaptation *at a large scale* by securing additional large refugia. In other words, looking beyond our own back-yard in the Okanagan to the few remaining great pristine places, and forcefully protecting them in new National and Provincial Parks. We then need to ensure these and existing Parks are fortified with rules and regulations that make it clear they are off limits to development. This is the most effective way to safeguard the genetic and ecological integrity of many fish and wildlife populations—don’t ruin them to begin with.

3. ECONOMIC ACTIVITIES, CLIMATE CHANGE, AND SALMON IN THE QUESNEL RIVER WATERSHED: A WEB OF INTERACTIONS

WHAT IS HAPPENING?

Within the central interior plateau, the Quesnel River watershed is a major tributary of the Fraser River draining 11,400 km2 (Figure 7). Based on physical geography, the watershed is essentially split in two: headwater rivers and streams have relatively steep valley sidewalls that drain the Cariboo Mountains (with elevations up to 2,500 m), while the higher order mainstem and tributaries near the confluence with the Fraser drain the lower elevation Quesnel Highlands (Rood and Hamilton 1995). Forest cover is dominated by Sub-Boreal Spruce (SBS) and Interior Cedar Hemlock (ICH) biogeoclimatic zones, both of which provide opportunities for forest harvesting (Meidinger and Pojar 1991).

The watershed includes several large river sub-basins (Cariboo and Horsefly Rivers) and lake systems (Cariboo, Quesnel, Horsefly, and Mitchell Lakes). Many main valley lakes are the result of blockages by glacial debris. Hydrology of the Quesnel River and its tributaries are representative of interior, snowmelt driven systems: annual maximum streamflows correspond with summer rainstorms and snowmelt events in the early summer (Figure 8). Key differences with the Okanagan are that the watershed has no artificial storage, though glaciers provide some natural storage. In the context of climate change, however, it is questionable whether the presence of glaciers will help maintain flows in the long-term. Recent work indicates that overall runoff from glaciers in the Bridge River system is declining due to their reduced size despite faster rates of melting (Dan Moore, University of British Columbia, pers. comm.). On average the Quesnel region receives 540 mm of precipitation (30–50% of which falls as snow) with the largest accumulations in early summer (June–July). Historically, average monthly summer temperatures have ranged from 14–16°C, with average winter temperatures from -7 to -8°C, though extremes can exceed 30°C and - 30°C[12].

The Quesnel River watershed contributes significantly to resident and anadromous fish production. The basin supports a relatively diverse fish community of bull trout, kokanee, rainbow trout, as well as sockeye, chinook, and coho salmon, with limited use of the lower Quesnel River mainstem by pink salmon (Child and Millar 1995; Hickey and Trask 1994). Rainbow trout are provincially and nationally significant, supported almost entirely by natural production. The Horsefly, Quesnel, and Mitchell Rivers provide the majority of spawning for rainbow, while the large lakes provide important rearing habitats. Kokanee occur in significant numbers, and are the main prey item for rainbow trout. They rely on direct tributaries to Quesnel Lake and lake shoals for spawning.

The Horsefly system is one of the most important contributors to sockeye salmon production in the Fraser River basin. From 1995 to 2005 (excluding 2002), escapement on the Horsefly River ranged from 4,059 to 1,816,693, demonstrating an increasing trend in abundance with a persistent 4-year cycle in abundance (Ricker 1997; e.g., Figure 9). Escapement estimates to Quesnel Lake in 2002 ranged from 3.1 to 3.8 million (Hume *et al.* 2004). Current abundance represents the outcome of re-building efforts following devastating impacts early in the 20th century: a dam with no fish passage was built at Quesnel Lake and a rock slide at Hell's Gate hindered upstream migration. Quesnel sockeye are part of the Summer Run timing group, co-migrating with sockeye destined for the Chilcotin, upper Nechako, and Stuart Rivers. This timing group enters the lower Fraser River from mid-July to mid-September, with adults arriving on the spawning grounds starting in mid-August. Peak spawning occurs from mid-September to early October[13]. Sockeye rear in the large lakes (e.g., Quesnel and Horsefly) for one or more years before outmigrating to the ocean.

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[12] Environment Canada. Canadian climate data for Quesnel British Columbia. Available at: http://climate.weatheroffice.ec.gc.ca/climateData/canada_e.html

[13] Fisheries and Oceans Canada. 2006 Summer Run Sockeye Salmon Preliminary Escapement Estimates. Available at: http://www.pac.dfo-mpo.gc.ca/fraserriver/Escapement/2006SUMMERPRELIMINARIES.htm

FIGURE 7. Map of major rivers and lakes of the Quesnel River watershed.

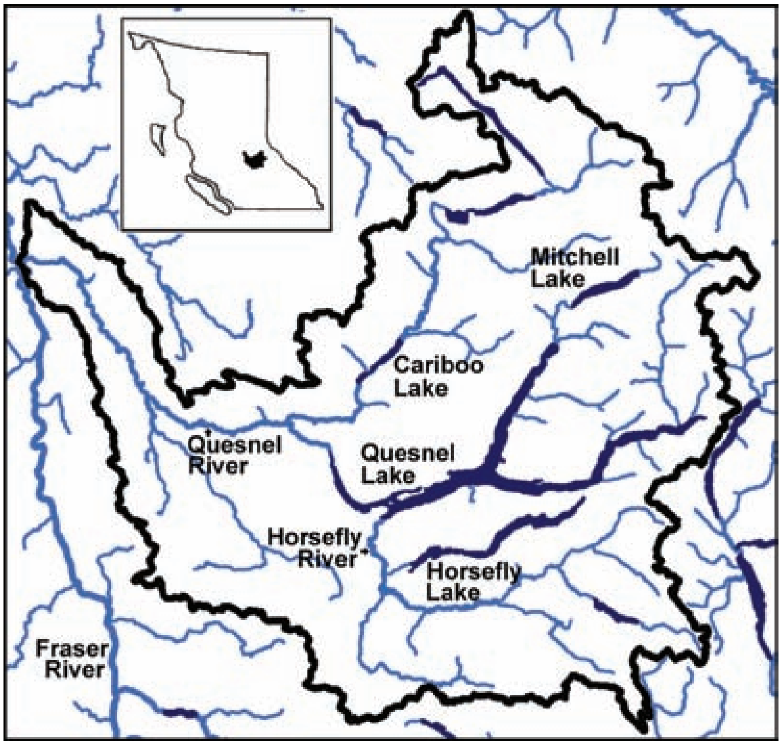


FIGURE 8. Maximum, minimum, and average daily discharge for the Horsefly River (station 08KH010) measured over 45 years of record (1955–2005).

Discharge data from 2005 are also provided. Source: Water Survey of Canada, Hydrometric Data. Available at: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm

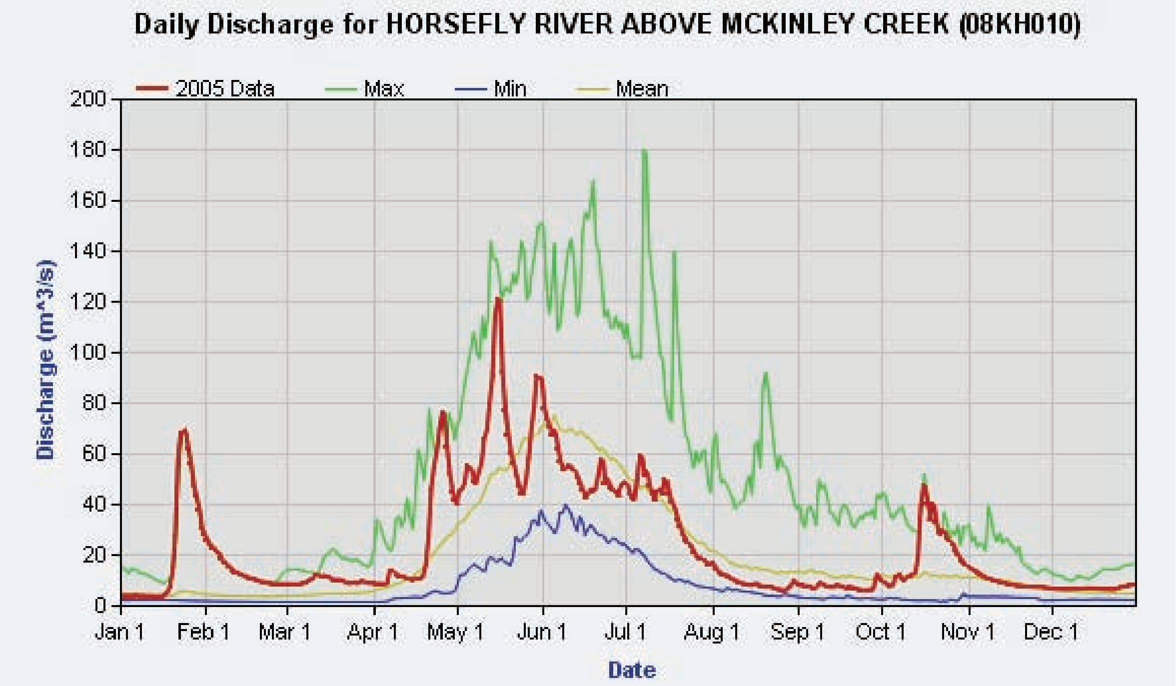


FIGURE 9. Summary of escapement for sockeye salmon in the Horsefly River from 1945 to 2005.
Note that escapements from 2002 were not available. Source: Fisheries and Oceans Canada, Salmon Escapement Data System (nuSEDS). Available through Mapster: http://www-heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm

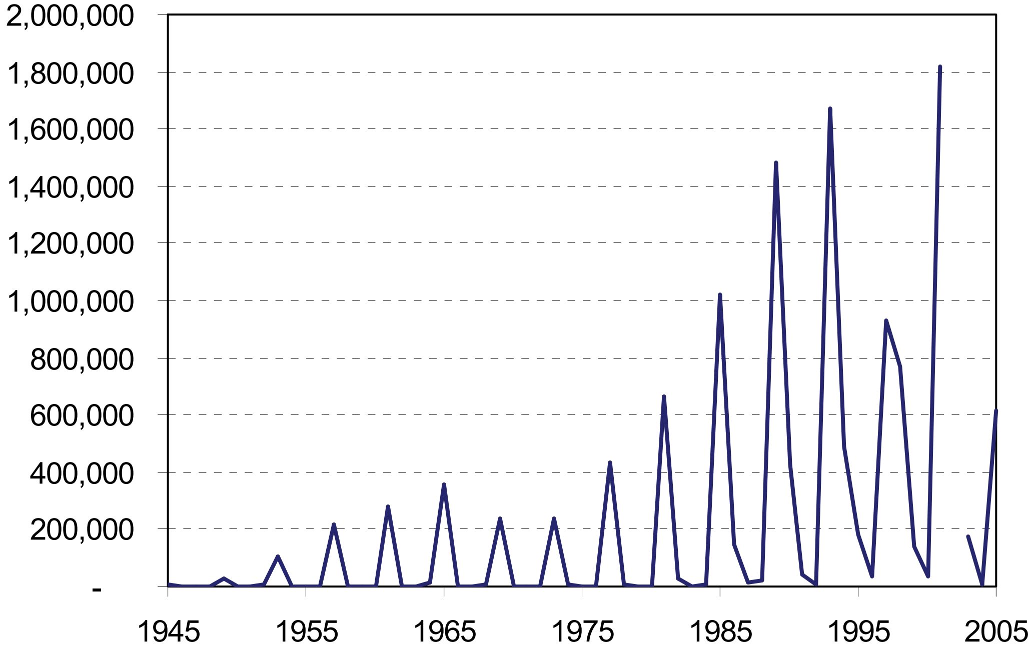
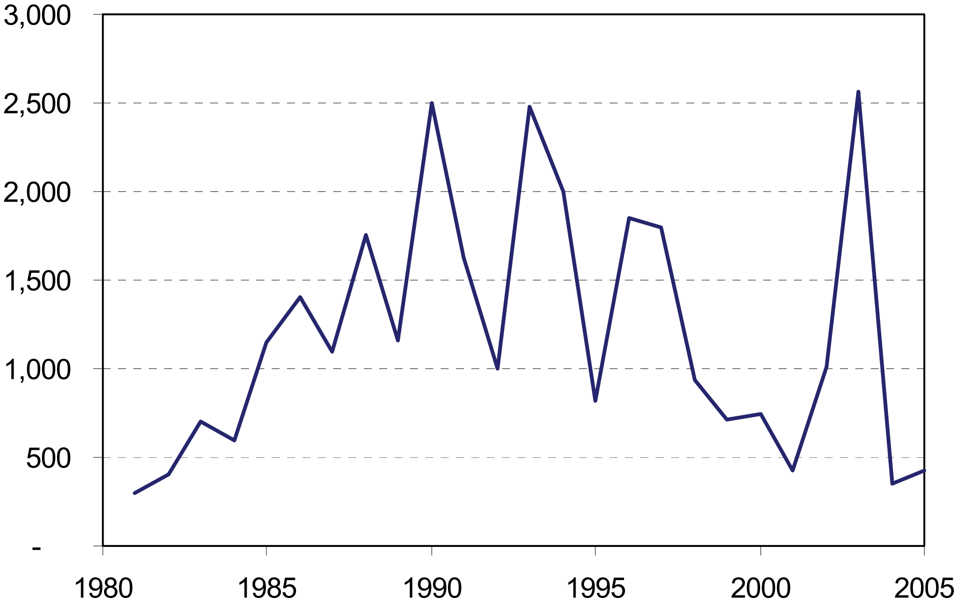


FIGURE 10. Summary of escapement for chinook salmon in the Cariboo River from 1981 to 2005.
Source: Fisheries and Oceans Canada, Salmon Escapement Data System (nuSEDS). Available through Mapster: http://www-heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm



Although significantly less abundant than sockeye, interior chinook and coho salmon also use habitats in the watershed (e.g., Figure 10). The Quesnel, Cariboo (below and above Cariboo Lake), and Horsefly Rivers provide focal spawning areas for chinook, while Mitchell River and McKinley Creek support a limited number of spawners. Rearing occurs in higher order streams for two or more years before smolt outmigration (Child and Millar 1995). Coho are reported to spawn and rear in smaller tributaries such as the McKinley, Summit, and Cameron Creeks, though their distribution and abundance is poorly understood.

WHY IS IT HAPPENING?

Quesnel sockeye survival is affected by a variety of human activities and climate-sensitive factors across their life history. First, land use changes which have the potential to affect spawning and rearing habitats, have been a dominant factor in the watershed for many years. Forestry activities (e.g., logging and road development), agricultural practices (e.g., water withdrawals and mainstem development), and more recently the influence of mountain pine beetle directly affect salmon habitats. The Cariboo-Chilcotin Land Use Plan (CCLUP) assures the local forest industry access to 70% of the productive forest land within the region (Government of British Columbia 1995). The mountain pine beetle (MPB) outbreak has lead to dramatically rapid and broad-scale changes to the forested landscape. Across the province 7.1 million hectares have been affected between 1999 and 2005 (Aukema *et al.* 2006) (Figure 11) and the level of infestation of an individual stand varies widely (from 15% to 100%). Although agricultural activities are less dominant, they still affect mainstem channel conditions and instream water availability in some areas. Some salmon streams have large portions of flow allocated for agricultural withdrawals (e.g., Beaver Creek, Rood and Hamilton 1995).

Collectively, these actions can lead to a variety of adverse effects on hydrology and water quality in salmon habitats (e.g., water temperature and suspended sediments). Similar to the general effects of forestry, research from other regions indicates beetle infestations can: (i) increase annual water yield; (ii) exacerbate late summer and fall low flows; (iii) variably affect magnitude of peak flow (increase or no effect); and (iv) possibly lead to earlier timing of peak flows (Uunila *et al.* 2006). Agricultural water demands can exacerbate low flow conditions during late summer and winter; losses to riparian shading along mainstem and tributary channels can lead to increases in water temperatures. Within the watershed, water temperatures in the Horsefly River and McKinley Creek, are known to sometimes exceed 20°C during sockeye spawning (Figure 12). In 2006 low water levels were noted as possibly restricting access to small streams including Cameron, Moffat, Tisdall, Summit, Devoe, Isaiah, Long, Sue, Hazeltine, Spusks, Tasse, and Whiffle Creeks. Water temperatures, however, remained within acceptable ranges with no observed increases in rates of en-route mortality[14].

River conditions in the Fraser River (e.g., Yale to Bridge River Rapids) during adult migration is a second potential factor that could affect Quesnel sockeye survival in the context of climate change. As noted by PSC (1999), migration timing of summer-run sockeye has become progressively later. Prior to 1981 the average 50% migration date was July 26. In 1997 the timing had shifted 20 days to August 15. For late-run sockeye stocks, a shift towards progressively earlier migration timing has lead to greater overlap with Quesnel summer-runs (Cooke *et al.* 2004). For the late-timing group, this shift in migration timing has coincided with increases in enroute mortality (90–96% in some stocks). Although not fully understood, changes to in-river conditions (e.g., discharge and temperature) and the associated increases in energy expenditures by salmon may help explain some observed increases in mortality. Such observations are important considerations for Quesnel sockeye given that average summer water temperatures on the Fraser River are projected to increase 1.9°C, thereby increasing exposure of migrating salmon to water temperatures above 20°C (Morrison *et al.* 2002).

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[14] Fisheries and Oceans Canada. 2006 Summer Run Sockeye Salmon Preliminary Escapement Estimates. Available at: http://www.pac.dfo-mpo.gc.ca/fraserriver/Escapement/2006SUMMERPRELIMINARIES.htm

FIGURE 11. Maps of mountain pine beetle affected areas and associated tree mortality in 1999 and 2003.
Source: Aukema et al. (2006).

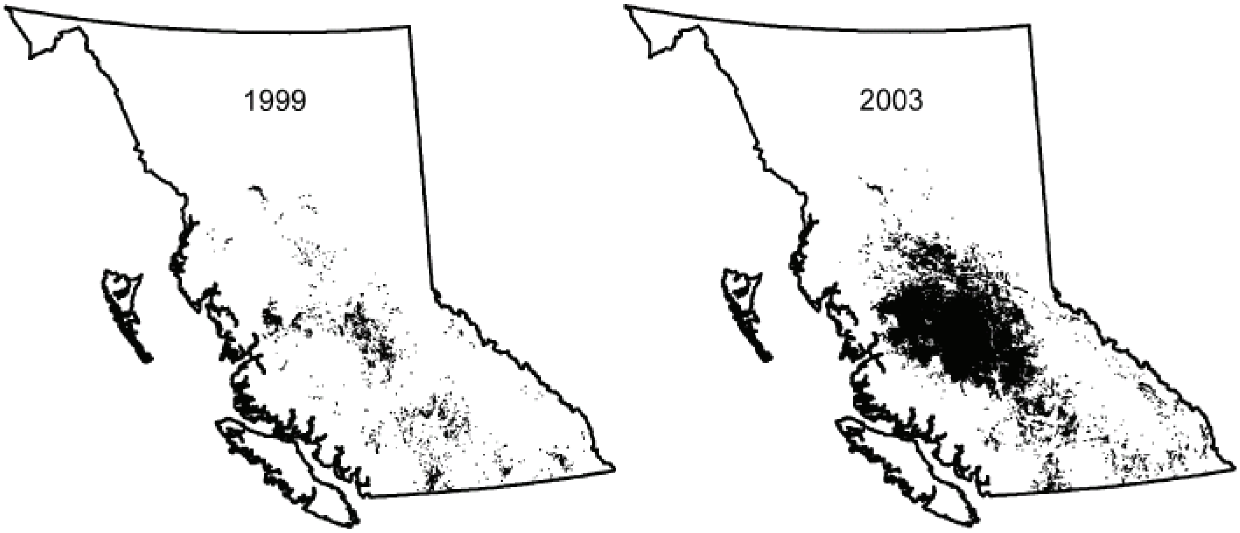
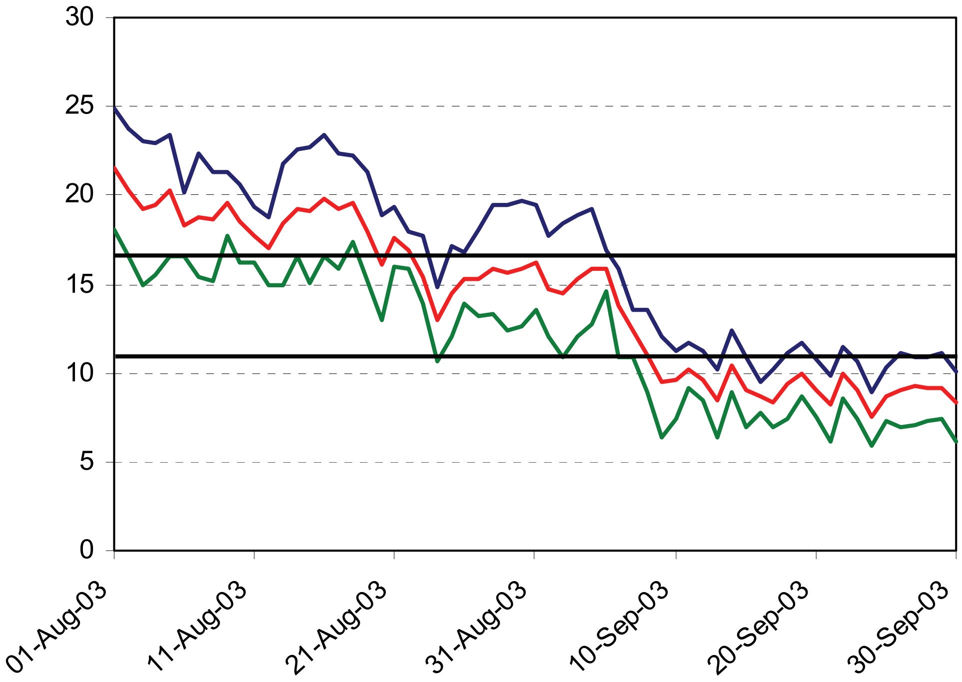


FIGURE 12. Daily maximum, minimum, and average water temperatures from McKinley Creek in 2003.
Zone between dark horizontal lines represent optimal temperatures (10.6–16.1˚C) for sockeye spawning (Oliver and Fiddler 2001). Data extracted from Fisheries and Ocean Canada's WATEMP database.



WHY IS IT SIGNIFICANT?

Including the communities of Likely and Quesnel, the watershed supports a population of 50,000 concentrated around the Quesnel River mainstem and Quesnel / Horsefly Lakes (Child and Millar 1995). In addition to supporting salmon production, the local economy is dominated by forestry, mining, agriculture, and to a limited extent tourism—activities providing: (i) large local and provincial economic benefits, and (ii) cumulative pressures on salmon habitats. In 1993 (a dominant cycle year) the Horsefly River provided 50.6% of Fraser River sockeye production yielding a catch of $68 million (DFO file data as cited in Dolighan and Charnell 1999). In the same year revenues from the forest industry in the Quesnel Timber Supply Area exceeded $570 million, providing $96 million to provincial and federal government revenues (BC MOF 1995). In addition to the obvious changes to the landscape, regional increases in annual allowable cut (AAC) associated with the MPB infestation are anticipated to create boom-bust changes in the regional economy. For instance, in nearby districts MPB-induced increases in regional economic activity are expected over the next 10–15 years. However, as harvestable resources dwindle, decreases in AAC are projected which will lead to decreases in resource revenues, loss of employment, and a decrease in total labour income (Patriquin *et al.* 2005).

WHAT CAN WE DO ABOUT IT?

The adaptation strategies discussed below focus on mitigating adverse effects from the climate-induced threats to sockeye salmon as discussed above: (i) broad landscape-level changes due to mountain pine beetle and related logging activities, and (ii) changes to in-river conditions through downstream migration corridors.

SOFT INFRASTRUCTURE STRATEGIES

Adjust fisheries management practices: Adjustments to marine harvest rates on Quesnel and co-migrating sockeye stocks are important for two reasons. First, development of “harvest rules” that account for year-to-year variations in conditions of the Fraser River (i.e., water temperatures and flows) could help compensate for potential increases in enroute and pre-spawning mortality under future climate regimes. Second, reductions in harvest rates of off-cycle years may help build up long-term abundance, which also has the potential of increasing long-term economic benefits (Marsden *et al.* 2006).

HARD INFRASTRUCTURE STRATEGIES

Implement low impact forestry practices / restore riparian ecosystems: In dealing with the MPB outbreak, the management approach of the B.C. Ministry of Forests and Range has been to conduct aggressive “sanitation harvesting” targeting recently attacked tress, thereby limiting rates of spreading to non-infected areas. In some districts this strategy accounts for 30–80% of logging. Recognizing that forest ecosystems and hydrologic recovery require long response times, the consequences of today’s decisions may be longstanding. In the face of climate change, the impacts of MPB infestations and related forest harvesting on salmon habitats are even more uncertain.

Given large uncertainties (i.e., relatively limited research and understanding) and potential for long standing changes to the landscape and salmon habitats, precautionary approaches to forest management seem prudent. For instance, logging practices should ensure retention of conservative riparian buffers in headwater areas given strong linkages to stream temperatures, reduced shading potential, and greater vulnerability of beetle infested areas to windthrow. Also, extensive monitoring should occur to help reduce uncertainties around habitat changes associated with MPB and related logging practices, even though some compliance and effectiveness monitoring has occurred (Forest Practices Board 2004). Such monitoring could be expanded in geographic scope and the strength of the indicators improved to better understand habitat responses.

Release cold water: Elevated summer water temperatures have been documented in some locations across the watershed (e.g., McKinley Creek and Horsefly River). Given the potential for disease outbreaks and associated relationship with pre-spawn mortality, a temperature control structure was built in 1969 to draw cold water from McKinley Lake into McKinley Creek (Roos 1991). Other opportunities for cold water releases should be explored within the watershed.

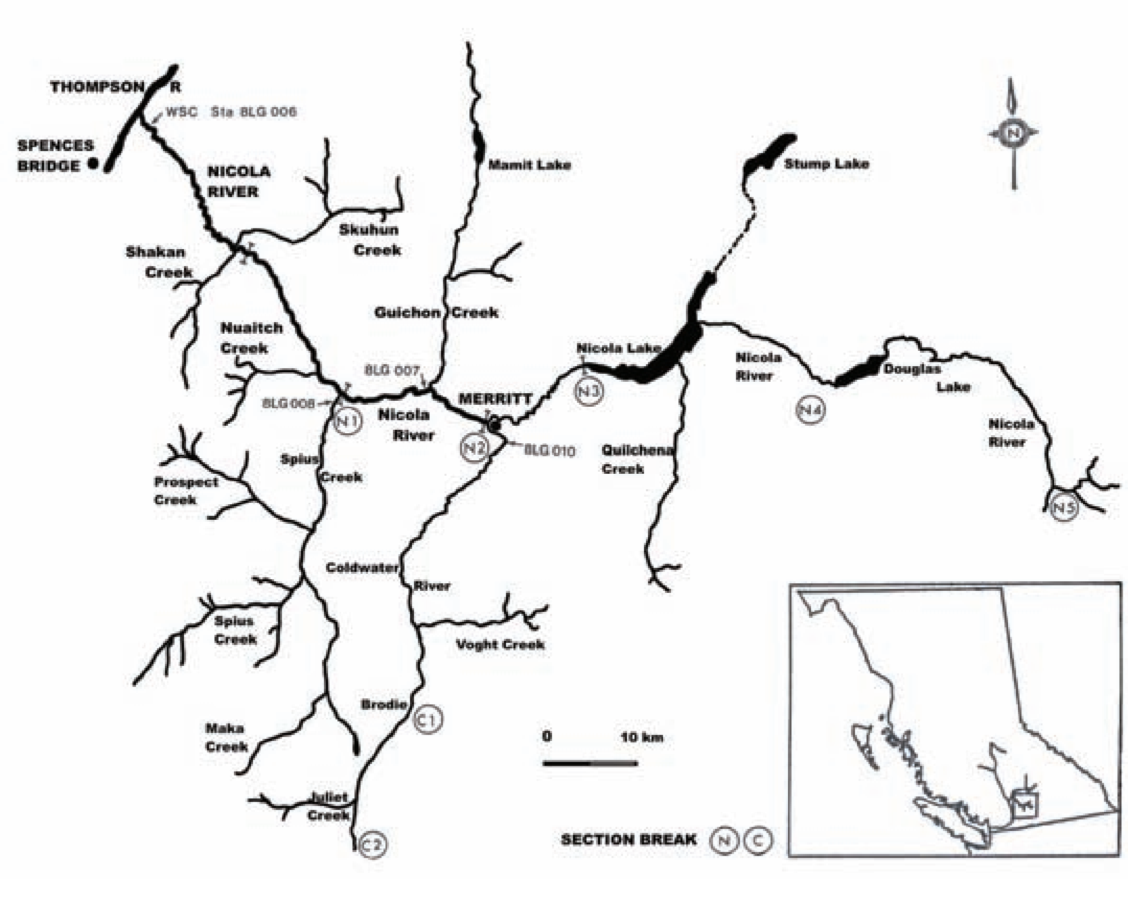
Conserve pristine habitats: Developing salmon "strongholds" in the watershed seems a reasonable strategy given the economic importance of Quesnel sockeye to salmon fisheries and development pressures within the watershed. New protected areas would likely be difficult to implement, however, given that the Cariboo-Chilcotin Land Use Plan has already undergone an exercise of designating land uses that recognize trade-offs among multiple resources uses (Child and Millar 1995): (i) Protected areas (12% of land area), (ii) Special Resource Development Zones (26%), (iii) Integrated Resource Development Zones (14%), and (iv) Enhanced Resource Development Zones (40%). Given the pervasiveness of mountain pine beetle infestations, it may be worth revisiting these designations for the sake of protecting salmon and other ecosystem values.

4. CLIMATE CHANGE, WATER, AND FISH IN THE NICOLA RIVER BASIN: FEELING THE PRESSURE

WHAT IS HAPPENING?

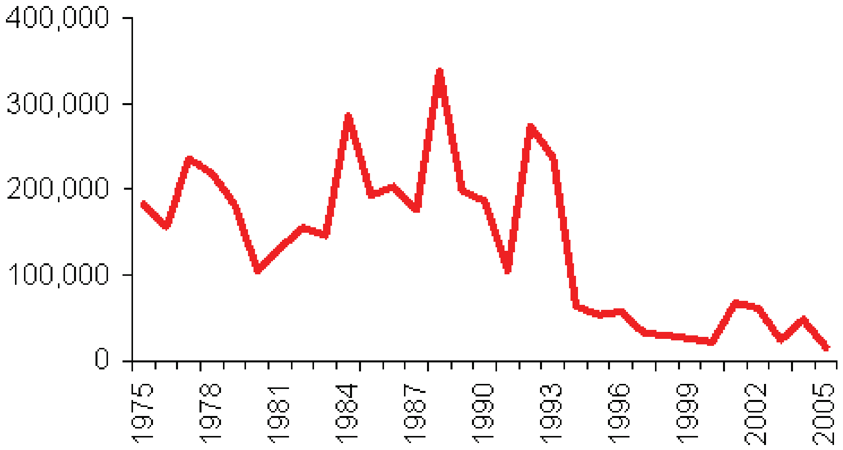
The water resources of the Nicola basin face increasing pressures due to population growth, extensive ranching, forestry activities, mining, recreational activities (i.e., resort development), climate change and other landscape disturbances such as the watershed's large mountain pine beetle infestation. Water users that rely on streams, reservoirs or groundwater (especially ranchers) are already experiencing shortages in drought years, and in 5 out of 8 years downstream fish flow targets are not being met (Rosenau and Angelo 2003). This has led to a growing trend of drilling for groundwater. Appropriate management of groundwater extraction will be very important in the Nicola watershed, which has the highest per capita rate of new well permits anywhere in Canada. Water taken from wells that tap alluvial aquifers reduces the supply of cool water that enters surface streams in the valley-bottom. As highlighted below, groundwater input to streams in the Nicola, even in relatively small quantities, can provide critical thermal refuge for salmon. While all these stresses were recognized in the 1983 Nicola Basin Strategic Plan, a growing imbalance between demand and climate affected supply exacerbate the challenge of balancing competing water interests. Government agencies and various groups, including the Nicola Watershed Community Roundtable (which administers the Nicola Water Use Management Plan—WUMP), recognize that these pressures have ecological and socio-economic consequences.

FIGURE 13. Nicola watershed and its major tributaries.
Source: Rosenau and Angelo (2003).



The rolling plateau, 200+ small lakes, and tributaries of the Nicola basin (Figure 13) are home to a range of anadromous fish species including coho, early and late run chinook, steelhead, pink salmon and numerous resident fish species including burbot, kokanee, bull trout, mountain whitefish, dace, sculpins, redside shiner, and brook and rainbow trout. Indeed, the lakes and rivers of the Nicola basin are prized by many for their rich diversity of fish species. Some of these populations are doing better than others, and for many, little is known. Of higher profile, the Nicola River contribution to the overall Interior coho stock complex remains a priority concern (DFO 2002b). Estimates of coho escapement to the Nicola River watershed itself are unreliable prior to 1998, but have ranged from 500 to 3,500 adults since that time (Figure 14). Nicola chinook are more abundant, with escapements since 2,000 ranging from 8,000 to 14,000 individuals (Fisheries and Oceans Canada, Salmon Escapement Data System (nuSEDS)[15]). Steelhead escapement estimates to the entire Nicola River watershed have been available since 1983, but the reliability in these estimates varies. Total annual Nicola River steelhead escapements range from 3,300 in 1985 to 550 in 1992, with the overall trend being one of decline (Rosenau and Angelo 2003).

FIGURE 14. Escapements from 1975 to 2005 for Interior Fraser River coho salmon.
Source: Fisheries and Oceans Canada, BC Interior Office, Kamloops.



WHY IS IT HAPPENING?

For the anadromous populations inhabiting the Nicola basin, declines in coho and steelhead have been attributed to excessive harvest rates (mixed stock management challenges) whilst ocean survival was in decline during the 1990s (Nelson *et al.* 2001). Adding to this has been *extremely* high water temperatures and low flows (poor spawning, incubation and rearing conditions) in dry years. For example in the Coldwater River during drought years of 1998 and 2003, water temperatures reached as high as 32˚C (Dean Watts, Fisheries and Oceans Canada, pers. comm.), in the hot, dry, and low-flow summer of 1994 temperatures of 29˚C were reported, and in the more normal summer of 1995 temperatures reached 25˚C on several days (Nelson *et al.* 2001). As discussed in the Okanagan case study, elevated water temperatures affect fish through a variety of mechanisms during migration, spawning and rearing. Given that temperatures above 24˚C are lethal to salmon, the Nicola is clearly a temperature sensitive watershed. The hot summer climate and waters (Figure 15) and concomitant timing of peak agricultural demand on top of low summer base flows (Figure 16) is a major challenge for resource managers (Dean Watts, Fisheries and Oceans Canada, pers. comm.).

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[15] Data available through Mapster: http://www-heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm

FIGURE 15. Diurnal stream temperatures at one location in the Nicola River watershed in 2005.

The zone between the dark horizontal lines represent temperatures (5.6–13.9˚C) for optimum chinook spawning (Oliver and Fidler 2001). Data provided by Dean Watts, Fisheries and Oceans Canada.

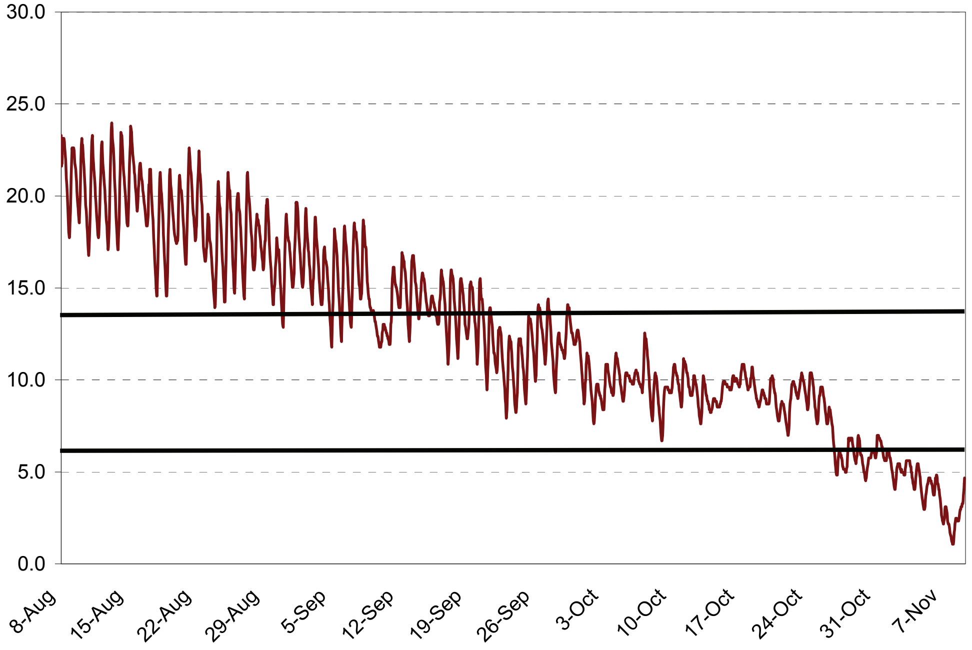

FIGURE 16. Upper Nicola River transect, Aug 25 2003 summer flow of 0.078 $m^3.sec^{-1}$.

Source: Dean Watts, Fisheries and Oceans Canada.

Other cause-effect pathways affecting salmon in the Nicola include channel simplification due to stream-bank grazing and loss of riparian forests, and linear confinement caused by roads and related stream bank protection measures. In some places, slope instability and erosion are contributing fine sediments that reduce spawning and incubation habitat quality. Off-channel irrigation canals can be a mixed blessing, with some of them providing suitable habitat, while others can contribute to "fish on fields" where they feed unscreened irrigation pumps, or where un-maintained screens impinge and kill salmon. In winter, natural events such as ice flows and jams can create serious flooding issues and may also scour salmon eggs. Though rare, limited flow releases from Nicola Lake dam in winter can contribute to downstream freezing conditions that kill incubating salmon eggs.

As with any open system, water management and restoration activities in the Nicola can be confounded by factors outside of the basin. As mentioned, of most concern are poor ocean survival rates for coho and steelhead, excessive harvest rates caused by mixed-stock fisheries and unfavourable flow/temperature conditions in the mainstem Fraser and Thompson Rivers themselves.

WHY IS IT SIGNIFICANT?

Relative to the Okanagan valley, the upward economic growth potential in the Nicola valley is large. The Nicola valley's only major city, Merritt has a population of approximately 8,000 people (~ 16,000 valley wide). Contrast this with the Okanagan valley, whose three biggest (of *seventeen*) communities (Kelowna, Penticton, and Vernon) have a population in excess of 185,000 (over 300,000 after adding in the valley's other 14 communities). It is interesting to consider these vastly different population totals alongside the similar watershed drainage areas of the Okanagan and Nicola valley: 8,280 km^2 and 7,280 km^2. According to the comprehensive 1974 Okanagan Basin Study, the average annual total *gross* inflow to Okanagan Lake (before diversions, evaporation, upland storage and consumptive uses, etc.) is 664,000 acre-ft (pg. vi, Water Quantity Technical Supplement OBA (1974)). The 1983 Nicola Basin Strategic Plan (page 12, Table 1, Ministry of Environment 1983) cites a total estimated gross natural supply of about 778,000 acre-ft[16]. While these supply totals are highly uncertain and variable, as proximal figures they highlight that the Okanagan has orders of magnitude more storage control over its water supply than the Nicola, and has managed to support a much larger population.

Indeed, only 41% of Nicola basin inflow is under regulated control (28,500 acre-ft) versus 74% (341,000 acre-ft) in Okanagan Lake alone. While Nicola Lake dam does not "control" the Nicola River, during dry years in summer months, releases from Nicola dam have an increasingly important influence on downstream flows and water temperatures (Figure 17). With its configuration of climate, population and dominance of unregulated tributary inflows, the Nicola basin is very much at the whims of Mother Nature. Given the climate projections for the region show less winter snow pack and water (see Okanagan case study) and that human demands are growing, low summer flow—high water temperature issues in the Nicola will become increasingly dire. Without significant adaptation and mitigation measures, an *intensification* of the low base flow, hot summer water problem is on its way. For salmonid species in the basin, such changes are significant given they relied on historic instream conditions to successfully utilize these habitats. Of legitimate water user's in the valley, instream values (e.g., salmon and their habitats) are at greatest risk of not having their water needs met if current trends continue. And if fish resources are unable to adapt to rapidly changing conditions, the risk of extirpation from the basin is high (Dean Watts, Fisheries and Oceans Canada). For conservationists and fish population managers in the Nicola valley, the current and growing story line is—vulnerability and limited control.

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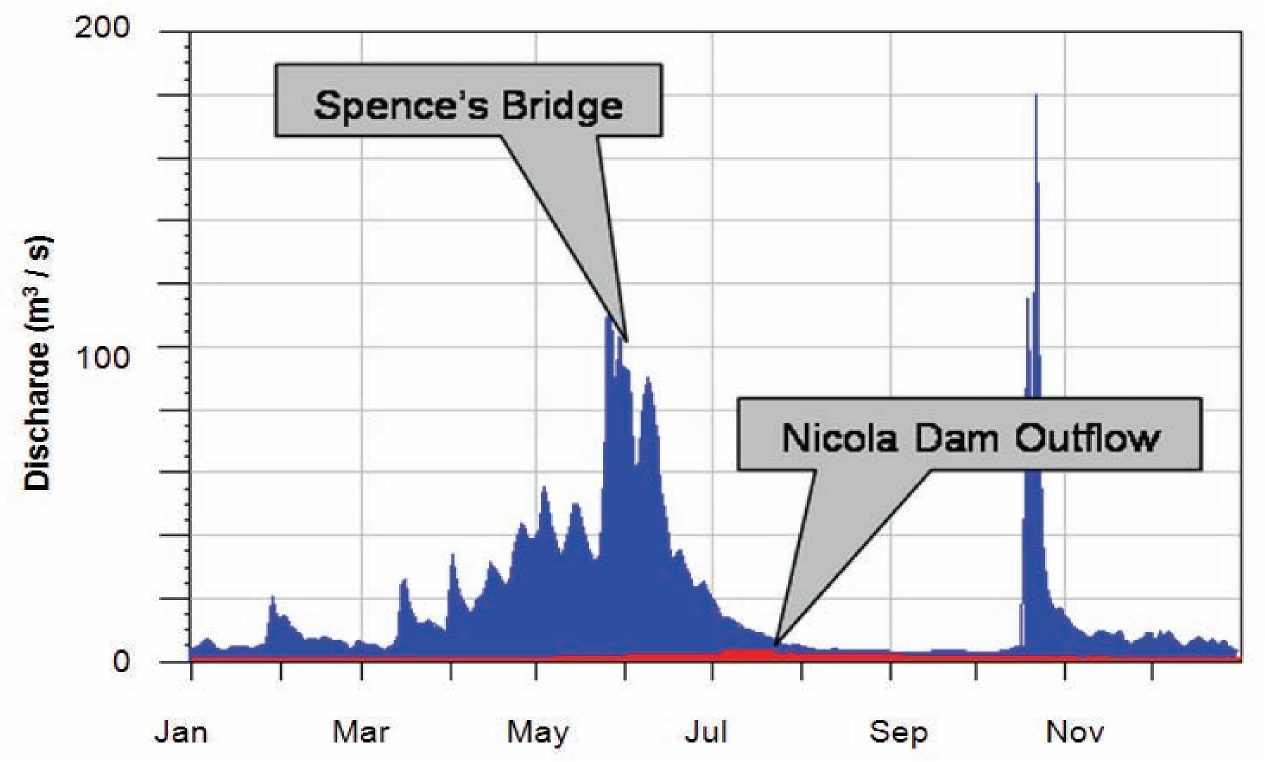
[16] It is unclear from the report whether this includes numerous small, upland storage reservoirs. The figure for the Okanagan does not.

FIGURE 17. “Dry year” hydrograph for Nicola River in 2003, comparing upstream regulated releases from Nicola Lake Dam vs. downstream unregulated tributary accretions at Spence’s Bridge on the Nicola River. *Provided by: Jepp Ball, BC Ministry of Environment, Water Stewardship Division.*



WHAT CAN WE DO ABOUT IT?

SOFT INFRASTRUCTURE STRATEGIES

Improvements in the way local interests manage water supply (i.e., storage) and demand (i.e., surface and groundwater water withdrawals) are required to sustain the integrity of ecological systems, the local community’s standard of living, and economic opportunities in the Nicola region. The soft infrastructure strategies discussed in the Okanagan case study apply equally well to all semi-arid water strapped regions, including the Nicola. These strategies include: (i) develop water budget / entrench ecosystem rights to water, (ii) require effective operating licenses, (iii) designate environmental aspects for special management considerations, (iv) use demand-side management tools and pricing signals; and (v) encourage partnerships for water / habitat stewardship activities. The following strategies are also relevant.

Develop a water budget: Currently, the Ministry of Environment, Water Stewardship Division has stopped allocating new surface water licenses with the basin (Douglas 2007), even though a review of water licensing information shows that water allocations are continuing (Hatfield 2007). Given that surface water is fully allocated, water users in the basin are more likely to turn towards unregulated groundwater withdrawals (Douglas 2007) which will continue to add pressures to water and fish resources in the basin.

Thus, a ‘notable’ priority for Nicola water management is to greatly improve understanding of groundwater-surface water interactions (a study is presently underway by the Nicola WUMP), since such relationships and sub-basin / basin-wide water budgets are largely unknown. This uncertainty has led to a kind of ‘running blind’ groundwater policy that is prone to overshooting rates of recharge and the sustainable supply. Groundwater extraction should be regulated and restricted within the context of a proper water budget. More broadly, it is important to establish a basin-wide water budget (which includes an in-stream flow component) to get a handle on water year and time of year supplies and demand, and the cumulative downstream impacts of water withdrawals. A water budget could then be used to properly inform water allocation decisions, especially surface and groundwater licensing.

Adjust fisheries management practices: Continuing to track commercial, recreational, and First Nation harvest will help ensure that harvest rates are consistent with marine survival and escapement goals. Managing marine harvest rates will be critical to helping recovery of threatened stocks, such as the Interior Fraser coho.

HARD INFRASTRUCTURE STRATEGIES

The water conflicts and pressures in the Nicola will only intensify unless meaningful strategies to intelligently plan for and adapt to the anticipated environmental changes are implemented. In the case of hard infrastructure adaptation strategies for salmon populations in the Nicola, the most promising options include the following.

Build additional storage capacity / manage water storage: A recent study indicated that completion of the Nicola Lake dam is technically feasible / cost effective, and would provide benefits to agricultural and fish interests (Urban Systems Ltd. 2006). Completion of this infrastructure (e.g., dredge the high spot at entrance to Dam) would provide an additional 13,100 acre-ft (16.2 million m^3) of active storage. In addition, there should be continued evaluation of options to add small storage in the Nicola watershed's major tributaries (e.g., Coldwater, Guichon, Spius, and areas above Nicola Lake).

A key requirement of building additional storage capacity, however, is that any new dams should be built with fish passage needs in mind, and water supplies managed in such a way that ecological flow criteria become *entrenched* in their operating "rule curves" (e.g., Kosakoski and Hamilton 1982; Richter and Thomas 2007). Given current conflicts between water supplies and water users in the basin, priorities for allocating potential increases in supply should focus on ecological needs and drought management, not new growth. Accompanying entrenchment of ecological needs into operating rules is a need to define, evaluate and refine ecological flow criteria in a manner that considers multiple species, socio-economic constraints, and a balance of downstream and in-lake needs (as done with the Okanagan Fish/Water Management Tools project). Then, storage facilities can be managed in a way where flow releases reflect and mimic natural flow patterns, which relate to biophysical requirements for fish and their habitats.

Manipulate surface / groundwater interactions: A potential 'win-win' form of acquiring 'extra' storage that should be vigorously studied includes artificial groundwater recharge or 'groundwater banking'. This strategy would center on evaluation of locations of 'banking' opportunities and potential for increasing winter/fall groundwater recharge (when surface water is more abundant), including medium to large-scale direct injection. Aquifers that feed valley bottom surface water streams should be a priority.

To help identify areas with important groundwater-surface water interactions, additional research and mapping is needed to improve our understanding of groundwater influenced portions of valley bottom streams (e.g., using aerial remote sensing technology to find hyporheic flow). Fisheries and Oceans Canada personnel (e.g., Richard Bailey) have found that adult chinook key in on thermal refugia (cool water) created by groundwater infiltration, and that the locations of these adults are predictable based on water depth and temperature. They have also observed juvenile chinook burrowing into the streambed during the hottest portion of the day in places where incoming groundwater is ~ 16–17°C, as they wait for cooler night time temperatures.

Restore riparian ecosystems: Establish protected riparian corridors and buy-back tracts of riparian lands. Develop a phased, meaningfully scaled riparian restoration plan to improve habitat quality and quantity. This plan amongst other things should consider re-connecting channels with their floodplains, creating back-water areas and side channels (esp. where there are shallow groundwater sources), re-establishing pools and riffles, improving spawning gravels (reducing fines), and increasing riparian shade and large woody debris sources and other in-stream features that act as thermal refugia. (Note, to avoid the need for repeated human interventions, restoration actions should allow for natural (high) flow driven processes to evolve the original planform design thereby helping to naturally sustain the quality of the restored habitat).

5. WATER: BRINGING INTERESTS TOGETHER IN THE COWICHAN RIVER BASIN

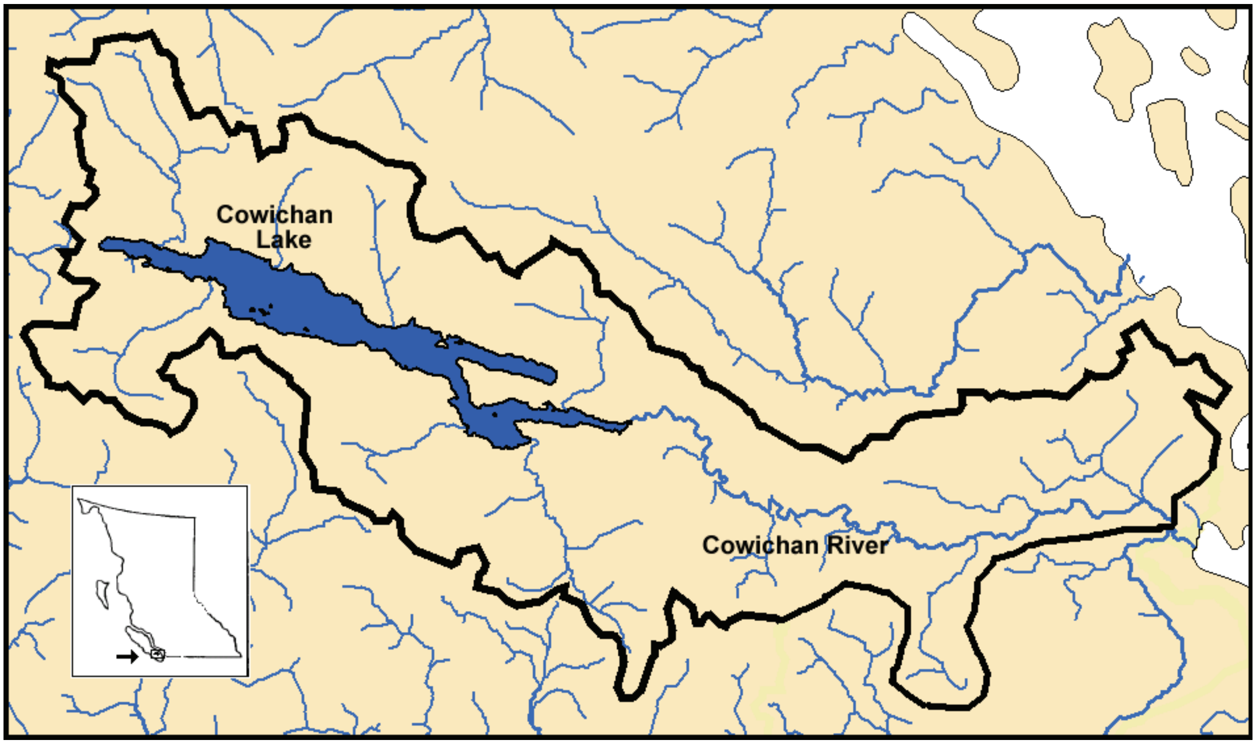
WHAT IS HAPPENING?

Three perspectives come together to shape a unique story about people, freshwater supplies, and Pacific salmon in the Cowichan River basin. First, from the perspective of its people, economic interests, communities, and local managers, this story is one of local perspectives undergoing transformative change. Concerns about water use and availability have been central to unifying interests in the Basin. A chronology of key events are as follows:

- In the 1950s a water license was issued to a pulp mill at Crofton to divert substantial volumes of water from Cowichan River.
- In 1957, a weir was built at the outlet Cowichan Lake to store water for the mill and control in-river flows during the summer.
- In 1991 a report sponsored by Fisheries Renewal studied options to increase the height of the weir on Cowichan Lake, but was rejected by lakeside property owners.
- In 2003, a summer with exceptionally low flows and a 5-day period of de-watering brought conflict between Norske Canada (the mill operator at the time) and Fisheries and Oceans Canada (charges were contemplated under the *Fisheries Act*).
- In 2004, an ad hoc Cowichan River Committee (drawing members from Cowichan Tribes, Norske Canada, Land and Water B.C., Fisheries and Oceans Canada, Ministry of Water, Air and Land Protection, and the Cowichan Valley Regional District) was formed to make flow management decisions during periods of drought.
- Later that year, the Cowichan Valley Regional District Board resolved to coordinate and manage a process of developing a Water Management Plan in response to recommendations from the ad hoc Committee.
- By the end of the year the funding Partners (Cowichan Valley Regional District, Ministry of Environment, Fisheries and Oceans Canada, Catalyst Paper, Cowichan Tribes, and the Pacific Salmon Commission) came together to start a 28-month process of developing a Water Management Plan for the Basin.
- In March 2007, BC's first community-based Water Management Plan (Westland 2007), providing over 90 recommendations, was released and approved by its supporting partners.
- Today, unified by a common interest in improving water management, historically disparate interests are working creatively and collaboratively through the Cowichan Stewardship Roundtable, Water Governance Roundtable, and Harvest Roundtable to resolve conflicts in the Basin.

A second contributing perspective is that of the Basin's physical geography. The watershed is relatively small draining an area of 930 km^2, located in one of the most hydrologically complex areas of Canada (Whitfield *et al.* 2003). The basin displays significant variations in topography and geology. The upper half of the basin is mountainous, while the eastern half is mostly situated in the coastal lowlands. Cowichan Lake lies in the upper portion of the basin. The lake basin was originally filled by glacial melt water, and more recently by rainfall runoff. Cowichan River, at 45 km in length, flows from Cowichan Lake to the estuary in Cowichan Bay on the east coast of Vancouver Island (Figure 18).

FIGURE 18. Cowichan River watershed, including the lake, mainstem, and smaller tributaries.



The climate in the Cowichan Basin is influenced by its mountainous topography and the seasonal weather patterns of the west coast. The upper catchment, which lies at the foot of the Insular Mountains, receives roughly 2,800 mm of precipitation per year while the lower more easterly area of the Basin only receives an average 1,100 mm (Westland 2005). Rainfall is the dominant form of precipitation, although there is also snow accumulation particularly in western areas of the watershed (Whitfield *et al.* 2003). Historically, the Cowichan Basin includes mild-wet winters and cool-dry summers with the highest precipitation occurring through March and warmest temperatures June through September (Westland 2005). Climate records for the region suggest long term trends of increasing annual temperatures by 0.5°C, with notable increases of 0.8°C in the spring and 0.5°C in the fall (MWLAP 2002). A climate model developed by Whitfield *et al.* (2003) predicts that rainfall dominant watersheds, such as Cowichan, will experience increased frequency of winter flood events, with low flow periods beginning earlier in the spring and extending later into the fall. This general pattern of winter / spring floods and summer / fall droughts has already been observed.

A third and final contributing perspective is that of Pacific salmon. The Basin is home to significant runs of chinook (Figure 19), coho, and chum salmon (Figure 20) (McMullan 2006). In particular, the Cowichan River has one of the largest remaining naturally spawning populations of chinook salmon in the Georgia Basin. Historically, chinook spawner abundance ranged from 5,000 to 10,000 individuals. Even during a decade of high commercial catch (1975–1984) the number of retuning salmon remained high (4,000 to 9,000 fish). In 1986 and 1987 the number of naturally spawning chinook decreased substantially. Although the precise reason for the decline is unknown, extremely low water levels during those years are speculated to have contributed to adult chinook mortality (DFO 1999).

Historically, substantial reductions in catch have been sufficient to sustain natural abundance of chinook in years with poor marine survival. The current outlook is one of concern for lower Georgia Strait chinook (DFO 2007a).

The 2005 and 2006 returns of chinook to the Cowichan River were the worst on record despite reduced sport and commercial catch (McMullan 2006; DFO 2007a). In 2006, extended summer drought conditions hampered freshwater entry allowing only 1,000 fish to make it to the counting fence on Lake Cowichan, 800 of which were transported upstream by trucks (Tom Rutherford, Fisheries and Oceans, pers. comm.). Returns for 2007 are expected to be very low due to continuing low marine survival, lack of hatchery production (2004 hatchery production died during a power outage), and increasingly low summer and early fall flows in the Cowichan River (DFO 2007a).

FIGURE 19. Escapements of chinook salmon in the Cowichan River from 1953 to 2005.
Source: Fisheries and Oceans Canada, Salmon Escapement Data System (nuSEDS). Available through Mapster: http://www-heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm

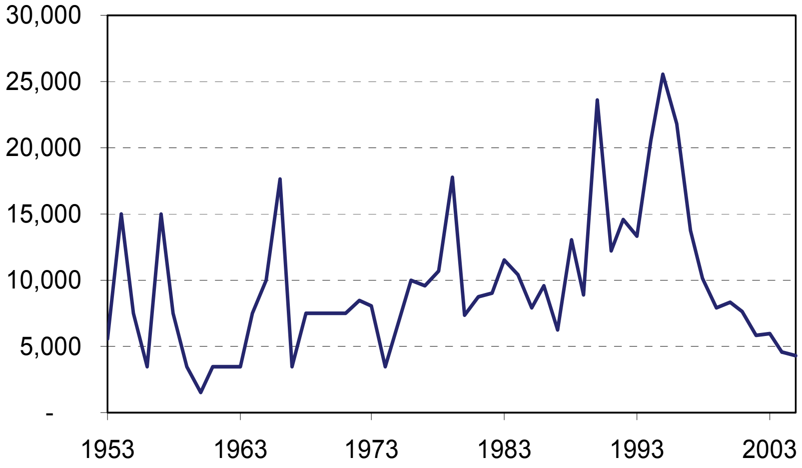
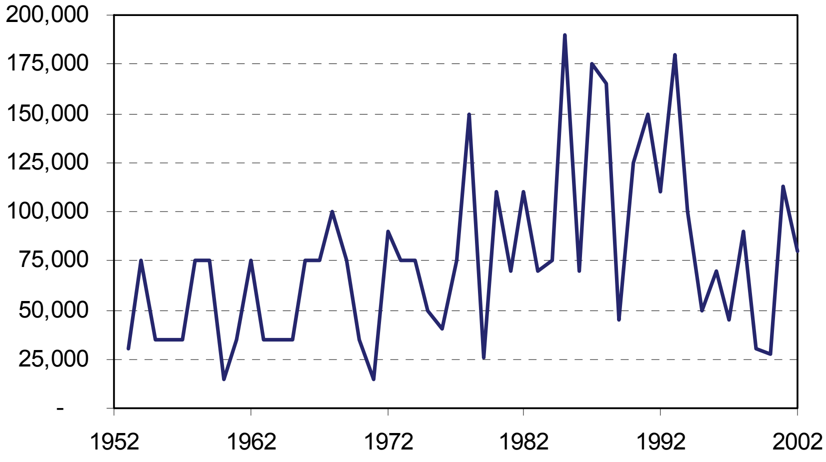


FIGURE 20. Number of chum salmon in the Cowichan River from 1953 to 2002.
Source: Fisheries and Oceans Canada, Salmon Escapement Data System (nuSEDS). Available through Mapster: http://www-heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm



WHY IS IT HAPPENING?

Together these perspectives of water management, geography, and salmon resources create unique challenges for managing the Basin. Driven by its geography and climate, recent years of drought have lead to low summer water levels, which in turn have lead to conflicts among users: its salmon resources, economic activities, drinking water supplies, water quality, and recreational interests (Westland 2005).

Cowichan Lake regulates the River's hydrology by stabilizing flows, settling sediment from inflow tributaries, moderating summer and winter water temperatures, and controlling organic and inorganic nutrients (MELP 1986 as cited in Westland 2005). River flows are also know to strongly link to life-stage specific survival; spawning, incubation, rearing, and migration success have all been linked to instream flows (Beechie *et al.* 2006). Changes in precipitation, flows, and temperatures have important influences on salmon in the Cowichan Basin. Cowichan chinook return to their natal rivers from late August to October. This period coincides with the time when air temperatures are highest (Figure 21) and precipitation is lowest (Figure 22). The principle factor limiting freshwater production of chinook in the Cowichan Basin is low flows because it prevents adults from migrating to upstream spawning areas (Tom Rutherford, Fisheries and Oceans Canada, pers. comm.). Furthermore, the productivity of the Cowichan River is a function of the quantity of accessible, low-gradient reaches, which provide suitable spawning and rearing habitat for salmon (Lill *et al.* no date, as cited in Westland 2005). Consequently, during times of low water flow the quantity of spawning habitat is decreased, thereby limiting productivity of the system.

FIGURE 21. Monthly precipitation and air temperature summaries from Lake Cowichan.
Source: Environment Canada, Canadian Climate Data. Available at: http://climate.weatheroffice.ec.gc.ca/climateData/canada_e.html

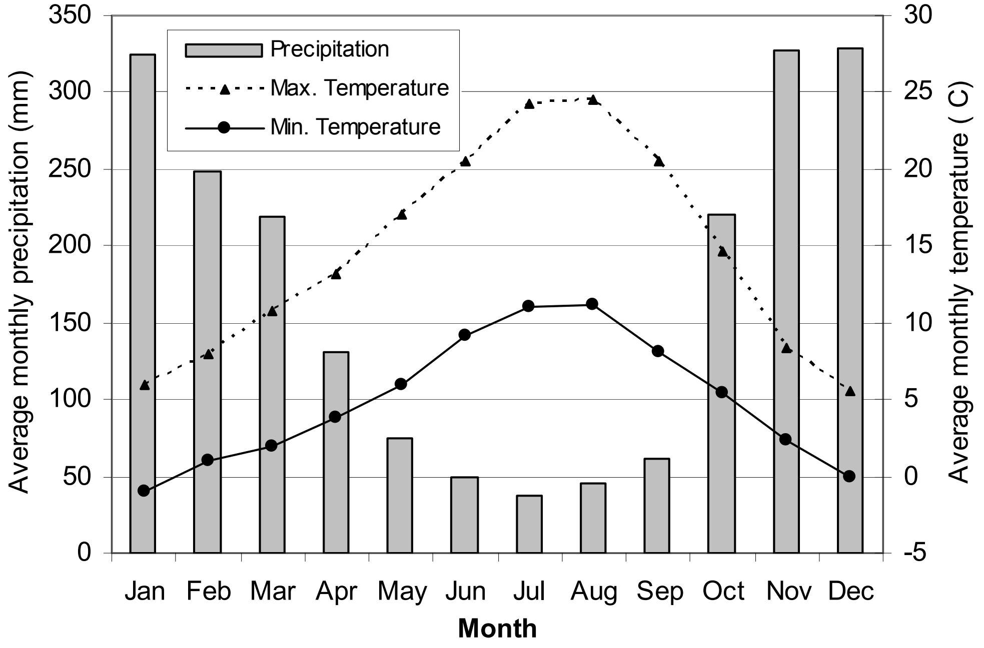
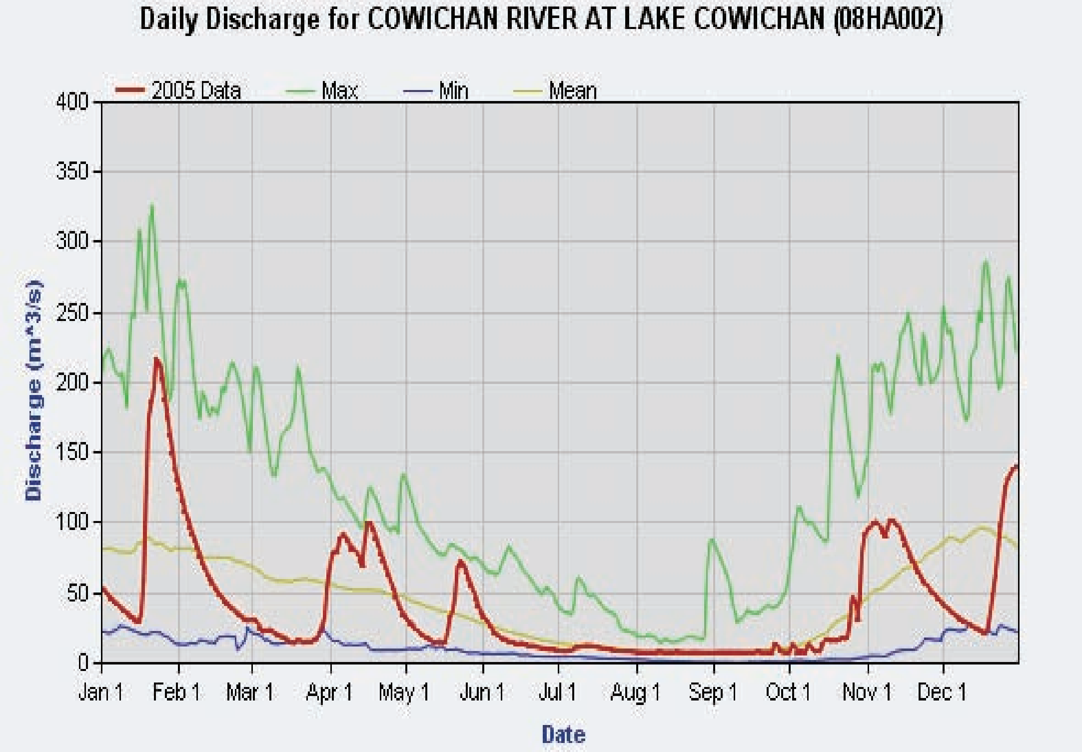


FIGURE 22. Maximum, minimum, and average daily discharge for the Cowichan River (station 08HA002) measured over 73 years of record (1913 to 2005).

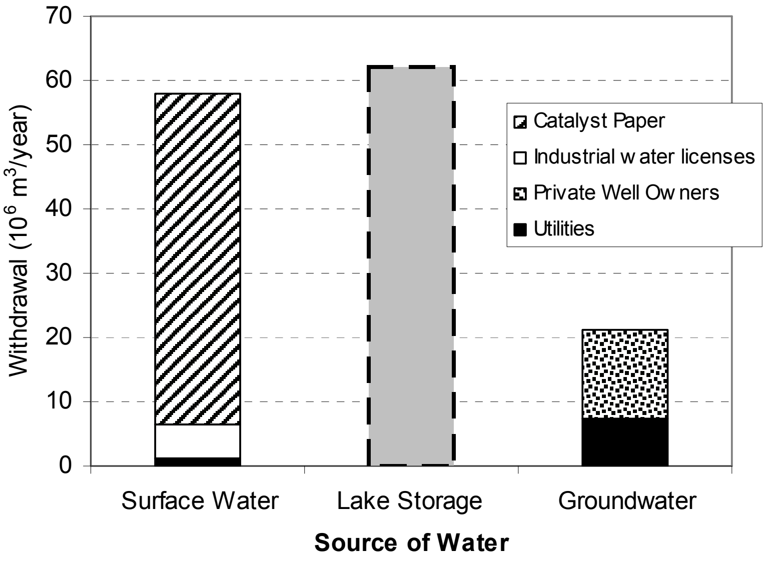
Data from 2005 are also provided. Source: Water Survey of Canada, Hydrometric Data. Available at: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm



WHY IS IT SIGNIFICANT?

The Cowichan River is a designated Heritage River and is one of the most important rivers on Vancouver Island for cultural First Nations, recreational, and commercial fisheries. Cowichan chinook are used as an Index Stock under the Canada-US Salmon Treaty to guide Georgia Basin chinook stock management. Water availability during summer months appears to be the issue of greatest concern in the Cowichan watershed for both salmon and people. The river is important for recreation users, such as tubers, kayaking, and canoeing, as well as a source of water for domestic, irrigation and industrial uses (Crofton Pulp Mill owned by Catalyst Paper). Figure 23 provides a summary of annual water withdrawals by user group and water source. Catalyst Paper is the primary water license holder for Cowichan Lake and is entitled to withdraw 1 meter of summer storage retained in the spring via licensed releases through the Lake's weir (licence is for 86 million m^3 per year, though actual withdrawals are within the range of 50 million m^3 per year; Westland 2005). The weir is operated by Catalyst paper and was initially built to ensure adequate water storage for the pulp mill over the summer drought period. If lake levels are high enough in wet years, one or two small pulses of water may be released in early fall to assist chinook salmon migration when requested by DFO.

FIGURE 23. Total surface and ground water withdrawals (includes utilities, private users, Catalyst Paper Corporation Crofton Division, and licensed storage).
Source: Westland (2005)

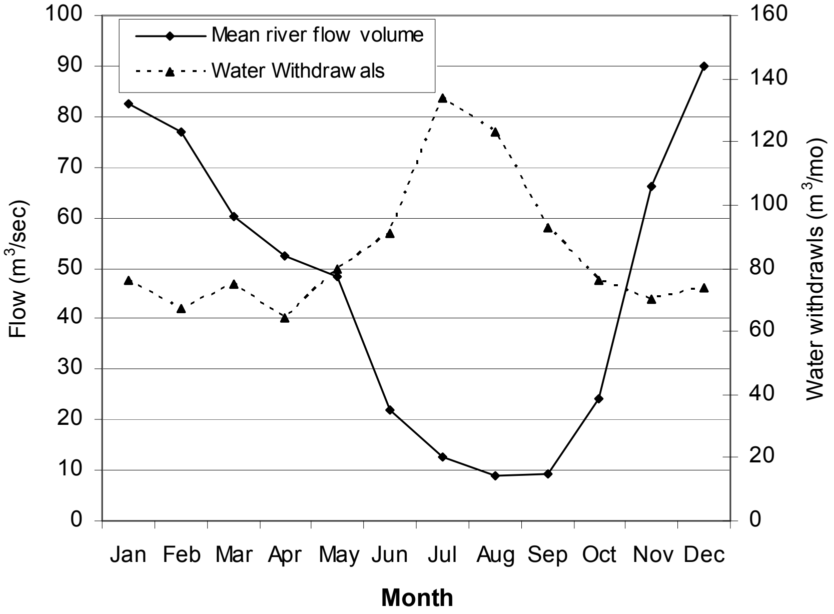


Downstream of the lake, pressures on water availability are exacerbated by groundwater extraction. Most water for agricultural irrigation and domestic supplies for Duncan and North Cowichan are obtained from groundwater sources. On average 7.4 million m^3 of ground water are withdrawn annually with extraction projected to increase over time (Westland 2005). Groundwater affects surface water by helping maintain summer base flows, moderating water temperatures, providing refugia for juvenile and adult fish, and influencing water quality (Douglas 2006). Thus, groundwater use has the potential to directly impact salmon, their habitats, and other water users.

In light of changing precipitation and flow patterns resulting from climate change, water management is becoming an issue of increasing importance in the Cowichan River watershed—well beyond its importance in maintaining flows for salmon. The search to answer the question of whether there is enough water for both people and instream needs is helping to focus the search for solutions to summer water shortages. Peak demand from June through September coincides exactly with the time when in-river flows are at their lowest (Figure 24). Presently, human withdrawals from the system greatly exceed inflows during periods of summer low flow, thereby increasing the risk that the existing weir cannot store enough water to sustain fisheries, ecological values, recreational opportunities, and dilute effluents within the river (Westland 2005). Moreover, water demand to satisfy population growth alone is expected to increase by 27% over the next 25 years (Westland 2005). Projected demands for water in the fall of 2031 under scenarios with low precipitation will be four times greater than the amount of water flowing into the system (Westland 2005). This increase in demand coupled with climate projections for drier summers is also problematic considering that 54% of annual water consumption occurs between May and September when water inflow to the Basin is lowest (Figure 21) (Westland 2005). If adequate spring inflow can not be stored in the lake, Cowichan River could run dry for much of the late summer / fall; a circumstance that would devastate salmon populations.

FIGURE 24. Relationship between average monthly river flow and human demand for water from the Cowichan Basin.

Source: Water Survey of Canada, Hydrometric Data, withdrawal data from Westland (2005).



Multiple user groups are dependent on receiving an adequate supply of water; inadequate supplies could lead to adverse effects on local communities. For example, commercial, recreational, and First Nation fisheries in 2004 were valued from $5.4 million to $6.2 million (McMullan 2006). If fisheries collapsed as a result of insufficient water this source of revenue would be lost to local communities, including the cultural losses associated with fishing opportunities, and loss of one of the last vestiges of naturally spawning chinook in Lower Georgia Strait. Low water levels can also affect economic benefits drawn from recreation, tourism, and Catalyst Paper mill (the dominant interest capturing and using surface water). For a variety of reasons, native and non-native communities are significantly reliant on water in the basin.

WHAT CAN WE DO ABOUT IT?

Soft and hard infrastructure strategies can both help to improve water supplies and reduce demands on water resources, which may ultimately benefit all water users including salmon. The Cowichan Basin Water Management Plan (Westland 2007) currently recommends a wide range of soft and hard infrastructure approaches to restructuring water management paradigms and coordinating local action. The strategies presented here are summarized with the intention of providing insights to decision makers in other areas.

SOFT INFRASTRUCTURE STRATEGIES

Coordinate / implement planning frameworks: Recognizing the past approach of responding to seasonal water management crises was not working, in 2004 an ad hoc Cowichan River Committee recommended that the Cowichan Valley Regional District lead development of a Cowichan Water Management Plan. In March 2007, the Cowichan Valley Regional District, BC Ministry of Environment, Fisheries and Oceans Canada, Catalyst Paper Corporation, Cowichan Tribes, and Pacific Salmon Commission released a Water Management Plan whose purpose was to: (i) have broad public support, (ii) protect the ecological function of the system, (iii) balance water supply and use, and (iv) increase understanding of the Cowichan Basin and its water issues (Westland 2007). The Plan is based on the fundamental belief that "*a new relationship between people and water needs to be established to ensure that there will be reliable water supplies available for human use, thriving ecosystems, and a healthy economy in the Cowichan Basin, both now and in the future.*" It also recognizes the essential need to balance ecological, social, and economic needs for water. This plan outlines the *Vision* for desirable future conditions in the basin, the specific *Goals* that will help achieve this vision, and the *Objectives / Actions* needed to achieve on-the-ground improvements. Although Part 4 of the provincial *Water Act* provides provisions for developing water management plans, this Plan represents a local planning process that is not subject to the provisions under the provincial *Act* (e.g., requiring approval by the Lieutenant Governor in Council prior to implementation).

As such, this Plan provides local managers and stakeholders with the foundation for taking direct and local action to better manage water resources in the Basin. The hope is that the Plan will help shift management to a more strategic paradigm that addresses issues around improving management of water supplies, reducing demands for water among users, and managing expectations for water availability across seasons and in years of drought (Brian Tutty, Fisheries and Oceans Canada, pers. comm.). The Plan's scope does not explicitly address water quality issues unless related to water supply.

In general, the Water Management Plan provides more than 90 recommendations targeted at: (i) increasing water-use efficiency, (ii) improving water supply and management, (iii) maintaining water supplies for freshwater and riparian ecosystems, (iv) minimizing impacts of flood and drought conditions, (v) educating local water resources users, and (vi) establishing accountable water management decision processes. Recommendations are consistent with the adaptation strategies summarized in Tables 1 and 2, which include but are not limited to:

- initiating improvements to water infrastructure;
- improving management of water demand in all sectors;
- ensuring local governments and institutions are leaders in water conservation;
- promoting land use that increases water use efficiency;
- storing sufficient runoff to support human use and sustain river flows during summer and fall;
- ensuring water storage decisions account for the potential effects of climate change;
- protecting surface and ground water resources from contamination that could reduce supply;
- managing land and resources to avoid adverse effects on quantity and timing of runoff;

- meeting recommended fish conservation flows over the entire year;
- maintaining, enhancing, and restoring freshwater and riparian habitats;
- establishing adequate setbacks to reduce potential hazards from flooding;
- increasing flood buffering capacity of floodplain and constricted channel areas; and
- promoting stormwater management that emphasizes infiltaration and detention and minimizes impervious surfaces to avoid increases in peak flows.

The Water Management Plan has developed clear goals, objectives, and actions that work to balance multiple and potentially competing water interests. The current focus of the Cowichan Stewardship Roundtable is to gain support and implement the Plan's recommendations. Challenges of implementing the Plan include: (1) endowing local interests with sufficient funds to implement the Plan's recommendations; (2) prioritizing among a long list of recommendations as funding becomes available; and (3) developing a monitoring and evaluation program to evaluate effectiveness of the recommendations in achieving intended Goals and Objectives.

Use demand-side management tools and pricing signals: The Cowichan Basin Water Management Plan (Westland 2007) recommends a range of demand-side management strategies to improve availability of water supplies. Installation of water meters and volume-based pricing are important and relevant strategies given that local water demand spikes in the summer, largely as a result of increased domestic use for lawn and garden irrigation, operation of campground facilities, and increased summer populations in various communities (Westland 2005). Water metering provides a method of collecting data over time that can be used to identify trends in water consumption and, in turn, factors contributing to these trends. These data can then be used to formulate local policies targeting appropriate sectors and help prioritize actions that most cost-effectively reduce demand. Although local residents are concerned that water metering will lead to privatization of water / public-private partnerships (Westland 2007), water metering can allow individuals, business, and industry to monitor their water consumption and may promote greater personal responsibility for water conservation, as demonstrated in other jurisdictions.

Require effective operating licenses: Consistent with the Basin's Water Management Plan, water licensing needs to be evaluated so that water is not allocated beyond the system's ability to provide water. As is occurring in other watersheds across British Columbia, groundwater use and extraction is increasing rapidly in the Basin with no adequate system of regulation and monitoring. Given known flow and temperature interactions between surface water and groundwater, a licensing mechanism for surface water without a parallel and effective system of groundwater regulation is short-sighted and will likely lead to serious water conflicts in the future. Increases in groundwater temperature from 10 to 11.7°C at a depth of 70 feet have already been observed by the Cowichan Tribe hatchery facility (Tom Rutherford, Fisheries and Oceans, pers. comm.).

HARD INFRASTRUCTURE STRATEGIES

Build additional storage capacity / manage water storage: The Water Management Plan considered a variety of options to increase storage across the Basin, including the addition of storage to small and large upland reservoirs, as well as increasing the height of the weir on Cowichan Lake. The weir was shown to be the only feasible option to be effective at increasing storage in the reservoir and flows in Cowichan River. Currently, the "preferred supply alternative" emerging from the Water Management Plan is to raise the weir by 30 cm by 2010. This action is also one of the most contentious because shoreline property owners are concerned that raising the weir will exacerbate winter flood levels and inundate beaches during the summer. Studies have been recommended to measure the adverse effects of increasing the height of the weir and compensation required to help alleviate these concerns.

Coupled with increasing the height of the weir, the “preferred supply alternative” includes a recommendation to install pumps (between 2012 and 2015) to allow for negative storage when required over the year. Pumps would draw additional water from below the depth accessible by the current height of the weir. Such an option would allow water to be released from the river irrespective of whether sufficient water is available within the normal capacity of the reservoir. An additional benefit of negative storage is that discharged water might help maintain cool water temperatures in downstream reaches. Shoreline property owners are concerned, however, that this action may result in loss of access to docks and beaches later in the year.

The operating rules for managing the Cowichan Lake weir and in-river flows require achieving a minimum of 15m^3/s up to June 15 and a minimum 7 m^3/s up to the date when lake levels are high and in-river flows are no longer controlled by the weir (typically November 1). Operating rules also allow for spring and fall pulse flows that enable fish migration (NHC 2006). The recent Water Management Plan (Westland 2007) recommends the following targets:

- maintaining spring flows of 20–30 m^3/s from April 1 to May 15, with flows of 15–30 m^3/s from May 2 to June 15 (meet 95% of the time to 2031);
- maintaining minimum summer flow of 7 m^3/s from June 15 to the end of the weir’s operating period, with increases in this minimum to 8.5 m^3/s by 2031 to compensate for the effects of increased demand and climate change (meet 95% of the time to 2031);
- in wet summers, increasing minimum flows to 9 m^3/s, while in dry summers reducing flows to 4.5 m^3/s if necessary (meet 95% of the time to 2031);
- providing pulses of water in the fall of 16 m^3/s for 30 hours each to enable salmon migration (meet 2 out of 3 years or 66% of the time)

The rationale for setting a minimum summer base flow target of 7 m^3/s was initially developed by the relevant government agencies in the 1950s when the water license was issued. At the time, this target was justified as having no net effect because the average minimum flows below the Crofton Mill’s intake after installation was recognized as being the same as those flows observed prior to installation (as cited in NHC 2006). In fact, the weir has been documented as having a positive effect on enhancing summer base flows over what would be observed without the weir (see Figure 25). In 1987, two instream flow studies investigated the suitability of this target for fish needs: Burns *et al.* (1987) investigated side channel connectivity, while Wightman and Ptolemy (1989) assessed juvenile rearing habitat use on an 8 km index reach of the mainstem above Skutz Falls. An additional study in 2006 examined side channel connectivity and steelhead spawning habitat above Skutz Falls (Pellett and Wightman, in preparation as cited in NHC 2006).

Given year-to-year variation in climate and the related implications on water supply in the Basin, a minimum flow target of 7 m^3/s has been difficult to achieve, however. In 1991, an engineering study acknowledged this target was supportable with available storage, but not in drought years (KPA 199). From 1985 to 2005 this target was met 60% of the time. The minimum flow target was not met in 1985, 1986, 1987, 1989, 1992, 2003, 2004, and 2005 with duration of flows < 7 m^3/s ranging from 21 to 97 days in those years (not met in 8 out of 20 years, see information from NHC 2006 and Water Survey of Canada[17]).

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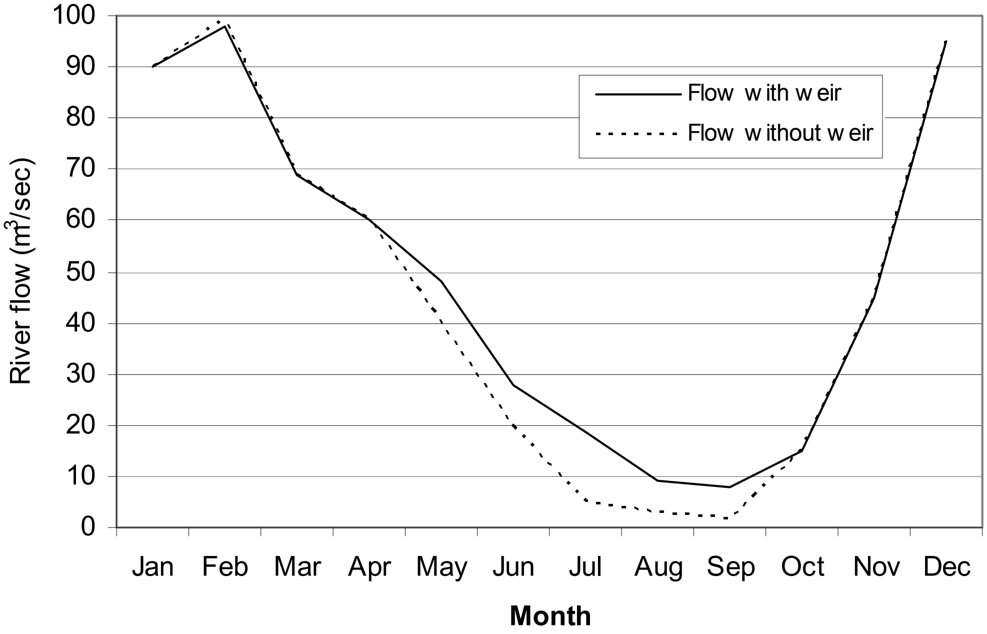
[17] Water Survey of Canada, Hydrometric Data. Available at: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm

In the context of these historic challenges and anticipated challenges due to climate change, it seems prudent that water managers be provided with management tools that: (i) facilitate flexibility in decision making and (ii) encourage "learning by doing". Use of a water budget for water management purposes can provide decision makers with the flexibility to better optimize decisions over the season and across years. For example, in times of excess water can be stored and released at times when releases have the greatest in-stream benefits. Water management tools such as those being applied in the Okanagan Basin (Hyatt and Alexander 2005) can also help decision makers learn about the consequences of in-season decisions and variations in flow releases. Good quality data and information systems will be essential to helping "close the loop" between a manager's decision (timing, magnitude, and rate of change of releases) and its effect on the environment (e.g., salmon productivity).

FIGURE 25. Effect of the Cowichan Lake weir on annual Cowichan River flows.
Source: Westland (2005)



Restore slope stability: Among other point sources, the Stoltz slide has already been identified as a major concern on the Cowichan River, dumping between 10,000 and 28,000 m^3 of fine sand and silt sediment into the watershed every year since 1993. This contribution of sediments represents between 35 and 45% of the total sediment load as measured 10 km downstream (McMullan 2006). A study in 2004/2005 found an average egg-to-fry survival rate of 86% upstream of the slide, while downstream survival ranged from 0.7% to 6.8% (McMullan 2006). Thus, restoring slope stability would help increase egg-to-fry survival. Although not directly affecting water temperature or water flows, actions to minimize these types of more controllable sources of juvenile mortality will be important measures to help offset the additional mortality imposed by climate-induced changes in freshwater habitats. This strategy has been pursued for some time, however. The 10-year Stoltz Bluff Remediation project was completed in 2006[18] with a more recent 3-year stabilization effort drawing support and collaboration among a wide variety of organizations, including:

- BC Conservation Foundation
- BC Ministry of Environment, BC Parks
- BC Ministry of Transportation
- Catalyst Paper Corp.
- Fisheries and Oceans Canada
- Georgia Basin / Vancouver Island Living Rivers Program
- Habitat Conservation Trust Fund
- Island Timberlands Limited Partnership
- Nilex Inc.
- Pacific Salmon Commission, Southern Endowment Fund
- RLC Enterprize Ltd.
- TimberWest Forest Corp

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[18] Premier's Awards Promoting Innovation and Excellence. 2005. 2006/07 Partnership Finalist Award Recipient–Craig Wightman, Acting Manager, Salmon and Steelhead Recovery Program, Ministry of Environment–Nanaimo. See: http://www.bcpublicservice.ca/premiersawards/2006/finalists/2006_partnership2.htm

6. THE NASS RIVER WATERSHED: A PERSPECTIVE ON RELATIVELY PRISTINE SALMON HABITATS

WHAT IS HAPPENING?

The Nass River drains 20,500 km^2, an area representing the third largest watershed in the province (Figure 26). It originates in the Skeena Mountains flowing south and southwest for 400 km before entering Portland Inlet on the north coast (Alexander and Koski 1995). Small tributaries drain steep valley side-walls onto a wide meandering valley along the mainstem. Larger tributaries, such as the Iknouk, Cranberry, Meziadin, Bell-Irving, and Damdochax rivers, drain wider valleys through the surrounding mountains flowing into the Nass and its coastal Inlet. The watershed is populated by few large lakes: Meziadin, Bowser, Kwinageese, and Damdochax, for instance. Climate is typical of coastal watersheds in the north—moderate air temperatures with abundant precipitation over the year (Figure 27). This annual pattern of precipitation leads to a hydrologic regime typical of coastal, rain-driven systems. Annual peak flows occur in the late-fall / early winter with short-term peaks driven by storm events over the year (Figure 28). In spite of a relatively limited distribution of large natural storage, flows are generally sustained over the year given an abundance of precipitation; though low flows can occur over the winter when snow is the dominant form of precipitation at higher elevations. In the lower watershed, forest cover is dominated by Coastal Western Hemlock, Mountain Hemlock (at higher elevations), and non-forested Alpine Tundra. Further upstream, forest cover is dominated by Interior Cedar-Hemlock in the lower valleys and Engelmann Spruce-Subalpine Fir (Meidinger and Pojar 1991).

Despite a recognition that the context of issues varies for each species and sub-basin, the intention is to present a general understanding of the status of salmon. Nass River is highly productive, supporting a variety of anadromous salmonid species including all Pacific salmon as well as steelhead, cutthroat trout, and Dolly Varden (Alexander and Koski 1995; Levy 2006). The watershed supports two sockeye life history types—lake and ocean. Meziadin Lake contributes approximately 75% to production, Bowser, Damdochax, and Kwinageese 25%, with smaller tributaries providing a small contribution of ocean-type sockeye. Chinook salmon demonstrate a diversity of life history traits (i.e., age-at-maturity, spawning time, and juvenile residence time): spring chinook enter first, migrating the furthest upstream; summer chinook are the most abundance, returning from mid-June to mid-August; late-run chinook return in the fall. Coho are widely distributed with the most productive streams consistently supporting over 1,000 spawners (averages from 2000 to 2005: Meziadin 4,621; Kwinageese 1,282; Zolzap 1,996)[19]. Coho production appears to be limited by tributary migration barriers, though productive capacity is high (e.g., 200,000 spawners) with the greatest potential in the upper watershed (Bocking and Peacock 2004 as cited in Levy 2006). Chum generally return from June to August with area populations demonstrating a ten-fold variation in abundance. Nass River pinks are the least abundant species with a relatively small population relative to other watersheds on the North Coast. Dominant returns are available in both even and odd years. Iknouk River, a pristine watershed, supports 90–95% of production (see Figure 29).

Status of these populations is generally strong. Prior to 1992 little monitoring occurred which changed with the establishment of the Nisga'a Fisheries Program. As well, the Lisims Conservation Trust Fund, established after signing the Nisga'a Final Agreement in 2000, ensured annual funds were available to (i) help protect and monitor salmon stocks in the future, and (ii) enable Nisga'a stewardship in management of Nass salmon resources. For sockeye, the Meziadin population has been stable, while the status of smaller populations are generally unknown with the exception of the Gingit population which has shown some stability since being consistently monitored in

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[19] Source: Fisheries and Oceans Canada, Salmon Escapement Data System (nuSEDS). Available through Mapster: http://www-heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm

2000 (Levy 2006). Chinook in the Meziadin River have shown a 5-fold variation in abundance from 1990 to 2005, showing neither an increasing nor decreasing trend, however, the chinook populations are naturally not as abundant as other salmon species returning each year (i.e., returns less than 30,000; Levy 2006). Data from Zolzap Creek indicate that coho in the watershed have recently recovered from lower abundances in the early and late 1990s (Levy 2006). Limited data are available for chum salmon, but regional analysis concluded abundance in the area have declined from 1950s to 2002 (Spilsted 2003). Finally, pink salmon escapements were historically higher, but current productivity still supports significant fisheries. High rates of straying help minimize risk of reduced abundance due to harvesting pressures.

FIGURE 26. Map of Nass River basin and its major tributaries.

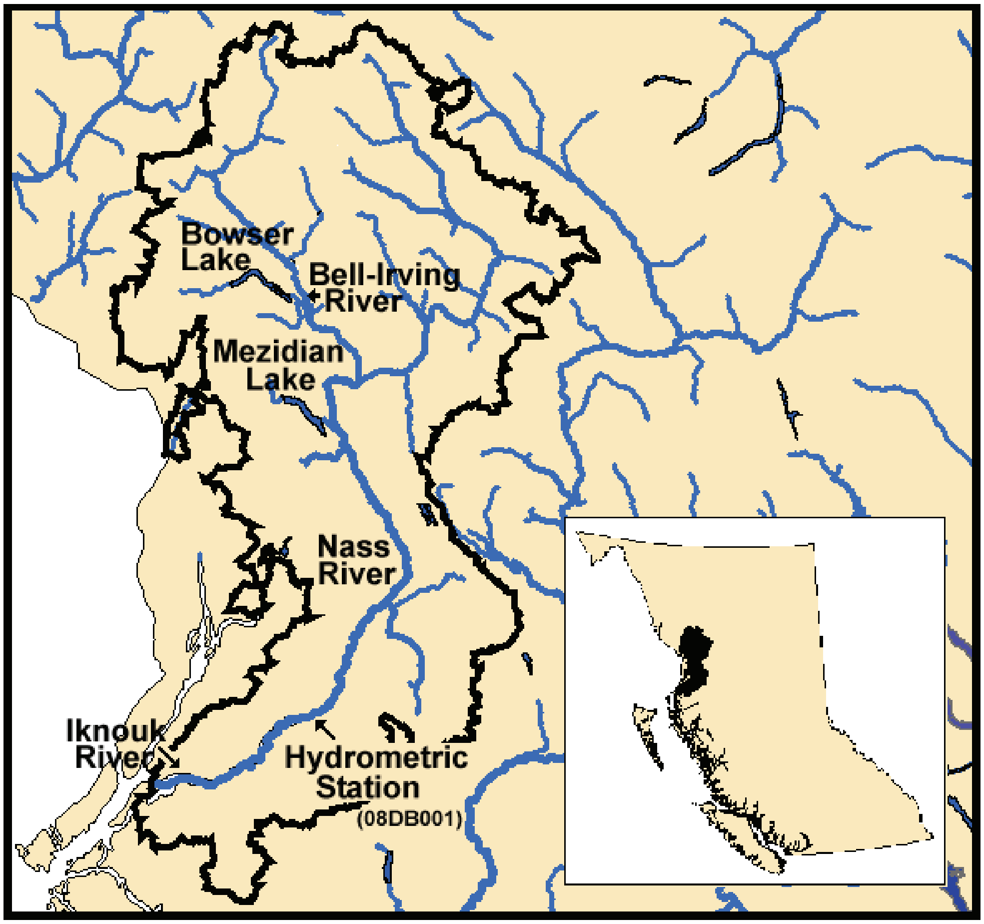


FIGURE 27. Summary of average monthly snowfall and rainfall (mm) from 1971 to 2000 at Prince Rupert.
Daily average air temperature for each month are also provided. Climate data from Environment Canada, Canadian Climate Normals or Averages 1971–2000. Available at: http://climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html

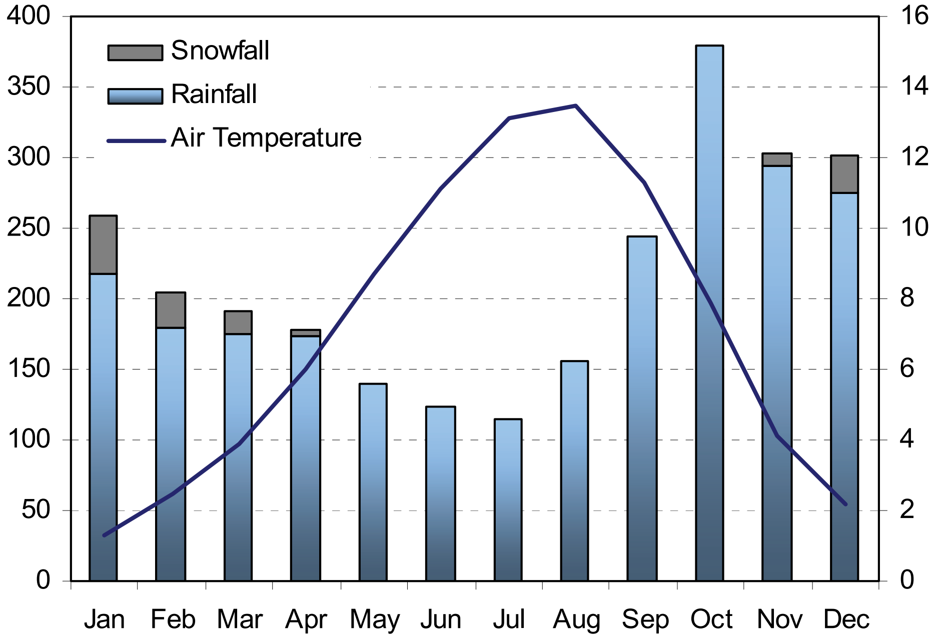


FIGURE 28. Maximum, minimum, and average daily discharge for the Nass River (station: 08DB001) measured over 71 years of record (1929–2005).
Discharge data from 2005 are also provided. Source: Water Survey of Canada, Hydrometric Data. Available at: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm

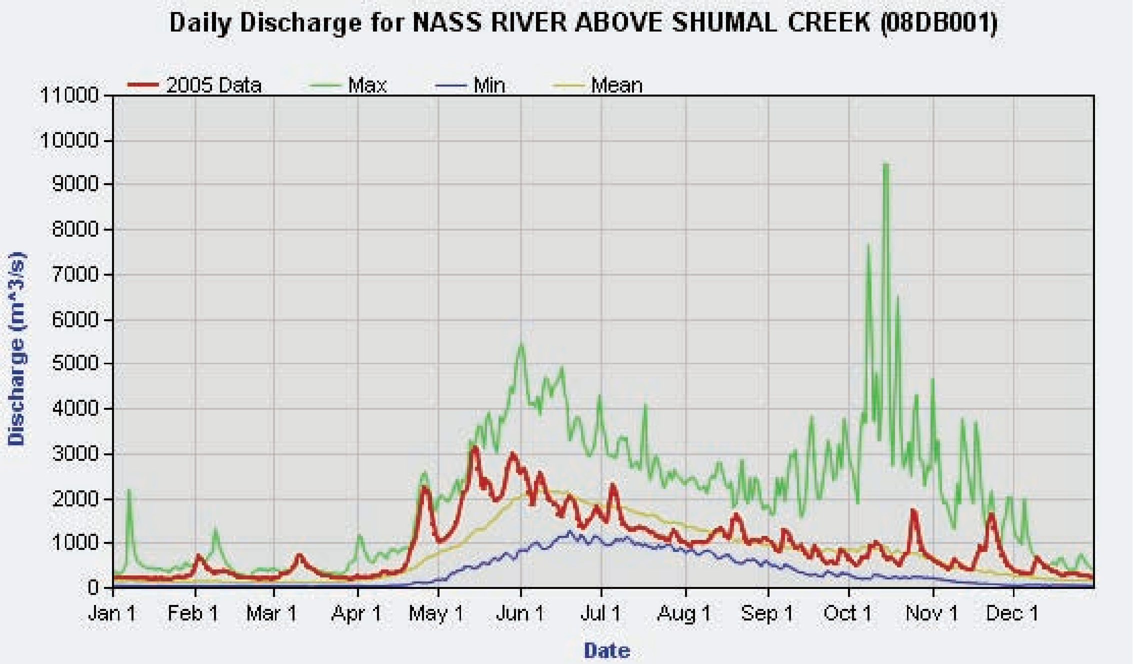
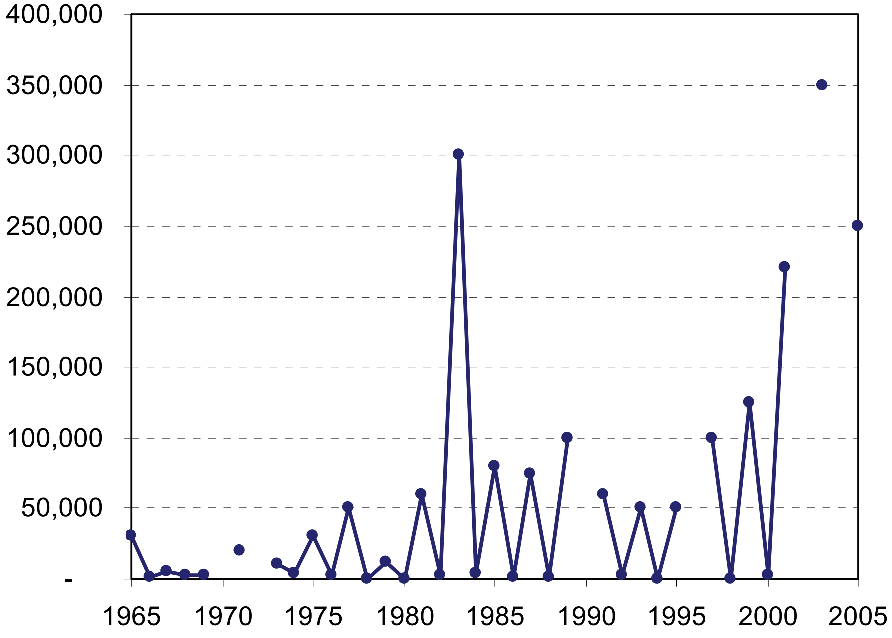


FIGURE 29. Summary of escapement of pink salmon in the Iknouk River from 1965 to 2005 (no data available for 1990, 1996, 2002, and 2004).

Source: Fisheries and Oceans Canada, Salmon Escapement Data System (nuSEDS). Available through Mapster: http://www-heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm



WHY IS IT HAPPENING?

Co-management, rigorous stock assessment, as well as habitat protection and rehabilitation have played major roles in protecting Nass River salmon stocks. Joint management through the Nisga'a Fisheries Program has been instrumental in minimizing impacts of over harvesting and habitat loss. Currently, managers use escapement estimates from fishwheels at Gitwinksilhkw to inform harvesting decisions to meet abundance-based allocations (e.g., Figure 30). Salmon are harvested in multi-species, mixed stock fisheries by a number of competing, though prioritized, interests. Priorities for allocation are based on: (i) conservation, (ii) Nisga'a and other First Nations, (iii) recreational, and (iv) commercial interests (focused on selective fisheries and gear types). The Pacific Salmon Treaty has played an important role in protecting returns of Nass stocks. Prior to 1985, Alaska harvests were much higher than today. Currently, the Treaty provides 13.8% of Total Allowable Catch of sockeye to Alaskan fisheries. Canadian seine and gillnet fisheries account for about 50%, while the Nisga'a Final Agreement allocates 23% of the sockeye harvest to the Nisga'a Nation, represented by four Nisga'a communities on the Nass River (i.e., Gingolx, Lakalzap, Gitwinksihlkw, and New Aiyansh communities). For pink salmon within Area 3, escapement has generally been constant, though exploitation rates (catch/total return) have been highly variable (Figure 31). Due to conservation concerns, there are currently no directed chum fisheries, and most are caught as by-catch in other fisheries. Significant numbers of chinook and coho are harvested in Alaskan fisheries. In Canada, the Nisga'a Treaty-protected fisheries take priority after conservation, with assurances of a fixed percentage of chinook and coho total returns (21% and 8% respectively).

FIGURE 30. Relationship between Total Returns to Canada (x-axis) and allocation (y-axis) of total chinook returns to escapement, Nisga'a, and other Canadian fisheries.

No axis labels were provided in original source. Source: Peacock (2005).

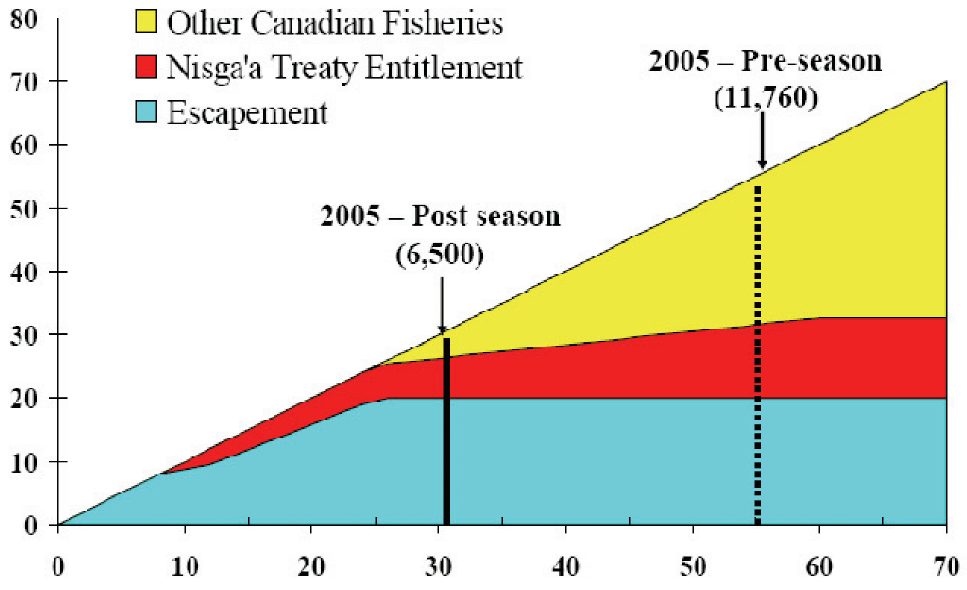
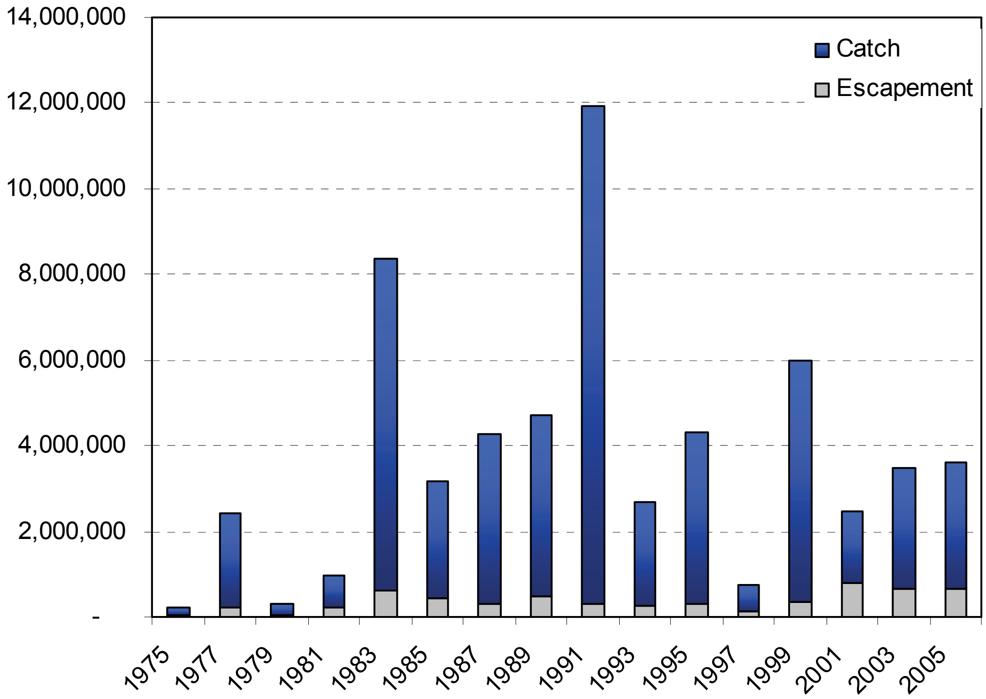


FIGURE 31. Summary of escapement and catch of odd-year pinks within DFO Statistical Area 3 (estimates from 1975 to 2005).

Graph reproduced from Potyrala (2005).



The Nass River watershed is large and relatively pristine, with fewer development activities than watersheds in the Georgia Basin or Southern Interior. Unlike the other case studies, there are no agricultural activities or large urban centres adding stressors to salmon habitats and water supplies. Forestry occurs in lower elevation areas from the mouth to the headwaters, however (Harvey and MacDuffee 2002). Logging in coastal watersheds can have significant impacts on salmon habitats. Scrivener *et al.* (1998) summarize impacts of logging based on the anticipated timing of response: (i) near-term responses associated with losses of forest cover and road development in upslope and streamside areas (e.g., increases in stream heating, increases in sediment deposition, or reductions in leaf litter contributions); (ii) moderate-term responses associated with increased risk of mass wasting, increased erosion and transport of sediment bedload, or changes in fluvial processes and channel morphology; and (iii) long-term responses related to in-stream habitat changes resulting from losses of large woody debris. These actions will affect salmon species differentially based on their freshwater habitat requirements. For instance, impacts on spawning habitats will affect all species, impacts on stream rearing habitats will only affect coho and chinook, while impacts on lake productivity will primarily affect juvenile sockeye.

Measures to off-set salmon mortality from marine harvest or logging-related impacts on habitats in the Nass River have been implemented. Because harvest is managed to achieve escapement goals, all mortalities between spawning and adult returns are taken into account when executing fisheries (i.e., harvest less when fewer returns regardless of the reason(s) for reduced abundance, e.g., Figure 30). As well, work was conducted between 1994 and 2000 to offset impacts of logging activities (e.g., road deactivation, stream rehabilitation; Cheryl Stephens, Nisga'a Lisims Government, pers. comm.). Initially constructed in 1913 (replaced in 1966) the Meziadin Lake Fishway was built to aid passage beyond Victoria Falls, a partial blockage at the outlet of Meziadin Lake, thereby improving access to abundance of spawning habitats[20].

Variations in abundance are not fully explained by changes in forestry activities or ocean harvesting, however. Inter-decadal changes in climate are also important drivers of salmon productivity in the Pacific, which ultimately affect returns to the watershed. For instance, Pacific Decadal Oscillation (PDO) and El Nino / Southern Oscillation (ENSO) can affect regional patterns of sea surface temperatures, ocean productivity, and salmon condition (Miller 2000). Given the northern location of the Nass River watershed, sockeye and pink salmon may demonstrate an opposite pattern of productivity relative to southern stocks (Mueter *et al.* 2002).

WHY IS IT IMPORTANT?

Maintenance of high productivity of salmon in the Nass River watershed is critical for economic, cultural, and ecological reasons. First, economic opportunities associated with commercial catch are significant. For instance, on average Meziadin Lake has annually provided harvests of over 570,000 sockeye with a value of more than $10 million (Bocking *et al.* 2002). Second, the Nisga'a Final Agreement and accompanying Nisga'a Nation Harvest Agreement[21] specify salmon management procedures and harvest allocations that help Nisga'a have greater control over their livelihood and maintain salmon-centred cultural activities. In 2000, the Nisga'a harvested $900,000 in revenues from salmon (Indian and Northern Affairs Canada 2001). A third reason is that salmon contribute marine-derived nutrients and biomass to forest, stream, and lake ecosystems (e.g., Gende *et al.* 2002; Temple 2005; Nelitz *et al.* 2006), which are especially important in nutrient-deprived coastal watersheds. These subsidies support abundance and diversity of wildlife populations, riparian communities, and other freshwater fish species.

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[20] Fisheries and Oceans Canada. Meziadin Fishway - North Coast. Available at: http://www.pac.dfo-mpo.gc.ca/northcoast/counts/meziadin/meziadin.htm

[21] Indian and Northern Affairs Canada. Nisga'a Final Agreement and Background Information. Available at: http://www.ainc-inac.gc.ca/pr/agr/nsga/index_e.html

WHAT CAN WE DO ABOUT IT?

With appropriate in-season harvest adjustments, sufficient assessment and monitoring, and protection of critical habitats, Nass salmon will have the best chance of coping in an era of climate change. Salmon in the Nass River are sensitive to two climate-driven physical processes: (1) climate driven changes in sea surface temperatures, and (2) hydrologic changes associated with changing patterns of precipitation and timing of snowmelt. Changes in these marine and freshwater physical processes are not independent, however, as both may be affected by Pacific Decadal Oscillation and El Nino / Southern Oscillation (e.g., Miller 2000; Wang *et al.* 2006). Regulatory agencies and local communities don't have direct control over these types of changes in the physical environment. Thus, strategies discussed below relate to the life stages affected by human activities over which we do have control.

SOFT INFRASTRUCTURE STRATEGIES

Adjust fisheries management practices: Given that climate-induced changes in ocean productivity can have an important influence on marine productivity of all species of salmon, changes in adult harvest is one mechanism by which climate-induced stresses in the marine environment may be moderated. For instance, harvest rates can be adjusted on the basis of changes in ocean productivity. Such a strategy would require that pre-season and in-season forecasting explicitly integrate year-to-year or decadal changes in ocean productivity. Then daily information can be used to rapidly inform in-season adjustments to harvesting. By adjusting harvest allocations based on year-to-year variation in total returns (e.g., Figure 30), and rapidly responding to daily escapement estimates, the Nisga'a Fisheries Program is already designed to accommodate for such factors. It is for these reasons, in part, that the Nisga'a Fisheries Program has been cited as an excellent example of fisheries management (Levy 2006).

One unique consideration of the Nass watershed, and the North Coast in general, relative to southern populations is that escapement monitoring of small runs is quite limited (Temple 2005; Levy 2006). In the face of climate change, small populations may provide important contributions to overall population diversity and resilience (Hilborn *et al.* 2003). Given that Nass salmon are harvested in multi-species and mixed stock fisheries small populations thus face a risk of being over-harvested in larger fisheries. Therefore, improved monitoring of escapement, better delineation of production goals, and genetic studies related to understanding importance of smaller stocks would help ensure that overharvesting is minimized. The Lisims Conservation Trust Fund is one mechanism that can be used to support additional research and monitoring, although current funding has limited capacity to sponsor such work (Cheryl Stephens, Nisga'a Lisims Government, pers. comm.). In the Nass, conservation risks may be greatest for sockeye and chum salmon (Levy 2006). Concern about declining chum populations caught incidentally in sockeye in pink salmon fisheries has already resulted in DFO adopting a non-retention policy for seines. However, under the new Wild Salmon Policy (DFO 2007b), initial proposals are to manage Nass chum as one conservation unit, suggesting that rebuilding may not be as difficult as Nass sockeye which occupy several conservation units and are composed of several genetically distinct populations (Cheryl Stephens, Nisga'a Lisims Government, pers. comm.).

HARD INFRASTRUCTURE STRATEGIES

Implement low impact forestry practices: Currently habitat is not a limiting factor for most salmon species in the Nass (Cheryl Stephens, Nisga'a Lisims Government, pers. comm.). Given past relationships among PDO, ENSO, and low flows, it is likely that climate-induced changes to hydrology will also occur in North Coast watersheds. An analysis of historic flow data from the Nass River by Wang *et al.* (2006) demonstrated that cool PDO phases are associated with an increased frequency and magnitude of low-flows. It was also illustrated that low flow conditions within the watershed can occur over the entire year, though generally more prevalent during the late fall / early winter. Within the context of future climate changes and related vulnerabilities of freshwater habitats, changes in the frequency, timing, and magnitude of such low-flow conditions may have greater effects on salmon migration, spawning, and incubation than today.

Logging is one factor that may exacerbate climate-induced changes in hydrology by further reducing success of adult reaching spawning grounds or increasing mortality of incubating eggs. For instance, the extent and location of harvesting in the watershed can affect water yield and timing of flows (potentially exacerbating low flows for migrating adults and incubating eggs), and sediment loading into streams (potentially smothering incubating eggs during the winter). Thus, low impact forestry practices and protection of critical habitats could help alleviate potential increases in salmon mortality.

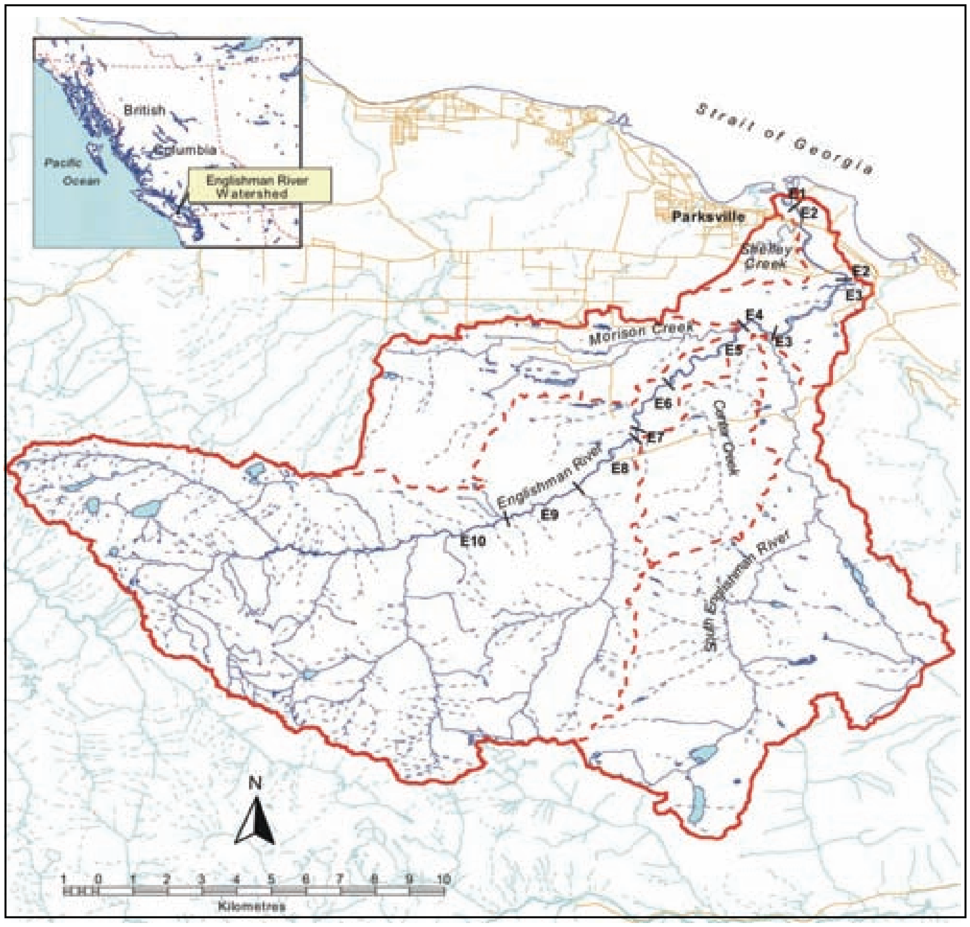
In spite of being the third largest watershed in BC, the Nass River catchment has only one Water Survey of Canada hydrologic monitoring station, though other water gauging stations have operated on the Cranberry, Meziadin, Kwinageese, and Kitsault rivers (Cheryl Stephens, Nisga'a Lisims Government, pers. comm.). Funding has not been available to continue operating these stations. Additional hydrological data will be critical to helping managers understand the potential implications of climate change on North Coast hydrology and salmon. Given better information, managers would then be better able to design forestry mitigation strategies that best off-set anticipated impacts on freshwaters habitats and salmon.

7. MANAGING WATER FOR LOW AND HIGH FLOWS IN THE ENGLISHMAN RIVER BASIN

WHAT IS HAPPENING?

Situated more than 80 km north of the Cowichan watershed on the east coast of Vancouver Island, the Englishman River watershed lies in the Coastal Western Hemlock biogeoclimatic zone. The watershed has a drainage area of 324 km^2 and an accessible mainstem length of 15.85 km, beyond which a barrier falls at Englishman River Falls Provincial Park blocks salmon passage (Bocking and Gaboury 2001). The Englishman River flows east from its headwaters at Mount Arrowsmith (1,817 m elevation), emptying into Georgia Strait near the City of Parksville (Figure 32).

FIGURE 32. Englishman watershed and its tributaries.
Anadromous distribution extends up to reach E7. Source: Gaboury (2005).



The majority of land within the Englishman watershed is privately owned, with Island Timberlands Limited Partnership and TimberWest owning the largest portions of land: 69% (formerly owned by Weyerhaeuser) and 18% respectively (Gaboury 2005). Much of the watershed was logged in the early 1900s and a large second cut rotation occurred in the 1950s and 1960s (Wright 2003). During this period logging occurred along the mainstem in most places (Bocking and Gaboury 2001). Over the last 30 years timber harvest levels have declined and tended to focus in the headwater areas (Bocking and Gaboury 2001). In addition to forestry, agriculture and urban development are the primary land uses. The largest water licenses are allocated for domestic use to the Nanaimo Regional District and City of Parksville.

The climate and hydrology of the Englishman watershed is influenced by its mountainous topography and the seasonal weather patterns of the Georgia Basin. Seasonal patterns in the Englishman are similar to those of the Cowichan—mild wet winters and cool dry summers. Like the Cowichan, precipitation is dominated by rainfall, meaning hydrology of the Englishman River and its tributaries are rain-driven (Whitfield *et al*. 2003). Heavy fall and winter rains create peak flows from October through April, while lower precipitation in the spring coupled with snow melt from April to May lead to decreasing flows and ultimately low summer flow from June to September (Weston *et al*. 2003).

The Englishman River is an important contributor to production of all anadromous salmonid species, including winter steelhead and coastal cutthroat trout. Chum is the dominant species in the river followed by coho (Bocking and Gaboury 2001). Steelhead, chinook, pink, and sockeye (very rare) are also present though in less abundance. Hatchery programs for coho, chinook, and pink are an integral part of fisheries management[22]. Coho enhancement is the only program to use stocks native to the Englishman (McCulloch 2005). Non-native pink salmon were introduced with the objective of sport fishery enhancement and added benefits of increasing the supply of marine nutrients for improving growth / survival of juvenile coho, steelhead, and cutthroat (GGBSRP 2006).

In response to declining fish stocks, the government of British Columbia designated the Englishman as a sensitive stream under the *Fish Protection Act* in 2000 (McCulloch 2005). The Outdoor Recreation Council of British Columbia has since identified the Englishman as one of the most threatened watersheds in BC (ORCBC 2002). Most recently, the Englishman River has been targeted for a salmon recovery process for coho and steelhead. Following initial development of the recovery plan, a study was commissioned to identify limiting factors to salmonid production and to "*identify opportunities to alleviate these constraints to fish production*" (Wright 2003). The study found that a reduction in summer rearing habitat as a result of low summer flows was the major limiting factor to fish production in the Englishman River (Wright 2003). In addition, a channel condition assessment identified the potential loss of surface flow through groundwater seepage as a factor contributing to a reduction in low flows (Wright 2003). This recovery planning process has been broadly supported (Craig Wightman, Ministry of Environment, and Faye Smith, Englishman Watershed Recovery Plan Steering Committee, pers. comm.), demonstrating collaboration among a diverse group of supporters, including:

- Arrowsmith Naturalists
- Arrowsmith Watersheds Coalition Society
- BC Ministry of Environment
- BC Ministry of Transportation
- City of Parksville
- DR Clough
- Environment Canada, EcoAction
- Errington Farmer's Group
- Fisheries and Oceans Canada, Public Involvement Program
- Georgia Basin / Vancouver Island Living Rivers Program

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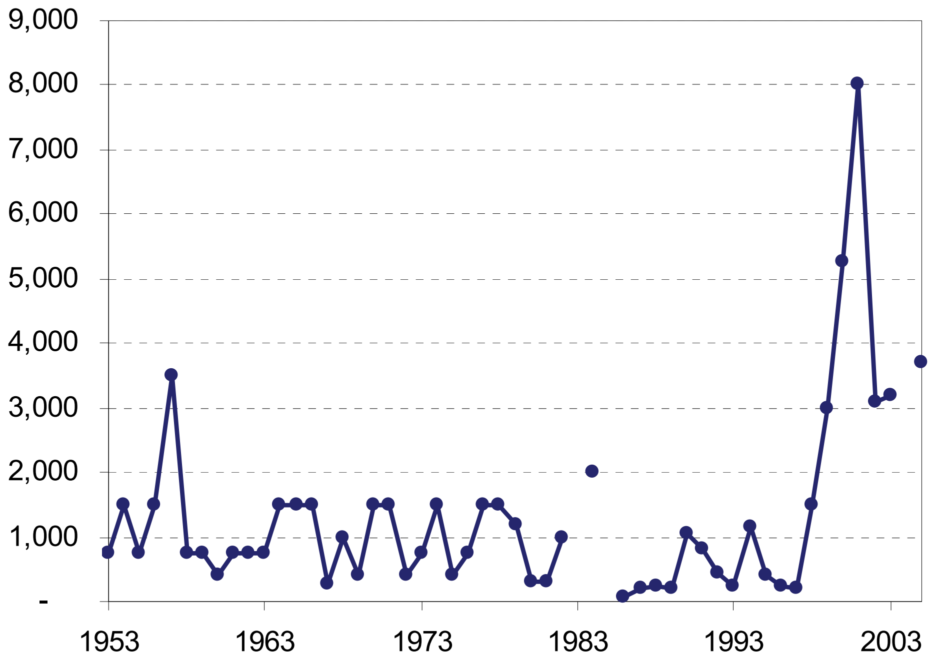
[22] There hasn't been an annual hatchery steelhead program on the Englishman since ~1997. From the early 1980s to the late 1990s the Englishman's annual steelhead hatchery program relied on capture of wild brood stock. This program was indefinitely suspended due to very poor adult returns in the late 1990s (Craig Wightman, Ministry of Environment, pers. comm.).

- Habitat Conservation Trust Fund
- Island Timberlands Limited Partnership
- Mountain Equipment Co-op
- Mid Vancouver Island Habitat Enhancement Society
- Pacific Salmon Commission, Southern Endowment Fund
- Pacific Salmon Endowment Fund Society, administered by Rick Hansen Foundation
- Pacific Salmon Foundation
- Parksville Qualicum Community Foundation
- Pieter de Reuver Foundation
- Qualicum Beach and Parksville Streamkeepers
- Real Estate Foundation of BC
- Regional District of Nanaimo
- SeaChange Conservation Society
- Shell Environmental Fund
- TD Friends of the Environment
- The Nature Trust of BC
- TimberWest Forest Corp.
- Vancouver Foundation
- Weyerhaeuser

The number of coho spawners returning to Englishman River has historically ranged between 750 and 1,500 adults, with a long term average of 960 adults (1953–2000) (Figure 33) (Bocking and Gaboury 2001). In 2000, a record number of 5,280 spawners returned to the Englishman. The anomalous return is attributed mostly to improved marine survival rather than a decrease in commercial harvest (Bocking and Gaboury 2001). For instance, commercial and recreational catches of lower Georgia Strait coho have been decreasing since the mid-1980s with recent catches declining from 1.55 million in 1995 to virtually zero in 1998 (DFO 2002a). Recent coho escapements to the Englishman have been substantially higher than the long term average with population estimates of 8,000 (2001) and 3,100 (2002) adults (McCulloch 2005). According to Baillie and Young (as cited in McCulloch 2005) the recent increase in coho abundance is likely a function of changes in enumeration methodology and decreases in catch rather than a significant increase in smolt production or ocean survival. However, Gaboury (2003) states the opposite, speculating that increased returns may be due to increased freshwater survival in artificial spawning and rearing channels and to recently improved marine survival. In 2006, extended summer drought created a substantial delay in entry to most systems, including the Englishman, which negatively affected spawners (DFO 2007a). The 2007 forecast for lower Georgia Strait coho returns does not bode well. Similar to 2006, the number of returning spawners is predicted to be below replacement level (DFO 2007a).

FIGURE 33. Coho escapement for the Englishman River from 1953 to 2005.
Source: Fisheries and Oceans Canada, Salmon Escapement Data System (nuSEDS). Available through Mapster: http://www-heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm



Historically, the number of wild steelhead returning to the Englishman ranged from 500 to 2,000 fish (Bocking and Gaboury 2001). Winter run steelhead abundance has declined significantly since mid 1990s, despite hatchery enhancement. Current estimates of steelhead escapement suggest 145 adults in 2002, 96 in 2003, and 81 in 2004 (McCulloch 2005). Decreased ocean survival and reduced freshwater habitat quality may be contributing factors (Lill 2002), while over-harvesting is unlikely. Wild steelhead harvest rates probably peaked in the late 1970s/early 1980s with the Vancouver Island Region having adopted a mandatory wild steelhead release since 1985/86 (Craig Wightman, Ministry of Environment, pers. comm.). Lill (2002) believe that wild steelhead stocks in most systems will not rebound without substantial enhancement of freshwater productivity to compensate for reductions in marine survival.

WHY IS IT HAPPENING?

Low summer flows are a consequence of three factors: (1) low amounts of precipitation during summer months; (2) insufficient storage capacity at Arrowsmith Lake; and (3) increased summer demand for water by agricultural, rural, and urban users. A dam on the outlet of Arrowsmith Lake, in the headwaters of the Englishman River, has been augmenting low summer flows for fisheries and domestic purposes since 1999 (Regional District of Nanaimo 2005). The dam has a live storage volume of 9 million m^3. A portion of this storage is allocated for fisheries' purposes (Regional District of Nanaimo 2005). The current water license requires that a minimum of 1.6 m^3/s be maintained in the lower river at all times of the year. Despite a provision for minimum base flows, in unusually dry years instream flows are not maintained at this level. When discharge falls below 1.6 m^3/s, there are reductions in the wetted-useable area of rearing and spawning habitats, and obstacles to upstream migration exacerbated by shallow riffles in the lower river (Wright 2003).

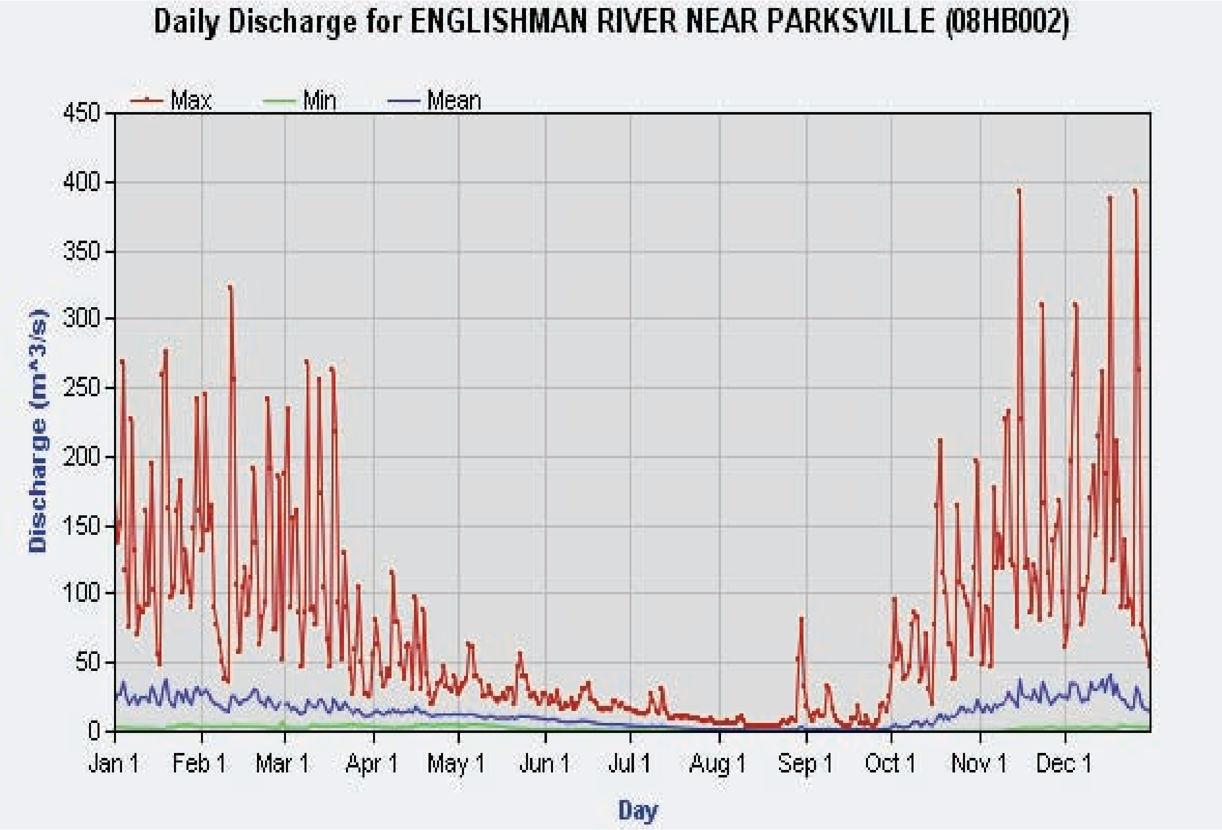
Habitat declines in the Englishman River have been attributed to the extensive channel widening and chronic sedimentation induced by past logging practices (Lill 2002). Channel widening can reduce habitat capacity in periods of low-flow because available water is spread too thinly across the widened stream channel (Rosenau and Angelo 2003). Deposition of coarse bed materials on a widened floodplain can cause water to go below ground, resulting in a decrease in wetted fish habitat (Rosenau and Angelo 2003).

Juvenile coho salmon rely on freshwater habitats for one or more years (DFO 2002a). Therefore, survival rates for juvenile coho are dependent on the availability of wetted habitats year round. During periods of low flow juvenile coho in tributaries may move downstream into the Englishman River mainstem where rearing habitat may be limited by low flows and already operating at full capacity (Rosenau and Angelo 2003).

Coho, chinook, chum, sockeye, and pinks all return to freshwater from July to December, with the majority of spawners returning in August through to October. This period coincides with the time of year when river flows are naturally at their lowest (Figure 34) and human demands are highest. In August 2003 river discharge dropped below 0.004m^3/s in Morison Creek (a tributary to the Englishman River), most likely the result of rural and agricultural water uses (Wright 2003).

FIGURE 34. Maximum, minimum, and average daily discharge for the Englishman River (station 08HB002) measured over 34 years of record.

Source: Water Survey of Canada, Hydrometric Data. Available at: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=main_e.cfm



Another factor contributing to in-river mortality is the lack of over-winter refuge in the mainstem, which is especially significant during winters with extreme flooding. The Englishman River watershed lacks lacustrine habitats thus limiting its ability to moderate peak flows through storage. Consequently, the river exhibits a ‘flashy’ hydrologic response to heavy winter rainfall events (Weston *et al.* 2003). In other words, the river rises rapidly in response to rainfall and accelerated snowmelt, falling quickly once a rain event finishes. On March 13, 2003, the Englishman River flooded rising approximately 2 m in 24 hours, representing an increase in discharge from 20 to 313 m^3/s (Weston *et al.* 2003). Such large increased flows can lead to egg and juvenile mortality by scouring spawning gravels and flushing overwintering juveniles from their overwintering habitats.

WHY IS IT SIGNIFICANT?

The Englishman River is well known for its steelhead fishing and considered to be one of the more important streams on the east coast of Vancouver Island (Rosenau and Angelo 2003). Decreases in abundance of salmonid populations have resulted in economic losses as angler attraction to the region has decreased. The economic prosperity and well being of communities within the Englishman watershed is inherently linked to the health of its rivers.

The issue of extreme flows and fish in the Englishman River is of incredible importance as it is an indicator of the overall health of the watershed and its ability to reliably supply water. Compounding the conflict between high flows and fish, are conflicts between low-flows and human extraction of water, a circumstance that will only increase in frequency and severity in the future as urban development grows, demand for water increases, and a changing climate increases length of low flow periods (Whitfield *et al.* 2003). Better water management systems are needed to mitigate against climate-induced conflicts between human and non-human uses in the watershed.

WHAT CAN WE DO ABOUT IT?

Recognizing the condition of the watershed and the poor status of steelhead and coho populations, the Englishman River watershed was selected by the Pacific Salmon Endowment Fund Society to receive attention in the Georgia Basin salmon recovery planning process. As a first step, the Pacific Salmon Endowment Fund Society supported development of a recovery plan (Bocking and Gaboury 2001) which profiled the watershed, its fish resources, and provided recommendations for focusing future actions / studies. Since that time, follow-up studies have been completed (e.g., Wright 2003), discovering that reduced summer flow is a critical factor limiting fish production. More recently, attention has been put towards developing a long-term strategy for protection / restoration by identifying immediate priorities for action (Gaboury 2005) whose goals have been to identify priorities for protecting current integrity / productivity, and increasing rate of restoration of high quality instream and riparian habitats.

SOFT INFRASTRUCTURE STRATEGIES

Soft infrastructure strategies that can help to ensure water availability during low flow periods in the Englishman watershed are generally the same as those described for the Cowichan Basin (e.g., use demand-side management tools and pricing signals, especially water metering and water pricing). Other measures include:

Develop a water budget: Discharge patterns are still not clearly understood and a more precise understanding of flows across seasons and years would help manager better allocate flow. Such an exercise would require additional flow measurements across the basin and may help managers achieve flow-release targets in the Englishman River, downstream from Arrowsmith Lake reservoir.

Require effective operating licenses: A review of the terms of water licenses is needed to ensure that water is not allocated beyond the watershed's ability to provide it across all seasons. In addition, an assessment of compliance with existing water licenses should occur because water in some tributaries is mysteriously disappearing and may be due to unauthorized extractions (Rosenau and Angelo 2003).

Restrict further water licenses unless supported by off-channel storage. The current discharges throughout the watershed during low-flow periods are not sufficient to satisfy acceptable levels of fish production. No new licenses should be issued without appropriate storage to replace withdrawals during the low-flow periods.

HARD INFRASTRUCTURE STRATEGIES

The following strategies have been identified as priorities for the Englishman River (see Wright 2003; Rosenau and Angelo 2003; Gaboury 2005).

Manage water storage: Currently, Arrowsmith Lake is used to augment downstream flows in the Englishman River where the water license specifies a minimum base flow of 1.6 m^3/s (10% of mean annual discharge) at the 19A Highway Bridge between June 1 and October 31. This target has proven to be inadequate during low flow periods as water extraction often exceeds the amount of water in the river, thus leaving it dry. At times this threshold has also been exceeded resulting in excessively low base flows that limit fish production (Wright 2003). Consequently, others have recommended development of more ecologically appropriate flow releases (e.g., Rosenau and Angelo 2003; Wright 2003). For instance, habitat suitability monitoring identified an ideal base summer flow of 2.76 m^3/sec (20% of mean annual discharge, Wright 2003). Although ideal, this target has been identified as not being attainable with existing storage facilities during extended periods of drought (Craig Wightman, Ministry of Environment, pers. comm.). Recognizing the need to improve flow releases, government agencies and dam operators recently revised the operating guidelines for managing magnitude and timing of releases from Arrowsmith Lake (Gaboury 2005). Accompanying such changes, however, is the need for continued monitoring and evaluation to ensure that water management is meeting instream needs in the face of competing human demands.

Build additional storage capacity: Investigate new or innovative options to provide more water in tributary streams via increased water storage. For those tributaries where storage in the headwaters is not feasible, use of weirs or water releases from groundwater storage is a possibility. Shelton and Healy Lakes (surface areas of 36 and 29 ha, respectively) in the upper South Englishman River have already been identified as candidates (Gaboury 2005).

Restore off-channel habitat: The Englishman River mainstem seems to have limited over-wintering habitats, thus affecting total survival and smolt production (Lough and Morley 2002 as cited by Gaboury 2005). This issue is of particular concern in Reach E3 of the mainstem, where enhancement opportunities have already been identified and existing off-channel habitats have successfully provided spawning / rearing habitats for coho, chum, pink, and steelhead (Gaboury 2005). The creation of off-channel rearing habitat can mitigate against the expected increases in incidences of winter flood events and adverse effects on survival of juvenile coho.

Enrich streams with nutrients: Fertilizing streams using salmon carcasses would increase productivity of the system, thus increasing the system's capacity to support more juvenile fish. This can help to mitigate against decreased marine or freshwater survival due to climate-induced changes in these environments.

Restore slope stability: Across the watershed a number of streambank and headwater areas vulnerable to erosion / slope instability have been identified as contributing coarse and fine sediments to downstream fish habitats. These areas include:

- three basins in the upper watershed (Basin 4, Basin 0-A, and Basin 3) affected by historic land uses, such as riparian logging (Higman *et al.* 2003; Lough and Morley 2002 as cited by Gaboury 2005);
- a clay bank on the mainstem river 150 m downstream of the confluence with the South Englishman River where lateral migration of the river channel is resulting in bank erosion and in-river sediment contributions; and
- three banks in Reach E3 that are vulnerable to continued erosion from channel movement.

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