Footprint Impacts of BC Hydro Dams on Kokanee Populations in the Columbia River Basin, British Columbia

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Executive Summary

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. The Fish and Wildlife Compensation Program (FWCP) has undertaken a project to quantify footprint impacts of these dams on fish and wildlife in the basin. Kokanee (*Oncorhynchus nerka*) are an important species in the region, being a key component of food webs in large lakes and reservoirs, a primary prey of piscivorous rainbow trout (*O. mykiss*) and bull trout (*Salvelinus confluentus*), and an important food source for many terrestrial birds and mammals. They also provide popular recreational and food fisheries. The objectives of this report are to review kokanee distribution in the basin, summarize life history traits in relation to limiting factors and footprint dam impacts, assess the status of populations before and after dams, and provide compensation and mitigation options and costs for populations that have declined.

Primary and grey literature, as well as agency file data, was researched for historical information and relevant studies on kokanee biology. Any available empirical data were used as the first resource for evaluating changes in population status and probable limiting factors. Habitat and primary productivity changes, summarized in separate reports, were also taken into consideration, especially for those areas where empirical data were lacking. To facilitate quantification in different parts of the basin, the FWCP area was divided into 18 dam units, generally corresponding to large catchment basins above and below dams.

Kokanee are the non-anadromous form of sockeye salmon, and have a relatively simple life history using two main habitat types. Spawning occurs in the fall, typically in low gradient streams, but sometimes along lake shorelines. Fry emigrate to lakes or reservoirs shortly after emergence the following spring and may spend several weeks in shallow inshore habitat before moving offshore. They feed primarily on plankton in the limnetic lake habitat for three or four years before returning to streams to spawn and die. There are a number of potential limiting factors that can interact during the lake phase of the life history including lake nutrient status, intra- and interspecific competition, and predation. Both bottom-up and top-down control mechanisms can affect kokanee, with maximum biomass determined by nutrient availability, and realized biomass by interactions between bottom-up and top-down forces. The most important interspecific food competitor in the program area is the introduced opossum shrimp (*Mysis relicta*). Intraspecific competition for food occurs among individuals of the same age class and among age classes. Studies with sockeye suggest that if age-0 stocking levels are too high, size may decrease even under fertilized conditions. A top-down effect of predation has been clearly demonstrated in lakes where piscivore populations are supplemented with hatchery fish; and there is also evidence of an effect when predators are dependent on natural reproduction. Predation is size-dependent, with larger rainbow trout and bull trout feeding mainly on age-2 and older kokanee.

Prior to dam construction, kokanee in the Columbia Basin were indigenous to lentic habitats in Kootenay, Duncan, Trout, Upper and Lower Arrow, and Slocan lakes. Introduced populations were found in several smaller lakes. In Kootenay Lake, kokanee from the north, west, and south arms were considered to be distinct stocks based on differences in life history and morphometrics. Footprint dam impacts affecting kokanee include habitat loss (spawning) and gain (lentic), habitat fragmentation, nutrient and turbidity changes, entrainment, and changes in aquatic-terrestrial interactions. Construction of dams expanded lentic habitat in the basin by approximately 700 km^2, including new reservoirs and increased surface area in previously-existing lakes. Introduced kokanee populations now occupy the new lentic habitat in Kinbasket, Revelstoke, and Kookanusa (Bonneville Power Administration) reservoirs, and utilize suitable spawning habitat in the upper Columbia and Kootenay drainages that previously was inaccessible.

In contrast to lentic area, the quantity and quality of spawning habitat was reduced by inundation for key indigenous populations. More than 100 km (4.4 km^2 area) of low gradient river and stream habitat that was previously accessible to fish from Kootenay Lake was blocked by Duncan Dam. This included significant areas in the Duncan River that were used by large numbers of kokanee for spawning. Riverine parts of the west arm with spawning potential were also inundated. In addition to the reduction in spawning habitat, historical spawning tributaries to the south arm of Kootenay Lake are not currently utilized. For Arrow Lakes kokanee, 132 km (3.2 km^2) of low and moderate gradient streams (orders 1-7) were blocked or inundated by Revelstoke and Keenleyside dams. It is likely that the inundated spawning areas included much of the better quality habitat since alluvial fans and low gradient reaches ideal for kokanee spawning were typically in the lower reaches that were lost.

Assessment of changes in population status in relation to footprint impacts was hampered by substantial uncertainty in regards to pre-dam kokanee abundance, and potential causes of declines (BC Hydro versus non-BC Hydro dams, footprint versus operational impacts, and important non-dam impacts such as mysid introductions and nutrient enrichment from fertilizer manufacturing). Key limiting factors for the populations are also as yet not well understood. In general, kokanee habitats in the FWCP area can be grouped into three categories: non-impacted lakes, new reservoirs or greatly enlarged lakes, and impacted historical lakes. Non-impacted, or minimally impacted areas, include Slocan, Trout and Whatshan lakes. New reservoirs, Kinbasket, Revelstoke, and Koocanusa, support robust populations. Duncan Reservoir has an expanded lentic area that may support more kokanee than the historical lake if the remaining spawning habitat or reservoir volume during drawdown is not limiting.

Impacted lakes are Arrow and Kootenay, which supported the largest and most regionally significant kokanee populations prior to dams. Population changes due to dams in these lakes are uncertain because of scarce data and the influence of other factors that affected kokanee abundance before and shortly after dam construction. Available pre-dam kokanee counts for Kootenay Lake were made during a period of phosphorus enrichment from a fertilizer plant so the un-impacted pre-dam abundance could not be determined. However, in these two lakes, stock diversity has decreased and abundance has decreased or could have decreased without intervention. Studies over the last 40 years provide good support for the hypothesis that Kootenay and Arrow populations were primarily regulated by lake productivity prior to dam construction; however the loss of major portions of spawning habitat may have caused reductions without intervention.

Compensation options considered for the decreased populations include lake nutrient additions, spawning channels, stream restoration and barrier removal, gravel additions, and stream flow conservation. Operational changes at upstream dams, dealt with separately from footprint impacts under the Water Licence Requirements Program, might also benefit kokanee. The cost of spawning channels and nutrient additions, the two major ongoing initiatives, currently total approximately $2.15 million annually, but there is minimal monitoring of bull trout and piscivorous rainbow trout in the lakes and minimal staffing and monitoring at the spawning channels with associated risks. An additional $0.47 million annually is estimated to allow monitoring of both kokanee and piscivore populations in Arrow and Kootenay lakes and more adequate staffing at the spawning channels. Another $2.1 million could be required if major facility upgrades to spawning channels are needed to improve safety and water security, and address downstream turbidity concerns during channel cleaning. The cost of fertilizer has increased at a rate above the inflation index and this is expected to continue to add to annual costs of the existing nutrient addition program.

In order to ensure efficient use of funds and optimum fish benefits, it is essential to work towards an improved understanding of how spawning channels and lake nutrient additions interact in reservoir trophic ecology and how these interactions are impacted by dam operations. Program level performance indicators should be incorporated into an adaptive management strategy aimed at determining optimal nutrient methods and fry production targets to promote efficient transfer of carbon to the upper trophic levels and optimal kokanee production, growth, and size structure for meeting provincial fishery objectives.

Keywords: footprint dam impacts, compensation, fish, lake, reservoir, spawning, pelagic, lentic, limnetic, kokanee, historic abundance, habitat, spawning channel

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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 (BCH). 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.

The FWCP has undertaken a project to evaluate and quantify the footprint impacts[1] of BC Hydro dams within the Canadian portion of the Columbia River basin. The objectives of the project are to:

a) establish and/or update understanding of original footprint impacts from BC Hydro dams in 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 the program for strategic planning and priority setting, monitoring effectiveness of compensation activities, and justifying quantum of funding for future compensation initiatives. Major components of this 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 and wildlife species. This report provides a species impact assessment for kokanee (*Oncorhynchus nerka*). Kokanee are important to compensation in the program area because they are a keystone species in the large lake food webs of several reservoirs associated with BC Hydro dams. Large piscivorous rainbow trout (*Oncorhynchus mykiss*) populations in Kootenay and Arrow lakes are dependent on adequate kokanee for growth and population persistence. Bull trout (*Salvelinus confluentus*) in the lakes and reservoirs also feed extensively on kokanee (Arndt 2004a). Kokanee also provide direct benefits to people as a recreational and food fishery that contributes to local economies and culture (Arndt 2004b).

The purpose of this report is to:

- review kokanee distribution within the basin,
- summarize life history traits in relation to potential limiting factors,
- summarize footprint impacts likely to affect kokanee,
- assess the status of individual populations (by dam unit) before and after dams, and
- provide compensation options and estimated costs, and recommended performance measures where populations have declined.

2.0 METHODS

Near the beginning of the project a two-day workshop was held in Nelson to review work done to date and inform methods to be used to assess dam footprint impacts (Murray 2005a). Participants were invited based on their knowledge of the basin and its fish habitat to ensure that important aspects were included. Attendees included staff from the BC Ministry of Water, Land and Air Protection, BC Ministry of Sustainable Resource Management, BCH, Fisheries and Oceans Canada, and the FWCP, as well as consultants with a history of working in the region (see Appendix B for list).

A key focus of the workshop was to provide direction as to what metrics should be considered for assessing impacts, and what performance measures should be used to monitor success of compensation initiatives. Participants emphasized that pre- to post-dam changes should be quantified if possible and provided a list of recommended metrics for assessing fish community impacts. These metrics included: changes in population abundance or escapement, loss of indigenous stocks, introductions of kokanee into new reservoirs, life history changes (e.g., fluvial to adfluvial), and changes in stock diversity or species complexes (Appendix C). With regards to performance measures, the participants noted the importance of understanding the limiting factors for populations (e.g. spawning

[1] See Appendix A for a summary and definitions of footprint impacts.

habitat versus lake rearing environment) and encouraged scientifically credible monitoring programs that would test assumptions of compensation initiatives and resolve uncertainties around population dynamics (Murray 2005b).[2]

For this report, information on life history traits and potential limiting factors was obtained by searching the primary literature using the keyword 'kokanee', and other related terms, concentrating mainly on the following journals: Canadian Journal of Fisheries and Aquatic Sciences, Transactions of the American Fisheries Society, North American Journal of Fisheries Management, and Journal of Fish Biology. Both grey and primary literature were reviewed for information on presence/absence, abundance, habitat use, and biological attributes (e.g.,size and age of spawners) of kokanee 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).

To evaluate changes in population status after dam construction, any available empirical data from earlier reports, MOE files, or FWCP files were used as the first resource. Physical habitat changes, as summarized in Thorley (2008), and estimates of primary productivity before and after dams (Moody et al. 2007) were also important factors taken into consideration for assessing population change and compensation options, however the evaluation did not focus strictly on habitat change. There is more uncertainty with the estimates of primary productivity changes than the physical habitat loss estimates because detailed limnological data on pre-dam productivity was largely lacking, or in the case of Kootenay Lake, greatly influenced by anthropogenic nutrient inputs starting in the 1950s. (See section 5.4 Nutrient and Turbidity Changes.)

Where there were sufficient data, I attempted to determine the factors most likely to be limiting to kokanee production within a dam unit as recommended at the workshop and emphasized by Reeve et al. (2006) and Jones et al. (1996). For some dam units (e.g., Arrow Lakes Reservoir, Kootenay Lake), substantial datasets were available from monitoring programs associated with fertilization and spawning channels funded by FWCP. These included spawner counts, size and age data, and hydroacoustic estimates of abundance. Hydroacoustic surveys were available for most large reservoirs in the basin in the last decade. To facilitate quantification in different parts of the basin and maintain consistency with other reports in the project, the FWCP area was divided into 18 dam units generally corresponding to catchment basins above and below dams (Fig. 1). Impacts related to the loss of anadromous salmon that have been blocked by Grand Coulee Dam in Washington since 1941 were excluded from the scope of this review.

3.0 OVERVIEW OF DISTRIBUTION AND POPULATION STATUS

Provincially, kokanee conservation status is ranked as yellow (not at risk of extinction) by the British Columbia Conservation Data Centre. Prior to dam construction, kokanee in the Columbia Basin were indigenous to lentic habitats in Kootenay, Duncan, Trout, Upper and Lower Arrow, and Slocan lakes and their associated streams (Fig. 1). Introduced populations utilized Whatshan, Wilson, and Moyie lakes. Several smaller lakes were also stocked periodically. In the Kootenay Lake drainage, spawning occurred in tributaries of the North Arm, especially the Lardeau and Duncan Rivers (Bull 1965; Fish and Game Branch 1965). A lesser amount of spawning also occurred in tributaries of the West Arm, the South Arm (Andrusak and Fleck 2005), and in Kootenai River tributaries likely as far upstream as Kootenai Falls (S. Ireland, Kootenai Tribe of Idaho, pers. comm.; Andrusak et al. 2004). In the Arrow Lakes drainage, spawning occurred in tributaries draining directly into the upper and lower lakes and also upstream of the lakes in Columbia River tributaries as far as Soards Creek (Martin 1976)[3]. Very little information is available on the abundance of kokanee prior to the 1960s. At that time Kootenay Lake was already subject to large inputs of phosphorus from a fertilizer plant (see section 6.15). Nevertheless, anecdotal accounts, First Nation records, and available lake data show that Kootenay Lake was the most productive for kokanee in the basin prior to settlement.

With respect to natural population divisions, kokanee movement was possible between the two Arrow Lakes, and among Duncan, Trout and Kootenay Lakes. However, even within Kootenay Lake, kokanee from the North, South,

[2] "Project level" performance measures (e.g., kilometers of habitat re-opened to spawning access) were differentiated from "program level" measures (e.g., increase in trout population).

[3] Mica Dam was already in place at the time of the Martin (1976) study, however (Maher 1954) did not observe kokanee in tributaries upstream of Soards Creek in his October survey, and Petersen and Withler (1965b) make no mention of kokanee during stream surveys in September and October. Rapids in the Columbia River downstream of the historical Kinbasket Lake may have impeded further upstream migration. Howard Paish & Associates (1974) surveyed kokanee spawning in September 1973 and observed spawning in tributaries only as far north as Kirbyville Creek (~45 km downstream of Soards Creek).

and West Arms were considered to be distinct stocks based on morphometric and life history differences (Vernon 1957). In Arrow Lake, kokanee spawning in two streams entering the lake only 2 km apart were found to differ in egg size and egg number (Murray et al. 1989). Slocan Lake kokanee were isolated from Kootenay Lake and the Arrow Lakes by natural barriers. Some straying of Kootenay fish into the Arrow and Slocan systems was possible if fish were washed over Kootenay River falls, but this would likely have been minimal[4]. After Duncan Dam was built, Duncan Lake kokanee were isolated from Kootenay Lake. Other population divisions within the *historical* kokanee distribution remain similar to pre-dam conditions, except that Arrow Lakes fish cannot access spawning areas upstream of Revelstoke, or downstream of Keenleyside Dam.

BC Hydro operates 11 dams in the study area (Table 1). Construction of dams expanded lentic habitats in the basin by approximately 700 km^2. This includes both new reservoirs (area is based on average reservoir areas during the May 1 to October 31 growing season) and increased surface area in existing lakes (Fig. 1; Moody et al. 2007). In the Kootenay drainage, 60 km^2 was added as the Canadian portion of Koocanusa Reservoir, and 39 km^2 by Duncan Reservoir (expansion of Duncan Lake). In the Columbia drainage, lentic area increased by 126 km^2 in Arrow Lakes Reservoir, 114 km^2 in Revelstoke Reservoir, and 370 km^2 in Kinbasket Reservoir (Moody et al. 2007). Introduced kokanee populations in Kinbasket, Revelstoke, and Kookanusa reservoirs now utilize suitable spawning habitat in tributaries of dam units C1 and C3 upstream as far as Columbia Lake. Fish from Koocanusa Reservoir spawn in units K1 and K3 in the upper reaches of Kootenay River.

Table 1. Dates of construction and area for dams in the Columbia River basin (from Moody et al. 2007 and Thorley 2008). Areas of reservoirs are based on average elevation and surface area during the growing season.

Year Completed	Location	Dam	Lake/Reservoir Area (km^2)
1922	Bull River (K2)	Aberfeldie	<1
1924	Elk River (K4)	Elko	<1
1939	Kootenay Lake (K6)	Corra Linn[a]	394
1952	Whatshan Lake (C8)	Whatshan	18
1954	Pend d' Oreille (C10)	Waneta[b]	na
1955	Spillimacheen River (C2)	Spillimacheen	<1
1959	Cranberry Creek (C6)	Walter Hardman	-
1967	Duncan River (K7)	Duncan	65
1968	Arrow Lakes (C11)	Keenleyside	476
1972	Wardner – U.S.A. [a] (K3)	Libby[c]	60[b]
1973	Donald - Mica (C3)	Mica	370
1976	Corra Linn - Brilliant (K9)	Kootenay Canal and four non-BC Hydro dams	<1
1979	Pend d' Oreille (C10)	Seven Mile	4.1
1984	Mica - Revelstoke (C4)	Revelstoke	115

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

[4] Mixing also presumably occurred through provincial stocking of kokanee from Kootenay Lake (BC Ministry of Environment Fisheries Inventory Data, http://srmapps.gov.bc.ca/apps/fidq).

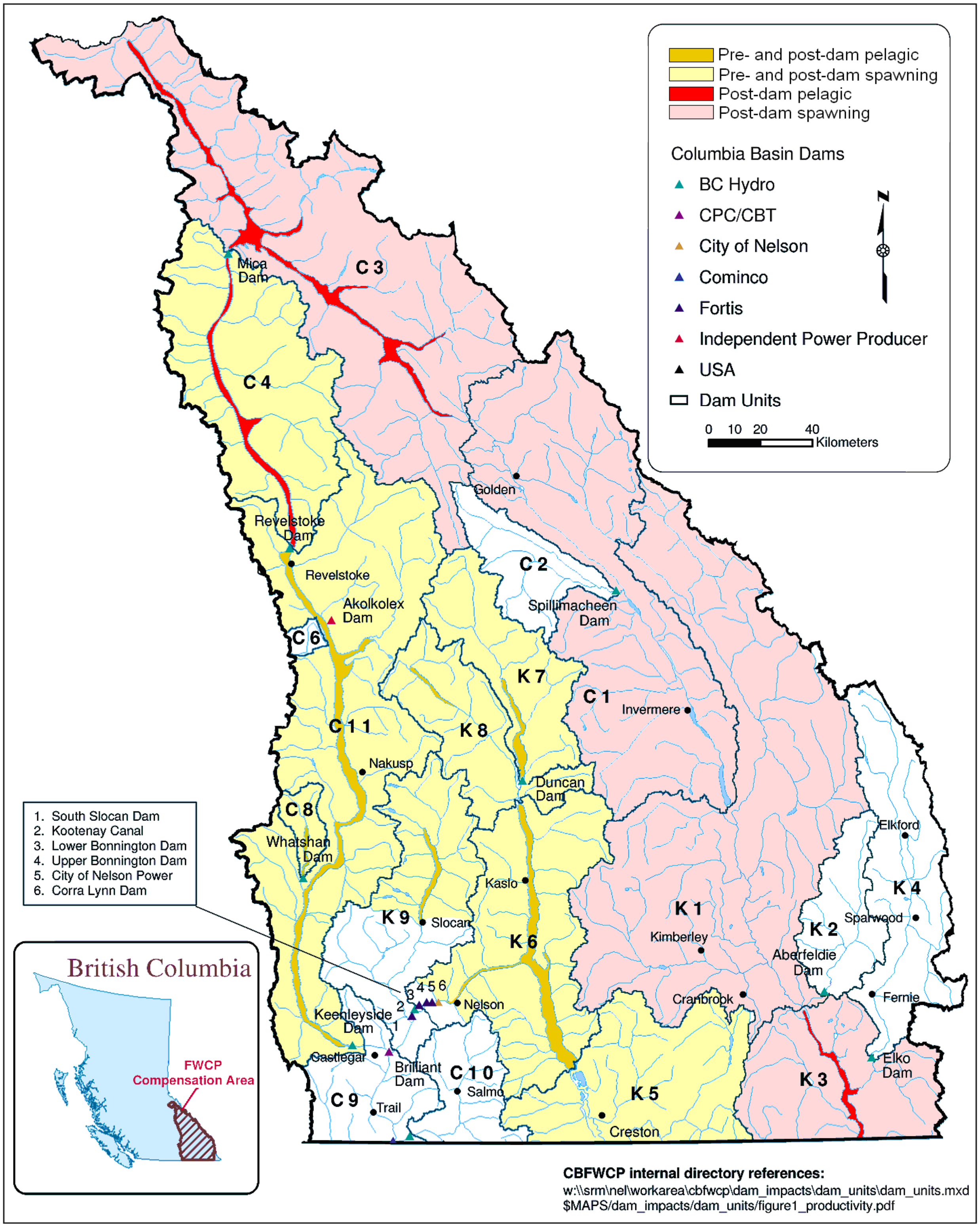

Figure 1. Distribution of kokanee before and after construction of dams in the FWCP program area. Yellow represents lentic habitats available both prior to and after dams. Red represents new lentic habitats created after dams. Corresponding lighter red and yellow shading indicates units providing spawning before and after dams. Pre-dam presence/absence of kokanee in C3 (Kinbasket Lake) is uncertain.

In contrast to lentic habitat, spawning habitat was inundated in many dam units. This includes lower reaches of tributaries upstream of Mica and Revelstoke dams, the lower reaches of Arrow Lakes tributaries, and the Duncan River upstream of Duncan Dam (Anon. 1972). Although not physically removed, spawning habitats in the South Arm of Kootenay Lake and Kootenai River are currently utilized only to a minor degree compared to prior to dams (Andrusak and Fleck 2005). Access to new spawning habitat has been added in dam units C1, C3, K1, and K3 (Fig. 1). In summary, lentic kokanee distribution has expanded in three dam units due to introductions into new reservoirs. Spawning presently occurs in four additional units (Fig. 1), but has been eliminated in some historical locations due to inundation or related impacts.

4.0 LIFE HISTORY AND POTENTIAL LIMITING FACTORS

Kokanee are the non-anadromous form of sockeye salmon, and have a relatively simple life history utilizing two main habitat types. Spawning occurs from late August through early October, typically in streams or rivers although the inshore area of lakes is sometimes used (Scott and Crossman 1979). Depth of lake-spawning sites is usually less than 10 m, but may be up to 30 m (McPhail 2007). Like other Pacific salmon, kokanee are semelparous, usually dying a few days or weeks after their first spawning. Eggs incubate over the winter and fry emerge from the gravel early in spring. Almost immediately after emergence, fry emigrate from the stream into lakes or reservoirs; in some populations movement to offshore habitat occurs almost immediately, whereas in others there is foraging in the littoral zone for variable lengths of time (McPhail 2007). Once in the offshore area, they feed on plankton for 3 or 4 years before returning to their natal stream to spawn and die. Benthic invertebrates are used to a lesser extent in some lakes (Scott and Crossman 1979; Beachamp et al. 1995). In summer, kokanee usually occupy the middle and upper zones of cool lakes, preferring temperatures in the 10-15 ^{o}C range. Ford et al. (1995) provide a good summary of life history and habitat. Potential limiting factors are outlined in the following sections.

4.1 Nutrient Availability and Lake Carrying Capacity

Kokanee can utilize lake lentic habitats ranging from oligotrophic to mesotrophic. Within this range there is strong evidence from studies with both juvenile sockeye and kokanee that lake productivity has a significant bottom-up effect on survival, growth, and production. Hyatt et al. (2004) reviewed 24 fertilization projects in sockeye nursery lakes and found that fertilization increased growth and biomass as well as egg-to-smolt survival in almost all cases. Rieman and Myers (1992) studied 10 oligotrophic lakes in Idaho, and found a positive relationship between growth and lake productivity for all ages of kokanee. In the Columbia basin, increases in kokanee densities and spawner returns have been demonstrated in both Kootenay Lake and Arrow Lakes Reservoir after fertilization (Pieters et al. 2003; Ashley et al. 1999). The effect of phosphorus releases from an upstream fertilizer plant on Kootenay Lake from 1953 to the early 1970s is also well documented (e.g., Northcote 1973; Ennis et al. 1983; Binsted and Ashley 2006), and links to high kokanee production during that period.

4.2 Competition and Food Web Structure

Although a bottom-up nutrient effect has been clearly demonstrated, food web structure is important for kokanee production. Phytoplankton species composition, which may be influenced by factors such as nutrient ratios, water quality, and temperature, is an important aspect of carbon transfer since some species are inedible to zooplankton (Hyatt et al. 2004, McQueen et al. 2007, Stockner 2007). Zooplankton species composition is also important for efficient nutrient transfer. Smaller zooplankton are less efficient at transferring nutrients up the food web (Mazunder and Edmonson 2002; McQueen et al.2007). Planktivore densities can influence the degree of competition and food web structure. A reduction in trophic efficiency when larger zooplankton are depleted accentuates the role of food competition (intraspecific, interspecific with fish and with mysids) as a significant limiting factor for kokanee. High levels of zooplankton predation can reduce zooplankton biomass, removing larger individuals and larger species of zooplankton from the food web (McQueen et al. 2007). In other large pelagic systems, high biomass of planktivores has had a top-down effect reducing zooplankton production even in the following year (e.g., herring, *Clupea harengus*, in the Norwegian Sea; Olsen et al. 2007).

Kokanee feeding rate and growth are dependent on prey density (Walters and Post 1993; Paragamian and Bowles 1995; McGurk 1999, Koski and Johnson 2002) and zooplankton size (Mazunder and Edmonson 2002). Competition with other fish species is probably a minor factor for populations in the FWCP area due to low densities of other planktivores relative to kokanee. However, intraspecific competition is a potentially significant factor, especially with the high fry production capacity of spawning channels on Kootenay and Arrow Lakes. Since kokanee diet is similar for all ages, intraspecific competition occurs among individuals from all age classes. Several studies have shown that high densities of kokanee (or sockeye) can overexploit *Daphnia*, a favoured food source. Effects of the age-0 cohort can be particularly strong because of their high abundance (Scott and Crossman 1979; Scheffer et al. 2000); Beauchamp et al. (1995) found they consumed more zooplankton than all other year classes combined in a lake with both sockeye and kokanee present. Under density-dependent growth conditions, the effect of intraspecific competition for planktivores increases with age and size (Rieman and Myers 1992) with competition favouring the smaller fish (Hamrin and Persson 1986; Walters and Post 1993). Sockeye studies suggest that if age-0 stocking levels are too high, fish size may decrease even under fertilized conditions (Mazumder and Edmundson 2002; McQueen et al 2007). Buktenica et al. (2007) found a recurring pattern of density-dependent kokanee growth and abundance that appeared to be driven by prey resource limitation in a 19-year study of an ultra-oligotrophic lake in Oregon. Kokanee size, condition and abundance increased during years when *Daphnia* were present, but *Daphnia* disappeared during years of high kokanee abundance until the kokanee population collapsed again. Skaar et al. (1996) suggested that manipulation of entrainment could be used to stabilize kokanee populations in Koocanusa Reservoir, and reduce age 0 densities so that the size of older fish would increase for better angling.

Opossum shrimp (mysids) can also be significant competitors with kokanee as shown by before/after introduction studies (Spencer et al. 1991) and by comparing lakes with and without mysids (Clarke et al. 2004). Both kokanee and mysids prefer larger zooplankton (Bowles et al. 1991; Nesler and Bergersen 1991; Rieman and Myers 1992; McQueen et al. 2007), and some studies have shown that mysid populations can consume four to 10 times as much zooplankton as sockeye or kokanee in the same lake (Chipps and Bennett 2000; Hyatt et al. 2004). Introduction of mysids can also result in the loss of certain *Daphnia* species and a delay in abundance peaks of those species that remain (Martinez and Bergersen 1991). Temperature and lake morphology (depth) play a role in interactions between mysids and kokanee because mysids avoid water > 15 ^{o}C (Northcote 1991). Thermal stratification in summer may reduce competition with kokanee for food, and in shallower lakes mysids are more likely to be consumed by kokanee. In general, food competition appears to be less important in lakes where mysids are absent (Beauchamp et al. 1995; Johnson and Martinez 2000).

Mysis relicta were introduced into Kootenay Lake in 1949 and Arrow Lakes in 1968 (Martin and Northcote 1991; Pieters et al. 2003). Their establishment initially resulted in an increase in the size of kokanee in the West Arm of Kootenay Lake (during the fertilizer plant era), but by the mid-1970s it was evident that mysid predation on cladocerans could alter the trophic structure to the detriment 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). Although larger kokanee consume mysids (Rieman and Myers 1992; Hyatt et al. 2004), they do not normally make up a large component of the diet because spatial overlap of kokanee and mysids is limited to very early or late in the day (Martin and Northcote 1991). Mysids are not present in Kinbasket or Revelstoke Reservoirs to our knowledge (K. Bray, BC Hydro, Revelstoke, pers. comm.).

In summary, competition for food is an important population mechanism for kokanee because it can affect the efficiency of nutrient transfer through the food web, and influence growth and survival in a density-dependent manner. Survival is reduced at slower growth rates because size is inversely related to predation rate for all age classes (McGurk 1999). In addition, fall fry weight for kokanee is inversely related to density in some lakes (McQueen et al. 2007) allowing competition to affect survival directly through over-winter starvation (Steinhart and Wurtsbaugh 2003; Biro et al. 2004). Growth rates also influence the size and age at maturation, which link directly with fecundity and population productivity.

4.3 Predation

Evidence for a top-down effect of predation limiting kokanee production is clear for lakes where piscivore populations are supplemented with hatchery stocking. For example, predation by lake trout (*Salvelinus namaycush*), a char closely related to the bull trout (*Salvelinus confluentus*) in Kootenay Region, altered kokanee behaviour (depths occupied) and significantly reduced kokanee numbers in Colorado lakes where lake trout were stocked (Stockwell and Johnson 1999; Johnson and Martinez 2000). Evidence also exists for predator populations dependent on natural reproduction; for example, Beachamp et al. (1995) showed that predation could limit sockeye production in a productive lake without mysids, and predation by naturally-produced lake trout and rainbow trout is thought to be a major factor depressing kokanee numbers in Lake Pend Oreille, Idaho (Columbia Basin Fish and Wildlife News Bulletin, January 5, 2007).

In the large reservoirs of the Columbia basin, kokanee are the major food source for larger piscivorous rainbow trout (*Oncorhynchus mykiss*) and bull trout (Sebastian et al. 2000; Arndt 2004). Both predator species appear to select for larger kokanee (Parkinson et al. 1989; Arndt 2004), and therefore predation may have a stronger affect on age-2 and older kokanee as was found by Beauchamp and Tassel (2001) in Lake Billy Chinook, Oregon.

In summary, kokanee are a major conduit in lentic systems for channelling energy from plankton to the higher trophic levels (Koski and Johnson 2002). There are a number of potential limiting factors that can interact during the lake phase of the life history including lake nutrient status, intra- and interspecific competition, and predation. Both bottom-up and top-down control mechanisms can affect kokanee, with maximum biomass usually determined by nutrient availability, and realized biomass by interactions between bottom-up and top-down forces (Perrin et al. 2006; McQueen et al. 2007).

5.0 DAM FOOTPRINT IMPACTS AFFECTING KOKANEE

Footprint impacts are those related to the construction and ongoing presence of the dams (regardless of how they are operated), whereas operational impacts are related to variations in reservoir levels and downstream flows on shorter temporal and spatial scales (days, weeks, seasons). A list of footprint and operational impacts with descriptions is provided in Appendix A. The following footprint impacts are considered to be relevant to kokanee.

5.1 Construction

Construction impacts are defined as temporary events associated with the building process (Appendix A). Such impacts (e.g., sedimentation, altered river flows and channelling) may have affected year classes of kokanee present at the time, however, these impacts were temporary and likely minor compared to long-term impacts listed below.

5.2 Habitat Loss and Gain

Kokanee habitats can be considered mainly as two types, spawning (usually streams) and rearing (lake or reservoir limnetic). As noted earlier, the littoral zone is sometimes used for a short period immediately after lake entry. The relative importance of spawning habitat versus lake rearing habitat in limiting kokanee populations has not been well investigated for lakes within the basin but is examined under Status by Dam Unit for those dam units with sufficient data.

5.2.1 Spawning

Kokanee typically spawn in stream reaches with gradient less than 5% (Anonymous, undated, Large Lake Information and Preliminary Biostandards), although Tredger and Taylor (1977) documented spawning where gradient was 7-12% in tributaries of the west arm of Kootenay Lake. They considered these higher gradient spawning areas to be secondary habitat but nevertheless noted that suitable spawning areas were available in microhabitats in the steeper sections of the creeks.

In the West Kootenay, large low gradient systems such as the Lardeau and Duncan rivers are used extensively where available. In the smaller streams, however, spawning is often concentrated more in the lower reaches close to the lake or reservoir, with upstream access being limited due to steep gradients. In the East Kootenay, streams typically have lower gradients over a longer distance, allowing longer spawning migrations. The only known locations of lake shore spawning (infrequent observations) within the basin are in the West Arm of Kootenay Lake[5] and in Wilson Lake (J. Bell, Ministry of Environment, pers. comm.). Shoreline spawning is not viable in reservoirs with significant overwinter drawdown.[6]

The quantity of spawning habitat actually used by kokanee prior to inundation is not known, however lotic habitat losses were quantified by gradient category (Thorley 2008) and low gradient, low elevation streams are expected to include habitat with good potential for kokanee spawning. The 0-3% category, especially in small and medium size streams, likely included the best quality spawning habitats that presumably would have higher egg to fry survival. Inundation by BC Hydro reservoirs resulted in the loss of 924 km (103 km^2 of area) of low gradient (0-3%), low elevation (≤ 1000 m) lotic habitat within the basin including large order rivers. Approximately a fifth of the low gradient

[5] The West Arm of Kootenay Lake has some flow and depending on the redd location might not be considered as true lake shore spawning. Spawning in this area is recorded only periodically.
[6] Some spawning occurs in the variable zone associated with tributary mouths in Arrow Lakes below floodline (D. Schmidt, Golder Associates, pers. comm.).

habitat in small and medium streams was lost, and over half for large rivers (Table 2). [See 6.0 Status by Dam Unit, and Thorley (2008) for losses by dam unit.] Canadian losses of low gradient habitat due to Libby Dam in Idaho were estimated as 124 km (15 km^2 by area), although kokanee were not present in this dam unit prior to the dam. As previously mentioned, the lower gradient areas would *include* kokanee spawning habitat, although not all low gradient reaches were used for spawning.

In the dam units that historically supported kokanee from the Arrow Lakes (C4 and C11), a substantial amount of known kokanee spawning habitat in the lower reaches of small and medium size streams was lost. This includes the area upstream of Revelstoke Dam, where 39 km (1 km^2) of low and moderate (<7%) gradient reaches of tributaries emptying into the Columbia River were lost, and direct Arrow Lakes tributaries, where accessible reaches below barriers were shortened or in some cases eliminated when the lake level was raised by Keenleyside Dam (C11). Total losses of low and moderate gradient streams due to Keenleyside Dam were estimated as 82 km (2 km^2); in addition, 110 km (19 km^2) of the Columbia River was flooded (Thorley 2008). Duncan Dam (K7) flooded 98 km (4 km^2) of low gradient habitat, much of which was used by kokanee from Kootenay Lake or Duncan Lake. Raising of Kootenay Lake (K6) by Corra Linn Dam caused losses of lower tributary and West Arm reaches, however, no pre-dam mapping was available to quantify the amount.

In addition to the quantity of stream losses described by gradient category above, there is a further issue of habitat quality related to alluvial fans where small streams entered lakes or larger rivers. The impoundment of these fans probably eliminated much of the best quality spawning habitats in impacted units, because these natural fans provide a regular deposition of sorted gravels that are ideal for kokanee spawning (E. Parkinson, Ministry of Environment, pers. comm.). Varying water levels in reservoirs result in smaller and less suitable fans that in some cases are not watered during the spawning season. In summary, both quantity and quality of spawning habitat was reduced; remaining habitat for indigenous populations is likely poorer quality than the pre-dam habitat because much of the lowest gradient habitat and natural alluvial fans were inundated. High quality spawning habitat presumably allows for quicker recovery from periods of low abundance, and higher fry output per given area.

In portions of the basin where kokanee were introduced into new lentic habitats, kokanee have accessed new spawning habitat that remains above the flood line. This applies to streams tributary to Kinbasket Reservoir (C3), and Koocanusa Reservoir (K1 and K2).

Table 2. Percentage 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	Stream Gradient	Stream Order			
		1-2	3-5	6-7	8-9
moderate (650-1000 m)	moderate (3-7%)	4	2	<1	95
moderate (650-1000 m)	low (0-3%)	7	3	20	46
low (300-650 m)	moderate (3-7%)	16	10	10	0
low (300-650 m)	low (0-3%)	34	16	22	67

5.2.2 Rearing, feeding, and overwintering

Kokanee use lake and reservoir habitats for all aspects of life history other than spawning. For the purposes of this report, lentic habitat is defined as average lake or reservoir area during the growing season (May 1 to October 31; Moody et al. 2007). Area of reservoirs is less than this during drawdown and greater during high storage periods. Lentic surface area during the growing season is the area that contributes to primary production and the limnetic food web leading to kokanee biomass. The portion of lentic habitat occupied by kokanee (other than fry) is often assumed to be the area greater than 20 m in depth (D. Sebastian, Ministry of Environment, pers. comm.) which of course is less than the total surface area (Table 3).

Table 3. Comparison of surface areas and areas of depth >20 m for selected lakes and reservoirs in the Columbia basin during the summer growing season (sources are Moody et al. 2007, D. Sebastian, MOE, pers. comm., FWCP file data).

Lake/Reservoir	Surface Area (km^2)		Area > 20 m Depth (km^2)		Elevation (m)	
	Pre-dam	Post-dam	Pre-dam	Post-dam	Pre-dam	Post-dam
Arrow	350	476	286	293	429.3*	434.3
Kinbasket	20	370	<20	245	673.9	741.7
Revelstoke	0	114	0	77	-	573.0
Duncan	26	65	NA	NA	548.3	568.1
Kootenay	390	394	NA	NA	531.9	531.9

*average of Upper and Lower Arrow Lakes

The *quantity* of lentic habitat available to kokanee in the basin has nearly doubled due to dam construction, increasing from about 800 km^2 to 1500 km^2 (Moody et al. 2007). The additional 700 km^2 includes three new large reservoirs (Kinbasket, Revelstoke, Koocanusa), and increased surface area in Arrow and Duncan Lakes. *Quality* of lentic habitat has also been impacted in historical habitats that now have reservoirs upstream (see 5.4 Nutrient and Turbidity Changes).

Use of littoral areas for one or two months after lake entry has been observed for kokanee fry in the west arm of Kootenay Lake (Andrusak and Northcote 1989, cited in Andrusak et al. 2007), and recent sampling in the north arm suggests that fry use the littoral zone close to the mouth of the Duncan River for a relatively short one to two week period soon after emergence from the gravels, as individuals disperse down the lake. (J. Thorley, Poisson Consulting, Nelson, BC, pers. comm.). In the west arm, fry in littoral areas utilized benthic organisms to some extent but their main food was limnetic zooplankton exported from the main lake that were available to fry whether they were in the littoral or limnetic zones (Andrusak et al. 2007).

The extent to which littoral areas were, or are, utilized by fry in other water bodies is unknown. Littoral primary production was estimated by Moody et al. (2007) to increase overall due to the expanded perimeter of reservoirs, however, the effect of dam-related changes in the timing and extent of water level fluctuations on kokanee fry is uncertain.

5.3 Habitat Fragmentation

Dam construction and accompanying kokanee introductions have restricted kokanee movement in some parts of the basin and expanded access in others. Some populations lost access to historical spawning sites, whereas introduced populations in new reservoirs now utilize previously un-used spawning habitats in areas where they are not indigenous.

In the pre-dam period, movement of kokanee could occur between Kootenay, Duncan, and Trout Lakes; Duncan Dam now prevents movement from Kootenay Lake into Duncan Lake. Kokanee from Arrow Lake migrated up the Columbia River as far as Mica Creek, but are currently isolated from these habitats by Revelstoke Dam. Kokanee that moved into the Columbia River downstream of Arrow Lakes were historically able to move back into the lake but are currently stopped by Keenleyside Dam (see 5.5 Entrainment). Dates of dam completion (Table 1) approximate the timing of blockages to migrating kokanee although in some cases migration was prevented a few years prior to completion. For example, Revelstoke Dam was completed in 1984, but construction started in 1977 and migration was blocked at the dam site starting in 1980 (Sebastian et al. 2000).

5.4 Nutrient and Turbidity Changes

Effects of the dams on nutrient availability and turbidity are detailed in the primary productivity report of Moody et al. (2007; see also Northcote et al. 2005). Primary productivity estimates for historical and current lakes and reservoirs were based on a review of available limnological information, historical reports and photographs, personal observations of biologists and residents of pre-dam conditions, paleolimnological data and carbon values in sediment cores from Kootenay and Arrow lakes, and professional judgement based on a database of primary productivity values from over 50 British Columbia lakes (see Moody et al. 2007 for further description of methods and assumptions). The presence of melting glaciers caused high turbidity in the large rivers and lakes of the Columbia

Basin during the early part of the growing season prior to dams. New reservoirs upstream of Arrow Lakes Reservoir and Kootenay Lake had a positive effect on primary productivity via reduced turbidity, and a negative effect via reduced nutrients. According to Moody et al. (2007), primary productivity was limited primarily by light penetration in these systems prior to dams, and nutrients after dams. Pre-dam lentic productivity is described in the excerpts below.

> In the 'historic' Kootenay Lake of the early 1800's, annual phosphorus loads were doubtless lower than when first measured in the 1960's, a period when Cominco mine phosphorus effluent was beginning to profoundly impact C production, lake-wide. Owing to the surface turbidity in the lake during freshet periods, light extinction and euphotic depths would have been very similar to, but likely lower than, those reported by Northcote et al. (2005) …
>
> Paleolimnological studies of the quantitative abundance of diatoms from sediment cores taken in 1974, dated to well before 1900, clearly show that prior to any human intervention the mid-portion of the lake, adjacent to the outlet to the west arm, was the most productive sector of the lake, followed by the north arm and then the south arm, which consistently had the lowest densities and highest sedimentation rates (Ennis et al. 1983). Clearly, the 'historic' south arm sector of the lake, despite having moderate to high nutrient concentrations, has experienced the most severe photosynthetic C limitation and lowest C production, owing mainly to the persistence of high turbidity throughout much of the growing season (Northcote 1973). The gradient of C primary production rates measured in the 1960's mirrored the paleolimnological studies of Ennis et al. (1983), showing lowest values in the south arm, highest mid-lake adjacent to lake outlet and lowest in the north arm in both May and August datasets. This trend was far less observable in the October dataset, nonetheless, the south arm remained the lowest and least productive in the lake (Northcote et al. 2005). [Moody et al. 2007, p.104]
>
> "The 'historic' Kootenay Lake average C production value (125 mgC m^{-2} day^{-1}) is considerably higher than estimated for historic Arrow lakes average (75 mgC m^{-2} day^{-1}) and this difference is corroborated by early studies in the 40's and 50's by T.G. Northcote on both lakes. He commented: "*historic Arrow production was like the south arm of Kootenay Lake and both were severely impacted by freshet turbidity*". But, based on his early studies of benthic insects from Ekman Dredge samples in both upper and lower Arrow lakes and north and south arms of Kootenay, he stated "i*t was clear that Kootenay Lake was a far more productive lake than Arrow*" (Northcote, personal communication). His observations of pre-dam conditions are further validated by paleolimnological studies of Kootenay by Ennis et al. (1983) and of Arrow by Vidmanic and Ashley (1996 unpublished data). They found quantitative counts of diatom frustules/mm^3 of sediment were considerably higher in Kootenay, especially mid-lake to north arm cores than in any of the cores from upper or lower basins of Arrow (Ennis et al. 1983)." [Moody et al. 2007, p. 104]
>
> The paleolimnological data from Arrow, albeit brief and preliminary, showed the effects of the impact of flooded soils and vegetation with the attendant nutrient releases had on key micro-fossils (biomarkers) like diatoms, e.g. *Cyclotella, Asterionella, Fragilaria,* and cladocerans (*Bosmina, Daphnia*) within the newly created reservoir (Vidmanic and Ashley in Pieters et al. 1999) . However, there were no readily discernable peaks or declines in C or N sediment analyses that could be correlated with biomarker increases in abundance in the surface 5 -7 cm. Dating of Arrow cores was confounded by the dense clay composition of the sediments that indicates a high rate of sedimentation and a high dilution of radioactive isotopes ^{210}Pb and ^{137}Cs used in dating. … The old lake sediment had extremely low biomarker abundance that strongly suggests a pre-dam low and invariant production level in the 'old' Arrow lakes. It is informative to compare these Arrow studies to, paleolimnological studies of Kootenay Lake sediment that showed a much greater abundance of diatom frustules than enumerated in Arrow, especially in cores from mid-lake and the north arm of Kootenay (Ennis et al. 1983). Collectively then, early historic reports and anecdotal personal observations when coupled with paleolimnological data clearly indicate that, with the exception of Kootenay and Whatshan Lakes, all of the Columbia River main stem lakes were strongly influenced by extreme turbidity events associated with the Columbia River annual 'freshet' discharge that peaked in June and extended well into early August (T.G. Northcote, personal communication). The high turbidity, which greatly diminished light penetration and reduced the depth of the euphotic zone greatly affected areal production rates in Kinbasket, Bush, and Arrow lakes. [Moody et al. 2007, p.78]

Taking into account increased light penetration and decreased nutrients due to upstream dams, Moody et al. (2007) estimated the post-dam primary productivity of the larger lakes to be about the same or slightly higher than pre-dam levels (Table 4). These estimates were then used with a photosynthetic rate (PR) model to estimate kokanee biomass for the pre- and post-dam productivity estimates (Table 4). Note that the kokanee model was adapted from a model developed for sockeye rearing in natural lakes without mysids, and has not been validated for kokanee in reservoirs.

Another recent analysis for Arrow Lakes Reservoir suggests that post-dam hydraulic alterations related to both footprint and operational effects of upstream and downstream dams (increased water level, changes in seasonal flows, and subsurface water withdrawal) may additionally reduce Arrow productivity by up to 30% (Matzinger et al. 2007). The same study estimated the effect of upstream dams to decrease productivity in Arrow by about 30% (contrasting with the estimate of Moody et al.), but they acknowledged a large degree of uncertainty due to the opposing effects of increased light penetration and decreased nutrients.[7] Daley et al. (1981) compared primary productivity in Kootenay Lake before and after Duncan and Libby dams, but did not attempt to estimate the natural primary productivity prior to inputs from a fertilizer plant in 1953. In addition to productivity impacts, the potential effect of decreased turbidity on kokanee feeding and vulnerability to predation is unknown, but could be significant.

Table 4. Primary productivity and predicted kokanee biomass (all age classes) in historical kokanee lakes before and after dams in the Columbia basin as estimated by Moody et al. (2007). Post-dam primary productivity estimates are for prior to the nutrient addition programs, and are based on professional judgement taking into account turbidity and nutrient changes. Kokanee abundance is estimated using a photosynthetic rate model sensitive to nutrient status and lake surface area. Surface area increased substantially for Arrow Lakes Reservoir and Duncan Reservoir.

Lake/Reservoir	Primary Productivity (daily mgC/m^2)		Kokanee Biomass (kg)	
	Pre-dam Period	Post-dams	Pre-dam Period	Post-dams
Kootenay	125	125	480,000	412,000
Arrow	75	92	220,000	367,000
Duncan	85	85	18,400	46,200
Whatshan	95	90	12,200	13,300

5.5 Entrainment

Locations where kokanee entrainment can 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[8],
- from Koocanusa Reservoir into Kootenay River,
- from Duncan Reservoir into Kootenay Lake, and
- from Kootenay Lake into lower Kootenay River.[9]
- 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 kokanee entrainment for kokanee populations is not known for any of the BC Hydro facilities. Hydroacoustic assessments combined with forebay gill-netting were made for Keenleyside Dam (C11) in 1983 and 1984 (Smith 1985), and it was estimated that 50,000 kokanee over 6 cm length could be entrained annually with a mortality of 6% assumed for entrained fish (R.L.& L. 1997). A recreational fishery for kokanee exists in the Columbia River below Keenleyside Dam in some years, and a small run of fish spawns in Norns Creek about 7 km downstream of the dam. These fish are most likely entrained from Arrow Lakes Reservoir, although there is a possibility of some strays from Roosevelt Reservoir below the Canada-U.S. border. The size of the Norns Creek spawning run and the fishery varies from year to year.

A comprehensive assessment of entrainment was completed for Libby Dam for the Bonneville Power Administration, in which it was determined that kokanee represented 97.5% of entrained fish with 74, 13, and 13% of the fish being age 0+, 1+, and 2+ respectively (Skaar et al. 1996). The majority of fish were entrained between sunset and sunrise. Low (1.15 million) and high (4.47 million) estimates of the number of entrained kokanee represented between 23 and 92% of the total population in the reservoir, implying potentially significant effects for both Koocanusa Reservoir and Kootenay Lake downstream. Since that study, the operating regime has been changed to benefit sturgeon, and

[7] Matzinger et al. (2007) used data from a lake in Switzerland to estimate the outcome of the change in water clarity and nutrients, whereas Moody et al. (2007) based their assessment on a database of British Columbia lakes, sampling and observations by T. Northcote, and paleolimnology core samples in the study lakes.

[8] Kokanee likely pass over the dam or through low level outlets during spills, and through the Arrow Lakes Generating Station (Columbia Power Corporation). Movement through the boat locks is also possible.

[9] Since completion of the Arrow Lakes Generating Station in 2002 (Columbia Power Corporation), entrainment may occur through the Kootenay Canal facility (BC Hydro) or the generating plant owned by Fortis. Prior to then all entrainment was via dam releases.

anecdotal information indicates that kokanee entrainment has been substantially reduced (R. Erickson, Cramer Fish Sciences, pers. comm.). A previously popular snag fishery below the dam has dwindled (J. Dunnigan, Montana Fish, Wildlife and Parks, pers. comm.). Nevertheless, large numbers of age-0 kokanee (~60 mm) are still observed in the Kootenay River downstream of Libby Dam in June (D. Miller, Kootenay Wildlife Services, Nelson, pers. comm.), and the number and significance of Libby-entrained fish rearing in Kootenay Lake remains unknown.

Anders et al. (2007) found that the contribution of Koocanusa fish to Kootenay Lake could not be resolved genetically because Koocanusa fish are largely derived from Meadow Creek stock. Fish that survive entrainment from Kinbasket and Revelstoke Reservoirs would be added to the populations downstream, and fish from Duncan Reservoir could find habitat in Kootenay Lake. Any entrainment through Boundary Dam and Seven Mile Reservoir is expected to be minor. These reservoirs do not provide good habitat for kokanee although there are kokanee upstream in Lake Pend Oreille, Idaho.[10] Mortality due to entrainment is addressed under a separate BCH operations strategy and is not discussed in this report.

5.6 Changes in Aquatic-Terrestrial Species Interactions

The amount and spatial extent of aquatic-terrestrial species interactions have been changed due to habitat loss and fragmentation and introductions of kokanee into new reservoirs. One of the most significant of these interactions is the input of carcasses to stream and riparian ecosystems during the kokanee spawning season. The spawning fish and carcasses are consumed directly by many terrestrial mammals and birds, as well as amphibians, invertebrates and fungus (Jauquet et al. 2003). Released nutrients from decomposed carcases enrich the stream and riparian communities.

In the larger natural lakes such as Kootenay and Arrow, the loss of natural spawning habitats and the construction of spawning channels with high fry production capacity have concentrated spawning fish in fewer locations. This in turn has restricted the distribution of ecosystem services that these carcasses provide in those drainage basins. In contrast, the introduction of kokanee into new reservoirs has added an input of carcasses to spawning streams in the upper Columbia and Kootenay drainages that previously was not available. In the Columbia drainage this may, to some extent, mimic the input from anadromous salmon that occurred before Grand Coulee dam was built in the United States.

6.0 STATUS BY DAM UNIT

Kokanee presence before and after dam construction is summarized in Figure 1 and Table 5. Prior to dams, there were two major lentic habitats supporting substantial kokanee populations (Kootenay Lake and the Arrow Lakes) with smaller populations in Duncan, Trout, Slocan and Whatshan lakes. After dams the basin supports kokanee populations in all historical lentic habitats, with introduced populations in Kinbasket, Revelstoke and Koocanusa Reservoirs.

For Kootenay and Arrow Lakes Reservoirs, there is substantial abundance trend and biological data. These systems are examined in more detail in an attempt to determine limiting factors for these populations which could link to footprint impacts and compensation initiatives.

[10] No kokanee were captured during electrofishing from 1991-1993 (Seven Mile Unit 4 Project Scoping: Aquatic Resources Scoping and Potential Impact Review. Report ER-94-18. Dec. 1994) and reservoir water temperatures are warmer than kokanee preferences (B. Westcott, BC Hydro, pers. comm.).

Table 5. **Summary of changes in kokanee presence and status within the FWCP program area before and after completion of dams. See text for detailed discussion.**

Dam Unit	**Lentic Habitat Used**		**Spawning Habitat Used**		**Population Change**	**Comments**
	Before	**After**	**Before**	**After**		
C1 Upper Columbia	No	No	No	Yes	Increase	Spawning habitat for Kinbasket Reservoir fish
C2 Spillimacheen	No	No	No	No	-	Not accessible to kokanee
C3 Kinbasket	Uncer-tain	Yes	No or very low level	Yes	Increase	Introduced to reservoir 1982-1985; possibly present in pre-dam Kinbasket Lake
C4 Revelstoke	No	Yes	Yes	Yes reduced	Increase lentic, Decrease spawning	Colonized by fish from Kinbasket Reservoir
C6 Cranberry	No	No	Yes	Yes	Decrease	Spawning capacity reduced for Arrow fish
C8 Whatshan	Yes	Yes	Yes	Yes	Possible increase	Slight increase in lentic production due to area
C9 Lower Columbia	No	No	No	No*	No change	Some entrained fish from C11 are present
C10 Pend d'Oreille	No	No	No	No	-	Habitat not suitable
C11 Arrow	Yes	Yes	Yes	Yes	Decrease	Prior to fertilization. See text for details.
K1 Upper Kootenay	No	No	No	Yes	Increase	Spawner habitat for Koocanusa Reservoir
K2 Bull River	No	No	No	No	-	Not accessible to kokanee
K3 Koocanusa	No	Yes	No	Yes	Increase	Introduced into Koocanusa in the 1970s
K4 Elko	No	No	No	No	-	Not accessible to kokanee
K5 Kootenay River	No	No	Yes	No	Decrease	Original spawning runs were relatively small
K6 Kootenay Lake	Yes	Yes	Yes	Yes	N. Arm – Uncertain W. Arm - Uncertain S. Arm - Decrease	No comparable pre-impact data for north and west arms. Original south arm stocks are probably extirpated. Loss of major spawning in Duncan R. replaced with spawning channel.
K7 Duncan	Yes	Yes	Yes	Yes	Uncertain, lentic increase, spawning decrease	Lentic area 2.5 times larger; 437 ha stream loss
K8 Lardeau	Yes	Yes	Yes	Yes	Trout Lake lentic unchanged; Spawning uncertain	No comparable pre-impact spawner data.
K9 Slocan Lake	Yes	Yes	Yes	Yes	No change	Not impacted by BC Hydro dams

* small numbers of kokanee spawners are regularly observed in Norns Creek and rarely in some other tributaries of the Columbia River downstream of Hugh Keenleyside Dam. This are likely entrained fish from Arrow Lakes Reservoir or possibly strays from Roosevelt Reservoir in the U.S. In some years there is a fishery for kokanee below the dam.

6.1 Columbia Lake to Donald Station (C1)

Prior to construction of Mica Dam, the closest large lentic habitat to this dam unit was the Arrow Lakes, and spawning kokanee from Arrow did not migrate upstream as far as this unit.[11] Following their introduction into Kinbasket Reservoir, kokanee colonized suitable habitats in C1 for spawning, including sections of the upper Columbia River below Columbia and Windermere lakes, and lower reaches of some tributaries upstream as far as Dutch Creek (Oliver 1995; Manson and Porto 2006). Aerial counts of spawning kokanee in C1 have been done since 1996 in six main index streams (Columbia River, Dutch, Toby, Horsethief, Forster, and Luxor Creeks)[12]. Total counts have ranged between 127,000 and 408,000 with the peak count occurring in 2001 (Manson and Porto 2006).

A section of the Columbia River near the headwaters at Columbia Lake is by far the most important of the surveyed streams in C1, typically accounting for more than half of the index total. These numbers represent a single count of active spawners near the peak of the run rather than the total number spawning. Counts are typically expanded by a total fish:peak count factor of 1.5 to account for early and late spawners in which case the estimated numbers would range from about 200,000 to 600,000 spawners in this dam unit, not including streams with less than 1,000 fish (Oliver 1995)[13].

Status in C1 has changed from *probably not present* to *present for spawning*. Number of spawning kokanee increased from zero to the hundreds of thousands.

6.2 Spillimacheen (C2)

Kokanee have not been present in C2 before or after dams; status has not changed.

6.3 Donald to Mica (C3)

Prior to construction of Mica Dam (1973), there is no record of kokanee presence in C3. They were never captured in pre-dam Kinbasket Lake fish sampling, although it is possible that they were too deep to be caught in conventional gill nets (Moody et al. 2007). Fulton (1970, cited by McPhail 2007) states that sockeye ascended the Columbia River as far as Windermere and Columbia lakes prior to Grand Coulee dam. This allows the possibility of an indigenous population if Kinbasket Lake provided adequate habitat. Kokanee spawners from Arrow Lakes apparently did not migrate this far as evidenced by fall stream surveys[14].

Kinbasket Reservoir provides 370 km^2 of new lentic habitat during the growing season (Moody et al. 2007) although the area is much less during winter drawdown. Kokanee were introduced in the early 1980s as a species that could utilize a system with little littoral production (Sebastian et al. 1995). Since then, they have colonized the reservoir and spawning habitats in suitable tributaries. Hydroacoustic estimates indicate a stable and abundant population with estimates ranging from 7 to 11 million for 2001 - 2005 (Scholten 2006). This compares to estimates of 2 to 4 million in the early 1990s (Sebastian et al. 1995). The recent estimates are close to the predicted 8,260,000 fish (all age classes) from the Photosynthetic Rate - Kokanee model (Moody et al. 2007).

Five tributaries to Kinbasket Reservoir have been surveyed as part of an annual spawner index (Bush, Kinbasket, and Wood rivers, Camp and Succour creeks; Porto and Manson 2006). The Sullivan River was also counted in 1995 (7,000 fish), but was dropped from the index streams due to high turbidity (BC Hydro data, K. Bray, pers. comm.). The number of spawners counted in the five index streams has ranged from 37,000 to 69,000 between 1996 and 2005 (Manson and Porto 2006) with Wood River, Camp Creek, and Bush River being most important. These counts represent a one time survey of active spawners rather than the total annual number spawning. If expanded by a factor of 1.5 to account for early and late spawners, the estimated numbers would range from about 55,000 to 103,000 spawners in this dam unit. Smaller runs occur in other tributaries not included in the index. As noted in the

[11] Fulton (1970, cited by McPhail 2008) states that sockeye ascended the Columbia River as far as Windermere and Columbia lakes prior to Grand Coulee Dam.
[12] In 1995, a total of 71 streams including sites in the mainstem upper Columbia River from Wood Arm to the headwaters were observed for kokanee spawners from Kinbasket Reservoir. Only 18 key tributary and mainstem locations had ≥ 1,000 fish present. An additional ten sites had less than 1,000 spawners present (usually < 100; Oliver 1995). Locations included in the index survey (units C1, C3) comprised about 70 percent of the total counts in 1995.
[13] Anon. (undated) uses a peak count:total expansion factor of 2, in which case the estimates for the index streams would be in the range of 250,000 – 800,000.
[14] Maher (1961) did not record any kokanee in the river or tributaries of this reach during surveys in the fall of 1960.

previous section, a much larger number of Kinbasket kokanee spawn upstream in dam unit C1. Mean length of kokanee spawners from Kinbasket Reservoir is typically around 25 cm (Bray 2001, Manson and Porto 2006)

<u>Status in C3 has changed from *not present* or *present at low abundance* to *present and abundant for spawning and rearing*</u>. Presently the unit provides rearing habitat for several million and supports up to 100,000 spawners in the index streams.

6.4 Mica to Revelstoke (C4)

Prior to Revelstoke Dam in 1984, tributaries of the Columbia River in C4 were used for spawning by kokanee from the Arrow Lakes. Mean size of kokanee sampled at the weirs was 25 cm (maximum 47 cm) in 1975 and 21.1 cm (maximum 28 cm) in 1976 (Lindsay 1977a). Lindsay (1977) describes most of the streams tributary to the Columbia to be *"of glacial origin, precipitous, and undergoing rapid fluctuations in flow; temperatures are low for much of the year*." Paish et al. (1974) noted that many of the tributaries had barriers near their confluence with the Columbia, and estimated that there was a total of 115 km of accessible habitat in 24 tributaries of this unit[15]; Downie and Bigmouth creeks were judged to be the most important for salmonid spawning in their assessment Martin (1976) lists seven primary, seven secondary, and three marginal tributaries providing kokanee spawning based on their observations and those of Hooton and Whately (1972). Pre-dam reports concur that kokanee spawning was concentrated in the lower reaches of tributaries near the confluences with the Columbia River, where lower gradients and smaller substrates were present (Paish et al. 1974, Lindsay 1977a). Martin (1976) also observed kokanee developing redds in the mainsteam Columbia River directly below the confluences of Mars, Downie and Seymour creeks. Revelstoke Dam flooded 141 km of the Columbia River, and the lower reaches of smaller tributaries in this unit (Thorley 2008). For stream orders 1-7, a total of 39 km (97 ha by area) of low and moderate gradient (<7%) habitat was inundated of which 27 km (80% by area) was <3% (Thorley 2008). These low gradient reaches are most likely to be suitable for kokanee spawning and many of them supported spawning prior to the dam as noted above. Stream losses amount to 20 - 46% of the available low and moderate gradient tributary habitat in this unit depending on stream order category (Thorley 2008). This should probably be considered a conservative estimate of potential spawning habitat losses since some of the remaining low gradient habitat in the unit may be inaccessible.

The number of spawners in this unit prior to completion of dams can be estimated from a combination of sources (Appendix G). Paish et al. (1974) conducted aerial counts in late September 1973 on eight streams (Kirbyville, Downie, Seymour, Bourne, Park, Mars, Frisby, La Forme). The objective of their survey was to assess the dependence of Arrow lakes game fish on streams above Revelstoke relative to tributaries of Upper Arrow Lake. They estimated a minimum count of 19,000 – 24,000 spawners above Revelstoke. However, this work did not provide a precise or complete assessment of spawning activity. For example, Downie Creek, the largest system in their survey, was assessed at 10,000+ spawners, with no indication of context for the "+" in this estimate. Additionally, the survey did not record numbers for any streams north of Kirbyville Creek. Aerial surveys also failed to note kokanee spawning in the mainstem Columbia River, contrasting with Martin's (1976) study noting fish near the confluences of some tributaries.

Another source of pre-dam data consists of shore-based visual estimates of spawners on several smaller tributaries in 1975 and 1976 (Martin (1976; Lindsay 1977a). Weir counts are also available for both years, but in most cases the period of weir maintenance did not allow sampling of the entire run. For example, in 1975, the weirs were installed in early September on four streams; in that year the visual estimates are 20-80% higher than the number of enumerated fish to account for some fish that had ascended prior to weir installation (Martin 1976) and possibly some fish spawning below the weirs. In 1976, weirs were installed prior to kokanee spawning on four streams (Seymour, Mars, La Forme, Holdich) but problems with weir maintenance are noted for all locations but one and visual estimates are up to five times more than weir captures (Appendix G).

The visual estimates for 1975 and 1976 included study of some of the same streams examined by helicopter in 1973. Applying an expansion factor of 1.5 to the aerial counts, based on standard peak-to-total count expansion practices applied for present day kokanee enumeration in the area (Sebastian et al. 2000), a comparison of aerial and weir escapement estimates is possible (Table 6). The estimates contrast notably in this comparison. Seymour Creek estimate is much larger in 1973; however, the fact that the aerial estimate range spans a factor of two suggests considerable uncertainty in their work. In contrast, shore-based visual estimates exceeded the aerial counts by a

[15] Martin (1976) and Lindsay (1977) felt this was an underestimate of the accessible length for bull trout and rainbow trout spawners because they might be able to pass some of the assumed barriers; the estimate may be more reasonable for kokanee.

factor of 2 to 8 - fold in streams with smaller runs. Overall aerial estimates exceeded the shore-based due to the effect of Seymour Creek (Table 6).

Table 6. Comparison of kokanee spawner estimates on select tributaries to the Columbia River in C4, based on air (1973) and shore visual estimates (1975, 1976), with average densities of spawners per kilometre. Escapement estimates are from Paish et al. (1974) and Lindsay (1977).

Stream	Accessible length (km)	Length Used by kokanee[a]	Estimated escapement 1973[b]	1975	1976	3 - Year Average Escapement	Kokanee Density (# per km)
Seymour	3.2	0.8	7,500-15,000	3,000	3,500	7,167	8,958
Park	1.6	0.4	150	1,500	1,000	883	2,208
Mars	0.2	0.8	750	2,000	1,200	1,317	1,646
Holdich	0.8	0.4	unk	unk	800	800	2,000
LaForme	0.8	0.8	150	1,500	1,000	883	1,104
Combined (repeat counts)*	6.6	3.2	12,300*	8000*	7,500*	11,050	3,453

[a] as described by Martin (1975) or Lindsay (1976) except for Holdich (assumed lower ¼ mile in accordance with general statements that kokanee spawning occurred in the lower ¼ to ½ mile).

[b] used highest value of range given to estimate average escapement

Differences between aerial count and weir-based estimates could have resulted from survey inaccuracy or from interannual variations in run strength. The potential for run size variability to confound population assessments is further supported by Lindsay (1977), who suggested that run size variation accounted for 20% variability in estimates between adjacent years. Similarly, Martin (1976) described kokanee as being absent in three tributaries (Horne, Hoskins and Pat) where they had been observed in a previous year during less formal surveys. Another key consideration is the timing of the 1973 aerial counts, which occurred on September 25 and 27. Martin (1976) described peak fence counts occurring during the second week of September and run timing as being similar to kokanee using the tributaries in the Arrow Lakes. Lindsay (1977) indicated the peak was during the second and third weeks of September, and suggested this may be one week later than Arrow tributary (Hill Creek) timing. Present day Hill Creek Spawning Channel data suggest that peak movements into the channel take place anywhere from 1 to 2.5 weeks before the start of significant die-offs. If peak live counts might be expected to occur just before the start of die-offs, this implies that the timing of aerial counts may have been near the peak abundance. However, because only two closely spaced flights were undertaken in a single year of study, variability in migration timing within and among years was not accounted for. Data from the Hill Creek Spawning Channel and from annual escapement estimates on the Arrow system also show at least one week of variation in the timing of peak live-spawner abundance (MOE, BCH, data on file). A review of recent escapement data from Arrow Lakes Reservoir show that single stream counts can drop by more than half one week past the peak and by up to an order of magnitude if counts are 2 weeks late, a possible deficiency in 1973 aerial observations.

Incomplete and changing survey methodologies, combined with variability in kokanee escapements, confound assessment of the pre-dam population. To estimate total returns using the available C4 data, a combination of approaches was used. First, four smaller streams with counts made in three years were used to estimate an average return per stream for each year. The three annual averages were then used to calculate a three-year mean with 95% confidence intervals (Appendix G). The mean and upper 95% confidence interval were expanded to a total of 17 smaller C4 streams which are believed to have had relatively similar habitat, and for which there is information to indicate kokanee were present in the lower reaches in some years. This small stream estimate was added to separate estimates for Downie and Bigmouth creeks, two larger tributaries. Downie was assessed at 25,000 based on the Paish et al. (1974) 1.5 expanded count of “15,000+” in 1973. Bigmouth was never counted, likely due to high glacial turbidity, and was estimated by multiplying the flooded length of 0.8 km (A. Waterhouse, FWCP, unpublished data) by the average density in the lower reaches of small streams in Table 6.[16] Upper 95% confidence intervals

[16] Although early surveys noted that Bigmouth Creek was accessible to salmonids for a much longer distance, a 2008 aerial survey under unusually low turbidity conditions showed that habitat above the reservoir level is not very suitable for kokanee spawning.

were estimated for the two larger streams using the same ratio of mean/upper 95% interval as for smaller streams.[17] It should be noted that three of the 17 small streams used for expanding the mean did not have kokanee runs in 1975-76, and six were not counted in any pre-dam survey (Appendix G). Finally the stream estimates were added to an estimate of fish spawning in the mainstem Columbia River as described below.

> Conflicting descriptions of spawning potential in the Columbia River in C4 confound estimation of losses in this area. Hooton and Whately (1972, cited by Martin 1976) stated that "*throughout most of its length the Columbia River occupies a relatively straight channel*" and "*prime fish holding areas such as side channels, back eddies and large deep pools interspaced with gravel riffles are not prevalent*"; Lindsay (1977a) noted "*a lack of quality spawning and rearing habitat*". Paish et al. (1974) described the Columbia River as having swift current from Revelstoke to Goldstream Creek, with less rapids from Goldstream to Mica. Unfortunately Paish et al. (1974) failed to record the presence or absence of main river kokanee in their aerial surveys. Although it seems likely they would have observed any present given that their stated objective was to compare the number of kokanee spawning upstream of Revelstoke to those spawning in upper Arrow tributaries and fact that they flew the valley at least as far north as Kirbyville Creek (based on the tributary counts provided), there is no way of knowing if they made a concerted effort to look because they also failed to record estimates for a number of other locations with known kokanee spawning potential. Conversely, Martin (1976) observed kokanee spawning at three of the tributary mouths and referred to these sightings as examples, with the caveat that "an unknown number of kokanee spawn in the main Columbia". This observation is supported by topographic mapping, which suggests that aquatic habitat quality may have been quite complex and productive at key locations (Fig.2). Martin (1976) also noted that "*in recent years exceptionally low discharge rates* [at Mica Dam] *have resulted in periodic exposure of much of the riverbed*" and suggested this might have had a detrimental effect on spawning success in the Columbia. Mica Dam became operational in March 1973[18], hence altered flows may have affected conditions at the time of the aerial counts in September of that year. Based on this evidence and Martin's (1976) observations, kokanee spawning undoubtedly occurred in at least a few sites along the main stem. Assuming spotty spawning at 10 tributary mouths, and 1,000 fish per site, roughly 10,000 spawners might have been expected in this area.

Using the above-described approach to estimate potential kokanee run size, the sum of estimates from 19 tributaries and the Columbia mainstem within unit C4 is 81,325, with an upper 95% confidence interval of 160,000 (Appendix G). With only three partially-counted years, there is a risk of underestimating true interannual variance that might have occurred over a decade or more. Unfortunately spawner counts for other pristine glacial lakes similar to pre-impact Arrow are not available for comparison. Typically, counts for interior systems start immediately before or during periods of significant anthropogenic influence, and therefore are confounded by other factors such as stream habitat degradation, dam entrainment, fish stocking, mysid introduction, or changes in nutrient loading.

In the anadromous form of the species (sockeye), there are often strong four year cycles (e.g., Fraser River) and much larger (10-fold or more) cycles over longer periods; however, these are typically associated with the Pacific Decadal Oscillation or other unknown factors (e.g. Schindler et al. 2006). These data provide examples of large variability in spawner returns for the species, but the differences in productivity (maximum and variability) and mortality factors between the Pacific Ocean and an interior glacial lake are such that it seems inappropriate to directly apply sockeye variability to kokanee returns in C4. Also, Rieman and Myers (1992) observed that the density-dependent growth response of kokanee in lakes and reservoirs was different than for sockeye, implying different mechanisms of population regulation for the two forms even during the freshwater stage of their life history.

[17] This may overestimate variance for Downie as it was evidently a core spawning area (compared to the smaller streams) and therefore likely to experience less interannual variation.
[18] http://hydroweb/our_bus/earg/facilities/Columbia/MCA.html

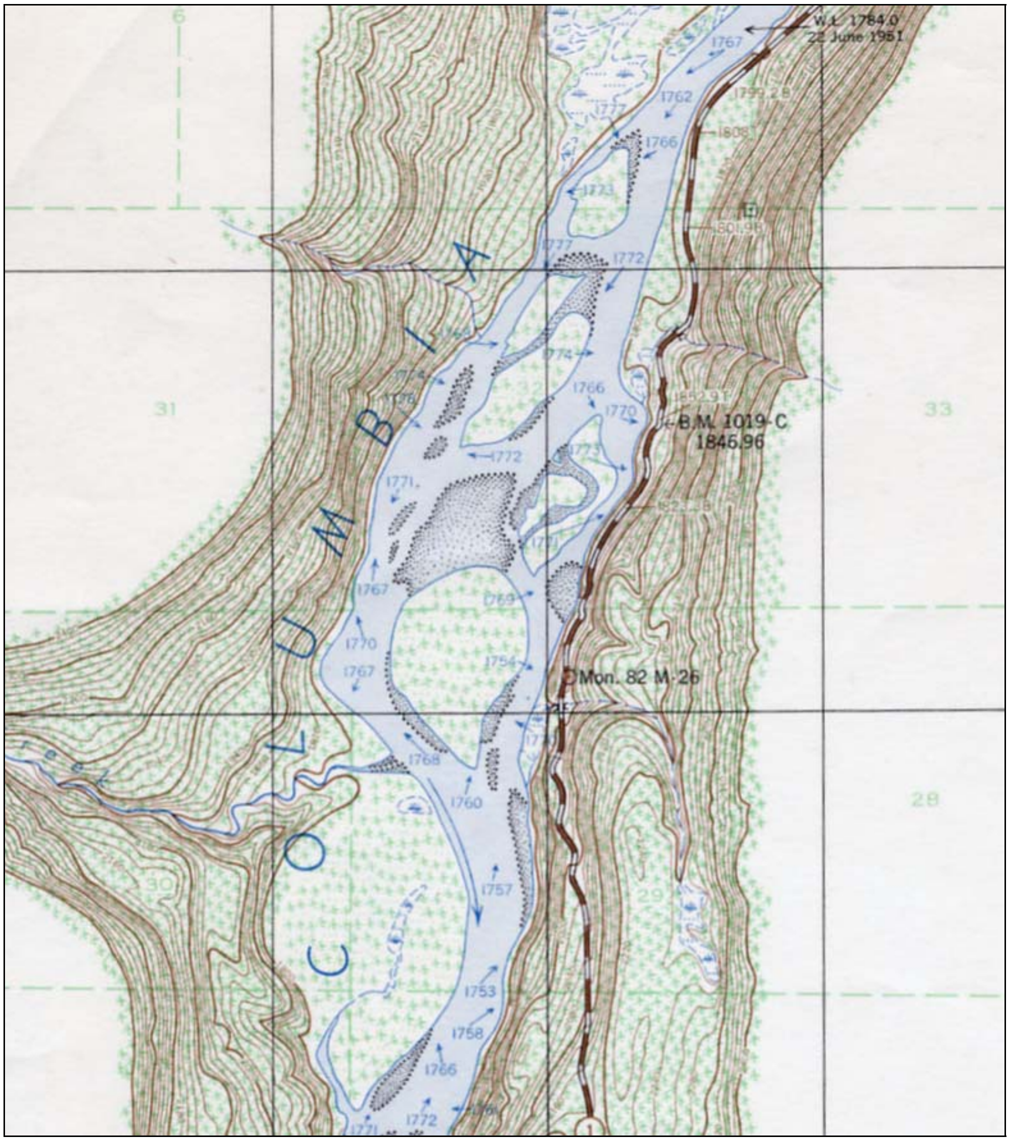

Figure 2. Sample topographic map of Columbia River in the vicinity of Horne Creek ca 1950-51, illustrating aquatic habitat complexity in Dam Unit C4, and a high abundance of gravel deposits.

A scoping exercise to compare interannual variability in upper Arrow and lower Arrow tributaries using the same rearing environment (C11) can be done where a suite of streams were counted repeatedly. The difficulty is in choosing a period not unduly affected by factors such as the onset of spawning channel production, mysids, or declines attributed to oligotrophication. In the upper basin, eight streams (Bridge, Drimmie, Halfway, Hill, Jordan, Kuskanax, St. Leon, Tonkawatla) were counted for a five year period (1988-1992) from after the spawning channel was established up to the beginning of the decline attributed to oligotrophication (Appendix D).[19] Range of returns in these streams was from 427,937 to 287,271 giving a high/low range factor of ~1.5. In the lower basin, six streams were counted for five years between 1978 and 1991 (Appendix D) with an aggregate difference of 210,950/122,375 or ~ 2.[20] These estimates show an observed range for short periods of time under fairly stable conditions in Arrow, but are likely to be underestimates for longer time periods as increasing the number of years would be expected to increase the range of variation. Over the 20-year period from 1988 to 2008, total spawner returns in ALR have varied more than 10-fold (Section 6.5), and similar variation has been observed for other interior systems such as Kootenay

[19] Hill Creek fry output to the reservoir increased from 2 to 9 million from 1981 to 1988 but was relatively stable 1988-1992.
[20] Note that fry output from Hill Creek spawning channel was increasing over this period and Revelstoke Dam was built in 1984; effects may have been less pronounced on lower basin streams.

Lake, Okanagan Lake (Andrusak et al. 2008) or Kinbasket Reservoir; however, as noted above this variability is influenced by anthropogenic impacts.

Another way to estimate the total number of spawners upstream of Revelstoke is to use the proportion of total Upper Arrow spawners as assessed by biologists during the pre-dam years. Paish et al. (1974) estimated that kokanee spawning above Revelstoke comprised 20-30% of all upper basin spawners, based on their aerial surveys; Martin (1976) concurred with 30%, and Lindsay (1977a) suggested 30-50% including any mainstem Columbia River spawning. Expanded aerial counts for Upper Arrow in 1969 and 1974 suggest an average escapement of 130,000 (Appendix D). Assuming the upper estimate of 50% gives an estimate for C4 spawner numbers of 130,000, whereas a 30% estimate would be 55,000. This is within the range of estimates from C4 count data above. However, given uncertainty around aerial count methodologies during this period, combined with the limited empirical background to support suggested proportions of spawning upstream from Revelstoke, these figures should be viewed cautiously. In summary, spawner returns in C4 during the mid-1970s may have been in the range of 55,000 – 160,000 based on the incomplete and imprecise estimates available, and noting the possibility of the 1973 counts missing peak abundance. It is probable that annual spawner returns varied substantially (by hundreds of thousands) in the decades prior to construction of Revelstoke Dam given the variation characteristic of the species, the effects of environmental variability, species interactions (predation, competition), and prey (food) limitation. The upper range of returns would be constrained by the productivity of the lake, which evidently was less than Kootenay Lake (Moody et al. 2007; Section 5.4).

In contrast to the loss of streams, 114 km^2 of reservoir lentic habitat was added (Moody et al. 2007). Kokanee in this dam unit now use the new lentic habitat and spawn in several tributaries above the current reservoir elevation. Spawner counts have been done in 13 years since 1991 in tributaries including Mica, Birch, Pit, Downie, Mars, Carnes and La Forme creeks. Total expanded (by 1.5) counts have ranged from 8,500 to >21,500 since 2003, with earlier estimates as low as 1,000 (BC Hydro data; K. Bray, pers. comm.). Downie Creek is by far the most important remaining tributary, typically accounting for more than 75% of the total; returns in recent years usually vary between 8,000 - 20,000 which is slightly lower than the pre-dam estimate used above. Bigmouth Creek does not appear to support significant kokanee spawning above the reservoir level; unusually low turbidity in 2008 allowed an aerial survey showing very little spawning gravel and only two kokanee present (K. Bray, BC Hydro, pers. comm.). Given the quality and amount of remaining spawning area, entrainment from Kinbasket Reservoir appears to be an important source of kokanee for Revelstoke Reservoir (Sebastian et al. 1995; K. Bray, pers. comm.).

Moody et al. (2007) estimated the kokanee carrying capacity of Revelstoke Reservoir to be 71,900 kg or 2,396,000 fish (all age classes) based on the Photosynthetic Rate – Kokanee model. Hydroacoustic estimates are somewhat less, ranging from 0.5 to 2 million fish between 2001 and 2005 (Scholten 2006). Kokanee are the most important species in the current recreational fishery in Revelstoke Reservoir (Bray and Campbell 2001); retained fish in 2000 ranged from 25 – 39 cm length, which is quite large relative to Arrow Lakes Reservoir (Arndt 2004), and larger than the spawner size of kokanee in this unit when they were coming from the Arrow Lakes (Lindsay 1977a, 1982). The large size is probably related to relatively low densities in Revelstoke Reservoir but may also reflect by the lack of competition from mysid shrimp.

Status in C4 has changed from *present for spawning* to *present for spawning and rearing*. Although lentic population estimates have increased from zero to as high as 2 million due to inundation of riverine habitats and entrainment from upstream, the key concern is the loss of spawning habitat and access for Arrow Lakes kokanee. The Arrow kokanee population was severely impacted, losing potential habitat for spawners in the hundreds of thousands. Present day spawning activity in C4 may be an order of magnitude or more reduced from historic levels due to the flooding of key lower elevation, low gradient habitats offering the highest potential for such activity.

6.5 Arrow Lakes (C11)

The original Arrow Lakes were two separate water bodies, separated 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. Lentic productivity prior to dams was strongly influenced by turbidity, and was estimated at 75 mgC/m^2/day, or 60% of that estimated for Kootenay Lake on a per area basis[21] [Moody et al. (2007); section 5.4 Nutrient and Turbidity Changes].

The Arrow 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 476.2 km^2 (Moody et al. 2007). Natural alluvial fans, which 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 203 km (21 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 (2.2 km^2) of smaller tributaries (orders 1-7) were flooded, almost all of which was <3% gradient (Thorley 2008).

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, Moody et al. 2007). Arrow Lakes Reservoir may have been affected by trophic upsurge from all three dams. Keenleyside Dam in 1968 would have affected the reservoir first by raising the water level of the original lakes. Soon after, Mica Dam (1973) flooded a very large area upstream containing many productive wetlands, and finally, Revelstoke Dam in 1984 flooded a narrower valley with less productive terrestrial habitats. The second two reservoirs could indirectly influence ALR if either released nutrients (Cole 1979) or subsequent biological production were transported downstream (see Matzinger et al. 2007 for an estimate of Arrow Lakes Reservoir nutrient export from sub-surface water withdrawals).[22] Considering all three dams together, it seems possible that there could be some increase in productivity from 1969 to the late 1980s or early 1990s. Petersen and Withler (1965) predicted 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, section 5.4); upstream reservoirs would be expected to decrease nutrient levels because a proportion of incoming nutrients settle out, and also 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 daily rate estimated to be slightly higher (92 mgC/m^2) 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. Another potentially significant impact on the lakes capacity to produce kokanee was the introduction of mysids, an important competitor for zooplankton food, between 1967 and 1974. It is noteworthy that *Mysis relicta* was introduced in an attempt to compensate for expected decreases in littoral productivity after Keenleyside Dam (Anonymous, undated).

Initial estimates of kokanee impacts in the Arrow Lakes were based largely on quantification of spawning habitat losses, under the assumption that available spawning habitat was fully utilized and limiting for the population. Given the short timeline and limited data on population dynamics then, this was a reasonable and feasible approach that resulted in useful biological information and recommendations for compensation initiatives at that time. However the hypothesis that spawning habitat was limiting for kokanee in this system is an area of uncertainty, as discussed below.

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[21] Arrow and Kootenay annual whole lake production were estimated at 4788 tC and 8775 tC respectively.

[22] 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 may have been closer to 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..).

6.5.1 Spawning Habitat and Abundance Trends

Counts of spawning kokanee in Arrow Lakes tributaries were made periodically starting in 1966, two years prior to the first dam. These counts are the best available reference data showing the general magnitude of historical returns in relation to the habitat changes, but must be interpreted with caution for a number of reasons. First, accuracy of counts can be affected by the survey date (too early or late will miss peak numbers), personnel (estimates in high density areas are somewhat subjective), and method used (air, land counts). Personnel and methods were not completely standardized from the 1960s to the 1980s, and the data show a fairly high degree of variability in relative contributions of different streams from year to year; this could suggest some inaccuracy in the counts. Second, other impacts in the drainages (e.g., highway construction impacts on habitat) may have affected returns in some tributaries. Third, spawner returns are determined by an interaction between size and age of maturity. During periods of high food availability kokanee may mature a year earlier than usual, whereas during periods of slow growth they may delay maturity until the fifth year (MOE file data). Nevertheless, these counts are a valuable time series and methods (and caveats) are essentially the same as current escapement monitoring.

Pre-dam spawning habitat for Arrow Lakes kokanee was described in 2 areas: the Columbia River and tributaries upstream of Revelstoke (C4), and streams emptying directly into the Upper and Lower Arrow Lakes (C11). Spawning was also “reported to take place in the narrows between the upper and lower lakes” (Maher 1961) although no records are available. As summarized in section 6.4, aerial and weir counts suggest that the number of kokanee spawning upstream of Revelstoke may have been ~100,000 fish in the 1970s, with spawning occurring mainly in the lower reaches of tributaries. This assessment is consistent with available lake productivity information and subsequent returns to Hill Creek Spawning Channel, which have never reached a target of 500,000 returning adults due to decreasing fry-to-adult survival with increased fry output (Sebastian et al. 2000). Spawning channel returns of this magnitude may exceed the carrying capacity of the Arrow Lakes when combined with the capacity of remaining tributaries, even under fertilized conditions.

For Arrow Lakes tributaries (C11), kokanee spawning occurred in the lower portions of streams along the length of both lakes (Maher 1961). Two spawner counts are available representing conditions prior to inundation from Keenleyside Dam in 1968. The first was conducted in 1966, and the second in 1969. Assuming a four-year egg-to-egg life cycle, the 1969 spawners would have emerged in 1965; it is unlikely that survival of this year class would have been strongly affected by the rising water level in their last summer. It is possible that flooding of the lower reaches may have affected observation efficiency in 1969, however, both counts were performed by government personnel using similar methods in these two years, suggesting that they should be comparable. Major spawning systems were included, but not every tributary was counted. No spawning was recorded along shorelines, however, this possibility cannot be ruled out. The two pre-Keenleyside counts (Fig. 3, Appendix D) suggest that lower basin returns made up about two thirds of the total for Arrow Lakes tributaries at that time. For both basins combined, counted fish totalled slightly over 300,000 (Appendix D). Upper basin counts were substantially higher in 1969, whereas lower basin counts decreased slightly. Expanded by 1.5, the counts project to spawner returns of 470,000 to 486,000, of which 40,000 to 140,000 were from the upper basin (Fig. 3). Considering several smaller systems were not counted, overall spawner returns to direct Arrow Lakes tributaries may have reached 0.5 to 0.6 million. Combining these estimates with 100,000 C4 spawners gives a pre-dam estimate of 0.7 million spawners for Arrow Lakes kokanee prior to any dams, not including the narrows between the original two lakes or possible shoreline spawning. This is similar to the lower range of estimates (0.77 to 1.64 million) made by Sebastian et al. (2000).[23] Annual returns probably varied by ±30% or more over the decades prior to BCH dams. The lower pre-dam spawner estimate for the Arrow Lakes in this report is due to the difference in the number of spawners assessed for the Columbia River and tributaries upstream of Revelstoke [0.1 million herein versus 0.5 million in Lindsay (1977a), see section 6.4]. Support for this lower estimate is provided by considering the Arrow Lakes in relation to Kootenay Lake using the following particulars:

1) It is well established that the Arrow Lakes were less productive than Kootenay Lake prior to large-scale human impacts (see section 5.4; Moody et al. 2007);
2) Early investigators concurred that spawning habitat upstream of Revelstoke (C4) was poor quality compared with streams directly tributary to the upper and lower basins (see section 6.4);
3) Early studies estimated that spawners upstream of Revelstoke comprised 20-50% of all returns north of Nakusp (section 6.4), and;
4) Pre-dam counts indicate that the number of spawners returning to Lower Arrow Lake tributaries was at least double the returns to tributaries emptying directly into Upper Arrow Lake (Fig. 3, Appendix D).

[23] Sebastian et al. (2000) accepted up to 500,000 as the estimate for the Columbia River upstream of Revelstoke (C4).

If 0.5 million is accepted as an estimate for upstream of Revelstoke and expanded using the ratios in (3) and (4) above, the whole lake estimate is 2.0 - 6.5 million as shown below. Arrow returns of this magnitude are not considered plausible given that returns to the Lardeau-Duncan complex in Kootenay Lake (which represented the vast majority of spawners) were estimated at slightly over 1 million for three of four years in the late 1960s when kokanee were enhanced by phosphorus loading well above natural levels (see sections 6.15, 6.17).

Area	Estimate (millions)	Derived from:
1. Columbia reach above Revelstoke	0.5	assumed
2. Upper Arrow Lake tributaries	0.5 - 2.0	0.5 is 20% to 50% of Area 1 and 2 combined.
3. Lower Arrow Lake tributaries	1.0 - 4.0	Area 3 returns are double Area 2
Total Areas 1,2,3	2.0 - 6.5	

Losses of kokanee spawning habitat due to Keenleyside Dam can be considered in terms of the proportion of *previously-used* spawning habitat that was lost, or the proportion of *available* spawning habitat that was lost. Sinclair (1967) used air and ground surveys in 1966 to estimate the number of spawners and their distribution above and below the predicted maximum flood line. The density of spawners decreased in an upstream direction, and he estimated that at least 50% of the spawning habitat used then would be lost. Maher (1961) estimated a 69% loss of spawning habitat using a similar method (not including the narrows between the two lakes). These estimates assumed that no spawning would occur below the maximum flood line and that all suitable habitat was being utilized. Thus, in terms of *previously-used* spawning habitat, the losses were very high.

Andrusak (1969) repeated the 1966 survey using the same methods as Sinclair (1967) and estimated much lower losses of about 20% because spawner distribution had shifted from the pre-dam survey, apparently due to displacement of stream or shore spawners[24]. In some streams, raising of the water level largely eliminated spawning because the new water level reached barriers (Maher 1961; Lindsay and Seaton 1978); of these, Whatshan, Akolkolex and Inonoaklin were considered to be major losses (Andrusak 1969). However, a considerable number of streams had more spawners in 1969 than 1966, possibly due to the addition of displaced fish from other nearby systems. In several tributaries (e.g., Burton, Snow, MacDonald, Deer, Mosquito, Tonkawatla), spawners simply moved upstream to areas not previously used, leading Andrusak to suggest that it was "very likely that suitable spawning areas were not fully occupied in 1966". Thus in terms of *available* spawning habitat, the losses may have been much lower. Nevertheless Andrusak (1969) noted that habitat quality and egg survival in the new spawning areas was likely to be poorer (see section *5.2.1 Habitat Losses and Gains - Spawning*).

The success of spawners utilizing the new areas is a key question. Were the upstream habitats less utilized before the dam mainly because they were further upstream, or were they non-viable in terms of egg survival? Spawning areas with very low egg to fry survival would not be expected to support viable populations over the long term. This can be examined with subsequent spawner counts. For example, Kuskanax, Halfway, and McDonald never had large kokanee runs prior to Keenleyside according to local residents, the local conservation officer, and the 1966 count; Tonkawatla also had a large 1969 run compared to 1966 (Andrusak 1969). These tributaries have continued to support returns comparable to the 1969 numbers up to recent years (Appendix D), indicating that they are viable spawning habitats at least under post-dam rearing conditions.

[24] Any fish spawning in the narrows between the two original lakes would also have been displaced.

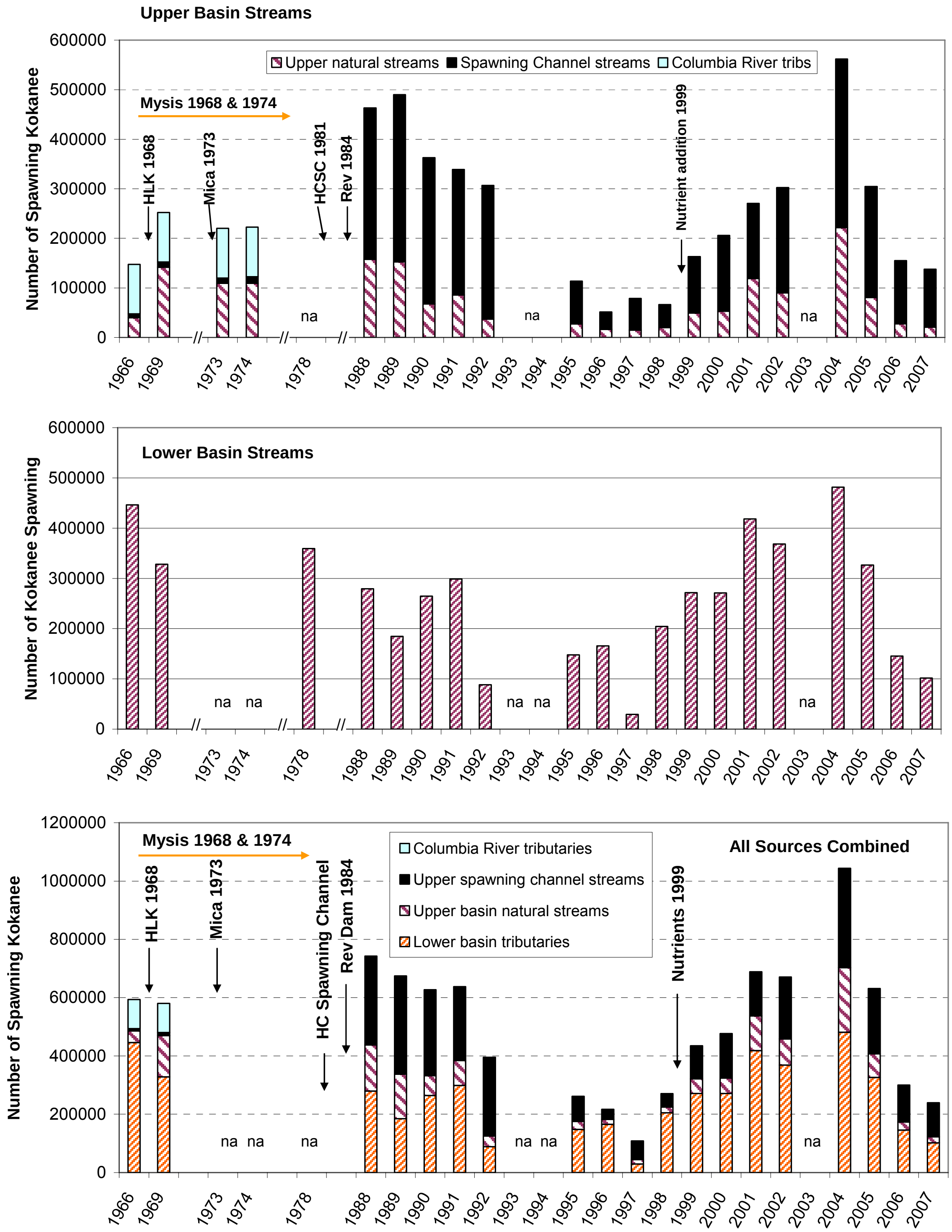

Figure 3. Reconstruction of kokanee spawning runs based on expanded counts in Arrow Lakes tributaries from 1966 to present. Lower panel shows only years when all source areas were estimated. Significant events indicated are completion of Hugh Keenleyside (HLK), Mica (Mica), and Revelstoke (Rev) dams, the beginning of fry production from Hill Creek Spawning Channel (HCSC), and nutrient restoration starting in 1999. See Appendix D for individual stream counts in upper and lower basin tributaries and section 6.4 for details on Columbia River tributaries. Spawning channel streams include fish spawning downstream of the managed channels.

Taken together, these observations suggest that spawning habitat probably was not limiting kokanee production in Arrow Lakes prior to Keenleyside Dam (clear evidence of un-used spawning habitat then that currently supports viable populations) or after Keenleyside Dam (based on no changes in spawner returns up to 10 years later). It cannot be determined whether spawning habitat would have been limiting after Revelstoke Dam because Hill Creek Spawning Channel started producing fry about the same time as migration was blocked. There is uncertainty here, however, since trophic upsurge may have increased fry to adult survival thereby masking potentially lower egg to fry survival in the remaining habitat after Keenleyside.

Counts starting in 1988 reflect the cumulative impact of all three dams, as well as the impact of spawning channels at Hill and Bridge Creeks, and the nutrient addition program beginning in 1999 (Fig. 3). From the late 1980s through to 1991, total returns were the same or higher than pre-dam levels, although upper basin returns became dominant over decreased lower basin returns after the addition of dams and spawning channels. Starting in 1992, returns declined to a low of about 100,000 in 1997, about one sixth of the pre-dam estimates. Following the beginning of nutrient additions, there was an initial increase to a peak of over 1 million, but since 2004 spawners have declined to about half of the pre-dam estimates.

Considering the available spawner trend data from 1966 to the present, three observations can be made. First, total returns were relatively stable up to 1991 (seven years after the last dam) except for the shift to higher upper basin returns after the onset of spawning channel production in 1988. Second, between 1991 and 1997 (7 – 13 years post-dams) there was a substantial decline to levels well below pre-dam counts. Third, post-fertilization returns exceeded, but then declined below, pre-dam levels.

Average length of Arrow spawners was typically 22 cm prior to dams according to Lindsay (1982). Post-dam fish have ranged from that size up to 30 cm with major peaks occurring from 1984 to 1987 and from 1998 to 2001 (Fig. 4). The latter period mainly reflects high food availability when kokanee densities were low during the first few years of fertilization. A smaller peak from 1993-1995 may be associated with a period when Hill Creek Spawning Channel spawner numbers and fry output were deliberately reduced (Andrusak 2007a). Small size from 2002-2005 coincides with a high number of returns as reservoir populations adjusted to higher reservoir productivity following nutrient additions and high fry output from Hill Creek Spawning Channel and natural tributaries. It is important to note that size was small in 1996-1997 at a time when spawner numbers were also at their lowest (Figs. 3 and 4). This is consistent with the notion that reservoir productivity was declining and limiting kokanee production (Pieters et al. 2003).

Although Moody et al. (2007) estimated increased lentic primary production after dams, spawner counts indicate a decline in kokanee returns to about one sixth of the pre-dam returns starting about 1992 or earlier, about eight years after completion of the last dam. Although there is some uncertainty about the accuracy of these counts for specific streams, it is clear that *<u>post-dam spawner returns declined substantially in C11</u> by 1997*. This decline is corroborated to some extent by hydroacoustic estimates from 1993 to 1997 (see below), and led to the nutrient restoration program starting in 1999.

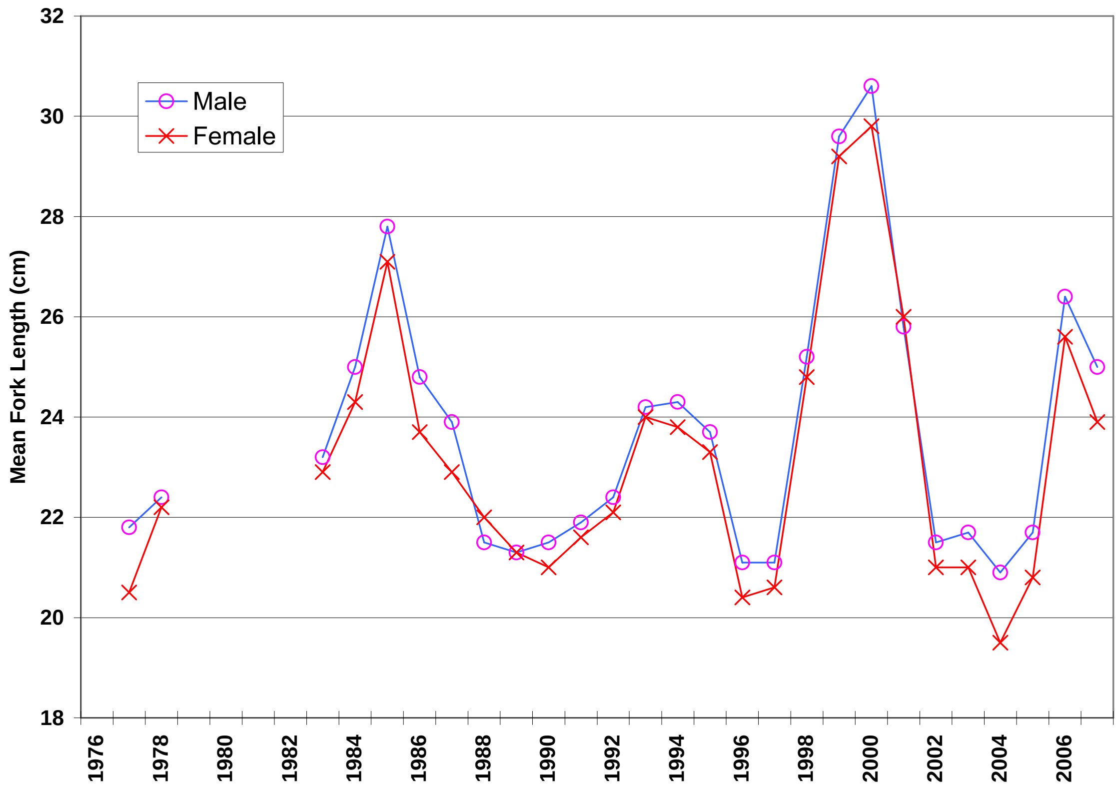

Figure 4. Mean fork length of kokanee returning to Hill Creek from 1977 to 2006. Data from Sebastian et al. (2000) and Andrusak (2007a).

6.5.2 In Lake Abundance

Hydroacoustic estimates beginning in 1988 reflect annual changes in the fall abundance and biomass of all year classes present in the reservoir after spawners have left. Trends correspond roughly with the spawner counts (Fig. 3) in that they indicate relatively stable kokanee abundance from the late 1980s to the early 1990s, followed by a decline to 1997, an increase starting in 1998, and a decline in recent years (Fig. 5). The moderate increase in 1998, shown in hydroacoustic and spawner estimates (and spawner size), is noteworthy because it occurred during the last year prior to nutrient additions. It is, however, within the range of values from 1993-1997. Hydroacoustic data differ from spawner counts in that post-nutrients biomass and abundance has remained above the 1988-94 period, whereas spawner returns are about half. Also, the post-fertilization peak of all age classes was about six times higher than the pre-fertilization era (Fig. 5), compared to about 1.5 times higher for spawner returns (Fig. 3). Clearly nutrient additions have resulted in consistently higher overall biomass, but high biomass of younger age classes does not necessarily transfer to higher survival to spawning age.

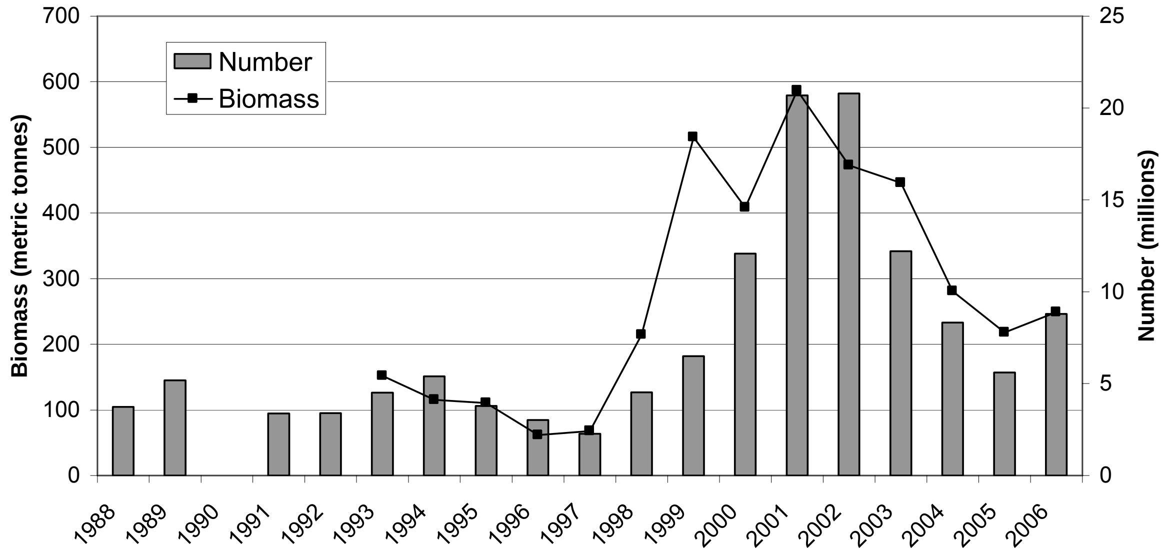

Figure 5. Fall hydroacoustic estimates of kokanee biomass and number (all age classes including spawners) from 1988 to 2006 in Arrow Lakes Reservoir (Ministry of Environment file data, D. Sebastian).

6.5.3 Overview

The cause(s) of the delayed decline are uncertain and interpretation is complicated by the possibility of three trophic upsurges. A decrease starting about 1992 is consistent in timing with a period of trophic upsurge lasting until the late 1980s (given a four-year life cycle) followed by a decline in productivity. Mysids were likely well established before the decline[25]; hence they seem unlikely to be the sole cause. However, their initial effect on the food web might have been concealed by the increased productivity during trophic upsurge period and they may have contributed to the later decline as appears to be the case for Lake Pend Oreille, Idaho (Clarke et al. 2004). Mysid biomass just prior to nutrient additions (13 – 25 kg/ha for 1997-1998)[26] exceeded average kokanee biomass (4.0 kg/ha; Schindler et al. 2006). Increased predation on kokanee, related to stocked Gerrard rainbow trout or bull trout, is another potential factor. The number of Gerrard trout stocked into Arrow Lakes Reservoir in the 1990s was about three times more than the previous decade, and the average size of released fish was nearly double (MOE file data); however, angler catch rates and harvest during the years of kokanee decline give no indication of higher predator numbers (percentage of stocked trout in the catch was <3%; Arndt 2002). Buktenica et al. (2007) found natural predator-prey cycles affected kokanee abundance in an ultra-oligotrophic lake in Oregon.

The decline in kokanee abundance during the 1990s is inconsistent with the primary productivity estimates of Moody et al. (2007) which predict a post-dam productivity higher than the pre-dam era due to increased light penetration and lentic area. Estimated biomass and numbers are only about one third of the predicted during the post-dam pre-nutrient period (Table 7). Again, competition from mysids is a possible explanation because the version of the Photosynthetic Rate model used to predict kokanee abundance in their report does not account for zooplankton used by mysids. Model predictions are close to empirical abundance estimates for Kinbasket Reservoir, a large system without mysids (section 6.3). Alternately, there could be other factors not considered in the Moody et al. (2007) productivity assessment, such as hydraulic changes (water level increase, levelling of seasonal flow, subsurface water release) that reduced or exported primary productivity in the reservoir after the trophic upsurge period

[25] Mysid densities in the reservoir were not measured until 1997 (Pieters et al. 2003), but mysids comprised the main food item in stomachs of kokanee below Keenleyside Dam in 1976 (Anonymous 1976) indicating that they were well established by then.
[26] Dry weights of 2-4 kg/ha reported in Vidmanic (2007) were converted to wet weight using the formula Wet weight = 6.23* dry weight + 0.26 (Smokorowski 1998)

(Matzinger et al. 2007; see 5.4 Nutrient and Turbidity Changes). Operating regimes have changed since dam construction.[27]

Table 7. Kokanee carrying capacity of Arrow Lakes as predicted by a Photosynthetic Rate model (Moody et al. 2007) compared to hydroacoustic estimates for the pre-dam era (before 1967), post-dams without fertilization (1984-1998), and post-dams with fertilization (1999-2006). Hydroacoustic data are from MOE file data (D. Sebastian, pers. comm.) and included spawners.

Period		Biomass (metric tonnes)		Number (millions)	
		PR Model	Estimate	PR Model	Estimate
Pre-Dams	Mean Range	220 -	na -	7.3 -	na -
Post-dams pre-fertilization	Mean Range	367 -	120.3 62 – 214	11.9 -	3.9 2.3 – 5.2
Post-dams with fertilization	Mean Range	510 -	397 218 - 587	17.0 -	11.9 6.5 - 20.8

In the post-fertilization era, both spawner and hydroacoustic counts indicate a wide range of kokanee abundance, and populations probably have not yet stabilized. The biomass and number estimates for all age classes remain well above pre-fertilization years, but this has not been reflected well in spawner returns. The reasons for the rapid increase and decrease since the beginning of fertilization are uncertain. Possible hypotheses include changes in the magnitude and timing of reservoir flushing (operational impacts), increased recruitment of kokanee predators, a delayed response from mysids, an inverse relationship between kokanee density (influenced by spawning channel output) and reservoir survival (i.e., food availability), reduced fry production in natural streams and the spawning channel due to fall floods, or changes in the efficiency of carbon transfer at lower trophic levels. Also the location and method of nutrient distribution was altered in 2005 (Schindler et al. 2007).

6.6 Walter Hardman (C6)

Kokanee were not present in the upper Cranberry catchment prior to construction of Walter Hardman generating station (1959), and the small headpond does not provide suitable kokanee habitat.

With respect to spawning, kokanee from Arrow Lakes used the lower reaches of Cranberry Creek near upper Arrow Lake for spawning before and after the dams on Cranberry Creek and Arrow Lakes. Petersen and Withler (1965c) mention that spawning may have also taken place in Little Fish Creek, a small tributary of Cranberry Creek about 5 km upstream of the mouth. No spawner counts are available prior to Walter Hardman. After the dam, Cranberry Creek was partially or completely de-watered immediately below the facility for periods in August and September (Northern Natural Resource Services 1976); upstream withdrawals also significantly reduce flows in the lower reaches where kokanee spawn (Andrusak and Slaney 2004). Construction of Hugh Keenleyside Dam further impacted the system by reducing the amount of habitat that is accessible below a barrier. The amount of suitable spawning habitat available prior to Keenleyside Dam is unknown. In 1976, it was estimated that about 1.2 km of stream was accessible below a velocity barrier of which less than 1% was good spawning habitat (Northern Natural Resource Services 1976). However, Andrusak and Slaney (2004) recently surveyed the creek and believed that the lower 1.7 km of the stream was accessible to kokanee. They felt that there was potential for improved kokanee spawning if stream flows were maintained. Post-dam spawner estimates between 1969 and 2007 have typically been less than 10,000 but are highly variable ranging from less than 1,000 to 41,000 in 2004 (MOE file data). Spawner returns could be affected by the quality of the remaining habitat as well as reservoir productivity changes or intra-specific competition with fry from other tributaries.

Overall, it is certain that the reduction in water supply and habitat in the lower creek due to the two hydro facilities would cause *reduced capacity of the system for kokanee spawning.* The relatively low flow and amount of accessible habitat suggest that its pre-dam spawner capacity might have been relatively small, probably less than 50,000 fish.

[27] A non-treaty storage agreement between Bonneville Power Administration and BC Hydro in 1984 resulted in greater drawdown of Kinbasket Reservoir, and in the early 1990s a further agreement was made to permit BPA to utilize additional storage at Kinbasket Reservoir for downstream uses.

6.7 Whatshan (C8)

Kokanee were introduced into Whatshan Lake by the early 1940s (J. Bell, MOE, pers. comm.), well before Whatshan Dam was built in 1971. About 4 km of lotic habitat (mostly order 3-5 streams of 0-3% gradient) was inundated (Thorley 2008). Dam construction increased lentic habitat from 15.4 to 17.6 km^2 (Moody et al. 2007), or about 14%; estimated kokanee carrying capacity based on a Photosynthetic Rate – Kokanee model increased slightly from 12,200 kg or 406,000 kokanee (all age classes) before the dam, to 13,300 kg or 443,000 fish post-dam (Moody et al. 2007). Spawning occurs in the Whatshan River upstream of the lake although the upstream extent is not known (Kokanee Forests Consulting 2000). Pre- or post-dam abundance data are not available.

Status of kokanee in this unit has probably not changed. Rearing capacity has increased slightly; spawning habitat has decreased and could be limiting recruitment.

6.8 Columbia River below Keenleyside Dam (C9)

The Columbia River downstream of the Arrow Lakes does not provide lentic habitat, however, kokanee have been observed in the recreational fishery in a slow-moving section of river downstream of Hugh Keenleyside Dam since 1976 (Andrusak and Martin 1982). There are no known records of kokanee spawning in tributaries of this reach in the pre-dam era. After Keenleyside Dam, kokanee have been observed spawning in Norns Creek, which enters the Columbia River about 7 km below the dam. These kokanee are probably entrained fish from the Arrow Lakes that are unable to reach their natal streams (Smith 1985, R.L.& L. 1997). It is also possible that some may be from Roosevelt Reservoir south of the border. Counts are not conducted in Norns Creek but limited observations suggest returns range from near zero to several hundred. Occasionally a few kokanee are observed in other small tributaries in C9 but none are believed to be self-sustaining populations.

Status of kokanee in this unit has not changed substantially, although entrained fish from C11 are often present below Keenleyside Dam.

6.9 Pend d' Oreille (C10)

Self-sustaining kokanee populations were not present in this unit prior to dams and the short water residence time of these reservoirs does not provide good limnetic habitat for them under current conditions. Some entrained fish may occur occasionally. Status is unchanged.

6.10 Upper Kootenay River (K1)

Prior to Koocanusa Reservoir, kokanee were not present in this dam unit, since the closest suitable lentic habitat was Kootenay Lake and kokanee could not migrate past Kootenai Falls near Libby, Montana (Anders et al. 2007). Following their accidental introduction into Koocanusa Reservoir in the late 1970s (Hartman and Martin 1987; Brown 1993), kokanee colonized suitable spawning habitats in the Kootenay River and tributaries upstream at least as far as Findlay Creek (Manson and Porto 2006). Aerial counts of spawning kokanee in K1 have been done from 1996 to 2005 in seven index streams. Total counts have ranged from 94,000 to 348,000 with the peak count occurring in 2001 (Table 8). The Lussier River is the most important of the spawning streams in K1, typically accounting for about half of the index total. These numbers represent a single count of active spawners near the peak of the run; if counts are expanded by a factor of 1.5 to account for early and late spawners the estimated numbers would range from about 143,000 to 521,000 spawners in this dam unit. Smaller runs occur in locations not included in the index so these estimates should be considered as minimum.

Status in K1 has changed from *not present* to *present for spawning*. Number of spawning kokanee has increased from zero to hundreds of thousands.

Table 8. Number of spawning kokanee counted in selected tributary streams upstream of Koocanusa Reservoir in dam unit K1, 1996 – 2005 (data from Manson and Porto 2006).

Stream	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Bull River	54,850	10,852	1,782	26,090	43,500	25,325	19,400	19,370	1,987	4,050
Findlay Creek	1,405	2,010	1,120	9,100	6,180	6,475	9,050	1,620	0	2,200
Kootenay River *	50,250	18,120	30,195	32,040	98,980	74,510	83,400	35,535	170	200
Lussier River	171,000	49,450	98,217	145,445	43,150	213,460	177,650	32,220	15,000	52,180
Norbury Creek	11,800	11,050	9,340	7,902	47,500	23,300	19,800	21,550	12,270	27,350
St. Mary River	12,175	3,810	5,856	8,825	11,440	4,701	16,375	1,350	648	6,270
Wild Horse River	4,595	100	20	1,470	277	0	5,500	0	1,125	1,650
Total Number	**306,075**	**95,392**	**146,530**	**230,872**	**251,027**	**347,771**	**331,175**	**111,645**	**31,200**	**93,900**

* includes only the side channel by the city fields

6.11 Bull River - Aberfeldie Dam (K2)

Kokanee were not present in this dam unit prior to dams and there is no suitable habitat for them under current conditions. *Status is unchanged*.

6.12 Wardner – U.S.A (K3)

Prior to Koocanusa Reservoir, kokanee were not present in this dam unit, since the closest suitable lentic habitat was Kootenay Lake and kokanee could not migrate past Kootenai Falls near Libby, Montana (Anders et al. 2007). Since their introduction, kokanee have utilized the lentic habitat in the reservoir and suitable spawning tributaries in this dam unit and upstream. About 60 km^2 of lentic habitat is available in K3 (north of the Canada-U.S. border) although it varies according to reservoir level. No estimates of reservoir kokanee abundance specific to the Canadian portion of the reservoir are available, however, kokanee are the dominant species in angler catch (Hartman and Martin 1987).

Aerial spawner counts in K3 have been done from 1996 to 2005 in 4 index streams. Totals have ranged widely from less than 1,000 to 121,000 with the peak count occurring in 2002 (Table 9). Sand Creek and Little Sand Creek are the most important of the K3 tributaries, typically accounting for most of the kokanee spawners in the index locations. If counts are expanded by a factor of 1.5 to account for early and late spawners the estimated numbers would range from less than 1,000 to 182,000 in this dam unit. Smaller runs occur in locations outside the index.

Status in K3 has changed from *not present* to *present for rearing and spawning*. Number of spawning kokanee has increased from zero to tens of thousands.

Table 9. Number of spawning kokanee counted in selected Koocanusa Reservoir tributary streams in dam unit K3, 1996 – 2005 (data from Manson and Porto 2006).

Stream	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Elk River	1,302	45	-	490	5,420	0	465	130	60	700
Little Sand Creek	7,250	3,000	488	9,402	13,050	2,450	37,000	2,400	3,580	5,700
Sand Creek	71,170	17,620	8	16,285	57,800	1,432	81,350	33,760	5,755	11,550
Wigwam River	11,900	260	0	1,768	1,450	0	2,750	395	0	3,910
Total Number	**91,622**	**20,925**	**496**	**27,945**	**77,720**	**3,882**	**121,565**	**36,685**	**9,395**	**21,860**

6.13 Elko Dam (K4)

Kokanee have not been present upstream of Elko Dam before or after dams; status has *not changed*.

6.14 U.S. border to Kootenay Lake (K5)

Andrusak et al. (2004) list four tributaries in K5 (Goat River, Corn Creek, Summit Creek and Boundary Creek) that were used by kokanee from Kootenay Lake for spawning. Of these, Goat River and Summit Creek had potential for the largest runs, which may have been in the tens of thousands at their peak. No count data are available prior to construction of Corra Linn Dam in 1932; however some counts are available for Summit Creek and Goat River about the time that Libby Dam (1973) and Kootenay Canal (1976) were completed. Peak counts in Summit between 1969 and 1979 when the lake was enriched by a fertilizer plant were in the order of 1,000 to 4,000 fish, but by the 1990s there were few or no returns; for the Goat River a count of 17,500 was recorded in 1972 but returns also declined to zero by the 1990s (Andrusak et al. 2004). Reasons for the decline in kokanee spawners in these streams are likely related to changes in Kootenay Lake nutrient status and possibly competition with fry from Meadow Creek Spawning Channel (Andrusak and Fleck 2005) or Koocanusa Reservoir, as is further discussed under dam unit K6 (section 6.15). The lower reaches of Goat River and Summit Creek were also severely impacted by channelization in the late 1960s (Andrusak et al. 2004).

Although spawning in this unit is now virtually absent, fry and adult kokanee still occur seasonally during migrations to and from locations in the US. Entrainment of young kokanee through Libby Dam is well documented and represents a substantial component of production in this dam unit (Skaar et al. 1996; Anders et al. 2007). Thousands of migrating kokanee young of the year can be observed in the Kootenay River during mid-summer, and these fish are likely entirely a result of production from Idaho (Colin Spence, Ministry of Environment, pers. comm.). Adults generated by this production, as well as from a few locations in Idaho, are also found in this area as they return to spawn.

Status of kokanee in this unit has <u>changed from *present for spawning* in small numbers to *present as entrained fry and migrant adults (Koocanusa Reservoir origin)*</u>.

6.15 Kootenay Lake (K6)

Kootenay Lake ecology has been significantly altered by anthropogenic influences since the 1930s (Table 10), making it difficult to assess the impacts of BC Hydro dams separate from other impacts occurring at the same time. It is clear that kokanee abundance and size is strongly affected by nutrient levels, as evidenced by their response to increases and decreases in phosphorus loading over the last 50 years. Cartwright (1961) noted that there had been an increase in angling effort for kokanee and rainbow trout “in recent years” and said that “in addition to the numerical data available, kokanee were reported by many anglers and resort operators to be more abundant than ever before in some areas of Kootenay Lake.” In some reports, the term “historical” is used in reference to the period just prior to construction of Duncan and Libby dams (1960s – 1970s), however this was an era of greatly enhanced productivity and expanded kokanee populations due to phosphorus inputs from a fertilizer plant upstream of the lake in Kimberley (Moody et al. 2007)[28]. Consequently, this period is not suitable as a representation of natural lake productivity prior to dams. To compare with post-dam status, an ideal “pre-impact” period would be prior to dams, prior to large scale nutrient enhancement from the fertilizer plant (pre-1953), but after the establishment of mysids (first introduced 1949). Unfortunately pre-impact information on kokanee abundance is limited to anecdotal newspaper references, a morphometrics study (Vernon 1957), some length information for spawners, and an estimate of First Nations use. Northcote (1973) approximated the quantity of fish taken from Kootenay Lake by First Nations residents using historical records of their population and diet assumptions. He believed that exploitation of all species during the late 1700s (period of peak population) was in the order of 100 tonnes annually of which kokanee may have comprised ~12.5 tonnes (125,000 fish averaging 0.1 kg).

[28] 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 10. History of dam construction, fertilizer plant operation, and biological manipulations in Kootenay Lake (from Daley et al. 1981; Northcote 1973; Ashley et al. 1997, MOE file data).

Year	Dam	Kimberley 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
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 spawning channels in operation
1984 – 1990			Meadow Creek Spawning Channel renovations greatly improve fry production capacity
1992			North Arm nutrient addition begins (FWCP funding)
2004			South Arm nutrient addition begins (BPA/KTOI funding)

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

A dominant feature of primary production in Kootenay Lake in its pre-impact state was the presence of high turbidity from May through early July, especially in the south arm due to the Kootenay River. Duncan River imparted some turbidity to the north arm but to a lesser degree because of the settling effect of Duncan Lake. Paleolimnological studies dated to before 1900 clearly show that prior to human intervention the mid-portion of the lake was most productive, followed by the north arm with the south arm last. The shallow euphotic depth limited carbon fixation in spring and early summer, but by August and September, nutrient limitation became more important. Major changes in the lake's trophic status began with the inputs of phosphorus starting in the 1950s. (Moody et al. 2007; see their report for further references; also see section 5.4)

After the period of major phosphorus enrichment from the late 1950s to early 1970s, there was a dramatic reduction in lake productivity due to pollution controls and eventual closure of the fertilizer plant, along with nutrient retention in upstream dams (Daley et al. 1981); kokanee abundance and size decreased accordingly. More detailed descriptions of historical changes in Kootenay Lake are provided by Northcote (1973), Daley et al. (1981), Ashley et al. (1997), Northcote et al. (2005), Vonk (2001) and Moody et al. (2007). North and south arm nutrient additions began in 1992 and 2004 respectively.

Dams affecting Kootenay Lake include Corra Linn at the lake outlet (1939, currently the control structure for BCH Kootenay Canal Plant), and also Duncan (1967, BCH flood control and storage) and Libby (1973, Bonneville Power Administration flood control and power production) dams located upstream on its two major tributaries. Corra Linn Dam raised the maximum lake level by 2.4 m, causing the loss of spawning habitat in the lower reaches of tributaries and narrows of the West Arm. Upstream dams reduced nutrient levels, and increased light penetration (Moody et al. 2007). Other effects of the upstream dams include reduced spring and early summer flows, higher winter flows, and lower spring water levels. Changes in lake levels may have had the greatest affect on West Arm stocks of kokanee if spawning occurred in riverine sections prior to dams as suggested by anecdotal accounts (Appendix E). Reduction in peak flows would influence all areas, including the north arm. It has been postulated that, prior to Libby Dam, deep currents carried nutrient rich water from the south arm into the north arm, thereby enhancing phytoplankton production during spring turnover and later (Northcote et al. 2005; Vonk 2001). Changes in annual temperature regimes are often associated with altered discharge patterns, although Cloern (1976) did not find a significant change in the south arm of the lake. Comparative temperature data for the north and west arms are not available, however, Hamblin and McAdam (2003) modelled thermal regimes and concluded that changes were likely too small to affect indigenous fish populations in the lake.

6.15.1 Spawning Habitat and Abundance Trends

Spawning habitat in Kootenay Lake can be considered in terms of three areas: the north, south, and west arms of the lake. Most kokanee spawn at age 3+ in the north and south arms, whereas in the West Arm the majority spawn at age 2+ (Andrusak et al. 2007). Quantity of spawning habitat decreased for all stocks as a result of both downstream and upstream dams[29].

North Arm

Kokanee escapements to north arm tributaries have likely always been far greater than the south and west arms (Andrusak and Fleck 2005). These north arm fish currently spawn almost entirely in Meadow Creek and the Lardeau and Duncan rivers. See Sections 6.16 and 6.17 (units K7 and K8) for a summary of changes in returns to these major spawning areas. There are also post-dam records of kokanee presence (in small numbers) in most of the small, relatively steep streams directly tributary to the east and west sides of the north arm (Fisheries Information Summary System database, BC Ministry of Environment). The extent to which these were used prior to dams is unknown.

South Arm

Twelve streams tributary to the South Arm have supported kokanee (Table 11). Most are steep (>5% gradient) with only a few hundred meters of suitable kokanee spawning habitat in the lower reaches; the biggest are Midge and Crawford creeks (Andrusak et al. 2004). Only Akokli Creek was sampled prior to the onset of phosphorus enrichment from the Kimberley fertilizer plant, but even in that stream there was not a complete count (Vernon 1957). Andrusak et al. (2004) provide a suspected run size for these tributaries for the years prior to Duncan and Libby dams (Table 11); numbers at that time would be influenced by fertilizer plant phosphorus enrichment and interactions with Meadow Creek Spawning Channel. A newspaper story prior to Corra Linn Dam and the fertilizer plant (Nelson Daily News, August 31, 1921; Appendix E) reports kokanee of 20-25 cm spawning in Midge and Cultus creeks but “not in their former numbers”; new regulations prohibited the use of gill and scoop nets in or near the creek mouth. This signifies that these streams must have had reasonably strong returns if people from Nelson travelled there to harvest them. Government stocking records show that kokanee introductions to south arm tributaries started as early as 1931 and continued through the 1940s and 1950s (Andrusak et al. 2004). This might imply that spawning runs in many of these tributaries were low at that time, or had possibly decreased. However, fish stocking decisions then were made by hatchery workers and introductions may have been done regardless of need (H. Andrusak, former regional fisheries biologist, pers. comm.).

Recent returns to South Arm streams have been almost non-existent (Table 11) even though spawning habitat could support more kokanee in many of the streams (Andrusak et al. 2004). The few fish returning probably include strays from north arm sources (Andrusak and Fleck 2005) and entrained fish from Koocanusa Reservoir. The original *south arm stock of kokanee appears to be extirpated,* possibly because of competition with fry from the enhanced North Arm stock (Andrusak and Fleck 2005) and/or altered feeding and predation conditions after the dams.

[29] Estimates of lost stream habitat are not available for Corra Linn Dam because the lake level was raised prior to detailed mapping.

Table 11. Available habitat and suspected peak run size in the 1960s and 1970s of kokanee in tributaries of the South Arm of Kootenay Lake compared with recent spawner counts (from Andrusak et al. 2004, Andrusak and Fleck 2005; Andrusak 2007b).

Stream	Accessible Length (km)	Suspected Peak Run Size	Peak Count in 2003	Peak Count in 2004	Peak Count in 2005
Crawford	4	1,000-10,000	5	0	0
Gray	<0.3	< 1,000	35	8	0
La France	0.7	-	0	0	0
Lockhart	<0.3	< 500	0	0	0
Akokli	<0.4	< 500	151	9	1
Sanca	<0.5	< 500	5	0	0
Boulder	0.4	< 500	0	0	0
Cultus	-	< 500	0	20	-
Next	<0.2	< 1,000	-	-	-
Midge	1.5	5,000-15,000	0	0	-
Wilson	0	0	0	-	-
Irvine	0	0	0	-	-

West Arm

In the West Arm, several tributaries were used for spawning with the most important being the lower reaches (250 - 500 m) of Redfish, Kokanee, Harrop, Duhamel, Lasca, and Grohman creeks (Anonymous, undated). Spawning also probably occurred in narrows of the West Arm prior to 1939, when Corra Linn Dam was altered to allow 1.8 m of storage in the lake. At that time the arm was a series of basins connected by short narrows and river-like sections. An additional 0.6 m of storage was added later, and Northcote (1973) noted that the raised water level would likely have deleterious effects on rainbow trout and other salmonids that spawned in the narrows. Although quantitative kokanee data are not available for this period, a local newspaper (Nelson Daily News, Sept. 20, 1948; Appendix E) stated that kokanee numbers in 1948 were lower than previous years, and suggested this was due to flooding of spawning areas in the West Arm and dredging of gravel beds at Grohman Narrows. According to the newspaper article “definite harm has occurred to the main forage food of the rainbows, namely the kokanee, which have dwindled in number in the West Arm over the last 15 years”.

Sporadic shore spawning still occurs in the West Arm, but numbers are very small relative to the tributary spawning channels, and it appears that the shore spawners are likely tributary-source fish that spawn on alluvial fans during low water years. Andrusak et al. (2007) note that numbers of shore spawners were high in a year of low stream flows when fish had difficulty moving upstream, and suggest that fish may be homing to groundwater of stream origin because of difficult access or high stream temperatures. Under current operating conditions, the arm provides poor spawning habitat for kokanee because dam-related lowering of the water levels over the incubation period leaves many shallow redds above the water level prior to emergence (Andrusak et al. 2007). The possibility of deep redds in unsurveyed reaches cannot be entirely ruled out. Scuba observations in several locations in late August 1970 and late September 1971 found some redds as deep as 10 m, but most were in shallower water in the vicinity of stream mouths (Andrusak et al. 2007). Tributary spawning channels funded by the Habitat Conservation Trust Fund in Redfish and Kokanee creeks currently support the vast majority of spawning in the West Arm, although lesser numbers of fish spawn in other tributaries without spawning channels (e.g., Lasca, Duhamel creeks).[30]

In spite of the loss of habitat in the narrows and the lower reaches of its tributaries, the West Arm supported a very productive fishery from the late 1960s to 1975, suggesting that the remaining spawning habitat in tributaries (prior to spawning channels) was adequate to support a large population when lake productivity was high and feeding conditions in the arm were favourable. This conclusion should be tempered by the possibility that fish from the main lake may have comprised about 50% of the catch (Martin undated, Martin and Northcote 1991). Also, in the early 1970s the BC Parks Branch channelized the lower reach of Kokanee Creek where the majority of west arm kokanee spawned (Martin undated). Recent spawner returns to tributaries (including spawning

[30] Although it does not currently support kokanee, Nelson Daily News (October 16, 1946, p. 8) reports on work to aid fish passage in a concrete flume in Cottonwood Creek and states “… through these stops, it will be possible to have a run of kokanee from the West Arm similar to years ago.” (cited by Thomson 2009)

channels) are in the order of 10,000 or more (Andrusak et al. 2007). The absence of counts prior to completion of the spawning channels in the 1980s prevents comparison of *pre-impact numbers to current status*.

Average length of spawners in West Arm tributaries was less than 25 cm for Kokanee and Redfish creeks in the early 1950s (Andrusak et al. 2007) prior to full establishment of *Mysis relicta*. Size increased markedly following the introduction of mysids and increased phosphorus loading in the 1960s and 1970s (mean annual lengths of 35-40 cm). Spawner length decreased as expected after the Kimberley plant closure and dam construction, but remained above the pre-impact size even in the years just prior to the start of the fertilization program (28–37 cm). Since fertilization, mean lengths in Redfish and Kokanee creeks have ranged from 25-37 cm (MOE file data). Adult kokanee were also less than 30 cm in the south and north arms in the late 1940s and 1950s, with a slight increase in size in north and south basins starting in the 1960s (Northcote 1973). Recent spawner lengths in the north arm (Meadow Creek) are in the range of 21-27 cm (MOE file data), similar to the pre-impact size.

When all spawning areas accessible to Kootenay Lake kokanee are considered (see also sections 6.14, 6.16, 6.17), a number of generalizations can be made. First, the majority of spawning habitat was in North Arm tributaries, and this continues to be the case after dams. Raising of the lake level slightly would have reduced spawning habitat in the lower reaches of all tributaries, but may have affected West Arm kokanee the most. A much more significant habitat loss occurred when Duncan Dam was built in the lower Duncan River (see section 6.17). Meadow Creek Spawning Channel is currently the most important spawning area for north arm fish, and is responsible for the majority of Kootenay lake fry production.

The amount of natural spawning habitat in the north arm decreased substantially after dams and would be expected to cause a reduction in Kootenay Lake kokanee abundance if spawning habitat was limiting prior to dams. Loss of this habitat also restricted the locations in which spawning could occur, impacting the overall potential of the ecosystem to support spawning and other organisms dependent on this process. Both spawner returns and size peaked in the 1970s in all areas during the years of highest phosphorus loading from the Kimberley plant, declining to much lower numbers after the closure of the plant and construction of the upstream dams. Since the nutrient program began, north arm spawner returns (Meadow Creek, Duncan-Lardeau) have increased to levels similar to the 1960s and 1970s (Section 6.17).

There has also been a loss of genetic diversity. South arm kokanee, which were considered to be a separate stock based on morphometrics and life history differences (Vernon 1957), are probably extirpated. West arm kokanee still retain some genetic distinction from north arm fish (Anders et al. 2007).

6.15.2 In Lake Abundance Estimates (Hydroacoustic and Creel Data)

Hydroacoustic estimates provide an assessment of fall kokanee abundance (excluding the West Arm) starting in 1985 after all dams were completed. The years from 1985 – 1991 represent a post-dam period prior to the start of the nutrient program in 1992. Moody et al. (2007) judged the primary productivity of the lake to be the same in this period as it was before dam impacts (whole lake average of 125 mg carbon/m^2/day), because of the interaction between increased light penetration and reduced nutrients when the upstream dams were built. A slight increase in post-dam surface area results in slightly higher whole lake carbon production but similar predictions of kokanee abundance of over 13 million and 400 tonnes biomass. Hydroacoustic biomass and abundance estimates during this era are substantially lower than the predicted, averaging 9.4 million fish and only 184 tonnes (Table 12). Since 1992, primary production has increased (172 mg carbon/m^2/day; Moody et al. 2007), and average kokanee abundance and biomass have more than doubled. In this period, model predictions are very close to the hydroacoustic estimates (Table 12). The discrepancy between model predictions and empirical data during the lower productivity period, and not during the fertilized period, could be an indication that mysid competition is more limiting to kokanee under lower productivity conditions, or possibly that kokanee responded more quickly to nutrient addition than mysids, in which case kokanee biomass would be expected to decrease in future years. Alternately, it could be an indication that post-dam carbon production estimates by Moody et al. (2007) are too high for the post-dams pre-fertilization period, or that operational impacts cause further productivity reductions.

An early promotional publication by the Nelson Board of Trade (1934) states that “fishing is a favourite pastime” in the west arm, and “it is quite usual in a couple hours to get enough kokanee and rainbow trout for breakfast.” Later west arm kokanee numbers can be inferred from creel data that was collected starting in 1967 as lake productivity and mysid export increased. These data show the development of an intensive fishery that peaked in the early 1970s, and declined through the late 1970s and 1980s (Andrusak 1987). Harvest estimates during the peak year (1975) exceeded 100,000 fish with the largest kokanee reaching 4 kg and an average size of nearly 1 kg (Andrusak

1981; Redfish Consulting 2002). This projects to a harvest of nearly 100 tonnes, eight times the Northcote (1973) estimate of whole-lake First Nations kokanee harvest mentioned earlier. During these years, over 75% of the total annual recreational catch on Kootenay Lake was coming from the west arm (Andrusak 1987). The west arm kokanee fishery declined after this period and the season was closed after 1980 and re-opened in 1994; recent harvest estimates are around 5,000 fish of 25 - 30 cm length (Redfish Consulting 2002), or about 1 tonne (at 0.2 kg/fish). As mentioned earlier, fish residing in the west arm during the growing season may originate from west arm spawning sites or move in from the main lake (Martin undated). Estimates of kokanee harvest for including the north and south arms ranged from 33,000 - 128,000 between 1968 and 1986 (Andrusak 1987); size of the fish in the main lake was 20 – 25 cm.

Table 12. Kokanee carrying capacity of Kootenay Lake as predicted by Moody et al. (2007) using a Photosynthetic Rate model compared to fall hydroacoustic estimates for three periods: pre-dam, post-dams without fertilization, and post-dams with fertilization. Biomass and number include all age classes in the lake plus spawners (MOE data, D. Sebastian, pers. comm.).

Period		**Carbon Production (tC lake^{-1})**	**Biomass (metric tonnes)**		**Number (X 1,000,000)**	
			PR Model	**Estimate**	**PR Model**	**Estimate**
Pre-impacts	Mean	**8,775**	480	na	13.6	na
	Range		-	-	-	-
Post-dams without fertilization	Mean	**8,865**	412	184.2	13.7	9.4
	Range		**-**	123 – 250	**-**	6.5 – 14.2
Post-dams with fertilization	Mean	**11,958**	567	500.9	18.9	22.9
	Range		**-**	218 - 948	**-**	9.0 - 36.8

Changes that occurred with the closure of the fertilizer plant and building of upstream dams had a major effect on both habitat and food supply in the west arm. During the period of peak abundance, the habitat in the west arm included large amounts of rooted aquatic plants, which had not existed prior to 1960 (Burns 1970). This heavy macrophyte cover largely disappeared after phosphorus loading was reduced. Kokanee fry in the west arm are unusual in that they stay in the littoral areas for 1-2 months after emigrating from the streams (Andrusak et al. 2007). The macrophytes might have reduced vulnerability to predation although the timing of plant growth in the spring may have been after most fry had moved to open water. Mysids exported from the main lake comprised an important component of kokanee diet in the West Arm after their introduction (Northcote 1973); however, they are not as abundant in the diet under recent conditions (Redfish Consulting 2002). This is related to a reduction in mysid export due to changes in the timing and magnitude of discharge, and altered water levels after Duncan and Libby dams. Aquatic insect larvae and terrestrial insects were also important in the diet of West Arm kokanee (Daley et al. 1981); the impacts of changed water levels and discharge on these food sources is unknown. An internal memo noted that the drawdown period of low water was prolonged after Libby Dam became operational in 1975, so that water levels in the west arm were lower during the time of kokanee fry entry than they were prior to the dam (Smythe 1977); this may have contributed to reduced fry-to-adult survival for west arm kokanee in the 1980s.

In the south arm, the reduction in turbidity after Libby Dam may have been significant for kokanee not only in terms of primary productivity, but also in terms of vulnerability to predation. Rainbow trout are sight feeders that typically benefit from an increase in water clarity (Behnke 1992). Catches of large rainbow trout in the north arm declined at that time while central and south arm catches increased (Andrusak and Crowley 1975; Irvine 1978). Angling effort also increased in the south arm, leading to speculation that the improved fishing there was related to the reduced turbidity, or other changes in limnology, temperature and food distribution after Libby Dam (Martin 1978, Irvine 1978).

6.15.3 Overview

Kokanee were present in Kootenay Lake for *rearing and spawning* prior to the dams. Kokanee are *currently abundant for rearing* but the amount of *spawning in this unit has decreased* (particularly in the south arm). Available pre-dam spawner escapement estimates for Kootenay Lake are from a period of phosphorus enrichment during which kokanee numbers were enhanced. Following closure of the fertilizer plant and dam construction there was a strong decline in escapement, followed by an increase after north arm nutrient additions started in 1992. Current biomass and abundance in the north and south arms is slightly greater than estimated by Moody et al. (2007) for the pre-impact era. Recent harvests in the west arm are a small fraction of the peak years when the Kimberley fertilizer plant was operational, and may be less than the pre-impact era. Recent harvest estimates are not available for the main lake but are likely less than that estimated by Northcote (1973) for the pre-impact era. Nearly all of the current reproduction comes from the Duncan-Lardeau Rivers and Meadow Creek Spawning Channel (see sections 6.16 and 6.17). Changes in water clarity in the south arm may have contributed to the loss of stocks there.

6.16 Duncan Dam (K7)

This dam unit originally provided lentic habitat for kokanee in Duncan Lake, and spawning habitat for these fish as well as those coming from Kootenay Lake to spawn in the Duncan River downstream of the dam site. Lentic habitat in Duncan Lake totalled 26 km^2 prior to Duncan Dam, although only the south bay of the lake was considered good for fishing due to highly glacial conditions in the remainder (Maher 1961). Dam construction more than doubled the summer lentic area to 65 km^2, and estimated kokanee carrying capacity increased from 18,400 kg (613,000 fish, all age classes) to 46,200 kg (1,540,000 fish) based on a Photosynthetic Rate - Kokanee model (Moody et al. 2007)[31]. However, this estimate does not take into account potential survival limitations that might occur during the drawdown period. No hydroacoustic estimates are available for kokanee in Duncan Reservoir to corroborate the model estimates, although Sigma (1979, cited by Vonk 2007) estimated that kokanee comprised about 90% of the total number of sportfish in the reservoir. Reservoir elevation fluctuates by 30 vertical meters annually (Vonk 2001) and reservoir area can be reduced by more than half in late winter.

A total length of 101 km (4.4 km^2 area) of river and stream habitat was flooded in this unit (Thorley 2007), almost all of which was low gradient (0-3%) habitat that would have included areas suitable for kokanee spawning. A large area of spawning habitat in the mainstem and side channels of the lower Duncan River, between the original lake outlet and the dam site, was very significant for kokanee from Kootenay Lake (Petersen and Withler 1965; Vonk 2001). In the years just prior to Duncan Dam, spawner estimates for this area were 2.8 and 0.5 million in 1964 and 1965 respectively (Arcara 1970). This was when the lake was enriched by fertilizer plant phosphorus additions. Unfortunately, no counts are available prior to enrichment, but see sections 6.17 for further discussion of spawning habitat losses in the lower Duncan River. With respect to spawning upstream of Duncan Lake, little information exists on habitat availability and fish use prior to the dam, and no tributary spawner counts are available after the dam. Nevertheless, the best quality habitat was likely the alluvial fans of smaller tributaries. These areas are now impounded, and alluvial depositions under current reservoir levels are unlikely to be of equivalent quality (see 5.2.1 Habitat Losses and Gains).

The Duncan kokanee population is now isolated from Kootenay Lake kokanee, as upstream movement is prevented by the dam. Significance of entrainment from the Duncan population is not known, although small kokanee made up 7 percent of the catch in a rotary screw trap below the dam in 2000 (Vonk 2001).

Kokanee were present in this dam unit for *rearing and spawning* before and after Duncan Dam. <u>*Lentic rearing capacity and abundance may have increased*</u> due to increased area (Moody et al. 2007), if remaining spawning or winter habitat is not limiting production above the dam. <u>*Spawning habitat has decreased substantially and could be limiting the kokanee population*</u>*.* Lentic abundance data and spawner counts are lacking. The implications of losses of Kootenay Lake spawners in the Duncan River below the original lake outlet are discussed under section 6.17.

6.17 Trout Lake, Lardeau and lower Duncan Rivers (K8)

This dam unit provides lentic habitat for kokanee residing in Trout Lake, and spawning habitat for these fish and those coming from Kootenay Lake (K6) to spawn in suitable areas downstream of Trout Lake. Movement between these populations can occur since the connection between the two lakes is unaffected by dams.

Trout Lake is a deep oligotrophic lake providing 2874 ha of lentic kokanee habitat upstream of direct dam effects. The most important spawning tributary for Trout Lake kokanee is likely Wilkie Creek (Burns 1979). No estimates of kokanee abundance in the lake or spawner counts are available. <u>Status of the Trout Lake population has *not changed* due to dams.</u>

The Duncan River downstream of the lake outlet, Lardeau River, and Meadow Creek provided very important spawning habitat for Kootenay Lake kokanee prior to dams. Total escapement to these systems was similar from 1965-1967 at about 1.2 million spawners, although 1964 was estimated much higher (Table 13). In the Lardeau River specifically, spawner numbers were estimated at 0.5 to 1.4 million from 1964 to 1967, just prior to and after

[31] These estimates assume that the daily rate of limnetic photosynthetic production did not change after Duncan Dam.

construction of Duncan Dam (Table 13). Counts for a pre-impact period prior to enrichment from the fertilizer plant are not available. Access to spawning areas upstream of the dam site in Duncan River was blocked starting in 1966, and the large increase in Meadow Creek returns starting in that year suggests that the majority of Duncan River kokanee shifted to Meadow Creek when blocked from their natal area (Acara 1970). A smaller but substantial proportion also apparently shifted into the Lardeau River. Meadow Creek Spawning Channel was built in 1967 to compensate for lost spawning area in the Duncan River. Acara (1970, p. 31) estimated that the fry production from Duncan River in 1967 would have been 10.5 million assuming the same egg-fry survival as Lardeau River (14%) and the same proportion of north arm fish spawning in Duncan as in previous years. If the same fecundity and egg-fry survival assumptions are used for the 1964 to 1967 return estimates (Table 13), Duncan fry production ranges from 7 to 44 million. Meadow Creek fry production was typically < 10 million up to 1992 and has ranged from 11-31 million since then, including spawning above and below the spawning channel (MOE file data).

Table 13. Estimated number (N) and percent (%) distribution of kokanee in the Lardeau-Duncan-Meadow system from 1964-1968 and 2002-2008. Duncan River was first blocked in 1966. Meadow Creek Spawning Channel (MCSC) was first operated in 1967. Data for 1964 are from Bull (1965), 1965-1968 from Acara (1970) and Taylor et al. (1972), and for 2002-2008 from Kootenay Environmental Services (2007) and MOE file data. Methods of enumeration are indicated in footnotes. See Appendix F for complete data set of north arm counts.

Year		Meadow Creek total	MCSC[1]	Lardeau River	Duncan River	Total
1964[2]	N	346,128	_	1,382,424	2,807,937	4,536,489
	%	7.6		30.4	62.0	
1965[2]	N	116,095	_	506,446	455,841	1,078,382
	%	10.8		47.0	42.2	
1966[3]	N	597,331	_	646,712	13,100	1,257,143
	%	47.5		51.5	1.0	
1967[3]	N	606,282	197,878	705,351	6,750	1,318,383
	%	46.0	15.0	53.5	0.5	
1968[4]	N	287,583	93,752	not counted	not counted	NA
	%	-	-			
2002[5]	N	354,000	302,500	109,950	6,000	439,950
	%	73.6	68.8	25.0	1.4	
2003[5]	N	856,100	336,545	174,000	26,000	1,056,100
	%	81.1	31.9	16.5	2.5	
2004[5]	N	1,132,600	514,791	246,000	3,000	1,381,600
	%	82.0	37.3	17.8	0.2	
2005[5]	N	1,036,600	463,614	232,400	2,200	1,271,200
	%	81.5	36.5	18.3	0.2	
2006[5]	N	371,200	331,194	107,000	2,300	480,500
	%	77.3	69.9	22.3	0.5	
2007[5]	N	386,700	241,891	146,821	24,320	557,841
	%	69.3	43.4	26.3	4.4	
2008[5]	N	939,600	437,236	409,731	NA	NA
	%					

[1] MOE file data, J. Bell, pers. comm.
[2] For 1964 and 1965, Lardeau and Duncan estimates were from a mark-recovery estimate using Petersen tags applied at Argenta and Marblehead and recovery of dead fish after spawning. Tag loss before recapture and tag detection rate were not estimated. In Meadow Creek enumeration was by fish counts at a weir. (Bull 1965; Acara 1970) Bull (1965) notes that recovery of dead fish was very difficult in the Duncan River.
[3] For 1966 and 1967, spawners were enumerated by direct counts through weirs and visual estimates in minor areas below the weirs for all three locations (Acara 1970).
[4] In 1968, Meadow Creek was enumerated by direct wier count and visual count (John Creek tributary).
[5] Enumerated by wier count in Meadow Creek and aerial surveys in Lardeau and Duncan.

The Duncan-Lardeau-Meadow system has continued to be the most important spawning area for kokanee from Kootenay Lake in the post-dam era. Recent spawner counts total in the same range as the 1965-1968 data for most years, but Meadow Creek (including the natural stream and spawning channel) now comprises about 80% of the returns in most years with Lardeau River returns substantially reduced (Table 13). Usually less than 10,000 spawn in the remaining reach of lower Duncan River. Number of spawners usually varies inversely with spawner size.

Kokanee were present in this dam unit for *rearing and spawning* before and after dams. Recent (2003-2005) spawner returns from Kootenay Lake (Duncan-Lardeau, Meadow Creek) are *similar to three of the years in the enriched period just prior to Duncan Dam* (1965-1967), but less than the 1964 estimate. The majority of spawning has shifted from natural habitat in the Lardeau-Duncan rivers to the Meadow Creek spawning channel. Although habitat in the Lardeau River has not been impacted by dams, returns have decreased to less than half of what they were in the 1960s, now comprising approximately 20% of total north arm spawners compared to 50% in the pre-dam counts. Since the earliest spawner counts for Kootenay Lake were during the enriched period, current status cannot be compared to a pre-impact period. The loss of one of the two main spawning areas for Kootenay Lake kokanee may have reduced in-lake abundance and production if Meadow Creek Spawning Channel had not begun production immediately after Duncan Dam was built.

6.18 Slocan Lake (K9)

Kokanee use lentic habitat in Slocan Lake and spawn in several tributaries. Dam construction in the basin has not affected this stock. Bonanza Creek is a known spawning stream, and possibly Wilson Creek (J. Bell, MOE, pers. comm.). Other spawning locations are not known. Some entrained kokanee may be present in the Kootenay River downstream of Corra Linn Dam, especially during periods of high abundance in the West Arm of Kootenay Lake.

Status of kokanee has *not changed* in this dam unit.

7.0 COMPENSATION OPTIONS AND COSTS

Kokanee populations in the FWCP area can be summarized in three categories: un-impacted lakes (Slocan and Trout), new impoundments or substantially enlarged lakes (Kinbasket, Revelstoke, Duncan and Koocanusa), and large impacted lakes (Arrow, Kootenay). Whatshan Lake was impacted slightly due to a small increase in lake elevation and surface area. Introductions of kokanee into new reservoirs increased the species' distribution and overall abundance in the basin, however, in Arrow and Kootenay lakes, two large impacted lakes with the most regionally significant populations prior to dams, kokanee abundance and stock diversity decreased or may have decreased without intervention. Quantity and quality of spawning habitat has been reduced for these populations. Compensation options are particularly relevant for the large impacted lakes.

The fish habitat management policy of the Canada Department of Fisheries and Oceans (DFO) provides a starting framework for discussing compensation. The goal of the policy is "no net loss of the productive capacity of habitats" (DFO 1986) where productive capacity is defined in relation to healthy fish safe for human consumption and the aquatic organisms upon which they depend. 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 production (e.g., fish hatchery) provided that genetic and biological factors are satisfied and proven techniques are available.

A second framework for determining appropriate compensation, particularly relevant when considering kokanee populations in a large lake ecosystem, 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 other factors are limiting. Reeve et al. (2006) recommend the following strategy:

1. identify limiting ecological conditions
2. set specific restoration objectives
3. monitor and evaluate a minimum of 10 years to track results in relation to the hypotheses of limiting factors.

They also note that compensation strategies should have a goal of maintaining the habitat required to provide a *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.

Lastly, clearly stated Ministry of Environment management objectives for the large lakes in the program area would be helpful to optimize benefits from compensation initiatives. These could include specific targets for kokanee size/age structure and abundance in relation to piscivore forage and/or angling, and objectives for biodiversity conservation. Alternative hypotheses about methods to achieve the objectives could then be tested as part of an adaptive management process. A summary of impacts, compensation options, estimated costs and performance measures is provided in Table 14 (also see Murray 2005ab). Additional details are provided below.

Table 14. Summary of dam impacts, compensation options, costs, and performance measures for kokanee in the FWCP program area.

Impact	Compensation Option	Estimated Cost	Performance Measures	
			Project Level	**Program Level**
Reduction in downstream nutrient inputs to lakes or reservoirs due to upstream impoundments	Large lake nutrient additions (or embayment fertilization)	• $873,000 Kootenay Lake (north arm) - • $1,024,500 Arrow Lakes (Columbia Power Corporation contributes $238,000) • $300,000 bull trout and piscivorous rainbow trout monitoring (both lakes)	• water quality parameters, N:P ratios • lower trophic level responses (algae, zooplankton species composition)	• kokanee production (kg/ha/yr) increased (see Spawning Channels). • kokanee abundance, growth, and size suitable for angling and piscivore growth• growth, condition and abundance of bull trout and piscivorous rainbow trout the same or higher than pre-nutrient era • angler effort, catch, and harvest higher than pre-nutrient level • spawner abundance for bull trout, rainbow trout maintained or increased • application method results in maximum uptake, retention, and efficient transfer of nutrients to fish level
	Operational changes at upstream dams	Not available (addressed under Water Licence Requirements)	• residence time of biologically productive layer in target reservoir increased • reduced export of nutrients and biological production from target reservoir	• reduced level of added nutrients needed to maintain primary productivity in target lake/reservoir • increased fish production in target lake/reservoir
	Mysid biomass reduction	Not available; possibly at no cost to program if commercial fishery economically viable	• reduced biomass/abundance in lake/reservoir • reduced zooplankton consumption by mysids	• increased kokanee production in target lake/reservoir • evidence that nutrient transfer to kokanee and higher trophic levels is improved
Loss or reduced viability of specific spawning stocks and genetic diversity (e.g., south arm Kootenay Lake, Arrow Lake stocks upstream of Revelstoke and direct tributaries)	Stream restoration and enhancement	$113,000 to $800,000 per km not including monitoring (Thorley 2008)	• km of stream restored • number of structures installed, etc. • area of suitable spawning habitat	• long term increase in spawner returns to viable levels • maintenance of remaining genetic diversity
	Stream gravel additions	$10,000 per stream annual cost	• tonnes of gravel added • area covered with suitable spawning gravel	• as above
	Stream barrier removal	$5,000-$10,000 (small, temporary barriers) >$1 million (permanent fishway)	• number of kokanee spawning upstream of former barrier/obstruction • length of stream opened to spawner use	• long-term persistence and maintenance of spawner abundance in enhanced stream • maintenance of remaining genetic diversity

Table 14 continued. Summary of dam impacts, compensation options, costs, and performance measures for kokanee in the FWCP program area.

Loss or reduced viability of specific spawning stocks and genetic diversity (continued)	Stream flow conservation	$10,000 per licence	• number of licences obtained • quantity of stream discharge increased or protected for fish habitat	• as above
	Re-introduction of eyed eggs to barren tributaries	$5,000 - $10,000 per stream per introduction	• number of egg planted by stream • number of returning spawners	• development of self-sustaining runs in natural streams
Inundation or blocked access to spawning habitat	Spawning channels	Hill Creek and Meadow Creek spawning channels (see Appendix H) • $426,000 (operations and maintenance) • $2.14 million (potential capital costs)	• adult returns adequate for target egg deposition • egg deposition target met • egg to fry survival high (≥ 30%) • total fry produced adequate to compensate for estimated fry losses or adequate to ensure reservoir production not limited by fry recruitment	• reservoir kokanee production (kg/ha/year) near or at optimum for fishery targets • kokanee abundance, growth, and size/age structure of population suitable for angling and piscivore growth • growth, condition, and abundance of bull trout and piscivorous rainbow trout high • angler effort, catch and harvest for kokanee, bull trout, piscivorous rainbow trout high • zooplankton productivity not reduced by overgrazing • fry to adult survival in reservoir allows persistence of natural stocks
	Dam fishways	Not available; expected to be very high; other migratory species also benefit.	• number of fish (kokanee and other species) migrating through fishway significant in relation to downstream population • size frequency of successfully-passing fish similar to below dam	• maintained or restored genetic variability • reservoir biomass near lake carrying capacity (see above) • natural recruitment adequate to sustain reservoir populations in drainage basin

7.1 Lake Nutrient Additions

The addition of limiting nutrients (phosphate and nitrogen) can be an effective method of increasing primary production that can transfer up the food chain to kokanee and other fish (Moody et al. 2007), and is a reasonable compensation option if primary production has been reduced by upstream reservoirs. It has the advantage that it is likely to benefit all kokanee stocks regardless of their spawning location. Current programs operate at large scales, but embayment fertilization could also be considered.

In Arrow and Kootenay lakes, fertilization has generally resulted in increased survival and fecundity of kokanee in the early years when kokanee densities are low (Ashley et al. 1999; Schindler et al. 2006), and total kokanee biomass of all age classes has remained higher under fertilized conditions (D. Sebastian, MOE file data). This has not always resulted in higher spawner returns, and there is a need to better understand density-dependence and other factors affecting transfer of nutrients through the food web. Interactions between nutrient additions and spawning channels need further investigation, as well as the roles of "bottom up" and "top down" mechanisms specific to these lakes as part of program level performance measurement.

Annual operating budgets for Arrow and Kootenay fertilization projects including partner contributions are currently $1,024,500 and $873,000 respectively for the 2008-09 fiscal[32]. Costs have increased substantially since their commencement; the largest component by far is the fertilizer mix, followed by limnological monitoring and distribution. Fertilizer costs are largely driven by natural gas and fuel prices as well as agricultural demand, and are therefore subject to price increases beyond the rate of inflation (E. Schindler pers. comm.). Given the finite supply of phosphorus deposits, costs could increase substantially in the future.

Monitoring is necessary to address water quality concerns and ensure that the program is successfully meeting program objectives. Current monitoring focuses on the lower trophic levels up to kokanee, and has been reduced in recent years on both lakes (no winter sampling). The response of piscivorous species (bull trout, rainbow trout) is not well tracked under the current programs. The only monitoring at this level in Arrow Lakes Reservoir is a creel survey that provides trend information on harvest, size and fish condition. A methodology for tracking bull trout spawner trends in the reservoir has been developed recently (Decker and Hagen 2007), but funding limitations have prevented its implementation (estimated annual cost of $50,000). To date large rainbow trout monitoring methods have not been developed for ALR, and the main spawning tributaries for piscivorous trout have not yet been identified (Redfish Consulting 2004). On Kootenay Lake, Gerrard rainbow trout are monitored at the Lardeau River spawning site, and there is a mail-out survey to anglers that purchase a special Gerrard licence (both funded by Habitat Conservation Trust Fund). There is no monitoring of bull trout spawners or smaller rainbow trout. Predator population trends should be important program level performance indicators since restoration of these species and the dependent fisheries is a primary rationale for the fertilization programs (Ashley et al. 1999). Ideally this would include measures of both harvest and escapement. If the programs were expanded to add annual tracking of harvest for Kootenay Lake, bull trout population trends on both lakes, and rainbow trout trends on ALR, the total costs listed above would increase by ~$300,000.[33]

7.2 Spawning Channels

Spawning channels have been used to compensate for lost spawning habitat in areas where stream habitat has been inundated or blocked by dams. With respect to the DFO hierarchy, this option can be considered near site like-for-like spawning habitat, the first compensation preference, or alternately as artificial production (Brian Ferguson, DFO, Nelson, pers. comm.). Unlike indoor hatcheries, fish return to spawning channels and select mates without human interference, their eggs incubate in natural stream water and substrates, and other species (aquatic and terrestrial) can use the channels. However, channels also require a the high degree of control over habitat conditions, and pose some of the same risks as hatcheries in terms of centralizing production, interrupting natural selection processes, and impacting naturally-spawning fish through mixed stock interactions or over-stocking.

Annual operating budgets including partner contributions for Hill Creek Spawning Channel (HCSC) and Meadow Creek Spawning Channel (MCSC) are currently $144,000 and $108,000 respectively[34], but the facilities are being

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

[33] Estimated as $50,000 each for bull trout on Kootenay and Arrow Lakes, rainbow trout on Arrow Lakes, and $75,000 each for creel surveys on Arrow and Kootenay.

[34] Hill Creek Spawning Channel has a more intensive monitoring program than Meadow Creek Spawning Channel.

operated at minimum level of funding. This approach involves considerable risk due to minimal staffing and monitoring levels, and the limited capacity of existing facilities to deal with sediment inflows and outflows to the channels.[35] Long term capital maintenance costs are also not included in these amounts, and there is a current need for infrastructure repair, maintenance and replacement at both facilities. Budgets should provide staffing to allow daily monitoring during the egg incubation period and two technicians to ensure safe and effective delivery during adult migration and fry emigration monitoring. 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 as well as increased operational costs. Funding to allow better staffing and monitoring is estimated to be ~$426,000 annually for the two channels in total not including any major capital costs for upgrading the facilities. Major facility upgrades could be in the order of $2.1 M (Appendix H).

Spawning channels are a proven technique for producing kokanee fry (Redfish Consulting 1999) and have become dominant fry producers in both Kootenay and Arrow lakes. They allow regulated fry outputs to meet restoration and fisheries management objectives and, if properly managed, offer a source of production somewhat sheltered from detrimental flows and other stochastic events. Surplus production from the facilities can be used to assist in recovering other populations both inside and outside the FWCP program area. Annual monitoring provides an important component of kokanee stock assessment programs. Spawning channels can also have unintended results including mixed stock intra-specific competition effects and loss of genetic diversity. Concentration of production in one or two dominant systems also reduces the distribution of ecosystem benefits that might otherwise be afforded through broader distribution of carcasses and fry. Water and channel maintenance requirements can also have aquatic ecosystem impacts that must be considered.

The objective of MCSC was to replace 1.5 million returning adult kokanee estimated to be lost due to Duncan Dam (Andrusak 1999; also see Table 13 in this report and Table 23 in Acara 1970). The objective of HCSC was to replace 0.5 million spawners estimated to have been impacted due to Revelstoke Dam. The hypothesis in both cases was that spawning habitat was the limiting factor in these lakes and that remaining natural habitat was not adequate to ensure that fry production was not limiting the population. Fry production targets were set based on estimated losses of spawners in flooded areas at the time of construction.

Since interactions between fry output and lake productivity are not yet well understood with respect to optimizing growth and survival of kokanee, channel objectives should continue to be reviewed as part of an ongoing adaptive management strategy in relation to different hypotheses about limiting factors, and Ministry of Environment objectives. For example, MCSC fry production in recent years has been approximately double the 1967 estimate of lost fry production (see section 6.17), providing a basis for ongoing assessments of channel and lake capacity.

7.3 Stream Restoration and Enhancement

The addition of large woody debris (LWD) or boulders to tributary streams could enhance kokanee returns to certain tributaries if suitable spawning gravel is limited. In many basins, large trees were harvested out of the valley bottoms in the early years of logging eliminating recruitment of large wood into the stream ecosystem. These trees play a vital role in increasing structural complexity, and dissipating stream energy to allow accumulation of naturally-recruited spawning gravels. This option could be considered as on site, like for like compensation for flooded spawning habitat.

The goal of this option would not primarily be to increase overall kokanee abundance as it is unlikely that kokanee in Arrow or Kootenay lakes are limited by spawning habitat given the current production capacity of spawning channels. Rather the goal would be to improve habitat conditions to provide a wider distribution of spawning streams and a *broad life history diversity* in natural spawning fish as recommended by Reeve et al. (2006). Better gravel quality should result in better egg to fry survival that would make small populations more viable, although it might still be necessary to reduce fry production from other sources (Andrusak and Fleck 2005) if it is determined that the system as a whole has excess fry production capacity that reduces in-lake survival.

Thorley (2007) provides estimates of $113,000/km for stream restoration of this nature based on projects in British Columbia (Slaney and Martin 1997). However, this may be a gross underestimate especially for areas where access is more difficult. The Environmental Law Institute (2007) gives an average cost of $787,000/km for projects in the United States. FWCP cost for installation of six in-stream structures in a 60 m section of the Salmo River in 2006 was

[35] 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).

~$50,000, or $800,000/km. Monitoring costs to determine benefits and allow learning in relation to unsuccessful attempts would be in addition to these estimates.

7.4 Stream Gravel Additions

In streams with sufficient complexity and suitable gradient, but lacking adequate gravel to support viable spawning populations, it may be possible to add gravel periodically as an enhancement technique. The goal would be as above for stream restoration. Costs would depend on the location and accessibility in relation to a suitable gravel supply, but would likely be in the range of $10,000 per stream. Re-introduction of eyed eggs could be done in suitable gravel to help re-establish kokanee runs if lake conditions are suitable for survival and a suitable stock is available.

7.5 Stream and Other Barrier Removal

Removal of barriers to allow access to low gradient spawning reaches (e.g., Zimmer 2007) is a feasible option to maintain biodiversity by enhancing the viability of natural populations. If these barriers are temporary (e.g. log jams), costs may be relatively low (<$5,000) and there are opportunities to involve volunteer groups. Other barriers (e.g. water survey weirs, water intake weirs) require substantial background data collection and negotiations. Removal of permanent natural fish barriers (e.g., a fishway over falls) could have implications for upstream resident fish and would require substantial background work before serious consideration. A fishway designed to pass rainbow trout and kokanee over natural barriers in the Inonoaklin River was estimated at $1.55 million in 1983 plus $27,000 per annum for operation and maintenance (Penner 1983).

In some cases there may be stream access issues related to reservoir level. BC Hydro has conducted aerial surveys of kokanee access on the ALR for a number of years as part of an ongoing study. This would be a starting point for any work in this direction.

Kokanee fry in the West Arm are unusual in that they spend 1-2 months in the littoral zone before moving offshore (Andrusak et al. 2007). Artificial migration barriers such as groins constructed to protect private beaches may reduce fry survival by forcing them out to deeper water where they are vulnerable to predation from larger fish as they move along the shoreline (Department of Fisheries and Oceans, unpublished data). These groins are constructed on public land, below the high water line. Removal or modification of these groins might contribute to higher in-lake survival for West Arm kokanee.

7.6 Stream Flow Conservation

Water withdrawals for domestic and agricultural uses can reduce flows and access to spawning habitat in the remaining streams, and demands are typically highest during the low water period in late summer when kokanee are spawning. Temperature increases are often associated with low flows and can cause mortality in spawning fish. Ensuring the protection of existing flows through providing information on fish habitat requirements to regulators, or increasing water volume through purchases of existing water licences are important ways to maintain or increase the remaining stream habitat. Cost of obtaining a water licence is $150. More significant costs would be involved in researching water allocations, planning and negotiations with a current licence holder to relinquish an allocation. This is estimated as $10,000 per licence, although I know of no precedents for comparison.

7.7 Operational Changes at Upstream Dams

Dam operations can have a strong effect on the seasonal flow patterns in downstream reservoirs that can affect nutrient cycling and kokanee entrainment. 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 fish production and nutrient addition success (Matzinger et al. 2007). Research to understand how water moves through the ALR in relation to dam operations is ongoing (R. Pieters, pers. comm.), and data are not yet available to quantify effects of different operations and make recommendations. It is likely that some schedules and related reservoir levels would be more beneficial for kokanee than others. For Kootenay Lake, Daley et al. (1981) suggested several options to explore 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 increase mysid supply to West Arm kokanee, enhancing kokanee production there.

Costs of operational changes would have to be measured in terms of lost power production and revenue, and put in the context of other alternatives for meeting provincial power production requirements. Biological impacts other than kokanee would also have to be considered. Costs would have to be modelled for specific requests, and the BC Hydro Water Use Plan process would be the appropriate avenue for further investigation.

7.8 Dam Fishways

Re-establishing movement of kokanee into upstream reservoirs and the associated tributaries (e.g. from Kootenay Lake into Duncan Reservoir, and from ALR into Revelstoke and Kinbasket Reservoirs would be experimental and expensive but might result in genetic benefits and increased natural fry production capacity. Substantial background research would be needed to assess potential benefits. This would directly address fragmentation and entrainment impacts.

7.9 Mysid Biomass Reduction

Methods of harvesting mysids with minimal kokanee bycatch are in development at Okanagan Lake. If developed to the point where mysid biomass and zooplankton consumption could be significantly reduced, this might be a worthwhile endeavour to consider for Arrow and Kootenay Lakes. Cost estimates are not available. Project level performance indicators would be an ecologically significant tonnage of shrimp removed. Program level indicators would include increased kokanee production for a given level of primary productivity and evidence that the efficiency of trophic transfer from algae to kokanee was improved.

8.0 PERFORMANCE MONITORING CONSIDERATIONS

The two major compensation initiatives of the FWCP for kokanee are spawning channels and nutrient additions in Kootenay and Arrow Lakes. In order to ensure efficient use of resources and optimum fish benefits, program level performance monitoring should incorporate an adaptive management approach to improve understanding about how these projects interact in reservoir trophic ecology. Mazumder and Edmundson (2002) studied fertilization and stocking of sockeye and state “it is of fundamental importance to understand how the structure of consumer communities can modify the efficiency and patterns of nutrient transfer along the food webs, to assess the effectiveness of fertilization as a technique to enhance growth, survival and productivity” (also see Rieman and Maiolie 1995, Martinez and Wiltzius 1995).

Ten to 15 years of monitoring data at most trophic levels are available for investigating relationships between the trophic levels. A formal statistical treatment of all data related to the nutrient additions and spawning channels would be beneficial to test alternative hypotheses on trophic ecology and kokanee population dynamics. A substantial body of literature exists on sockeye and kokanee biology pointing to areas of research that should be productive for Arrow and Kootenay lakes.

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Appendix A. Definition of Footprint Impacts

These definitions of operational and footprint impacts associated with BC Hydro's hydroelectrical 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) and the BC Hydro Fish & Wildlife Bridge Coastal Restoration Program.

Footprint Impacts:
These 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 reservoir is at full pool.

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 increased snow or precipitation due to thermal effects of reservoir, evaporative water losses, long-term groundwater effects, greenhouse gas release, cumulative effects from other uses (i.e. increased water withdrawal due to proximity to reservoir).

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 (from 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 MWLAP
Jeff Burrows	BC MWLAP
Eva Schindler	BC MWLAP
Ken Ashley	BC MWLAP
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 quantifying footprint impacts of BC Hydro dams on fish (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. Compilation of available kokanee spawner counts (unexpanded ground and air surveys) for Arrow Lakes tributaries prior to the beginning of fertilization in 1999. Reservoir filling from Keenleyside Dam occurred the summer of 1969. Data are from MoE file Arrow Kokanee Escapement Monitoring – Complete Data Set.xls unless indicated otherwise. The reason for the slight discrepancy for 1978 counts is unknown. Counts for Hill Creek and Bridge Creek are total counts for the duration of the run after 1988 because of the use of weirs and electronic counters.

Stream	**1966**	**1969**	**1973[c]**	**1974**	**1976[e]**	**1978[b]**	**1978**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Upper Basin																		
Akolkolex	8,000	flooded	≤ 5,000	-	-	-	-	-	-	-	-							
Bridge	-	-	-	-	-	-	-	7,000	14,000	18,000	18,000	28,000	7,981	13,875	12,696	5,758	4,836	3,600
Cranberry	-	4,000	-	-	4,741	-	-	-	7,500	4,100	7,800	1,350	1,600	65	420	500	3,016	1,217
Crawford			1,000	-	-	-	2,500	-	-	600	-	550	-	-	-	180	30	600
Drimmie	-	1,200	-	-	-	-	-	8,000	7,000	2,100	5,000	1,100	4,200	-	1,140	2,300	2,621	1,155
Fosthall	1,800[a]	flooded	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Halfway	600	8,000	5,000	15,540	-	-	-	19,000	20,000	14,100	4,000	1,800	-	-	1,120	600	350	783
Hill	4,500[a]	-	≤ 5,000	12,250	7,644	-	-	298,112	323,437	277,239	235,443	241,871	273,679	174,224	73,454	29,072	58,977	42,540
Jordan	0	20,000	-	17,000				6,250	8,000	2,100	3,200	2,100	-	-	720	100	110	50
Kuskanax	1,000	25,000	3,000	25,000	-	-	-	47,500	43,500	16,100	24,700	10,500	3,335	-	5,330	500	350	1,810
Mackenzie	2,500	-	-	727	4,278	-	-	3,000	1,750	-	-	-	-	-	50	-	-	-
McDonald	3,500	10,000	-	3,500	4,601	-	-	10,000	-	-	4,200	3,060	-	-	6,645	4,829	1,518	5,975
St. Leon	600	1,200	-	2,260	-	-	-	3,000	6,500	1,800	500	200	1,174	-	100	-	50	240
Tonkawatla	4,000	25,000	50,000	8,300	-	-	-	4,500	5,500	800	4,500	1,700	-	-	1,130	350	66	560
Total Upper	26,500	94,400	69,000	67,577	-	-	-											
Lower Basin																		
Burton & Snow	100,000	80,000	-	-	-	109,000	91,000	69,000	66,500	76,000	79,000	23,500	-	-	52,260	66,400	7,050	37,380
Caribou	100,000	52,000	-	-	-	26,000	24,000	31,500	17,000	57,000	48,000	10,500	-	-	14,175	37,000	6,750	28,900
Cayuse	50[a]	0[b]	-	-	-	1,200	-	-	-	-	-	0	-	-	-	-	-	-
Deer	700[a]	1,500	-	-	-	14,000	11,000	5,500	4,000	6,500	6,000	1,500	-	-	-	-	1,106	11,500
Dog	-	-	-	-	-	-	6,500	-	-	100	-	50	-	-	-	-	333	-
Eagle	-	-	-	-	-	-	16,500	-	500	-	500	200	-	-	-	-	1,450	610
Heart	-	-	-	-	-	-	500	300	250	300	500	200	-	-	-	50	20	370
Inonoaklin	22,000[a]	flooded	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Johnston	-	1,200[b]	-	-	-	400	-	-	-	-	-	30	-	-	-	-	-	-
Mosquito	45,000	80,000	-	100,000	-	85,000	78,500	75,000	33,500	34,000	61,500	22,000	-	-	32,200	4,050	1,518	45,500
Octopus	-	-	-	-	-	-	2,000	2,500	1,000	1,500	1,000	-	-	-	-	50	500	730
Taite	4,800	4,200	-	-	-	3,040	4,450	2,500	375	1,000	2,700	1,000	-	-	-	2,890	620	11,143
Whatshan	25,000[a]	flooded	-	-	-	1,000	-	-	-	-	-	0	-	-	-	-	-	-
Total Lower	297,550	218,900	-	-	-	239,640	234,450	186,300	123,125	176,400	199,200	58,980	-	-	98,635	110,440	19,347	136,133
Total Arrow Counts	324,050	313,300	-	-	-	-	-											

[a] Sinclair (1967), cited in Appendix 8 of Sebastian et al. (2000); [b] Lindsay and Seaton (1978); [c] Paish (1974); [d] Northern Natural Resources (1976); [e] Weir counts reported in Lindsay (1976)

Appendix E. Pre-dams newspaper references to kokanee status.

THE NELSON DAILY NEWS, TUESDAY MORNING, AUGUST 30, 1921.

REDFISH RUN UP CREEKS TO SPAWN

Government Builds Up Depleted Numbers; Imprisonment for Netting.

Kokanees, or redfish, are now starting to run in Midge and Cultus creeks and other creeks emptying into Kootenay lake, and in Kokanee creek on the West Arm, but not in their former numbers. In August and September these fish, that resemble red salmon eight or 10 inches in length, enter the gravelly creeks to spawn, but at other times of the year they are the silver trout, which strike on either fly or spoon in all Kootenay waters. At spawning time the lower jaws of the males are hooked, exactly like the lower jaws of real salmon.

The days when redfish can be shovelled out of the creeks by scoop or nets, or netted in gill nets set across the creek mouths, are now gone forever, and the department of marine and fisheries is now trying to build up the depleted numbers of this useful food and game fish, and is backed up with regulations that have teeth in them. No net of any kind can be used to take redfish, except in the open lakes, where persons who have first obtained special licenses may use drag nets. Snares, spears and gaffs are also prohibited for use in the creeks or in front of the creek mouths.

A year's imprisonment, in addition to a fine of $500, are possibilities for persons who contemplate a raid on the spawning beds to consider.

CITY COUNCIL MEETING IS POSTPONED

WALLACE MATRON DIES IN NELSON

Mrs. Stephanie McAllister Was Daughter of Slocan Pioneer; Operation Futile.

Mrs. Stephanie McAllister, wife of Harry C. McAllister, a broker, of Wallace, Idaho, died in Kootenay Lake General hospital at 4 o'clock yesterday morning from an acute attack of peritonitis.

Mrs. McAllister, with her adopted daughter Harriet, had been visiting Mr. and Mrs. J. M. Harris at their home in Sandon and was about to proceed to Halcyon hot springs when she was taken seriously ill. Her husband was notified by wire and she was brought to the hospital on Thursday.

Bringing with him Dr. F. L. Quigley, the family doctor, Mr. McAllister drove from Wallace to Nelson, a distance of 325 miles, in an automobile, and arrived here at 4 o'clock on Friday morning.

Dr. Quigley operated on Mrs. McAllister on Friday afternoon, but found there was no chance of her recovery. The body will be taken to Spokane today, where the funeral will be held tomorrow at noon.

The late Mrs. McAllister was 46 years old and was an accomplished musician. She studied at numerous conservatories in the United States and in Europe and became a highly finished performer on the harp. She was the daughter of Stephen Bailey, a Slocan pioneer and the first owner of the famous Payne mine, from which he amassed a fortune.

VISITING INVERMERE

Social and Personal

W. A. Calder, the Edgewood rancher, is a city visitor.

Jack Sapples, the Salmo merchant, is a business visitor to the city.

Mrs. D. A. Thorpe left last night for Castlegar where she will spend a few days.

R. C. Cunningham, the Crescent Valley merchant, was among arrivals yesterday.

I. R. Pool spent the week-end inspecting his mining properties at Sheep Creek.

Clarence Cunningham, the big mine operator of the Slocan, is registered at the Hume.

Miss M. E. Daly has arrived from Toronto to take charge of Meagher's Millinery Department.

Mrs. D. L. Rees and children, Lorna Kenneth and David have returned from a visit to Vancouver.

Jack Houston and Ted Mason swam

NELSON DAILY NEWS, MONDAY, SEPT. 20, 1948 — 7

OR SALE — CHEAP. CHRYSLER sedan in good running order. $350. Nelson Transfer Co.

OR SALE — 1947 ½ TON DODGE pick-up. Enquire at P. P. Hlookoff and Sons Ltd. Nelson, B.C.

'ANTED URGENTLY — 39 TO 41 model in good condition. Plymouth preferred. Phone 484-R-1.

IEW AND USED PARTS FOR ALL makes of cars. City Auto Wreckers. Box 24, Granite Road.

VILL PAY SPOT CASH FOR late model passenger cars, any make. Queen City Motors.

OR SALE—1941 PONTIAC CLUB coupe. Extras. Box 39, Salmo.

Winnipeg Grain

WINNIPEG, Sept. 19 (CP)—Winipeg grain quotations:

Oats:				
'ct. ..	.74¼	.74⅜	.73¾	.73¾
'ec ..	.70¾	.70¾	.70⅛	.70⅛
Iay	.72¾	.72¾	.71⅜	.71⅜
Barley:				
'ct. ..	1.04⅝	1.04⅞	1.04	1.04½
'ec ..	.99¼	.99¼	.98⅜	.98⅜
Iay ..	.99⅝	.99⅝	.98⅝	.98⅞
Rye:				
'ct. ..	1.51¼	1.52	1.49	1.49
'ec ..	1.50¼	1.50¼	1.48½	1.48½
Iay ..	1.53	1.53	1.50¾	1.50¾
Flax:				
'ov ..	4.01½	4.01¾	4.00¾	4.00¾
ec ..	4.02¼	4.02¼	4.01¾	4.01¾
Iay ..	4.05	4.05	4.02½	4.02½

Cash prices:

Oats: No. 2 C.W. 74; No. ex. 3 C.W. 2¼; No. 3 C.W. and ex. 1 feed 71¾; Io. 1 feed 71¼; No. 2 feed 69¼; Io. 3 feed 67¼; track 73¾.

Barley: No. 1 and 2 C.W. 6-row .16½; No. 1 and 2 C.W. 2-row .07½; No. 3 C.W. 6-row 1.18½; No. feed 1.07½; No. 2 feed 1.06½; No. feed 1.03½; No. 2 C.W. yellow .03½; No. 3 C.W. yellow 1.07½; rack 1.04½.

Rye: No. 1 and 2 C.W. 1.48⅝; No. C.W. 1.44½; rej. 2 C.W. 1.33; No. 4 :.W. 1.39; track 1.44.

Flax: No. 1 C.W. 4.03¾; No. 2 :.W. 3.99¾; No. 3 C.W. 3.86¾; No. 4 :.W. 3.70¾; Track 4.00¾.

The Chinese annual population rowth is estimated as high as 5,-00,000 a year.

ORD GAEA TRAM

Depletion of Fish Population Explain In Rod and Gun Brief To Commission

A brief presenting no opposition to the application of the West Kootenay Power and Light Company, Ltd., and the Consolidated Mining and Smelting Company of Canada, Ltd., to store an additional two feet of water in Kootenay Lake, was presented by the West Kootenay Rod and Gun Zone at last week's Creston hearing of the International Joint Commission. It asked, however, annual compensation for fish propagation.

R. T. Garland of Trail, Zone President, and M. F. Edwards, also of Trail, Secretary-Treasurer, attended the sessions.

The brief, presented on behalf of the 12 organized West Kootenay Rod and Gun Clubs, those in Nelson, Kaslo, Rossland, Trail, Castlegar, Nakusp, Salmo, Boswell-Gray Creek, Bonnington-South Slocan, Zincton, New Denver and Slocan City, follows in part:

"The famous sporting fish of Kootenay Lake, the Kamloops Trout, more commonly known as the Rainbow Trout, has had a terrific struggle for survival over the last 20 years, despite the efforts of the B.C. Game Commission in restocking the West Arm and Kootenay Lake.

"Unfortunately we, the sportsmen, were not fully organized in the early thirties and it was some years before we realized what had happened with the construction of Corra Linn dam, and subsequent work carried on several years later at Grohman Creek and Granite, just above Taghum Bridge, a few miles downstream from Nelson. The wonderful gravel beds and flowing water, so necessary for the natural spawning of those trout which spawned in this section of the river, were ruined entirely.

"This has had a most serious effect on the trout population, particularly in the West Arm both above and below Nelson. As far as Kootenay Lake is concerned, what foreshore is flooded by the raised level of the Lake, does not enter into the spawning habits of the Rainbow Trout because they naturally ascend the Lârdeau River at the North end of the Lake in their spawning migration each April and May. Some spawning, to a much lesser degree, does occur in the many streams flowing into Kootenay Lake, but these streams are unaffected by water storage in the Fall and Winter period.

"Definite harm has occurred to the main forage food of the Rainbows, namely the Kokanee or redfish, which have dwindled in number in the West Arm over the last 15 years. This shrinking of redfish population is due to flooded spawning beds, caused by the unnatural level of the lake in the Fall period.

"During the war years, the lower Kootenay River was closed to all fishermen, from the boom at Beasley, a few miles upstream from Corra Linn, to the mouth of the Slocan River, some miles downstream from the South Slocan plant of the power company. The fishermen throughout these years kept strictly to the letter of the law, and we are proud of this record. The fish population did not show an appreciable gain, except in the odd spot on the lower Kootenay River during the years of closure. This clearly indicates the handicap under which the trout exists with the eight foot level authorized during the war years.

"As no compensation for fish propagation has been made by the applicants for past damage as far as the existing six feet storage on Kootenay Lake, nor has mention been made as to the compensation for damage the additional two feet of water storage will add to damage already done, we hesitate to affirm this application.

"However, on the distinct understanding that a nominal amount will be forthcoming annually, to be used exclusively for sport fish propagation in the West Arm and Kootenay Lake, we will in every way affirm this application to store a further two feet of water in Kootenay Lake, in addition to the six feet of storage already authorized by the International Joint Commission.

"The amount of compensation to be paid annually will be determined by friendly negotiations with the applicants, and would be handled by a board of trustees representing the applicants, the B.C. Game Commission and this Association. It should be specifically noted that this effort on behalf of the sportsmen of the West Kootenay District will not result in the annual compensation being paid into the B.C. Game Commission nor into the consolidated revenue fund of the Province of British Columbia. The purpose of this annual compensation will be to augment the present restocking campaign of the B.C. Game Commission and will principally be used for raising trout in rearing ponds until six or eight inches in size, for liberation only in the waters of the West Arm and Kootenay Lake."

Canadian Football

BIG FOUR SENIOR

Ottawa Rough Riders 32, Toronto Argos 12.

O.R.F.U. SENIOR

Toronto Beaches Indians 14, Windsor 6.

Sarnia Imperials 7, Hamilton Tigers 22.

W.I.F.U.

Winnipeg Blue Bombers 15, Saskatchewan Roughriders 9.

HIS BROTHER WINS

VICTORIA, Sept. 19 (CP) — The speedy brown gelding His Brother, and jockey Ken Coppernoll, a consistent in-the-money team, Saturday captured the featured $1000 "Times Handicap" at Willows Park.

BRITISH RUGBY

LONDON, Sept. 19 (Reuters)—Results of rugby matches played in the United Kingdom Saturday:

Huddersfield 22, Australians 3.

RUGBY LEAGUE

Batley 18, Rochdale Hornets 9.
Bradford Northern 9, Wigan 16.
Bramley 16, Liverpool Stanley 8.
Belle Vue Rangers 31, Dewsbury 5.
Castleford 7, Widnes 3.
Hull 17, Wakefield Trinity 5.
Hunslet 15, Salford 0.
Keighley 16, York 3.
Leigh 2, Barrow 12.
Oldham 26, Hull Kingston Rovers 8
Saint Helens 8, Workington Town 2.
Swinton 0, Halifax 12.
Warrington 39, Leeds 17.
Whitehaven 10, Featherstone Rovers 8.

RUGBY UNION

Harlequins 3, St Mary's Hospital 5.
Bath 0, Swansea 14.
Bedford 39, Old Merchants Taylors 8.
Camborne 5, Falmouth 8.
Cheltenham 18, Rugby 3.
Crosskeys 13, Birmingham 3.
Exeter 5, Devonport Services 13.
Gloucester 9, Mosley 9.
Leicester 19, Plymouth Albion 0.
Llanelly 0, Cardiff 3.
Neath 27, Penarth 8.
Newton Abbot 6, Rosslyn Park 29
Newport 6, Bristol 3.
Northampton 29, Richmond 8.
Notts 11, Nuneaton 11.
Pontypool 11, Blaenavon 3.
Sale 9, Coventry 16.
Sheffield 6, Huddersfield 14.
Stroud 21, Aldershot Services 3.
Torquay Athletic 3, Aberavon 3.
United Services Portsmouth 20, London Irish 17.
Waterloo 8, Headingley 0.
Weston-Super-Mare 16, Abertillery 3.
Glasgow High School Former Pupils 3, Kelvinside 3.
Hillhead High School Former Pupils 16, Glasgow Academicals 3.
Wasps 43, R.E.E.E. Army 0.
Guys Hospital 27, Catford Bridge 3.
Aberdeen 8, Pontypridd 3.
Maesteg 9, Bridgend 0.
Old Blues 3, Saracens 12.

IS ALL-ROUND COWPOKE

PENDLETON, Ore., Sept. 19 (CP) —Veteran cowpoke Everett Shaw, 40, of Stonewall, Okla., Saturday was awarded the all-round cowboy championship of the annual round-up here.

He captured the coveted Sam Jackson Trophy and top money by piling up a total of 1600 points in three days of competitions. He last captured the title in 1933.

Appendix F. Estimated number (N) and percent (%) distribution of kokanee in the Lardeau-Duncan-Meadow system from 1964-2008. Duncan River was first blocked in 1966. Data for 1964 are from Bull (1965), for 1965-1968 from Acara (1970) and Taylor et al. (1972), for 1969-1992 from Bell (1990, 1992) and for 1994-2008 from Kootenay Environmental Services (2007) and MoE file data. Methods of enumeration are indicated in footnotes. Note that after 1967 the Lardeau and Duncan numbers are an estimate of peak numbers (rather than total run) and are based on aerial or road-based counts done on one day. Over 1 million kokanee fry were released from net pens in Kaslo Bay from 1990 to 1993. Meadow Creek Spawning Channel (MCSC) was first operated in 1967 but fry production was very low 1986-1988 (Bell 1990).

Year		Meadow Creek total	MCSC[1]	Lardeau River	Duncan River	Total
1964[2]	N %	346,128 7.6	_	1,382,424 30.4	2,807,937 62.0	4,536,489
1965[2]	N %	116,095 10.8	_	506,446 47.0	455,841 42.2	1,078,382
1966[3]	N %	597,331 47.5	_	646,712 51.5	13,100 1.0	1,257,143
1967[3]	N %	606,282 46.0	197,878 15.0	705,351 53.5	6,750 0.5	1,318,383
1968[4]	N %	287,583 -	93,752 -	NA	NA	_
1969[5]	N %	407,380 -	121,238 -	NA	NA	_
1970[5]	N %	723,158 -	218,957 -	NA	NA	_
1971[5]	N %	977,188 -	143,262 -	1,000,000	NA	_
1972[5]	N %	529,040 -	16,175 -	NA	NA	_
1973[5]	N %	616,524 -	159,735 -	2,400,000*	NA	_
1974[5]	N %	822,500 -	190,010 -	NA	NA	_
1975[5]	N %	1,060,000 -	194,770 -	NA	NA	_
1976[5]	N %	1,281,190 -	218,350 -	NA	NA	_
1977[5]	N %	1,378,695 -	214,977 -	NA	NA	_
1978[5]	N %	1,346,763 -	173,607 -	NA	NA	_
1979[5]	N %	378,534 -	97,185 -	1,500,000	NA	_
1980[5]	N %	461,534 -	155,534 -	700,000	NA	_
1981[5]	N %	983,646 -	200,000 -	1,000,000	NA	_
1982[5]	N %	473,706 -	200,000 -	500,000	NA	_
1983[5]	N %	301,529 -	100,000 -	<500,000	NA	_
1984[5]	N %	484,494 -	226,186 -	600,000	NA	_
1985[5]	N %	901,059 -	287,252 -	NA	NA	_
1986[5]	N %	697,610 -	256,410 -	500,000	NA	_
1987[5]	N %	425,885 -	236,062 -	250,000	NA	_
1988[5]	N %	467,895 -	291,895 -	192,000	NA	_
1989[5]	N	333,000	230,000	145,000	NA	_

	%	-	-			
1990[5]	N %	322,500 -	203,197 -	105,820	NA	_
1991[5]	N %	237,088 -	168,775 -	35,650	NA	_
1992[5]	N %	477,190 -	253,545 -	65,100	NA	_
1993[5]	N %	594,959 -	291,368 -	254,000	NA	_
1994[5]	N %	853,000 -	300,000 -	>400,000	NA	_
1995[5]	N %	688,095 -	302,063 -	168,000	NA	_
1996[5]	N %	1,068,000 -	371,000 -	114,000	NA	_
1997[5]	N %	1,044,227 -	352,093 -	400,000	NA	_
1998[5]	N %	1,138,000 -	336,636 -	1,061,464	NA	_
1999[5]	N %	1,204,720 -	353,674 -	526,380	NA	_
2000[5]	N %	377,716 -	250,056 -	186,240	NA	_
2001[5]	N %	431,308 -	303,808 -	163,460	NA	_
2002[5]	N %	354,000 73.6	302,500 68.8	109,950 25.0	6,000 1.4	439,950
2003[5]	N %	856,100 81.1	336,545 31.9	174,000 16.5	26,000 2.5	1,056,100
2004[5]	N %	1,132,600 82.0	514,791 37.3	246,000 17.8	3,000 0.2	1,381,600
2005[5]	N %	1,036,600 81.5	463,614 36.5	232,400 18.3	2,200 0.2	1,271,200
2006[5]	N %	371,200 77.3	331,194 69.9	107,000 22.3	2,300 0.5	480,500
2007[5]	N %	386,700 69.3	241,891 43.4	146,821 26.3	24,320 4.4	557,841
2008[5]	N %	939,600	437,236	409,731	NA	NA

[1] MoE file data, J. Bell, pers. comm.
[2] For 1964 and 1965, Lardeau and Duncan estimates were from a mark-recovery estimate using Petersen tags applied at Argenta and Marblehead and recovery of dead fish after spawning. Tag loss before recapture and tag detection rate were not estimated. In Meadow Creek enumeration was by fish counts at a weir.
[3] For 1966 and 1967, spawners were enumerated by direct counts through weirs on all three locations.
[4] In 1968, Meadow Creek was enumerated by direct wier count and visual count (John Creek tributary).
[5] Enumerated by extrapolated wier count in Meadow Creek and aerial or road-based surveys in Lardeau and Duncan. The Lardeau and Duncan counts
*average of 2 numbers (1,800,000; 3,000,000) recorded for this year

Appendix G. Summary of information from Lindsay (1977), Martin (1976), and Paish & Associates (1974) and estimate methods for kokanee spawning upstream of Revelstoke Dam.

This method uses the mean annual number of spawners and 95% confidence intervals calculated from four streams counted over three years (Table G1) to estimate returns and upper confidence intervals for 17 small streams that had kokanee runs in at least some years prior to Revelstoke Dam (Table G2 - A). Added to this is an air count estimate for Downie Creek (added 10,000 fish to 15,000+ expanded air count), a density-derived (kokanee/km) estimate for Bigmouth Creek, and an estimate of Columbia River mainstem spawners (Table G2 - B,C). Confidence limits for the two larger streams and the mainstem are estimated using the ratio of upper 95% confidence interval/estimate for small streams. This assumption that variance among annual returns would be the same as for small streams is probably reasonable for the mainstem areas and Bigmouth Creek, but Downie variance might be less as core spawning areas tend to be less variable (J. Hagen, pers. comm.).

The estimate for Seymour Creek was 7,500 – 15,000. This could be treated as confidence limits for an estimate of 11,250 or the upper and lower range can be used to incorporate uncertainty. Using the upper range of estimates from the air counts, the overall total is ~81,000 spawners with upper confidence interval of 160,000 (Table G2). Note that there is a risk of underestimating true variance when only three means (years) are used for the estimate; also observer efficiency is not included in the variance. Not all of the 17 streams used to expand the average spawners had kokanee in the three counted years. Available information is summarized in Table G3. See section 6.4 for further explanation.

Table G1. Spawner counts in four streams counted over three years, and calculation of mean annual spawners per year and 95% confidence intervals. The estimate is made using the lower, upper, and average for 1973 counts because a range of 7,500-15,000 was given for Seymour Creek. The 1973 estimates are made from a single air count expanded by 1.5; 1975 and 1976 are shore-based visual estimates.

	1973				
Stream	**lower estimate**	**upper estimate**	**mean**	**1975**	**1976**
Seymour	7500	15000	11250	3000	3500
Park	150	150	150	1500	1000
Mars	750	750	750	2000	1200
La Forme	150	150	150	1500	1000
Mean (4 streams in one year)	2137.5	4012.5	3075	2000	1675
Grand Mean (4 streams over 3 years)	**1937.5**	**2562.5**	**2250.0**		
SD of grand mean (4 streams over 3 years)	237.5	1266.2	732.7		
95% confidence interval*	**465.5**	**2481.8**	**1436.1**		

* calculated as 1.96 X SD of grand mean

Table G2. Estimation of spawner returns using available data from dam unit C4.

A) Small Streams
Assuming a maximum of 17 small streams that might have had kokanee returns in some years (see Table G3, Downie and Bigmouth estimated separately) and using mean and 95% confidence limits calculated from 4 streams over 3 years repeated measures

no. streams	**Mean spawners**	**95% c.i. of mean**	**Estimate**	**Upper 95% c. interval**	
17	2562.5	2481.8	**43563**	**85753**	using 1973 high range (Table G1)
17	1937.5	465.5	**32938**	**40851**	using 1973 low range (Table G1)
17	2250.0	1436.1	**38250**	**62664**	using 1973 mean (assumes 7,500-15,000 are confidence limits; Table G1)

B) Downie and Bigmouth	**Estimate**	**Upper 95% c. interval***	
Downie	**25000**	**49212**	added 10000 to 15,000+ for estimate
Bigmouth	**2763**	**5438**	estimated by multiplying the average 3,453 kokanee/km in lower reaches of 5 creeks by 0.8 km that was flooded (see section 6.4 for further explanation).
C) Mainstem Columbia	**10000**	**19685**	assuming 10 locations at 1,000 each (see section 6.4)
TOTAL SPAWNERS (19 streams and 10 Columbia River sites)	**81326**	**160088**	using 1973 high range
	70700	**87686**	using 1973 low range
	76013	**124530**	using 1973 mean

*estimated using the ratio of upper 95% interval/estimate from small streams (e.g., 25000 X 85753/43563 for the 1973 high range). This assumes among year variance was the same as small streams.

Table G3. Summary of available habitat and count information, and run size estimates for tributaries of the Columbia River prior to Revelstoke Dam. Numbers in italics were multiplied by 1.5 to expand a peak count into an estimate of total stream spawners. Shaded streams are those believed to support kokanee spawning in at least some years.

Stream	Accessible Length (km) [a]	Used by Kokanee (km) [b]	Year	Sample Method	Dates	Kokanee Count [c]	Lindsay Estimate [d]	Comments
Soards	0.3	na	-	Not counted	-	-	-	Martin (1976) lists as kokanee utilization
Mica	0.8	na	-	Not counted	-	-	-	Martin (1976) lists as kokanee utilization
Nagle	0.2	na	-	Not counted	-	-	-	Martin (1976) lists as marginal habitat potential (no species indicated); no data to suggest kokanee observed here historically.
Sibley	0.4	na	-	Not counted	-	-	-	Martin (1976) lists as marginal habitat potential (no species indicated); no data to suggest kokanee observed here historically.
Pat	3.2	na	1975	Weir	Oct. 10 – Oct. 16	0	-	Weir in late but Martin (1976) says Pat did not support kokanee run in 1975; apparently in a previous year; listed as kokanee primary habitat potential but this seems inconsistent with habitat description (“lower mile of stream has high gradient with large boulders dominating”, p. 4-6).
Bigmouth	12.8	0.8	-	Not counted	-	-	-	Martin (1976) describes as kokanee “primary habitat potential” and noted kokanee presence; similar size to Downie but more glacial; Martin (1976) and Lindsay (1977) considered Downie and Bigmouth to be major exceptions to general rule of barriers in lower reaches, however, reaches upstream of flood zone have large substrate and little or no gravel, and only two kokanee were counted in 2008 (Karen Bray, BC Hydro, pers. comm.), hence length used by kokanee is assumed to be the flooded reach (0.8 km).
Scrip	24.0	na	-	Not counted	-	-	-	Lindsay (1977) indicated “...undoubtedly supports larger run...” than creeks where weirs were operated; Martin (1976) lists as kokanee "primary habitat potential" and noted kokanee presence; numerous lakes in headwaters.
Horne	1.6	na	1975	Weir	Oct. 9 – Oct. 16	0	-	Weir in late but Martin (1976) says Horne did not support kokanee run in 1975; apparently in a previous.
			1976	Weir	Oct. 13 – Oct. 25	0	-	
Ruddock	3.2	na	-	Not counted	-	-	-	Martin (1976) lists as kokanee utilization
Nicholls	0.2	na	-	Not counted	-	-	-	Martin (1976) describes as marginal habitat potential (no species indicated); no data to suggest kokanee observed here historically.
Hoskins	8.0	na	1975	Weir	Oct. 9 – Oct. 15	0	-	Weir in late but Martin (1976) says Hoskins did not support kokanee run in 1975 but apparently in a previous year; slightly turbid in October, moderate gradient near confluence with a good gravel substrate
			1976	Weir	Oct. 7 – Oct. 26	-	-	
Kirbyville	8.0	na	1973	Air count	Sept. 25 or 27	*1,500*	-	Martin (1976) lists as primary habitat potential (kokanee, dolly varden, rainbow trout); Lindsay (1977) indicated “...undoubtedly supports larger run...” than creeks where weirs were operated; lake headed.

Table G3 continued.

Stream	Accessible Length (km) [a]	Used by Kokanee (km) [b]	Year	Sample Method	Dates	Kokanee Count [c]	Lindsay Estimate [d]	Comments
Goldstream	1.6	-	-	Not counted	-	-	-	No record of kokanee use in Paish (1974), Martin (1976), Lindsay (1977); very glacial with barrier near historical mouth, probably high silt load (K. Bray, BC Hydro, pers. comm.); Martin (1976) describes as marginal habitat potential (no species indicated).
Liberty	1.1	-	-	Not counted	-	-	-	Martin (1976) describes as marginal habitat potential (no species indicated); no observations of kokanee reported in this system.
Fissure	0.2	-	-	Not counted	-	-	-	Martin (1976) describes as marginal habitat potential (no species indicated); no data to suggest kokanee observed here historically; outlet appears too steep.
Fortynine	0.3	na	-	Not counted	-	-	-	Martin (1976) lists as kokanee utilization.
Downie	40.0	na	1973	Air count	Sept. 25 or 27	*15,000+*	-	Lindsay (1977) indicated “...undoubtedly supports larger run...” than creeks where weirs were operated and noted exception to spawning only in lower reaches; Martin (1976) describes as kokanee "primary habitat potential"; “+” in Paish et al. (1974) estimate not defined.
Keystone	0.1		-	Not counted	-	-	-	No information on habitat potential or kokanee presence; not listed in Martin 1976
Seymour	3.2	0.8	1973	Air count	Sept. 25 or 27	*7,500-15,000*	-	Lindsay (1977; p. 15) says "lower reaches good spawning habitat for kokanee; Martin (p. 4-1 to 4-4) says lower reaches of moderate gradient with extensive spawning gravel present in lower half mile; above this gradient increases sharply; falls at one mile is barrier to kokanee; kokanee spawning confined to lower half mile.
			1975	Weir	Sept. 4 – Oct. 17	1,779	3,000	
			1976	Weir	Aug. 12 – Oct. 27	283	3,500	
Bourne	1.6	na	1973	Air count	Sept. 25 or 27	*1,500*	-	Martin (1976) lists as kokanee utilization.
Park	1.6	0.4	1973	Air count	Sept. 25 or 27	*150*	-	Martin (1976) lists as marginal habitat potential (kokanee, dolly varden); kokanee utilized the lower quarter mile of stream (p. 4-4); observed siltation probably results in low spawning success; bull trout fry were captured; violent fluctuations in flow; short precipitious stream.
			1975	Weir	Sept. 12 – Oct. 16	1,257	1,500	
			1976	Weir	Sept. 28 – Oct. 26	0	1,000	
Big Eddy	0.2	-	-	Not counted	-	-	-	Martin (1976) lists as marginal habitat potential (no species indicated); no data to suggest kokanee observed here historically.
Mars	0.2	0.8	1973	Airplane count	Sept. 25 or 27	*750*	-	Lindsay (1977; p. 15) says best suited for dolly varden spawning; Martin (1976, p. 4-5) says short, precipitious but clear-flowing in October; substrate typically boulder-rubble with small pockets of spawning; kokanee used only lower half mile
			1975	Weir	Sept. 5 – Oct. 27	1,450	2,000	
			1976	Weir	Aug. 10 – Nov. 3	359	1,200	

Table G3 continued.

Stream	Accessible Length (km) [a]	Used by Kokanee (km) [b]	Year	Sample Method	Dates	Kokanee Count [c]	Lindsay Estimate [d]	Comments
Frisby	1.6	na	1973	Air count	Sept. 25 or 27	*1,500*	-	Glacial; limited length; Martin (1976) lists as marginal habitat potential (no species indicated). Lindsay (1977; p.15) describes lower 0.6 km as poor spawning habitat for migratory species.
Holdich	-	0.4	1976	Weir	Aug. 8 – Oct. 14	158	800	Martin (1976) lists as marginal habitat potential (no species indicated); Lindsay (1977; p.15) says "best suited for dolly varden spawning".
Carnes	0.8	na	1973	Not counted	-	-	-	Martin (1976) lists as primary habitat potential (kokanee, dolly varden); kokanee observed in 1992 survey (Triton 1992); short accessible reach.
La Forme	0.8	0.8	1973	Airplane count	Sept. 25 or 27	*150*	-	Martin (1976) lists as secondary habitat potential (kokanee, dolly varden, rainbow); clear in September-October; steep gradient with very large substrate prevailing throughout; kokanee use only lower half mile
			1975	Weir	Sept. 9 – Oct. 19	821	1,500	
			1976	Weir	Aug. 14 – Oct. 29	298	1,000	

[a] Useable length to first barrier was estimated for all migratory fish species by Paish & Associates (1974); Lindsay (1977) stated that except for Downie and Bigmouth, kokanee spawning occurred in the lower quarter to half mile of streams near the confluence with the Columbia where low gradients and smaller substrate were present. The Paish Acccessible Lengths probably underestimate for bull trout (Martin 1976).
[b] Lengths used by kokanee are from Martin (1976) or Lindsay (1977) when specifically mentioned.
[c] When Sample Method is weir, count is the number of fish captured during the indicated dates from Lindsay (1977); Air counts are from Paish & Associates (1974)
[d] Estimates were made by shore-based visual counts (Martin 1976, Lindsay 1977), and account for fish passing through the weirs or upstream before weir installation. They may also include any fish spawning below the weir.

Appendix H. Summary of recommended capital costs, and existing and recommended operations and maintenance costs for Hill Creek and Meadow Creek spawning channels (C. Spence, MOE, pers. comm.).

	Activity	Hill Creek	Meadow Creek	Estimated cost
Capital – one time costs				
	Purchase of adjacent private lands to secure water supply		x	$1,000,000
	Improvements to settling ponds to reduce scarification impacts and improve egg-to-fry survival	x	x	$250,000
	Improvements to scarification effluent treatment to meet DFO requirements	x	x	$250,000
	Staff gauges and related benchmarking	x	x	$5,000
	Development of lower enumeration fence at Meadow Creek to improve safety and channel management/assessment		x	$100,000
	Counter system for Hill Creek lower fence to improve safety and channel management/ assessment	x		$50,000
	Winter monitoring system (combination of alarms and webcams)	x	x	$50,000
	Internet access (satellite or wireless)	x	x	$5,000
	Enhanced fry monitoring facilities	x	x	$75,000
	Replacement of wood walkways, steel fence wheels and related aging, antiquated and dangerous infrastructure	x	x	$200,000
	Accommodation renovations	x	x	$80,000
	Plan and implement interpretive and public safety program, including signage, gates and other structures related to public/ bear safety	x	x	$75,000
	TOTAL – Capital costs			**$2,140,000**

	Activity	Hill Creek	Meadow Creek	Estimated cost
Operations and Maintenance – annual costs				
	Existing operations and maintenance	x	x	$252,000
	Increase staffing compliment to 2 person crew throughout critical operations and monitoring cycles	x	x	$70,000
	reimbursement value for MOE in-kind time	x	x	$50,000
	In-season egg development and survival monitoring (labour and equipment)	x	x	$5,000
	Winter monitoring	x	x	$10,000
	Periodic gravel monitoring and refurbishment as required	x	x	$5000
	Improved scarification approach (excavator and Cat) if survivals show declines	x	x	$20,000
	Enhanced riparian brushing, conifer release and related clean-up	x		$5,000
	Periodic stop log replacement	x		$2,000
	Periodic review and adjustment of operations and maintenance protocols (O&M manual)	x	x	$1,000
	Internet access (satellite or wireless)	x	x	$2,000
	Periodic workshops with DFO and other channel operators to communicate issues and discuss solutions (for FWCP, MOE and O&M staff/contractors)	x	x	$2,000
	Development and maintenance of electronic data management system	x	x	$2,000
	TOTAL – Operations and Maintenance Costs			**$426,000**