Footprint Impacts of BC Hydro Dams on Rainbow Trout in the Columbia River Basin, British Columbia

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Executive Summary

The Fish and Wildlife Compensation Program (FWCP) – Columbia Basin has undertaken a project to assess the footprint impacts of BC Hydro dams in the Columbia River drainage in British Columbia. This review includes a primary productivity assessment (Moody et al. 2007), habitat gain/loss (Thorley 2008), and several species impact reviews. This report provides an impact assessment for rainbow trout, *Oncorhynchus mykiss*. Available information on population status before and after dams is summarized and compensation options for addressing losses are provided.

Rainbow trout are a highly diverse species with respect to habitat use, life history, and phenotype. Five rainbow trout ecotypes are used to describe impacts in the basin (small-stream resident, fluvial, small lake adfluvial, large lake insectivorous, large lake piscivore). This species is arguably the most important fish in the basin in terms of its recreational and food use that contributes to quality of life and economic activities in the region. In large lakes and reservoirs, it occupies an important niche as one of the main species preying upon kokanee, *Oncorhynchus nerka*. Conservation status for the species as a whole is ranked as yellow (not at risk) in BC. Conservation status is not currently evaluated for individual ecotypes, but adfluvial piscivore and large river fluvial fish are relatively rare provincially. Prior to dams, rainbow trout were indigenous throughout the Columbia River drainage, and in the Kootenay River drainage below Kootenai Falls, Idaho. Introductions of rainbow trout in recent years, primarily into Koocanusa Reservoir (Montana) have resulted in an expansion into the upper Kootenay River drainage.

Evaluation of footprint dam impacts was hindered by a lack of comparable information from the pre-dam era, potential interactions between footprint and operational effects, impacts of non-BC Hydro dams, and significant anthropogenic impacts not related to dams in some units including phosphorus enrichment from a fertilizer plant, and introductions of mysids, an important competitor with kokanee. As a result, in many cases it was not possible to compare population abundance in the pre- and post-dam eras, and in some cases the cause of a population change was uncertain. Nevertheless some general conclusions can be made.

Distribution and abundance of the fluvial ecotype in the basin has been greatly reduced due to inundation of most of the large river and some medium-sized river habitat from Kinbasket Reservoir downstream to Keenleyside Dam. Significant remaining fluvial populations in the West Kootenay are limited to the remaining 68 km of the Columbia/Kootenay rivers downstream of Keenleyside and Brilliant dams (robust population) and small populations in the Salmo and Slocan rivers. This major, direct impact of dams has not been addressed by the FWCP to date, except on a very small scale.

Loss of access to stream habitats due to inundation or blocked migration also significantly reduced spawning and rearing habitats for adfluvial ecotypes (insectivorous and piscivorous) with uncertain effects on their abundance in associated lakes and reservoirs. Major habitat losses affected trout from Arrow and Kootenay lakes, the two most important large lake habitats in the basin. In the Arrow lakes, a unique indigenous “yellowfin” rainbow trout was extirpated. These fish are believed to have spawned in Camp Creek above Mica Dam; access to their historical adult habitat was blocked, and Kinbasket Reservoir apparently was not suitable for their survival at least in the early years. In Kootenay Lake, an important spawning area for piscivorous adfluvials was lost due to Duncan Dam. Recent observations have shown that some spawning persists below the dam; however, it is not known whether these fish are the same (genetically) as

the original stock. In addition to the losses of stock diversity, abundance of piscivores may have declined without intervention to support the prey species, kokanee, which was affected by changes in the productivity of Kootenay and Arrow lakes related to nutrient retention in upstream dams.

Extensive fragmentation by dams has blocked historical habitat connections that previously allowed extensive migrations and interactions between fluvial and adfluvial populations in different parts of the basin. This has resulted in a substantial reduction in rainbow trout life history diversity with accompanying reductions in phenotypic and likely genetic diversity. Genetic integrity has also been compromised in Arrow Lakes Reservoir by stocking programs aimed at compensating for lost natural production. Isolated fluvial populations (e.g., Salmo River) may be less productive because they no longer have access to larger river habitats.

Several small-lake adfluvial populations were lost due to inundation of their habitats, including some productive lakes capable of producing fish >2 kg. Loss of river fishery options and small lakes represent a significant lost opportunity for the region in terms of fisheries management, recreation, and biodiversity. The stream-resident ecotype was affected to a relatively minor degree by habitat loss because they are typically found above the flooded zone, however, smaller hydropower plants that divert water from upper stream reaches have reduced stream capacity in some areas.

Compensation measures proposed for loss of river habitats are by necessity off-site (i.e., in remaining rivers outside the flood zone). These include in-stream habitat and riparian restoration, reconnection of isolated habitats, and nutrient additions to enhance productivity and viability of remaining fluvial populations. Stream flow conservation through conservation water licences is proposed to protect discharge in remaining stream habitat. The East Kootenay provides many opportunities for river enhancement with a closely related indigenous species, westslope cutthroat trout, *Oncorhynchus clarkii lewisi*. Rainbow trout are not indigenous to this area. Preservation of existing high quality habitats through conservation covenants, land purchases, and provision of information on key habitats to resource regulators may be the most cost-effective way of ensuring the maintenance of remaining genetic and ecotypic diversity in the region.

Measures to compensate for lost spawning and rearing habitat for adfluvial fish include spawning channels, stream gravel additions and artificial propagation. Before large investments are made, however, sources and levels of remaining natural reproduction should be determined to judge whether spawning and early rearing habitat is likely to be limiting to the target population. In large lake habitats downstream of reservoirs continued support for nutrient additions is recommended, as well as kokanee population management. Operational changes may also have potential to mitigate effects of upstream and downstream dams (investigated under Water Licence Requirements).

Small lake enhancement projects could include habitat restoration, nutrient additions, or fish stocking in remaining lakes with fish. Also there is the possibility of developing new fishery opportunities in lakes currently without fish by introducing sterile hatchery fish, if risks to other species (amphibians, invertebrates) are low.

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1.0 INTRODUCTION

The Columbia River drainage in British Columbia has been significantly altered by dams built on the major rivers and some of their tributaries for hydroelectric power production and flood control. Eleven of the dams within the basin are under the jurisdiction of BC Hydro (Table 1). The Fish and Wildlife Compensation Program – Columbia Basin (FWCP) was established in 1995 to offset impacts resulting from construction of BC Hydro dams. It delivers conservation and enhancement projects for fish and wildlife on behalf of its program partners with funding provided by BC Hydro.

Table 1. Dam units and dates of construction for dams in the Columbia River basin [from Moody et al. (2007) and Thorley (2008)]. Areas of reservoirs are the average during the growing season.

Dam Unit	Location	Dam	Year Completed	Lake/Reservoir Area (km^2)
C1	Columbia - Donald	-	-	-
C2	Spillimacheen River	Spillimacheen	1955	0.01
C3	Donald - Mica	Mica	1973	370
C4	Mica - Revelstoke	Revelstoke	1984	114.5
C6	Cranberry Creek	Walter Hardman	1959	-
C8	Whatshan Lake	Whatshan	1952	17.6
C9	Keenleyside - U.S.A.	-	-	-
C10	Pend d’ Oreille	Seven Mile	1979	4.1
C11	Arrow Lakes	Keenleyside	1968	476
K1	Kootenay – Wardner	-	-	-
K2	Bull River	Aberfeldie	1922	0.12
K3[a]	Wardner – U.S.A.	Libby[a]	1972	60[a]
K4	Elk River	Elko	1924	0.18
K5	U.S.A. – Kootenay Lake	-	-	-
K6	Kootenay Lake	Corra Linn[b]	1939	394
K7	Duncan River	Duncan	1967	65
K8	Lower Duncan - Lardeau	-	-	-
K9	Corra Linn - Brilliant	Kootenay Canal (and four non-BC Hydro dams built earlier)	1976	0.5

[a] Libby Dam is operated by the Bonneville Power Administration (BPA); area is for Canada only.
[b] Corra Linn dam is owned by Fortis BC but forms the control structure for the Kootenay Canal power plant owned by BC Hydro.

The FWCP has undertaken a project to evaluate and quantify the footprint impacts of BC Hydro dams within the Canadian portion of the Columbia River basin. Footprint impacts are defined in Section 2.2 and a list of operational impacts is provided in Appendix A. The overall objectives of the project are to:

a) establish and/or update understanding of original footprint impacts from BC Hydro dams in the Canadian portion of the Columbia basin,
b) identify the full range of compensation opportunities,
c) provide a summary of approximate costs to implement the compensation opportunities, and
d) identify performance measures for program monitoring and evaluation.

Results are intended to provide guidance to and justification for the program with respect to strategic planning and priority setting and monitoring the effectiveness of compensation activities. Major components of the project include: pre-impoundment mapping (Ketcheson et al.

2005), a primary productivity assessment (Moody et al. 2007), quantification of physical habitat losses and gains (Thorley 2008), and evaluation of population impacts for specific fish species.

This report provides an impact assessment for rainbow trout *Oncorhynchus mykiss*. Provincially, the conservation status of rainbow trout is ranked as yellow (not at risk) by the British Columbia Conservation Data Centre (http://www.env.gov.bc.ca/cdc/). Conservation status is not currently evaluated for individual ecotypes, but some ecotypes in the Columbia and Kootenay River basins, such as adfluvial piscivores and large river fluvial fish (see Section 4.0) are relatively rare at the provincial level. Adfluvial piscivores typically exist at low densities, and are vulnerable to overexploitation and habitat loss.

In the Columbia River basin, rainbow trout occupy a diverse range of habitats from small headwater streams to large lakes and reservoirs. In the large reservoirs of the basin, they occupy an important niche, along with bull trout *Salvelinus confluentus*, as the top piscivore, preying primarily on kokanee *Oncorhynchus nerka*. Rainbow trout also provide direct benefits to people in the form of recreational fisheries and food that contribute significantly to local culture and economies (e.g., Arndt 2004b, Andrusak 2007). The potential impact on specific rainbow trout populations was a major concern to residents and fishery managers when the dams were built.

The purpose of this report is to:

- review rainbow trout distribution within the basin,
- summarize life history traits in relation to potential limiting factors,
- summarize footprint impacts likely to affect rainbow trout,
- assess the status of individual populations (by dam unit) before and after dams, and
- provide compensation options and estimated costs where populations have been negatively impacted by dams.[1]

2.0 METHODS

2.1 Consultation and Literature Review

Near the beginning of the project a two-day workshop was held in Nelson to review existing work and discuss how to best assess dam footprint impacts (Murray 2005a). Participants were invited based on their knowledge of the basin and its fish habitat, and included staff from the BC Ministry of Environment, BC Ministry of Sustainable Resource Management, BC Hydro, Fisheries and Oceans Canada, and FWCP, as well as private consultants (see Appendix B). A key focus of the workshop was to provide direction regarding what metrics should be used to assess impact, and what performance measures would be most appropriate for monitoring the results of compensation initiatives. Participants emphasized that pre- to post-dam changes should be quantified, where possible, and provided a list of recommended metrics for assessing fish community impacts. These metrics included habitat impacts, population impacts (e.g., changes in population abundance or escapement, loss of indigenous stocks, life history changes such as fluvial to adfluvial), and changes in stock diversity or species complexes (see Appendix C for a complete list).

[1] BC Hydro Dam Footprint Impact Study Draft Terms of Reference (Murray 2005b).

With regards to performance measures, the participants noted the importance of identifying the limiting factors for population regulation (e.g. spawning habitat versus lake rearing environment), and encouraged scientifically credible monitoring programs that would test assumptions and resolve uncertainties around population dynamics (Murray 2005b). Participants also differentiated project level performance measures, which are intended to measure effectiveness at the project level (e.g., spawning channel fry output in relation to production targets), from program or management level indicators, which are intended to measure success in relation to ultimate restoration and management objectives (e.g., increase in adult population or increase in fish harvest). Examples of performance measures are provided in Appendix F. To facilitate quantification in different parts of the basin, the FWCP area was divided into 18 dam units, generally corresponding to catchment basins above and below dams. Losses of anadromous fish due to dams downstream of the Canada-United States border were excluded from the scope of this study.

For this report, information on distribution, life history, and factors important to population regulation was obtained from the reviews of Behnke (1992), McPhail (2007), Ford et al. (1995), and others. Both primary and grey literature were reviewed for information about the life history, presence/absence, abundance, habitat use, and biology (e.g., size and age of spawners) of rainbow trout populations within the basin prior to and after dam construction. Grey literature sources included the FWCP library, the Ministry of Environment (MOE) Ecological Reports Catalogue (http://www.env.gov.bc.ca/ ecocat/), and an earlier data review by Ahrens and Korman (2004). Local biologists were interviewed to obtain an initial list of relevant agency documents and files. We also relied on available empirical data from earlier reports and MOE and FWCP files to evaluate changes in population status and life history diversity after hydroelectric development,. Physical habitat changes, as summarized in Thorley (2008), and estimates of primary productivity before and after dams (Moody et al. 2007) were taken into consideration for assessing potential population impacts and compensation options, but evaluation was not based strictly on these estimates unless there were no other data. Primary productivity estimates are highly uncertain due to the paucity of pre-dam limnological data for lakes and rivers (Moody et al. 2007). The relationship between primary production and fish production was also highly uncertain (Moody et al. 2007).

In cases where data were sufficient, an attempt was made to determine the factors most likely to be limiting to trout production within a dam unit as recommended by the workshop participants. For some dam units (e.g., Kootenay Lake), substantial data were available from historical monitoring programs including spawner counts, and some size and age data. However, pre-dam information was limited in the majority of cases.

2.2 Definitions of Footprint Impacts

Definitions of footprint impacts associated with BC Hydro's hydroelectric facilities in B.C. have been proposed to provide clarification to the Fisheries Technical Committees as well as committees involved in Water-Use Planning (WUP). Footprint impacts would occur primarily as a result of inactive storage and construction of dam structures, and are largely irreversible. Some impacts are re-occurring but the causative agent is usually a one-time action or event. Any footprint impacts should be considered when a reservoir is at full pool. Operational impacts (see definitions in Appendix A) are beyond the scope of this report, and are addressed under another program (BC Hydro Water Licence Requirements).

Types of footprint impacts:

1. Construction impacts (e.g. sediment, water quality) temporary events associated with building and construction.
2. Habitat loss from facilities or structures (e.g. habitat inundation by reservoir): includes loss of riparian area for LWD recruitment and permanent lotic - lentic habitat change and impact.
3. Permanent loss of upland and riparian terrestrial habitats within the full pool footprint and their associated impacts on biodiversity.
4. Fragmentation and loss of habitat connectivity at landscape scale.
5. Changes in the amount and spatial extent of aquatic-terrestrial species interactions due to loss of seasonal habitats, shifts in primary productivity or habitat fragmentation.
6. Nutrient or contaminant effects (e.g. trapping, downstream release, methylation) related to flows released from the reservoir).
7. Water quality in reservoir (e.g. temperature, TGP, DO) related to water quality within the water column of the reservoir.
8. Erosion, sediment transport, erosion and morphological change due to reservoir could include effects of interception of bed load and increased earth slides and instabilities caused by reservoir drawdowns.
9. Impacts to fish movement and migration often due to structures like dams or barriers exposed during reservoir drawdown.
10. Fish entrainment and loss of fish includes loss of fish from reservoir populations with the inability to return to natal areas resulting in a loss of fishing potential or damage to the population numbers, dynamics, etc.
11. Ice regime impacts due to reservoir and effects on tributary systems and ice effects within the reservoir or due to the thermal action of the stored water.
12. Local hydrological effects such as increased snow or precipitation due to thermal effects of reservoir, evaporative water losses, long-term groundwater effects, greenhouse gas release, and cumulative effects from other uses (i.e. increased water withdrawal due to proximity to reservoir).

2.3 Societal Values Affected by Footprint Impacts

In assessing footprint impacts, it is important to acknowledge linkages with societal values, and to identify the types of values that have been affected (BC MOE 2007). In our evaluation we considered two types: biodiversity values (with respect to rainbow trout), and socio-economic values. Biodiversity values are often linked to rarity and representativeness (rare elements and representative examples of common elements must both be protected). This might mean, for example, that preservation of small lake adfluvial rainbow trout populations would be a lower priority because this ecotype is relatively common elsewhere in the province, whereas preservation of large lakes piscivore and large river fluvial populations, which are much less common, would be the highest priority. Life history (ecotype) and genetic diversity are considered to be the most important aspects of biodiversity for rainbow trout in the FWCP area. Socioeconomic value is generally the value of a fishery (i.e. angler days, weighted by the perceived (non-monetary) relative values of the different types of angling experiences it offers (e.g., wilderness stream fishery versus reservoir troll fishery). In general, the type of fish present (wild vs. hatchery, ecotype, or even species) is less relevant than the density, accessibility, number and size of fish available for harvest or catch-and-release. Socioeconomic values include other activities such as fish and wildlife viewing, but not existence values. First Nations cultural values are outside the scope of this review, and are a combination of the previous two, but with a strong link to place (i.e., other locations are not substitutable). In Section 7.0, where footprints impacts for the Columbia basin are summarized as a whole, we attempt to link impacts to the values described here.

3.0 HISTORICAL DISTRIBUTION IN THE COLUMBIA RIVER BASIN

Prior to hydroelectric development, rainbow trout were native to the Columbia River drainage to its headwaters (Figure 1). In the Kootenay River their natural distribution extended as far as Kootenai Falls between Troy and Libby, Montana, the furthest interior natural distribution of the species (Behnke 1992; Ford et al. 1995). The upper Kootenay drainage in the East Kootenay of British Columbia was physically isolated from indigenous rainbow trout by Kootenai Falls.[2] However, populations existed in many small lakes in both the Columbia and Kootenay drainages as a result of stocking programs. As well, following the completion of Libby Dam in 1972 (Bonneville Power Administration), rainbow trout stocked into Koocanusa Reservoir by the State of Montana, established non-indigenous spawning populations in upstream tributaries, and in some cases, have hybridized with indigenous westslope cutthroat trout *Oncorhynchus clarkii lewisi* (Ford et al. 1995; Rubidge et al. 2001). Before dams, rainbow trout were relatively ubiquitous (though not necessarily abundant) within their indigenous range in the Columbia and Kootenay drainages, occupying small streams, large rivers, and large and small lakes. Movement and gene flow among populations was possible throughout the indigenous range, with the exception that Bonnington Falls on the Kootenay River (16 km downstream of Nelson) was a natural barrier preventing fish from the Columbia River drainage from moving upstream into Kootenay Lake and its drainage. Lower reaches of lake or reservoir tributaries below barriers tend to be dominated by juveniles of adfluvial populations (Northcote and Hartman 1988), whereas many headwater reaches contain either indigenous small-stream resident populations that were established during periods of glacial activity that raised lake levels, or non-indigenous populations descendent from stocking programs in headwater lakes.

[2] A winter creel survey on the Kootenay River between Fort Steele and the Canada-U.S. border in 1966 recorded eleven rainbow trout (0.1% of the catch; Whately 1972) indicating a minimal presence at that time. This presumably resulted from a small degree of expansion from stockings of rainbow trout upstream of the barrier (mostly in lakes).

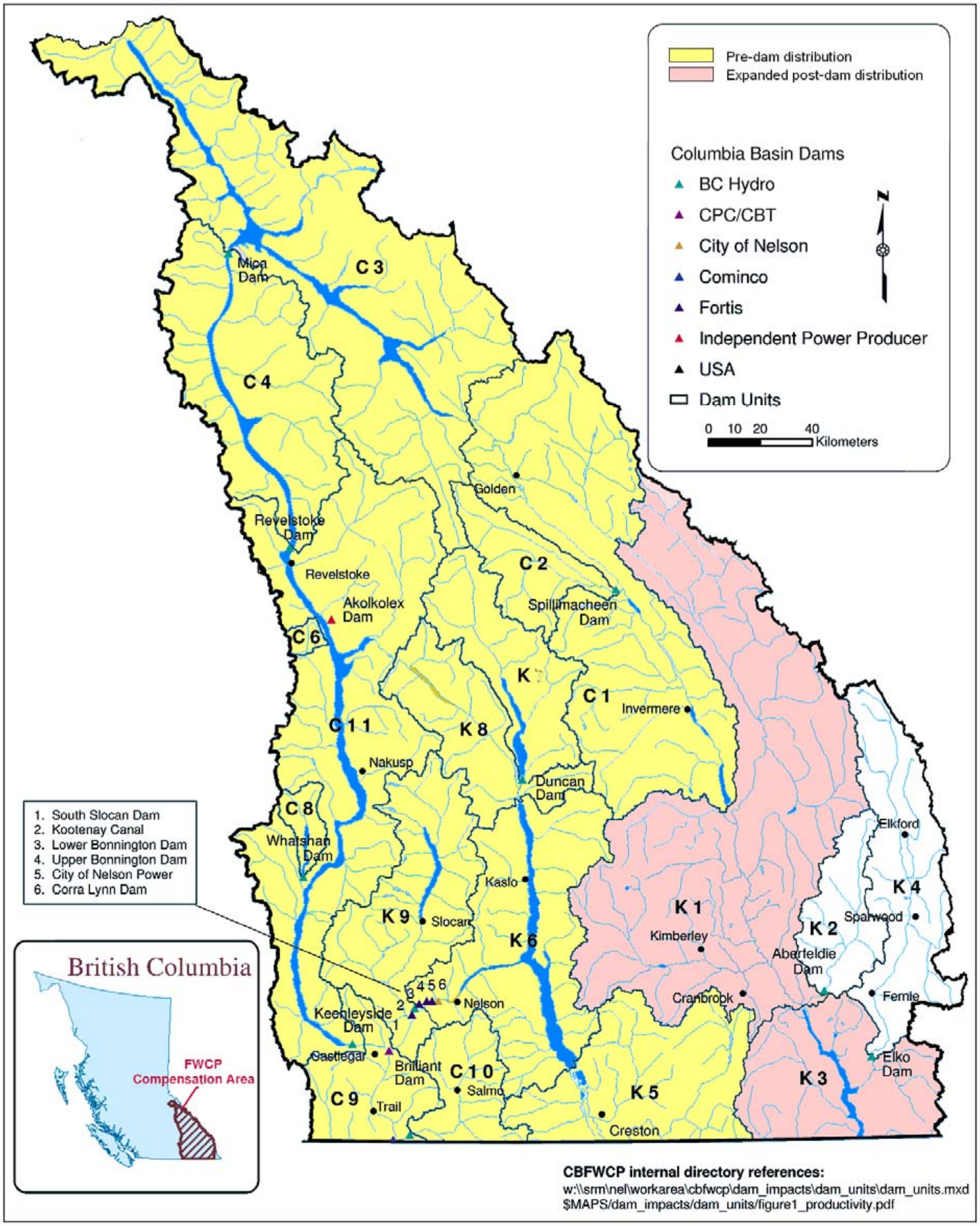

Figure 1. Distribution of rainbow trout in the FWCP dam units before and after dams. Yellow areas indicate the indigenous range. Rainbow trout were present in the upper Kootenay drainage (pink area) as a result of introductions prior to Libby Dam but at very low abundance. The upper Elk and Bull river drainages are separated from the upper Kootenay River by natural barriers but have some rainbow trout present due to stocking of small headwater lakes**.**

4.0 LIFE HISTORY

4.1 Life History Ecotypes and Genetic Diversity

Rainbow trout are a highly diverse species with respect to phenotypes and life history (Scott and Crossman 1973; Behnke 1992; Keeley et al. 2005). In British Columbia, Keeley et al. (2005) demonstrated morphological differences between five ecotypes of rainbow trout: large-lake piscivores, headwater stream residents, large river (fluvial), small lakes (adfluvial), and anadromous; much of the phenotypic variability appears to represent adaptation to local conditions, and a genetic contribution to differences has been demonstrated (Keeley et al. 2007). Rainbow trout indigenous to the Columbia and Kootenay River basins are sometimes referred to as the redband subspecies (*O. m. gairdneri*), being characterized by a pronounced red colouration along the lateral line in spawning males, the frequent presence of an orange or red cutthroat mark under the jaws, and a tendency towards a yellowish colouration (Behnke 1992).[3]

For the purposes of this review, we used four ecotypes of the categories proposed by Keeley et al. (2005), with a further subdivision of large lake adfluvial fish into insectivorous and piscivorous groups (Table 2). Piscivorous and insectivorous refer to the primary items in the diet, and do not imply that no insects or fish are eaten by the respective ecotypes. The anadromous ecotype has not occurred in the Canadian portion of the Columbia basin since the construction of Grand Coulee Dam (U.S. Bureau of Reclamation) in the 1930s (McPhail 2007; Scholz 1985).

The adfluvial piscivorous ecotype is very rare compared to other ecotypes of the species (including the anadromous), and typically occurs only in lakes or reservoirs at least 10,000 ha in size, with kokanee populations available as a food source (Keeley et al. 2005). DeGisi (2002) lists 15 lakes and reservoirs in British Columbia and one in Washington thought to contain indigenous populations, but notes that in some cases it is difficult to determine whether a population is strictly adfluvial piscivorous, or adfluvial insectivorous with a small subset of a primarily piscivorous fish. Piscivorous rainbow trout are present in Kootenay Lake (Gerrard rainbow trout), Trout Lake[4], and the Arrow Lakes Reservoir (ALR) as self-sustaining populations. Slocan Lake also supports piscivorous trout that may be self-sustaining, although the lake is stocked with Kootenay Lake piscivores periodically. Duncan Lake probably supported some piscivorous rainbow trout prior to hydroelectric development, and has received stockings of piscivores since, but current status is unknown. Kinbasket Reservoir has been stocked with piscivorous trout and some rainbows over 5 kg have been reported in angler catch (See Section 6.3.3). Wilson Lake is regularly stocked with piscivores and may support a modest spawning population (J. Bell, MOE biologist, pers. comm.).

[3] This classification is not officially recognized by the American Fisheries Society.
[4] Kootenay Lake piscivorous trout may move into Trout Lake periodically.

Table 2. Comparison of life history characteristics for five ecotypes of rainbow trout found in the Columbia basin. Sources of information are given in footnotes.

Life History Aspect	Ecotype				
	Small stream resident[a]	Fluvial[b]	Small Lake Adfluvial	Adfluvial Insectivorous[c]	Adfluvial Piscivore[d]
Age at Maturity (years)	1-3	4-5	varies	5-6	5-6 (Cartwright 1961)
Maximum Life Span (years)	3-4	5-7	5-12	8-10	5-7
Size at First Maturity (cm)	12-15	40 - 45	varies	35-45	46-86 (Cartwright) >40 (McPhail)
Maximum Size (cm)	13-20	60	varies	50	75-90
Primary Food	aquatic and terrestrial insects	aquatic and terrestrial insects	aquatic insects	zooplankton and aquatic and terrestrial invertebrates	kokanee for fish > 45 cm*
Adult Habitat	low order streams, often above barriers	medium to large rivers	smaller lakes (maximum size, and age at maturity depend on lake productivity)	mainly littoral zone of large lakes although sometimes off shore	offshore (pelagic) area of lakes with kokanee; usually >10,000 ha

[a] Northcote and Hartman 1988; Behnke 2002; McPhail 2007
[b] Hagen and Baxter 2004
[c] Sebastian et al. 2000; Behnke 2002; Arndt 2004a
[d] Cartwright 1961; Andrusak and Parkinson 1984; DeGisi 2002; Arndt 2004a, 2004b; Keeley et al. 2005
* Andrusak and Parkinson (1984) found that the volume percentage of kokanee in stomach contents increased from 35% for fish < 30 cm to over 90% for fish ≥ 60 cm.

Genetic analyses of rainbow trout have been done in some parts of the FWCP area. Taylor (2002) found low levels of genetic subdivision (using 10 microsatellite loci) among fluvial rainbow trout from several main stem Columbia River and tributary spawning locations below Keenleyside Dam, suggesting considerable gene flow among naturally spawning fish. However, these indigenous or naturalized populations exhibited substantial genetic differences from two hatchery strains used to stock Roosevelt Reservoir downstream in Washington State, and from resident rainbow trout sampled from headwater reaches above barriers in the same tributaries; only 1% of sampled fish below Keenleyside Dam were classified as being of Roosevelt hatchery origin. Fluvial and stream resident trout from the Salmo River, a secondary tributary of the Columbia River below Keenleyside Dam, were also clearly distinct from the Columbia River locations (Taylor 2002). Taylor (2002) nevertheless cautions that the markers used in this study are selectively neutral, and the lack of substantial differences among the Columbia spawning locations does not necessarily mean that these populations are genetically identical. There could be important genetically-based life history traits that differ (e.g. timing of spawning).

For the adfluvial ecotype, Taylor and Tamkee (2005) analyzed microsatellite markers from pre-dam (1966-1969) ALR piscivores and compared them to samples from 1975, 1986-1988, and 1995-2004, as well as to samples from Kootenay Lake piscivores (Gerrard population). Up to the mid-1980s, ALR samples were similar to the pre-dam ALR samples, whereas the majority from 1995 and later were classified as being of Kootenay Lake origin. Genetic introgression appears to have occurred after a significant expansion of hatchery supplementation of Gerrards starting in 1984.[5] In contrast, insectivorous adfluvials in the ALR appear to have been less affected by introductions from other locations (Taylor and Tamkee 2005). Significant among-population differences were also found between Kinbasket and Arrow reservoirs and some of their tributaries in a sample of juvenile and adult adfluvials (Taylor 2000; note that samples likely included both insectivorous and piscivorous fish).

Prior to hydroelectric development, the Arrow Lakes contained one or more populations of adfluvial rainbow trout (apparently represented by both piscivorous and insectivorous fish) described as 'yellow-fins', that showed a distinctive yellow colour on the belly and lower fins (Spence et al. 2005). Loss of access to Camp Creek[6], the presumed primary spawning area of these fish, due impoundment of the Columbia River at Revelstoke and Mica dams, and the accompanying loss of fluvial rearing habitats in the mainstem Columbia River is thought to have been a major factor in their decline. Fish of the yellowfin phenotype could not be differentiated with the available markers, although by the time attempts were made to examine these fish genetically, few were available to sample and hybridization with introduced Gerrards had likely occurred (Taylor and Tamkee 2005). Restoration of these fish was one of the highest priorities of the FWCP during the 1990s (e.g. Triton Environmental Consultants 1994), but this work was discontinued after concerns over introgression were raised. More recently, a plan was developed with FWCP funding to address the loss of these fish (Spence et al. 2005); however, implementation has been delayed because of funding constraints.

4.2 Life History Patterns Among Ecotypes

This section provides a brief summary of life history and associated habitats for the five rainbow trout ecotypes in the FWCP area, which the reader may find helpful in interpreting potential dam effects and assessing the feasibility and effectiveness of competing compensation options. More detailed summaries are provided by McPhail (2007), Scott and Crossman (1973), and Raleigh et al. (1984). DeGisi (2002) provides a more complete review of piscivorous life history and habitats specific to British Columbia.

4.2.1 Spawning

Unlike Pacific salmon in the *Oncorhynchus* genus, rainbow trout are iteroparous, having the potential of spawning more than once. Spawning takes place in the spring at temperatures of 6-9 ^{o}C. Fecundity ranges from 1,200-3,200 eggs/kg of female body weight with larger fish having slightly larger egg size (Behnke 1992). Timing of spawning in the FWCP area is typically late April to early June, although it has been observed as early as late February in the Kootenay River downstream of Brilliant Dam. Populations at higher elevations spawn later due to the delay in snowmelt and water temperature warming.

Eggs are deposited in redds in streams with gravel substrates, often in pool-riffle transition areas, with depth and velocity tending to increase depending on the size of the fish (Keeley

[5] Numbers of Gerrards stocked in Arrow Lakes increased from less than 10,000 annually in the early 1980s to over 80,000 in 1997, and size of stocked fish changed from primarily fry to yearlings (Sebastian et al. 2000).
[6] Camp Creek was the only stream where anecdotal reports suggest yellow-fin rainbow trout spawning, but it is likely that other streams were used as well.

and Slaney 1996). Substrate composition must allow sufficient sub-surface flow to provide oxygen to the developing eggs; high proportions of fines can reduce survival and size at emergence for surviving alevins (Keeley and Slaney 1996). Fry typically emerge from redds in early to mid-summer depending on the timing of spawning and incubation temperatures.

Populations of the small stream resident ecotype spawn in low-order streams where they spend their entire life; fluvial populations may move upstream into smaller tributaries, including intermittent streams (Ford et al. 1995; Behnke 1992), or spawn in the same reaches where adult rearing occurs (Hagen and Baxter 2004). Adfluvial populations usually spawn in inlet streams, but can also use lake outlets (Northcote 1969).

4.2.2 Juvenile Rearing

Newly emerged fry establish feeding territories in spawning areas, or disperse to downstream habitats as a result of interspecific competition (Northcote 1969). Upstream fry dispersal has also been observed (Northcote 1969). Following emergence, juveniles from fluvial and adfluvial populations spend anywhere from a few weeks to three rears in spawning reaches before migrating to larger streams or lakes, respectively, with 1-2 years being most common (Allen 1969; Northcote 1969). Migration soon after emergence usually occurs from spawning streams that have low summer discharge and high summer temperatures (Northcote 1969). In streams, fry prefer channel margins, side channels and smaller tributaries in their first few months, moving to progressively deeper habitats as they grow (Behnke 1992). Fry and parr that have emigrated to lakes use shallow areas with suitable temperatures and cover (McPhail 2007).

4.2.3 Adult Habitat and Diet

In fluvial populations, adults make use of pools, riffles, and runs, preferring depths of 0.3 m or more, and selecting feeding positions in areas of slower current adjacent to faster water carrying food; protective cover is also important, especially in smaller streams (Behnke 1992; McPhail 2007). In adfluvial populations in large, deep, mesotrophic or oligotrophic lakes (e.g., Kootenay or Arrow), rainbow trout prefer zones with temperatures less than 18 ^{o}C and oxygen levels above 3.0 mg/l (McPhail 2007). As fish progress from juveniles and subadults to adults, they tend to shift from near-shore to off-shore areas to pursue kokanee, the timing of which is difficult to determine in many cases because samples of smaller fish include those from insectivorous populations as well (McPhail 2007). However, Andrusak and Parkinson (1984) found that kokanee made up 35% by volume of the diet of rainbow trout 17-30 cm in length from the north arm of Kootenay Lake, compared to 90% for fish over 60 cm. In the ALR, kokanee were found in trout as small as 45 cm, and comprised the main diet item of all fish over 50 cm (Arndt 2004a). Outside of the Kootenay Region, kokanee have been reported as a dominant food item for piscivorous trout as small as 43 cm and 36 cm ((Pend Oreille Lake, Idaho: Ford et al. 1995; Crescent Lake, Washington: Behnke 1992, respectively).

5.0 POPULATION REGULATION

In order to assess how hydroelectric development has impacted rainbow trout in the FWCP area, it is first necessary to consider how these populations are regulated naturally. Given the debate over the meaning and relevance of population regulation among ecologists (Murray 1999), a clear definition is warranted. There are three basic aspects to population regulation in animal populations: carrying capacity, resilience, and limits to distribution. Carrying capacity is the maximum number of individuals that can be sustained at a specific life stage in an unexploited (i.e., un-harvested) population, and is governed by density-dependent factors (e.g., the total amount of spawning or juvenile rearing habitat in a stream; food abundance in a stream or lake). Resilience is the rate at which a population will return to a single steady or cyclic state following a perturbation, and is governed by density-independent factors (e.g., quality of spawning habitat; intrinsic population growth rate). With respect to limits to distribution, even prior to hydroelectric development, not all habitats in the FWCP area were suitable for rainbow trout. Factors that may limit rainbow trout distribution in the FWCP area include temperature, habitat characteristics, and competitive exclusion by other species.

In this section we consider, for each ecotype, which life stage(s) are likely to be most important in determining overall population abundance and resiliency, and which environmental factors have the largest influence at these specific stages. Focus is given to those life stages and environmental factors that are most likely to have been impacted by hydroelectric development. This assessment was informed by an excellent review by Behnke (1992), in which he describes the types of habitat that are crucial at different life history stages (spawning, rearing, adult, and overwintering) for all rainbow trout ecotypes. In the case of migratory rainbow trout ecotypes (i.e., large lake adfluvial and large river fluvial), it is important to recognize that population regulation can be relatively complex because fish occupy discrete habitats at different life stages, and the factors governing abundance and resilience are often specific to each habitat. This can make assessing dam footprint impacts much more difficult. For example, dam construction that leads to loss of spawning and rearing habitat in streams may reduce juvenile carrying capacity, but at the same time increase growth potential for adults in newly-created reservoir environment.

5.1 Spawning Habitat as a Limiting Factor

For most populations of large and small lake adfluvials and large stream migratory fluvials in the FWCP area, rearing habitat rather than the spawning habitat would be most likely to limit recruitment to the adult population. This is because in salmonid species where juveniles spend a lengthy period in nursery streams before migrating to adult rearing habitats, it is typical for more to be produced than the stream can support. For example, in many streams in BC that support rainbow trout and steelhead populations, the density of emergent fry in spawning areas in early summer might be 200 fish/m^2, whereas maximum fall fry densities are generally well below 10 fish/m^2 in good fry habitat (E. Parkinson, MOE, pers. comm.). In relatively high gradient streams, which are common in the FWCP area, spawning gravel is often scarce because most gravel is carried downstream or pushed into stream margins (Behnke 1992). The total amount of available spawning habitat can also be relatively low for adfluvial populations in lakes or reservoirs such as the ALR or Kinbasket, where tributaries either have short accessible lengths due to barriers, or carry heavy loads of glacial sediments which limit gravel permeability and oxygen exchange thereby reducing survival of eggs and alevins prior to emergence (Behnke 1992). Similarly, spawning habitat can be limited for adfluvial stocks in small lakes with few inlet streams. In these cases, spawning habitat quantity or quality could potentially be more limiting to recruitment than juvenile rearing habitat if the latter were in abundant supply or of high quality. However, this is unlikely because the above-mentioned factors will reduce not only spawning habitat, but also the quantity and quality of rearing habitat for juveniles (see next section).

The highly restricted distribution of spawning exhibited by large lake adfluvial piscivores (Gerrards) in Kootenay Lake (spawning appears to occur almost exclusively in the Lardeau River at the outlet of Trout Lake) does raise the question of whether spawning habitat requirements are more specific for this ecotype. This is relevant because large, lake-headed, low-gradient, non-glacial rivers occur infrequently in the FWCP area. However, Gerrard populations established in other systems have demonstrated an ability to reproduce in much smaller streams. For example, in the ALR, Gerrards spawn in the 6 m wide spawning channel at Hill Creek (McCubbing and Andrusak 2007), and in Lake Pend Oreille, Idaho they spawn in streams ranging in width from 2.5–10 m (Hartman 1969). In the Great Lakes in Eastern Canada, piscivorous adfluvial rainbow trout also spawn in small streams (e.g., Dietrich et al. 2008). Presumably, the outlet of Trout Lake represents the best spawning habitat available for large piscivores in Kootenay Lake, and the concentration of spawning there is the result of more fish homing to a site where the egg-to-fry survival is very high, and fish selecting this habitat because it possesses optimal characteristics (depth, velocity, etc.).

5.2 Factors limiting juvenile production

All rainbow trout ecotypes begin life in streams. For adfluvial ecotypes, the amount of time juveniles spend in streams depends on growth rate and the type of rearing environment they will encounter when they migrate to a lake or reservoir. Age-at-lake-entry is typically one or two years for individuals that survive to adulthood in mixed-species lakes with significant predation risks, whereas survival can be relatively high for age-0 fry in small monoculture lakes (Parkinson et al. 2004). Studies of rainbow trout and other species often shown that survival during the first year of life (particularly during the first winter) is highly density-dependent, and represents a bottleneck to recruitment to subsequent life stages (Kennedy and Crozier 1993; Ward and Slaney 1993; Hartman et al. 1996; Mitro and Zale 2002). Providing that spawner escapement is sufficient to seed available habitat, the quality and quantity of juvenile rearing habitat likely plays a primary role in regulating recruitment to the adult life stage (but not necessarily overall abundance) for many rainbow trout populations in the FWCP area.

Habitat quantity acts to limit carrying capacity for juvenile rainbow trout in streams because juveniles are strongly territorial (Keeley 2003). Individual fish defend territories that provide food and shelter during the summer. Competition for territories can be intraspecific (intra- and inter-cohort) and interspecific when other salmonids are present (McFadden 1969; Behnke 1992). Territory size increases with fish size thereby limiting trout density and production (Allen 1969; Keeley 2003). Because habitat requirements can vary seasonally, when assessing losses or gains in habitat quantity, focus should be given to those habitats required during critical survival periods. For example, winter habitat is thought to be important for regulating carrying capacity of trout in streams as suitable refuge habitats are often limiting (see later). In cases where stream habitat for juveniles is very limited, but extensive adult habitat is available (e.g., large reservoir or fertile small lake with limited accessible tributary habitat), juvenile rearing habitat may play a primary role in regulating abundance at all life stages. For fluvial populations in larger river systems in the FWCP area, this would be less likely, as juvenile rainbow trout (unlike bull trout) are adapted to rearing in a wide range of stream sizes and types.

With respect to the FWCP area, the most important density-independent factors determining habitat quality for juvenile rainbow trout are likely temperature, flow regime, and food availability. In stream reaches downstream of dams, dam footprint impacts can directly affect these factors. In reaches upstream of dams and reservoirs, the impact of dams is more likely to be on habitat quantity (i.e., inundation of stream habitat by reservoirs).

Preferred mean temperatures for summer rearing and optimum growth are in the range of 13 – 16^{o}C (Behnke 1992); Reaches with maximum summer temperatures >19 ^{o}C are often avoided unless there are cool water refuge areas (Ebersole et al. 2001). Generally, feeding and growth are reduced at temperatures over 16-20 ^{o}C (Wurtsbaugh and Davis 1977; Linton et al. 1997) and stop at 22-25 ^{o}C (Behnke 1992), but juveniles may be less susceptible to negative effects from high temperature than adults (Rodnick et al. 2004). While summer temperatures in some habitats regularly exceed 20^{o}C (e.g., Slocan River, portions of the Columbia River headwaters), and may limit growth and production, unfavourably high water temperatures are not an important factor with respect to juvenile rainbow trout production in the majority of the FWCP area. In contrast, many streams in the FWCP area are fed by glaciers and permanent snowfields, and cool water temperatures in these streams reduces habitat suitability and potential distribution significantly for rainbow trout. Low summer temperature can limit trout distribution in higher elevation streams. Mullner and Hubert (2005) studied trout distribution in a Rocky Mountain catchment and found age-0 rainbow trout were present only where maximum July temperature was at least 13^{o}C, and adults were present only where July temperature reached 12^{o}C. Importantly, juvenile rainbow trout and bull trout occupy a similar niche in the FWCP area, and bull trout, which are adapted to colder temperatures, tend to be dominant in colder streams (i.e., maximum summer temperature < 15^{o}C; Haas 2001; Decker and Hagen 2007). In glacial streams, habitat suitability for rainbow trout is further reduced by the combined effect of low water temperature and reduced water clarity. Rainbow trout are strongly visual predators and drift-feeders, and a decrease in water clarity will decrease niche volume for this species (Behnke 1992). In glacial tributaries of the ALR and the Lardeau River, rainbow trout are nearly absent (Decker and Hagen 2007; Decker and Hagen 2009).

Carrying capacity for both juveniles and stream-resident adults can also be strongly influenced by both the magnitude and degree of variability in annual discharge. Binns and Eiserman (1979) found that annual flow regime was a primary determinant of trout biomass in Wyoming Streams, with higher standing stocks occurring in streams with higher base flows and less difference between maximum and minimum flows (see also McKinney et al. 2001 for application to a regulated river). Binns and Eiserman (1979) reported that the best trout streams had late summer flows at least 55% of annual mean daily flow. High gradient and high elevation streams tend to support lower standing stocks of trout as they have greater flow variability and lower base flows (Lanka et al. 1987). Reduced stream flow may also lower growth rate (Harvey et al. 2006). Winter flow regime is also important, as severe floods and frazzle ice can lead to high mortality for juvenile and adult fish (Seelbach 1987). Juvenile rainbow trout are strongly photo-negative at winter temperatures, often sheltering beneath rubble or boulder substrate (Cunjak 1996), which makes them vulnerable to bedload movement during flood events.

When stream temperatures are within a suitable range and physical habitats are available in excess, food availability can be a main constraint on trout populations (Behnke 1992; Binns and Eiserman 1979). For example, the addition of opossum shrimp, *Mysis relicta,* from an upstream reservoir to the Fryingpan River, Colorado, caused a five-fold increase in the standing biomass of trout through effects on growth and survival (Behnke 1992). Conversely, Clarke and Alexander (1985, cited by Behnke 1992) found slower growth and maximum size of brown trout, *Salmo trutta,* after reductions in nutrient inputs to a Michigan river. The best trout streams in a Wyoming study had benthic invertebrate densities of over 5,000 organisms/m^2 (Binns and

Eiserman 1979). Using a large database of BC streams, Ptolemy (1993) found that juvenile rainbow trout and steelhead biomass was correlated with total alkalinity (which provides an index of nutrient availability) at a provincial scale. In a small stream within the FWCP area, increased benthic invertebrate biomass resulting from experimental nutrient enrichment led to an increase in size-at-age for juvenile rainbow trout and bull trout, but little change in abundance (Decker 2008).

Winter habitat is considered to be potentially very important for regulating maximum capacity of trout in streams if suitable refuge habitats are limiting. Quantitative field research demonstrating its importance is rare because there are few winter studies (Behnke 1992, Cunjak 1996, Hurst 2007). Nevertheless, several studies have investigated winter mortality in relation to habitat use for juvenile rainbow trout (e.g., Smith and Griffith 1994, Annear et al. 2002, Mitro et al. 2003, see also references in Cunjak 1996). Mitro and Zale (2002) found evidence that availability of appropriate winter habitat limited trout recruitment in the Henrys Fork of the Snake River, Idaho. Density-independent limitation may also occur in winter when conditions such as severe floods and frazzle ice affect survival regardless of food or space (Seelbach 1987). In a regulated river, Mitro et al.(2003) found that higher discharge increased winter survival of age-0 fish and suggested that this was because a greater amount of suitable bank habitat was available; in this case density-independent (discharge) and density-dependent (amount of suitable habitat) factors appear to be interacting.

Active feeding is reduced in winter as the temperature drops, and fish move to habitats that minimize energy expenditure; movements and migrations to overwintering areas can be extensive in some streams (Behnke 1992, Cunjak 1996). Cunjak (1996) gives three habitat criteria for winter habitat selection, with protection from adverse physicochemical conditions (e.g., ice formation, low oxygen, winter freshets) as the most important, followed by protection from predators. Endothermic predators (e.g., mink, otter, merganser) can be very effective at this time of year because fish swimming ability is reduced at low temperatures (Cunjak 1996). The third criterion, access to food, is considered to be of lesser importance although it may become more important if there is a rise in temperature that increases metabolic demand during late winter.

Winter habitats differ depending on the size of the fish since they typically shelter beneath rubble or boulder substrate where rock diameter is proportional to the size of fish beneath (Cunjak 1996). Generally, survival is related to the amount of deep water with low current velocity and protective cover such as large boulders or large woody debris (Behnke 1992). Large bodied adults usually overwinter in pools unless there are accumulations of frazil ice, in which case off channel areas or locations of groundwater input may be more important (Cunjak 1996). Groundwater may not always be a benefit, if it prevents ice formation (Barrineau et al. 2005). Juvenile rainbow trout will use macrophytes or complex bank habitat as early winter cover, but cobble-boulder substrate is probably more important (Griffith and Smith 1995, Behnke 1992, Cunjak 1996). Rock riprap placed for bank protection is also used by rainbow trout juveniles (Swales et al. 1986).

5.3 Factors Limiting Adult Production

5.3.1 Lake habitat

For adfluvial fish, a different suite of factors act once fish enter lentic environments. Water quality, food availability, and competitive interactions with other species are likely the most important factors regulating adult populations in lakes and reservoirs. Water quality can limit habitat suitability, especially for small, relatively shallow lakes. As in streams, summer temperatures (at some depth) below 18 ^{o}C are required, and winter dissolved oxygen levels must remain above 3 mg/l to provide suitable adult habitat year round (Ford et al. 1995). High turbidity probably reduces habitat suitability because it may hinder visual feeding, especially if it persists well into the growing season. In the large lakes and reservoirs of the FWCP area, high water temperature and low dissolved oxygen are not significant factors, but the degree of temperature stratification in mid to late summer could affect vulnerability of kokanee prey to piscivorous fish.

Food availability is generally the primary factor regulating rainbow trout growth rates in lakes. Rainbow trout juveniles and adults feed on benthic organisms (e.g., nymphs of aquatic insects, amphipods) and organisms found in the water column (e.g., chironomid pupa, cladocerans) as well as terrestrial insects (McPhail 2007). Fish over 50 cm are assumed to be piscivorous in the large oligotrophic lakes based on diet studies in Arrow and Kootenay lakes (Andrusak and Parkinson 1984; Arndt 2004a). These fish begin feeding on larger kokanee at a fairly early age and have the potential to reach large size (> 75 cm), whereas insectivorous rainbow trout do not consume larger kokanee and typically plateau at about 45 cm (Arndt 2004a). In the ALR, terrestrial insects such as flying ants seem especially important for the adfluvial insectivore ecotype, although this may be a consequence of poor aquatic littoral production.

As previously mentioned, large piscivorous rainbow trout occur naturally in large, oligotrophic lakes only when kokanee are available (Keeley et al 2005). Valand et al. (2008) noted that the abundance and growth of top piscivores in lentic systems is often tightly coupled to the availability of prey species, especially in relatively simple pelagic systems. There is substantial evidence that growth and perhaps survival of piscivorous rainbow trout are food limited. For example, Behnke (2002) describes how Gerrard rainbow trout from Kootenay Lake, when first introduced to Lake Pend Oreille, Idaho in 1942 encountered a superabundance of kokanee, and reached maximum sizes of 14.5 kg in four years, and 17 kg in five years. After kokanee abundance declined in subsequent years, average size of Gerrards decreased substantially, with 7 kg fish being exceptional. In the ALR, the size and number of piscivorous rainbow trout in angler catches increased following an increase in the mean size and abundance of kokanee brought about by reservoir fertilization (Arndt 2004b). In contrast, prior to nutrient enrichment, increased stocking of yearling rainbow trout did not result in an appreciable increase in angler catch (Arndt 2004b). In Kootenay Lake, an increase in the spawning population of Gerrard rainbow trout in the 1970's, from about 500 to 1,500 individuals, coincided with an increase in kokanee abundance (Ashley et al. 1999).

Prey size, as well as abundance, is important with respect to piscivorous trout growth and maximum size. Parkinson et al. (1989) and Arndt (2004a) found positive relationships between the size of rainbow trout and the size of consumed kokanee, implying that larger fish select (or may require) larger kokanee, as expected from optimal foraging theory (Behnke

1992). Length of consumed kokanee can be as high as 30% of predator length (Arndt 2004a). In Quesnel Lake, size and growth rates of piscivorous rainbow trout declined under conditions where a superabundance of sockeye fry caused a reduction in older year classes of kokanee (Sebastian et al. 2003).

Interspecific competition for food is another potential factor regulating the piscivorous ecotype. Kokanee make up the majority of the diet for both piscivorous rainbow trout and bull trout in the ALR (Arndt 2004a) and in Kootenay Lake. In the ALR, bull trout appear to be more adaptable either in their diet or foraging methods, as their abundance and body condition does not seem as closely tied to kokanee abundance as that of piscivorous rainbow trout, which appear to rely almost exclusively on kokanee (FWCP file data).

5.3.2 Stream habitat

For the small-stream resident ecotype, and perhaps the fluvial ecotype as well, productivity at the adult life stage is likely to be more important than that at the juvenile stage with respect to population regulation. Firstly, large rainbow trout are more food-limited in a small stream than small trout (McPhail 2007) because they are at an energetic disadvantage. If fish are unable to find larger prey items as their size increases, energy expenditure for feeding increases resulting in asymptotic growth, although highly productive streams may produce large fish due to the low energy required to obtain abundant but relatively small aquatic insects (Behnke 1992). Secondly, according to Behnke (1992), adult habitat is most likely to limit population biomass of trout in smaller streams since spawning and juvenile rearing habitat and food supply would be capable of supporting more biomass if more adult habitat was available. Adult rainbow trout generally exhibit a much more ‘clumped’ spatial distribution in streams than juveniles, which presumably reflects more specific habitat requirements. In small streams, adult trout prefer relatively deep (> 0.5 m) habitats such as pools and runs that are often much less common than shallow habitats (e.g., riffles, glides) preferred by juveniles. Adults are also more susceptible to negative effects from high stream temperature than are juveniles (Rodnick et al. 2004). Lastly, the relatively small size of small-stream resident adults translates to relatively low fecundity, which may be a greater limiting factor to recruitment than the availability of juvenile habitat.

6.0 STATUS BY DAM UNIT

6.1 Columbia Lake to Donald Station (C1)

This reach of the Columbia River is very low gradient (mean 0.3%) and characterized by frequent braids, backchannels, and standing water (Ahrens and Korman 2004). The majority of the mainstem from Invermere downstream to Golden supports an expansive wetland system adjacent to the main channel (Moody et al. 2007). Rainbow trout are present up to the headwaters including Columbia and Windermere lakes and the in the Columbia River between them. Tributaries in this unit that provide rearing habitat for rainbow trout include Dutch Creek (Hagen 1993), the Spillimacheen River below the dam (Edeburn 2001), Kicking Horse River, Horsethief Creek, and Frances Creek. The wetland areas of the Columbia River downstream of Columbia Lake likely provide only marginal habitat for juvenile and adult rainbow trout during the growing season due to shallow depth and warmer summer temperatures. Productivity and habitat suitability of the Columbia River and some of the tributaries in this reach may also be limited by high glacial turbidity at other times of the year (Ahrens and Korman 2004). It is likely that adfluvial trout from Kinbasket Reservoir spawn in tributaries within this unit. Little information is available for these fish, but given the highly glacial nature and cold temperature of most of the tributaries that empty directly into the reservoir downstream in unit C3, it is conceivable that Columbia River tributaries in unit C1 may provide a high proportion of the usable spawning and juvenile rearing habitat for these fish. An estimated 0.2 to 0.6 million kokanee from Kinbasket reservoir spawn in several tributaries in unit C1, as well as in limited sections of the Columbia River mainstem (Oliver 1995, Arndt 2009). Eighteen other fish species are listed as present in this dam unit (Ahrens and Korman 2004).

Physical habitat conditions have not been changed for fluvial and resident trout in this reach, but the fish community has been affected by the reservoir downstream and the introduction of kokanee. Trout productivity in this unit may benefit from the kokanee since eggs, fry, and carcasses are consumed directly by rainbow trout (Bilby et al. 1998); also nutrients released by the carcasses can have a positive effect on the food web and invertebrate production (Jauquet et al. 2003, Nakajima and Ito 2003, Reimchen et al. 2003).

Some fluvial rainbow trout stocks in this reach of the Columbia may have adapted to an adfluvial life history after the creation of Kinbasket Reservoir. Remaining fluvial fish may have to compete with adfluvial fish from the reservoir for spawning and juvenile rearing habitats. Resident fish in headwater streams above barriers have not been affected. No trend or quantitative data are available to compare fluvial rainbow trout populations in this dam unit before and after dams, but impacts are believed to be very minor because there have been no substantial changes in habitat. Adfluvial rainbow trout (Kootenay Lake Gerrard stock) were planted in one tributary in this unit (Blackwater Creek), and a large redd was observed in this stream during follow-up surveys in the early 1990s (C. Spence, Ministry of Environment, pers. comm.).

6.2 Spillimacheen River (C2)

Habitat in this dam unit consists of 116 km of the Spillimacheen River (order 6-7) and its tributaries upstream of the Spillimacheen Dam (Thorley 2008). The dam is 15 m high and is operated as a run-of-the-river facility without storage. A penstock diverts water from the stream into the generating station, reducing flows in a 1.5 km long section of the river between the dam and the powerhouse. The headpond is approximately 1 ha in area (Moody et al. 2007), and inundates less than one kilometre of the river upstream of the dam. There are two falls in the canyon between the dam and the powerhouse, the highest being 10 m (Ahrens and Korman 2004), that probably limited or prevented upstream migrations of fish from the Columbia River prior to dam construction.

Based on reconnaissance surveys by Edeburn et al. (2001), rainbow trout are present upstream of the dam, as well as westslope cutthroat trout, bull trout, brook trout and mountain whitefish *Prosopium williamsoni*. Rainbow trout are apparently present in nearly all of the drainage including a section above a 5 m falls about 1 km downstream of McMurdo Creek that appears to be a barrier to bull trout. Ecotypes present include fluvial and small-stream resident (especially above falls and in headwater areas). Many lakes within the drainage have been stocked with rainbow trout over the last 20 years and stocking may contribute to abundance of trout in some reaches, including those above barriers.

Some trout likely use the headpond as habitat but data are lacking. The impact of the dam in this unit is believed to be relatively minor because of the small headpond and the location near a previously existing falls. No trend or quantitative data are available to compare rainbow trout populations in this dam unit before and after dams. The reduction in flow in the canyon reach between the dam and powerhouse probably causes a reduction in habitat capability, but its pre-dam carrying capacity was likely modest.

6.3 Donald Station to Mica Dam (C3)

Kinbasket Reservoir flooded the largest amount of aquatic and terrestrial habitat of any reservoir in the study area. Losses of stream and river habitat in this dam unit totalled 744 km (51 km^2 in area, Thorley 2008), of which 132, 208, 110, and 294 km were large, medium, and small river, and small stream habitat, respectively.[7] However, by area, large and medium size rivers made up nearly 90% of the losses (Thorley 2008). This included the Columbia River mainstem and lower portions of the Canoe, Wood, Bush, Gold, Sullivan, Kinbasket and Cummins Rivers (Peterson and Withler 1965). Lotic gross primary productivity losses in this unit were estimated as 1,674 tonnes of carbon per year (tC/year; Moody et al. 2007). Also at least five small and medium lakes with a combined surface area of 24 km^2 and ~6 km^2 of shallow water were inundated (Thorley 2008).

Lentic reservoir habitat created by the dam is 370 km^2 based on the average elevation during the growing season (Moody et al. 2007) [8], although at full drawdown the area is much smaller (Figure 2). Reservoir productivity is described as ultra-oligotrophic (Hirst 1991) with an estimated primary production of 80 mg C/m^2 during the growing season, or 5,453 tC/year including littoral production and macrophytes (Moody et al. 2007). An analysis by Moody et al. (2007) suggested higher per area primary production rates for Kinbasket and Bush Lakes prior to dam construction (130 and 135 mg C/m^2, respectively, with a total annual production of 602 tC including littoral areas), but these estimates are highly uncertain (see Moody et al. (2007).

Estimates of rainbow trout abundance prior to the construction of Mica Dam are not available. However, a fairly intensive survey of fish habitat and species presence was carried out during the summers of 1962 and 1963 to document conditions prior to dam construction (Peterson and Withler 1965b). All streams were walked from their mouth to an elevation of 742 m (the proposed maximum flood level) and habitat characteristics were described. Significant lakes in the flood zone were also surveyed. Fish were sampled using rotenone, primacord explosives, seine nets and angling in streams; and gill nets and angling in lakes. Preliminary surveys reported by Maher (1954, 1961) also provide useful information. A summary of these studies and those by Moody et al. (2007) on fish productivity in the streams and lakes present before dams, is included below.

[7] Thorley (2008) categorized lotic habitats as follows based on maps of approximately 1:20,000 scale: small stream (orders 1-2), small river (orders 3-5), medium river (orders 6-7), large river (orders 8-9).
[8] Maximum surface area is 420 km^2 (Moody et al. 2007).

Figure 2. View of Kinbasket Reservoir from the west side between Beaver and Bachelor Rivers ca 1994, showing the extent of reservoir drawdown in late spring before water levels increased. (John Hagen photo)

6.3.1 Fluvial and Stream Resident Impacts

The quantity of lotic habitat inundated in this unit was very high, as described above, but the quality of this habitat for rainbow trout varied. The Columbia River above Kinbasket Lake, along with several of its tributaries, was turbid until September due to glacial inputs; Kinbasket Lake allowed much of the suspended sediment to settle, such that the river downstream was only moderately turbid in early summer (Moody et al. 2007). High turbidity likely reduced rainbow trout use of the Columbia River mainstem (see Section 5.2). In addition, temperature in this reach was also likely sub-optimal for rainbow trout, as maximum summer temperature was less than 13^{o}C even below Kinbasket Lake (Hamblin and McAdam 2003). Adult rearing habitat in this reach was likely dominated by bull trout (Haas 2001). There was little angling effort on the main river prior to the dam, but this may have been largely due to the difficulty of access and high number of mosquitoes at that time; Maher (1954) reported that angling for bull trout and burbot occurred on the Columbia River between Beavermouth and Mica Creek, and felt that the area had the potential for a fishery of some size. Most of the angling that did occur on the Columbia River occurred at the mouths of tributary streams, where bull trout and rainbow trout could be taken (Maher 1954, 1961).

Nearly all of the larger tributaries in this unit were of glacial origin, with heavy sediment loads and little spawning gravel (Maher 1961, Peterson and Withler 1965b, Moody et al. 2007). These characteristics, along with high turbidity and large fluctuations in discharge during the spring freshet, made them relatively poor habitat for rainbow trout spawning and rearing, as noted by Petersen and Withler (1965b). They concluded that these streams were better suited to fall-spawning species such as whitefish and bull trout because of the lower fluctuation in discharge and reduced sediment load in the fall. Large tributaries in which rainbow trout were not captured during surveys in 1962 and 1963 included Sullivan, Kinbasket, Cummins, Bush, Gold, and Wood (Peterson and Withler 1965b). The absence of rainbow trout in their limited samples does not indicate that none were present, but does suggest relatively low abundance compared to other species such as mountain whitefish, which were captured in nearly every sampled stream.

Rainbow trout were captured in 12 of the 27 streams sampled (Petersen and Withler 1965b; see Appendices ii and iv in their report) although in smaller numbers than whitefish and bull trout. Succour Creek is described by Peterson and Withler (1965b) as having an excellent trout fishery. This stream had clear water with ideal substrate and gradient for trout over the entire 10 km of flooded length, and was easily accessible from the highway (Maher 1954, Peterson and Withler 1965b); 76 rainbow trout were captured in 150 m of habitat in Succour Creek, representing all life stages from fry to adult. In several other Columbia River tributaries (e.g., Caribou, Game, Ptarmigan creeks) in this unit, adult rainbow trout were captured that appeared to be stream residents based on their small size (as opposed to larger fluvial fish from the Columbia River). Standing stock losses of all salmonids utilizing the lotic habitat in this dam unit were estimated as 16,800 kg based on stream alkalinity and useable area estimates (Moody et al. 2007). Whitefish probably comprised the majority of this biomass, with a smaller proportion being rainbow trout and bull trout.

6.3.2 Adfluvial Impacts

Kinbasket Lake, the largest lake in C3 prior to dams (2042 ha), was a widening of the Columbia River about 11 km in length (Maher 1961). Moody et al. (2007) suggest that combined pre-dam heterotrophic and primary productivity of the lake was unusually high based on large catches of eight different species in standard gill nets reported by Peterson and Withler (1965b). However, the gill net catches included only two rainbow trout. Angling effort was reported as light for this lake, but good catches of rainbow trout and bull trout were possible at the mouths of Tsar Creek and Kinbasket River; the gravel floodplains at the mouths of these creeks provided good casting locations that were easily accessed from the highway (Maher 1961). It should be noted that anglers can commonly achieve high catch rates on sparse populations by focusing on small concentrations of lightly exploited fish (E. Parkinson, MOE, pers. comm.). Peterson and Withler (1965b) confirm that most angling occurred at the mouths of tributaries "*where rainbow trout and Dolly Varden*[9] *up to 10 pounds (4.5 kg) are taken*". They mention that the productive littoral zone of Kinbasket Lake was very small (perhaps due to turbidity or sedimentation from the river). Groundwater and slough channels entering the lake near the Sullivan River and at the south end appeared to be important feeding areas for 1 – 2 kg rainbow trout in late summer, as indicated by angler catches; these trout were apparently taking advantage of aquatic insects and small forage fish from the adjacent wetlands (Moody et al. 2007).

The two Bush lakes were the next largest in size (156 and 144 ha), and are described as being readily accessible from the highway and having the most important single fishery in the affected area (Maher 1961). These lakes were stocked regularly with rainbow trout and offered good fishing for rainbow trout to 2.3 kg (5 lb) and bull trout to 3.6 kg (8 lb). The fishery attracted many residents of the Golden area, as well as non-residents from Alberta (Maher 1954, 1961; Peterson and Withler 1965b). Maher (1954) mentions that tourists were directed to these lakes by motel operators in the area. The first lake was shallow (1.5 – 3.0 m) for its entire area and contained a large quantity of suckers *Catostomus* spp., and northern pikeminnow *Ptychocheilus oregonensis* (Maher 1954). The best trout fishing was in the second lake, which was shallow (1.5 – 3.7 m) for two thirds of its area, with the remaining third about 9 m deep (Maher 1954). Catches of 15 rainbow trout per day (1-2 kg in size) were reported (Peterson and Withler 1965b). Unlike Kinbasket Lake, the Bush Lakes were separated from the direct influence of the Columbia River and other turbid sources (Peterson and Withler 1965b). These lakes appeared to be productive, with aquatic insect hatches and large numbers of leeches observed during a 1964 survey (Moody et al. 2007). Peterson and Withler (1965b) describe the substrate of both lakes as mud with *Chara* growing over much of it; there were small gravel deposits along the shoreline of both lakes, and good gravel (2800 m^2) in the 400 m of stream between the two lakes, and at the mouth of two tributaries (1400-1850 m^2). They state that rainbow trout were more common than bull trout or whitefish in the Bush Lakes. It is likely that these lakes supported indigenous adfluvial rainbow trout before they were flooded. Peterson and Withler (1965b) also described a fourth small un-named lake of 60 ha in the Bush River drainage, about 3 m deep, that provided good fishing for rainbow trout up to 4 lb (2 kg). They mentioned that many small lakes of similar size were located along the Bush River within the flood zone, the extent of which are estimated by MacKillop (2008; see Section 7.1). Lake Lil was located on the opposite side of the Columbia River from the highway and was therefore difficult for anglers to access (Maher 1954). This lake was quite small (13 ha). Although the lake was not sampled, Maher (1954) believed it was likely shallow since it was surrounded by marsh, and suggested that it likely did not support salmonids.

[9] Now classified as bull trout in the study region.

In summary, the small lakes in this unit would have had high biodiversity values because they supported a diversity of species in habitats that are now rare or absent in the dam unit. They also likely supported modest rainbow trout fisheries under low angling pressure.

There is evidence that this dam unit provided spawning habitat for adfluvial piscivorous rainbow trout from the Arrow Lakes. Camp Creek, a tributary of the Canoe River, was noted by Peterson and Withler (1965b) as an important spawning ground for large rainbow trout that were "possibly migrants from Arrow Lakes". Paish et al. (1974) also make mention of large rainbow trout spawning in Camp Creek. The exact timing of the run and fish numbers were not reported, but anecdotal information suggests that some poaching of large fish occurred in May and early June. The construction of Mica Dam permanently blocked access to fish from the Arrow Lakes, and rainbow trout in spawning condition including those with "yellowfin" colouration were captured below the dam in 1975 and 1976 (see sections 6.4 and 6.5 for further details).

6.3.3 Post-Impoundment Habitat and Populations

The creation of Kinbasket Reservoir added a substantial amount of new lentic habitat to this dam unit, and to the FWCP area as a whole during the May to October growing season, and this habitat currently supports naturally-sustained adfluvial rainbow trout populations. Reservoir temperatures in mid to late summer are conducive to good growth rates for rainbow trout (>12 ^{o}C) from the surface down to 20 or 30 m (BC Hydro, Revelstoke, K. Bray, unpublished data). However, littoral production from this reservoir is minimal (Moody et al. 2007), and reservoir area and habitat quality changes substantially over the course of a year due to the large annual fluctuation in water levels (25-35 m) for flood control and power production. The lack of available littoral vegetation and associated benthic production reduces the suitability of the reservoir for the insectivorous adfluvial ecotype and perhaps juvenile piscivores as well. Seasonal turbidity in the reservoir may also reduce habitat capacity to an extent. A study has been initiated recently under BC Hydro Water Licence Requirements that may provide useful information on limiting habitats for rainbow trout in the reservoir (Kinbasket Reservoir rainbow trout life history and habitat use assessment, CLBMON-7).

In a 1995 creel survey, rainbow trout made up about 25% of angler catch in Kinbasket reservoir and were the favoured target species from July to September (Pole 1996). Overall effort was relatively low, partially due to its remote location, but anglers from the Okanagan are attracted to the area (64% of effort). Catch per unit effort (CPUE) for rainbow trout was 0.17 fish/hr for anglers interviewed at the end of their trip, which is similar to that in the ALR between 2001 and 2007 (Arndt, S. FWCP, unpublished data). Length range of sampled fish was 29 – 41 cm, indicating the adfluvial insectivorous ecotype. This size range is smaller than that reported for Kinbasket and Bush lakes prior to dam construction (see above).

Piscivorous fish (Kootenay Lake Gerrard progeny) were stocked in Kinbasket reservoir from the 1980s to 1992 (BC MOE Fisheries Inventory Data), and appear to be present at a very low proportion in the fishery. None were recorded in angler catches up to 1995 (Pole 1996), but Bray (2002) recorded three possible Gerrard rainbow trout (56 – 63 cm fork length) of 56 fish sampled from Kinbasket Reservoir at fishing derbies held between 1997 and 2000, and 9% of the stomachs examined during derby sampling contained fish and insects (Bray 2002). A recent magazine article also mentions rainbow trout of 5 to 7 kg in the reservoir (Kimble

2008). Introduced kokanee have been abundant in this reservoir since the 1990s or earlier (Arndt 2009), providing the required food source for the piscivorous ecotype. No spawning locations for piscivorous fish are known, and their presence may be dependent upon hatchery stocking. However, Gerrards have not been planted since 1992, suggesting that limited natural reproduction in recent years is a possibility. Camp Creek, the presumed historical spawning location of Arrow Lakes piscivores, was sampled by weir in 1994 with only small (<22 cm) rainbow trout captured. Part of the spawning run was missed due to high water (Fidler 1994), but the lack of other evidence for indigenous (yellowfin) piscivorous rainbows in the reservoir from construction to 1995 suggests that the original Camp Creek piscivorous stock did not survive in the new reservoir.

The main impact in unit C3 has been a reduction in ecotype diversity, and associated genetic diversity. The construction of Mica Dam resulted in the loss of a unique adfluvial piscivorous stock, most or all fluvial rainbow trout, several small lake populations, and some small stream resident fish in unit C3. Remaining streams appear to be too small and unproductive to support the fluvial ecotype, and previous fluvial stocks were likely either extirpated or adapted to the reservoir by shifting to an adfluvial life history. Some stream resident populations remain, although most streams in unit C3 are too cold and turbid for good rainbow trout production. Succour Creek upstream of the maximum reservoir elevation is likely the best remaining habitat for resident rainbows, but the lower 10 km of this stream, described by Peterson and Withler (1965b) as having ideal gravel and flow conditions, were inundated.

The loss of several small lake fisheries represents lost socio-economic opportunities as well: small lake fisheries with wild fish growing to over 2 kg are rare in the West Kootenay. These natural lakes would have provided angling opportunities without the need for a large investment in boats and equipment, which are often required in larger lakes and reservoirs. Large- and medium-sized river fisheries are also rare and highly valued in the West Kootenay. Post-dam angler catches indicate insectivorous adfluvial trout in Kinbasket reservoir provide angler CPUE similar to that in the ALR, but it appears that the remaining stream and post-dam lentic habitat is not well-suited to piscivorous trout given the relatively low incidence in angler catch.

6.4 Mica Dam to Revelstoke Dam (C4)

Inundated lotic habitat related to Revelstoke Reservoir totalled 268 km (or 27 km^2 in area) (Thorley 2008); 141 km of this was the Columbia River, with the remainder being the lower reaches of medium and small rivers (46 km) and small streams tributary to the Columbia. By area, the Columbia River made up 96 % of the losses with small and medium rivers comprising nearly all of the remainder (Thorley 2008). Lotic primary productivity losses in this dam unit were estimated as 1566 tC annually (Section 7.4.2).

Although no lakes were inundated by the reservoir, 0.27 km^2 of shallow open water habitat was lost (Thorley 2008). Pre-dam gross primary production exported to the aquatic habitat from adjacent wetlands and floodplain in this dam unit was estimated as 6,800 tC/year (Moody et al. 2007). Large lake/reservoir habitat created by the dam is estimated as 114 km^2 based on the average elevation during the growing season (Moody et al. 2007). The productivity of the reservoir is described as ultra-oligotrophic and there is some turbidity during the snowmelt period due mainly to the inflows from Downie Creek (Hirst 1991). Estimated gross primary production in the reservoir is 75 mg C/m^2 during the growing season (similar to pre-dam Arrow Lakes), or 1,662 tC/year including littoral production and macrophytes (Moody et al. 2007).

6.4.1 Fluvial and Stream Resident Impacts

Prior to dams, the Columbia River in this reach was turbid during the freshet, although less so than the river upstream of Kinbasket Lake (Moody et al. 2007). This reach was on average narrower than other reaches, and side channels, back eddies, and large pools were not prevalent; average gradient was < 1% (Martin 1976). Most of the tributaries were of glacial origin, precipitous, and had low temperature and total dissolved solids indicating low productivity (Martin 1976). These characteristics, along with rapid discharge fluctuations and the presence of impassable falls, probably restricted their habitat value for migratory rainbow trout spawning and rearing, although stream resident populations of rainbow trout were believed present above the barriers (Martin 1976). Stream resident rainbow trout populations are listed for Kirbyville, Mars, Seymour, Fortynine, and Holdich creeks (Martin 1976, Lindsay 1977).

Three major tributaries to the reach had low to moderate gradients (Goldstream, Downie, and Bigmouth creeks), and Bigmouth and Downie were exceptions to most streams in that they did not have barriers close to the Columbia confluences and therefore had potential to provide extensive spawning and rearing habitat for migratory fish (Martin 1976). Seymour Creek is also described as having extensive spawning gravel in the lower 800 m (Martin 1976). Productivity of streams would have been enhanced somewhat by the presence of carcasses from spawning kokanee in tributaries of this reach (Lindsay 1977; Arndt 2009). Migratory (fluvial or adfluvial) spawning runs were reported for Downie and Kirbyville Creeks (Martin 1976), and Lindsay (1977) reported the capture of a 45 cm mature rainbow trout in Park Creek in early June. It is likely that the species utilized all streams with any suitable habitat as long as temperature regimes were not too cold (i.e., those without strong glacial influence).

Pre-dam assessments were conducted during 1975 and 1976 using a variety of methods (Martin 1976, Lindsay 1977); however, assessment of rainbow trout use of the Columbia River and tributaries upstream of Revelstoke was difficult due to the size of the main river and the high discharge fluctuations in the tributaries. Weirs installed on suspected spawning streams in 1976 had to be abandoned due to unmanageable freshet conditions, leaving gill netting below Mica Dam (May, October) and angling in the Columbia River (April to October) as the primary means of fish collection (Lindsay 1977).

Lindsay (1977) reported a “first class fishery” for rainbow trout on the mainstem Columbia River between Mica and Revelstoke in 1976. Rainbows dominated the catch (594 of 606 fish). This might reflect the method used (fly fishing) to some extent, nonetheless, it is clear that rainbow trout were abundant enough to support a good fishery in the Columbia River at that time. Angler-caught rainbow trout ranged from 19 – 60 cm in length, with an average of about 35 cm (Lindsay 1977). Size and slow growth rates (based on scale ages) led Lindsay (1977) to conclude that most of these were fluvial Columbia River fish rather than adfluvial migrants from the ALR. He also noted the possibility of entrained fish from Kinbasket Reservoir. This sampling occurred shortly after the completion of Mica Dam in 1973, and the clearing effect of the upstream reservoir may have improved feeding and temperature conditions for rainbow trout in the river compared to historical conditions.[10] However, despite reports of good angling success, pre-dam productivity for rainbow trout was likely quite low in this section of the Columbia River. Prior to Mica Dam, temperatures exceeded 12^{o}C for only a short period in the summer (Hamblin and McAdam (2003), and bull trout rather than rainbow trout would be expected to dominate production (Mullner and Hubert 2005; see section 5.2). In other comparable, large glacial rivers in BC without flow regulation (e.g., north Thompson, upper Fraser), bull trout are dominant, and rainbow trout, though distributed throughout, are found in fairly low abundance, and generally at small body size. High angler catch rates are not unexpected for a sparse population of fish that is lightly exploited and concentrated at limited locations, and angling, particularly fly fishing, can be highly selective for rainbow trout relative to other species, as demonstrated by comparison with catches obtained with other gear types (E. Parkinson, pers. comm.; S. Decker, pers. comm.).

Standing stock losses of all salmonids utilizing the lotic habitat in this dam unit were estimated as 12,020 kg based on stream alkalinity and useable area estimates (Moody et al. 2007). Glacial tributaries in this reach and the mainstem river probably would be more highly utilized by bull trout and mountain whitefish than rainbow trout, but, as noted above, rainbow trout supported a high quality fishery (at low intensity) on the mainstem Columbia River in 1976.

6.4.2 Adfluvial Impacts

This dam unit was a migration corridor for adfluvial fish from Arrow Lakes spawning upstream (section 6.5), and tributaries with less glacial influence and more accessible length would have supported adfluvial spawning. Juvenile rearing would have occurred in these tributaries and the Columbia River. Adult adfluvial fish likely also utilized the Columbia and tributary mouths for feeding at certain times of the year.

Gill netting, conducted at the base of Mica Dam during low flow periods in October 1975 captured 115 rainbow trout from 15 – 65 cm in length (Martin 1976). About 10 % were over 50 cm. Scales showed a wide variation in growth rates implying more than one ecotype; fast growth and large size of some suggested the adfluvial piscivorous ecotype. Smaller fish may have been adfluvial insectivorous or fluvial. Further gill netting in 1976 captured 124 rainbow trout in May (77% of total fish catch) and 35 in October (28% of total). In the May sample, size range was 24 – 84 cm, with nearly a third of the fish being over 50 cm. Most of the captured fish were sexually mature, indicating a spawning migration (Lindsay 1977). About 20 % of the gill net catches in both years had yellow paired fins and operculum indicative of the “yellowfin” rainbow trout found in the Arrow Lakes (Lindsay 1977).

6.4.3 Post-dam Habitat and Populations

Mean depth of Revelstoke Reservoir is about 15 m, but the maximum reaches 125 m in the forebay; average water retention time is 27 days (Hirst 1991). A thermocline develops in the reservoir by June, with lower layers affected by cold inflows from Kinbasket Reservoir (Hirst

[10] One Revelstoke angler reported that rainbow trout fishing between Mica and Revelstoke improved after Mica Dam because river turbidity was much reduced (K. Bray, BC Hydro, Revelstoke, pers. comm.).

1991). Water level fluctuations are relatively minor since it is operated as run-of-the river using storage in Kinbasket Reservoir[11] (Bray 2001).

The reservoir currently supports insectivorous adfluvial rainbow trout, as evidenced by size and diet studies (Bray 2002, Bray and Campbell 2001). Rainbow trout dominated angler catch and gill net surveys shortly after the formation of the reservoir, but their abundance has declined as the reservoir has aged (Hirst 1991, Bray and Campbell 2001). Average rainbow trout CPUE was 0.03 fish/hour in the early 1990s but only 0.007 fish/hr in 2000 (Bray and Campbell 2001). The reservoir continues to attract anglers from Revelstoke, the Okanagan, and Alberta. Kokanee are the main target species from May to August, although bull trout and rainbow trout are sought after in the early spring and fall (Bray and Campbell 2001). Average length of rainbow trout in recent creel surveys is 33 – 35 cm with a maximum of 46.5 cm in sampled fish (Bray 2002, Bray and Campbell 2001).

In summary, the available data show that significant numbers of adfluvial rainbow trout migrated through this reach, and fluvial (or possibly adfluvial migrant) rainbow trout comprised a significant component of the pre-Revelstoke Dam fish community. Revelstoke Dam eliminated all mainstem fluvial habitat and blocked access for adfluvial rainbow trout. The fluvial ecotype has been extirpated from this reach or assimilated into adfluvial populations. This reach and upstream tributaries in C3 also provided spawning and juvenile rearing habitat for adfluvial insectivorous and piscivorous trout from the Arrow Lakes as evidenced by the presence of fish in spawning condition during spring netting; loss of these habitats would have reduced productivity of adfluvial rainbow trout in Arrow Reservoir if spawning habitat was limiting (see 5.0 Population Regulation). Blocked migration at Revelstoke and Kinbasket dams resulted in the loss of a native phenotype known as “yellowfins” (see C11). Habitat for the stream resident ecotype was also reduced through flooding of the lower reaches of tributaries, but probably to a lesser extent, since lower reaches tend to be dominated by migratory fish. Overall, rainbow trout life history and genetic diversity was reduced in this dam unit due to the loss of fluvial and adfluvial piscivores. Overall abundance of rainbow trout may also have declined based on the low CPUE in the reservoir compared to the river fishery reported by Lindsay (1977) after Mica Dam. This river fishery would have the potential of attracting very high angling interest at the present time and represents a significant lost opportunity for fisheries management and tourism in the region.

6.5 Arrow Lakes (C11)

The original Arrow Lakes were two separate water bodies, divided by a narrows south of Nakusp, with a total area of 350.1 km^2. Natural lake levels fluctuated annually by up to 12 m (Maher 1961) although the average elevation of Lower Arrow Lake was 1.2 m less than Upper Arrow Lake. The lakes were impacted by three dams. Keenleyside Dam raised the maximum water level by 14 m to form Arrow Lakes Reservoir (ALR), flooding spawning habitat in the lower reaches of tributaries to Upper and Lower Arrow lakes, and increasing lentic area during the growing season to 476 km^2 (Moody et al. 2007). Natural alluvial fans, which can provide high quality spawning habitat, were lost. Revelstoke Dam blocked access to spawning habitat in Columbia River tributaries upstream of the reservoir, and both Mica and Revelstoke Dams caused long-term changes in light penetration and nutrients in the lentic habitat of Arrow Lakes Reservoir (Moody et al. 2007). Total stream habitat losses in C11 were estimated as 203 km (21

[11] Annual drawdown is about 1.5 m and daily fluctuation 0.15 m (Bray 2001).

km^2 by area); about 90% of this by area was low gradient (0-3%) reaches of the Columbia River upstream of, and between, the original two lakes. Ninety-three kilometres (220 ha) of smaller tributaries (orders 1-7) was flooded, almost all of which was <3% gradient (Thorley 2008).

6.5.1 Dam-related Habitat Impacts

Following initial impoundment, reservoirs typically go through a period of increased productivity called trophic upsurge, caused by the release of nutrients in flooded terrestrial habitats. This period of enhanced productivity can affect fish populations for 5 to 10 years after dam construction depending on the type of habitats flooded (Kimmel and Groeger 1986; Rosenberg et al. 1997). The ALR may have been affected by trophic upsurge from all three dams. Keenleyside Dam (1968) would have affected the reservoir first by raising the water level of the original lakes. Soon after, Mica Dam (1973) flooded a large additional area upstream containing many productive wetlands, and finally, Revelstoke Dam (1984) flooded a narrower valley with less productive terrestrial habitats. The second two reservoirs could indirectly influence primary production in the ALR if either released nutrients (Cole 1979) or subsequent biological production were transported downstream (see Matzinger et al. 2007 for an estimate of ALR nutrient export from sub-surface water withdrawals).[12] Considering all three dams together, it seems possible that there could be some increase in productivity from 1969 up to the late 1980’s or early 1990’s. Petersen and Withler (1965) anticipated a period of increased primary production after the building of Keenleyside dam.

After the trophic upsurge phase, primary productivity often decreases and stabilizes at a lower level than the pre-dam period. The Arrow Lakes, however, were unusual in that their pre-dam productivity may have been limited by light penetration rather than nutrients due to glacial turbidity that peaked in June and extended into early August (Moody et al. 2007); upstream reservoirs typically remove a portion of nutrients and decrease turbidity due to settling of sediments. Moody et al. (2007) judged that primary productivity in the new reservoir shifted from light limitation to nutrient limitation after the dams, with the post-dam rate estimated to be slightly higher (92 $mgC/m^2/day$) than the pre-dam (75 mgC/m^2). When combined with the larger lentic area, total annual C production was estimated to be 1.6 times higher after dams than before (Moody et al. 2007). This agrees with the early speculation of Maher (1961), who noted that Kinbasket Reservoir might have a clearing effect on the Arrow Lakes that could contribute to increased productivity in Arrow (but see also section 7.4 Nutrient Effects and Turbidity Changes). Another potentially significant impact on the lakes’ production was the introduction of *Mysis relicta* (1967-1974), which became an important competitor with kokanee for zooplankton. It should be noted that mysids were introduced in an attempt to compensate for expected decreases in littoral productivity after Keenleyside Dam (Anon. undated; Anon. 1969).

[12] The distance from the reservoir surface to the upper intake at Mica Dam ranges from about 12-65 m during the growing season depending on reservoir level; kokanee entrainment is believed to be fairly high in some years, and therefore it seems possible that some plankton entrainment could occur (K. Bray, BC Hydro, Revelstoke, pers. comm.). From 1973 to 1977, when Kinbasket Reservoir was still filling, the intakes would have been closer to, or at, the reservoir surface. At Revelstoke Dam, the intake is typically 46–48 m from the surface at current operating levels (K. Bray, BC Hydro, Revelstoke, pers. comm.).

6.5.2 Fluvial and Stream-resident Impacts

Fluvial rainbow trout probably utilized the Columbia River between Revelstoke and the original Upper Arrow Lake at Arrowhead (Sebastian et al. 2000) although the suitability of this habitat is uncertain during spring flooding (Moody et al. 2007). Upstream of Revelstoke, there was a good late summer fishery in the 1970s (see section 6.4). This ecotype has probably been largely assimilated into adfluvial stocks because most of the large river habitat has been inundated. Stream-resident populations in C11 were probably not affected to a significant degree, since the lower stream reaches that were flooded are dominated by adfluvial juveniles (see below). Standing stock losses of all salmonid species (fluvial and adfluvial) utilizing the lotic habitat in this dam unit were estimated as 2,870 kg based on stream alkalinity and useable area estimates (Moody et al. 2007).

6.5.3 Adfluvial impacts

Adfluvial rainbow trout existed in Arrow Lake as at least two life history types and two phenotypes. A smaller insectivorous ecotype of 1-3 pounds (0.5 - 1.4 kg) was common, and a larger piscivorous ecotype was present. The majority of Arrow fish had typical rainbow trout colouration, but a local indigenous strain known as “yellowfins” occurred in both the large and smaller adfluvial ecotypes (Spence et al. 2005). These fish were characterized by distinctive yellow colouration on the ventral part of the body and paired fins that was particularly visible during the spawning season.[13]

The lower reaches of non-glacial tributaries that were inundated by Keenleyside Dam are typically dominated by adfluvial rainbow trout juveniles, often at high densities, whereas the cooler upper reaches above major obstructions are dominated by bull trout, and sometimes stream-resident rainbow trout (Decker et al. 2006; Decker and Hagen 2007). Therefore stream losses in this dam unit would have reduced adfluvial juvenile production for the Arrow Lakes. Most of these juveniles were likely the insectivorous ecotype because the spawning distribution of piscivores appears to be much more restricted (see below).

An approximation of total juvenile rearing losses between Revelstoke and Keenleyside dams can be made using recent parr density estimates in remaining tributaries. Snorkel-based estimates of rainbow trout densities (age-1+ and older) in the lower reaches near the reservoir of six non-glacial tributaries (Burton, Caribou, Halfway, Kuskanax, MacDonald, Taite) ranged from 86-403 parr/100 m linear and 6.6-21 parr/100 m^2 area over 2004 and 2005 (Decker and Hagen 2007). Mean (95% confidence limits) linear density in 2004 was 184.6 (62.9 – 306.2) fish/100 m (derived from Table 6 in Hagen and Decker 2007). Excluding age 0+ fish (which were not estimated), 86% - 100% of the rainbow trout in these lower reaches were age 1+ or 2+ (Decker and Hagen 2007) indicating most adfluvial fish emigrate to the reservoir before their fourth summer.

Total habitat losses for stream orders 3-7 in C11 (comparable to streams sampled in the Decker and Hagen study) were estimated as 63 km (linear) and 212 ha (area) respectively (Thorley 2008), of which about 8.5 km or 50 ha were comprised of glacial streams

[13] The extent to which the colouration showed may have varied. Photographs of angled fish showing the yellowfin colouration are available, but some individuals were observed to lose the yellow colour after capture in 1994 and 1996 spawner collections (Toth and Tsumura 1996).

(Illecillewaet, Incomappleux, FWCP file data[14]) that supported very low rainbow trout densities (Decker and Hagen 2007). Subtracting the length and area of the glacial streams leaves 54.5 km and 162 ha as estimates of non-glacial stream losses. Combining habitat loss estimates with linear densities above gives an estimated juvenile rearing loss of 100,600 (34,280 - 166,880).[15] This loss estimate is based on 2004 densities which were higher than 2005 in three streams measured both years. Since the upstream limit of adfluvial rainbow trout distribution is unknown for most tributaries, the proportion of juvenile abundance lost from C11 tributaries cannot be estimated for all streams, but for the six streams with adfluvial juvenile estimates, the range of loss is from 17 to 54% (Table 3) with a total of 25%. The proportion of spawning and rearing losses to Arrow including units C3 and C4 upstream of Revelstoke Dam (sections 6.3 and 6.4) is unknown. Also note that the loss estimate does not include age-0 trout, which made up a large proportion of emigrants in some early studies (Sebastian et al. 2000).

Table 3. Standing stock estimates of adfluvial rainbow trout parr (age 1+ to 4+) lost due to Keenleyside Dam inundation in six Arrow Lakes Reservoir tributaries based on 2004 - 2005 densities and linear distance of habitat in streams of orders 3-7.

Tributary	Fish/100 m[a]		Standing stock (2 year average)[a]	Inundated Habitat (m)[b]	Standing Stock Loss[c]	Percent Loss
	2004	2005				
Burton	109.0	-	**3,574**	1165	**1,269**	26.2
Caribou	212.0	103.3	**3,433**	2551	**4,021**	53.9
Halfway	403.1	272.8	**17,620**	1052	**3,555**	16.8
Kuskanax	170.0	-	**7,574**	1268	**2,156**	22.2
MacDonald	88.8	85.5	**2,800**	771	**672**	19.4
Taite	124.4	-	**1,583**	535	**666**	29.6

[a] data from Decker and Hagen (2007, Table 6) using lower reaches dominated by adfluvial juveniles
[b] FWCP data
[c] assumes fish densities in inundated reaches were same as surveyed lower reaches

Insectivorous ecotype

The Arrow Lakes provided good rainbow trout fishing for this ecotype prior to dams (Petersen and Withler 1965c, Maher 1961). Significant reductions in juvenile production might be mitigated by higher survival in the reservoir; however no data are available to determine whether this is the case.

Piscivorous ecotype

The exact origin of piscivorous fish in the Arrow Lakes is uncertain. Introductions of piscivorous rainbow trout eyed-eggs or fry collected from the Gerrard (Kootenay Lake) stock occurred from 1915 through to the 1950s (Sebastian et al. 2000, Appendix 3a), allowing the possibility of introgression with indigenous rainbow trout. The yellowfin colouration, however, is not reported in Kootenay Lake, and it is probable that an indigenous piscivorous

[14] Akolkolex River has glacial influence but was assumed to be suitable rainbow trout habitat as it supports a good cutthroat population above a falls.
[15] Linear-based estimates are more appropriate to use for extrapolation because field densities in Decker and Hagen (2007) were measured during the low water period in late summer, whereas area estimates in Thorley (2008) are based on wetted width at higher flows.

ecotype would be present in a large lake supporting adequate kokanee populations (Keeley et al. 2005).

Size of pre-dam piscivores is not available from fisheries assessments, but newspaper stories record exceptional rainbow trout of 6 to 10 pounds (4.5 kg) caught in the lower Arrow in 1954, and a record catch of 13 pounds (6 kg) captured in 1935 at St. Leon (recorded at the Nakusp Historical Society and Archives; Prince 2001). Petersen and Withler (1965c) note angler reports of fish up to 20 pounds (9 kg) prior to the dams, and fish to 9.7 kg were captured below Revelstoke Dam in 1992 (Sebastian et al. 2000). Abundance and size of piscivores in the pre-dam lakes was likely linked to kokanee abundance and size, and possibly feeding conditions in the lake (e.g., level of turbidity and temperature stratification). Anecdotal information suggests that piscivorous fish in the pre-dam Arrow lakes were not as abundant or large as those in Kootenay Lake, but to some extent this may reflect the more limited access to the Arrow lakes at that time. Kokanee spawner returns in Arrow Lakes Reservoir initially increased following construction of the upstream and downstream dams, peaking in the late 1980s at about 700,000, and then decreased to about 100,000 by 1997 (Arndt 2009). Average size of kokanee spawners prior to the dams was ~22 cm, peaked in the mid-1980s at 25 – 28 cm, and was about 21 cm in 1996-1997 (Arndt 2009). If the kokanee spawner returns are indicative of feeding conditions, carrying capacity may have decreased in the 1990s for adfluvial piscivores.

The yellowfin phenotype became progressively less common following construction of the upstream dams and appears to be extirpated. The presence of these fish at the base of Mica and Revelstoke dams during construction suggests that some or all of these fish spawned in the upper Columbia drainage prior to fragmentation by the dams. It was reported, although not confirmed, that Camp Creek (upstream of Mica Dam) was a spawning location for piscivorous fish; other possible spawning locations are the narrows between the two original lakes (Spence et al. 2005) and the outlet river (see section 6.8). The loss of access to these habitats is thought to be the main reason for the loss of these fish.

Attempts were made to capture and artificially culture piscivorous fish of the yellowfin phenotype in the 1980s and early 1990s, but these attempts were largely unsuccessful due to problems with maintaining weirs in streams during the spawning run, difficulty in capturing adequate numbers of piscivorous adults showing the phenotype, and apparent hybridization of non-yellowfin and non-yellowfin morphs (Toth and Tsumura 1996; Andrusak 2004 and references therein). Progeny from fish captured in the Columbia River were initially stocked into Tonkawatla Creek (Spence et al. 2005). In 1996, a last trapnetting and angling program was conducted at the mouths of several tributaries of the Arrow Lakes and in the Columbia River downstream of Revelstoke in a further attempt to locate indigenous spawning populations of yellowfin piscivores and obtain gametes for artificial propagation (Toth and Tsumura 1996). Tonkawatla Creek was the only stream from which yellowfin piscivores were captured (only two fish), although several smaller fish (< 54 cm) showing some yellowfin colour were captured in Halfway River. Other piscivorous spawners of a more typical phenotype were also captured in Tonkawatla and Eagle creeks in that effort. When it appeared impossible to maintain the yellowfin phenotype, a decision was made to switch to stocking Gerrard piscivores from Kootenay Lake. Between 1978 and 1988, about 84,000 Gerrards (mostly fry) were released, increasing to 600,000 yearlings during 1984-1997 (Andrusak and Slaney 2004; MOE Fisheries Inventory Data).

6.5.4 Post-dam habitat and populations

Post-dam populations of rainbow trout in ALR have substantially less spawning and rearing habitat available than pre-dam populations since they are isolated from the Columbia River upstream and downstream of the reservoir and the narrows between the two original lakes, plus the lower reaches of direct tributaries are inundated. It is not certain to what extent spawning or rearing habitat was limiting to the adfluvial populations. For the yellowfin phenotypes, it appears to have been critical, as they have not persisted in the reservoir. Other piscivorous and insectivorous populations still reproduce naturally in remaining habitat. Andrusak and Slaney (2004) provide a list of streams likely to support spawning rainbow trout.

Reduced turbidity in Arrow Lakes Reservoir, after Kinbasket and Revelstoke dams, is an aspect of changed habitat that may have increased lentic habitat capacity for kokanee initially (Arndt 2009). This might be expected to benefit remaining piscivores until the later decline. The long term effect of turbidity changes on kokanee (or juvenile trout) vulnerability to predation is unknown. Introduction of mysids may have inadvertently contributed to reduced kokanee production in the reservoir (Arndt 2009) which in turn would be expected to reduce carrying capacity for the piscivorous ecotype unless increased water clarity results in more successful foraging at a given kokanee abundance.

There are no estimates of current rainbow trout abundance in the reservoir, but a creel survey provides catch trends from 1976 to the present (Sebastian et al. 2000, Arndt 2004b). The insectivorous ecotype is targeted more in the summer and larger fish in cooler months. Fish of the insectivorous ecotype (<50 cm) make up >90% of the harvest in most years (FWCP file data). Average annual catch and success rates were fairly consistent from the 1970s except for a slight decrease in 1996 and 1997 in the upper basin (Sebastian et al. 2000), giving no indication of a decline in the years immediately after the dams. In the first two years after the beginning of the nutrient addition program in 1999, catch and harvest approximately doubled (Arndt 2004b). Harvest numbers have declined since then, although they were still above the 1998 level up to 2008 (FWCP file data). Angler effort is relatively low in the reservoir and catch may not reliably reflect population trends.

Available data for piscivorous harvest is extremely variable. Weigh-in records for Olson's Marina in Nakusp provide an indication of post-dam, pre-nutrient addition trends that suggest a decrease in the early 1980s, and an increase starting in the late 1980s and peaking in the mid-1990s (Figure 3).[16] Number of piscivores (defined as >50 cm fork length) recorded at creel survey stations after 1998 shows a substantial increase shortly after the beginning of nutrient additions, followed by a decline to a level similar to that prior to nutrient additions by 2007 and an increase again in 2008 (Figure 4). Although the reservoir has been stocked with Gerrard piscivores, nearly all of the harvest since 1998 has been natural recruits, indicating that some viable spawning and rearing habitat still remains for this ecotype (Arndt 2004b).

Hill Creek Spawning Channel has recently supported a run of up to 300 adfluvial rainbow trout spawners of which about half appear to be the piscivorous ecotype (McCubbing and Andrusak 2007). Redd counts totalled 236 in 2008, and fish up to 70 cm in length have been

[16] Prior to 1998, size data were not recorded in the creel survey.

observed recently in the channel (B. Barney, HCSC operator, pers. comm.). Rainbow trout fry densities in the spawning channel are very high in summer, although most yearling fish move out of the channel some time before the second summer (Porto and Arndt 2006). These fish are likely derived from previous stockings as Hill Creek Hatchery was located at the channel and stocked rainbows until 1999. Piscivorous rainbows were not sampled in Hill Creek prior to dams (Lindsay 1979). Genetic studies for Arrow Lakes rainbow trout are summarized in section 4.1.

Sebastian et al. (2000) suggest that a residual population of fluvial fish probably exists downstream of Revelstoke Dam. However, very few rainbow trout presently utilize the short section of the river between Revelstoke Dam and Big Eddy; a good fishery exists for rainbow trout in Revelstoke Reach of the reservoir, which could perhaps be defined as fluvial when reservoir elevations are lower and discharge is high (Spence et al. 2005).

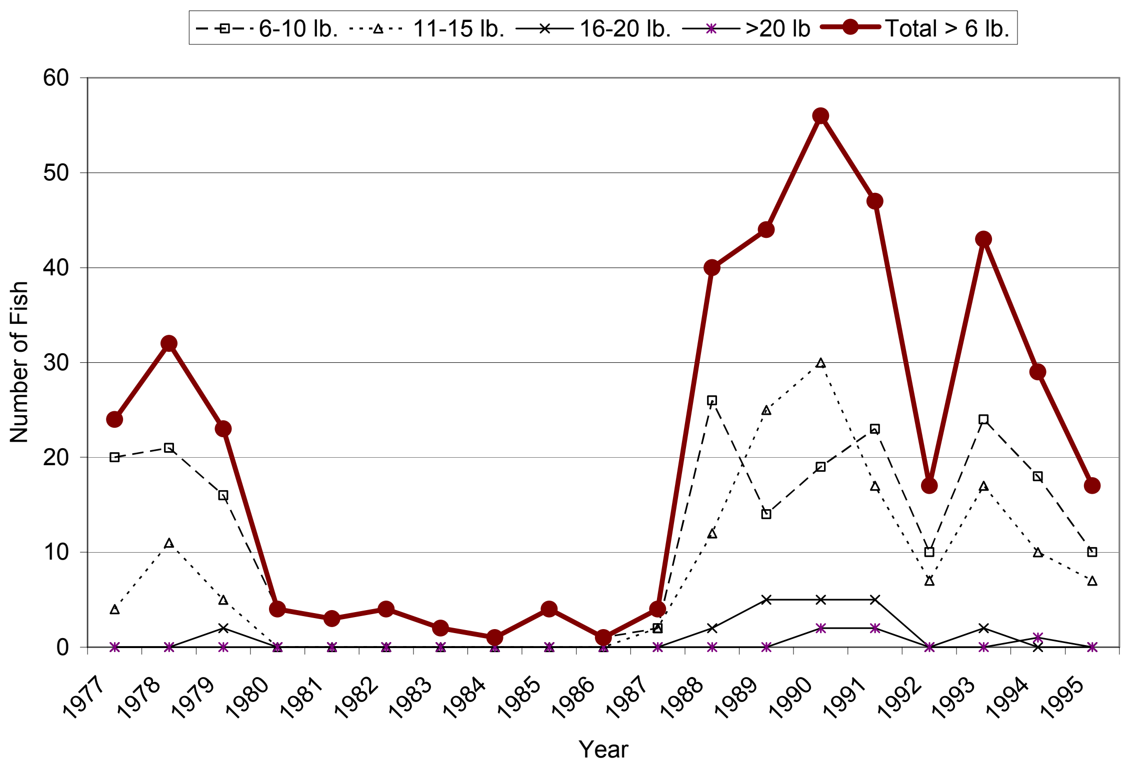

Figure 3. Weigh-in records by size class for rainbow trout at Olson's Marina in Nakusp from 1977 to 1995 (from Sebastian et al. 2000).

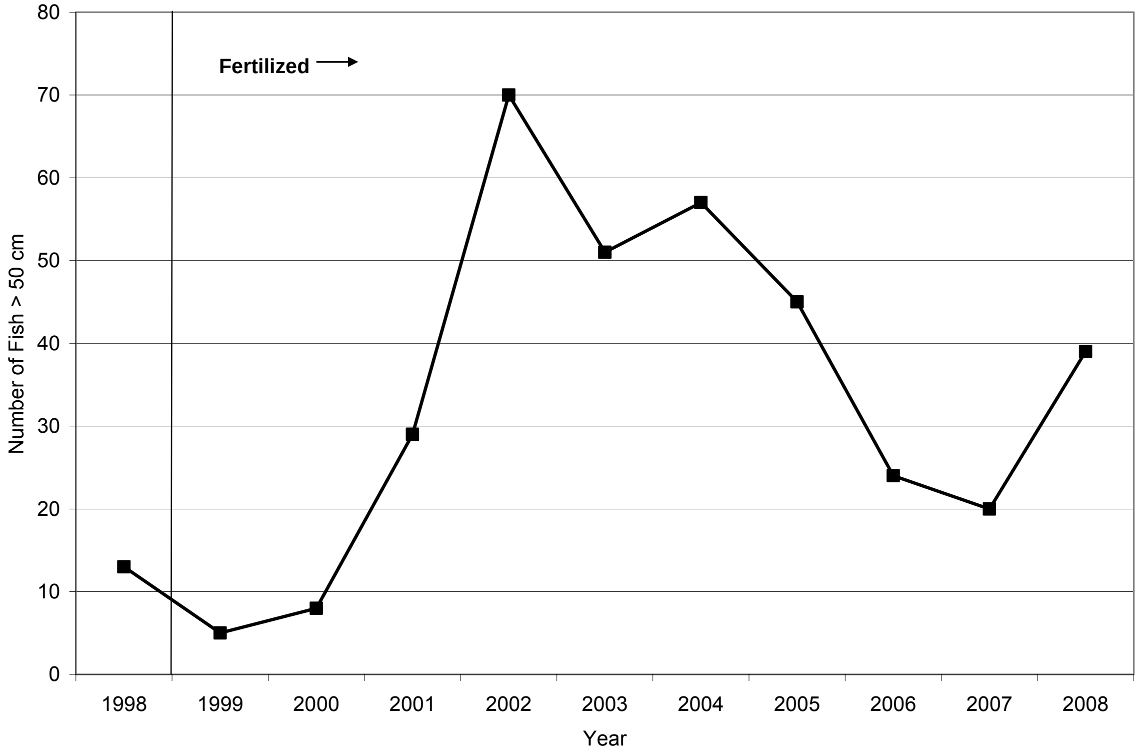

Figure 4. Number of harvested rainbow trout >50 cm brought to three access points during five sampled days per months (January to December) on Arrow Lakes Reservoir (FWCP file data).

In summary, the reservoir continues to provide a reasonably good rainbow trout fishery supported by natural reproduction in the remaining tributaries, but it is uncertain whether the overall abundance of rainbow trout in this dam unit has changed since the upstream and downstream dams were constructed. There has been a loss of life history and phenotypic diversity, and a substantial loss of spawning and rearing habitat that could limit recruitment. Fluvial populations in the Revelstoke reach are extirpated or substantially reduced, and the yellowfin phenotype, previously present in insectivorous and piscivorous adfluvials, appears to be extirpated.

6.6 Cranberry Creek – Walter Hardman (C6)

The Walter Hardman generating facility, including Coursier Reservoir (1.5 km^2) and a diversion tunnel, were built near the headwaters of Cranberry Creek in 1959 for the City of Revelstoke, and later transferred to BC Hydro. The 19 m dam at Coursier Lake was decommissioned and removed in 2003; leaving a smaller natural lake in place of the reservoir with no water storage capacity. However, most or all of the creek discharge at the diversion (up to 3.9 m^2/s) is still routed to the power plant, substantially reducing flows to the stream below. This effect is most pronounced immediately below the diversion where up to 13 km were de-watered from mid-summer through winter (Andrusak and Slaney 2004). Although the reduction in stream discharge carries through to the creek mouth, downstream drainage contributes to more discharge in the lower reaches. During the summer of 2008, a device was installed in the diversion channel to provide a minimum flow of 0.1 m^2/s to the stream directly below the diversion; water in excess of plant capacity is also be spilled into the stream channel below the diversion. (K. Bray, BC

Hydro, Revelstoke, pers. comm.) Mean annual discharge at the mouth was estimated at 6.4 m^3/s using limited data (Water Hardman Water Use Plan Consultative Committee Report 2004).

A good description of Cranberry Creek habitat is provided by Northern Natural Resources (1976). Resident rainbow trout are found through most of the drainage including Coursier Lake with a maximum length about 25 cm (Ramsay 2005, BC Hydro Coursier Lake Environmental Assessment CB05-17648). The lower reach of the creek close to Arrow Lakes Reservoir continues to provide spawning habitat for variable numbers of kokanee (Arndt 2009). This reach also supports spawning and rearing of adfluvial rainbow trout from the ALR (Hirst 1991). A barrier 1.2 km from the creek mouth probably prevents further upstream movement by adfluvial spawners (Northern Natural Resources 1976). An estimated 10 km were inundated when Keenleyside Dam raised the level of the Arrow Lakes by 14 m (Maher 1961).

Decommissioning of the dam in 2003 has allowed Coursier Lake to return to its natural level, negating the effects of the reservoir on stream and lake habitat in the upper reaches. The diversion of stream discharge below the Walter Hardman tunnel would have eliminated resident trout in a portion of the stream and substantially reduced carrying capacity in other reaches during the time of operation without a minimum flow. In future years, the minimum flow should allow year-round residency of trout in the stream channel below the diversion, although it is expected that stream carrying capacity for resident fish will still be substantially reduced by diversion of more than 90% of the flow from upper reaches. For some reaches, it is possible that the combination of a minimum flow and reduced severity of the spring freshet (due to the diversion) might create favourable conditions for residents. Inundation of the lower reaches of the creek by Keenleyside Dam has reduced spawning and rearing capacity for resident and adfluvial rainbow trout from the ALR. Some loss of genetic diversity is possible both for resident fish in the upper reaches of the creek where the diversion caused de-watering, and for adfluvial fish in the lower inundated reach, although these effects are likely relatively minor. Andrusak and Slaney (2004) describe habitat conditions in the lower reaches of the creek and provide recommendations for large woody debris structures that would add adult holding or spawning habitat and juvenile rearing for resident rainbow trout and reservoir migrants (conditional on release of flows into stream during late summer and winter).

6.7 Whatshan (C8)

Lentic habitat losses in this unit include two small and one medium-sized lake totalling 15 km^2; these lakes were inundated by a 6 m high dam to create Whatshan Reservoir with an area of 17.6 km^2 (Hirst 1991, Thorley 2008). The pre-dam lakes were oligotrophic with clear water and several shoals (Moody et al. 2007). Rainbow trout were present in the three natural lakes before the dam (Hirst 1991), and they likely provided good quality rainbow trout habitat because of their water clarity, suitable temperature regimes, and good shoal production. Inundated lotic habitat totalled 4 km (or 15 ha in area) of the Whatshan River (Thorley 2008). Another kilometre of the river is de-watered between the dam and Barnes Creek, as all water from the drainage upstream of Whatshan Dam is diverted to the power plant except for a small amount of dam leakage (K. Bray, BC Hydro, Revelstoke, pers. comm.). This diversion of water to the power plant also reduces discharge in the remaining river below Barnes Creek (~5 km) by approximately half (based on area of the drainage basins). No minimum flow is supplied to the river below the diversion, but habitat enhancement structures below Barnes Creek have been proposed as an alternative (Naito and Bates 2008). Prior to dam construction there was a natural barrier at the lake outlet that apparently prevented upstream movement from the river into the lake, and also a falls 50 m from the river mouth that blocked upstream movement from ALR adfluvial migrants (Hirst 1991).

6.7.1 Fluvial and Stream-Resident Impacts

Rainbow trout are found throughout the entire mainstem of the Whatshan River and are the most abundant species (Merriman 2000). Inundation and dewatering of about 9 km of the river reduced the amount of rearing and spawning habitat for resident trout in the drainage basin. Abundance of resident trout in the river downstream of Barnes Creek is also likely reduced by the diversion of about half of the discharge.

6.7.2 Post-dam Habitat and Populations

Whatshan Reservoir has a mean depth of approximately 50 m, thermally stratifies in the summer, and is drawn down over the winter (Hirst 1991). Although slightly larger in area, estimated gross primary production of the reservoir at 298 tC/year was judged to be decreased slightly from the pre-dam lakes (307 tC/year), because of reduced littoral and macrophyte production (Moody et al. 2007). Small lake adfluvial rainbow trout are present and spawn in tributaries of the reservoir (Hirst 1991).

The main impact of the reservoir and water diversion has been a reduction in stream habitat capacity for resident trout in the river. Adfluvial trout still exist in the reservoir, perhaps at slightly reduced abundance or reduced growth/size because of the loss of littoral production due to drawdown in the reservoir. Length of river available to adfluvial trout from ALR was reduced due to Keenleyside dam (see section 6.5).

6.8 Columbia River from Keenleyside Dam to U.S. border (C9)

This reach from Keenleyside Dam to the Canada-U.S. border is the last remaining un-impounded section of the Columbia River in the FWCP area still providing good habitat for fluvial rainbow trout. Combined with a short section of the lower Kootenay River between Brilliant Dam and the confluence with the Columbia, an estimated 68 km of large river habitat remains in this unit (Thorley 2008). No lotic habitat has been inundated, although upstream dams in the Columbia and Kootenay drainages have caused significant habitat changes (see section 6.8.3). A significant detrimental footprint impact to rainbow trout is fragmentation. Prior to dams this reach was contiguous with the lower Kootenay drainage as far as Bonnington Falls (including the Slocan River), the Arrow lakes and its tributaries, and the Pend d' Oreille drainage including the Salmo River. Rainbow trout presumably used these habitats for spawning and rearing, and migrated for feeding and seasonal habitat preferences among the drainages. Some gene flow would be expected to occur among populations in the different drainages.

In the pre-dam era, the Columbia River downstream of Arrow Lakes supported fluvial rainbow trout and may have provided seasonal feeding and spawning habitat for adfluvial fish from Arrow Lakes. There is a paucity of fisheries data prior to Keenleyside Dam as most investigations at that time focused on the lakes. The following observations were kindly provided by two long time residents of the area:

> The most obvious difference in habitat prior to the upstream dams was the more variable discharge regime, with very high spring and early summer levels. River gauge readings

were still rising in late June when school was finished and in some years a mill located near the current Castlegar sewage treatment lagoons was closed temporarily due to flooding. Turbidity was not particularly high even during the freshet as most turbid streams are well upstream of the Arrow Lakes outflow (allowing clearing); high turbidity never prevented angling. Kootenay River tended to be more turbid than the Columbia due to inputs from Slocan River, as still occurs in some recent years. There was good fly fishing and bait-fishing. Rainbow trout were the main target species with size of fish being comparable to the present (3/4 to 1 ½ pounds was typical with a few very large fish up to 20 pounds caught in the spring). Favourite fishing spots (in the Castlegar area) included the mouth of Pass (Norns) Creek, and several eddies and bays both upstream and downstream of the Kootenay River confluence. Angling effort was much less than it is now and all angling was done from the shore. It was known that there was a spawning run into Pass (Norns) Creek. (Fred Salekin, Robson, BC, pers. comm.)

Aquatic insect hatches prior to dams were heavy and more consistent than now. Fishing occurred from June through August after which there were less fish rising. There were more rainbow trout at the time and they looked different than now (pink stripe in the middle), average size was bigger, and they jumped more. High water levels in the Columbia River during fry emigration from tributaries allowed them to go into grassy areas where they may have had better survival. (Victor Conzon, Trail, BC, pers. comm.)

Creel surveys and fishery assessments done shortly after Keenleyside Dam in the 1970s and 1980s showed that rainbow trout were the second most abundant sportfish in the river (after mountain whitefish) based on electrofishing, and that rainbow trout attracted the greatest amount of angling effort (Andrusak and Withler 1970, Ash et al. 1982, Andrusak and Martin 1983).[17] Rainbow trout CPUE was relatively high (mean 0.20 fish/hr, monthly range 0.06 to 0.50) and the area was described as “an important river fishery for Region 4” (Andrusak and Martin 1983). Average size of harvested rainbow trout in the early 1980s was ~1 kg with fish up to 4 kg reported (Andrusak and Martin 1983). Scale interpretations indicated that most spawners were 3-5 years old, and that fish recruited to the fishery at age 2+ (Andrusak and Martin 1983). Spawning in the early 1980s was reported as being largely limited to tributaries (Hirst 1991).

6.8.1 Fluvial and Stream-resident Impacts

Fluvial rainbow trout in C9 have been isolated from three major drainages (Kootenay, Pend d’ Oreille, upper Columbia) by BC Hydro (Keenleyside, Seven Mile) and non-BC Hydro (Waneta, Brilliant) dams. Remaining accessible tributaries are limited to small streams emptying directly into the Columbia River downstream of Keenleyside Dam, and many of these have barriers near the confluence that prevent upstream migration by fluvial spawners (Arndt and Klassen 2004). This has altered life history and possibly genetic diversity.

The above dams and other upstream facilities (Arrow Lakes Generating Station, Mica, Revelstoke, Duncan, Libby, Kootenay Canal, and Corra Linn) also have contributed to significant changes in the Columbia River habitat that may have expanded the niche for fluvial rainbow trout (see Section 6.8.3).[18] Another 24 km of river habitat remains downstream of the Canada-U.S. border before it reaches Lake Roosevelt Reservoir created

[17] The impetus for these surveys was an additional dam being considered for construction at Murphy Creek, downstream of Keenleyside Dam.
[18] This is not the case for some other species such as sturgeon (Porto 2008) or bull trout (Hagen 2008).

by Grand Coulee Dam. Populations and habitat of the stream resident ecotype (primarily present upstream of barriers) in this unit have not been affected by BC Hydro dams.

6.8.2 Adfluvial Impacts

There is anecdotal evidence, based on the large size of some spawners (F. Salekin, pers. comm.)[19], that some adfluvial fish from the Arrow Lakes may have spawned downstream of the current location of Keenleyside Dam. Outlet spawning occurs for some other adfluvial populations (Northcote 1969), and if such was the case in this reach, Keenleyside Dam would have reduced spawning and rearing habitat for ALR fish.

6.8.3 Post-dam Habitat and Populations

Changes to the timing and magnitude of discharge, turbidity, temperature regime, and possibly food availability have occurred in C9 since dams were constructed in the upper Kootenay and Columbia drainages (Table 4). Water quality and productivity of this reach is affected by Keenleyside Dam, export from Arrow Lakes Reservoir, Kootenay Lake and River conditions, Brilliant Dam, and effluent discharged from the Celgar pulp mill, Castlegar, and Nelson. More constant flow typically reduces the diversity of the aquatic insect community below a dam, but some taxa flourish (Clarke et al. 2008). The river below Keenleyside Dam is very productive with dense hatches of caddisflies and other insects. Food supply is augmented by entrainment of lentic zooplankton from Arrow Lakes Reservoir (including mysids) that continues through the winter (Andrusak and Martin 1983). Rainbow trout growth is rapid; ageing of fish from this reach has been difficult or impossible due to the lack of annuli on some scales (Golder Associates 2007) suggesting that growth can occur for most or all of the year. Temperature in the reach is suitable for good rainbow trout growth (10-20 ^{o}C) from May through October, and usually stays above 3 ^{o}C even during the coldest months (http://waterquality.ec.gc.ca/ WaterQualityWeb/). The largest known rainbow caught from this reach to date was 94 cm (10.4 kg) landed in February 2004.[20] Fish of 0.5 to 1.0 kg are common in angler catches, and spawning aggregations often include fish up to 3 kg. Golder Associates (2007) provides an excellent description of life history and abundance of rainbow trout in this reach for recent years. (See section 4.1 for genetic description).

Prior to 1992, spring operations at Keenleyside Dam typically included a decline in flows from March to May and an increase in June and July. The decline in early spring is opposite to a natural hydrograph, and resulted in de-watering of trout redds in some locations (Hagen and Baxter 2008). Implementation of a modified discharge regime by BC Hydro in 1992 has significantly reduced redd de-watering and may have improved fry carrying capacity (Hagen and Baxter 2008). Maximum likelihood estimates of the number of mainstem spawners increased from less than 1,000 in 1999 to 9,572 (90% confidence limits 7,373-12,281) in 2008 (Hagen and Baxter 2008). The three most important river spawning areas are the gravel fan at the mouth of Norns Creek, a series of gravel bars near Genelle, and the lower Kootenay River below Brilliant Dam. These three areas accounted for 62% of the peak (mainstem river) redd count in 2008. Spawning in the river locations can start as early as February and peaks in April, with fry emergence from mid-May to late June. Reductions in

[19] A location where two large fish were caught was near cribbing that was built alongside Tincup Rapids to help pass stream boats. There may have been gravel depositions associated with the cribbing.
[20] Scale interpretation indicated an age of 8+ or 9+ when caught with a rapid growth increase at age 5+ probably indicating piscivory and possible Arrow Lakes Reservoir origin (Burrows 2004).

maximum discharge may have allowed greater accumulation of spawning gravels at depths usable by spawners in some sections of the river (Petts 1979, cited by Clarke et al. 2008), particularly below the confluences with smaller tributaries (e.g. Norns fan and Genelle). Higher winter flows below dams can also provide more bank cover for juvenile trout, which may improve survival (Mitro and Zale 2002, Mitro et al. 2003); however, data are lacking to test this in C9.

Very substantial spawning runs of rainbow trout also occur in remaining accessible tributaries of this reach including Norns (Pass), Blueberry, China, Champion, Murphy, and Beaver creeks. Artificial obstructions on Blueberry Creek have recently been mitigated to a large degree by the FWCP and several partners including the BC Ministry of Transportation and Highways, allowing spawning fish to access 26 km of the stream above Highway 22 (Arndt and Klassen 2004)[21]. This creek now has the longest accessible length for fluvial spawners of any tributary between the dam and the border; a crude estimate of spawner numbers, based on expanded counts of fish passing through a culvert, exceeded 2,000 fish in 2003. Norns Creek was surveyed by snorkelling from a barrier falls to the Columbia confluence (2.5 km) on April 29, 2008 with a total of 440 redds and 548 spawners recorded; this redd count was ~20 % of the total peak redd count in mainstem river areas indicating the high importance of this stream also (Hagen and Baxter 2008). Area-under-the-curve estimates of spawners in a side channel of Murphy Creek have been as high as 400 (FWCP unpublished data). Upstream spawning migrations in the tributaries typically start near the beginning of May and continue to the second or third week of June, coinciding with the period of peak discharge and water temperature ≥ 6 ^{o}C (Arndt and Klassen 2004). Emergence and downstream fry migrations occur from late June to early August. The majority of fry in smaller tributaries emigrate to the Columbia River during their first summer, but some juveniles rear in the creeks for more than one year (Arndt 2000). Fry and juvenile production from the creeks is high (Arndt 2000, FWCP file data).[22]

[21] The Highway 22 culvert still causes a velocity obstruction during part of the migration period.
[22] Trap-based estimates of fry moving into the Columbia River from Blueberry, China and Murphy Creeks were 21,000, 82,000 and 89,000 respectively in the summer of 2000 (FWCP file data).

Table 4. Habitat changes in the Columbia River downstream of Keenleyside Dam (C9) as a result of footprint and operational impacts of BC Hydro and other dams, and potential impacts on rainbow trout niche.

Habitat Aspect	**Change**	**Potential Impact on Rainbow Trout**
Discharge (annual profile)	Reduced maximum discharge during spring freshet and higher minimum monthly flows (Hirst 1991); increased flow stability and reduced discharge during period following fry emergence	Positive? – reduced peak may allow more spawning gravel to remain in Columbia River and alluvial fans of smaller creeks; spring and early summer stability may benefit fry survival (Hagen and Baxter 2008); higher flow in late summer and winter may increase lentic zooplankton export and assist in moderating winter temperature. Negative? – reduced water level during fry emergence may reduce shallow water cover
Discharge (daily and weekly)	Increased variability at some times due to operational impacts (power production)*	Negative – decreases can result in egg stranding and cause juvenile stranding if rapid (Hagen and Baxter 2008). Short-term fluctuation probably reduces benthic production.
Access to habitat in other drainages	Dams isolate lower Columbia from spawning, rearing, and feeding areas in the upper Columbia, Kootenay, and Pend d' Oreille drainages.	Negative – reduced options for spawning and rearing; possible reduced natural recruitment; main impact reduced life history diversity and possible reduction in genetic diversity.
Temperature	About 2 ^{o}C warmer from June to August and slightly warmer in winter (January – February) due to inflow and outflow operational effects, subsurface withdrawal at the dam, and changed depth of outflow sill. Maximum summer temperature changed from 15 to 17 ^{o}C, and minimum winter from ~1 to 3 ^{o}C. Lower Kootenay slightly warmer all year. (Hamblin and McAdam 2003)	Positive and Negative– temperature warms to the ideal for rainbow trout growth (13 – 16 ^{o}C) earlier in spring but marginally exceeds optimal for about 2 weeks in mid-summer; overall excellent regime for growth potential, and early mainstem spawning especially in the lower Kootenay below Brilliant. (If long term climate change further increases temperatures, they may exceed growth optima for a longer period.) Higher temperatures could be detrimental if available food was not sufficient to meet increased metabolic demand.
Water clarity	Possibly increased in spring and early summer due to greater settling of suspended sediments in upstream reservoirs	Positive – better clarity generally expands niche width for rainbow trout as a sight-feeding species (Behnke 1992).
Food supply	Mysids introduced to Arrow Lakes Reservoir and Kootenay Lake are exported via surface (night) and subsurface withdrawals; nutrient addition programs may increase biological production and dam operations may increase lentic export into river. Greater stability of discharge may increase benthic production in the river below the zone of daily fluctuation.	Positive – increased export of mysids and other biological production or nutrients probably enhances growth.
Gas supersaturation	Keenleyside Dam causes gas supersaturation below the dam. Operation of Arrow Lakes Generating Station may reduce levels.	Negative – detrimental effect on fish physiology that may restrict utilization of shallower habitat. Population level effect unknown.

* greatest short-term effects are likely from the closer power plants such as Brilliant and Arrow Lakes Generating Station (owned by Columbia Power Corporation) and Kootenay Canal (BC Hydro).

In summary, a lack of comparable pre-dam data prevents a determination of whether the current abundance of rainbow trout in C9 has changed compared to the pre-impact period. The reach supported a high quality fluvial rainbow trout fishery prior to dams, and was ecologically and genetically diverse with connections to other large drainages. Currently this reach supports a very robust population of fluvial fish that is isolated from other major drainages with reduced life history and probably genetic diversity. Nonetheless, it still includes numerous sub-populations, significant life history diversity (e.g., mainstem and tributary spawners), and a genetic makeup distinct from other parts of the province and hatchery fish. This naturally-sustained, ecologically-diverse population is probably the most robust fluvial population remaining in the FWCP area, and supports one of few quality river fishing opportunities remaining in the West Kootenay (ARA Consulting Group 1992). The recreational fishery has been featured in angling magazines in Canada and the U.S.

Regulated streams with stabilized flows can have very high abundance and biomass of rainbow trout (McKinney et al. 2001). Maintaining or improving access to remaining tributaries, and ensuring adequate flows in them, should be a high priority to conserve existing biodiversity in this dam unit. This will also ensure that the fluvial population does not become dependent on mainstem spawning, which is more vulnerable to dam operations.

6.9 Pend d’ Oreille River (C10)

The Pend d’ Oreille River in Canada is impounded by Seven Mile (BC Hydro 1979) and Waneta (Teck-Cominco, 1954) dams. A 16 km length (179 ha area) of large river habitat was flooded, creating 4 km^2 of reservoir lentic habitat (Thorley 2008). The Salmo River is a significant tributary in the reach, and 1 km of the lower river is backwatered when the reservoir is full. Losses of smaller tributaries in this unit are <1 km due to the steep sides of the valley. The Canadian dams isolate this reach from 68 km of large river habitat in Canada below Waneta Dam (C9), and Boundary Dam at the Canada-U.S. border blocks access to the Pend d’ Oreille drainage upstream.

Prior to hydroelectric development, the Pend d’ Oreille River was swift-flowing with sections of rapids and whirlpools, limited pool habitat, and a relatively narrow channel (Envirocon Ltd. 1973, Moody et al. 2007). Average gradient from Boundary Dam to the confluence with the Columbia River is listed as 0.5% (Envirocon Ltd. 1973), and average gradient in the Seven Mile reach as 2.5 % (Envirocon Ltd. 1975). A 1973 study estimated 5-10 % of the substrate in the river as appropriate for spawning trout, with the remainder mostly large boulder and silt (Envirocon 1973). Pre-impact productivity of this river was likely relatively high given the size of the upstream drainage, but at the time of the pre-dam surveys, the river was strongly affected by daily flow fluctuations from upstream U.S. dams and inputs of mining tailings of up to 4,000 tons/day in the U.S. and Canada (Envirocon Ltd. 1973, 1975).

Both the Pend d’ Oreille and Salmo rivers provided habitat for fluvial rainbow trout, but accessibility for angling was limited due to the steep canyon along most of the large river. Test angling in the Pend d’ Oreille in August 1973 resulted in a catch of 12 rainbow trout (20 to 42 cm length), all taken within 1.6 km or less of the Salmo River confluence, however the majority of the catch was non-salmonids (Envirocon 1973, 1975). The Salmo River supported moderately good angling prior to Seven Mile Dam, with rainbow trout by far the most abundant species and the majority of trout in snorkel counts < 20 cm (Envirocon Ltd. 1975).

6.9.1 Fluvial and Stream-resident Impacts

Fluvial rainbow trout in the Pend d' Oreille River were extirpated or restricted to the Salmo River due to inundation, and Salmo River trout are isolated from their historical connection to the Pend d' Oreille and Columbia rivers. Prior to the dams, it is likely that at least a portion of the larger adults from the Salmo would have moved into these larger rivers during low discharge periods (late summer to winter), which would have increased the carrying capacity of the drainage as a whole. Isolation of the Salmo River population has reduced life history and probably genetic diversity. Impacts on stream-resident populations are likely negligible in this unit because this ecotype, if present, would be found above barriers and outside of the footprint area.

6.9.2 Adfluvial Impacts

There is no known use of this area by adfluvial rainbow trout prior to the dams. The closest adult habitat at that time was Lower Arrow Lake, and it seems unlikely that adfluvial spawning would occur this far from the adult habitat with both downstream and upstream migration necessary.

6.9.3 Post-dam Habitat and Populations

The reservoirs replacing the previous large river habitat in this dam unit are relatively unproductive (Ahrens and Korman 2004, Moody et al. 2007), and daily water level fluctuations due to hydropower production limit the development of a littoral zone. They do not provide good quality rainbow trout habitat as summer temperatures typically exceed their optimal range, and the fish community is dominated by warmwater species including centrarchids. The Salmo River upstream of Seven Mile Reservoir continues to provide good habitat for rainbow trout, with summer temperatures usually 12 - 17 ^{o}C (Arndt 1998, Hagen and Baxter 2003). Discharge in the Salmo varies widely from more than 250 m^3/s at peak freshet to lows of less than 10 m^3/s by late summer and fall (Hagen and Baxter 2003).

Fluvial rainbow trout in the Salmo drainage have been well-studied in recent years through funding by the FWCP and several partners (Hagen and Baxter 2003, 2004, 2007). Radio-telemetry showed most spawning occurs in the mainstem river, with limited use of the lower reaches of tributaries. Overlap of spawning with stream-resident populations in the tributaries may be minor. Off-channel areas within the floodplain are important refuge areas during high discharge events. Most spawning adults are > 40 cm and age 4+ or older, based on the condition of fish sampled shortly after the spawning season and scale age assessments. Feeding conditions in the river are sufficient to produce an occasional fish up to 60 cm, which is unusual for a river of this size, although the majority of catchable trout are less than 30 cm.

Population estimates in the Salmo River indicate an increase from 2002 to 2006 for two length categories of fish in reaches with different harvest restrictions. The adult population estimate (95% confidence limits) has varied from 165 (145 - 217) to 366 (314 - 484) which is close to a minimum level considered to be adequate for long-term conservation[23] (Hagen and

[23] This number is based largely on studies with birds and mammals where populations of $50<N<200$ are considered to be marginally secure, and $N>200$ secure (Boyce 1992, cited in Hagen and Baxter 2003).

Baxter 2003; Hagen and Baxter 2007). Hagen and Baxter (2003) suggest that space may be limiting for sub-adult and adult trout > 30 cm as they are found only in a limited number of deeper pools, usually with wood cover, during low discharge periods in late summer and winter (see section 5.2). A relationship between trout abundance and discharge in the previous year is shown in Figure 5.

In summary, abundance of fluvial rainbow trout has decreased in C10 due to the inundation of all free-flowing reaches of the Pend d' Oreille River, and life history and likely genetic diversity has been reduced by fragmentation. The indigenous Salmo River population is genetically differentiated from other populations in the province (Taylor 2002) and is an important component of trout biodiversity in the region (Section 4.1). Although not as robust as the Columbia River population (C9), it provides a valuable angling opportunity in the West Kootenay, where small to medium (wadeable) river fisheries are rare.

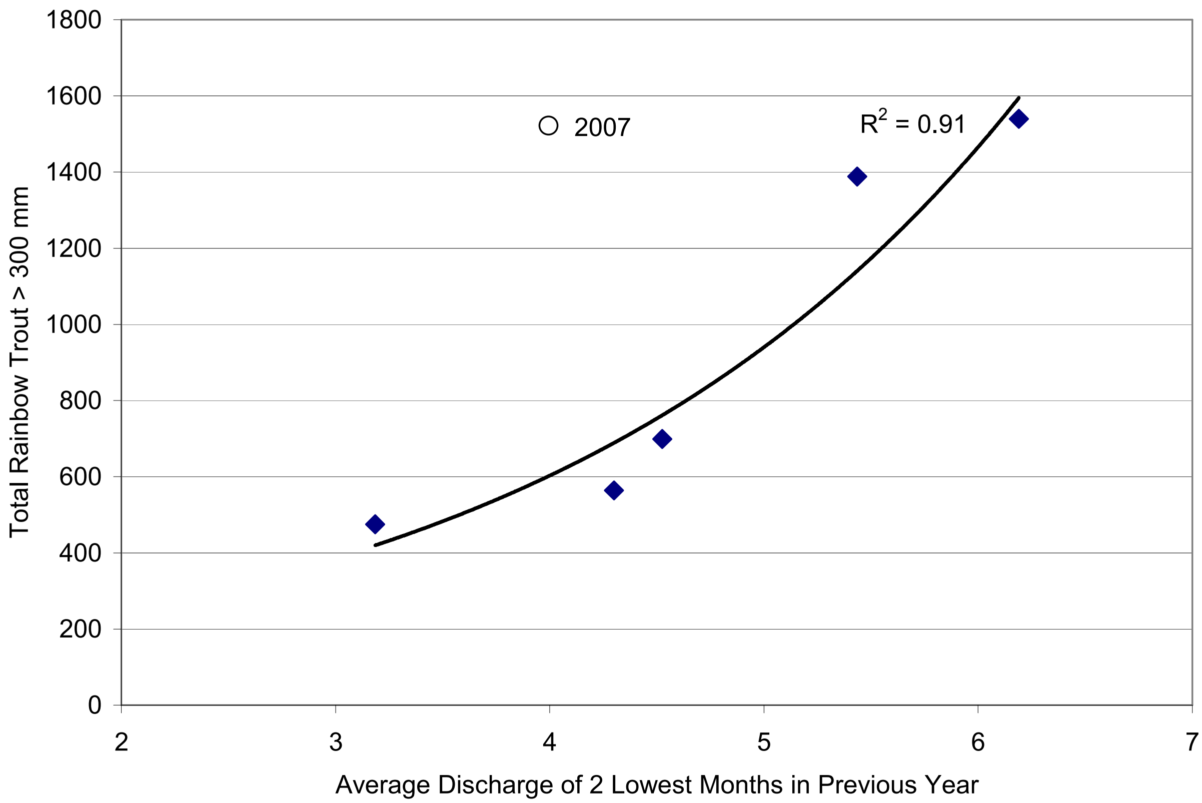

Figure 5. Relationship between the number of rainbow trout > 300 mm and average discharge (m^3/s) during the two lowest months in the previous year for the Salmo River from 2002 to 2007. Line and R^2 value use only 2002-2006 population estimates. Fish abundance estimates are from Hagen and Baxter (2007) and discharge data from the Water Survey of Canada (Stn 08NE074). Mean annual discharge (MAD) is 31.8 m^3/s. Flows ranging from 3 to 6.4 m^3/s correspond to 9 to 20 % of MAD.

6.10 Kootenay River from headwaters to Canada-U.S. border (K1, K2, K3, K4)

As noted earlier, rainbow trout are not indigenous in the Kootenay drainage above the falls near Libby, Montana. However, they were present at low abundance prior to Libby Dam as a result of provincial stocking programs (Rubridge et al. 2001). Creel surveys indicate they made up a very small percentage of angler catch in the Kootenay River at that time (Whately 1972; Lindsay 1976). Dam units K2 (Aberfeldie Dam, Bull River) and K4 (Elko Dam, Elk River) remain outside the distribution of rainbow trout because of natural barriers at the dam locations and are not further discussed.[24] These are the only two units with BC Hydro dams in the upper Kootenay drainage.

Koocanusa Reservoir extends from Libby Dam (Bonneville Power Administration) in Montana upstream ~70 km into the FWCP area at full pool (Hartman and Martin 1987). This creates 60 km^2 of lentic habitat with an estimated gross primary production of 1058 tC/year at average reservoir levels during the growing season (Moody et al. 2007). At low pool (end of winter and early spring) all but one or two kilometres of the reservoir in Canada is drawn down (L. Ingham, FWCP, Cranbrook, pers. comm.). Lotic habitat losses total 128 km (1,500 ha) of low gradient stream and river, most of which was the Kootenay River (Thorley 2008). Lotic primary production losses were estimated at 877 tC/year, and wetland and floodplain export to the aquatic realm 5,756 tC/year (Moody et al. 2007). Thus overall there has been a decline in aquatic primary production in K3.

Soon after reservoir filling, rainbow trout were reported as being fairly abundant in Koocanusa Reservoir, making up 9% of the June angler catch in Gold Creek, a west side tributary (Lindsay 1976). Rainbows increased rapidly after 1976, and it was believed that the source was natural reproduction from a previously stocked coastal type (Phelps and Allendorf 1980). Later Kikomun Creek, a tributary of the reservoir in British Columbia, received stocked Gerrard strain fish from Kootenay Lake from 1981 to 1997 (BC Ministry of Environment stocking records). A suitable food source for these fish is available since kokanee, introduced accidentally in the late 1970s, have become abundant in the reservoir (Arndt 2009). The reservoir is also currently stocked with rainbow trout by the State of Montana (Montana stocking records). Trout from Koocanusa Reservoir utilize accessible reaches of streams directly tributary to the reservoir for spawning (Lindsay 1976), and have also moved into the upper Kootenay drainage below barriers (Ford et al. 1995).

Currently both fluvial and adfluvial ecotypes utilize the upper Kootenay River (K1), with adfluvial fish present in Koocanusa Reservoir (K3). Adfluvial fish include insectivorous and probably piscivorous ecotypes. No recent records of trout catch in the reservoir are available to assess current status. Abundance of rainbow trout in the upper Kootenay drainage appears have increased after Libby Dam leading to increasing levels of hybridization with westslope cutthroat trout, a blue-listed species (special concern) in several East Kootenay streams (Rubridge et al. 2001; B.C. Conservation Data Centre 2008). Stocked rainbow trout in higher elevation lakes have not been affected by dams. BC Hydro dams have not impacted rainbow trout in these units.

6.11 Kootenay Lake and Kootenay River from the Canada-U.S. border to Kootenay Canal (K5, K6)

Kootenay Lake has three main arms (north, south, and west) and a total area of 394 km^2. Major inflows enter the south arm via the Kootenay River (units K1 to K5) and the north arm via the Duncan/Lardeau (K7 and K8) drainage (Figure 1). The west arm is the outlet for the lake and has a water residence time of only a few days, compared to 1.8 years for the main lake (Martin and Northcote 1991). The north and south basins are over 150 m deep whereas the west arm is a

[24] Some rainbow trout may be present due to stocking of headwater lakes.

series of shallow basins joined by riverine sections. Temperature and limnology of the west arm are similar to the epilimnion of the main lake. Dam unit K6 also includes the Kootenay River downstream of the lake as far as the Kootenay Canal power plant.

The natural productive status of Kootenay Lake is oligotrophic. Nevertheless it was the most productive of the large lakes in the West Kootenay in pre-European times, as evidenced by paleolimnology cores and other early descriptions (Moody et al. 2007). Significant First Nations use of Kootenay Lake fish is described by Northcote (1973).

6.11.1 Non-dam Impacts

The ecology of Kootenay Lake has been significantly altered by anthropogenic influences since the 1930s (Table 5), making it difficult to assess the impacts of BC Hydro dams separate from other impacts occurring at the same time. In some reports, the term “historical” has been used to reference the period just prior to construction of Duncan and Libby dams (1960s – 1970s), however, this was an era when lake productivity and fish populations were greatly enhanced due to major phosphorus inputs from a fertilizer plant in Kimberley upstream of the lake (Moody et al. 2007; Arndt 2009).[25] Consequently, this period is not suitable to represent natural lake productivity prior to dams, and will be referred to herein as the *phosphorus-enriched* period. To compare with post-dam status, an ideal pre-dam period would be prior to dams, prior to large scale nutrient enhancement from the fertilizer plant (beginning in 1953), but after the establishment of mysids. Hence the best comparison period is likely from 1949 (first introduction of mysids) to 1953 (opening of the Kimberley fertilizer plant), although mysid colonization was only beginning at this time. This will be referred to in this section as the *pre-Columbia River Treaty (CRT)* period. Anecdotal information from earlier than this (referred to as *pre-mysid*) is also useful for representing natural lake productivity prior to both mysids and large scale nutrient enrichments.

After the *phosphorus-enriched period* from the late 1950s to early 1970s, there was a dramatic reduction in lake productivity due to pollution controls and eventual closure of the Kimberley fertilizer plant, in combination with nutrient retention in upstream dams (Daley et al. 1981). Abundance and size of kokanee, the main food of piscivorous trout, subsequently decreased. More detailed descriptions of changes in the limnology of Kootenay Lake during and following the *phosphorus-enriched* years are provided by Northcote (1973), Daley et al. (1981), Ashley et al. (1997), Northcote et al. (1999), Vonk (2001) and Moody et al. (2007).

[25] Phosphorus loads to the lake peaked in 1968 at over 2,000 tonnes/year, and decreased by 1979 to 36 tonnes/year (Moody et al. 2007).

Table 5. History of dam construction, fertilizer plant operation, and biological manipulations in Kootenay Lake (from Daley et al. 1981; Northcote 1973; Ashley et al. 1997).

Year	Dam	Fertilizer plant	Biological manipulations
1931	Corra Linn Dam completed on lake outlet		
1939	Corra Linn Dam controls lake outlet[a]		
1948	Additional 0.6 m of storage level added		
1949			Mysid shrimp introduced as a food for rainbow trout
1953		Production begins	
1961			Mysids first detected in surface water samples
1962		Production doubles	
1965		Production triples	
1967	Duncan Dam controls Duncan River flows		
1968			Meadow Creek Spawning Channel in operation
1969		Settling ponds installed	
1973	Libby Dam (Bonneville Power) controls Kootenay River flows		
1975		Complete effluent recycling begins, significantly reducing P loading	
1977[b]		Plant closed	
1980s			West arm kokanee spawning channels in operation
1992			North Arm fertilization begins
2004			South Arm fertilization begins

[a] associated with dredging of Grohman Narrows upstream of the dam.
[b] some references indicate 1987 as the year of plant closure.

Introduction of mysids in 1949 had a significant impact on lake ecology that further complicates analysis of dam impacts. The shrimp was introduced as a food source for rainbow trout in an effort to enhance growth and survival of piscivorous trout during the transition from smaller invertebrates to fish, and was found in stomach contents of fish by the early 1960s (Martin 1978; Martin and Northcote 1991). Mysid establishment was followed by an increase in the size of kokanee in the West Arm of Kootenay Lake, and an increase in the abundance of intermediate-sized rainbow trout. (Note that phosphorus inputs from the fertilizer plant were also increasing during this period.) By the mid-1970s, however, it was evident that mysid predation on cladocerans could alter lake trophic structure to the disadvantage of kokanee (Martin and Northcote 1991; Bowles et al. 1991). In particular, the abundance of two large cladocerans, *Daphnia* and *Bosmina*, declined between 1949 and 1970 (Zyblut 1970). Mysids do not appear to be a major food item for rainbow trout in the main lake, comprising less than 5% by volume of the stomach contents of rainbow trout <30 cm, and less than 1% for fish over 40 cm in one study (Andrusak and Parkinson 1984).[26] In a comparison of two coldwater reservoirs in Colorado, Johnson et al. (2002) found that mysids short-circuited the pathway channelling primary production into fish biomass, shifting pelagic production into the hypolimnion and benthic pathways.

6.11.2 Dam-related Habitat Impacts

Dams affecting Kootenay Lake include Corra Linn at the lake outlet (1939, currently a control structure for BCH Kootenay Canal Plant as well as a Fortis power plant), and Duncan (1967, BCH flood control and storage) and Libby (1973, Bonneville Power Administration flood control and power production) upstream on its two major tributaries. Grohman Narrows in the west arm downstream of Nelson was enlarged by dredging between 1929-1932 and again from 1939-1941 to allow more efficient power generation and flood control at Corra Linn. Kootenay Canal power plant was built in 1976 to take advantage of the water stored in Duncan and Libby dams (Daley et al. 1981).

Physical habitat losses and gains were not quantified for Kootenay Lake (K6) because pre-impoundment maps were not available (Thorley 2008). Stream losses would be small relative to impacts in other dam units due to the small change in average lake level. Nevertheless, when the lake level was raised 2.4 m by Corra Linn Dam, there was a loss of spawning and rearing habitat in the lower reaches of tributaries and in the narrows of the west arm (Northcote 1973). Local angling clubs at the time alleged that the rainbow trout population in the west arm was seriously affected by loss of quality spawning areas due to Corra Linn Dam and associated dredging (Nelson Daily News, September 20, 1948). An additional habitat impact in K6 is the reduction of discharge in 4.5 km of the Kootenay River between Corra Linn Dam and Slocan Pool, due to the bypass that carries water to Kootenay Canal power plant.

Habitat losses due to inundation, and fragmentation from construction of Duncan Dam (see section 6.12) also had significant influences on spawning and rearing for Kootenay Lake fish. Although some bull trout were transferred through the Duncan Dam, no passage was provided for rainbow trout or kokanee (Vonk 2001). Forty-six kilometres (406 ha) of the Duncan river, above and below the original lake, plus over 50 km of smaller tributaries were inundated by the dam (Thorley 2008). The dam was located near, or directly on, spawning areas previously used by piscivorous rainbow trout from Kootenay Lake (Maher 1961; section 6.11.4).

Upstream impoundments also had very significant impacts on Kootenay Lake's lentic primary productivity and water clarity. These changes affected rainbow trout habitat directly and kokanee, the primary prey of piscivorous fish. Duncan and Libby dams reduced nutrient levels, but increased light penetration (Northcote et al. 1999, 2005; Moody et al. 2007). Moody et al. (2007) judged the pelagic productivity of the lake after dams to be approximately the same as it was in the *pre-CRT* period (8,865 and 8,775 tC/year, respectively; see section 7.4.1) with the lake switching from primarily light limitation prior to dams to nutrient limitation after. Kokanee biomass, however, was substantially lower in the post-dam era than predicted by the model in their report suggesting that mysid establishment, or other productivity impacts not included in their evaluation may have affected kokanee

[26] Relative contribution might be underestimated if mysid digestion occurs more quickly than for other foods.

production and productivity (Ashley et al. 1999, Arndt 2009). The substantial increase in water clarity in the south arm of the lake after Libby Dam (Northcote et al. 2005) may have affected predator-prey interactions in that part of the lake aside from changes to productivity (see below).

Operational regimes at upstream dams changed discharge patterns, reducing flows and lake level during spring and early summer, and increasing winter flows (Daley et al. 1981). The reduction in peak flows would influence all lake basins; for example, it has been postulated that prior to Libby Dam, deep currents carried nutrient rich water from the south arm into the north arm, enhancing phytoplankton production during spring turnover and later (Northcote 1999; Vonk 2001). However, changes in discharge and lake levels might have influenced west arm fish the most, since this arm is shallow and narrow with a short residence time. Although changes in temperature regimes are often associated with altered discharge, Cloern (1976) found no significant changes in summer temperatures in the south arm after Libby Dam. Winter conditions in the west arm have changed as it was often ice-covered prior to the upstream dams, but does not freeze with current winter discharge.

6.11.3 Fluvial and Stream-resident Impacts

Rainbow trout are present in K6 in the Kootenay River downstream of Corra Linn Dam. For the purposes of this review they will be considered as the fluvial ecotype, although it is likely that entrained fish from the west arm contribute to recruitment. This reach is affected by BC Hydro's Kootenay Canal plant and four dams (owned by City of Nelson, and Fortis) in the natural river channel.[27] There is very little information on rainbow trout in this reach, however, anecdotal angler reports suggest trout abundance increased in the mid-1950s with high numbers of large trout caught in the 1960s and early 1970s (Arndt 1999). The Kootenay River immediately downstream of Nelson had a high CPUE of 0.24 rainbow trout per hour in 1972 but CPUE was believed to be lower by 1980 (Anon. 1981). A decline in the late 1970s coincides with the beginning of operations at Kootenay Canal as well as the reduction in upstream nutrient loading to Kootenay Lake. Both river discharge and associated food export from Kootenay Lake were reduced by the canal diversion of flows, suggesting a potential negative effect of the canal plant on rainbow trout production. No losses of fluvial trout are expected in the Kootenay River upstream of Kootenay Lake (K5) as the deep, slow-moving flow has not been modified to a great degree. Rainbow trout occur in this reach in modest numbers in summer (C. Spence, MOE, pers. comm.).

Stream resident rainbow trout were not likely affected by dams in K5 and K6 because the small losses of stream habitat in the lower reaches of Kootenay Lake tributaries are typically dominated by adfluvial stocks.

6.11.4 Adfluvial Impacts

Adfluvial rainbow trout in Kootenay Lake have sometimes been considered as three stocks, a piscivorous ecotype spawning in north arm rivers, an insectivorous ecotype in the main lake spawning in smaller tributaries, and an insectivorous west arm stock (Andrusak 1981). Main lake insectivorous fish were sometimes called the south arm stock as they appeared to be more abundant there (Nelson Board of Trade 1934), but for the purposes of this review non-

[27] Corra Linn, Upper Bonnington, Lower Bonnington, South Slocan

piscivorous adfluvials are treated as one group that probably utilizes spawning streams in all arms of the lake as well as the Kootenay River. Recent radio telemetry and tag studies have shown some rainbow trout spawning in a tributary of the Kootenay River in Idaho migrating as far as the west arm (Downs 2000), and it seems likely the west arm could be utilized by rainbows spawned in all parts of the lake given its high suitability for feeding.

Piscivorous Ecotype

Prior to dams, piscivore spawning occurred mainly in the Lardeau River at the outlet of Trout Lake near the Gerrard town site (Hartman 1969), although Cartwright (1961) and Maher (1961) noted considerable spawning also occurred at other locations downstream in the Lardeau and in the lower Duncan River. The number of Duncan spawners, though significant, was much less than at Gerrard, with Northcote (1973) estimating their number at up to 100 and Anderson and Crowley (1975) at 100-150.[28] Up until very recently it was believed that the Duncan stock was extirpated when Duncan Dam was constructed, but recent observations have documented piscivorous trout spawning in the tailrace area (Baxter 2008). Radio telemetry has confirmed that while the Gerrard area is still the major spawning site, a substantial proportion occurs at other locations in the Lardeau, and about 20% of tagged fish spawned below the Duncan Dam tailrace (Hagen et al. 2007). Fish currently spawning in Duncan River may be related to the original Duncan stock or may be straying from the Lardeau (Hagen et al. 2007). The degree of reproductive isolation between these two locations prior to hydroelectric development is not known.[29]

The biology of the Gerrard stock has been studied intensively. Detailed life history accounts are provided by Cartwright (1961), Hartman (1969), Hartman and Galbraith (1970), and Irvine (1978), with more recent studies by Hagen et al. (2007). These fish mature late, can reach 17 kg, and feed extensively on kokanee starting when they are 30 cm or less (Table 2); growth is rapid in the lake and appears to be linked to the incidence of kokanee in the diet (Andrusak and Parkinson 1984). Juveniles stay in the Lardeau River for up to 2 years (Hagen et al. 2007), although some emigrate to the lake during their first summer (Cartwright 1961).

The piscivorous ecotype was abundant and large enough to attract specific angling and management attention in the early 1900s (Northcote 1973). Federal Department of Fisheries constructed a hatchery at Gerrard and seined spawning fish for egg collections annually from 1912 to 1932; provincial authorities collected eggs from 1939 to 1949 and again in 1952 (Irvine 1978). A 1934 publication (Nelson Board of Trade) refers to these rainbow trout as “Kootenay Lake salmon” which could exceed 20 pounds (9 kg), and notes weekend fishing parties trolling on the main lake for the large trout with boats available for rent. Most angling for piscivorous fish was done in Queens Bay or the north arm up to the 1970s, but after Duncan and Libby dams, catches of large rainbow trout in the north arm declined while central and south arm catches increased (Andrusak and Crowley 1975; Irvine 1978). Angling effort also increased in the south arm at this time, leading to speculation that the improved fishing there was related to reduced turbidity or other changes in limnology, temperature and food distribution after Libby Dam (Martin 1978, Irvine 1978).

[28] Petersen and Withler (1965) observed 24 large rainbow spawners in the Duncan prior to the dam but observations were difficult because of the high turbidity.
[29] One radio-tagged fish in a recent study resided for 4 days at the Lardeau spawning area and then moved to the Duncan tailrace for 4 days.

Estimates of the number of piscivorous trout spawning at Gerrard are available from 1913 to the present (J. Burrows, MOE, pers. comm.). Early estimates were extrapolated from egg collection records using assumptions on the number of eggs per female, sex ratios, and proportion of the total run captured by seining (Irvine 1978); estimates starting in 1957 are based on expanded spawner counts. Although there is more uncertainty around the early years because of the necessary assumptions, a reasonable trend analysis spanning nearly a century is a remarkable achievement! Escapement estimates for Gerrard have fluctuated considerably over the years ranging from ~ 200 fish to nearly 1,500 (Figure 6). Narver (1984) notes that the Federal government wanted to end the egg takes due to declines in 1923 but local pressure kept the operations open for several more years. Irvine (1978) and Cartwright (1961) suggested the apparent decline from 1939-1949 was due to the effects of removing eggs from a large proportion of the population, possibly high harvest from a fishing derby,[30] and progressively deteriorating fish passage at a log jam in the Lardeau River (downstream of the counting area). This decline also follows Corra Linn Dam, but recovery in later years argues against a dam effect. Returns in the years following Duncan Dam are lower than 1965 and 1966, but numbers increase again following Libby Dam. Overall, returns in recent decades are similar to those prior to hydroelectric development at around 800 spawners. There is no clear indication of a response to either the peak phosphorus additions in the late 1960s, or the dams in later years; however, escapement could have been strongly influenced by harvest (see below) which would obscure dam effects. It is likely that at least some component of the Duncan spawning group was lost in the years following Duncan Dam.

Angling trend data are available for Kootenay Lake, but must be interpreted cautiously because of changes in effort, regulations, fishing technology (e.g., advent of recreational sonar fish finders), and ecological factors (e.g., prey abundance, water clarity). Northcote (1973) provides a valuable compilation up to 1970 indicating that angler effort and catch of rainbow trout > 2 kg was higher in the *phosphorus-enriched* 1960s (just prior to Libby and Duncan dams) than it was in the *pre-mysid* 1940s (Appendix E). Recorded catch in the 1940s ranged between 242 and 595 fish with the largest size being over 8 kg, whereas 1960s surveys estimated catches of 1000 to 1700 large trout.[31] A length frequency comparison of the *pre-mysid* (1941-1949) to *phosphorus-enriched* period (1963-1967) showed little difference in the length of harvested north arm fish (primarily piscivores), but an increase in fish condition (weight at a given length) in the 1960s for trout over 40 cm (Northcote 1973). Lake-wide creel surveys for the *post-CRT* period cannot be used for tracking piscivore abundance because size data were not recorded. Changes in regulations and fees reduced effort and harvest in the 1970s[32], and the percentage of released fish (especially piscivores) increased starting in the 1980s (Andrusak 1987).

[30] During the 1940s the Nelson Gyro Club sponsored a Kootenay Lake fishing derby in which over 3,000 trout over 2 kg were recorded over a 10 year period (Irvine 1978).

[31] Data for 1940-49 were from trout derby and resort records (Northcote 1973).

[32] Regulation changes in 1974 increased licence fees for non-Canadian anglers, and reduced their access to the west arm fishery (Andrusak 1974). This reduced non-Canadian licence sales by about half and decreased angling effort in all parts of the lake (in 1973, 67% of Balfour area anglers were non-Canadian). Other changes included a gear restriction of artificial fly only in the west arm starting in the 1980s, an annual quota of 5 fish >40 cm in 1985 (Andrusak 1987) and the requirement of a Kootenay Lake Rainbow Trout stamp to retain fish >50 cm in 1986 (Redfish Consulting 2005).

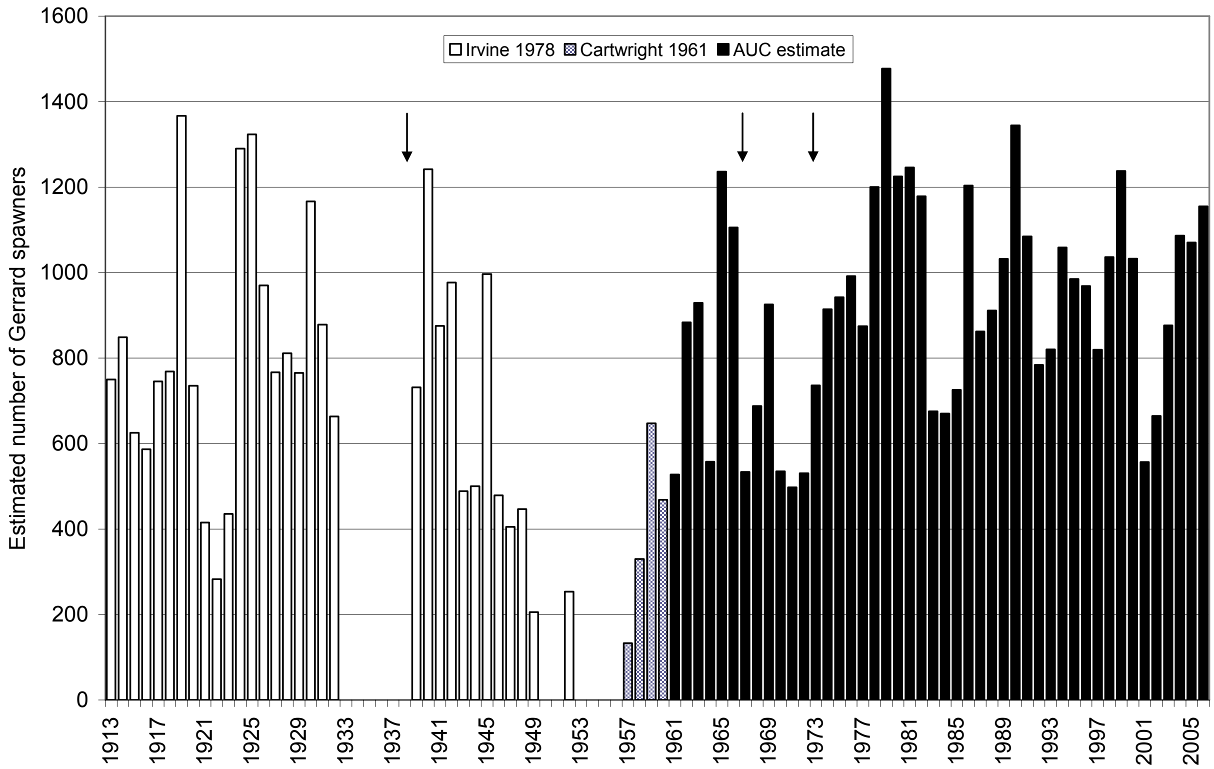

Figure 6. Estimated number of rainbow trout spawning at Gerrard in the Lardeau River from 1913 to 2007. Numbers for 1913-1952 are based on egg collection records with assumed sex ratios and seining efficiency (see Irvine 1978, Table 11), 1956-1960 are expanded peak counts of spawners (Cartwright 1961, Irvine 1978), and 1961-2007 are area under the curve estimates calculated from daily counts and average residence times (Hagen et al. 2007). Arrows indicate the timing of Corra Linn, Duncan, and Libby dams. Missing bars are years with no data.

Catch records from Kaslo marina in the north arm are useful for tracking piscivores starting just prior to Duncan Dam (Table 6), although again they need to be interpreted with caution because of the factors mentioned above and the observation that angling for piscivorous fish expanded into the south/central areas after Libby Dam. Nonetheless this is the only index of rainbow trout harvest providing records by size category from the *phosphorus-enriched* to the *post-CRT* era. The size category of > 7 kg (15 pounds) includes only larger piscivores whereas the category of > 35 cm could include both piscivorous and insectivorous fish. Peaks in north arm piscivore harvest apparently occurred in the early 1960s and from the late 1970s to early 1980s, with a decline after that. Catches declined after Duncan Dam (1968-1975), but increased following Libby Dam (1973 to early 1980s). Piscivore catch (>7kg) seems to follow trends in kokanee abundance (Figure 7) as might be expected given their strong dependence upon kokanee for food. Kokanee abundance, in turn, was strongly affected by changes in primary productivity due to changes in the output of the Kimberley fertilizer plant and the effects of the dams on nutrients and turbidity. It is possible that a stocking program may have obscured short-term dam effects of the dams on piscivore recruitment, although this seems unlikely given that only 5-7% of the annual catch of rainbow trout during the period of stocking was believed to be hatchery-origin (Andrusak and Crowley 1975; Bell 1989).[33]

Table 6. Summary of daily catch records from Kaslo Marina from 1962 – 1986 (from Andrusak 1987).

Year	Angler hours (all species)	Rainbow Trout		
		<35 cm	>35 cm	> 7 kg
1962	23,472	829	979	115
1963	26,353	1,222	976	158
1964	29,547	1,037	1,443	169
1965	26,028	839	1,255	93
1966	32,133	569	1,156	70
1967	34,339	617	838	102
1968	29,172	733	847	81
1969	32,789	508	900	61
1970	33,376	916	700	46
1971	29,168	534	620	101
1972	30,200	662	601	72
1973	34,118	278	333	44
1974	34,104	185	388	74
1975	34,401	242	419	88
1976	46,162	52	575	132
1977	39,798	57	581	173
1978	43,163	33	601	250
1979	45,155	19	690	255
1980	39,074	1	563	194
1981	33,071	-	424	186
1982	31,430	-	373	111
1983	27,491	18	490	59
1984	27,518	-	512	71
1985	25,048	15	346	100
1986	26,290	41	243	99
1987*	19,249	-	-	-
1988*	14,329	-	193	44

* Ministry of Environment file data

In summary, Gerrard spawner estimates indicate that escapement has been relatively stable from the *pre-mysid* era to the present except for major reductions that occurred prior to Duncan and Libby dams. Anecdotal and other reports clearly indicate that piscivores were abundant enough to support popular fisheries in all pre-dam eras. Kaslo angler records suggest an increase in piscivore harvest in the north arm from 1973 to the early 1980s followed by a decrease in the late 1980s that was at least partly related to a shift in the locations of piscivore feeding. High phosphorus loading in the 1960s was reflected in fish condition but not spawner numbers or available (albeit limited) harvest data. Increases in harvest in the late 1970s may have been a result of increased water clarity following Libby Dam, which occurred in the last few years of enhanced phosphorus loadings from the Kimberley plant. Without more detailed harvest and escapement data including size

[33] Releases from about 10,000 – 35,000 piscivorous trout (mostly yearlings) were made between 1975 and 1987 (Bell 1989).

measurements, it is not possible to reconstruct piscivore population abundance trends over the period of interest.

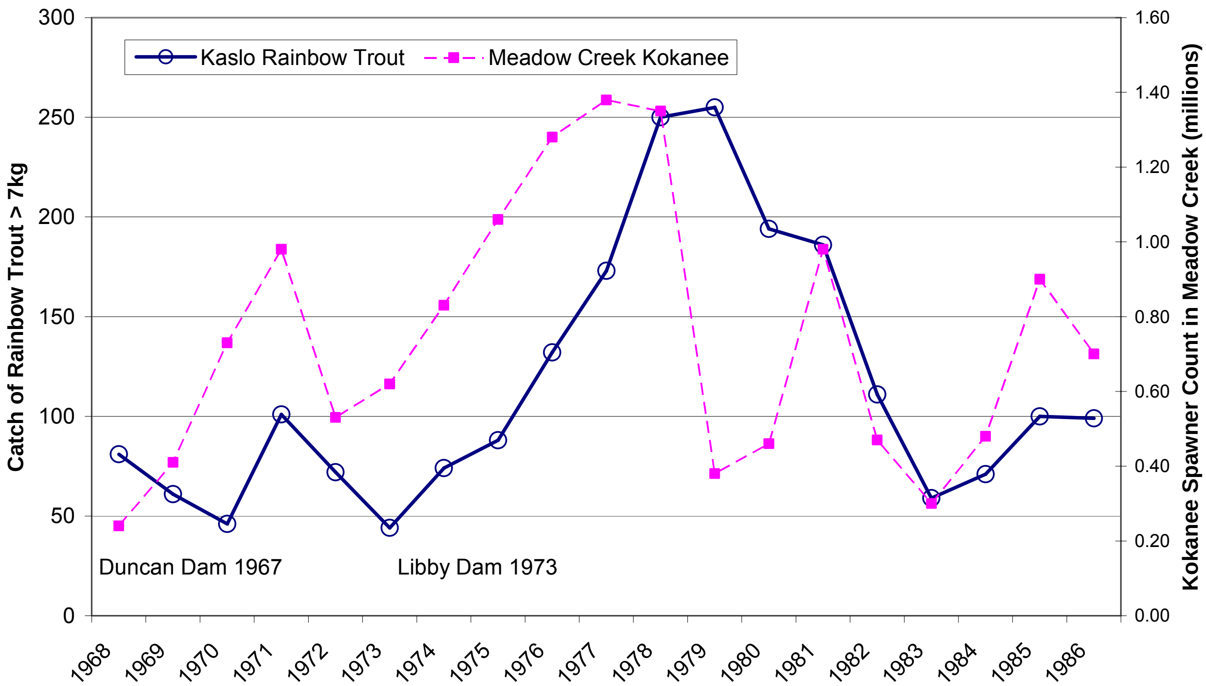

Figure 7. Catch of rainbow trout > 7 kg at Kaslo Marina and kokanee spawner returns to Meadow Creek from 1968 to 1986 (data from Andrusak 1987 and Ministry of Environment file Meadow Creek Kokanee.xls).

Insectivorous Ecotype

This ecotype likely spawns in all tributaries of Kootenay Lake that do not have barriers close to the mouth or strong glacial influence. Cartwright (1961) lists the Goat River and Midge, Cultus, and Summit creeks as known or suspected spawning systems for smaller rainbows, and as noted earlier, spawning occurs in at least one tributary of the Kootenay River in Idaho (Downs 2000), as well as riverine sections of the upper west arm (Andrusak 2006).

Insectivorous trout were abundant in the *pre-mysid* period. Northcote (1973) estimated peak First Nations harvest to be about 20,000 rainbow trout averaging 1 kg prior to European arrival. By the 1930s, recreational angling for smaller rainbows was popular, especially in the west and south arms. A 1934 tourist book (Nelson Board of Trade) states that fishing was a favourite pastime and although big fish were not to be expected in the west arm, “it is quite usual in a couple hours to get enough kokanee and rainbow trout for breakfast.”

No index of spawner abundance is available for this ecotype, but angler surveys provide abundance and size trends from the *pre-mysid* era to 1986.[34] Catch rate, harvest, and size distributions increased for insectivorous rainbow trout (< 2 kg) from the 1940s (approximately 2,500-6,000) to the *phosphorus-enriched* 1960s (4,000-7,000) (Northcote

[34] Three years of creel data were collected after a whole lake creel survey was discontinued in 1986, but the sampling frequency was reduced and only the central area and west arm of the lake were surveyed. These data have not been analyzed and reported on. (J. Bell, Ministry of Environment, pers. comm.).

1973, Appendix E; Andrusak 1987). Kaslo marina records (Table 6) also indicate peak catches for smaller trout in the 1960s. Rainbow trout CPUE peaked in the late 1950s, with earlier and later periods being fairly similar (Appendix E). In addition to the increase in harvest during the *phosphorus-enriched* years, there was a notable increase in size in the west and south arms of the lake, where the fishery was primarily comprised of the insectivorous ecotype (Figure 8). Growth rates of trout also increased from 1953 up until the mid-1960s or later (Cartwright 1961, Northcote 1973) implying a link with the Kimberley phosphorus additions.

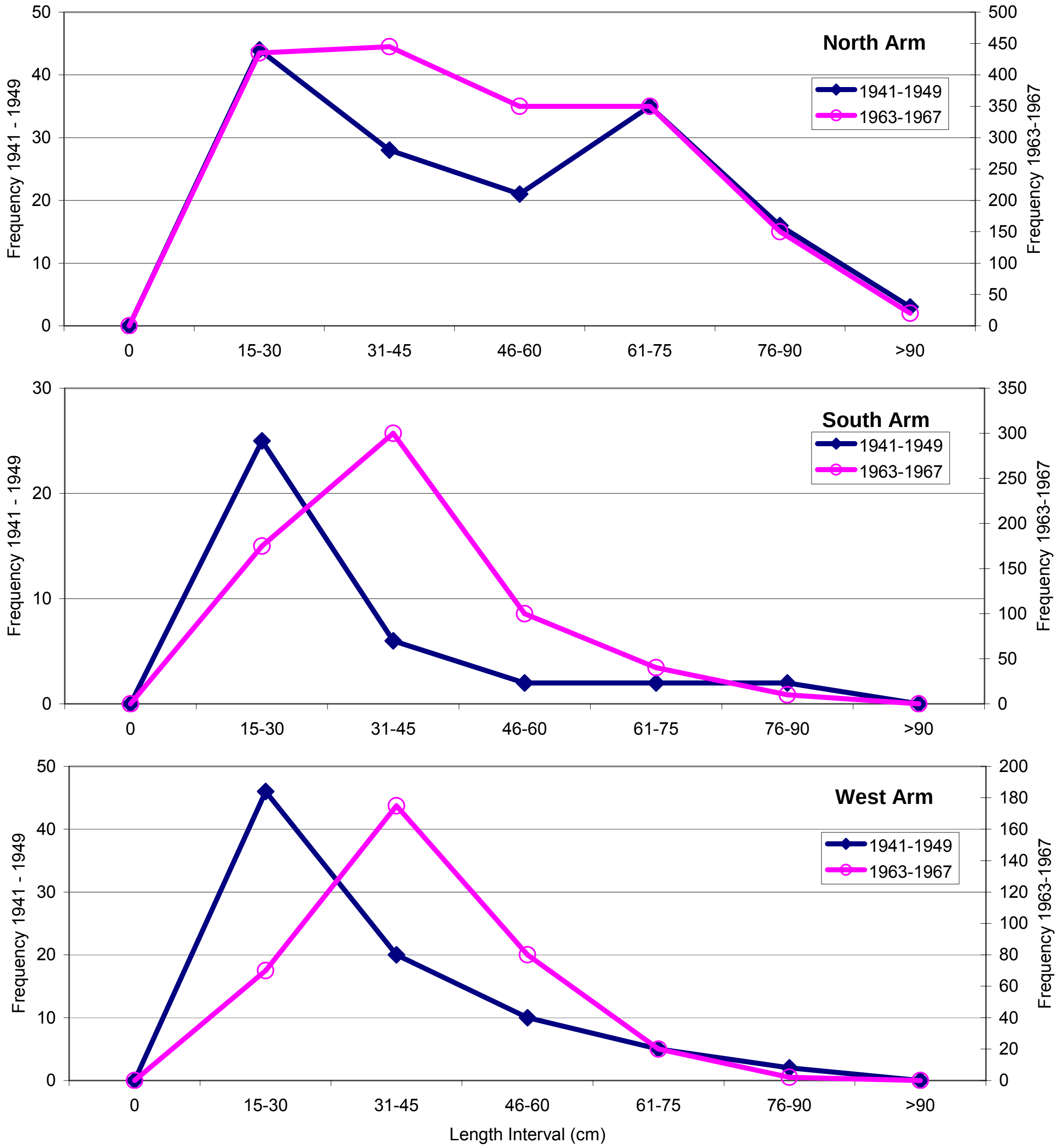

Figure 8. Fork length frequency distributions of angler caught rainbow trout from Kootenay Lake from before (1941-1949) and during (1963-1967) the Kimberley fertilizer plant period (from Northcote 1973).

Whole lake creel surveys from 1968-1986 (Andrusak 1987) provide about two decades of harvest and catch trends starting immediately after Duncan Dam. A lack of size data prevents separation of the insectivorous and piscivore components of the harvest, although length-frequency distributions in Northcote (1973) suggest that 40 - 50% of the north arm harvest was piscivores in the late 1960s, whereas nearly all of the south and west arm fish were insectivorous (<45 cm). In the West Arm, harvest of rainbow trout remained relatively high and variable to the end of the *phosphorus-enriched* period, after which it declined; in the south and north arms, declines did not begin until the 1980s (Figure 9, upper panel). Total lake harvest in *post-CRT* years declined from the 1960s but was in the same range (2,500 – 6,000 fish) as Northcote's (1973) estimates for the *pre-mysid* period. (Note that methods of estimation were not the same for the two periods.) Andrusak (1987) attributed a decline in 1980s west arm angling effort to the closure of the kokanee season (previously both species could be harvested), an artificial fly only regulation, and possible decrease in the average size of fish.[35] CPUE in the south arm declined from the peak in the late 1960s in agreement with harvest trends (Figure 9, lower panel). In the west arm, CPUE did not decline in the 1980s, suggesting the decline in effort was largely responsible for the decreased harvest.

Taken together the available creel data suggest that insectivorous rainbow trout increased in size and abundance during the *phosphorus-enriched* years, and decreased in the years following Kimberley plant closure and Duncan and Libby dams to harvest levels perhaps similar to the *pre-mysid* and *pre-CRT* periods. Similarity in harvest levels before and after dams does not necessarily signify similar population abundance and productivity, because of substantial changes in regulations and angling effort over these decades. Unfortunately creel data are not available for the five years prior to the beginning of the fertilization experiment in 1992.[36]

[35] Habitat changes are another potential influence on west arm rainbow trout. Burns (1970) notes the extent of rooted vegetation in the west arm expanded significantly after 1960 due to the eutrophication occurring at that time, and states that this habitat change altered the aquatic insect hatches and rainbow trout distribution in the upper west arm. This probably reversed when nutrient levels declined after closure of the fertilizer plant.

[36] A mailed survey of anglers who purchase the Kootenay Lake Rainbow Trout stamp for retaining fish over 50 cm replaced the on-lake creel survey in 1987. While valuable as a trend indicator for its sampled period, it has inherent biases (Cryer 1996) that prevent comparisons to the earlier creel surveys. Also it was not intended to provide information on harvest of insectivorous rainbow trout.

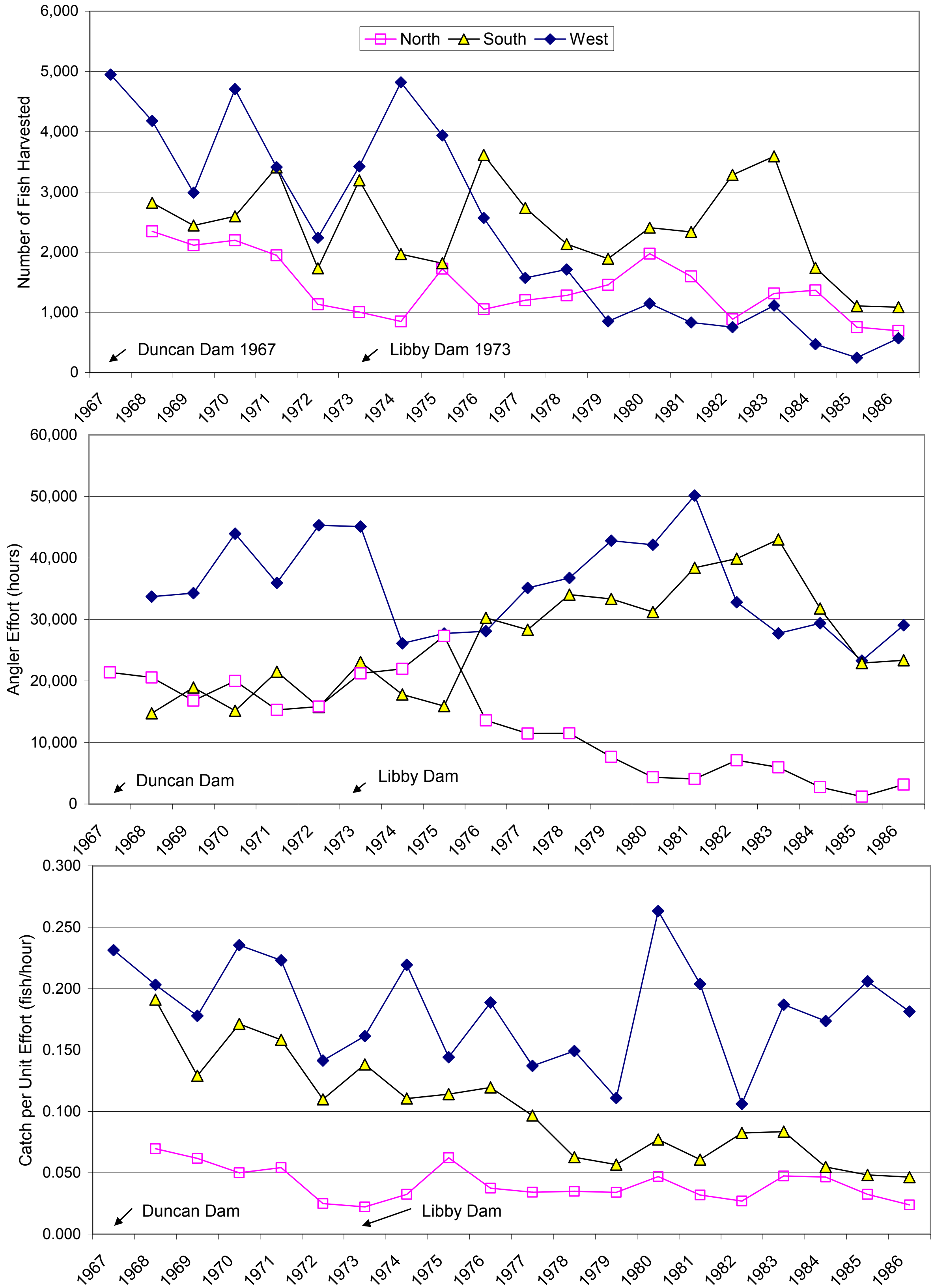

Figure 9. Trends in rainbow trout harvest (upper panel), effort (middle) and catch rate (lower) in the north, south and west arms of Kootenay Lake from 1967 to 1986 (from Andrusak 1987). Catch per unit effort includes only harvested fish. West Arm includes from the main lake outlet to the Harrop ferry.

6.11.5 Post-dam Populations and Habitat

Reductions in spawning and stream rearing habitat as a result of dams probably affected Duncan River piscivore spawning the most and fish recently spawning below the dam may or may not be the original stock. No other spawning populations are known to be eliminated in this unit by dams, and it is not known whether stream habitat is limiting to the populations. *Post-CRT* Kootenay Lake had reduced nutrient loads (prior to fertilization) but greater water clarity. Direct effects of increased water clarity on feeding of rainbow trout may have been beneficial, particularly in the south and west arms. Primary productivity changes are discussed in Section 7.4.1.

Kokanee declines in the late 1980s led to concerns that piscivorous rainbow trout and bull trout declines would soon follow (Andrusak and Andrusak 2006), and the north arm fertilization experiment was started in 1992. [37] Since the initiation of this program, kokanee spawner numbers have increased to approximate peak abundances in the 1960s (Arndt 2009). The extent to which piscivorous trout might have declined had the nutrient restoration project not been initiated is uncertain. A decrease seems likely given their almost exclusive dependence upon kokanee for feeding. As noted earlier, previous changes in lake nutrient status were not well reflected in spawner returns, but catch rates appear somewhat related to kokanee abundance.

For the adfluvial insectivorous ecotype, it is uncertain whether *post-CRT* abundance is lower than that prior to the *phosphorus-enriched* period. Andrusak (2006) suggests that current angler effort in the west arm is less than 10% of what it was in the 1970s (peak period). Present size, condition, and growth rates in the west arm are slightly lower than 1966 samples (Table 7) but still higher than lengths in the 1940s (compare to Figure 8, lower panel).

Table 7. Mean (±SE) length, weight, condition factor, and growth rate for west arm rainbow trout compared for 1966 and 2005 (from Andrusak 2006).

Year	**N**	**Length (mm)**		**Weight (kg)**		**Condition Factor**	**Length at Age 4+**
		Mean	**Range**	**Mean**	**Range**		
1966	202	413 (±8.2)	205-677	1.04 (±0.06)	0.08-3.70	1.17 (±0.01)	529 (±33)
2005	81	397 (±7.3)	206-568	0.73 (±0.04)	0.11-2.13	1.10 (±0.02)	391 (±18)

Fluvial rainbow trout in the Kootenay River adjacent to Kootenay Canal (downstream of Corra Linn Dam) currently attract very little angling effort and are likely to be at lower levels of abundance than they were prior to hydroelectric development, based on the reduction in discharge and export of lentic foods. Anecdotal information suggests that current abundance is much less than it was during the *phosphorus-enriched* years (Arndt 1999).

In addition to the uncertainty about *pre-* and *post-CRT* differences in population abundance, there remains substantial uncertainty around the relative importance of BC Hydro dams

[37] The extent of public concerns about fishery declines following the dams in the Kootenay Region is indicated by the fact that the Regional District of Central Kootenay requested an independent review of the Kootenay Region fisheries program from the Minister of the Environment (Narver 1984).

compared to Libby Dam and other habitat impacts. Fertilization of the south arm of the lake started in 2004 (funded by Bonneville Power Administration) as a compensation measure for retained nutrients behind Libby Dam. The impact of the additional nutrients on fish populations has yet to be determined.

6.12 Duncan and Lardeau Drainages (K7, K8)

The creation of Duncan Reservoir (65 km^2) in 1967 inundated a natural lake of 26 km^2 (Thorley 2008). Moody et al. (2007) estimated the combined annual pelagic and littoral primary production to be about 420 tC/year for the lake compared to 1,000 tC/year for the reservoir. In addition, they estimated a loss of 127 tC/year of stream primary production and over 3,000 tC/year of wetland production exported to the aquatic realm in K7. Stream habitat losses were significant, and may have affected spawning of salmonids from Kootenay Lake more directly than those in unit K7 upstream of the dam (see section 6.11).

Prior to the Duncan Dam, the main body of the lake was glacially turbid until mid to late summer except for the south-east basin, which was isolated from direct Duncan River flows and significantly more productive (Moody et al. 2007). Local residents fished for rainbow trout and other species primarily in this basin, but angling use was low (Maher 1961, Volk 2001). No records of fish size or harvest are available to compare the fishery from before and after the dam, and angling use remains low at least partly due to the remote location (Volk 2001).

It is probable that prior to the dam Duncan Lake was used to a minor extent by piscivorous rainbows spawning at the lake outlet, although feeding conditions would be less suitable than in the north arm of Kootenay Lake where water clarity and kokanee abundance were higher. Losses of fluvial and/or stream resident trout are possible due to the flooding of lotic habitat in this unit, although the glacial nature of the upper Duncan drainage would be more suited to bull trout and mountain whitefish production than rainbow trout. Standing biomass losses of salmonids (all species) in the area flooded by Duncan Dam were estimated at 1,360 kg (Moody et al. 2007).

The Lardeau River drainage including Trout Lake (K8) was not directly affected by dams, but the loss of spawning habitat in the lower Duncan River (and subsequent operation of the Meadow Creek Spawning Channel) reduced the number of kokanee spawners in the Lardeau-Duncan, which could affect river productivity for rainbow trout juveniles. The relative number of piscivorous rainbow trout spawning in the Lardeau and Duncan rivers (below the dam) appears similar to what it was previously, with the majority of spawning taking place in the Lardeau and a smaller number (100-150) in the Duncan (Section 6.11.4). Trout Lake at the headwaters of the Lardeau River provides 29 km^2 of deep oligotrophic habitat that is suitable for adfluvial piscivorous and insectivorous trout. It is likely that some trout of both ecotypes move between Kootenay and Trout Lake as both afford similar feeding opportunities. Status of rainbow trout in Trout Lake has probably not changed due to dams.

6.13 Slocan Lake, Slocan River, Lower Kootenay River (K9)

Slocan Lake is a deep oligotrophic lake of 69 km^2 that provides habitat for adfluvial insectivorous and piscivorous ecotypes. Adfluvial spawning is known to occur in the Slocan River near the lake outlet (fish up to 5 kg), and several tributaries including Bonanza Creek and Wilson Creek (J. Bell, pers. comm.). The lake supports a kokanee population and may have had indigenous piscivorous rainbow trout, although introductions of Kootenay Lake Gerrard stock occurred as early as 1915 (Ministry of Environment stocking records). In more recent years the lake has received stockings of 20,000 Gerrards annually. Habitat for these fish has not been affected by dam construction.

Fluvial trout are present in the Slocan River and Kootenay River (Brilliant headpond) between Slocan Pool and Brilliant Dam (1942, currently operated by Columbia Power Corporation). The Slocan River/lower Kootenay River fish should properly be considered as one population, since there are no barriers to movement and radio telemetry has demonstrated that the majority of fish move frequently between the two rivers; the Slocan River appears to provide important feeding and spawning habitat (Golder Associates 2002a). Spawning also presumably occurs in smaller tributaries that are accessible and may occur in the mainstem Kootenay River (no documentation available). An intensive mark-recapture program in the Brilliant headpond in 2001 provided a rainbow trout population estimate (95% confidence limits) of 3,194 (2,899 to 3,602) of which 1,154 (958 to 1451) were >250 mm (Golder Associates 2002b).

Habitat in this reach of the Kootenay River is impacted by changes in the hydrograph due to upstream dams and Kootenay Canal (1976, BC Hydro), and downstream Brilliant Dam impounds most of the 20 km of large river habitat, increasing depth and reducing water velocity. The canal plant and South Slocan Dam (FortisBC) which form the upstream boundary for the population are located close to a historical falls that probably was a natural barrier to upstream movement. Brilliant Dam downstream prevents access to the Lower Kootenay and Columbia rivers. The impounded reach below Slocan Pool is relatively poor quality habitat for rainbow trout as evidenced by decreasing catch rates with increased distance downstream (Golder Associates 2002b). Entrainment into this reach probably occurs, especially during periods of high abundance in the West Arm of Kootenay Lake, and some entrainment from this reach occurs via Brilliant Dam and power plant (Golder Associates 2002a). Slocan Pool and the Kootenay River apparently supported a high number of rainbow trout prior to hydroelectric development. The Pool hosted a well-known fishing lodge until the 1950s and was still regarded as a good place to fish for rainbow trout even after anadromous salmon runs ended (Cominco Magazine 1952).[38] Current angling effort in Slocan Pool is low (author observations).

The Slocan River, entering the Kootenay River about 2 km below Slocan Pool, is one of the larger rivers remaining in the West Kootenay. Anecdotal information going back to the 1940s gives fairly good evidence that the mainstem of the river supported a moderate number of fluvial trout at that time (Arndt 1999 and references therein); most angling in the drainage was done in the Little Slocan River and its tributaries, and Lemon Creek (for stream resident trout). Fluvial trout in the main river were typically 45 cm or less. An era of improved angling occurred from the mid-1950s to the mid-1970s, coinciding with the peak of phosphorus inputs and high productivity in Kootenay Lake, during which fish of 2-3 kg were common. These large fish apparently were moving from Kootenay River into the Slocan primarily in the spring and fall when temperatures are cooler. Following the decline in phosphorus loading, the population appears to have returned to a lower equilibrium that may be similar to the 1940s, however comparable data are lacking. Changes in Kootenay River discharge after the construction of Kootenay Canal also coincide with the decline and may be partially responsible for the fishery decrease.

[38] Prior to Grand Coulee Dam in Washington (1941) the Kootenay and Slocan rivers supported runs of Pacific salmon (Westslope Fisheries 2001).

Overall abundance of fluvial rainbow trout has probably declined in this unit, particularly in the Kootenay River, due to habitat alterations and the loss of a connection with the Columbia River. Genetic diversity may also be reduced by the fragmentation at Brilliant Dam. The loss of a large river fishery productive enough to support an angling lodge is a significant lost opportunity for the FWCP area.

7.0 SUMMARY OF PRIMARY IMPACTS AND LOSSES ACROSS THE FWCP AREA

7.1 Habitat Losses and Gains

7.1.1 Streams

Construction of dams greatly reduced lotic habitat in the FWCP area. BC Hydro reservoirs inundated over 1,000 km (105 km^2 of area) of stream habitat, with medium and large (orders 6-9), low gradient rivers making up the majority of the losses (92% of total based on area; Thorley 2008). These losses comprised 67% of the large (order 8-9), and 22% of the medium-size (order 6-7) stream habitat that originally existed in the affected dam units at low elevations, and about half of the large river habitat at moderate elevations (Table 8). If the impacts of Koocanusa Reservoir (Bonneville Power Administration) are included, basin-wide losses total about 1,600 km (120 km^2 wetted area; Thorley 2008). The areal extent of losses of wetted side channels in this analysis is uncertain and may be underestimated because smaller channels would not likely be captured at the 1:20,000 scale of historical mapping that was used to quantify the losses (Moody et al. 2007).

Table 8. Kilometres (and percent based on length) of original stream length inundated by BC Hydro dams in the Columbia River basin by elevation, slope and stream order class (from Thorley 2008).

Elevation	**Slope**	**Stream Order**			
		1-2	**3-5**	**6-7**	**8-9**
moderate (650-1000 m)	barrier (>30%)	3 (1)	<1 (<1)	0 (0)	0 (0)
moderate (650-1000 m)	high (7-30%)	13 (3)	19 (2)	<1 (7)	0 (0)
moderate (650-1000 m)	moderate (3-7%)	6 (4)	22 (2)	<1 (<1)	3 (95)
moderate (650-1000 m)	low (0-3%)	55 (7)[a]	48 (3)	199 (20)	88 (46)[b]
low (300-650 m)	barrier (>30%)	5 (26)	2 (20)	0 (0)	0 (0)
low (300-650 m)	high (7-30%)	21 (14)	20 (9)	<1 (27)	0 (0)
low (300-650 m)	moderate (3-7%)	9 (16)	21 (10)	2 (10)	0 (0)
low (300-650 m)	low (0-3%)	82 (34)	59 (16)	84 (22)	309 (67)
Total for elevation <1000 m		195 (9)	192 (4)	287 (20)	400 (61)

[a] An additional 4% of this habitat category was inundated by Koocanusa Reservoir (B.P.A. dam).
[b] An additional 21% of this habitat was inundated by Koocanusa Reservoir.

The large scale flooding of lotic habitat caused a major reduction in rearing and adult habitat for fluvial rainbow trout in the basin, and reduced spawning and rearing habitats for adfluvial populations. Lost stream reaches included much of the better quality habitats in the basin, because all inundated reaches were at elevations less than 1,000 m, and lower gradient reaches were disproportionately affected. Lower elevation reaches have a longer growing season and are often more productive, in terms of species richness and fish biomass, than much of the higher elevation, steeper gradient streams remaining (Thorley 2008; Beecher et al. 1988). Losses in stream habitat would also have affected stream resident populations, but to a lesser degree since it was usually the lower reaches of smaller streams that were flooded and these tend to be dominated by juvenile adfluvial fish (Northcote and Hartman 1988).

As a scoping exercise, Moody et al. (2007) provided a first approximation of standing stock losses of salmonids (all species) in the inundated reaches of 56,250-112,500 kg based on an alkalinity-trout biomass model and assumed useable areas from air photos. Due to the very limited information available on habitat and fish population densities prior to dams, the accuracy of this estimate is uncertain.[39] Glacial turbidity and unfavourably low water temperatures limited the productivity of some reaches and made them less suitable for rainbow trout than other salmonids, particularly in the upper Columbia drainage (Moody et al. 2007; see sections 6.1, 6.4).

7.1.2 Lakes

For the adfluvial ecotype, the overall quantity of lentic rearing habitat increased in the FWCP area due to the gain in large reservoir habitat, but there was a loss of medium- (10-50 km^2) and small-sized (<10 km^2) lakes (Table 9). Three medium-size lakes (Duncan, Kinbasket, and Upper Whatshan) with a combined area of 58 km^2 were inundated. (If Whatshan Reservoir is considered a new medium-sized lake, the net basin-wide decline in area for medium-sized lakes is 40 km^2, or a 29% loss of pre-dam area). Seven small lakes at low to moderate elevations with a combined area of 7 km^2, plus 11 km^2 of wetlands and sloughs (Tables 9 & 10) were flooded. This represents 7% of the pre-dam small lake habitat at these elevations (Thorley 2008). With respect to the quality of small lake habitat, the inundated lakes would be expected to be among the more productive in the basin because of the longer growing season in comparison to remaining higher elevation lakes. Furthermore, the majority of the lakes, wetlands and sloughs were located near or in the Columbia River floodplain, which would substantially enhance their biodiversity value, since they could potentially provide habitat for multiple rainbow trout ecotypes. High turbidity from glacial flows in the Columbia River, however, may have reduced the suitability of Kinbasket and Bush lakes for rainbow trout until later in the growing season (Moody et al. 2007). Four small reservoirs (headponds for run-of-the-river facilities) were created by hydroelectric development (Table 9), but these habitats are mostly outside of the indigenous distribution of rainbow trout, and are likely relatively unproductive compared to natural lakes.

[39] The alkalinity-biomass model was derived from coastal waters supporting cutthroat trout and char. Moody et al. (2007) discuss the limitations in detail in section 5.2.1 of their report and recommend field testing of the model in remaining streams.

Table 9. Lake area prior to dams (km^2), total loss (km^2), total gain (km^2), current area (km^2) and net percent change in area due to inundation by BC Hydro dams in the Columbia River basin by elevation, slope, and size category (from Thorley 2008). Values in brackets indicate the number of lakes. Reservoirs are counted together with lakes for this summary.

Elevation	Size	Prior	Loss	Gain	Current	Change
moderate (650-1000 m)	large (>50 km^2)	0 (0)	0 (0)	370 (1)	370 (1)	Inf*
moderate (650-1000 m)	medium (10-50 km^2)	88 (4)	20 (1)	0 (0)	68 (3)	-23
moderate (650-1000 m)	small (<10 km^2)	81 (607)	3 (4)	<1 (3)	78 (606)	-3
low (300-650 m)	large (>50 km^2)	809 (4)	350 (2)	656 (3)	1115 (5)	38
low (300-650 m)	medium (10-50 km^2)	50 (3)	38 (2)	18 (1)	30 (2)	-40
low (300-650 m)	small (<10 km^2)	13 (73)	4 (3)	4 (1)	14 (71)	6
	Total	1041 (691)	415 (12)	1048 (9)	1675 (688)	

* Inf = percent change is infinity due to zero as the starting value.

Table 10. Shallow water habitat (km^2) inundated by dam construction in the FWCP area (from MacKillop 2008). All losses except for K3 are due to BC Hydro dams.

Dam Unit	C3	C4	C8	C11	K3	K7	All
Area Lost	5.55	0.27	0.05	1.03	2.11	1.72	10.73

Two large natural lakes (Upper and Lower Arrow) were inundated (350 km^2) and replaced by a single reservoir (ALR; 476 km^2). Kinbasket, Revelstoke, Duncan and Koocanusa Reservoirs have also provided gains for large lake/reservoir habitat (676 km^2 in total; Thorley 2008). Quality of lentic habitat has also changed in lakes that now have reservoirs upstream (section 7.4). Although lakes and reservoirs are considered together in this report to simplify the lentic habitat summary, as noted earlier, reservoirs are generally less diverse ecologically and less productive for fish compared to natural lakes, particularly those that have large draw downs in water level during the winter (e.g. Duncan, Kinbasket; Figure 2).

Wetlands and sloughs (including those described as 'shallow water habitat' in Table 10) that were associated with the floodplain of larger rivers were probably highly productive (Moody et al. 2007) and are described by Petersen and Withler (1965a,b) as being very important for fish rearing in the Kinbasket (C3) and Duncan (K7) dam units. Although not usually considered to be prime rainbow trout habitats, these areas may have been exploited by rainbow trout juveniles or adults seasonally, or may have provided rearing for other fish or invertebrates that they preyed upon.

These habitat losses have direct consequences with respect to societal values and affect both local and provincial residents. Extirpation of fluvial and small lake adfluvial populations (or amalgamation with adfluvial ones) represents lost biodiversity values for the region as a whole. While not necessarily reducing overall rainbow trout abundance for individual dam units or the FWCP area as a whole, there have nevertheless been socioeconomic consequences such as lost opportunities for large river and small lake trout fisheries (and associated economic benefits to local communities) which are relatively uncommon in the West Kootenay.

7.2 Habitat Fragmentation and Impacts to Fish Movement and Migration

Migrations by adults from rearing habitats to spawning areas, and by juveniles from spawning to adult habitats, are an integral part of the life history for fluvial and adfluvial populations (Behnke 1992). Movements from summer to winter habitats are also critical to the survival of trout in many streams and rivers (Cunjak 1996). Dam construction substantially fragmented rainbow trout migration corridors in the West Kootenay. In the pre-dam period, the only barriers to upstream movement in large rivers were Bonnington Falls[40] on the Kootenay River about 20 km upstream of the Columbia-Kootenay confluence, and Kootenai Falls upstream of Kootenay Lake near Libby, Montana, which was the eastern limit of indigenous rainbow trout distribution. In the Kootenay drainage, movement of rainbow trout was possible among Kootenay, Duncan, and Trout Lakes and the connecting streams before dams. In the Columbia drainage, movement was possible from the Arrow Lakes upstream to the headwaters of the Columbia River, and throughout the Canadian portion of the lower Columbia River and tributaries such as the Pend d' Oreille, lower Kootenay, Slocan and Salmo.

After hydroelectric development, Revelstoke and Keenleyside dams isolated the Arrow Lakes from the remainder of the Columbia River drainage, leaving only tributaries adjacent to the ALR for spawning and rearing of remaining adfluvial populations in ALR. Among the populations affected was a unique adfluvial piscivorous stock of 'yellowfin' rainbow trout in the Arrow Lakes (section 6.5.3), which appears to have been extirpated as result of blocked access to spawning habitat in Camp Creek upstream of Mica Dam. (Kinbasket Reservoir adjacent to Camp Creek was apparently not suitable for their survival.) The Columbia drainage upstream of ALR is further divided by Mica Dam, and downstream of Keenleyside Dam, the Columbia drainage is fragmented by Seven Mile and Waneta (Teck Cominco) dams, which prevent access to the Pend d' Oreille and its tributaries. Brilliant Dam fragments the Columbia from the lower Kootenay River and its tributaries. The remaining tributaries accessible to fluvial trout in the lower Columbia River are small relatively steep systems between Keenleyside Dam and the U.S. border (section 6.8). In the Kootenay drainage, habitat fragmentation has not been as extensive, although Duncan Dam has eliminated fish movement between Kootenay and Duncan lakes (section 6.12).[41] Habitat fragmentation may have also occurred in some of the smaller sub-basins as a result of hydroelectric development (e.g., Whatshan, Walter Hardman), but impacts were likely relatively minor given that natural barriers were already present or close by.

The loss of access to historical spawning and rearing habitat can result in the loss of genetically distinct populations as mentioned above, and other genetic and life history biodiversity that cannot be maintained by hatchery programs (Behnke 1992). It may also have resulted in decreased abundance or resilience of some of the remaining populations (discussed by dam unit in section 6.0), which in turn would reduce the socioeconomic value of the fisheries. Some potential fish migration viewing opportunities may also have been eliminated in the region (e.g., Bonnington Falls).

[40] One long-time resident of Nelson, B.C. (cited in Westslope Fisheries 2001) was of the opinion that salmon could pass over Bonnington Falls prior to the construction of the power plant in 1929. If this is true there might also have been passage of rainbow trout.

[41] The four other dams on the Kootenay River downstream of Kootenay Lake (Corra Linn, Upper Bonnington, Lower Bonnington, and South Slocan) are operated by Fortis BC, and are built in a steep reach where passage was doubtful or limited prior to dams.

7.3 Changes in the Amount and Spatial Extent of Aquatic-Terrestrial Species Interactions

The large-scale conversion of river and streams habitats to impoundments has resulted in a major reduction in connectivity between streams and their riparian zones, and wetland habitats associated with the former floodplains of large rivers within the basin (Moody et al. 2007). One impact of this change that has the potential to affect rainbow trout and other stream fish is the loss or reduction in the recruitment of large woody debris in rivers downstream of dams, particularly Duncan, Elko, Spillimacheen, and Aberfeldie dams. This is an important component of stream structural diversity and fish production (Keeley and Slaney 1996). Compared to that for previously existing lakes, aquatic-terrestrial connections along the shorelines of the large reservoirs have also been greatly reduced because of the drawdown zone separating the wetted edge from the zone of permanent vegetation (except when reservoirs are at full pool). One potential consequence of this change is a reduction in availability of terrestrial food for adfluvial insectivores.

7.4 Nutrient Effects and Turbidity Changes

7.4.1 Lentic

Primary production in lakes and reservoirs can be separated into littoral zone production, where light reaches the substrate, and offshore pelagic production. Changes in littoral primary production would likely have a greater influence on insectivorous adfluvial populations of rainbow trout, whereas altered pelagic productivity is likely to affect mainly piscivorous stocks (in lakes where they are present) because of the latter's reliance on kokanee and the close connection between kokanee production and pelagic productivity (Parkinson et al. 1989, Rieman and Myers 1992, Pieters et al. 2003).

Basin-wide estimates of post-dam littoral production were judged to be higher overall compared to the pre-dam period (Table 11) because of the increase in total shoreline length, although in some cases post-dam littoral habitat was considered to be less productive per unit area than pre-dam habitat (Moody et al. 2007). Kootenay Lake and Revelstoke Reservoir, with their relatively stable water levels, have relatively high littoral and macrophyte production estimates compared to Kinbasket, Duncan, and Koocanusa reservoirs, which have more severe drawdowns (Moody et al. 2007). Littoral productivity is generally poorer in reservoirs because of a much greater magnitude and altered timing of fluctuations in water level. However, in the original Arrow Lakes, the pre-dam annual fluctuation in water level was quite high (7-12 m; Maher 1961, Moody et al. 2007) due to the large freshet of the Columbia River. Consequently its pre-dam littoral production was judged to be lower than natural lakes with lesser inflows. Kootenay Lake also experienced large fluctuations in water level in conjunction with the Kootenay River freshet (~7 m; http://fortisbc.com/customer_service/lake_levels_history.html).

The overall increase in littoral primary production due to the increase in lentic area (Table 11) would not necessarily benefit the adfluvial insectivorous ecotype in large lakes/reservoirs because the pattern of water level fluctuations under present dam-regulated regimes usually differs significantly from a natural hydrograph. This reduces macrophytes and benthic invertebrate production (Ploskey 1986). Also, the relative value of large areas of low productivity littoral habitat in comparison to small areas of highly productive habitat is unknown. Available diet studies suggest that terrestrial insects, rather than aquatic, are most important to insectivorous adults in post-dam ALR (Arndt 2004a), implying relatively low production of aquatic insects. No diet studies for juvenile adfluvial fish are available.

Table 11. Estimated primary productivity for pre- and post-dam lakes and reservoirs in the Columbia River basin (from Tables 10 and 11 in Moody et al. 2007). Post-dam primary productivity estimates are based on professional judgement taking into account turbidity and nutrient changes, and paleolimnological data for the Arrow Lakes.

Dam Unit	Lake	Surface Area (km^2)	Daily Pelagic Primary Production (mg C/m^2)	Annual Primary Production (t C/year)		
				Pelagic	Littoral	Macrophytes
PRE-DAMS						
C3	Kinbasket Lake	20	130	477	29	13
	Bush lakes	3	135	75	5	3
C11	Arrow Lakes	350	75	4,788	143	15
C8	Whatshan Lake	15	95	263	39	5
K6	Kootenay Lake	390	125	8,775	263	20
K7	Duncan Lake	26	85	395	18	8
POST-DAMS						
C2	Spillimacheen headpond[a]	<1	85	3	<1	0
C3	Kinbasket Reservoir	370	80	5,328	107	18
C4	Revelstoke Reservoir	114	75	1,546	93	23
C11	Arrow Lakes[b]	476	92	7,886	157	33
C8	Whatshan Reservoir	18	90	285	11	2
C10	Pend d' Oreille Res.	4	70	54	2	1
K2	Aberfeldie headpond[a]	1	75	16	1	0
K3	Koocanusa	60	95	1,026	31	1
K4	Elko headpond[a]	2	80	26	1	0
K6	Kootenay Lake[b]	394	125	8,865	355	18
K7	Duncan Reservoir	65	85	995	30	6
K9	Corra Linn Brilliant	1	75	7	<1	0

[a] rainbow trout not present
[b] prior to nutrient additions

With respect to pelagic productivity, the presence of melting glaciers caused high turbidity in the large rivers and lakes of the FWCP area during the early part of the growing season prior to hydroelectric development (Northcote et al. 2005). Impacts of new reservoirs upstream of the ALR and Kootenay Lake on primary production were both negative (reduced nutrient input) and positive (reduced turbidity) (Moody et al. 2007; Northcote et al. 1999). According to Moody et al. (2007), primary productivity was limited primarily by light penetration in these systems prior to dams and nutrients after dams. The large uncertainty in the two opposing effects makes determination of pre-dam productivity difficult (Matzinger et al. 2007; Moody et al. 2007). Nevertheless, the analysis by Moody et al. (2007) suggests that post-dam pelagic primary production exceeded the pre-dam level (Table 11), resulting in increases in kokanee abundance [42] (Table 12). Three of the reservoirs (Kootenay, Arrow, and Koocanusa) have adfluvial piscivore populations that could benefit directly from expanded kokanee abundance. However, predicted kokanee abundance does not always match well with post-dam hydroacoustic estimates or spawner trends (Arndt 2009). In the ALR and Kootenay Lake, for example, spawner counts indicate that kokanee populations may have declined in the post-dam period, although here again there is uncertainty because

[42] The model used to predict kokanee abundance was modified from a sockeye model developed in coastal lakes that do not have mysids.

of the lack of reliable pre-dam data (Arndt 2009). A separate primary productivity analysis for the ALR suggests that operational hydraulic alterations not specifically considered in the Moody et al. (2007) report (such as changes in seasonal flows, increased water level, and subsurface water release), may have reduced post-dam productivity in the reservoir by up to 40% in addition to (footprint) reductions from upstream nutrient retention (Matzinger et al. 2007). Other post-dam changes may have affected the efficiency of food webs in the large lakes as well. In particular, the establishment of mysids in both Kootenay Lake and ALR may have diverted resources away from kokanee because they are effective competitors for large zooplankton (Northcote 1991). In contrast, decreased turbidity could make kokanee more vulnerable to sight-feeding predators like rainbow trout (Behnke 1992) as suggested by the increased presence of piscivorous fish in the south arm of Kootenay Lake after Libby Dam (section 6.11.4).

Table 12. Estimated pelagic primary productivity and predicted kokanee abundance (all age classes) in historical kokanee lakes before and after dams in the FWCP area (from Moody et al. 2007). Kokanee abundance is estimated using a photosynthetic rate model sensitive to primary production and lake surface area. Surface area increased substantially for Arrow Lakes Reservoir and Duncan Reservoir (see Table 11). The model does not account for mysid competition.

Lake/Reservoir	Primary Productivity (daily mgC/m^2)		Kokanee Abundance (millions)	
	Pre-dam Period	**Post-dams**	**Pre-dam Period**	**Post-dams**
Kootenay	125	125	13.60	13.73
Arrow	75	92	7.34	11.90
Duncan	85	85	0.61	1.54
Whatshan	95	90	0.41	0.44

7.4.2 Lotic

River and stream productivity losses due to inundation were generally proportional to the areas impounded and are estimated to be around 5,500 tC/year for the entire basin (Table 13). Many of the streams upstream of Kinbasket Reservoir had high glacial turbidity, which tends to reduce biological productivity; much of the production in these systems was likely heterotrophic. As mentioned earlier, stream production loss estimates may be conservative because side channels were difficult to quantify at the map scale used (Moody et al. 2007). The post-dam reduction in spring and early summer turbidity likely benefited rainbow trout (Behnke 1992) in the large river habitats remaining below dams (see section 6.8 for an example).

Moody et al. (2007) also estimated a very large loss of wetland and floodplain primary productivity after dams. They considered the pre-dam wetlands and floodplain habitats within the footprint zone to be highly connected to the lotic and lentic environments, and believed that 45 – 90% of the net primary production in the floodplain was likely to export to aquatic food chains. Gross primary production[43] export was estimated to be 75,380 tC/year prior to dams compared to 10,800 t C/year post-dams (Table 14), a reduction of 86%. The extent to which this export would be incorporated into lentic and lotic rainbow trout production is highly uncertain (but see section 6.3.2 for an example).

[43] Gross primary production (GPP) was estimated as two times net primary production (NPP) by Moody et al. (2007).

Table 13. Estimated gross primary production losses from rivers and streams impounded by dams in the Columbia River basin listed in order of importance (from Table 18 in Moody et al. 2007).

Dam Unit	**Reservoir or Dam**	**Gross Primary Production (t C/year)**
C3	Kinbasket	1,676
C4	Revelstoke	1,566
C11	Arrow Lakes (Revelstoke-Arrowhead)	369
C11	Arrow Lakes (Arrowhead-Keenleyside)	792
K3	Koocanusa	877
K7	Duncan	127
C10	Pend d' Oreille (Seven Mile and Waneta Dams)	106
C8	Whatshan	6
C2	Spillimacheen	<1
K2	Aberfeldie	<1
Total		**5,519**

Table 14. Estimated pre- and post-dam gross primary production (GPP) carbon export from wetlands and floodplain to the aquatic realm in tonnes of carbon per year (from Tables 25 to 27 in Moody et al. 2007).

Dam Unit	**Estimated Export (tC $year^{-1}$)**	
	Pre-Dams	**Post-Dams**
C3	44,078	4,096
C4	6,824	-
C11	11,916	5,862
C8	28	-
C10	10	-
K3	5,756	478
K7	6,762	362
K9	4	-
Total	75,378	10,798

7.5 Water Quality and Temperature Regime in and Downstream of Reservoirs

Footprint and operational impacts can alter temperature, dissolved oxygen, and other water quality parameters in reservoirs and downstream habitats that in turn affect distribution, depth utilization, and feeding of rainbow trout. For the most part, rainbow trout distribution in the FWCP area has not been affected by water quality; however, in the impoundments of the Pend d' Oreille River drainage, temperature and other parameters are less suitable for rainbow trout than was likely the case prior to hydroelectric development, and this reach has reduced habitat value for rainbow trout (section 6.9). Feeding or behavioural effects (either detrimental or beneficial) may also be influencing the life history of some populations. For example, warmer winter temperatures below dams could be detrimental if increased metabolic requirements cannot be offset by adequate food, but could be beneficial under good feeding conditions, and gas supersaturation below Keenleyside and Brilliant dams may inhibit use of shallow water (see section 6.8). Flooding of terrestrial soil and vegetation often causes mercury concentrations in aquatic biota to increase, but sampling to date has shown that fish mercury levels in Columbia basin waters are low (<0.5 ppm; Aqualibrium Environmental 2002).

7.6 Sediment Transport, Morphological Change Due to Interception of Bedload

In some cases, trapping of gravel in reservoirs and release of clear water downstream can eliminate smaller, mobile grains from streambeds below dams leaving only coarser particles that are too large for use by spawning salmonids (Kondolf 2000). It is also possible that the elimination of peak discharge results in less gravel movement and thus more embedded substrate that inhibits spawning. These factors have the potential to negatively affect all lotic habitats below dams including smaller run-of-the-river facilities, but there are no data to examine this potential impact for the FWCP areas.

In the Columbia River below Keenleyside Dam, gravel inputs from small tributaries appear to be providing good spawning habitat for rainbow trout in certain reaches (e.g., Norns Creek fan, Genelle reach), and the reduction in peak flow due to flood control and power storage operations may allow gravels recruited from these streams to remain at depths suitable for mainstem spawning. Capture of fine sediment by dams may also contribute to the maintenance of spawning gravels in this reach and in the Duncan River below Duncan Dam, although again, data to test this notion are largely lacking (but see section 6.8).

7.7 Entrainment

Locations where rainbow trout entrainment can potentially occur within the basin include:

- from Kinbasket Reservoir into Revelstoke Reservoir,
- from Revelstoke Reservoir into Arrow Lakes Reservoir,
- from Arrow Lakes Reservoir into the Columbia River[44],
- from Koocanusa Reservoir into Kootenay River,
- from Duncan Reservoir into Kootenay Lake,
- from Kootenay Lake into lower Kootenay River,[45]
- from the Slocan and lower Kootenay into the Columbia River,
- from Boundary Dam into Seven Mile Reservoir, and
- from Seven Mile Reservoir into Waneta Reservoir on the Pend d’ Oreille River.

The biological significance of entrainment for rainbow trout populations is not known for any of the BC Hydro facilities, although large fish are less susceptible to entrainment velocities than small fish (Taft et al. 1992, cited by R.L. & L. 1997). Data are not available for most of the dams, although hydroacoustic assessments combined with forebay gill-netting were done for Keenleyside Dam (C11) in 1983 and 1984 (Smith 1985). Crude estimates from that study suggest that 6,000 rainbow trout could be entrained annually with a mortality of 6% assumed for entrained fish (R.L. & L. 1997).[46] Installation of a fourth turbine at Seven Mile Dam is expected to increase fish entrainment; estimates based on forebay sampling and a number of assumptions were in the order of 500 to 700 rainbow trout (>170 mm) per year, with estimated mortality rates for larger fish from 10% to 30% (study authors caution that these numbers should not be used in a quantitative manner; R.L. & L 1995). Fish that survive entrainment would be able to find suitable habitat below the dams, but are lost to their original populations. A methodology for

[44] Some trout likely pass over the dam or through low level outlets during spills, and there is entrainment through the Arrow Lakes Generating Station (Columbia Power Corporation). Minor movement through the boat locks is also possible.
[45] Entrainment may occur through the Kootenay Canal facility (BC Hydro) or the generating plant owned by Fortis.
[46] Hydroacoustic targets were assumed to be fish over 6 cm length.

assessing the magnitude and nature of entrainment at BC Hydro facilities has recently been developed (BC Hydro 2006), and estimates are not yet available.

7.8 Lost Opportunity

The inundation of most large river habitat, some medium and small rivers, and the lower reaches of tributaries and several small lakes has resulted in lost opportunities for fisheries enhancement and recreation in the basin. Loss of possibly unique genetic resources (e.g., yellowfin trout in the ALR or Duncan River piscivores) also represents lost opportunity to develop unique fishing and viewing opportunities.

7.9 Summary of Major Changes in Rainbow Trout Production and Diversity

Habitat changes (section 7.1) and population changes detailed in section 6.0 are summarized in Table 15. As mentioned earlier, the fluvial rainbow trout ecotype was impacted the most by hydroelectric development, with their distribution and abundance greatly reduced in the FWCP area. This loss has not been addressed by any large-scale FWCP projects to date. In addition, fluvial populations in dam units C9, C10, and K9 (Salmo, Columbia, and Slocan rivers) are isolated from other habitats and populations, which, in some cases, may have reduced the productivity of remaining habitat. For adfluvial ecotypes, phenotypic and genetic diversity has been reduced due to blocked assess or inundation of spawning and juvenile rearing habitat (Table 15). Regionally significant populations of adfluvial piscivores in the ALR and Kootenay Lake may have experienced additional decreases in productivity without intervention (lake fertilization) to enhance kokanee populations. The stream resident ecotype has been impacted a lesser degree than other ecotypes (Table 15). Smaller power plants that divert water from higher elevation reaches (e.g. Whatshan, Cranberry) have likely had the most significant impact on this ecotype.

Establishment of rainbow trout in Koocanusa Reservoir (not a BC Hydro facility) has increased rainbow trout distribution and abundance in the upper Kootenay River drainage basin, but this has resulted in competition and genetic hybridization with the blue-listed westslope cutthroat trout indigenous to these rivers (Rubridge et al. 2001, McPhail 2007).

Table 15. Summary of habitat changes and potential population change by rainbow trout ecotype for dam units within the FWCP program area. Ecotypes are stream resident (R), fluvial (F), adfluvial insectivore (AI), adfluvial piscivore (AP) and adfluvial small lake (Asl).

Dam Unit	Habitat Change by Life History Stage			Population Change by Ecotype	Comments
	Spawning	Juvenile Rearing	Adult		
C1 Columbia headwaters	No change	No change	No change	Uncertain	Adfluvial fish from Kinbasket Reservoir probably utilize this reach for spawning. Kokanee spawners from reservoir may increase productivity of rearing habitats in the Columbia River and lower reaches of some tributaries.
C2 Spillimacheen	Minor	Minor	Minor	Uncertain	Dam built on existing barrier; reduced flows to 1.5 km between headpond and plant may decrease habitat capacity.
C3 Kinbasket	Decrease	Decrease	F- 100% loss R- Decrease Asl-Decrease AI- Increase AP- Increase	F- Extirpated R- Slight decrease Asl- Decrease AI, AP – Possible increase	Large river fluvial ecotypes and at least four small lake adfluvial populations replaced with adfluvial insectivorous life history in large reservoir. Overall abundance possibly increased although reservoir fluctuations limit habitat suitability for both AI and AP. Piscivore abundance appears very low and may depend on stocking. Original Arrow (yellowfin) stock extirpated.
C4 Revelstoke	Decrease	Decrease	F- 100% loss AI- Increase	F- Extirpated AI-Increase	Resident ecotype likely uncommon in lower tributary reaches that were flooded. Conversion of large river fluvial habitat to reservoir lentic.
C6 Cranberry	Decrease?	Decrease	R-Decrease	R-Decrease AI-Uncertain	Decommissioning of dam has allowed Coursier Lake to return to historical level. Diversion of flow reduces stream carrying capacity for resident fish and may reduce spawning for adfluvial migrants.
C8 Whatshan	Decrease?	Decrease	R-Decrease Asl-Uncertain	R-Decrease Asl-Uncertain AI -Uncertain	Flow diversion reduces capacity for stream resident fish and may reduce spawning and rearing for adfluvial in lower reaches. Lentic area has increased slightly but primary productivity slightly decreased.
C9 Lower Columbia	Possible increase in mainstem Columbia River	Uncertain; possible increase due to post-emergence stabilization and higher winter flows; possible decrease due to short-term fluctuations	Quantity unchanged; possible increase in food supply and longer growing season	F- Uncertain R- No change	Quantity of fluvial habitat is unchanged but factors such as a more stable discharge and moderated temperature may have expanded niche for juvenile and adult rearing. Reduction in peak flows probably links to increase in mainstem spawning. Probable increase in export of nutrients and mysids from Arrow Lakes Reservoir nutrient additions could benefit growth in river. Anecdotal accounts describe high quality fishing prior to dams. Current fishing high quality.
C10 Pend d' Oreille	Minor Decrease	Decrease	F- 100% loss in Pend d' Oreille River mainstem	F- Decrease AI– negligible increase R– No change	Fluvial habitat eliminated; reservoir habitat is marginal for trout. An isolated fluvial population remains in the Salmo River that is probably limited by adult rearing habitat.

Table 15 continued.

Dam Unit	Habitat Change by Life History Stage			Population Change by Ecotype	Comments
	Spawning	Juvenile Rearing	Adult		
C11 Arrow Lakes	Decrease	Decrease	AI,AP- Uncertain F- Decrease	AI,AP- Uncertain F- Decrease R- No change	Dams blocking access to upstream and downstream spawning areas, and flooding of lower reaches has significantly reduced juvenile rearing capacity. Lentic area and water clarity increased, but it is uncertain how this affects AI ecotype. Decrease in kokanee abundance probably linked to decrease in AP ecotype. Yellowfin stocks appear to be extirpated. Resident ecotype is uncommon in lower tributary reaches that were flooded.
K1 Kootenay headwaters	No change	No change	No change	F- Increase AI, AP- Increase	Outside historical distribution. Establishment of strong adfluvial populations in Koocanusa Reservoir has resulted in substantial increase in the presence of adfluvial spawning in this reach and also establishment of fluvial trout that are hybridizing with indigenous cutthroat trout. No BC Hydro impact.
K2 Bull River	-	-	-	Not Present	Rainbow trout are not present in the river due to natural barriers.
K3 Koocanusa	Decrease	Decrease	AI, AP - Increase	AI,AP- Increase	Introduced adfluvial rainbow trout utilize the reservoir. No BC Hydro impact.
K4 Elko	-	-	-	Not Present	Rainbow trout are not present (or are at very low abundance) in Elk River due to natural barriers.
K5 Kootenay River to border	No change	No change	No change	Uncertain	Present in moderate abundance in summer (possibly adfluvial fish use).
K6 Kootenay Lake	Decrease	Decrease	Uncertain	AI,AP- Uncertain R- No change	Decreased nutrients and increased water clarity in the lake. Comparable pre-impact abundance not available. Duncan Dam blocked access to upper Duncan drainage and flooded piscivore spawning area. Recent evidence of spawning below dam. Non-dam impacts complicate analysis.
K7 Duncan	Decrease	Decrease	AI, AP – Increase F-Decrease	Uncertain	Possible loss of genetic diversity in relation to fish spawning in the lower Duncan River, although continued spawning below the dam has been recently confirmed. Increase in lentic area may benefit adfluvial fish.
K8 Lardeau	No change	No change	No change	Uncertain	Habitat is not directly affected by dams.
K9 Lower Kootenay River and Slocan drainage	Minor	Decrease	F-Decrease	F- probable decrease in Kootenay R. and possibly Slocan	Large river habitat affected by changes in hydrograph and impoundment by Brilliant Dam. Kootenay and Slocan rivers isolated from previous connection with Columbia River.

8.0 COMPENSATION OPTIONS AND COSTS

8.1 Compensation Context

One framework for prioritizing compensation is the fish habitat management policy of the Canada Department of Fisheries and Oceans (DFO). The goal of the policy is “no net loss of the productive capacity of habitats” (DFO 1986), where productive capacity is defined in terms of healthy aquatic environments that support fish populations that are safe for human consumption. If disruption of the natural productive capacity has occurred, the hierarchy of preferences is first to replace “like for like natural habitat at or near the site” of damage. If this is not possible, the second preference is “off-site” replacement habitat, or increasing the productivity of remaining habitat. The lowest preference, for cases where no habitat replacement options are feasible, is artificial propagation (i.e., fish hatcheries or spawning channels), provided that genetic and biological criteria are met, and proven techniques are available.

A second framework for determining appropriate compensation is provided by Jones et al. (1996) and Reeve et al. (2006). Both emphasize the need to address primary limiting factors when attempting to maintain productive capacity, rather than having a strict focus on habitat loss. For example, replacement of lost spawning habitat will result in minimal population increase if factors later in the life history are more limiting (Mason 1976). This approach may be particularly relevant when considering rainbow trout populations in a large fluvial or lake ecosystem, since in some cases juveniles are spending at least one winter in smaller tributaries before moving into lake or larger fluvial adult habitat. Reeve et al. (2006) recommend the following strategy:

1. identify limiting ecological conditions
2. set specific restoration objectives
3. monitor and evaluate for at least 10 years to test hypotheses about limiting factors.

They also note that compensation approaches should have a goal of maintaining the habitat required to provide broad life history diversity in natural spawning fish, and recognize that evaluation of project success should be based on quantified ecological improvement rather than easily measured outputs such as funds spent or the number of fish stocked. Jones et al. (1996) noted that habitat change may result in no change to overall production, but a pronounced shift in species composition and diversity.

Like for like compensation for inundated lotic habitat, arguably the most significant impact on rainbow trout in the basin, must necessarily be off-site. Maintaining and enhancing the productivity of remaining streams that support fluvial trout populations in the FWCP area should be a priority whether or not they are in impacted dam units. It must also be recognized that many of the best opportunities for restoration or enhancement are in areas that have been affected by other impacts; therefore it may be necessary to collaborate with other agencies (e.g. Ministry of Transportation, Ministry of Forests, agricultural and domestic water users) to achieve an improvement in remaining habitats. Compensation initiatives for spawning and juvenile rearing habitat are potentially applicable to all rainbow trout ecotypes in the FWCP area because they all use streams for spawning and rearing. In contrast, adult habitat enhancement options differ between stream ecotypes and adfluvial ecotypes.

A plan providing a list of activities and priorities aimed at more effective inventory, restoration, and habitat protection has been developed for ALR rainbow trout (Spence et al. 2005). To better understand the population dynamics of these fish, it will be necessary to first identify spawning streams (particularly for piscivorous fish) and then develop, if possible, a reliable method of monitoring population trends. Creel surveys are valuable for measuring the harvested component of a population, but are not always a reliable indicator of abundance because catch rates can be influenced by other factors such as changes in angler effort or prey abundance. Compensation options with potential for general application are discussed below and summarized in Appendix F.

8.2 Spawning Habitat Enhancement or Replacement

Spawning enhancements are popular with the public and biologists alike because the results are tangible (visible spawning fish and measurable fry production), and intuitively seem likely to be beneficial. However, Behnke (1992) notes that in many instances more young are produced than the population can absorb, and recommends that agencies be certain that poor spawning success actually limits population size before attempting to improve spawning habitat or juvenile production. The following techniques are listed as options for compensating for lack of adequate spawning habitat. Large investments in these are advisable only when there is evidence that spawning is limiting. Small investments (especially small public projects) might be done on an experimental basis, or perhaps rationalized as maintenance of resilience in unique local populations.

8.2.1 Spawning Channels

Hill Creek Spawning Channel (HCSC) was designed to provide spawning habitat for adfluvial rainbow trout and kokanee in the ALR (Lindsay 1982), and is currently used by both piscivorous and insectivorous rainbow trout ecotypes (see 6.5.4). At this time there is insufficient information on the population dynamics and spawning locations of rainbow trout in the ALR to determine whether spawning and early rearing habitat are likely to be limiting for adfluvial populations. However, given the paucity of information on spawning especially for piscivorous fish, it is recommended that HCSC continue to be operated to facilitate trout use. This should include a delay in the start of summer gravel cleaning to allow trout fry to emerge from the gravel, maintenance of deeper holding pools at the end of each gravel platform, and avoidance of bank damage during the gravel cleaning process. Holding pools appear to be important for cover during spawning as adults typically stay in this deeper water during daylight and spawn overnight (B. Barney, channel operator, pers. comm.). They may also provide winter habitat for juveniles. Fry densities in summer are generally highest close to banks with overhanging vegetation. Temporary spikes in turbidity during late summer gravel cleaning do not appear to reduce rainbow trout fry densities in the channel (Porto and Arndt 2006).

Redfish and Kokanee Creek spawning channels in the west arm of Kootenay Lake also appear to support rainbow trout spawning populations (Andrusak 2006). Meadow Creek Spawning Channel (MCSC), on the other hand, is not used for spawning by rainbow trout to a significant degree (J. Bell, MOE, pers. comm.). Reasons for this are unknown, although MCSC lacks the deeper holding pools that are present in HCSC.

Spawning channels could be considered as near site “like for like spawning habitat” for rainbow trout, which is a compensation option preferred by the DFO. Unlike kokanee, the number of juvenile rainbow trout produced by the existing spawning channels represents a small fraction of total production in each system (at least for adfluvial insectivores), and therefore some of the detrimental effects associated with artificial production (e.g., loss of genetic diversity due to competition between enhanced and wild stocks in the reservoir) may be less of a concern. Nevertheless, water withdrawals from other tributaries to support spawning channels (e.g., McKenzie Creek) likely reduce the juvenile carrying capacity of the donor stream.

Annual operating budget for the HCSC, including partner contributions, is currently $150,000. Most of the costs are related to kokanee production, with minimal monitoring of rainbow trout. Annual gravel cleaning is a necessity for both species.[47] Long-term capital maintenance costs are not included in the above amount, and there is a current need for repair and maintenance work at both facilities. There is also a possibility that more stringent environmental regulations will be applied to the gravel cleaning process in the future, in which case there would be significant capital costs and increased operational costs (see section 8.5.2). Specific funding for existing rainbow trout monitoring (redd counts and minimal fry emigration) is $5,100 annually. Addition of cover structures in existing pool habitats might enhance habitat for older juveniles (section 8.3.4).

Project level performance indicators for spawning channels include annual counts of spawners or redds (by ecotype), sampling of emergent fry or late summer juvenile densities, or trapping of juvenile out-migrants. Program level performance indicators would need to be developed in the context of overall reservoir populations, and could include an annual creel survey to estimate total angler effort and harvest in the reservoir. Once important spawning streams are identified (Spence et al. 2005), annual monitoring of spawner escapement in index streams using calibrated resistivity counters (where possible) should also be considered.

8.2.2 Stream Gravel Additions

It is possible that some streams may be deficient in suitable-sized gravel due to a lack of gravel deposits in the drainage. In such cases, the addition of gravel could be tried as a relatively inexpensive spawning habitat enhancement measure. Lack of gravel deposits can also be indicative of hydraulic conditions that do not allow gravel to remain in the stream, and habitat restoration (see 8.3.4) may be needed to provide the hydraulic conditions to allow naturally-recruited or added gravel to be retained in areas where fish can use them for spawning. This was a goal of a previous project on Norns (Pass) Creek, a spawning tributary for fluvial trout below Keenleyside Dam. Post-restoration observations suggest some degree of success with this project (Zimmer 2000). Another example is Sproule Creek, a tributary of the west arm, where an FWCP project used boulder structures and gravel as a means of enhancing spawning and juvenile production (Arndt 2002a, 2003). A gravel addition experiment is currently ongoing in Boulder Creek, a south arm tributary of Kootenay Lake. Project level performance indicators could include post-freshet assessments of gravel retention and spawning use.

[47] Kokanee egg-to-fry survival at Hill Creek Spawning Channel was less than 5% in 2004 and 2005, most likely due to high deposition of sediments in the gravel associated with record fall rainfalls in those years (Porto 2006).

8.2.3 Artificial Propagation

If spawning or stream rearing habitat is deemed to be the limiting factor for a trout population and there are no options for restoring a self-sustaining population, a hatchery program can be considered for preventing extirpation of a particular stock or maintaining the presence of a particular ecotype. For example, white sturgeon *Acipenser transmontanus* recruitment in the FWCP area is currently being maintained by a hatchery program, and piscivorous rainbow trout have been stocked in the ALR in the past. Stocking of small lakes with limited inlet or outlet streams is also an option, particularly those supporting populations that were introduced to provide recreational fishing opportunities.

This method is the least preferred of the DFO compensation hierarchy, and is not always successful at the program level. Hill Creek Hatchery was funded from the 1980's to 2000 in an attempt to compensate for lost spawning and rearing habitat for adfluvial rainbow trout (and bull trout) in the ALR at an annual cost of ~$200,000. Stocking of Kootenay Lake Gerrard stock up to the 1990's appears to have resulted in interbreeding with indigenous rainbow trout in the lake (Taylor and McLean 1999; see section 4.1). Ultimately Hill Creek Hatchery was closed as project level targets (i.e., the number of juveniles stocked) were met in some years but program level targets (i.e., number of hatchery fish in the adult population) were not; proportions of marked hatchery rainbow trout and bull trout in angler catch were typically < 2%, indicating very low survival and negligible contributions to the adult population (Arndt 2002b, 2004b). At present, no other large lake hatchery programs are recommended for FWCP, although this could be an option as better information on population dynamics is obtained. Taylor and Tamkee (2005) and Taylor (2000) provide genetic recommendations specific to the FWCP area if hatchery stocking of rainbow trout is considered. Currently some stocking of sterile Gerrard rainbow trout continues in the ALR on an experimental basis (Freshwater Fisheries Society of BC) with FWCP monitoring of fin-clipped fish in angler catch ongoing.

Hatchery stocking is more likely feasible for compensating for lost fisheries in small lakes, as there are many examples of successful small lake fisheries maintained by hatchery stocking in the province. The role of the FWCP would be to identify lakes with potential for development of high quality small lake fisheries, and to fund investigations to determine their suitability and any related risks (e.g., impacts to invertebrate and amphibian communities). Hatchery fish could be obtained by an arrangement with the Freshwater Fish Society of BC. Use of sterile fish would allow the introduction to be reversed if necessary, and also allow for control of densities to meet size objectives. Cost of these preliminary investigations is estimated at $20,000 per small lake.

Project level performance indicators for hatchery propagation include number of adults spawned, eggs collected, and number and size of juveniles stocked. Program level indicators include an increase in trout abundance in the target lake or reservoir, changes in the number and size of trout in angler catch, and the proportion of marked fish in the catch. A high proportion of hatchery fish in the catch indicates success only if there is a net increase in trout abundance, since stocking large numbers of hatchery fish could result in decreased survival for wild fish and eventual replacement of natural populations with hatchery fish.

8.3 Restoration and Enhancement of Stream Rearing Habitat

For most populations in the FWCP area, juvenile habitat is more likely than spawning habitat to limit recruitment (see Section 5.1). With respect to population regulation for adfluvial and fluvial ecotypes, the relative importance of adult carrying capacity in lake or reservoir habitat versus juvenile carrying capacity in tributary stream habitat has not been investigated, and likely varies among systems depending on the quantity and productivity of the two habitat types. However, it quite possible that juvenile production plays an important role for some populations.

8.3.1 Stream Flow Conservation and Restoration

Many, if not most, of the remaining streams providing habitat for rainbow trout in the FWCP area have licensed water withdrawals for domestic or irrigation purposes. These withdrawals directly reduce the volume of habitat available for fish and can result in increased water temperatures in summer or lower temperatures in winter, which may negatively impact fish survival or growth (Hay 2004; Harvey et al. 2006). Unfortunately, water demands are typically highest during late summer when water levels are at their lowest. Current provincial water allocation legislation does not consider fish habitat when granting licences. The cumulative impact of numerous water licenses (even small ones) can be significant, particularly for resident populations in small streams.

Ensuring the protection of existing streamflows by providing information on fish habitat requirements to water regulators, or by increasing discharge during low flow periods through purchases of existing water licences are two effective means of protecting trout populations. The cost of obtaining a water licence from the crown to acquire unallocated water rights is $150. More significant costs would be involved in researching water allocations, planning, and negotiations to acquire existing rights from current licence holders. This is estimated as $10,000 per licence, although no precedents for comparison are known.

Project level performance indicators could include the volume of water protected for fish habitat. Program level indicators would relate to maintenance or increases in fish standing stocks and/or production. A preliminary review of existing conservation water licences and priorities for future acquisition in the region is provided by Zimmer (2009). Much work remains to be done in identifying and protecting threatened habitats.[48] Protection of spawning channel flows is a priority.

8.3.2 Reconnection of Isolated Habitats

Removal of barriers to allow access to spawning and juvenile rearing habitat is a feasible option for maintaining regional biodiversity by increasing carrying capacity or habitat quality (i.e., resilience) for specific populations (e.g., Shrimpton et al. 2008). If these barriers are temporary (e.g. log jams), costs may be relatively low (<$5,000) and there are opportunities to involve volunteer groups. Long-term anthropogenic barriers (e.g. hanging culverts, water survey weirs, water intake weirs) require substantial background data collection and negotiation, and would cost a minimum of $20,000 per site (e.g., Arndt and Klassen 2004). Removal of permanent natural barriers (e.g., construction of a fishway over a natural falls)

[48] The Nelson office of Canada Fisheries and Oceans compiled a preliminary list of vulnerable streams (reviewed in Zimmer 2009).

could negatively impact indigenous resident populations upstream, and would require substantial background work before serious consideration. The estimated capital and annual operating costs for a proposed fishway to pass rainbow trout and kokanee over natural barriers in the Inonoaklin River were $1.55 million and $27,000/year, respectively (Penner 1983).

Project level performance indicators would include the linear distance of reconnected habitats. Program level indicators would be evidence that the newly available habitat had been colonized by a self-sustaining natural population. If the objective was to increase carrying capacity for a migratory population, changes in adult abundance would also be a program level measure.

8.3.3 Riparian Restoration

Although not a direct dam effect, much of the remaining lotic habitat in the basin has degraded riparian habitat due to timber harvesting, cattle ranching, housing development, and other activities. This presents an opportunity to enhance trout production in the basin through off-site restoration. Restoration of riparian habitat can reduce peak summer temperatures through shading (potentially increasing usable habitat for rainbow trout), reduce sedimentation (potentially enhancing spawning conditions and benthic insect production), and increase long-term natural recruitment of large woody debris to increase cover and channel complexity. Restoration methods could include fencing to restrict cattle access, planting of trees and shrubs along stream banks, and fertilization of existing trees in the riparian zone to increase growth. Costs would vary depending on the treatment. This is a long-term objective and in most cases, could be combined with measures having more immediate benefits such as adding habitat structures.

8.3.4 Stream Habitat Restoration

A basic premise of habitat restoration or enhancement is that the target population is limited by suitable habitat (space, cover), rather than food. Therefore, before a large investment is made in this direction, it is advisable to determine whether the existing food base is likely to support a larger biomass (Binns and Eiserman 1979). Habitat restoration could be conducted in conjunction with nutrient enrichment in streams where both factors appear limiting. Small stream resident populations and fluvial populations in rivers small enough for treatment to be feasible (e.g., Salmo River) would be the most likely to benefit, because both juveniles and adults would be present in the treated habitat. Adfluvial populations in which juvenile production in stream habitat was an important limiting factor would also be candidates for habitat restoration.

Reaches downstream of dams often have reduced recruitment of large woody debris (LWD) due to interception of wood from upstream sources and reduced variation in annual discharge with associated reductions in channel migration. Also, as noted above, many drainages that were not flooded have greatly reduced natural recruitment of LWD due to logging in the riparian zone. Large LWD recruited from old growth forests prior to logging is likely decomposing at a rate of 5-10% per decade (Redfish Consulting 2005). Second growth trees are generally much smaller than historical ones, and will not create the same type of habitat nor last as long in the stream channel. Yet trees can play a vital role in maintaining structural complexity, and dissipating hydraulic energy to allow accumulation of naturally recruited spawning gravels.

Since the time required for riparian forests to return to historical conditions would be several decades, or even a century in some cases, consideration should be given to habitat restoration measures in the short-term. Addition of LWD or boulder clusters and weirs can enhance juvenile and adult densities in cases where depth and cover are limiting. Restoration can also include bank stabilization, riparian planting, (see above) and development or restoration of side-channels [see Moody et al. (2007) and Slaney and Zaldokas (1997) for detailed descriptions].

The goal of habitat restoration would be to increase trout abundance and production in remaining streams, and also to increase the resilience of as many populations as possible to preserve remaining population diversity. However, even in small streams, conducting habitat restoration at a sufficient scale to achieve a meaningful increase in available habitat or productivity for the stream or fish population as a whole can be very costly. Thorley (2007) provides estimates of $113,000/km for stream restoration of this nature based on projects in British Columbia (see Slaney and Martin 1997). However, this may be a gross underestimate especially for areas where access is more difficult. The Environmental Law Institute (2007) in the United States gives an average cost of $787,000/km. FWCP cost for installation of six in-stream structures in a 60 m section of the Salmo River in 2006 was ~$50,000, or $800,000/km. Monitoring costs to determine benefits and gain knowledge about which techniques are most effective in streams in the FWCP area would be in addition to these estimates.

Restoration or enhancement of habitat could be considered as on-site compensation in situations where upstream dams have reduced LWD recruitment, or off-site, like for like compensation for flooded lotic habitat in other parts of a stream system or in a different stream. Project level performance measures could include the number of structures completed, the areal or linear extent of stream habitat that has been enhanced, or observations of increased growth and size of fish in treated reaches compared to control reaches over time. Program level measures could include increased abundance or fish productivity (abundance or biomass) at the stream or population level. Examples of recent habitat restoration initiatives in the FWCP area include a prescription for installing structures in Cranberry Creek tributary to the ALR (Andrusak and Slaney 2004), the Salmo River project mentioned above, and Sproule Creek, where boulder clusters and weirs were added to address a lack of deeper habitat and fish cover (Arndt 2003).

8.3.5 Stream Nutrient Additions

Enhancing the productivity of remaining streams beyond their natural levels to compensate for inundated streams is consistent with a like for like policy, and could benefit all ecotypes of rainbow trout. Nutrient enrichment using both liquid and slow release fertilizers has been evaluated as a means of increasing fish size and biomass in several studies in BC with varying success (Stockner 2003). The effect of stream fertilization on juvenile production in small stream resident rainbow trout and fluvial bull trout is also currently being tested in a tributary of the Salmo River in dam unit C10. Moody et al. (2007) and Stockner (2003) provide more comprehensive descriptions of methods and options for stream fertilization. Cost depends on stream flow and the type of fertilizer used. Moody et al. (2007) estimate the annual cost for a small river (10 m^3/s MAD) to be $3,000 to $7,000 annually for the fertilizer plus application costs; cost for Sheep Creek (Salmo River tributary with summer flow <1 m^3/s) is $4000 (S. Decker, pers. comm.). If slow release applications are possible, there may be opportunity for volunteers to participate in the distribution to help reduce costs. Project level performance indicators are quantity of nutrients applied and length of stream treated; program level indicators include changes in fish populations (growth and abundance) in the treated reaches or streams compared to pre-treatment control years and/or concurrent control reaches or streams. Monitoring costs would be in addition to above. Total project cost for the Sheep Creek study (monitoring + fertilizer application) varied from $40,000-$70,000 per year (excluding capital costs), depending on the extent of monitoring of other trophic levels (periphyton, invertebrates) that occurred each year (S. Decker, pers. comm.).

8.4 Habitat Protection

Protection of remaining non-impacted stream or small lake habitat does not fall under any of the DFO categories because there is no net gain in habitat or productivity to replace a loss. Nevertheless it should still be considered a priority for the FWCP when opportunities arise, because restoration is typically more expensive than protection (Roni et al. 2002) and protection of remaining habitat is probably the most effective way of preserving remaining ecotypic and genetic diversity in the basin. Conservation easements and land purchases are two methods of habitat protection. This strategy would be particularly effective if the productivity of the protected habitats could be increased by habitat enhancement projects. Another important aspect of habitat protection is that information on critical habitats (under Crown ownership) be disseminated to regulatory agencies that are charged with protecting fish habitat.

Costs of land purchases and easements are variable depending on the location and potential for other uses, as well as prevailing market conditions. Project level performance indicators could include area of land and linear kilometres of stream protected from further degradation, rainbow trout populations or sub-populations protected, and any measures of enhanced productivity on the secured lands.

8.5 Restoration and Enhancement of Lake Habitat

8.5.1 Lake Nutrient Additions

Nutrient enrichment of lakes or reservoirs can be an effective method of increasing the size and abundance of kokanee and other prey fish through increases in primary production and a positive ‘bottom-up’ effect on higher trophic levels (Moody et al. 2007). This is a feasible on-site, like for like compensation option if primary production in large lakes has been reduced by reservoir impacts. It has the potential advantage of providing benefits for all adfluvial rainbow trout stocks in a lake or reservoir regardless of their spawning location. Nutrient addition in oligotrophic small lakes is also an option as off site, like for like compensation for the inundation of other lakes. Lake nutrient additions could also be considered as an off site, unlike habitat compensation measure if there are no other means of compensating more directly for losses of fluvial habitat.

During the initial years of nutrient enrichment in the ALR and Kootenay Lake, kokanee populations experienced increases in survival and fecundity at low densities (Ashley et al. 1999; Schindler et al. 2006), and total kokanee biomass (all age classes) in the lakes has remained higher under continued treatment (D. Sebastian, MOE file data). However, kokanee spawner escapement and benefits to piscivorous rainbows have been more varied. During the initial years of nutrient additions (1999- 2003), ALR angler catch of insectivorous adfluvial rainbow trout increased, as did angler catch and weight of piscivorous rainbow trout (Arndt 2004a), but catch and average size declined to near pre-fertilization levels by 2007 (FWCP file data). Interactions between nutrient additions and kokanee spawning channels need further investigation (see section 8.5.2), as well as the roles of “bottom up” and “top down” mechanisms specific to these lakes.

Annual operating budgets for the ALR and Kootenay Lake fertilization projects including partner contributions are currently $1,024,500 and $873,000, respectively, for the 2008-09 fiscal year[49]. Costs have increased substantially since the commencement of these projects, with fertilizer being by far the most expensive component, followed by limnological monitoring and fertilizer distribution in the lakes. Fertilizer costs are largely driven by natural gas and fuel prices as well as agricultural demand, and are therefore subject to price increases well beyond the rate of inflation (E. Schindler, Fertilization Coordinator, pers. comm.). Given ongoing demand and the finite supply of phosphorus sources, costs could increase substantially in the future.

Monitoring is necessary to address water quality concerns and ensure that the program is successfully meeting fishery objectives. Current monitoring focuses on the lower trophic levels up to kokanee, and has been reduced in recent years in both systems (no winter sampling). The response of top piscivore species (bull trout, rainbow trout) has not been evaluated under current programs, other than an annual creel survey in the ALR that provides trend information on harvest, fish size and condition. An inexpensive method (redd count surveys) for monitoring system-wide trends in bull trout spawner escapement in the ALR was developed recently (Decker and Hagen 2007), but funding limitations have prevented continuation of this work beyond the initial feasibly study (estimated annual cost of $50,000). To date, methods for monitoring spawner escapement for piscivorous rainbow trout populations in the ALR have not been developed, nor have spawning tributaries even been identified (Spence et al. 2005). On Kootenay Lake, Gerrard rainbow trout escapement is monitored at the principal spawning site in the Lardeau River, and there is a mail-out survey directed at anglers who purchase a special license for harvesting Gerrards (both funded by the Habitat Conservation Trust Fund). There is no monitoring of adfluvial insectivorous rainbow trout or adfluvial bull trout populations in Kootenay Lake. Better monitoring of these populations is needed since restoration/preservation of these populations and the fisheries dependent upon them is a primary rationale for the FWCP nutrient enrichment programs (Ashley et al. 1999). Ideally monitoring would encompass both harvest and escapement. If the nutrient enrichment programs were expanded to include annual monitoring of angler harvest on Kootenay Lake, bull trout spawner escapement in both systems, and piscivorous rainbow trout escapement in the ALR, total annual cost would increase by ~$470,000.[50]

[49] Of these totals, BC Hydro (FWCP) pays $715,900 and $823,000 respectively with the balance contributed by Columbia Power Corporation ($238,600) and Ministry of Environment (in kind).

[50] Estimated as $70,000 and $50,000 respectively for bull trout on Kootenay and Arrow Lakes, $50,000 for rainbow trout on Arrow Lakes, and $150,000 each for creel surveys on Arrow and Kootenay. Monitoring at a frequency less than annual would be valuable.

Project level performance measures include quantity of nutrients added and responses at lower trophic levels up to kokanee. Program level measures would include increased growth, condition, survival, and abundance of piscivorous and insectivorous rainbow trout, and increased angler catch, harvest, and CPUE.

8.5.2 Prey Population Management

The presence of kokanee prey appears essential for the persistence of the adfluvial piscivore ecotype, and both size distribution and abundance of kokanee is important (see Section 5.3.1). Spawning channels are a proven technique for enhancing kokanee abundance in large lakes and reservoirs, and have become the dominant contributors to populations in both Kootenay Lake and the ALR with fry production exceeding pre-dam estimates in some cases (Arndt 2009). Current operating cost of the HCSC and MCSC operations is $252,000 per year, but the facilities are being operated at minimal staffing and monitoring levels that acknowledge some risk due to limited capacity to address sediment inflows and outflows in the channels. Additional funding required to allow for higher staffing and monitoring levels would be ~$174,000 annually (~$426,000 per year in total) for the two channels not including any major capital costs for upgrading the facilities. Major facility upgrades could be in the order of $2.1 M (Arndt 2009).

The effect of artificial production of kokanee in spawning channels on natural production in the ALR and Kootenay Lake, requires evaluation, but, in general, for a given level of primary production, increased fry production results in more abundant but smaller kokanee (i.e. kokanee growth rates are strongly density-dependent). From a bioenergetics perspective, relatively high abundances of smaller kokanee may not be optimal for growth of larger piscivores (Kerr 1971a, 1971b; see Section 5.3.1). Relationships between kokanee population size structure and abundance, and piscivore diet preferences and growth efficiency require further investigation in order to develop appropriate kokanee production targets. There may be opportunities to enhance the abundance and size of large piscivores in these systems (in accordance with MOE management priorities) by adaptive management of prey populations with no cost increase. Project level performance measures include number of kokanee eggs deposited and fry produced annually. Program level indicators include abundance, size structure, and production of kokanee in relation to targets intended to benefit rainbow trout and bull trout piscivore populations.

8.5.3 Operational Changes at Dams

Dam operations can have a strong effect on seasonal flow patterns in downstream reservoirs and can affect cycling and export of nutrients and biological production (Hall and Van Den Avyle 1986). For example, the residence time of the biologically active layer in ALR can vary substantially depending on system flow, and this has the potential to affect reservoir productivity (Matzinger et al. 2007). Research to understand how water moves through the ALR in relation to dam operations is ongoing (R. Pieters, University of British Columbia, pers. comm.), and data are not yet available to quantify effects of different operating regimes. It is likely that some schedules and related reservoir levels would be more beneficial for rainbow trout and their kokanee prey than others. For Kootenay Lake, Daley et al. (1981) suggested exploring several options that might selectively withdraw nutrient-rich water from upstream dams to increase the downstream supply in Kootenay Lake. They also suggested that increased outflow from Kootenay Lake during spring and summer might force more *mysid* shrimp into the West Arm to enhance kokanee and rainbow trout production there.

Costs of operational changes would have to be measured in terms of lost power production and revenue, and the cost of seeking alternatives for meeting provincial power production requirements. Biological impacts to non-target species would also have to be considered and modelled where necessary, and the BC Hydro Water Use Plan process would be the appropriate avenue for further investigation.

8.5.4 Small Lake Habitat Enhancement

There may be opportunities in existing small lakes for like-for-like off-site compensation for lost fisheries in lakes that were inundated by dams. These would include restoration of spawning and rearing habitat in tributaries, installation of in-lake habitat structures (for fish or aquatic insects), or water volume or quality manipulation. The types of projects chosen and associated costs would vary for individual lakes. Examples could include installation of water circulation pumps in lakes with low dissolved oxygen levels (Ward and Associates 1998), or maintenance of appropriate water levels to enhance invertebrate product in shoal habitats. Further suggestions are provided in Hall and Van Den Avyle (1986) and Kohler and Hubert (1999).

8.6 Dam Fishways

Re-establishing access to upstream reservoirs and associated tributaries for rainbow trout and other species (e.g. from Kootenay Lake into Duncan Reservoir, or from the ALR into Revelstoke and Kinbasket Reservoirs) would be experimental and expensive, but may help to restore ecotype and genetic diversity within the basin and increase natural carrying capacity. Substantial background research would be needed to assess potential benefits and costs.

8.7 Enhancement of Alternative Indigenous Species

In the East Kootenay, rainbow trout are not indigenous and pose a threat to the genetic integrity of numerous indigenous populations of westslope cutthroat trout, which are a blue-listed species in BC. Rainbow trout enhancement work should not occur here. However, the area contains some of the best remaining stream habitat in the FWCP region, and offers excellent potential for off-site compensation of fluvial salmonid populations. Therefore it is recommended that opportunities for enhancement of cutthroat trout be explored as a substitute for lost fluvial rainbow trout populations in other dam units. There are also good options for developing or enhancing small lake fisheries for wild cutthroat trout in the East Kootenay (C. Spence, MOE, pers. comm.).

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Appendix A. Definitions of Operational Impacts

Operation impacts tend to occur over restricted temporal and spatial, and typically represent the seasonal or operational variation in reservoir elevation and downstream flows within a matter of hours, days, within season or recurring over a multi-year period.

1. Habitat impacts due to hydrological/hydraulic changes: impact on habitats due to fluctuations in flows, velocities or water levels in riverine habitats related to biological suitability, food production, etc.
2. Littoral zone/ shoreline or riparian habitat and vegetation impacts: impact on habitats due to water levels or hydroperiod
3. Erosion, sediment transport and morphological habitat effects related to flow: includes erosion scour-deposition, sediment quality and geomorphological habitat changes caused by diversions or re-regulation of flows from facilities
4. Entrainment and destruction of fish: includes entrainment and destruction of fish in turbines, stranding due to flow fluctuations
5. Water quality in discharge operations (e.g. temperature, TGP, DO): water quality related to the timing, location and nature of release from reservoirs or operations
6. Impacts to fish movement and migration: includes blockage and delays in upstream and downstream migrations of fish due to operations, flows and water quality impacts
7. Seasonal lentic/lotic habitat change and impact: seasonal, within-year changes in habitat due to operational changes and conditions (i.e. drawdown zones, exposed creek fans)
8. Ice regime impacts: ice effects due to operational changes such as flows and temperature
9. Local hydrological effects: includes seasonal groundwater effects, flooding and seasonal inundation

Appendix B. Participants at the BC Hydro Dam Footprint Impact Workshop in Nelson, BC, January 5-6, 2005 (Murray 2005a).

Name	**Affiliation**
Carol Murray (facilitator)	ESSA Technologies Ltd.
Lynne Betts (recorder)	Imprint Creative Solutions
John Stockner	Consultant
Harvey Andrusak	Consultant
Greg Andrusak	Consultant
Bob Lindsay	Consultant
Tom Northcote	Consultant
Al Martin	BC MWLAP
Albert Chirico	BC MSRM
Colin Spence	BC MOE
Jeff Burrows	BC MOE
Eva Schindler	BC MOE
Ken Ashley	BC MOE
David Wilson	BC Hydro
Gary Birch	BC Hydro
James Baxter	BC Hydro
Jayson Kurtz	DFO
Harald Manson	CBFWCP
Steve Arndt	CBFWCP
John Krebs	CBFWCP

Appendix C. Potential candidate (and some required) metrics for measuring fish losses and gains related to BC Hydro dam footprint impacts as recommended by participants at the BC Hydro Dam Footprint Impact Workshop in Nelson, BC, January 5-6, 2005 (from Murray 2005b)

Impacts	Potential candidate metrics (required metrics are in bold)
Habitat – Streams	▪ **Km of lost habitat by stream order, width, gradient (km flooded)** ▪ Km^2 of lost habitat, and suitability index by category ▪ High / low discharge level ▪ **Inundation/loss of past/natural/historical barriers** ▪ **Area (km^2) change in seasonal productivity** ▪ Loss of spawning gravel (m^2) ▪ Area and ranking of rearing, spawning and over-wintering habitat
Habitat – Rivers	▪ **Km of lost habitat by stream order, width, gradient (km flooded)** ▪ Km^2 of lost habitat, and suitability index by category ▪ **Km lost to fish passage (blocked to migratory fish passage)** ▪ **Area (km^2) change in seasonal productivity** ▪ Loss of spawning gravel (m2) ▪ Area and ranking of rearing, spawning and over-wintering habitat ▪ Change in channel width (full bank width), complexity, and sinuosity
Habitat – Lakes / Reservoirs	▪ **Size (hectares) inundated** ▪ Change in flushing rate ▪ **Loss of nutrients due to change in flow (nutrient retention) - phosphorous loading, tonnes/year** ▪ Metres of draw-down
Habitat – Wetlands	▪ **Area inundated (hectares) and productivity (grams of carbon per m^2 per day)**
Habitat – System-wide	▪ **Tonnes of carbon lost; or carbon balance** ▪ Loss of wood (forest production) in the system and how that impacts fish production (loss of forest) and other species (m^3 per km) ▪ Area (ha) lost or gained ▪ Lost opportunity (fishery)
Fragmentation	▪ Km of stream blocked to access (percentage of historical range) by species and by life stage ▪ Loss of populations from the above impact ▪ Change in population size (n, or biomass loss) ▪ Genetic bottlenecks (Ne) ▪ Fish passage (n). Can be positive as well as negative, if it blocks transfer of disease or invasions of alien species (# of non-indigenous species blocked) ▪ Inventory of barriers that break up single, contiguous species (barrier inventory by species) such as Sturgeon
Fish Community	▪ Kokanee introductions to Koocanusa, Kinbasket and Revelstoke ▪ Indigenous vs. non-indigenous populations (ratio of non-native vs. native species) ▪ Loss of indigenous stocks (n, inventory of lost stocks) ▪ Life history change – e.g. Bull and Rainbow Trout changing from fluvial to adfluvial ▪ Weakened or strengthened stocks (population size or escapement). ▪ Change in species complex: from salmonids to Northern Pike Minnow (squaw fish) ▪ Hybridization of species/stocks (species/stock diversity)

Productivity	▪ Change (plus or minus) in carbon production by area, per year (could be an increase, due to fertilization)
	▪ Nutrient retention (phosphorous, mostly, and nitrogen in metric tonnes)
	▪ All reservoirs decline in productivity over time.
	▪ Sedimentation of phosphorous and nitrogen (particulate matter) in metric tonnes
	▪ Fish population size and species
	▪ Note that two habitats are subject to productivity impacts:
	    ▪ Littoral zone production (impacted by water level fluctuation) – could be restored through the growing season
	    ▪ Pelagic habitat

Impacts	Potential candidate metrics (required metrics are in bold)
Other	▪ Effects of fish impacts on wildlife. ▪ Climate change. Local micro climatic impacts (change in air temperature, stream temperature, snowfall, precipitation) due to reservoir inundation ▪ Temperature change (maximum, minimum, duration) resulting from impoundments/storage ▪ Change in aquatic vegetation and invertebrates (change in species abundance and composition) ▪ Entrainment, upstream and downstream (number of fish per year) ▪ Change in biogenic and abiogenic turbidity (TSS, NTUs, or secchi disk) ▪ Hydrological changes ▪ Ice regime changes

Appendix D. List of lakes flooded by hydroelectric dams in the Canadian portion of the Columbia River basin. Shaded lakes are included in the count and area list of lakes lost within the footprint area (12 lakes in total). Others are losses not quantified by the JMJ mapping data but mentioned in earlier reports as fish habitat. Kootenay Lake is considered as a remaining but affected by upstream and downstream dams.

Dam Unit	Lakes Flooded	Size (ha)	Pre-dam Elevation[a] (m)	Reference	Comments
C1	None	-	-		
C2	None	-	-		
C3	Kinbasket	2042	671	Maher 1961	Bull trout to 4.5 kg; ling in large numbers
	Bush 1	156	723	Maher 1961, Petersen and Withler 1965b	Lakes are very close together. Reports say rainbow trout to 2.3 kg; bull trout to 3.6 kg; whitefish (Petersen and Withler)
	Bush 2	144	723		
	Lil	13	721	Maher 1961	Across from mouth of Bush R.; JMJ coded as open water
	"small lake"	61	-	Petersen and Withler (1965b) note a "small lake" of 61 ha and "many small lakes of similar size along the Bush River". JMJ mapping does not have a 61 ha lake but has several small ponds and shallow water areas.	At 759 m in Bush River drainage (not sure if this is below flood line).
	Unnamed	1	692	Moody et al. 2007	coded as lake in JMJ mapping (Polygon 3904)
C4	None	-	-		
C6	None	-	-		
C8	Upper, Middle, and Lower Whatshan	1185	640	Moody et al. 2007	pre-dam Whatshan Lake was actually 3 small lakes joined together by narrows; replaced by Whatshan Reservoir; Polygon 5048
		42	640		
		302	640		
C9	None	-	-		
C10	None	-	-		
C11	Upper Arrow	21,316	425	Moody et al. 2007	Replaced by Arrow Lakes Reservoir
	Lower Arrow	13,676	424	Moody et al. 2007	
	Montana	10	439	Maher 1961; Petersen and Withler 1965c	JMJ codes as open water; there are 2 other OW polygons near 0.15 ha, 0.27 ha
	Montana Slough	unknown	-	Petersen and Withler 1965c	Reference states suckers, squawfish, carp, peamouth, rainbow trout, cutthroat, ling found here
K1	None	-		-	
K2	None	-		-	
K3	None	-		-	
K4	None	-		-	
K5	None	-		-	

K6	Kootenay	39,000	532[b]	Moody et al. 2007	
K7	Duncan	2584	548	Petersen and Withler 1965a	Replaced by much larger Duncan Reservoir
	18 permanent open water sloughs	182	-	Petersen and Withler 1965a	These areas noted as "used for juvenile rearing"
K8	None	-	-		
K9	None	-	-		

[a] Kootenay Lake elevation is from Fortis website using the "typical" year. Other elevations are from the maps used by JMJ; in cases where a maximum and minimum was provided I have used the average of the two values.

[b] Cora Linn Dam regulates the lake level and it is higher in fall and winter than it was historically, however the upstream dams hold back much of the freshet so that the spring and early summer level is lower than it was prior to dams.

Appendix E. Changes in salmonid catch and angler effort on Kootenay Lake from 1949-1970 (Figure from Northcote, T.G. 1973. Some Impacts of Man on Kootenay Lake and its Salmonids. Technical Report No. 25. Great Lakes Fishery Commission 46 p.)

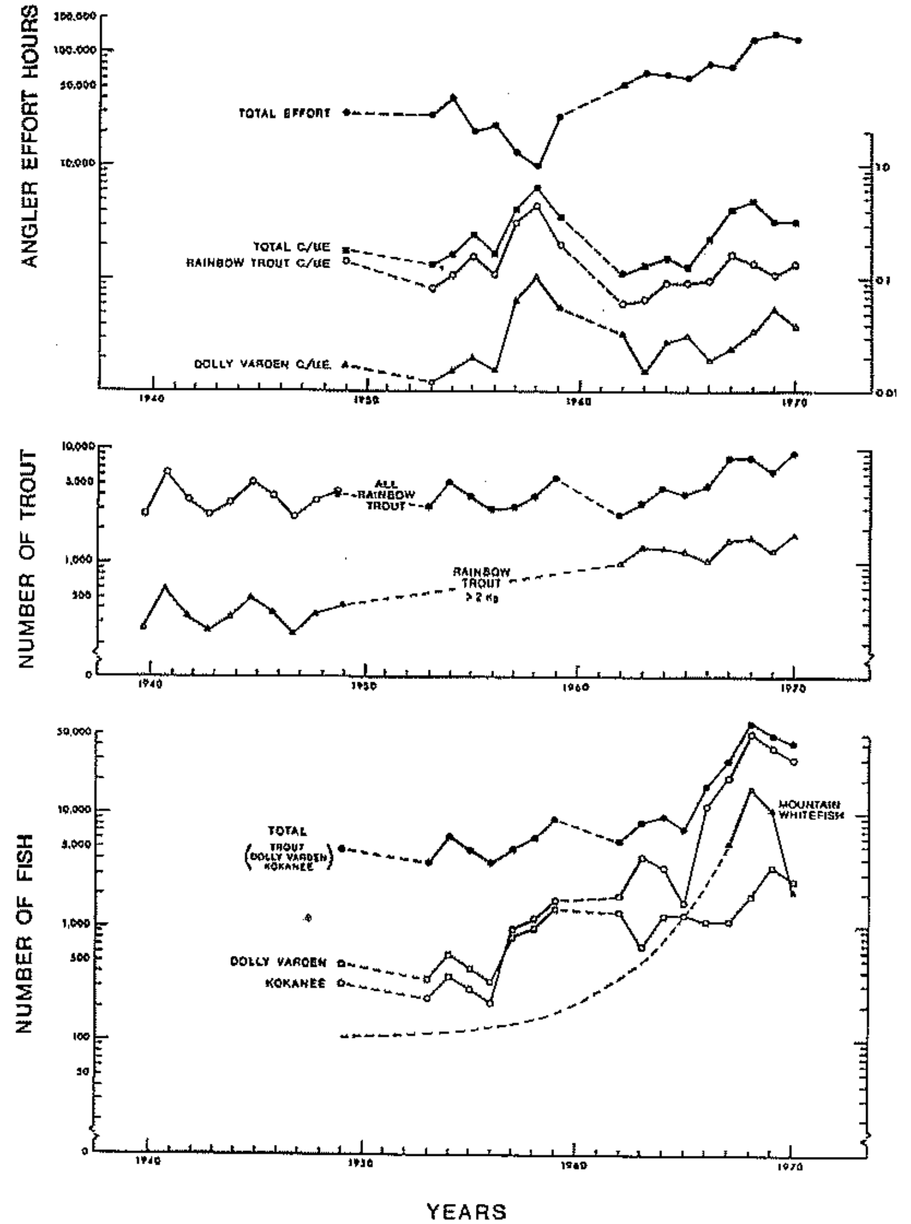

Fig. 11. Changes in salmonoid catch and angler effort in the Kootenay Lake sport fishery estimated for 1949-1970 from B.C. Fish and Wildlife Br. creel census and other records; note *logarithmic* ordinates. Lower; broken line for mountain whitefish shows probable trend. Middle: data (Δ – Δ) for trout > 2 kg from 1940-1949 show only recorded catches in Nelson Gyro Club trout derby (May-mid-November), and for other years from creel census; catches for all trout from 1940-1949 (o – o) estimated from Gyro Club records, assuming ratio between trout >and < 2 kg in 1949 creel census held for previous years when Club recorded catch only of > 2 kg trout; note that 1949 estimate so obtained from Club records and from creel census are close. Upper: total effort pertains only to trout, Dolly Varden and kokanee; that for mountain whitefish or other sport fishes not included; C/UE for rainbow trout calculated from effort applied to that species only, where possible; effort for Dolly Varden assumed to be same as for rainbow (undoubtably an overestimate).

Appendix F. Summary of dam impacts to rainbow trout, compensation options, costs, and performance measures.

Impact	Dam Units Affected	Compensation Option	Estimated Cost	Performance Measures	
				Project Level	Program Level
Inundation of stream and river habitat results in major loss of fluvial adult habitat, and loss of spawning and juvenile rearing habitat for all ecotypes	C3, C4, C8, C10, C11, K3, K7	Off-site like-for-like stream habitat restoration and enhancement	$113,000 to $800,000 per km not including monitoring (Thorley 2008)	• km of stream restored or enhanced • number of structures installed, durability, etc.	Increase in abundance and/or population productivity for remaining fluvial and resident populations in all dam units with particular emphasis on remaining fluvial populations.
		Enhancement of alternative indigenous salmonid species (fluvial cutthroat trout)	As above	As above	As above for cutthroat trout in K1, K2, K4
		Riparian restoration	Included in above	As above	As above; summer temperatures more suitable for rainbow trout or other coldwater species.
		Reconnection of isolated stream habitat	Site specific ($5,000 to $2 million)	• km of stream re-connected with other fluvial habitat • confirmation of use by migratory or resident trout	Changes in abundance, maintenance of genetic variability
		Stream flow conservation and restoration (conservation water licences)	$10,000 per licence	• number of licences obtained • quantity of stream discharge restored or protected for fish habitat	Increase in abundance and/or growth of trout in affected reaches.
		Stream nutrient additions	$10,000 annual for each small river; $50,000/year per stream (based on Salmo River tributary cost) including monitoring	• amount of nutrients added, km of stream enhanced, lower trophic level production measurements	Increase in abundance and/or growth/size of trout in affected reaches.
		Habitat Protection	Variable depending on market conditions and location	• km of habitat protected from development • quantity of critical habitats (private or crown) identified for protection by regulating agencies	Status of populations on protected and adjacent areas. Maintained genetic and ecotypic diversity basin-wide.
Inundation or blocked access to historical spawning and rearing habitats for adfluvial ecotypes	C3, C4, C8, C9, C10, C11, K6, K7, K9	Spawning channels	Hill Creek - $150,000 (includes kokanee monitoring, annual scarification and rainbow redd counts; cost to monitor juvenile outmigration at creek mouth estimated at $10,000)	• adult returns • redd counts • number of fry and older juveniles emigrating from channel • summer densities of fry in channel • number of juveniles (all ages) recruited from SC into reservoir	• evidence that spawning channel is providing a biologically significant proportion of natural recruitment. (This requires determination of other spawning locations and relative contributions to adfluvial populations.) • reservoir biomass, abundance of piscivorous and non-piscivorous rainbows maintained or increased • angler effort, catch and harvest of piscivorous and non-piscivorous rainbow trout maintained at higher level

		Dam fishways	Not available; expected to be very high	• number of fish (all species) migrating through fishway significant in relation to downstream population • passage not limited by fish size	• maintained or restored genetic variability • as above for spawning channels • natural recruitment adequate to sustain reservoir populations in drainage basin
		Reconnection of isolated stream habitat (Stream barrier removal)	$5,000-$10,000 (small, temporary barriers) >$1 million (permanent fishway)	• number of trout spawning upstream of former barrier/obstruction • length of stream opened to spawning and rearing use	• long-term persistence and maintenance of spawner abundance for enhanced population • maintenance or enhance remaining genetic diversity
		Stream gravel additions	$10,000 per stream annual cost	• tonnes of gravel added • area covered with suitable spawning gravel • gravel used by spawning fish	• as above
		Artificial propagation (fish hatchery)	$200,000/year (past operating cost of Hill Creek hatchery); FWFSBC is provider at present	• number of adults used for spawning is not compromising genetic integrity of hatchery fish or donor populations • number of eggs collected • egg to release survival • number of fish stocked	• evidence that hatchery recruits are providing a biologically significant proportion of natural recruitment that is resulting in increased abundance and production of the population. (This may require determination of natural spawning locations and relative contributions to the population.) • reservoir biomass, abundance of trout increased compared to un-stocked conditions • angler effort, catch and harvest increased in association with the incidence of hatchery fish in creel surveys • persistence of rare fish stocks (e.g., “yellowfin” in Arrow Lakes) and indigenous populations
Reduced stream discharge due to diversion of flow for power production	C2, C6, C8, K9	As for inundation of streams (above)	As for inundation of streams (above)	As for inundation of streams (above)	As for inundation of streams (above)
		Operational changes to maintain/improve habitat viability if necessary	Determined via Water Licence Requirement studies); would need to be modelled for specific requests	Increased discharge in affected reaches	Increased population abundance or growth in affected reaches)
Alterations in seasonal and daily discharge in rivers due to flood control and power production reservoirs upstream	C9 (lower Columbia River), K9 (lower Duncan River)	Operational changes	Determined via Water Licence Requirement studies); would need to be modelled for specific requests	Project specific (e.g., reduced incidence of redd stranding, increased minimum flow)	Increased population abundance or growth in affected reaches)

Reduction in downstream nutrient inputs to lakes or reservoirs due to upstream impoundments	K6, C11	Large lake nutrient additions	Kootenay Lake (north arm) - $873,000 Arrow Lakes - $1,024,500 [2009 budget]	• water quality parameters, N:P ratios • lower trophic level responses	• kokanee abundance, growth, and size distribution • growth, condition and abundance of bull trout and piscivorous rainbow trout • angler effort, catch, and harvest • spawner abundance trends for bull trout, rainbow trout
		Operational changes at upstream dams	Determined via Water Licence Requirement studies); would need to be modelled for specific requests	• residence time of biologically productive layer in target reservoir is increased • reduced export of nutrients and biological production from target reservoir; possibly increased export from non-target upstream reservoir	• reduced level of added nutrients needed to maintain primary productivity in target lake/reservoir • increased fish production in target lake/reservoir
Reduction in prey (kokanee) abundance	K6, C11	Spawning Channels	Hill Creek and Meadow Creek $426,000 annual operating costs; $2.1 million capital costs over several years (Arndt 2009)	• adult returns adequate for target egg deposition • egg deposition target met • egg to fry survival high (≥ 30%) • fry produced adequate to seed lake at appropriate level	• kokanee growth, size/age structure of population suitable for angling and piscivore growth • growth, condition, and abundance of piscivorous rainbow trout and bull trout high • kokanee production and abundance near or at lake carrying capacity • angler effort, catch and harvest for kokanee, bull trout, piscivorous rainbow trout increased • zooplankton productivity and trophic efficiency not reduced by overgrazing • fry to adult survival in reservoir allows persistence of natural kokanee stocks
Alterations in seasonal and daily discharge and water level in lakes and reservoirs	C11, K6	Operational changes	As above	Project specific (e.g., residence time of biologically active layer increased during growing season)	Project specific (e.g., reduced need for nutrient additions, increased kokanee and trout production)
		Nutrient additions	As above	As above	As above
Inundation of small lakes and lost fisheries opportunity	C3 (at least 5 lakes), C11, K7 (shallow water areas)	Development of fisheries in new lakes with fish introductions		• number of lakes investigated for potential • number of lakes stocked	• requires prior risk assessment for invertebrate and amphibian use. • number of lakes with successful fisheries developed • angler use and catch
		Small lake habitat enhancement	Project specific	Project specific	Increased trout abundance, growth, and/or size and angler catch
		Artificial propagation	FWFSBC is provider at present	• number and size of fish stocked	Increased trout abundance and angler catch
		Nutrient additions	Not available	• amount of nutrients added • lower trophic level response	Increased trout abundance, growth, and/or size and angler catch

Loss or reduced viability of specific spawning stocks and genetic diversity	C11 (yellowfin) K7 (Duncan piscivores) C10 (Salmo River)	Stream habitat restoration and enhancement	$113,000 to $800,000 per km not including monitoring (Thorley 2008)	• km of stream restored • number of structures installed, etc.	• increase in adult abundance and/or population productivity and viability • long term maintenance of remaining genetic diversity
		Stream gravel additions	$10,000 per stream annual cost	• tonnes of gravel added • area covered with suitable spawning gravel • gravel used by spawning fish	• as above
		Stream barrier removal	As above	As above	• long-term persistence and maintenance of spawner abundance for enhanced population • maintenance or enhance remaining genetic diversity
		Stream flow conservation	As above	As above	As above
		Stream nutrient additions	As above	As above	Maintenance of remaining genetic diversity over long term