Impacts of dam construction in the upper Columbia Basin, British Columbia, on bull trout (*Salvelinus confluentus*) production, fisheries, and conservation status

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ABSTRACT

Bull trout, blue-listed as a species of special concern by British Columbia's Conservation Data Center, have a widespread distribution in the upper Columbia Basin. A serious lack of information about the pre-impoundment distribution and abundance of the species along the Kootenay and Columbia river systems in BC preclude direct estimation of the impacts of dam construction on bull trout production in this report. Instead, production losses were estimated from inundated rearing tributaries by factoring together previous estimates of inundated lengths of streams with empirical estimates of average bull trout production/km developed from quantitative stock assessment in representative habitats in the upper Columbia Basin. For bull trout, in contrast to other species, important spawning and juvenile rearing habitats are located well above reservoir full pool elevations in most dam units. Extensive tributary rearing habitat losses, however, were likely in the coldwater streams inundated by Kinbasket, Revelstoke, and Duncan reservoirs. An estimated 180 km of inundated stream habitat was likely to have been utilized by bull trout for spawning and juvenile rearing in these dam units, which equates to estimates of 57,000 age-1+ and older juveniles (low: 46,200; high: 68,200 = 50% confidence limits) and 2,300 adult spawners (low: 1,900; high: 2,630). It is currently not possible to integrate the effects of production changes for both juvenile and adult life stages in order to estimate footprint impacts on the overall population dynamics in each dam unit. However, bull trout appear to have good growth and survival in large, cold reservoirs, which has likely been mediated in part by the successful introduction of kokanee salmon populations. This, plus the fact that abundant suitable tributary rearing habitats remain even in heavily impacted dam units, means that bull trout have fared better than some other sport and non-sport fish species in the flooded valleys of the upper Columbia Basin. The most significant impact of dam construction on bull trout populations is likely to have been the amalgamation of adult rearing habitats within homogenous reservoirs, and the highly probable loss of genetic and ecological diversity that was associated with localized adaptations to these formerly diverse habitats.

Conservation status for remaining bull trout, with respect to the likelihood of long-term persistence of multiple, interconnected populations, appears to be secure for most dam units. However, one population in the Salmo River watershed is of serious conservation concern as a result of dam construction, due to the loss of connectivity with demographic and genetic support from other populations, and a substantial reduction in the suitability of the adult rearing environment. Populations in the Blueberry Creek and Slocan River watersheds, and Arrow Lakes Reservoir populations south of Nakusp may also be of conservation concern. Reservoir fisheries for adult bull trout can be productive and appear generally to be well accepted. The principal footprint impact on fisheries has been the loss of hundreds of kilometers of river angling opportunity, due to inundation or dam impact-related fishery closures, and no quality bull trout river angling opportunities remain in the upper Columbia Basin outside the East Kootenay valley.

Measures proposed for compensation for lost stream and lacustrine productivity have included reservoir and stream fertilization, side channel development, fish access improvement, instream structure placement, and riparian restoration. Lacustrine fertilization appears to be necessary to compensate for the reduced productivity of Kootenay Lake and the Arrow Lakes Reservoir relative to pre-existing natural lakes. The removal of migration barriers has to date been extremely significant in compensating for spawning and rearing habitat losses – approximately 2,400 spawners now utilize habitats above breached barriers on the Illecillewaet, Halfway, and Kaslo Rivers. However, given that genetic diversity losses have been a primary impact of dam construction, barrier removal is inappropriate if highly-invasible resident populations inhabit above-barrier reaches. Riparian restoration along streams is highly likely to benefit bull trout, given that water temperatures above 13ºC reduce habitat suitability and favour other species. Stream fertilization and side channel development also hold promise for bull trout, but should be treated as experiments accompanied by rigorous population level assessment. In contrast, the use of instream structures in core bull trout rearing areas, which are frequently steep, inaccessible, and have high

peak flows and bed load transport, is probably inappropriate. Efforts to facilitate the preservation of existing, core bull trout rearing reaches in good ecological condition may be the most cost-effective way to ensure that continued genetic diversity and production losses do not outweigh benefits from artificial enhancements, and these should therefore also be considered as suitable compensation measures for bull trout in the upper Columbia Basin.

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1.0 INTRODUCTION

Impoundment on major reaches of the Canadian portion of the Columbia River watershed began in 1908, with the construction of the Upper Bonnington Dam on the lower Kootenay River downstream of Nelson. Dams built in the decades following included: Aberfeldie (1922) on the Bull River; Elko (1924) on the Elk River; Lower Bonnington (1925), South Slocan (1928), Cora Linn (1932), Brilliant (1944), and Kootenay Canal (1972), also on the lower Kootenay River; Whatshan (1952), Spillimacheen (1955), and Walter Hardman (1959) on smaller tributaries to the Columbia River mainstem; Waneta (1954) and Seven Mile (1979) on the Canadian portion of the Pend d'Oreille River; Duncan (1967) on the Duncan River at the north end of Kootenay Lake; and Keenleyside (1967), Mica (1973), and Revelstoke (1984) on the Columbia River mainstem (Hirst 1991). BC Hydro owns and operates eleven of these dams: Aberfeldie, Elko, Duncan, Kootenay Canal, Whatshan, Spillimacheen, Walter Hardman, Seven Mile, Keenleyside, Mica, and Revelstoke (Ahrens and Korman 2004). These dams, along with Libby Dam (1974) constructed on the upper Kootenay River mainstem in Montana, have altered the aquatic ecosystems of the upper Columbia watershed tremendously. A total of over 1,600 km of stream habitat was inundated by reservoirs (Thorley 2008). The facilities are operated in a manner that severely alters the natural flow regime, and, in addition, nutrients retained within reservoirs are no longer available for transport downstream to the watershed's natural large lakes Kootenay and Arrow (Ashley et al. 1999), affecting their capacity for fish production (Moody et al. 2007; Schindler et al. 2006). With the exception of the Duncan Dam, fish passage was not provided for at any of the facilities, meaning that critical habitats for some populations were lost, and others were permanently isolated between dams such that future gene flow or immigration from other areas had become impossible.

The Fish and Wildlife Compensation Program – Columbia Basin (FWCP) was established as a collaboration between BC Hydro and the British Columbia Ministry of Environment (MOE), with a mandate to deliver projects to conserve and enhance fish and wildlife populations affected by BC Hydro dam 'footprint' impacts throughout the Columbia River basin in Canada. Canada's Department of Fisheries and Oceans (DFO) is a more recent partner. Footprint impacts to fish and wildlife populations are defined as the largely irreversible effects of water storage and the construction of the dam structures themselves (Appendix 1). This study is part of a multi-phase FWCP project to evaluate the footprint impacts of BC Hydro developments within the Columbia Basin by estimating habitat, primary productivity, and fish and wildlife community changes resulting from dam construction. Preceding reports included within the footprint impacts study are: 1) a compilation of background information relevant to estimating footprint impacts (Ahrens and Korman 2004); 2) an evaluation of aquatic primary productivity changes in the Columbia Basin resulting from dam construction (Moody et al. 2007); and 3) an analysis of aquatic habitat losses and gains (Thorley 2008). The phase of the dam impacts study to which the present analysis belongs is the summarization of footprint impacts for individual fish species in the Columbia Basin, which will assist FWCP to develop, prioritize, and monitor compensation projects. Footprint impacts to Canadian populations of bull trout (*Salvelinus confluentus*), one of the most widespread and economically important fish species of the upper Columbia Basin, are the subject of this report.

Bull trout, which have only recently been recognized as a species distinct from the Dolly Varden char (Cavender 1978; Haas and McPhail 1991), have a relatively widespread distribution in North America, which historically extended from the upper Sacramento watershed in California to upper reaches of the Yukon and Mackenzie Drainages in Canada. Bull trout are found in certain larger streams right out to the coast in the Pacific Northwest and British Columbia. Their distribution extends east to the continental divide in the contiguous United States, and crosses the continental divide into Alberta in Canada (Cavender 1978; Haas and

McPhail 1991; Leary et al. 1993). In coastal areas north of Puget Sound, when bull trout are present they are typically sympatric with Dolly Varden. This zone of overlap, which is also a zone of hybridization between the species, is relatively broad in Northern BC, and crosses the continental divide north of the Skeena watershed in to the headwaters of Peace and Liard systems (Taylor et al. 2001).

Bull trout populations have declined in many areas of their native range, particularly in southern parts of their range in the U.S.A. (Rieman et al. 1997) and in Alberta (Paul and Post 2001; Post and Johnston 2002), which appears to be due to the frequently compounded effects of habitat degradation, non-native species introductions, overharvest, and fragmentation of watersheds caused by dam construction (Rieman and McIntyre 1993). Listing of U.S. populations as threatened under the Endangered Species Act (ESA) commenced in June 1998, starting with the Columbia system, and all U.S populations south of Canada had been listed by November 1999 (Lohr et al. 2000). In British Columbia, bull trout were blue-listed as a species of special concern by the BC Conservation Data Center in 1994 (Cannings and Ptolemy 1998). In the same year Alberta launched its bull trout management and recovery plan (Berry 1994), and the species is now considered "Sensitive" in the Province (Post and Johnston 2002). Bull trout are also listed as an Identified Wildlife Species at Risk under British Columbia's Forest Practices Code (Haas and Porter 2001).

Bull trout populations are widespread throughout the Columbia Basin in Canada, and are still present in each of the reaches designated in this report (Table 1). The impacts of dams on fisheries and fish populations, including bull trout populations, in the Canadian portion of the Columbia Basin have been estimated in several earlier reports (e.g. Maher 1961; Peterson and Withler 1965a, 1965b, 1965c; Paish and Associates 1974; Martin 1976; Lindsay 1977; Lindsay and Seaton 1978). However, because of the vast geographical extent of flooding, remote access, difficult sampling conditions (many large and turbulent streams), and limited available resources, very little systematic sampling took place prior to flooding. As a consequence, very little quantitative information is available for comparison with current population states. In the case of bull trout specifically, knowledge about habitat requirements, interactions with other species, and population structure was generally limited during prior analyses, which affected the assessments of changes in habitat carrying capacity wrought by dams.

The distributions of bull trout can be highly clumped even in pristine watersheds, with core spawning and rearing reaches frequently making up only a small fraction of the total available habitat (Bustard and Schell 2002; Decker and Hagen 2007). The fact that little information had been collected prior to dam construction about the specific distribution of spawning and rearing areas, therefore, poses a substantial challenge for the estimation of impacts from estimates of the number of kilometers of lost stream habitat alone. Furthermore, a realistic assessment of the effects of habitat alterations on bull trout populations requires that they be integrated across all life stages, which requires an understanding of factors that regulate population size (limiting factors). A third challenge in assessing impacts exists, one which was not addressed in prior estimates of footprint impacts, or in compensation plans. This is the recent prioritization of conservation management at the sub-specific level of evolutionary divergence, and the growing awareness of how important ecological and genetic diversity is for the long-term persistence of the species as a whole (Leary et al. 1993; Moritz 1994; Waples1995; Taylor et al. 2001). Fisheries scientists have recognized the importance of diversity in maintaining the productivity of a fishery as well, as genetically based ecological adaptations to local conditions that occur within fished stocks act to maximize the carrying capacity of the environment (Hilborn and Walters 1992). However, the conservation of genetic diversity as a priority in management policy can have strong implications for compensation planning. In particular, the breaching of natural waterfalls (such as occurred on the Halfway River in the 1980s) to allow adfluvial fish access to upstream reaches would not be desirable if they were already inhabited by genetically distinct resident populations, which would have a very high risk of being extirpated or amalgamated (Latham 2002).

To provide the background information for considering the potential impacts of dam construction on bull trout in the upper Columbia Basin, the following sections of the report address the biology and evolutionary history of bull trout in the upper Columbia Basin, specifically bull trout life history traits (Section 2), limiting factors for bull trout production (Section 3), and population spatial structure (Section 4). Section 5 then presents the methods used to estimate footprint impacts and conservation status among the 17 identified reaches in the upper Columbia Basin. The footprint impacts for each of the identified reaches are addressed in Section 6. Three general categories of footprint impacts are addressed, which are: 1) changes in the conservation status for bull trout populations inhabiting the reach; 2) net changes in the habitat capacity for bull trout production; and 3) impacts to the sport fishery potential, recognizing the high recreational and economic value of bull trout fisheries in the region (Bray and Campbell 2000; Arndt 2004; Andrusak 2007). Compensation options suitable for bull trout habitats in the upper Columbia Basin, and a framework for prioritizing them within a basin-wide context, are discussed in Section 7.

2.0 BULL TROUT LIFE HISTORY TRAITS

2.1 Generalized life history

Following sections of this life history review are detailed and technical, mainly because the report is an aid to planning compensation activities, and therefore must be able to provide as much insight as possible into the unique biology of bull trout. Many British Columbia residents would think of bull trout primarily as the large-bodied inhabitants of large, cold lakes (adfluvial life history) and rivers (fluvial), which migrate upstream in the fall to spawn in smaller streams in the province's mountainous areas. It is important to be aware of the ecological and genetic diversity represented by all life history forms (Section 2.2) including resident fish that do not migrate from their rearing tributaries. As mentioned previously, compensation activities that improve access for fluvial and adfluvial fish may come at the cost of stream resident populations, which are genetically unique and of high conservation value.

In general, the bull trout's most important habitat requirement is for clean, cold stream reaches of small-to-moderate size, where spawning and rearing take place for all bull trout populations, and where resident populations spend their entire life cycle. Without specific knowledge of the criteria for suitable stream reaches (Section 2.3), compensation activities targeting streams have only a small chance of providing increased production for bull trout populations. The principal impact of BC Hydro's dams on bull trout streams has been to inundate reaches formerly utilized for spawning and rearing.

The dams have also cut off migration routes between stream habitats and areas that older life stages of fluvial and adfluvial bull trout populations would have formerly used for rearing (Section 2.4). Reservoir environments are also much more homogenous than the pre-impoundment rivers and lakes of the upper Columbia Basin, which means that some of the ecological diversity formerly existing among bull trout populations has been lost.

2.2 Life history forms

In interior regions of western North America, the three general life history forms are stream resident, fluvial, and adfluvial, but there are coastal populations where limited movements into saltwater also occur (anadromy). However, few details of the movements of these anadromous bull trout are known (McPhail and Baxter 1996).

Stream resident populations are typically separated from migratory populations by some kind of migration barrier, either physical (e.g. waterfalls, dams) or caused by areas of high water temperature affecting southern populations particularly (Rieman and McIntyre

1993). Limited natural sympatry of resident and adfluvial forms has been described for certain areas of the Arrow Lakes Basin (McPhail and Murray 1979; Latham 2002), but this may represent the 'falling' of resident individuals over migration barriers, individuals which do not contribute substantially to recruitment to the below barrier population (Latham 2002). Resident bull trout in the upper Columbia River tributaries Dutch and Toby Creeks matured for the first time at 4-5 years of age and at a size of approximately 200 mm (maximum 312 mm and age-7+; Triton 1993), somewhat larger than the 186 mm average size of mature fish (maximum: 246 mm) sampled by Ladell (2003) in tributaries to the Arrow Lakes Reservoir. Mature, resident bull trout up to 8 years of age and ranging in size from 115-300 mm have been reported in published accounts (Goetz 1989; McPhail and Baxter 1996)

In tributaries of the upper Columbia Basin and throughout their geographic range, fluvial and adfluvial bull trout rear in natal tributaries for 1-4 years before undergoing migrations downstream to larger rivers and lakes, respectively, with age-2+ migrants most common (McPhail and Murray 1979; Oliver 1979; Shepard et al. 1984; Pratt 1992; Downs et al. 2006). Age-0+ fry also emigrate from spawning tributaries, but their survival appears to be poor. Downs et al. (2006) recently found that substantial numbers of age-0+ adfluvial bull trout emigrated from a spawning tributary to Lake Pend Oreille, Idaho, but otolith microchemistry suggested that age-0+ emigrants did not make a significant contribution to adult returns. In a sample of 47 adults, most of the bull trout entered the lake at age-3 or age-4, and none entered at age-0+. McPhail and Murray (1979), however, based on their examination of growth patterns on otoliths of Arrow Lakes Reservoir-caught fish, suggested that as many as 15% of bull trout surviving to adulthood may have entered the reservoir before their first winter.

Pratt (1992) reported that adfluvial bull trout spawners in the interior regions of western North America were 4-9 years old, and Goetz (1989) lists average spawner sizes among populations ranging from 440-690 mm, with a range of 300-875 mm. It is clear that migratory Canadian bull trout populations frequently include individuals that are older than this, with the oldest recorded being a 24-year-old male belonging to a fluvial population in the North Thompson River (Hagen and Baxter 1992). In the upper Columbia Basin, adfluvial bull trout populations frequently include particularly large and old individuals, suggesting lower growth rates and exploitation than for southern populations. Wigwam River spawners, which migrate from Lake Koocanusa Reservoir, are most commonly 7 years old, with ages 5-13 years and sizes of 430-860 mm (mean = 670 mm) having been recorded (Westover and Conroy 1997). Bull trout of up to 14 years of age and 9.1 kg (20 pounds) or more have been captured in the Arrow Lakes Reservoir (Sebastian et al. 2000), and in Kootenay Lake, where spawners measured at the Duncan Dam range from 320-970 mm (mean =670 mm; BC Hydro data on file), a bull trout of 13.6 kg was captured in 1995 (Sebastian et al. 2000). A 1025 mm, 14.5 kg fish caught in Lake Pend Oreille, Idaho is listed by Goetz (1989) as the record bull trout, but a larger fish weighing 18.3 kg, which was probably a Kootenay Lake adfluvial fish, was reportedly captured in the Lardeau River (Hart 1973, as cited in Armstrong and Morrow 1980).

Although fewer descriptions are available for comparative purposes, it appears that among fluvial populations there exists a greater range of adult body size. Means from several northwestern British Columbia populations range from 380-480 mm (McPhail and Baxter 1996; Bustard and Schell 2002), while fluvial fish utilizing the Peace River below Peace Canyon dam and the upper Kootenay River above Lake Koocanusa can be as large as those belonging to adfluvial populations (up to 900 mm and 9.1 kg or more; McPhail and Baxter 1996; Westover and Heidt 2004).

2.3 Early life history

Egg development and hatching are related to water temperature, with optimal development and survival for bull trout occurring at 2-4ºC (McPhail and Murray 1979). In a laboratory setting, alevins emerged from the gravel approximately three weeks after hatching, which occurs in early spring in the upper Columbia Basin (McPhail and Murray 1979). Emergence success is negatively related to the proportion of fine substrates present in the redd site, suggesting a sensitivity of the species to sedimentation. However, where present, groundwater or streambed recharge may compensate for the negative effects of fines (Pratt 1992). In a tributary of the Peace system in Northern BC, areas of groundwater were experimentally shown to result in significantly higher egg-to-alevin survival relative to randomly available sites (Baxter 1997). Newly-emerged fry observed by McPhail and Murray (1979) in the laboratory did not fill their swim bladders, and acquire neutral buoyancy, until approximately 3 weeks post-emergence, which the authors suggested may be an adaptation to the swift streams typically utilized by bull trout for spawning and rearing.

Young-of-the-year bull trout (also referred to as fry, age-0+) use shallow, slow areas along channel margins in proportion to their availability irrespective of whether they occur in pools or riffles (Saffel and Scarnecchia 1995), with low velocity side channels being particularly valuable for fry (McPhail and Murray 1979; Saffel and Scarnecchia 1995; Bustard 2004). Age-0+ fry studied by Baxter (1995) preferred areas of 10-18 cm depth, and were generally found in less than 40 cm of water, while preferred velocities have been suggested to be less than 15 cm/s, with an upper limit of approximately 30 cm/s (Baxter and McPhail 1996). Age-1+ and older juveniles, and resident fish of comparable size, prefer pools and pocket pools along the main channel and side channels (McPhail and Murray 1979; Saffel and Scarnecchia 1995; Hagen and Taylor 2001). Preferred depths and velocities for older juveniles appear to be approximately 20-45 cm and 5-35 cm/s, respectively (Baxter and McPhail 1996; Hagen and Taylor 2001). Low velocity areas along channel margins may be even more important than is apparent from typical day time sampling, as juvenile bull trout make diel movements from main channel areas with cover to shallow, calm water at the channel margin or in side channels at night (Thurow 1997; Hagen and Taylor 2001; Muhlfeld et al. 2003).

Large, unembedded substrate appears to be the most important cover variable among studies (Oliver 1979; Pratt 1992; Baxter and McPhail 1996), particularly with respect to winter habitat when daytime concealment occurs (Thurow 1997; Bonneau and Scarnecchia 1998), although instream wood cover is also important (Fraley and Graham 1981; Fraley and Shepard 1989; Baxter 1995; Jakober et al. 1998). In the upper Columbia Basin, instream wood cover is probably not as important during most of the year in many larger streams, as most wood debris is not wetted because of large variation in discharge throughout the year. Wood debris cover is likely to be a much more important cover component in smaller bull trout streams, and smaller reaches above barriers that may be occupied by resident populations (Ladell 2003). The importance of wood debris in larger Columbia Basin streams probably lies in its role in promoting channel complexity (Ralph et al. 1994).

Juvenile bull trout are closely associated with the stream bottom (McPhail and Murray; Baxter and McPhail 1996; Hagen 2000), and feed primarily on aquatic insects (Shepard et al. 1984; Hagen 2000). Fish make up a small portion of the diet (<1%; Hagen 2000) for juveniles greater than approximately 100 mm (Shepard et al. 1984; McPhail and Baxter 1996; Hagen 2000). The fact that consumed fish are frequently conspecifics (Hagen 2000) may play a role in the overall population dynamics of the species. Bull trout maintain and defend feeding stations in areas of flow, feeding from the drift, but also move about in low velocity areas and feed benthically, particularly at night (Nakano et al. 1992; Hagen 2000).

Bull trout are clearly coldwater-adapted, and juvenile growth does not appear to be curtailed by low water temperatures to the degree that it is for other salmonids (McPhail and Murray 1979; Pratt 1992). At the end of their first, second, and third years of life, juvenile bull trout in the non-glacial Flathead River Basin had mean sizes of 50-70 mm, 100-

120mm, and 150-170 mm, respectively (Shepard et al. 1984). In the upper Columbia Basin, juvenile bull trout from the glacial Incomappleaux and Illecillewaet systems were of comparable size at the end of their second and third growing seasons, averaging 118 and 156 mm, respectively (derived from Decker and Hagen 2007).

For fluvial and adfluvial populations, migration of juveniles at the end of tributary residence occurs throughout the summer from May through to the fall (Fraley and Shepard 1989; McPhail and Murray 1979; Oliver 1979).

2.4 Sub adult and adult life history

In large riverine and lacustrine environments bull trout eat primarily fish, with individuals becoming progressively more piscivourous with increasing size. Bull trout of all sizes are capable of eating prey of up to 50% of their own length (Beauchamp and Van Tassell 2001. Kokanee salmon and other salmonids appear to be the most important fraction of the diet in lacustrine environments, although cottids, cyprinids, catostomids are also consumed (Shepard et al. 1984; Pratt 1992; Beauchamp and Van Tassell 2001). In rivers mountain whitefish appear to be a highly important prey source for fluvial bull trout (Boag 1987; Swanberg 1997). In Lake Billy Chinook, Oregon, cannibalism on smaller bull trout (age-0+ and age-1+) was detected in the stomachs of bull trout of <450 mm, but not in larger fish (Beauchamp and Van Tassell 2001). Kokanee are also seasonally available in large numbers to fluvial fish in the upper Kootenay, lower Duncan, and upper Columbia rivers in the upper Columbia Basin, and may have a strong effect on bull trout distribution and growth (Westover and Heidt 2004; Olmsted and den Biesen 1998).

The distribution of bull trout in rivers and lakes appears to be strongly affected by water temperature. Bull trout tend to avoid areas where water temperatures exceed 15ºC for extended periods (Pratt 1992; McPhail and Baxter 1996). Water temperature influences the movements of fluvial bull trout as well, probably affecting the timing of migrations into tributaries, which may occur two months before spawning, and influencing movements by non-spawning fish into both spawning and non-spawning tributaries (Swanberg 1997; Westover and Heidt 2004).

In Flathead Lake, where individual bull trout migrate up to 200 km or more to spawn, movements from winter locations are initiated between April and June (Fraley and Shepard 1989). The peak of migration of adfluvial bull trout through the Duncan dam, located approximately 10 km above Kootenay Lake, typically occurs between early June and mid-July (Hagen 2003). For fluvial populations in larger systems, such as the upper Kootenay River above Lake Koocanusa reservoir, movements from winter locations are initiated between mid-May and mid-June, and spawning tributaries are entered throughout July (Swanberg 1997; Westover and Heidt 2004). In contrast, when migrations to spawning areas are short, bull trout may not leave lacustrine habitats until August, much closer to the time of spawning (McPhail and Murray 1979).

In the Flathead Basin of Montana, adfluvial bull trout preferentially select larger, lower gradient tributary reaches for spawning that have abundant gravel and cobble substrates (Graham et al. 1981). This also appears to be true in tributaries to the upper Kootenay River, and in glacial tributaries to the upper Columbia River mainstem. However, in non-glacial systems dominated by rainbow trout or Pacific salmon in their lower reaches, bull trout spawn primarily in the furthest upstream areas accessible, which are often of higher gradient, and above obstacles to migration that block access to migrants of other species (Bustard and Schell 2002; Decker and Hagen 2007). Spawning sites (redds) are not necessarily directly associated with cover, but cover in the form of pools, large wood debris, undercut banks, and overhead vegetation is nevertheless an important attribute of spawning streams, as adult bull trout may hold for up to a month or more in tributaries prior to spawning (McPhail and Murray 1979; Graham et al. 1981; Baxter 1995). Bull trout do not appear to spawn in large mainstem reaches, such as the Columbia and Kootenay River mainstems (McPhail and

Baxter 1996; Golder Associates 2004; Westover and Heidt 2004).

Bull trout spawning generally takes place between mid-August and mid-October (McPhail and Baxter 1996), although spawning as early as July has been observed in Oregon (Ratliff 1992). In the upper Columbia Basin, spawning for fluvial and adfluvial stocks appears to occur between mid-September and mid-October (McPhail and Murray 1979; Oliver 1979; Westover and Heidt 2004). Decker and Hagen (2007) found that the majority of spawning activity had been completed by October 1 in tributaries to the Arrow Lakes Reservoir. Water temperatures of 9ºC have been associated with the onset of spawning (McPhail and Murray 1979; Fraley and Shepard 1989), although this does not appear to be a precise predictor of spawning timing at many locations (personal observation).

Stream substrate at spawning sites averages 25 mm to 60 mm, and is probably related to availability and the size of spawners (McPhail and Murray 1979; Hagen and Taylor 2001). Spawning site selection may be highly specific, and redd superimposition may occur. In larger streams spawning sites are often associated with aggrading areas and areas of groundwater infiltration (Oliver 1979; Graham et al. 1981; Fraley and Shepard 1989; Baxter 1995; Oliver 2001), while in some smaller streams all pockets of suitable looking substrate have been used (personal observation). Depths at redd locations average 24-58 cm, and appear to always be less than 90 cm, while velocities average 14-52 cm/s and are typically 65 cm/s or less (reviewed in Baxter and McPhail 1996).

Migratory bull trout do not appear to deviate greatly from a 1:1 sex ratio (McPhail and Baxter 1996). Spawning behaviours, sexual dimorphism, and fecundities are described in detail in McPhail and Murray (1979), Leggett (1980), and (Goetz 1989). In brief, a spawning event involves: excavating an egg pocket by the female, release of gametes by the paired adult bull trout, fanning of the fertilized eggs to settle them into interstitial spaces of the gravel, and the sweeping of additional gravel from immediately upstream of the excavation to cover the eggs. During the covering of the eggs a second egg pocket is excavated immediately upstream of the first, and additional spawning events may occur at the same location over a period of several days. The entire excavated area is termed a redd, the size of which can range from 0.5 m^2 (McPhail and Murray 1979) to 3.0 m^2 (Baxter 1995) on average, depending on the size of the female and the nature of the substrate being utilized. Bull trout redds in Camp Creek in the upper Columbia Basin averaged 1.6 m^2 (Oliver 2001). It also appears that a single female can spawn in more than one redd if gravel accumulations at the first location are of limited size (Leggett 1980). Precocious males have been observed in the upper Columbia Basin (McPhail and Murray 1979) and in tributaries of the Peace system (Baxter 1997), but it is unknown how widespread this life history strategy is. Female bull trout leave for downstream lacustrine or fluvial habitats shortly after spawning, but males may remain at spawning sites in the upper Columbia Basin until late October (McPhail and Murray 1979; Oliver 1979).

3.0 POPULATION REGULATION

3.1 Production dynamics over the life cycle

Migratory fluvial and adfluvial bull trout populations are those that have primarily been affected by the construction of dams in the upper Columbia Basin. Estimating the effects of dam construction on the overall dynamics of each of these populations requires that the effects on potential limits to production in both stream (Section 3.2) and adult rearing habitats (Section 3.3) be considered. Furthermore, for compensation activities to result in increased production of bull trout adults, a production bottleneck that determines population size must effectively be targeted.

3.2 Stream rearing

Although the possibility that age-0+ migrants from rearing streams contribute to the adult population cannot be discounted (McPhail and Murray 1979), the fact that most bull trout surviving to adulthood appear to have undergone an extended tributary residence of 1-4 years suggests that juvenile production from tributaries is a primary bottleneck regulating population size. This has frequently been assumed in previous assessments of the population impacts of stream habitat losses caused by dam construction in the upper Columbia Basin (Martin 1976; Lindsay 1977).

Bull trout distribution in a watershed is often limited such that core rearing habitats of relatively high density represent a small fraction of the total amount of stream habitat available (McPhail and Baxter 1996; Bustard and Schell 2002); this has been demonstrated for tributaries to the Arrow Lakes Reservoir in the upper Columbia Basin (Decker and Hagen 2007). Bull trout in Idaho appear to be limited to streams of >2 m wetted width and <10% gradient (Rieman and McIntyre 1995; Dunham and Rieman 1999). Water temperature and competitive interactions with other species, the outcome of which may be mediated by temperature, have been suggested to be the most important determinants of bull trout distribution and abundance, with most other habitat variables being poorly related. Haas (2001) studied bull trout abundance in tributaries of the upper Columbia Basin and found that bull trout were not present when summer maximum water temperatures were greater than 16°C. Bull trout and rainbow trout parr (an alternative name for age-1+ and older juveniles in this analysis) abundance were also strongly negatively correlated in his study, with bull trout dominating numerically and showing relatively high growth rates and condition factor at sites with summer maximum water temperatures less than 13°C, and rainbow trout dominating at water temperatures greater than 14°C. Temperature thresholds for bull trout presence in watersheds in Montana and Idaho are consistent with the observations of Haas (2001). Fraley and Shepard (1989) found few bull trout juveniles in the upper Flathead system, Montana when maximum water temperatures were greater than 15°C, and Saffel and Scarnecchia (1995) found that reaches with high bull trout densities in Idaho streams had summer maximum water temperatures of 7.8 to 13.9°C. Dunham et al. (2003) found that at the southern limit of the distribution, temperature was the only biophysical variable that was strongly associated with bull trout presence, and that the probability of occurrence in a reach exceeded 50% when the maximum daily water temperature was less than 14-16°C. The notion that water temperature can limit bull trout distribution and abundance is consistent with laboratory trials demonstrating that bull trout have among the lowest upper thermal limits and growth optima of North American salmonids (Selong et al. 2001).

Competition with rainbow trout and non-native brook trout also appears to limit production. Parkinson and Haas (1996), working in tributaries of the upper North Thompson and Mesilinka River systems, suggested that low water temperatures favoured bull trout in competitive interactions with rainbow trout, with a threshold value for bull trout dominance of 13°C. The range of overlap between bull trout and rainbow trout was less than 2°C, comparable to water temperature differences observed between upper reaches in Arrow Lake Reservoir tributaries dominated by bull trout and lower reaches dominated by rainbow trout (Decker and Hagen 2007). Small shifts in stream temperature profiles may therefore be highly significant with respect to habitat suitability for bull trout. Bull trout, particularly populations in southern portions of the upper Columbia Basin or in watersheds without permanent snowfields, are likely to be highly vulnerable to water temperature increases resulting from forest harvesting activities or climate change.

Difficult access for migrating spawners may also favour bull trout relative to other salmonid species. In Gosnell Creek, a tributary to the Morice River in northern BC, Bustard and Schell (2002) discovered a major, migratory bull trout population spawning upstream of a 1.9 m waterfall that was a barrier to the migration of steelhead and coho salmon. Obstructions on the Halfway River and Caribou Creek in the Arrow Lakes Reservoir basin, which are passable to adfluvial bull trout, delineate the downstream boundaries of core juvenile rearing habitats in these streams (Decker and Hagen 2007). The abrupt shift in rainbow trout age-class structure above them suggests that these obstructions constitute barriers to adfluvial rainbow trout. Greater recruitment from the highly fecund, adfluvial adults may provide bull trout with the advantage necessary to compete successfully with resident rainbow trout above the obstructions. Competition and hybridization with brook trout has also been identified as a major threat to bull trout populations (Ratliff and Howell 1992; Rieman and McIntyre 1993; Paul and Post 2001; Rich et al. 2003). Bull trout populations appear to have increased resistance to the invasion of brook trout when streams are cooler, have had less habitat degradation, and have high interconnectivity among neighbouring stream reaches (Paul and Post 2001; Rich et al. 2003).

Although evidence for the importance of other habitat features in defining the distribution and abundance of bull trout in stream environments is more limited, the associations of bull trout with pools, wood debris cover, and unembedded large substrate (see Section 2) suggests strongly that degraded watersheds will have a reduced habitat capability for bull trout, even if stream temperatures remain below threshold values.

Little is known about the role of stream productivity in regulating populations of juvenile bull trout. A study underway in the Salmo River watershed is investigating the effects of experimental stream fertilization on bull trout production, and preliminary results suggest that bull trout are larger for a given age and more abundant (S. Decker, Kamloops BC, pers. comm. 2008).

Even in core rearing areas, juveniles of fluvial and adfluvial bull trout populations appear to limited to relatively low densities (Table 2), with the highest recorded mean reach density, for age-1+ and older juveniles, being 12.1 fish/100 m^2 for a reach in the Thutade Lake watershed of northern British Columbia, in which bull trout were the only species present (Hagen and Taylor 2001). However, these densities probably reflect the limited carrying capacity of the cold environments used by bull trout populations.

A time series of juvenile abundance estimates from Kemess Creek, in the Thutade Lake watershed, strongly indicates that, within suitable reaches, density dependent survival limits production of age-1+ parr to an overall reach density of less than approximately 8 fish/100 m^2 (derived from Bustard 2004), and therefore that the stream environment plays an important role in regulating population size. In this unexploited population age-0+ abundance in late summer is positively related to redd counts from the previous fall (Figure 2a), with variance in the relationship related to variation in how long spring freshet lasts (extended periods of high runoff result in lower egg-to-fall fry survivals; D. Bustard, Smithers BC, pers. comm. 2007). However, fry-to-1+ parr survival is strongly density-dependent (Figure 2b), resulting in highly similar age-1+ parr abundance over a three-fold range of previous-year fry abundance (Figure 2c: mean = 7.4/100 m^2 $\pm$0.25/100 m^2).

An important, long-term study of the recovery of a severely overexploited bull trout population in Lower Kananaskis Lake, Alberta (Johnston et al. 2007), which incorporated estimates of juvenile abundance and counts of first-time and the total number of spawners, also indicated density-dependent survival in the tributary environment regulating population size. Density-dependent survival, estimated over a twenty-fold range of spawner population size, occurred in the period between egg deposition and age-1+, with survival between age-1+ and the age of first spawning being density-independent.

3.3 Lacustrine and fluvial habitats

Although intuitively probable, it has not been demonstrated that adfluvial bull trout populations are regulated by the primary productivity of lacustrine environments. The paucity of bull trout stock assessment data for the upper Columbia Basin confounds efforts to investigate this directly, although the limited amount of existing data does offer some support for this notion. Higher nutrient input levels from the more calcareous Rocky Mountain Trench drainage, that used to enrich Kootenay Lake, now enhance productivity in Koocanusa Reservoir (Moody et al. 2007). Redd densities of up to 36/km (estimated over the entire accessible stream length) in the Wigwam River (Westover and Heidt 2004), the reservoir's principal spawning tributary, are the highest to have been observed in the upper Columbia Basin. Among other reservoirs, Kootenay Lake under the current fertilization regime is estimated to have the highest primary productivity per square km, which is approximately 32% higher than that of the fertilized Arrow Lakes Reservoir (Moody et al. 2007). Overall redd density in the Kaslo River, a major spawning tributary to Kootenay Lake, was 17/km in 2007, higher than observed densities among all major spawning tributaries to the Arrow Lakes Reservoir, which ranged from 3.5/km in the Halfway River to 15/km in MacDonald (Slewiskin) Creek in 2004 (Decker and Hagen 2007). These comparisons assume that tributary production is density dependent and the bottleneck regulating spawner abundance, and that the asymptotic juvenile density in tributary environments is comparable among watersheds (which may not be reasonable given the small amount of juvenile stock assessment data). In this simplified scenario of density-independent survival to adulthood, higher redd densities would imply better survival and/or growth in the reservoir environment.

Because bull trout are mostly piscivorous after leaving natal rearing streams, the mechanism by which primary productivity changes in lacustrine or fluvial environments would affect survival and growth is through changes to prey fish communities or conditions for foraging. Dams upstream of the largest natural lakes in the upper Columbia Basin, Kootenay and the Upper and Lower Arrow lakes, now catch spring runoff in reservoirs, reducing turbidity and nutrient content of outflow waters (Moody et al. 2007). Kokanee populations showed a delayed response to these changes following dam construction, but had declined to a fraction of pre-impoundment abundance by the late 1980s in Kootenay Lake[1] (Ashley et al. 1999), and by the mid-to-late 1990s in Arrow Lakes Reservoir (Arndt 2008). Experimental fertilization conducted by FWCP appears to have been able to reverse these declines (Arndt 2008; Schindler et al. 2006; Schindler et al. 2007). Although these reversals indicate that the Kootenay Lake and ALR kokanee populations were nutrient limited, competitive interactions with introduced mysid shrimp at low nutrient levels may also have influenced kokanee abundance (Arndt 2008). Unfortunately, reliable bull trout abundance estimates are not available to relate to the kokanee abundance time series. Recent creel survey data from the ALR (Arndt 2004; S. Arndt, FWCP Nelson, pers. comm. 2008) do appear to show increases in bull trout growth, abundance, and recruitment from younger age classes following fertilization. However, catch-per-effort data between 1976 and 2002 do not exhibit declines associated with declining kokanee abundance in the mid-late 1990s (Arndt 2004). This lack of close correlation should not be used, however, to demonstrate a lack of response in bull trout population dynamics to post-impoundment ecological conditions. Bull trout in the ALR are long lived and lightly exploited (Sebastian et al. 2000), meaning annual recruitment variation may be masked by relatively high standing stocks of older fish. Decreased abundance of bull trout could also be masked by changes in angler proficiency over time, resulting from improved technology or knowledge, or by changes in angler behaviour or composition of the angler community (e.g. mostly locals with better knowledge) when stock sizes are low.

A small amount of information from the upper Columbia Basin suggests that the composition of prey fish communities affects bull trout growth and survival, and that the introduction of kokanee to lacustrine environments enhances their capability for bull

[1] Note that pre-impoundment productivity data for Kootenay Lake were strongly influenced by phosphorus inputs from a fertilizer plant upstream, and good pre-impact data for kokanee on Kootenay Lake do not exist (Arndt 2008).

trout production. Bull trout spawners captured in 1996 in the Wigwam River were more abundant and 140 mm longer on average than those captured in 1978, when introduced kokanee were not yet established in Koocanusa Reservoir (Westover and Conroy 1997). Anglers have also expressed that bull trout in Kinbasket Reservoir used to be skinny, but had become deep-sided, red-fleshed, and more abundant following introductions of kokanee by the BC Ministry of Environment from 1982-1985 (Pole 1996). Twenty percent of the Kinbasket bull trout catch sampled by Pole (1996) was comprised of individuals >700 mm in length[2].

Bull trout appear to do well in the relatively cold reservoirs of the upper Columbia Basin, and it appears likely that the capability of some of these reservoirs for bull trout production exceeds that of the fluvial habitats that were lost. Adfluvial bull trout utilizing the Wigwam River are part of a formerly fluvial population that has adapted to Koocanusa Reservoir. This population appears to be more than an order of magnitude larger than fluvial populations utilizing the Skookumchuck and White rivers (as determined by radio telemetry; Westover and Heidt 2004) despite comparable juvenile densities at index sites and watershed areas (Cope 2007). Anecdotal reports of an impressive late fall and early spring fishery in Kinbasket Reservoir (Pole 1996; Westslope Fisheries 2001) also indicates a substantial population, although there is currently no stock assessment for this reach. In the Deschutes River system of Oregon, juvenile bull trout that reach the reservoir created by the Round Butte Dam (Lake Billy Chinook) grow at much faster rates than in fluvial habitats in the same system (Ratliff 1992).

In Lake Billy Chinook, Oregon, cannibalism on smaller bull trout was detected only in the stomachs of bull trout up to 450 mm, but it accounted for up to 10% of the identifiable prey in the diet (Beauchamp and Van Tassell 2001). Losses of age-0+ and age-1+ bull trout due to cannibalism in the reservoir were estimated to be 11-49% and 4-18%, respectively, suggesting that predation and cannibalism may be important mechanisms regulating bull trout production in reservoirs.

Although it seems plausible that reservoirs and lacustrine environments would have a carrying capacity for adult bull trout production, little information is available with which to evaluate the possibility of density-dependent survival in this life stage. In Lower Kananaskis Lake, recruitment of bull trout to the adult population (i.e. the number of first-time spawners), across a twenty-fold contrast in spawner abundance, was regulated by density-dependent survival in the first year of life. In the latter stages of population recovery, however, survival of adult bull trout from their first to subsequent spawning events had become density-dependent, implying that intercohort competition among adults was also important in regulating population size (Johston et al. 2007). For this population, it appears that asymptotic production of juveniles in the tributary environment was eventually able to saturate the lake environment as well. Incidentally, if the juvenile bull trout production from tributaries in the upper Columbia Basin is also able to saturate reservoir carrying capacities, it may have implications for the monitoring of lower trophic levels, which could exhibit ‘top-down’ regulation driven by exploitative competition among adult bull trout. ‘Bottom-up’ regulation is usually assumed implicitly.

Within the upper Columbia Basin, it is unknown whether juvenile production from tributaries is able to saturate reservoir bull trout carrying capacities. With respect to this analysis, this could suggest that losses of rearing stream reaches would be mitigated by increases in survival and/or growth of bull trout from remaining reaches. Until such information is available, however, it should be conservatively

[2] It should be noted that condition alone is not necessarily an indication of the habitat quality, as it can also be affected by density and therefore by per capita consumption rates. The extremely limited nature of pre-impoundment sampling makes comparisons of relative abundance impossible in most cases.

assumed that the loss of core rearing areas will result in a proportional loss in the adult population, provided lacustrine or fluvial habitats used by migrating fish remain the same. In situations where adult rearing environments have been highly modified, as in most reaches identified in Table 1, a realistic appraisal of footprint impacts on populations, or related groups of interconnected populations, will require that habitat capability changes be integrated over the entire life cycle.

4.0 POPULATION SPATIAL STRUCTURE

4.1 Evolutionary history

Given the conservation concern associated with bull trout populations, genetic studies have been conducted to identify phylogenetic structure across the species' range, one purpose of which has been to establish a basis for delineating conservation units (Leary et al. 1993; Spruell et al. 1999; Taylor et al. 1999; Taylor et al. 2001; Costello et al. 2003; Taylor and Costello 2006; Whiteley et al. 2006). The late Pleistocene geological history of the province played an important role not only in forming the aquatic habitats of the upper Columbia Basin, but also in determining which habitats could be colonized by bull trout and by which source population. Both mitochondrial and microsatellite DNA analyses (Taylor et al. 1999; Taylor and Costello 2006) indicate, at the broadest scale, two major evolutionary lineages in bull trout: a coastal lineage inhabiting areas west of the coastal mountain ranges, and an interior lineage found in areas east of these mountains. These lineages reflect isolation in two refugia south of the Cordilleran ice sheet during the Pleistocene: the Chehalis (coastal) and Columbia refugia (Taylor et al. 1999). Within the interior lineage, in BC, genetic diversity found within populations of the Peace system and within populations of the mid-Columbia system is nested within the diversity exhibited in the upper Kootenay watershed, suggesting that post-glacial colonization occurred from a single refugium and the upper Kootenay watershed was colonized earlier and more directly from this refugium. Low levels of genetic variation exist within individual populations, and progressively lower genetic diversity occurs within populations located further from the upper Kootenay watershed (Latham 2002; Costello et al. 2003). This was likely caused by repeated stochastic factors such as population bottlenecks, founder events, and genetic drift in small populations especially during post-glacial recolonization (Taylor et al. 1999).

Latham (2002), funded by FWCP, conducted research at a finer scale within the upper Columbia Basin, and suggested, based on mitochondrial and microsatellite DNA evidence collected from above and below current migration barriers, that multiple waves of colonization had occurred from genetically distinct source populations within the Columbia refugium. An early group appears to have originally colonized the upper Kootenay River watershed, and had access above barriers (via flooding associated with pro-glacial lakes) and eventually across Canal Flats into the upper Columbia system and many of its above-barrier habitats as far south as Nakusp, where access was barred by ice that had not melted. A second, later group replaced (or amalgamated with) populations below barriers in the upper Kootenay system, which were no longer passable, and colonized habitats in the Columbia system to the south of Nakusp (MacDonald Creek and south), which had become accessible by that time. At least three other genetically distinct populations or groups of populations also exist in the upper Columbia system between Castlegar and the Mica Dam, all found only above current migration barriers on the Woden, Whatshan, and St. Leon/Payne systems (Latham 2002). These populations suggest the occurrence of other waves of colonization that were not successful in below barrier habitats, and that the resident life history has evolved independently a number of times. In addition to representing the evolutionary legacy of BC bull trout, these populations include a considerable number of rare or unique genetic variants, and as such have high conservation value (Latham 2002).

4.2 Genetic population spatial structure among and within bull trout populations

Across the whole geographic range of bull trout, individual populations appear naturally to possess relatively limited genetic variation, indicating the commonness of strongly bottlenecked ancestries (Taylor et al. 1999). At the same time, however, genetic differentiation among populations is substantial, even between populations in adjacent streams (Latham 2002). Within the upper Columbia Basin, strong population subdivision within major sub-basins appears to be typical. In the upper Kootenay watershed, adfluvial populations utilizing Koocanusa Reservoir appeared to be genetically and demographically separated from fluvial populations using tributaries upstream of the Bull River, which are genetically distinct from each other (Taylor et al. 1999; Costello et al. 2003). Latham (2002) found that population subdivision was strong along the mainstem of the Columbia downstream of the Mica dam, where migratory populations exhibit 'northern' genotypes north of MacDonald Creek, and 'southern' genotypes in MacDonald and south, associated with different colonizing source populations as described in the previous section. Lacustrine samples from reservoirs created by Mica, Revelstoke, and Keenleyside dams were well differentiated from each other, and were even spatially segregated to some extent within a reservoir. Assignment of Arrow Lakes Reservoir-caught genetic samples tended to be to nearby streams. For example, 33% of fish caught near Shelter Bay were assigned to the Incomappleaux River, and assignments to 'southern' tributaries accounted for 40% of assignments for fish captured near Nakusp (Southern populations were 20% of assignments in total in the ALR, comparable to the proportion of total redd counts presented in Decker and Hagen 2007).

Genetic subdivision among bull trout populations appears to be ancient in the upper Columbia Basin, and appears to be maintained currently by strongly limited gene flow, via high site fidelity and natural selection against strays (Latham 2002; Costello et al. 2003). The highly similar nature of genetic samples from adult and juvenile bull trout from below-barrier sites indicates that precise homing is occurring (Latham 2002). Adaptation to unique local environments may be highly significant in the upper Columbia Basin. The potential for strong natural selection in tributaries is illustrated by the example of Caribou Creek, where an estimated 35-40 adult bull trout perished trying to ascend a waterfall during the exceptionally low flow of summer 2006 (note: the falls was modified at the base by BC Environment to prevent a recurrence). Only two kilometers of stream are accessible beyond this falls, but these provide the large majority of the system's juvenile bull trout production (Decker and Hagen 2007). Bull trout above and below barriers in the upper Columbia Basin are genetically distinct despite the fact that 'falling' of residents in to downstream reaches appears to be common (Latham 2002), suggesting successful recruitment into the below barrier population is rare. The probable basis for selection against fallers is ecological: above and below barrier populations exhibit morphological adaptations to stream resident and migratory life histories, respectively (Ladell 2003).

The fact that bull trout genetic diversity is high among and not within populations suggests that, to be effective, conservation of bull trout biodiversity must focus on the conservation of as many populations as possible rather than a few populations of particularly high value. Inferred strong local adaptation and restricted gene flow may even suggest the possibility that populations driven to near extirpation will not be easily 'rescued' by larger adjacent populations, as is suggested in theories of metapopulation dynamics (e.g. Rieman and McIntyre 1993). Even if the habitats of extirpated populations are recolonized, the loss of local adaptation will result in the permanent reduction of the productivity of the environment for bull trout production, and therefore the reduction of the fishery potential of the resource (Hilborn and Walters 1994).

Bull trout conservation efforts in the U.S.A are directed at the level of the 'recovery unit,' of which 27 have been identified (USFWS 2002). These are primarily based on genetic population structure, but take other management considerations into account as well. The amount of bull trout population structure covered in recovery units ranges from single, isolated local populations to multiple 'core areas,' or 'metapopulations' made up of multiple local populations that have at least some level of genetic exchange amongst themselves. With the exception of the Duncan facility, dams in the upper Columbia Basin do not have the capability for passing migratory fish. Because bull trout are isolated within many of the 17 dam units identified in Table 1, these represent the minimum level of subdivision for assessing bull trout population status in the Columbia Basin. Subdivision at a finer scale may be possible as future genetic studies identify distinct evolutionary lineages, such as the 'southern' and 'northern' genotypes of the Arrow Lakes Reservoir.

4.3 Effects of Columbia Basin dams on population structure

Impoundment of mainstem reaches of the Columbia, Kootenay, and Pend d'Oreille Rivers has resulted in the replacement of highly diverse riverine, wetland, natural lake, riparian, and littoral habitats by a monomorphic pelagic environment (Moody et al. 2007). Adaptation to diverse local environments is a major cause of differentiation among salmonid populations (reviewed in Taylor 1991), and appears to be a critical factor maintaining existing population subdivision in the upper Columbia Basin (Latham 2002). Ecological and genetic diversity probably also plays an important role in buffering bull trout populations from the short- and long-term effects of climatic and environmental change. Because hydroelectric developments have compromised the evolutionary relationship between Columbia Basin bull trout population and their environment, significant losses of genetic diversity through local population extirpation or amalgamation have likely occurred and may be ongoing, despite the fact that some populations are doing well in reservoirs. Unfortunately, data pertaining to population structure, life history or even basic distribution of the species prior to impoundment are lacking, meaning that the magnitude and significance of these losses remain uncertain.

Two studies funded by the FWCP have used molecular genetic techniques to evaluate the impacts of Columbia Basin dams on bull trout population structure, with very different results. The results of O'Brien (2001), from his study of the Duncan watershed, are in sharp contrast to other studies of genetic diversity in bull trout, and support the notion that a reduction of genetic diversity and local adaptation can accompany dam construction (although note that this is not the conclusion of the author). Molecular genetic data indicated little population subdivision among identified spawning tributaries in the upper Duncan River, which appeared to be due to a high rate of straying between streams, and, presumably, a lack of natural selection against strays. Adfluvial bull trout spawners from both Kootenay Lake and Duncan Reservoir currently spawn in these tributaries of the upper Duncan River, with little evidence of reproductive isolation (O'Brien 1999). Although Kootenay Lake is more productive, and adfluvial bull trout utilizing it are larger than spawners from the Duncan Reservoir, this potential fitness advantage may be compromised by the fact that they must successfully navigate the Duncan dam to reach spawning areas. Tagging studies have indicated that with each transfer procedure through the Duncan Dam (see O'Brien 1999 for details), about half the number of adult bull trout attempting to ascend the dam are not successfully transferred to the reservoir, and of these, another half will be discouraged from trying again that year (O'Brien 1999; Hagen 2003). Reduced fitness of Kootenay Lake migrants may have resulted in unoccupied tributary rearing habitats in their natal streams, providing a mechanism by which strays from other populations (i.e. Duncan Lake migrants) experience a reduced intensity of intraspecific competition. This scenario of course assumes that the tendencies to migrate to either Duncan Lake or Kootenay Lake are genetically based, and that some degree of reproductive isolation among these populations occurred prior to dam construction.

It should also be noted that relatively little population structure has been identified among tributaries utilized by adfluvial Koocanusa Reservoir bull trout, although these populations are well differentiated from fluvial fish utilizing tributaries further upstream along the upper Kootenay River mainstem (Costello et al. 2003).

In contrast, Latham (2002) studied the impacts of dam construction and hatchery production on existing population structure in the ALR, and found that negative impacts were relatively localized and historical population structure had been maintained in most populations. Hatchery production of bull trout began after construction of the Revelstoke dam, which blocked access to a substantial portion of the spawning and rearing area available to Arrow Lakes Reservoir bull trout. Operations continued at the Hill Creek facility from 1983 to 2002, when they were stopped because of poor contributions to the Arrow Lakes Reservoir fishery, as well as concerns that bull trout spawners were declining in tributaries used for broodstock collection (Winsby and Stone 1996; Sebastian 2000; Arndt 2004). Broodstock removal from a stream appeared to result in a more significant reduction in the genetic uniqueness of populations than did outplanting of juveniles. Surprisingly, genetic diversity losses were more than would be predicted for the simple removal of the individual spawners. A mechanism for homogenization in broodstock donor streams was proposed whereby the reduction in population density resulted in an environment of reduced intensity of intraspecific competition, as had been shown in other studies, in which hatchery or other strays were better able to colonize available habitats (Latham 2002).

Of Arrow Lakes Reservoir tributaries, Hill Creek itself, which required appropriation of McKenzie Creek flows for hatchery and spawning channel operation, and which had only a minor run of bull trout prior to the hatchery's operation, had the most highly homogenized population genetic structure. Latham (2002) also identified genetically 'southern' populations in the Jordan and Halfway Rivers, which was inconsistent with their geographic location, and speculated that these were directly or indirectly of anthropogenic origin. Outplanting of juveniles above the Jordan River falls appeared to be the source of the Jordan River population (initially, outplanting was not to the same geographic location as broodstock removal; mixed 'southern' and 'northern' parentage also occurred), and in the case of the Halfway River a migration barrier was dynamited in 1990, opening up a large amount of previously inaccessible habitat for colonization (Latham 2002) in which genetically 'southern' strays would not be selected against in intraspecific competition with a previously-established 'northern' population.

A resident population inhabited the upper Halfway River prior to barrier removal in 1990. The relatively rapid invasion of below-barrier genotypes into the reach following the breaching of the waterfall (Latham 2002) indicates that populations above falls and their genetic diversity are vulnerable to replacement by migratory populations, likely due to the swamping of juvenile rearing habitats by the highly fecund adfluvial fish. Costs in terms of the lost genetic diversity of resident, above barrier populations must therefore be factored into considerations of the compensation value of barrier removal, which has been proposed as a compensation measure for bull trout populations in the Revelstoke reservoir and Mica dam units (Fielden et al. 1992; Triton 1992). Because genetic diversity losses and reduced viability of small, isolated populations are probably the greatest impacts of hydroelectric development in the upper Columbia Basin, compensation activities that further threaten the remaining population spatial structure should be considered inappropriate with one important exception: the case where agency biologists accept that a threshold conservation situation for a bull trout exists below the barrier, and the conservation value of the below barrier population outweighs that of the resident population. This stipulation is necessary because of the generally greater conservation threats to migratory populations, given their need for spatially extensive, interconnected basins and greater vulnerability to temperature increases associated with forestry activities and climate change.

5.0 METHODS – ASSESSMENT OF DAM IMPACTS

5.1 Assessing impacts of habitat losses

In the preceding phase of the FWCP footprint impacts study, Thorley (2008) estimated losses and gains of lacustrine (lentic) and riverine (lotic) habitats due to inundation by dams constructed in the upper Columbia Basin. Other estimates of losses due to the construction of the Mica and Revelstoke dams have also been made previously (Maher 1961; Peterson and Withler 1965a; Paish and Associates 1974; Lindsay 1977; Fielden et al. 1992). The impacts of the habitat losses and gains estimated in Thorley (2008) for each dam unit, in terms of changes in the capacity for bull trout production, are estimated in Section 6.

As indicated in Section 3.1, the distribution of core areas for bull trout production often makes up only a small fraction of the total amount of stream habitat in a watershed. Because pre-impoundment information about bull trout distribution and abundance is so limited, the fraction of the more than 1,600 km of lotic habitats inundated due to dam construction (Thorley 2008) that was bull trout habitat cannot be estimated directly. Estimating the changes in habitat capacity associated with habitat losses and gains, therefore, requires that a number of assumptions be made about historical bull trout habitat use in the upper Columbia Basin, and also about adult survival and growth in new habitats in reservoirs (including Kootenay Lake) relative to pre-impoundment large rivers and lakes.

With respect to adult habitat use, this analysis assumes that bull trout were found in all large mainstem reaches in the upper Columbia Basin prior to dam construction, and in low elevation reaches of the largest tributaries. This is strongly indicated by pre-impoundment sampling and anecdotal information (Maher 1961; Peterson and Withler 1965a; Martin 1976; Hirst 1991; Westslope Fisheries 2001), as well as by current use by fluvial and adfluvial bull trout of mainstem reaches that remain free-flowing (Fielden et al. 1993; O'Brien 1999; Golder Associates 2004; Westover and Heidt 2004). It is also assumed here that these reaches do not provide spawning and early rearing habitats – studies of remaining free-flowing reaches have detected the presence of juvenile salmonids but bull trout use has been negligible, even in reaches with glacial influence (R.L. and L. 1997; Baxter and Hagen 2002; Golder Associates 2004; Hagen and Decker 2007).

Defining the distribution of juvenile bull trout rearing as a proportion of stream habitat losses is more difficult. As discussed in Section 4.1, among habitat attributes water temperature appears to be the only consistently reliable predictor of bull trout distribution and abundance, with maximum daily temperatures of >15°C and >13°C defining the upper limit for bull trout distribution and bull trout competitive dominance, respectively. Although maximum daily water temperature could form the basis of a predictive model, these data are lacking for the impact area. As a surrogate for stream temperature data, therefore, in this report geographic location is used in predicting historical occurrence of bull trout juveniles in inundated areas. In dam units located in the southern portion of the upper Columbia Basin (Columbia dam units C5-C11; Kootenay dam units K2-K5, K8-K10), concentrations of juvenile bull trout are only found well above the footprint impact zone (upper Kootenay tributaries: Cope et al. 2007; Arrow Lakes Reservoir: Decker and Hagen 2007; Salmo River: Sigma Engineering 1996; lower Duncan River: Hagen and Decker 2007), probably due to warmer water temperatures and competitive interactions with other species in more accessible lower reaches. For example, rapid naturalization of introduced rainbow trout in tributary reaches adjacent to Koocanusa Reservoir (Baxter and Hagen 2002; B. Westover, BC Environment, pers. comm. 2002) strongly suggests that these low elevation reaches did not have conditions favouring bull trout production. Losses of bull trout spawning and rearing habitats due to dam construction, therefore, is unlikely in these dam units, and dam impacts for the stream rearing life stage should be considered with respect to other species.

In contrast, in Columbia dam units upstream of the Revelstoke Dam (C1-C4), in the Kootenay River upstream of Wardner (Kootenay dam unit K1), and in the upper Duncan watershed (Kootenay dam unit K7), where icefields within watersheds result in cold and often turbid flows within tributary reaches, bull trout are often the most widely distributed salmonid and are common in tributaries in the first reach above reservoir full pool marks (Triton 1992; Fielden et al. 1992; Fielden et al. 1993; O'Brien 2001). It is likely, therefore, that a substantial length of bull trout spawning and rearing habitat was inundated within these dam units.

Not all inundated tributary reaches, of course, provided bull trout rearing habitat even in dam units with icefields. Bull trout rearing in Idaho, for example, is generally limited to stream reaches of >2 m width and <10% gradient (Rieman and McIntyre 1995; Dunham and Rieman 1999). Within the Arrow Lakes Reservoir dam unit (C11), where quantitative bull trout stock assessment has been initiated, it appears that adfluvial bull trout production occurs in stream sections of 7% gradient or less and of stream order 4-6 (Decker and Hagen 2007; FWCP data on file). Stream resident populations identified in Latham (2002) are found in tributaries of stream order 4-5 (FWCP data on file). Map-based predictions of stream losses for dam unit C4 (J. Thorley, Poisson Ecological Consultants, data on file 2008) according to these criteria are identical to losses previously estimated on the basis of field observations and professional judgment (29 km; Paish and Associates 1974). Analyses in this report assume that migratory populations would be disproportionately affected by flooding. Note that inundation of a migration barrier, and therefore of resident bull trout rearing habitat, was predicted only for one tributary in dam unit C4 by Paish and Associates (1974).

Even within streams of 7% gradient or less and of 4^{th} to 6^{th} order, it is highly likely that bull trout production was of a patchy nature due to variation in habitat quality, species interactions, and water temperature, which should be accounted for in estimates of lost productive capacity. An empirically-estimated 'biostandard' (defined hereafter as the predicted mean density) of 13 spawners/km, based on captures of bull trout at a counting fence on Mars Creek in dam unit C4, was used by Martin (1976) to develop the first estimates of adfluvial bull trout losses caused by the Revelstoke Dam. Recent stock assessment information from the ALR dam unit C11 (Decker and Hagen 2007) has provided much more extensive data for predicting bull trout production within watersheds. For this analysis, biostandards for estimating adult and juvenile bull trout production losses in inundated stream sections, and that account for lightly used stream reaches as well as core rearing areas, were developed from the ALR sampling.

Biostandards for predicting mean density over the entire accessible length of streams were estimated by first summing standing stock estimates for six bull trout spawning and rearing systems (Table 3), which are thought to account for the large majority of annual production in the catchment. The overall mean production/km was then estimated by dividing the total standing stocks by the total accessible stream length summed for all six streams. Bull trout spawner numbers were estimated as two times the redd count, assuming a 1:1 sex ratio, perfect detection of redds, and one redd/female[3]. The resulting estimates were 316 juvenile bull trout (age-1+ and older)/km and 12.6 spawners/km. These were utilized in Section 6 for estimating bull trout production losses associated with inundated stream habitats of 7% gradient or less

[3] This 2:1 expansion factor is uncertain, as redds are missed by observers and some females construct more than one redd. Although calibration studies from the Arrow Lakes Reservoir are not available, the expansion factor is within the range commonly observed in calibration studies elsewhere. Redd counts made by the same field crew that conducted the ALR counts were calibrated with spawner counts madde using an electronic resistivity counter in the Kaslo River, a tributary of Kootenay Lake, and the expansion factor was 2.2 spawners/redd (McCubbing and Andrusak 2006).

and of stream orders 4-6, for dam units upstream of the Revelstoke Dam along the Columbia mainstem and in the upper Duncan watershed.

Limits of 50% and 95% confidence for the mean production/km biostandards were estimated using 2,000 iterations of a non-parametric bootstrap procedure (Haddon 2001)[4], and were, for parr, 257-379/km and 221-476/km, respectively, and for spawners 10.5-14.6/km and 7.9-18.8/km, respectively. 'High' and 'low' estimates of footprint impacts presented in Section 6 are based on the 25^{th} and 75^{th} percentile confidence limits (i.e. upper and lower 50% confidence limits).

The estimates do not include density estimates from the general literature because these generally do not include sampling from systems of comparable geography and hydrology, especially the glacial systems that are prevalent in impacted dam units of the upper Columbia Basin. Including such estimates would probably inflate estimates of uncertainty unrealistically and introduce bias into the overall mean production/km biostandards. Sampling from the ALR was believed to be more likely to be representative of production in the coldwater environments of these dam units because 61% of the stream length surveyed, 64% of the adult population estimate, and 75% of the total parr standing stock were associated with the glacial Incomappleaux and Illecillewaet systems (Decker and Hagen 2007).

5.2 Assessing conservation status of populations within dam units

McElhany et al. (2000) introduced the 'viable salmonid population' (VSP) concept and defined it as an "independent population that has a negligible risk of extinction due to threats from demographic variation (random or directional), local environmental variation, and genetic diversity changes over a 100-year time frame." They identified four parameters for determining a population's conservation status relative to this definition:

1. *Abundance.* Population dynamics processes, including demographic stochasticity, genetic process (severe inbreeding and long-term genetic losses/genetic drift), and the effects of environmental stochasticity and catastrophes, work differently in small populations. It can be stated generally, however, that extirpation risks posed by these forces are magnified greatly at very small population sizes (Simberloff 1988; Nunney and Campbell 1993). Genetics- and population dynamics-based models of extinction tend to reach similar conclusions about minimum viable population sizes. The importance of genetic drift in fixing deleterious alleles in a population is related to N_e, the effective population size, which is a measure of how many individuals are contributing their genes to the next generation (Nunney and Campbell, 1993). According to the commonly cited "50/500" guideline in conservation biology, effective population sizes of 50 and 500 are required to minimize inbreeding effects and maintain adaptive genetic variation, respectively (Franklin 1980, as cited in Nunney and Campbell 1993; Rieman and Allendorf 2001). Effective population size for bull trout has been estimated at approximately 0.5 to 1.0 times the average number of adults spawning annually (Rieman and Allendorf 2001), suggesting conservation concern thresholds of 50-100 and 500-1,000, respectively, for populations or groups of interconnected populations when individual population sizes are small. Empirical studies of extinction in mammals and birds have generally suggested that an adult population size of $N < 50$ is clearly insufficient for a population's long-term persistence, populations of $50 < N < 200$ are marginally secure, and those of $N > 200$ are secure at least over time frames as limited as those used in the studies (reviewed in Boyce 1992).

2. *Population growth rate.* The population growth rate is the trend in the population's abundance and is either positive (increasing population) or negative (declining). Although genetic effects and demographic and

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[4] In each iteration reach densities weighted by their associated stream lengths were sampled with replacement in calculating the mean density. The parr density estimate from Kuskanax Creek was not included in the analysis, because sampling was limited due to poor access.

environmental stochasticity reduce the long-term viability of small populations, if negative population growth forced by natural or anthropogenic causes is not remedied extirpation is inevitable.

3. *Population spatial structure*. A salmonid population's spatial structure affects extirpation risk through processes increasing resilience to environmental stochasticity (variability in environmental conditions) and through evolutionary processes (genetic diversity) that affect a population's ability to respond to environmental change. A population consisting of multiple, connected sub-populations are generally thought to be more robust to extirpation forces than is a single group (Simberloff 1988).

4. *Diversity*. Phenotypic and genetic diversity is an important part of salmonid population viability, for three general reasons. First, diversity allows a population to use a wider range of environmental conditions. Second, it protects a species against short-term spatial and temporal changes in the environment, and third it provides the raw material for surviving long-term environmental changes (McElhany et al. 2000), hence the "500" part of the "50/500" guideline (Rieman and Allendorf 2001). Gene flow via strays from other populations and sub-populations is one potential source of diversity that can be cut off by dams. Conversely, stocking hatchery fish, as in the case of the Arrow Lakes Reservoir, can dilute important genetic adaptation of the population if a large degree of introgression (successful interbreeding) between the native and hatchery fish occurs, or if natural selection for alternate genotypes in alternate habitats is reduced via reduction of wild populations (see section 4.3).

In the draft recovery plan for bull trout listed under the Endangered Species Act, the United States Fish and Wildlife Service (USFWS 2002) has developed four non-genetic criteria for assessing bull trout conservation status that are consistent with the above guidelines. These are based on distribution, abundance, population growth rate, and connectivity, and have already been applied in the upper Kootenay watershed in Canada (Westover and Heidt 2004). As summarized in Westover and Heidt (2004), distribution criteria are met when the total number of identified local populations is maintained or increased, abundance criteria are met when core areas have at least 1,000 spawning bull trout and host at least five local populations, population growth rate criteria are met when overall abundance is stable or increasing, and connectivity criteria are met when anthropogenic passage barriers inhabiting bull trout migration in smaller streams have been remedied. The USFWS (2002) criteria, as well as genetic information where available, are used as a basis for estimating footprint impacts on bull trout conservation status for each dam unit in Section 6.

5.3 Assessing impacts on fisheries

Quantifying the footprint impacts of Columbia Basin dams on fisheries is very difficult, because of the highly diverse nature of the angling community. Although large drawdowns on reservoirs inevitably act as a deterrent for some anglers (MOE 1984), sport fisheries have developed in areas where they were not well developed prior to dam construction (Maher 1961; Peterson and Withler 1965a; Hirst 1991; Pole 1996). High catch rates of large bull trout have been reported for reservoirs, in the case of Kinbasket Reservoir greatly exceeding that of the traditional troll fishery on famed Kootenay Lake (Pole 1996). In Section 6, changes in lacustrine angling are evaluated in a mostly qualitative manner, but assume generally that changes in bull trout productivity, integrated over both adult and juvenile rearing environments, change angling quality proportionally.

Stream fisheries are in high demand in British Columbia, and because the angling communities are often different (reservoir fisheries mostly require the use of relatively substantial boats), the loss of stream angling opportunities is not mitigated by the creation of new reservoir angling opportunities. A major impact of dam construction in the upper Columbia Basin is the loss of so many kilometers of potential stream angling for bull trout, which took place primarily on the medium and large rivers most affected by flooding (Paish and Associates 1974; Thorley 2008). In addition to lost stream reaches, dam construction in the upper Columbia Basin also severed migration routes, meaning that even for some cases where river sections were not impounded (e.g. Slocan and Salmo rivers) productive downstream environments were no longer accessible, and remnant fluvial populations were reduced to such low levels that total fishery closures have been necessary. In contrast, in the upper Kootenay basin stream angling has been enhanced in some reaches above the full pool mark of Koocanusa Reservoir, due to the explosion of bull trout numbers in populations utilizing the reservoir, and probably also because of the seasonal availability of kokanee to fluvial populations (Westover and Heidt 2004). In section 6, losses of stream angling are equated to losses of low gradient, mainstem river sections, with qualifications that are specific to individual dam units.

6.0 ESTIMATED FOOTPRINT IMPACTS BY DAM UNIT

6.1 Columbia River dam unit C1 – Columbia Lake to Donald Station

6.1.1 Description

Detailed study area, dam, and habitat descriptions for all upper Columbia Basin dam units are available in Hirst (1991), Ahrens and Korman (2004), and Moody et al. (2007). Footprint impacts on bull production are summarized for all dam units in Table 4 (production losses) and Table 5 (mitigation and net footprint impacts), while impacts on conservation status and fisheries are summarized in Table 6.

Reach C1 extends from just above the Kinbasket Reservoir full pool mark (Figure 1) 180 km upstream to the origin of the Columbia River, and encompasses Lake Windermere and Columbia Lake. The reach is of relatively gentle gradient and supports extensive and productive off-channel wetlands along its length (Moody et al. 2007). The adjacent Rocky and Purcell mountain ranges reach high elevations along Reach C1, and glacial influence in tributaries grows more intensive in major tributaries with more northerly locations.

Migratory bull trout populations have been identified in accessible reaches of the Dutch, Toby, and Horsethief Creek systems (Fielden et al. 1993), and in the lower Blaeberry River (Triton 1991). Bull trout are known to utilize the mainstem of the Columbia River and Windermere Lake (Westslope Fisheries 2001). Although no migration barriers exist along the Columbia mainstem that separate accessible tributary reaches from Kinbasket Reservoir, none of the 32 transmitters deployed by Oliver (2001) in the reservoir exhibited spawning migrations into reach C1, suggesting that Kinbasket and upper Columbia populations are spatially segregated.

Bull trout habitat enhancements to date have been limited to a FWCP-funded construction of spawning platforms in Whitetail Creek (Hagen 1995), a small, groundwater/seepage-fed stream accessible to migratory bull trout and rainbow trout, and utilized by high densities of fry of both species (Fielden et al. 1993). Bull trout spawner use of the platforms has not been quantified except during the fall immediately following construction (Hagen 1995), when two redds were observed. A major biological alteration of the reach resulted from the introduction of kokanee into Kinbasket Reservoir in 1982-1985 (Sebastian et al. 1995), with resulting spawning migrations as far upstream as the headwater of the upper Columbia at Dutch Creek. A FWCP-supported kokanee spawning habitat improvement at the outlet of Windermere Lake (Ahrens and Korman 2004) represents an enhancement of the reach for bull trout populations as well, given the seasonal availability of migrating adult and juvenile kokanee for fluvial bull trout, and enrichment resulting from decomposing kokanee bodies.

6.1.2 Impacts on habitat capability for bull trout production in dam unit C1

Habitats utilized by bull trout in reach C1 are located upstream of the extent of flooding from Kinbasket Reservoir, and negative footprint impacts to their productive capacity are therefore not likely to have occurred. In contrast, seasonal abundance of kokanee adults and juveniles (Arndt 2008) probably represent an enhancement of the reach's productive capacity for fluvial bull trout populations, and for adfluvial bull trout utilizing Lake Windermere.

6.1.3 Impacts on bull trout conservation status in dam unit C1

A number of tributary reaches supporting migratory and resident bull trout populations have already been identified within reach C1 (Triton 1991; Fielden et al. 1993), and no barriers to movement separate these populations from the core bull trout production areas existing in the Kinbasket Reservoir dam unit C3. It appears likely, therefore, that the conservation status criteria of USFWS (2002), with respect to distribution, abundance, population growth rate, and connectivity, are currently being met. It should be noted that fishery declines over time have been reported anecdotally (Westslope Fisheries 2001), and forestry impacts to the Blaeberry Creek drainage have also been identified (Triton 1991). Periodic abundance monitoring, via redd counts and possibly also juvenile abundance monitoring in selected locations (e.g. Decker and Hagen 2007) are therefore required to confirm the absence of immediate conservation concern for reach C1. Given the segregation of upper Columbia River populations from Kinbasket Reservoir bull trout (Oliver 2001), however, and the fact that flooding does not enter into the reach, changes in the conservation status of bull trout in reach C1 are unlikely to be related to dam construction in the upper Columbia Basin.

6.1.4 Impacts on bull trout fisheries in dam unit C1

Because inundation of existing waters has not occurred, this reach does not appear to have incurred footprint impacts to its bull trout fisheries, notwithstanding the possible enhancement of bull trout populations resulting from the successful introduction of kokanee. It should be noted that the potential for stream fisheries in this reach is limited seasonally by turbid inputs from glacial tributaries.

6.2 Dam unit C2 – Spillimacheen

6.2.1 Description

The Spillimacheen River is a relatively turbid, coldwater stream that originates in the Purcell Mountains, and flows 90 km before joining the Columbia River Reach C1 at a location approximately 55 km upstream of the town of Golden. A 14.5 m high by 45 m long dam, which is operated as a run-of-river facility, creates a small head pond of 2.4 ha, and diverts up to 8.5 m^3/s of flow (of approximately 35 m^3/s MAD – Hirst 1991) through a 1.5 km diversion to a BC Hydro powerplant located on the lower Spillimacheen River below an impassable canyon (Ahrens and Korman 2004). Because of the relatively low diversion rate, the dam likely has little influence on river habitats in the immediate environs except at low flow periods (Triton 1991; Moody et al. 2007).

Triton (1991) did not capture bull trout in the lower reach accessible to migratory fish, and were not aware of bull trout use of this reach, which they characterized as slow moving, meandering channel with predominantly fines substrate. Above the falls, however, stream resident populations of brook trout, bull trout, rainbow trout, and mountain whitefish were identified. Stream habitat complexing was suggested by Triton (1991) as a potential enhancement of bull trout habitat capability above the falls.

6.2.2 Impacts on habitat capability for bull trout production in dam unit C2

The Spillimacheen Dam and its head pond have probably had little impact on the flow and habitats of the system, given that the dam and diversion are located in an impassable canyon. Head ponds are known to be able to support resident bull trout (Dave Bustard, Smithers BC, pers. comm. 2007). Entrainment mortality is furthermore not likely to be biologically significant, given the low diversion rate and the high likelihood that stream resident genotypes belonging to 'fallers' could not recruit into migratory populations anyway in accessible habitats elsewhere in the upper Columbia Basin (Latham 2002). Because it has been constructed adjacent to a natural migration barrier, the Spillimacheen facility is not likely to have had significant effects on the capacity of the Spillimacheen system for bull trout production. A very short length of stream, which presumably lies between the dam and the upstream extent of the canyon (<1 km; Thorley 2008), has not been surveyed for fisheries values and so a specific estimate of habitat losses cannot currently be made.

6.2.3 Impacts on bull trout conservation status in dam unit C2

The upper Spillimacheen is a relatively extensive system that appears to have more than one population of bull trout (Triton 1991). Because the dam was built adjacent to a natural migration barrier and likely did not alter the productive capacity of the system, it is also likely that footprint impacts of the Spillimacheen Dam to the conservation status of the resident bull trout population(s) inhabiting the upper Spillimacheen system are not significant. However, competition and hybridization between brook trout and bull trout in locations in the U.S. and Alberta have been identified as major threats to bull trout persistence in those areas (Paul and Post 2001; Markle 1992; Rieman and McIntyre 1993). The presence of brook trout within the distribution of resident bull trout populations in the upper Spillimacheen River, therefore, should be viewed with concern even though it is unrelated to the construction of the Spillimacheen facility.

6.2.4 Fisheries impacts in dam unit C2

The Spillimacheen system was not known for its fishing potential (Triton 1991), given the small body size and low abundance of stream resident fish, and relatively poor water clarity. The construction of the Spillimacheen Dam would have had a negligible effect on this potential.

6.3 Dam unit C3 – Donald Station to Mica Dam (including Canoe Reach)

6.3.1 Description

The Mica Dam, built and operated by BC Hydro, was completed in 1973, is a 244 m high by 792 m long concrete and earth fill structure located below the Big Bend of the Columbia River (Figure 1). The amount of riverine habitat flooded after the creation of Kinbasket Reservoir has been variously estimated at: 1) 586 km, including 372 km of ‘mainstem and major tributary’ habitat and 214 km of ‘tributaries’ (Ahrens and Korman 2004, based on Maher 1961, Fielden et al. 1992); 2) 448 km, including 334 km of mainstem and major tributary habitat and 114 km of tributaries (Peterson and Withler 1965a); and most recently 3) 539 km, including 340 km of ‘medium’ and ‘large’ rivers, and 199 km of streams of stream order 5 or less (Thorley 2008). The combined, post-impoundment length of the reservoir’s two arms, Canoe Reach and Columbia Reach, is about 216 km with the reservoir at full pool (Oliver 2001). Annual drawdown extends approximately 47 m below the full pool line, resulting in extensive areas of exposed sediments and a greatly reduced reservoir surface area (Hirst 1991). In addition to the Columbia River, three other major river systems enter Columbia Reach – the Wood, Sullivan, and Bush Rivers.

Data from adult bull trout radio telemetry studies (Oliver 2001), in combination with data collected during a basin-wide juvenile fish sampling program (Fielden et al. 1992), suggest that at least 23 tributaries are utilized by adfluvial bull trout. At least 5 other tributaries are likely to be supporting resident populations as well, based on length-frequency data from juvenile sampling and information about the locations of barriers or high gradient stream sections (Fielden et al. 1992). Most streams sampled by Fielden et al. (1992) contained bull trout, which were more widely distributed than any other fish species. Highly glacial streams often had relatively good access and spawning habitats within their lower reaches, but appeared to be associated with low juvenile bull trout densities, whereas moderately glacial and clear streams were associated with moderate-to-high levels of bull trout use in specific areas that were limited by difficult access (Fielden et al. 1992; Oliver 2001).

6.3.2 Impacts on habitat capability for bull trout production in dam unit C3

An estimated 340 km of 'medium' and 'large' river habitats (stream orders 6-7 and 8-9 in Thorley 2008), which would have been utilized by fluvial populations of bull trout, have been replaced by a large reservoir of highly variable size. Bull trout appear to do well in Kinbasket Reservoir. Catch rates for bull trout in Kinbasket Reservoir appear to be highest among lacustrine fisheries in the Kootenay Region (0.33 fish/hr in 1996; Pole 1996), and captures of very large bull trout (up to 10 kg) are common (Pole 1996; Oliver 2001). High survival and growth in Kinbasket Reservoir appear to be mediated in part by the successful introduction of kokanee between 1982 and 1985, which exhibit high growth rates in Kinbasket Reservoir despite oligotrophic conditions, dominate catches of pelagic fish in the reservoir, and are of comparable densities to those found in other upper Columbia Basin water bodies (Sebastian et al. 1995; Arndt 2008).

It is assumed here that bull trout rearing was widely distributed below the Kinbasket Reservoir full pool elevation in tributary reaches of 4th to 6th order and of 7% gradient or less (see Section 5.1). Lost stream habitats among these low-to-moderate gradient, mid-sized reaches totalled an estimated 142 km (Joe Thorley, Poisson Ecological Consulting data on file 2008; see Thorley 2008 for methods). Applying mean bull trout production/km biostandards of 316 age-1+ and older juvenile bull trout/km and 12.6 spawners/km (Section 5.1) results in estimated losses of 44,900 juvenile bull trout and 1,800 adult bull trout, respectively due to inundation by the Mica dam. 'Low' and 'high' estimates of bull trout losses correspond to the upper and lower 50% confidence intervals of the mean bull trout production/km estimates (Section 5.1), and are 36,400-53,800 for age-1+ and older juvenile bull trout and 1,500-2,070 for spawners

Integrating the footprint impacts of the Mica Dam over the entire migratory bull trout life cycle, in order to estimate cumulative impacts to the overall population dynamics, is not possible because of missing pre-impoundment distribution and abundance data, and the difficulty of acquiring such data even under post-impoundment conditions. It appears likely, however, that high survival and growth in the reservoir environment have mitigated the losses of tributary rearing habitats to a large degree, and in expressed in terms of potential adult bull trout production dam unit C3 retains very high habitat capability for bull trout production.

6.3.3 Impacts on bull trout conservation status in dam unit C3

Very high catch rates of bull trout (Pole 1996) indicate a substantial overall population of adfluvial bull trout in Kinbasket Reservoir, which consists of more than 20 sub-populations even after dam construction (Fielden et al. 1992; Oliver 2001). Population size changes caused by the loss of tributary rearing have probably been mitigated in large part by high survival and growth of bull trout in the reservoir associated with the successful introduction of kokanee. It is therefore probable that the USFWS (2002) conservation status criteria are easily being met in dam unit C3. However, the inundation of 340 km of mainstem and major tributary habitats by a single reservoir with a relatively homogenous, pelagic rearing environment has greatly reduced the diversity of sub-adult and adult rearing habitats. Loss of genetic and ecological diversity associated with the loss or homogenization of diverse adult rearing habitats should be considered an important footprint impact from Mica dam construction unless detailed genetic investigation of the remaining population structure demonstrates otherwise. Although genetic and ecological diversity losses cannot be restored by compensation activities, it is important that they be acknowledged and taken into consideration when designing and prioritizing compensation measures (Section 7).

6.3.4 Fisheries impacts in dam unit C3

Pre-impoundment studies suggest that fishing pressure in areas within reach C3 was light, and that its potential was relatively unexplored. Fishing effort appeared to be focussed on the Bush Lakes, where the presence of bull trout was not indicated (Maher 1961; Peterson and Withler 1965a). The potential for riverine fisheries for bull trout, especially at the mouths of less turbid tributaries and in the reach of the mainstem Columbia River below Kinbasket Lake, which acted as a settling basin for sediments, was considered to be high (Maher 1961; Moody et al. 2007).

Catches of deep-bodied, red-fleshed bull trout from reservoirs have been identified by some anglers as improvements in the fishery that are due to dam construction (Pole 1996; Westslope Fisheries 2001). However, stream fisheries for bull trout, where open, are in high demand in other reaches of the upper Columbia Basin. It is likely, therefore, that the stream fishing community of British Columbia would consider these lost river angling opportunities to be highly significant.

6.4 Dam unit C4 –Mica Dam to Revelstoke Dam

6.4.1 Description

The Revelstoke Dam, a BC Hydro facility completed in 1984, is a 175 m high by 1180 m long structure located a short distance upstream of the town of Revelstoke (Figure 1). Revelstoke Dam is operated as a run-of-river facility, meaning annual drawdowns are minimal (less than 3 m; Hirst 1991). The reservoir extends 141 km to the base of the Mica Dam, and inundated a mainstem reach that had a well-developed pool-riffle sequence with some side channel development (Moody et al. 2007; Thorley 2008).

Both fluvial and adfluvial (from the Arrow Lakes) bull trout populations made use of this reach of the Columbia River and its tributaries prior to impoundment. Construction of the Revelstoke Dam was expected to be a major impact to Arrow Lakes Reservoir bull trout populations, as well as to their prey, ALR kokanee (Paish and Associates 1974; Martin 1976; Lindsay 1977). For bull trout, losses of ALR bull trout (expressed in terms of the number of adults spawning annually) were estimated in Martin (1976) and Lindsay (1977) by applying a biostandard of 13 spawners/km, based on a population estimate for Mars Creek derived from a kelt fence count (Martin 1976), to estimates of lost stream length suitable for spawning adults. Martin (1976) estimated that 116 km of habitat was suitable for bull trout spawning, resulting in an estimate for bull trout losses of 1,440 adults spawning annually, while Lindsay (1977) considered this be an underestimate and suggested that as many as 230 km of stream habitat could have been utilized by 2,990 bull trout for spawning annually. Lindsay (1976) also suggested that if the mainstem Columbia River was also used for spawning then an estimate of 3,000 to 5,000 was reasonable. This appears to have been the basis for the target of 4,000 bull trout spawners later set for production from the Hill Creek hatchery (Sebastian et al. 2000). Arndt (2008) estimated losses of up to 100,000 kokanee spawners based on pre-impoundment aerial count data.

The recaptures of bull trout in the ALR that were tagged in reach C4 (Lindsay 1977) confirmed that adfluvial bull trout made significant use of the reach. It is likely, however, that spawning and rearing habitats were not utilized exclusively by adfluvial fish. A large population of fluvial bull trout probably utilized the mainstem of the Columbia River as well, which can be inferred from substantial pre-impoundment catches of bull trout made at the base of the Mica Dam during late October and early November (Martin 1976). Average fork lengths for adfluvial, female bull trout collected in immediate tributaries to the ALR, for broodstock during hatchery operations, ranged from 530-610 mm (Sebastian et al. 2000), while the most frequently sampled lengths by Martin (1976) in the Columbia River were 380-500 mm, indicating a significant presence of smaller fluvial fish.

Following impoundment, bull trout populations appear to have become relatively abundant in Revelstoke Reservoir (Pole 1976; Bray and Campbell 2001), indicating that adfluvial bull trout populations that formerly utilized the Arrow Lakes have adapted to the new reservoir. Whether fluvial bull trout populations adapted to an adfluvial life history, or were replaced by/amalgamated into colonizing adfluvial populations better adapted to reservoir existence, is unknown. It should be noted, however, that a genetic sample collected from Bigmouth Creek indicated an amalgamated population with little genetic differentiation (Latham 2002), suggesting that the latter scenario has played out at least once.

6.4.2 Impacts on habitat capability for bull trout production in dam unit C4

It is clear that the construction of the Revelstoke Dam cut off tributary production of bull trout that was important to the Arrow Lakes Reservoir. Migratory bull trout utilizing tributaries of dam unit C4 were not extirpated, however, and appear to be utilizing Revelstoke Reservoir. Quantitative stock assessment has not occurred on tributaries to Revelstoke Reservoir following impoundment, making assessment of the relative productivity of stocks in pre- and post-impoundment environments extremely difficult. Anecdotal information reported in Pole (1976) suggested that catch rates could seasonally be very high in the reservoir, and that captures of large individuals of 7-9 kg were relatively common. Creel survey data suggest much lower success (0.012-0.014 bull trout/hr), although it should be noted that bull trout were being targeted by only 3% of anglers during the summer months when the surveys were conducted, and thus the results may not be highly relevant (Pole 1976).

In terms of pelagic productivity, however, Revelstoke Reservoir is estimated to be the least productive of the upper Columbia Basin's large reservoirs at 81% of the primary productivity of the untreated ALR (on a per area basis; Moody et al. 2007). Kokanee entrained from Kinbasket Reservoir have naturalized in Revelstoke Reservoir, enhancing its capability for bull trout production. Mysids are not present in the reservoir, suggesting that the potential for production of kokanee relative to the ALR cannot be determined from primary productivity estimates alone (Arndt 2008). Kokanee are less abundant than in other Kootenay Region reservoirs, although larger (Sebastian et al. 1995; Arndt 2008), suggesting that recruitment may be a limiting factor for the kokanee population. With respect to bull trout growth and survival, the larger size of kokanee may compensate for reduced abundance because of increased piscivore growth efficiency (Kerr 1971a, 1971b). Conversely, it is also possible that lower kokanee abundance indicates that Revelstoke Reservoir is a less favourable environment for bull trout sub-adult and adult survival and growth than that the pre-impoundment Arrow Lakes, which adfluvial fish originating in dam unit C4 would have utilized. Relative to the pre-impoundment Columbia River mainstem, however, bull trout growth and survival is likely higher, and bull trout populations, as indicated by gill net catch-per-effort data in the reservoir, appear to have increased in dam unit C4 following impoundment (Hirst 1991).

Because estimating bull trout losses in dam units C4 and C11 (C5+C7) was complicated by the fact that ALR bull trout production cut off by the Revelstoke Dam was not lost, but instead contributes to recruitment to Revelstoke Reservoir, losses for these two dam units were quantified in two alternative ways. First, losses and gains for bull trout production resulting from habitat alterations were estimated within each dam unit. Second, losses and gains were estimated in a manner that accounted for cut off recruitment from outside the dam unit. Paish and Associates (1974) estimated that a total of 29 km of spawning and rearing habitat in tributaries to reach C4 would be inundated due to Revelstoke Dam construction, which is identical to the estimate of habitat losses derived from stream order (4-6) and gradient (7% or less) criteria (Joe Thorley, Poisson Ecological Consultants, data on file 2008). Utilizing the bull trout production biostandards developed in Section 5.1, the 29 km of habitat losses correspond to estimates of lost production of 9,200 age-1+ and older juveniles (low: 7,440; high: 11,000) and 370 bull trout spawners (low: 305; high: 424). The amount of remaining habitat that is accessible to migrating fish has been estimated from post-impoundment field observations at 125 km (Triton 1992; more recent estimates in Thorley 2008 for FWCP are not used because migration barriers are not currently incorporated into the analyses), suggesting that 19% of the original 154 accessible km was lost. As mentioned above, the capability of subadult and adult habitats in dam unit C4 for bull trout production has likely increased.

However, under the second approach to accounting for production losses, which is utilized for Tables 4-6, recruitment to the adult rearing environment of dam unit C4 has actually increased despite tributary losses, because adfluvial fish now remain in Revelstoke Reservoir instead of migrating to the ALR. This, in addition to the potential increase in bull trout production in the reservoir relative to riverine adult rearing habitats, suggests that net bull trout production that occurs wholly within dam unit C4 is now higher than under pre-impoundment conditions.

6.4.3 Impacts on bull trout conservation status in dam unit C4

Similar to dam unit C3 (Kinbasket Reservoir), the forced adoption of an adfluvial life history for all migratory stocks has probably reduced genetic diversity among populations. The low level of genetic differentiation in post-impoundment Bigmouth Creek (see above) is consistent with this notion. Notwithstanding this loss of diversity, the conservation status of remaining populations is probably secure. Many populations exist (Triton 1992), and a relatively large amount of rearing habitat (125 km; Triton 1992) remains among accessible streams, which should mean that total population size for the dam unit meets or approaches the minimum 1000 adult spawners suggested by the USFWS (2002) guidelines (based on the 12.6 spawners/km biostandard).

6.4.4 Fisheries impacts in dam unit C4

Fishing on Revelstoke Reservoir is popular, and bull trout are targeted in the late fall-early spring months. Visitors appear to be happy with the range of facilities available, and value the mountain scenery and good access to the reservoir (Bray and Campbell 2001). Good catches of bull trout up to 9.1 kg (20 pounds) or more are possible when bull trout are targeted (Pole 1996). Prior to impoundment, fluvial bull trout and resident rainbow trout river fisheries would have been possible prior to and following turbid, freshet conditions in the late spring and summer months (Martin 1976; Lindsay 1977; Moody et al. 2007), and large, adfluvial fish would have been available in late summer and fall during spawning migrations from the ALR. Even though quality fishing opportunities remain on Revelstoke Reservoir, a principal footprint impact resulting from dam construction, and which is cumulative over all the dam units, is the widespread loss of river angling opportunities.

6.5 Dam unit C6 –Cranberry Creek-Walter Hardman

The presence of bull trout does not appear to have been recorded within dam unit C6 (reviewed in Ahrens and Korman 2004), and therefore bull trout-related footprint impacts within the reach are not considered within this report.

6.6 Dam unit C11 (Dam units C5+C7) – Arrow Lakes Reservoir

6.6.1 Description

The combination of dam units C5 (Revelstoke Dam to Arrowhead; Table 1) and C7 (Arrowhead to Keenleyside Dam) is referred to hereafter in the report as the Arrow Lakes Reservoir (ALR), which is depicted as dam unit C11 in Figure 1. Keenleyside Dam, constructed in 1967, is a 58 m high, 869 m long concrete dam located at the downstream end of Lower Arrow Lake (Figure 1). Keenleyside Dam raised the maximum water level of the Arrow Lakes by roughly 20 m, and annual drawdowns are 15-20 m (Hirst 1991). As a result of impoundment, all but 3 km of the 45 km of formerly riverine habitat extending from Beaton Arm in Upper Arrow Lake to the present-day location of the Revelstoke Dam (dam unit C5) are seasonally flooded. Approximately 25-30% of the total pre-impoundment spawning area in ALR tributaries was also flooded, as was the shallow, 30 km narrows separating the Arrow Lakes (Lindsay and Seaton 1978).

In attempts to mitigate bull trout and kokanee losses resulting from construction of the Keenleyside and Revelstoke dams, some of the most substantial fisheries compensation activities undertaken in the Kootenay Region have been directed at the ALR system. A bull trout hatchery program was conducted between 1982-2000, after which it was stopped because of poor contributions to the fishery and concerns about population declines in donor streams (Winsby and Stone 1996; Sebastian et al. 2000; Arndt 2004). A kokanee spawning channel constructed in 1980 continues to operate and is a major contributor to kokanee production in the reservoir (Schindler et al. 2006; Arndt 2008). Two major barriers to migration have also been successfully altered to allow passage of bull trout spawners, increasing the amount of accessible spawning and rearing habitat by approximately 60 km. On the Illecillewaet River, a City of Revelstoke Dam located near the mouth was removed in 1977, and in 1990 a falls on the Halfway River was dynamited to allow access to a reach that had formerly been inhabited by a resident population (Latham 2002). Barrier removal was also proposed for the Jordan and Inonoaklin Rivers but not carried out, because of concerns upstream resident fish populations in the case of the former, and because of opposition from local agricultural interests in the case of the latter (S. Arndt, FWCP Nelson, pers. comm. 2008). Finally, a large-scale reservoir fertilization experiment was initiated in 1999 (Schindler et al. 2006)

6.6.2 Impacts on habitat capability for bull trout production in dam unit C11

Kokanee stocks in the ALR had declined substantially by the mid-1990s, likely due to nutrient retention in upstream reservoirs following construction of the Mica and Revelstoke dams (Schindler et al. 2006). Fertilization between 1999-2004, probably in combination with production from the Hill Creek spawning channel, appeared to have been successful at restoring kokanee abundance to pre-impoundment levels (Schindler et al. 2006), although it should be noted that recent spawner returns since 2004 are lower (Arndt 2008). Bull trout growth and survival conditions following reservoir fertilization also appeared to have been enhanced (Arndt 2004), suggesting that the program has the potential to successfully mitigate footprint impacts for bull trout in the lacustrine phase of their life cycle.

Although much of the pre-impoundment tributary habitat located upstream of the Revelstoke Dam in dam unit C4 now produces recruitment for Revelstoke Reservoir (see section 6.4), this production has been permanently lost to the ALR. Total estimated losses to the ALR would have been as high as 1,950 adult bull trout (low: 1,620; high: 2,250) and 49,000 age-1+ and older bull trout juveniles (low: 39,500; high: 58,400), based on the mean bull trout production/km biostandards of Section 5.2 (and limits of 50% confidence) and an estimate of approximately 154 km of accessible, pre-impoundment tributary habitat in dam unit C4 (29 km inundated: Thorley 2008 data on file; Paish and Associates 1974; 125 km accessible habitat remaining: Triton 1992). Realistically this number should be set at a lower level because some of these fish would have had a fluvial life history, and not contributed to the ALR standing stock, but for simplicity's sake an adfluvial life history is assumed for estimating net losses. In contrast to information from more northern, glacially-influenced dam units, Decker and Hagen (2007) found that in tributaries within the ALR basin bull trout rearing was distributed well above the reservoir full pool line, suggesting that footprint impacts from Keenleyside Dam construction on ALR juvenile rearing habitats were to rainbow trout populations instead.

Production from the Illecillewaet and Halfway systems, which comes almost entirely from the approximately 60 km accessible above the breached barriers (Decker and Hagen 2007), has been empirically estimated at approximately 1,180 spawners and 29,700 age-1+ and older juveniles (Table 3). This is probably more than half the total remaining ALR spawning population (Decker and Hagen 2007), pointing to the significance of these compensation measures. The maximum estimated net loss to ALR bull trout production from spawning stream losses, when recruitment from outside the dam unit is also considered (the approach utilized in Tables 4-6), is therefore approximately 770 (low: 441; high: 1,070) spawners and 19,300 (low: 9,820; high: 28,700) bull trout juveniles (less if pre-impoundment fluvial populations are accounted for). Note that even the maximum estimated losses in this analysis are substantially less than the 4,000 adult bull trout compensation target of the defunct hatchery program (Sebastian et al. 2000). This difference may suggest a reason for the very minor drop in bull trout catch rate, other than changes in angler behaviour or capture efficiency, during and after the construction of the Revelstoke Dam in the 1980s (from 0.067 fish/hr 1976-1979 to 0.051 fish/hr 1980-1989 and 0.059 fish/hr 1990-1997; Sebastian et al. 2000).

In the second approach, bull trout production changes are considered for populations within dam unit C11 only, and populations from dam unit C4 are assessed independently (see section 6.4). Because losses of bull trout tributary rearing habitat were probably negligible (Decker and Hagen 2007), this approach results in a net estimated gain of the 1,180 spawners and 29,700 age-1+ and older juvenile bull trout (Table 3) estimated to be utilizing sections of the Illecillewaet and Halfway Rivers upstream of the breached barriers. This approach also assumes that the fertilized ALR will be have a capacity for bull trout production equal to the pre-impoundment Arrow Lakes.

Net production changes for the formerly interconnected population can also be estimated by considering bull trout population dynamics as integrated over all populations in dam units C4 and C11 as an amalgamated whole. In this approach, the net change in adult rearing environments may be a slight decrease in growth and survival related to the potentially lower suitability of Revelstoke Reservoir relative to the pre-impoundment Arrow Lakes for bull trout production (Moody et al. 2007), although this is probably mitigated in part by increases in growth/survival in Revelstoke Reservoir relative to pre-impoundment adult rearing habitats in the mainstem Columbia River (see Section 6.4). With respect to tributary space for spawning and rearing, because of the breached barriers on the productive Halfway and Illecillewaet systems, estimated net increases of 20,200 age-1+ and older juveniles (low: 16,400; high: 24,300) and 810 spawners (low: 674; high: 935) have occurred. Under this approach, even if growth and survival in Revelstoke Reservoir are lower for bull trout, total bull trout production for the amalgamated dam units is probably no lower than under pre-impoundment conditions.

6.6.2 Impacts on habitat capability for bull trout production in dam unit C11

Latham (2002) suggested that the principal footprint impacts to genetic population structure in the ALR were mostly related to compensation activities, and were the erosion of genetic differentiation in tributaries utilized for broodstock collection and the invasion of below-barrier genotypes above the Halfway River barrier. Among remaining populations of the 'northern' lineage of ALR bull trout north of MacDonald Creek (see Section 4.1), conservation status appears secure (Table 6). The total annual spawning population exceeds 1,500 individuals (Table 3), distributed among several watersheds, and glacial inputs to the Illecillewaet and Incomappleaux Rivers buffer these systems against temperature increases resulting from forestry activities or climate change. In contrast, among 'southern' populations (MacDonald Creek and south), the number of adults spawning annually is probably less than the 1,000 adult guideline of USFWS (2002). Habitats are probably also highly vulnerable to temperature changes resulting from habitat degradation, as indicated by the domination of the lower reaches of these streams, which are only 1-3ºC warmer than bull trout rearing areas, by rainbow trout (Decker and Hagen 2007). Changes in the status of the southern populations, however, are unlikely to be footprint-related.

6.6.4 Fisheries impacts in dam unit C11

Angling for bull trout in the ALR is renowned, and bull trout have long been a targeted species (Westslope Fisheries 2001). Effort (approximately 16,000 rod hours) and catch rates (approximately 0.06 bull trout/hour) appear to have been relatively stable in bull trout-directed fisheries since the 1970s, when the collection of fishery statistics was initiated, although a greater fluctuation in estimated catch rate was evident during and following construction of the Revelstoke Dam in the 1980s (Arndt 2004). Catch estimates from the period following fertilization indicate a near doubling of catch and effort (to >30,000 angler hours) and an increase of catch rate to 0.08 bull trout/hour up to 2002 (Arndt 2004). Over the 1998-2002 period, catch records can be compared to those for bull trout-directed fisheries in Kootenay Lake (Andrusak 2007). Catch statistics for the ALR compare favourably to those indicated by the KLRT questionnaire, where approximately 30,000 hours of angler effort were directed at bull trout and annual catch rates ranged from 0.06-0.08 bull trout/hour. With respect to the sport fishery, therefore, these observations support the notion that reservoir fertilization can be a successful measure for increasing bull trout production.

6.7 Dam unit C8 – Whatshan River

6.7.1 Description

The Whatshan Dam is a 12 m high by 104 m long structure constructed in 1957 on the Whatshan River, downstream of the original outlet of Whatshan Lake (Figure 1). Post-impoundment Whatshan Reservoir is 17 km long, and is subjected to drawdowns of approximately 4-6 m per year (Hirst 1991; Ahrens and Korman 2004).

Populations of bull trout, kokanee, and rainbow trout in the Whatshan system are currently supported by natural production. Kokanee and rainbow trout were stocked in Whatshan Lake, which is not accessible from the Arrow Lakes Reservoir, prior to impoundment (Hirst 1991). No record exists of bull trout stocking, and genetic analysis by Latham (2002) suggested that the Whatshan population was highly unique.

6.7.2 Impacts on habitat capability for bull trout production in dam unit C8

Given the southern location of the reservoir and presence of rainbow trout, it is highly likely that bull trout spawning and rearing areas in the upper Whatshan River were not inundated as a result of dam construction. Bull trout do well in reservoirs, and the introduction of kokanee, if they were not present before, has probably enhanced the capability of the lacustrine environment for bull trout production. Post-impoundment sampling suggests a high proportion of sport fish (Ahrens and Korman 2004). Although pre- and post-impoundment data are not available for direct comparison, the creation of this reservoir may not have had a substantial negative impact on the bull trout population.

6.7.3 Impacts on bull trout conservation status in dam unit C8

It is also probable that the Whatshan Lake population does not meet abundance criteria established by the USFWS (2002), even if current population levels are stable. Although footprint impacts to the productive capacity of the system may not be significant, it is important to establish some basis for evaluating the conservation status of this genetically unique population of high conservation value (Latham 2002). At least one survey of adult abundance, using redd counts as a methodology, and an evaluation of maximum temperature based on at least one year's monitoring, relative to established thresholds, are therefore warranted.

6.7.4 Fisheries impacts in dam unit C8

Recreational angling in Whatshan Lake prior to impoundment had been described as excellent (Hirst 1991). Evaluation of post-impoundment conditions does not appear to have occurred.

6.8 Dam unit C9 – Keenleyside to US border

6.8.1 Description

This 68 km reach (Thorley 2008) remains one of the last free-flowing sections of the Columbia River mainstem. The Columbia below the Arrow Lakes Reservoir (Figure 1) is a huge, clear water system that is subject to substantial water level fluctuations related to power generation and water releases at the Keenleyside Dam, as well as at dams along the lower Kootenay and Pend d'Oreille rivers (dam units K9-K10, C10, respectively), which also join the Columbia system in this reach (Hirst 1991).

Bull trout, are currently present in low numbers in the mainstem Columbia below the Keenleyside Dam (Westslope fisheries 2001), and have declined in abundance since dam construction (Andrusak and Martin 1982; Hildebrand 1991, as cited in McPhail and Baxter 1996). It is unknown whether these fish have exclusively been entrained from the ALR, or whether some are progeny of a self-supporting population that exists in the reach. Bull trout do not appear to be present in Lake Roosevelt reservoir (Baldwin et al. 1998), and access to tributary reaches in the lower Kootenay and Pend d'Oreille Rivers has been permanently cut off by construction of the Brilliant and Waneta dams, respectively.

Three individuals of 450 mm or more captured in upper Blueberry Creek in 2000 suggest that a self-supporting population remains in the reach. Until recently remedied, migration obstacles associated with linear developments in the lower reach of this stream have been assumed to be impassable by mid-summer (S. Arndt, CBFWP Nelson, pers. comm. 2008). The sampled fish may therefore be recent colonizers, or indicate that a remnant population exists that had either been able to adapt to these conditions, or sustain itself over a period of cut off access by adapting to a resident life history.

6.8.2 Impacts on habitat capability for bull trout production in dam unit C9

Prior to dam construction, a number of bull trout populations probably made extensive use of the Columbia River mainstem for subadult and adult rearing as well as migration. These probably include a fluvial population now isolated in the Salmo River, bull trout destined for Lemon Creek and Koch Creek in the Slocan River system (Westslope Fisheries 2001), and ALR populations. Pre-impoundment captures of exceptionally large bull trout have been reported (to 13 kg; Westslope Fisheries 2001). Although large bull trout, likely entrained through Keenleyside Dam, are still captured (a 13.2 kg individual was captured below the dam in 2000; Westslope Fisheries 2001), it appears likely that dam construction on the Columbia River and its major tributaries have permanently isolated dam unit C9 from all major natal streams. The 68 km of the reach should therefore be considered lost productivity (Table 4). Production of juveniles from Blueberry Creek, even if confirmed, will be inadequate to mitigate losses of spawning and rearing habitats cut off by dam construction.

6.8.3 Impacts on bull trout conservation status in dam unit C9

The intensive fragmentation of this portion of the upper Columbia Basin has reduced the viability of small bull trout populations now isolated above the dams on the lower Kootenay and Pend d'Oreille rivers. These populations are now restricted to reaches in the Salmo and Slocan rivers that are probably marginal for bull trout production because of high summer temperatures, and they should be considered of significant conservation concern (see C10, K9).

The Blueberry Creek population is of serious conservation concern. This remnant population may have been bottlenecked through very low abundances if access was indeed interrupted and the population sustained only through residualization in upper Blueberry Creek. Current population sizes may be approaching or below thresholds where inbreeding depression is a concern, and the isolation of reach C9 has nearly cut off demographic and genetic support from other populations. A study to further evaluate the conservation status of this population should be undertaken as soon as possible.

6.8.4 Fisheries impacts in dam unit C9

A popular sport fishery exists along the mainstem Columbia River in dam unit C9. While sportfish abundance generally appears to be increasing in the reach (Ahrens and Korman 2004), bull trout catches have declined presumably because of the fragmentation of migration routes that has left the population isolated and supported only by entrainment.

6.9 Dam unit C10 – Pend d'Oreille

6.9.1 Description

Seven Mile Dam (BC Hydro; 1979), a 79 m high, 348 m long concrete structure, and Waneta Dam (Teck Cominco; 1954), 76 m high by 290 m concrete and earth fill dam, are run-of-river facilities that are the last in a series of dams on the Pend d'Oreille River (Figure 1). Only a 2 km section of unimpounded mainstem remains in Canada below the tailrace of the Seven Mile Dam (Hirst 1991). Prior to the construction of the dams, bull trout and rainbow trout were present in the system, but currently non-sport fish dominate catches. Bull trout are no longer captured in reservoir sampling and appear to have been excluded from these environments, probably because of an isothermal temperature profile that exceeds 20ºC in summer (Hirst 1991), although it should be noted that at a cooler, deepwater pocket was identified in 2007 sampling (A. Prince, Westslope Fisheries, pers. comm. 2008). Elevated levels of heavy metals in the reservoirs have also been reported (Hirst 1991).

Bull trout in dam unit C10 are isolated within the Salmo River system, the only substantial tributary to Seven Mile Reservoir. Telemetry studies conducted in the late 1990s confirmed that Salmo River bull trout have a fluvial life history, and do not typically enter the reservoir (J. S. Baxter, FWCP Nelson, pers. comm.). It appears that coldwater tributaries to the mainstem Salmo utilized for spawning and rearing also provide coldwater refuge for adult and subadult bull trout when temperatures in the mainstem reach 15ºC or more.

Recognizing that the small size and isolation of the bull trout population in the Salmo River makes it of conservation concern, BC Hydro has funded redd counts in the system since 1998 to monitor abundance (Baxter 2008). A controlled stream fertilization experiment, with the goal of boosting juvenile production, is also underway on Sheep Creek, an important bull trout spawning and rearing tributary (S. Decker and Associates, Kamloops BC, data on file 2008).

6.9.2 Impacts on habitat capability for bull trout production in dam unit C10

The construction of Teck Cominco's Waneta Dam eliminated 7.5 km of fluvial habitats that were available to subadult and adult Salmo River bull trout, and BC Hydro's Seven Mile dam eliminated a further 10 km (Table 4; Hirst 1991). These dams permanently isolated the population from 68 km of suitable riverine habitats in the Canadian portion of the mainstem Columbia River. The productivity of remaining habitats along the mainstem Salmo River are probably a small fraction of pre-impoundment conditions. Year-round access to cold water, adult rearing habitat and an abundant prey fish base is no longer available. Mountain whitefish, a typical prey fish base for bull trout populations when kokanee or anadromous Pacific salmon are not available, are found only in very low abundance in the Salmo system (Hagen and Baxter 2008), and the Salmo River may even be space-limited given the small size of the system and requirements of these large fish for cold temperature holding water of suitable depth and cover. In recent years, average daily temperatures in the mainstem of the Salmo River have exceeded the 15ºC threshold for adult bull trout preference for most of the summer (A. Prince, Westslope Fisheries, pers. comm. 2008). Low capacity of the system for adult bull production is suggested by the 2007 estimate of spawner density of 1.0 bull trout per km (accessible lengths of spawning tributaries only; derived from Baxter 2008), which compares to the ALR average of 12.6/km for adfluvial fish and the maximum upper Columbia Basin density of 36/km for the Wigwam River population utilizing lake Koocanusa (Section 3.2).

Footprint impacts to juvenile rearing are negligible, as this takes place well above the reservoir level. Abundance and growth of juvenile bull trout in Sheep Creek appear to have increased since the beginning of fertilization (S. Decker and Associates, Kamloops, data on file 2008), suggesting that the stream is now more productive for juvenile bull trout. Although summary data with which to quantify this increase are not yet available, it will be a small proportion of the huge productivity losses in the fluvial portion of the Salmo River bull trout life cycle. Furthermore, if adult rearing environments are currently limiting the population, increasing juvenile production may not result in substantial benefits. Continued monitoring of population status, in terms of adult population size, should be therefore be a top management priority.

6.9.3 Impacts on bull trout conservation status in dam unit C10

The Salmo River bull trout population is of serious conservation concern, which is directly a result of the construction of the Waneta and Seven Mile dams on the Pend d'Oreille River and dams upstream in the US. Currently none of the USFWS (2002) conservation status criteria (see Section 5.2) are being met in the watershed. No connectivity exists with other lower Columbia River populations, and basin-wide population estimates, derived from redd counts, suggest negative population growth (Figure 3), despite introduction of a no-harvest angling regulation in 1999. Total population sizes for 2006 and 2007 were estimated to be less than 100 adults (Baxter 2008), indicating a risk of inbreeding depression and the need for continued monitoring. The need for immediate conservation measures will be apparent if declines continue. Population declines are even more dramatic in areas outside Sheep Creek, indicating that a reduction of the species distribution among spawning tributaries may be immanent.

6.9.4 Fisheries impacts in dam unit C10

The bull trout fishery in the Salmo River has been permanently closed because of conservation concerns.

6.10 Kootenay River dam unit K1 – Headwaters to Wardner

6.10.1 Description

This unregulated reach of the Kootenay River originates in pristine Kootenay National Park and extends to Koocanusa Reservoir (Figure 1). Radio telemetry has indicated that most bull trout utilizing tributaries to this reach exhibit a fluvial life history, and do not migrate to Koocanusa Reservoir (Westover and Heidt 2004). Seven bull trout populations have been identified, which are populations utilizing Verdant Creek, the Palliser River, the White River, Findlay Creek, Skookumchuck Creek, and the Lussier and St. Mary rivers (Westover and Heidt 2004).

6.10.2 Impacts on habitat capability for bull trout production in dam unit K1

Because this reach is above the full pool elevation of Koocanusa Reservoir, and most populations do not make significant use of the reservoir, productivity losses resulting from the construction of the Libby Dam are unlikely to have occurred. In contrast, the seasonal availability of kokanee, which appears to affect bull trout distribution in late summer and fall (Westover and Heidt 2004), has probably had a significant positive effect on the productivity of the upper Kootenay watershed for bull trout. Nutrient enrichment due to decaying spawner carcasses is potentially also of benefit to fish populations of dam unit K1.

6.10.3 Impacts on bull trout conservation status in dam unit K1

The conservation status of bull trout in dam unit K1 is secure, as measured against normal criteria (Section 5.2), and has probably not been significantly affected by the construction of the Libby, Aberfeldie, and Elko dams. Each of these dams was built adjacent to an existing migration barrier, and therefore connectivity within the entire upper Kootenay watershed has not changed relative to pre-impoundment conditions. A high level of genetic diversity exists within fluvial bull trout populations of dam unit K1, with individual populations being well-differentiated from each other and from populations utilizing Koocanusa Reservoir (Taylor et al. 1999; Costello et al. 2003), suggesting footprint impacts to population spatial structure have been small. Population abundance criteria are also easily met, as at least seven individual populations have been identified and total abundance is probably much greater than 1,000 spawners annually (Westover and Heidt 2004).

6.10.4 Fisheries impacts in dam unit K1

Hundreds of kilometers of excellent river angling potential exist for bull trout, which have reached sizes of up to 895 mm in the upper Kootenay River (Westover and Heidt 2004). Angling quality varies seasonally, and is best prior to and following the high, turbid water conditions of spring and summer. The BC Ministry of Environment has recognized the high recreation value of stream fishing for bull trout in the upper Kootenay system, and the fishery is managed intensively to provide a wide range of angling experiences while ensuring conservation needs are met. This area is unique within BC management jurisdictions in that population status in the most important spawning tributaries (White River, Skookumchuck Creek in reach K1) is monitored regularly using a calibrated redd count methodology (Westover and Heidt 2004).

Negative footprint impacts to the upper Kootenay bull trout fishery are probably insignificant, and there may even be a net positive influence, to the degree that the presence of kokanee from Koocanusa Reservoir enhances the productivity of the reach for bull trout.

6.11 Dam units K2, K4 – Bull River (Aberfeldie) and Elk River (Elko)

6.11.1 Description

Both Aberfeldie and Elko dams, which are run-of-river projects now owned by BC Hydro, are built on or adjacent to natural migration barriers, and are discussed together because of similar footprint impact considerations. Aberfeldie Dam, constructed in 1922, is 27 m high and 134 m long, and impounds approximately 3 km of the upper Bull River (Figure 1). Elko Dam, constructed in 1924, is 10 m high and 66 m long, and impounds approximately a kilometer of the Elk River above its falls (Hirst 1991; Thorley 2008). Historically isolated fluvial bull trout populations utilize both the Bull and Elk rivers above their barriers. Substantial numbers of fluvial bull trout from the upper Kootenay River utilize the lower Bull River in the summer and fall, even though it does not appear to be utilized as a spawning and rearing stream (Baxter and Hagen 2002; Westover and Heidt 2004). Adult bull trout not spawning in that year have spent extended periods of time in the lower Bull River, from July through to late-October. It is likely that the lower Bull provides a coldwater refuge in summer, when temperatures in the mainstem of the Kootenay can exceed the 15ºC threshold of preference for bull trout, and a substantial population of spawning kokanee (R.L. and L. 1997) provides a prey fish base for fluvial bull trout rearing between August and late-October.

The lower Elk River is likely not an important spawning and rearing stream for bull trout, given its size and proximity to the reservoir, but very large numbers of bull trout pass through the lower Elk River en route to the Wigwam River, the primary spawning tributary for adfluvial Koocanusa Reservoir fish (Westover and Heidt 2004).

6.11.2 Impacts on habitat capability for bull trout production in dam units K2 and K4

Use of the respective 3 km and 1 km head ponds of the Aberfeldie and Elko dams has not been documented, although fish surveys that have occurred may have been inadequate to assess this properly (R. L. and L. 1997). Bull trout use of such head ponds has been observed in northern BC (D. Bustard and Associates, Smithers, pers. comm. 2007), so it is not clear whether these lost fluvial habitats represent lost productive capacity for bull trout populations. Sampling adequate to assess the presence of bull trout in the head ponds and in adjacent stream habitats is required before production losses can be quantified. Note that if density-dependent regulation of the Bull and Elk River bull trout populations occurs primarily in spawning tributaries, then such minor losses of stream habitats would be unlikely to have a significant effect on the overall population dynamics. Entrainment mortalities at the facilities are not likely to result in impacts to either above- or below-barrier bull trout populations, as genetic studies of strongly-differentiated populations above and below barriers have suggested that the successful recruitment of 'fallers' into below-barrier migratory populations is unlikely (Latham 2002; Costello et al. 2003).

Based on the large size of these stream reaches, it is unlikely that head ponds have inundated significant juvenile bull trout rearing areas. Aberfeldie and Elko dams have limited storage capacity and maximum diversion rates are 7.4 and 25 m^3/s, respectively. With respect to rearing habitats below the dams, which are utilized seasonally by fluvial and adfluvial bull trout, Hirst (1991) suggested that dam operations would have only minor effects on the natural hydrograph.

6.11.3 Impacts on bull trout conservation status in dam units K2 and K4

Dam construction has probably had only minor impacts on conservation status, if any, given that the dams were built on natural migration barriers and impacts on the systems' productive capacity are likely to have been small. Bull trout populations utilizing the lower Bull and Elk Rivers belong to populations of secure conservation status (Sections 6.10, 6.12). Above-barrier bull trout populations are genetically unique and of high conservation value (Costello et al. 2003), but sufficient information to assess their status does not exist.

6.11.4 Fisheries impacts in dam units K2 and K4

Both the Bull and Elk rivers are famed for their angling opportunities, particularly for native westslope cutthroat trout. The 3 km head pond of the Aberfeldie Dam is avoided by anglers traveling to the upper Bull River, and should be considered a fishery loss given that stream angling opportunities are in high demand in southeastern BC. The 1-km section of the Elk River inundated by the Elko Dam was considered inaccessible to anglers by Hirst (1991).

6.12 Dam unit K3 – Wardner to US border

6.12.1 Description

At full pool elevation Koocanusa Reservoir, created by the Libby Dam in Montana (completed in 1972 by the US Army Corps of Engineers and operated by the Bonneville Power Administration), extends 70 km into BC to Wardner (Thorley 2008; Figure 1), a section of river that was known for its excellent fishing potential prior to impoundment (Maher 1961).

Bull trout populations utilizing Gold Creek (Cope and Morris 2005), the Wigwam River (Oliver 1979), and other tributaries to Koocanusa Reservoir would have utilized the pre-impoundment Kootenay River, and have now adapted to an adfluvial life history. Kokanee salmon, an important prey fish for bull trout, were introduced inadvertently into Koocanusa Reservoir in the late 1970s from the Kootenay Trout Hatchery at Wardner, and substantial populations now utilize the Canadian tributaries to the upper Kootenay River for spawning (Arndt 2008).

6.12.2 Impacts on habitat capability for bull trout production in dam unit K3

Habitat losses for the subadult and adult life stages of formerly fluvial bull trout populations include the 70 km of the Kootenay River mainstem that were inundated as well as 15 km of medium-sized rivers including the lower Elk River (Thorley 2008). It appears highly likely that Koocanusa Reservoir currently is a more productive environment for bull trout than was the pre-impoundment Kootenay River. Redd density along the Wigwam River, which has been identified as the principal spawning tributary during radio telemetry studies and adult enumeration studies using kelt counting fences, has grown steadily since counts began (Oliver

1979; Westover and Conroy 1997; Westover and Heidt 2004; Cope and Morris 2005), and now exceeds those estimated for all other bull trout spawning tributaries in the Kootenay Region. Increases in growth and survival of bull trout relative to pre-impoundment conditions have probably been mediated in part by the establishment of kokanee salmon in the reservoir, as described in Section 3.2. As mentioned, bull trout spawners captured in 1996 in the Wigwam River were more abundant and 140 mm longer on average than those captured in 1978, when kokanee were not yet established in Koocanusa Reservoir (Westover and Conroy 1997). The introduction of more restrictive harvest regulations in both Canada and the United States in the 1990s may also have played a role (B. Westover, BC Ministry of Environment, Lands, and Parks, pers. comm. 2002).

Important bull trout spawning and juvenile rearing areas are not located adjacent to Koocanusa Reservoir (Westover and Conroy 1997; Baxter and Hagen 2002; Cope and Morris 2005), suggesting that impoundment due to the Libby Dam did not result in losses of tributary rearing production for bull trout.

6.12.3 Impacts on bull trout conservation status in dam unit K3

Although well differentiated genetically from fluvial bull trout utilizing the Kootenay River mainstem above Wardner, most populations closely associated with Koocanusa Reservoir are not significantly differentiated from each other (Costello et al. 2003). These observations may indicate a loss of genetic diversity associated with impoundment (see Section 4.3 for a discussion).

Notwithstanding potential genetic impacts, the conservation status of bull trout utilizing Lake Koocanusa appears to be secure based on demographic criteria (USFWS 2002). A number of interconnected sub-populations exist, both within the Wigwam system and at other locations (Cope and Morris 2005; Costello et al. 2003), population growth remains strongly positive as indicated by redd counts in the Wigwam River and tributaries, and total abundance is greatly in excess of 1,000 individuals within the Wigwam system alone (Westover and Heidt 2004).

6.12.4 Fisheries impacts in dam unit K3

The fishing potential of the lower Elk and Kootenay Rivers was considered to be excellent prior to impoundment (Maher 1961). As indicated by a rapidly growing river fishery for bull trout in the upper Kootenay watershed (Westover and Heidt 2004), the loss of 75 km of stream angling opportunities is significant. However, a major focus for anglers currently is the growing population of bull trout ascending the lower Elk and Wigwam Rivers, destined for spawning areas above the Wigwam's entrenched lower section. For some anglers, increases in the body size and abundance of these fish due to their post-impoundment adfluvial life history probably mitigate to some degree the loss of space available for river angling. Fishing opportunities in the Canadian portion of Koocanusa Reservoir do not adequately mitigate lost river angling, as they are limited by reservoir elevation to a three-month fishing season in the summer. Bull trout catches during this period in the Canadian section of the reservoir were negligible, as observed by Hartman and Martin (1987).

6.13 Dam unit K5 – US border to Kootenay Lake

6.13.1 Description

This section of the Kootenay River is now regulated by the Libby Dam, and is characterized by low gradient, silt substrate, abundant macrophyte vegetation, and frequent channelization between dykes (Ahrens and Korman 2004). Bull trout tagged in other tributaries to Kootenay Lake have utilized the reach seasonally (O'Brien 2001), and seasonal use by bull trout has also been reported for the Goat River, the major Canadian tributary. Adfluvial or fluvial bull trout populations are likely to utilize coldwater tributaries of this dam unit for spawning and rearing, but this has not been established.

6.13.2 Impacts on habitat capability for bull trout production in dam unit K5

A severe lack of pre- and post-impoundment fisheries data for the mainstem Kootenay River in this reach (Ahrens and Korman 2004) makes estimation of footprint impacts highly speculative. Although seasonal use of the reach by bull trout has been observed, seasonal temperature increases due Koocanusa Reservoir have probably reduced its productivity for subadult and adult bull trout rearing, especially for fluvial populations (if they existed) that would now require a coldwater refuge during summer.

The Kootenay River mainstem in this reach was highly unlikely to provide spawning and juvenile rearing habitats for bull trout even under pre-impoundment conditions, given its large size and unsuitable temperature regime.

6.13.3 Impacts on bull trout conservation status in dam unit K5

Habitats in this reach of the Kootenay River are likely not particularly important to bull trout populations originating in other tributaries to Kootenay Lake, given the availability of lacustrine habitat in the lake and coldwater stream environments in the Lardeau and lower Duncan Rivers. Populations in reach K5 exhibiting a fluvial life history may be threatened by warm temperatures in the Kootenay mainstem, and ultimately reduced to remnant, stream resident populations, but the pre-impoundment existence of such populations has not been established.

6.13.4 Fisheries impacts in dam unit K5

Whether or not a targeted bull trout fishery on this reach of the Kootenay River existed, or in the lower Goat River, does not appear to have been recorded. Incidental captures of bull trout are probably now infrequent relative to pre-impoundment conditions unless a healthy adfluvial population(s) still utilizes one or more coldwater tributaries for spawning and rearing. This has not been established.

6.14 Dam unit K6 – Kootenay Lake and tributaries

6.14.1 Description

Kootenay Lake is 107 km long, and 85% of its inflow comes by way of the Duncan, Kootenay, and Lardeau Rivers (Figure 1). Flow through Kootenay Lake is highly regulated, with inputs from the Duncan and Kootenay rivers being regulated by the Duncan and Libby dams, respectively, and outflow by Corra Linn Dam on the lower Kootenay River. The construction of the Corra Linn Dam (owned by Fortis BC) in 1939 added 2.5 m of storage to Kootenay Lake (Ahrens and Korman 2004).

Bull trout are an important sportfish species in Kootenay Lake and are targeted specifically by anglers (Andrusak 2007). Despite extensive investigation of the physical limnology and ecology of the lake (Ahrens and Korman 2004), bull trout stock assessment (beyond a mail-in angler questionnaire) and even basic distribution studies have been virtually non-existent.

6.14.2 Impacts on habitat capability for bull trout production in dam unit K6

Productivity changes in Kootenay Lake have been the subject of a large number of studies (Ashley et al. 1999; Moody et al. 1997; Arndt 2008). Of much relevance to bull trout was the well-documented decline of kokanee stocks in the 1980s, resulting from oligotrophication of Kootenay Lake following closure of an upstream fertilizer plant, and construction of the Duncan and Libby dams and nutrient retention in their reservoirs. The introduction of mysids into Kootenay Lake has also likely had a negative effect on kokanee abundance. As discussed in section 3.2, it is likely that this directly affected bull trout growth and survival in the lake, although stock assessment data are not available to confirm this. Fertilization of Kootenay Lake, which began in 1992 on an experimental basis, by 1998 appeared to have increased kokanee abundance to levels comparable to peak abundance in the 1970s (Arndt 2008). Angler questionnaire results for Kootenay Lake support the notion that this increase in lake productivity has resulted in increased productivity for bull trout as well. Catch-per-effort data for anglers targeting bull trout averaged <0.04 bull trout/hr in the early 1990s, based on questionnaire returns, but had increased to approximately 0.06/hr in the late 1990s following the start of fertilization. A steady increase in catch-per-effort began after 2001, up to a high of 0.10/hr in 2005, the last year analyzed by Andrusak (2007).

Losses of bull trout spawning and rearing habitats in Kootenay Lake tributaries have not occurred in dam unit K6 (upper and lower Duncan River reaches K7 and K8 are treated in Sections 6.15 and 6.16, respectively). The breaching of a concrete weir on the Kaslo River in the 1980s (H. Andrusak, Redfish Consulting, Nelson, pers. comm. 2006), which made accessible approximately 30 km of particularly high quality spawning and rearing habitat, was highly significant as a mitigation measure for lost spawning and rearing habitats in the Duncan system. Approximately 1,170 adult bull trout spawners returned to the Kaslo in 2007, based on a count of 585 redds above the obstruction (G. Andrusak, Redfish Consulting, Nelson, pers. comm. 2008) and the simple 2:1 expansion of redd counts used in this report to estimate population size.

6.14.3 Impacts on bull trout conservation status in dam unit K6

Although bull trout production has probably been affected by the oligotrophication of Kootenay Lake, and subsequent restoration efforts, productivity changes have probably not greatly affected the conservation status of the dam unit's bull trout populations (with the possible exception of upper Duncan, dam unit K7 – see Section 6.15). Because natural barriers existed on the lower Kootenay River at Bonnington falls and at the present location of the Libby Dam in Montana, and because adult and juvenile bull trout can successfully pass through the Duncan Dam, connectivity has not been significantly altered relative to pre-impoundment conditions. Recent catch-per-effort trends are positive (Andrusak 2007), multiple sub-populations exist, and total abundance among populations is probably much greater than 1000 spawners annually, suggesting current conservation status for bull trout in dam unit K6 is secure.

6.14.4 Fisheries impacts in dam unit K6

The pre-impoundment creel survey of Sparrow (1962), based on angler interviews, indicated a mean catch-per-effort of 0.030 bull trout/hr. Estimated in a comparable manner (total bull trout catch/total effort directed at all species), mean catch-per-effort over the period from 2003-2005 is 0.041/hr based on questionnaire returns (derived from Andrusak 2007). Although the potential for positive bias in questionnaire-based inferences has been suggested (Andrusak 2007), the favourable comparison with historical data supports the notion that footprint impacts on the Kootenay Lake bull trout fishery are being adequately mitigated at present.

6.15 Dam unit K7 – upper Duncan River and Reservoir

6.15.1 Description

The Duncan Dam (BC Hydro) is a 40 m high and 792 m long earth-filled structure located 10 km upstream of Kootenay Lake (Figure 1), and was built in 1967 for water storage purposes only. Annual drawdowns are 25-27 m. Flooding due to the Duncan Dam inundated 46 kilometers of the upper Duncan River (Thorley 2008).

Discharge at the Duncan Dam is operated such that migrating bull trout accumulating at the base of one of the discharge tunnels, through which a minimum 3 m^3/s fish attracting flow is maintained, are allowed to swim through the dam into Duncan Lake on a bi-weekly basis (O'Brien 1999). An unusual situation exists within the upper Duncan, therefore, in that adfluvial bull trout from both Kootenay Lake and Duncan Lake utilize the upper Duncan River and its tributaries for spawning and rearing. Resident bull trout are also present above migration barriers (O'Brien 2001). It has not been established whether a fluvial bull trout population was present in the pre-impoundment upper Duncan River.

6.15.2 Impacts on habitat capability for bull trout production in dam unit K7

A productivity change in Duncan Reservoir relative to pre-impoundment conditions was estimated to have been negligible in the analysis of Moody et al. (2007). Based on anecdotal reports of anglers, pre-impoundment Duncan Lake contained a relatively small population of bull trout (Maher 1961; Hirst 1991). Currently, fishing is reported to be good seasonally (J. Burrows, MOE Nelson, pers. comm. 2006), and substantial populations of Duncan Reservoir fish are thought to spawn in tributaries of the upper Duncan system (O'Brien 1999).

Although it is unknown whether the 46 km of the upper Duncan River that was inundated (Thorley 2008) was utilized year-round by a fluvial population, sub-adult use and seasonal adult use of the upper Duncan River almost certainly occurred, given the suitable water temperature regime (cold) and adequate size of the stream for these life stages.

Tributaries to the upper Duncan system have varying degrees of glacial influence, and inundated lower reaches of medium-sized tributaries were therefore likely to have been utilized for spawning and rearing. Losses of tributary habitats of 7% gradient or less and stream order 4-6 total 8.9 km (J. Thorley, Poisson Ecological Consultants, data on file 2008), which equates to estimates of lost production of 110 bull trout spawners (low: 94; high: 130) and 2,800 age-1+ and older juvenile bull trout (low: 2,280; high: 3,370) based on biostandards of section 5.1. Because connectivity remains with Kootenay Lake, bull trout production gains resulting from the breaching of a concrete dam on the Kaslo River, which were estimated in Section 6.17 to be approximately 1,170 spawners annually, should be considered mitigation for tributary losses in the upper Duncan system.

A substantial population of bull trout remains in Duncan Reservoir, but quantitative data do not exist for comparison with pre-impoundment conditions. Kootenay Lake migrants (O'Brien 1999) into the upper Duncan system are larger, but this is probably not a sufficient basis for comparing the two systems' habitat quality. Good recent angling success in Duncan Reservoir may indicate merely a shift in the life history of upper Duncan fish from utilizing lacustrine habitats in Kootenay Lake to utilizing Duncan Reservoir, resulting from the erosion of fitness benefits to Kootenay Lake migrants caused by the necessity of migrating through the Duncan Dam.

6.15.3 Impacts on bull trout conservation status in dam unit K7

Recent analysis has indicated that little genetic population subdivision occurs among bull trout populations in accessible tributaries to the upper Duncan system. This is in contrast to results from other studies of population spatial structure in bull trout, with the exception of results for tributaries to Koocanusa Reservoir, and may indicate a significant impact of dam construction on these populations. The partial obstruction posed to juvenile and adult Kootenay Lake migrants, and fitness consequences relative to fish utilizing Duncan Reservoir, is a potential mechanism for this homogenization (see section 4.3). Under this scenario Kootenay genotypes in areas they formerly dominated are less able to resist invasion of Duncan genotypes, because of reduced productivity of this strategy in the migrant life stage.

According to USFWS (2002) demographic criteria alone, upper Duncan bull trout on the whole are probably of relatively secure conservation status, as the system is not isolated from future demographic and genetic support from other Kootenay Lake populations. Even within the upper Duncan system, multiple, interconnected populations exist and the number of adults spawning annually is probably substantial (O'Brien 1999).

6.15.4 Fisheries impacts in dam unit K7

As mentioned, recent anecdotal reports suggest that fishing can be good seasonally in Duncan Reservoir. The larger size of the reservoir relative to pre-impoundment conditions was anticipated to have a clearing effect, and potentially increase suitability for angling (Maher 1961). For the significance of the loss of 46 km of river angling opportunities to be evaluated, the potential for a quality recreational fishery on the upper Duncan River needs to be assessed. This is because the upper Duncan River is a glacial stream and relatively turbid during times of peak bull trout abundance.

6.16 Dam unit K8 – lower Duncan River and tributaries

6.16.1 Description

Flows in the lower Duncan River are regulated to a large extent by the Duncan Dam, although the Lardeau River, which joins the Duncan River just below the dam (Figure 1), contributes approximately 37% of the total Duncan flow into Kootenay Lake and is unregulated (Ahrens and Korman 2004). Water is released from the Duncan Dam at a depth 35 m below full pool, which acts to maintain cool water temperatures downstream in the lower Duncan River, but releases are highly erratic and typically at their highest in December and January, the opposite of the unregulated hydrograph (Hirst 1991). This is probably of considerable significance to Kootenay Lake limnology, and represents a substantial impact on fish populations utilizing the lower Duncan River for spawning and rearing. Flow regulation has also resulted in narrowing of the lower Duncan River channel, reduction in substrate size, and blocking or reduction of flow to side channel habitats important for juvenile salmonid rearing (M. Miles and Associates 2002; Hagen and Decker 2007).

Fish population studies in the reach have been relatively extensive. Large numbers of adult and subadult bull trout utilize the lower Duncan River. Adfluvial spawners are present primarily from April through August, and fish that are not going to spawn in that year utilize the lower Duncan River for feeding on abundant kokanee spawners from August to November (Olmsted and den Biesen 1998; O'Brien 1999; Hagen et al. 2007). Extensive spawning and feeding migrations into the Lardeau River system occur in summer and fall as well (personal observations during field studies for Decker and Hagen 2008).

6.16.2 Impacts on habitat capability for bull trout production in dam unit K8

Although the lower reaches of tributaries to the Lardeau and lower Duncan Rivers are utilized by bull trout for spawning and juvenile rearing, it does not appear to take place along the mainstems of either stream (Hagen and Decker 2007; Decker and Hagen 2008). It appears, therefore, that construction of the Duncan Dam has not impacted the productive capacity of dam unit K8 for this life stage.

The Lardeau and lower Duncan Rivers provide a highly significant adult and subadult feeding and rearing environment, however. Because the effects of the operation of the Duncan Dam are not footprint impacts, and are beyond the scope of this report, the importance of the reach for bull trout production should be acknowledged during Water Use Planning (WUP) studies.

6.16.3 Impacts on bull trout conservation status in dam unit K8

Although distribution and stock assessment data are not available, it is likely that tributaries to the lower Duncan and Lardeau rivers make a substantial contribution to overall bull trout production in the Kootenay Lake watershed. The conservation status of this group of populations is probably secure and has not been impacted by dam construction, as connectivity has not been interrupted. The total abundance of spawners annually is likely to be very high, more than five populations are suspected, and glacial inputs to tributary habitats ensure they are buffered against temperature increases resulting from forestry and climate change.

6.16.4 Fisheries impacts in dam unit K8

The Lardeau and lower Duncan rivers are currently closed year round for fishing for bull trout. This may have been a protective measure following dam construction, but the cumulative effect of this closure plus the inundation or isolation of all other mainstem fluvial reaches, due to dam construction, is that accessible, quality river angling opportunities for bull trout do not exist in the West Kootenay region of the province. Given the high demand exhibited for remaining river fisheries in the East Kootenays (Westover and Heidt 2004), the loss of all river fisheries in the West Kootenay represents a significant impact to the region's angling community.

6.17 Dam unit K9 – Corra Linn Dam to Brilliant Dam

6.17.1 Description

Four hydroelectric facilities were constructed on the Kootenay River between Corra Linn Dam (21 m x 518 m, Fortis BC, 1932) and the Slocan River confluence prior to BC Hydro's construction of the Kootenay Canal in 1972: Upper Bonnington (6 m x 330 m, 1908), Lower Bonnington (11 m x 180 m, 1925), and South Slocan (21 m x 552 m, 1928). All four facilities are currently operated by Fortis BC. The construction of Brilliant Dam (39 m x 190 m, Columbia Power Corporation, 1947) was of most significance to fish populations because of its blockage of all fish migration into the Slocan River system (Ahrens and Korman 2004).

Pre-impoundment populations of large bull trout migrated through the lower Kootenay River and into the Slocan system, utilizing Lemon and Koch creeks for spawning and rearing. Since dam construction, bull trout have been reported from the head pond of the Brilliant Dam (Hirst 1991).

6.17.2 Impacts on habitat capability for bull trout production in dam unit K9

Pre-impoundment, fluvial bull trout production in the section of the Kootenay River that existed between the Corra Linn and South Slocan dams was probably not significant, given the steep gradient and presence of a natural migration barrier (Bonnington Falls; Ahrens and Korman 2004). The productivity of populations now isolated in the Slocan system, however, has been greatly reduced by the construction of the Brilliant Dam, which permanently cut off access to productive adult rearing habitats in the mainstem Columbia system. Similar to the situation for Salmo River bull trout in dam unit C10, bull trout survival and growth in the Slocan system have probably deteriorated significantly relative to pre-impoundment conditions – warm summer temperatures greatly exceed bull trout preference thresholds and probably restrict bull trout distribution to cold tributaries and mainstem locations near their mouths. The Brilliant head pond is also unlikely to be suitable for year-round bull trout production to the degree that summer water temperatures exceed 15ºC, suggesting that the approximately 20 km of the lower Kootenay River between Bonnington Falls and the Brilliant Dam should also be considered a loss of bull trout habitat.

Juvenile production is likely to occur only in cold tributaries of the Slocan system, which have not been affected by dam construction.

The 3 km of the lower Kootenay River below the Brilliant Dam is now effectively isolated from upstream spawning and juvenile rearing habitats, and can be considered lost with respect to bull trout production. This reach is continuous with Columbia River reach C9, so refer to Section 6.8 for further discussion of productivity, conservation status, and fishery changes.

6.17.3 Impacts on bull trout conservation status in dam unit K9

The likely marginal productive capacity of the Brilliant head pond and Slocan River relative to widely-distributed pre-impoundment habitats has probably reduced fluvial Slocan River populations to levels where conservation concern is warranted. However, connectivity with suitable lacustrine habitat in Slocan Lake remains, and if Slocan River bull trout can adapt to an adfluvial life history *upstream* of natal rearing tributaries, the likelihood of their future persistence will be significantly increased. Acquiring stock assessment and distribution data from this watershed should be a management priority, in order to assess conservation status and appropriate management actions.

6.17.4 Fisheries impacts in dam unit K9

In recognition of the deteriorated conservation status of Slocan River bull trout, harvest is not permitted. Abundance in any case is probably too low to support a river fishery, a significant loss of opportunity for West Kootenay river anglers, especially considering that bull trout of up to 13 kg in size migrated through the Slocan River prior to impoundment (Westslope Fisheries 2001).

7.0 COMPENSATION FOR IMPACTS ON BULL TROUT POPULATIONS

7.1 Summary of footprint impacts from BC Hydro dams

Losses of spawning and rearing tributary stream reaches (Table 4) were probably restricted to Columbia dam units C3 (Kinbasket Reservoir) and C4 (Revelstoke Reservoir), and Kootenay dam unit K7 (upper Duncan River including Duncan Reservoir), where cold stream environments and juvenile bull trout rearing presently occur down to the level of the reservoir full pool lines. All these tributary habitat losses are therefore within dam units affected by BC Hydro dams. Spawning and rearing tributary losses were most significant in dam unit C3, totalling 142 km equating to estimates of 1,800 adult spawners annually (low: 1,500; high: 2,070) and 44,900 age-1+ and older juvenile bull trout (low: 36,400; high: 53,800). In dam unit C4 estimated bull trout natal stream losses were 29 km equating to 370 spawners annually (low: 305; high: 420) and 9,200 parr (low: 7,440; high: 11,000), while in K7 estimated habitat losses were 8.9 km of stream or 110 spawners annually (low: 99; high: 130) and 2,800 parr (low: 2,280; high: 3,370). An estimated total of 180 km of spawning and rearing stream losses, equating to estimates of lost bull trout production of 2,280 spawners (low: 1,900; high: 2,630) and 56,900 age-1+ and older juveniles (low: 46,200; high: 68,200), therefore resulted from flooding caused by BC Hydro dams in the upper Columbia Basin.

Substantial mitigation for tributary rearing lost due to BC Hydro dams has already occurred within the upper Columbia Basin, as a result of the breaching of migration barriers on the Illecillewaet and Halfway Rivers in dam unit C11 (C5+C7; Arrow Lakes Reservoir) and the Kaslo River in dam unit K6 (Kootenay Lake). Although total stream habitat gains are 60 km for C6 and 30 km for K6, these reaches are substantially more productive than average, and the total number of spawners utilizing them in a year has been empirically estimated at 2,360 (Table 5), which is approximately equivalent to the total lost production from reaches inundated by BC Hydro dams.

Kootenay Lake (K6) and the Arrow Lakes Reservoir (C11) were formerly large, natural lakes, which now receive regulated inflows of reduced nutrient content. It has been assumed in the preceding analyses that the impacts of this flow regulation and nutrient retention have been negative for bull trout, based on declines of kokanee salmon, the primary prey fish base for adfluvial bull trout, following the construction of upstream dams. This is despite the fact that angler interviews for the ALR do not indicate substantial declines in bull trout catch rates. Because fertilization of the ALR and Kootenay Lake appears to have increased kokanee production to peak levels seen prior to declines, it is also assumed that these fertilization programs are adequate mitigation for bull trout production changes in lacustrine environments in these dam units resulting from the construction of upstream dams.

The most significant habitat alteration resulting from the construction of BC Hydro dams in the upper Columbia Basin has been the inundation of 583 km of fluvial adult bull trout habitat in dam units C3, C4, C11, C10 (Pend d'Oreille), K2 (Aberfeldie/Bull River), K4 (Elko/Elk River) and K7, and the severing of access to 48 km of formerly productive fluvial adult habitat in dam units C9 (Keenleyside to US border), C10 (Pend d'Oreille), and K9 (lower Kootenay; Table 4).

Bull trout have adapted well to the reservoirs created by BC Hydro dams in dam units C3 (Kinbasket), C4 (Revelstoke), and K7 (Duncan), despite low estimated primary productivity, and survival and growth in these reservoirs is probably substantially greater than in the river sections they inundated. The Seven Mile Reservoir in dam unit C10, however, does not provide adult rearing, and furthermore cuts off access for Salmo River bull trout to productive adult rearing habitats downstream in the mainstem of the Columbia River. Whatshan Reservoir (dam unit C8) has likely not been greatly affected by dam construction relative to pre-impoundment conditions in Whatshan Lake.

When footprint impacts are integrated over the entire bull trout life cycle for individual dam units, bull trout productive capacity, expressed as the number of adults spawning annually, is probably as high as under pre-impoundment conditions in many cases. Among dam units associated with BC Hydro dams, C1 (upper Columbia), C2 (Spillimacheen), C8 (Whatshan), K1 (upper Kootenay), K2 (Bull River), K4 (Elko), and K8 (lower Duncan/Lardeau) have probably not been subject to significant negative footprint impacts on bull trout production. In dam units C3 (Kinbasket) and C4 (Revelstoke), the substantial tributary losses were mitigated by the introduction of a lacustrine environment and kokanee prey fish base. It is conceivable that the bull trout population in C3 is larger now than under pre-impoundment conditions. The lacustrine environment and kokanee prey fish base in Revelstoke Reservoir, in addition to recruitment from natal streams in C4 that would have utilized dam unit C11 (ALR) prior to dam construction, suggests that the number of adults utilizing the reservoir is probably larger than the number previously utilizing the Columbia River as part of a fluvial life history. However, estimated production of up to 49,000 age-1+ and older juvenile bull trout in tributary streams (low: 39,500; high: 58,400), equating to 1,950 bull trout spawners annually (low: 1,620; high: 2,250), were permanently cut off from the ALR. These losses are mitigated in part by production of 29,700 age-1+ and older juveniles and 1,190 spawners annually above breached barriers on the Illecillewaet and Halfway Rivers, but a shortfall of 770 spawners annually (low: 642; high: 891) or 19,300 juvenile fish (low: 15,700; high: 23,100) remains. Because connectivity between Duncan Reservoir (K7) and Kootenay Lake (K6) remains, production of 1,170 adult bull trout annually from above the breached barrier on the Kaslo River adequately mitigates for the natal stream habitat for 110 bull trout spawners (low: 99; high: 130) inundated by Duncan Reservoir.

Bull trout production (integrated over the whole life cycle) has been most severely impacted (relative to pre-impoundment production) by BC Hydro dams in Columbia dam units C9 (Keenleyside to US border) and C10 (Pend d'Oreille). A total of 53 km of formerly productive mainstem river habitat in Canada is now inundated and unusable or cut off permanently from natal streams in a number of dam units. A remnant population in the Salmo watershed of dam unit C10 is probably a small fraction of its pre-impoundment abundance as a result of dam construction and impoundment of the Pend d'Oreille mainstem, and is of serious conservation concern.

The commitment to fund bull trout work within the FWCP should not be based solely on measurable gains and losses of bull trout individuals or biomass, however. Probably the most serious impact of BC Hydro dam construction in the upper Columbia Basin on bull trout as a species would have been the loss or amalgamation of populations adapted to diverse adult rearing environments, which were homogenized after reservoir filling had occurred. The loss of this genetic and life history diversity is permanent and should be considered highly significant, as provincial legislation identifies that bull trout are to be managed as a species of special conservation concern. In addition to the loss of evolutionary heritage, the ability of the species to adapt to short- and long-term environmental and climatic change has likely been compromised as well. Although changes in fish community structure resulting from impoundment are beyond the scope of this analysis, which is focussed on bull trout populations, the loss of diversity in community structure caused by homogenization of the aquatic environment is also significant. The natural diversity in community structure has intrinsic value to British Columbians, and like ecological and genetic diversity within a species it is probably an important buffer to short- and long-term environmental and climatic change.

7.2 Compensation priorities

The establishment of compensation priorities is dependent on the biological or legal perspective taken. Even if compensation recommendations are focussed based on the nature of losses, fish population losses can be delineated in at least three ways: 1) losses of habitat types specific to particular life history stages, such as area of spawning habitat or length of natal streams utilized by juveniles for rearing; 2) losses to the overall productive capacity of the population, which requires identification of limiting factors; and 3) deterioration in the population's conservation status, or likelihood of long-term persistence. Alternative approaches could have significantly different implications for compensation prescriptions for bull trout in the upper Columbia Basin. Net losses of natal tributary stream habitat, for example, are restricted to dam units C3 (Kinbasket) and C4 (Revelstoke) and an approach emphasizing losses of specific habitat types would prescribe large-scale enhancements in natal streams in these dam units. Net production of bull trout, however, integrated over the entire life cycle, may conceivably be as high or higher in these dam units than under pre-impoundment conditions. An approach emphasizing losses to the overall productive capacity of each dam unit would suggest that compensation activities be focussed on dam units C11 (ALR), C9 (Keenleyside to US border), and C10 (Pend d'Oreille), where net production of bull trout is probably (C11) or certainly (C9, C10) lower. Focussing compensation activities on populations that have been put at risk of extirpation due to BC Hydro dam construction would mean that populations in C9 and C10, where small remnant populations have been permanently isolated, would receive first priority.

The "no net loss" principle, as applied to fish habitats in Canada as part of the habitat management policy of the Department of Fisheries and Oceans, is summarized in Moody et al. (2007). Three categories of habitat compensation are identified, in descending order of preference:

1. The maintenance of natural productive capacity by avoiding loss or degradation of fish habitat.

2. "Like for like" compensation approaches that replace the lost natural habitats at or near the site of impact. If "like for like" compensation is not possible, then preference shifts to off-site compensation increasing the productivity of existing habitats.

3. Compensation by artificial production.

Compensation option 1 above has already been eliminated for all fish populations of the upper Columbia Basin dam units, given that extensive habitat alterations have already taken place. For bull trout, option 3 has already been evaluated as ineffective and a risk to remaining population structure, after a two-decade trial in the Arrow Lakes Reservoir (Winsby and Stone 1996; Sebastian 2000; Arndt 2004), and has been rejected. Given the large-scale losses of habitat associated with many of the upper Columbia Basin dams, off-site compensation (rather than at the site of impact; option 2 above) is probably necessary given the remote location of many impacted habitats, and the fact that compensation options would not exist in many watersheds. Off site compensation would furthermore be more cost-effectively applied close to population centers in the upper Columbia Basin (Moody et al. 2007).

The "no net loss" policy as summarized above is limited by its lack of explicit recognition of 1) limiting factors regulating population size or 2) conservation status of populations in assigning priorities or urgency for compensation. In the case of the former, a consideration of limiting factors, if they have been reliably determined, may ensure that compensation activities are as cost-effective as possible, or even effective at all at increasing the target population (Jones et al. 1996). As an example of the perils of disregarding conservation status, note that relatively small amounts of habitat degradation may threaten a small population near the edge of a species range with extirpation. Little change in the viability or genetic diversity among populations, however, may result from major habitat alterations in core areas, provided that interconnected, abundant suitable habitats remain and population sizes remain above thresholds necessary to maintain adaptive potential and avoid inbreeding depression (McElhany et al. 2000).

For bull trout of the upper Columbia Basin, the most biologically and ecologically significant impact of dam construction has been the loss of genetic and life history diversity, as indicated by scientific studies (O'Brien 2001; Latham 2002; Costello et al. 2003), associated with the loss or amalgamation of populations adapted to diverse adult rearing environments, which were homogenized after reservoir filling had occurred. Restoration of lost diversity is in this case impossible. The only alternative remaining is to conserve as much of the remaining biological diversity as possible, which, in the case of bull trout, requires the conservation of as many populations as possible (see Section 4). To be consistent with recent legislation that lists the bull trout as a species of conservation concern across its native range (see Section 1), the prioritization of compensation actions for bull trout in the upper Columbia Basin must also reflect a focus on areas where population status is of serious or degraded conservation concern, in addition to priorities set according to the "no net loss" principle, or priorities set based on footprint impacts to factors regulating population sizes in dam units. Only in these areas of serious conservation concern is there an urgency associated with compensation measures, as the cumulative effects of small population sizes, negative population growth rates, and the lack of connectivity with other groups put the long-term persistence of such populations at risk. Because the approach to setting compensation priorities is likely to vary among citizens, resource management agency personnel, and scientists, a balanced approach is probably most appropriate, whereby the desire for "like for like" compensation, estimates of footprint impacts integrated over the entire life cycle (i.e. incorporating limiting factors), and footprint impacts to conservation status are all given weight in assigning compensation priorities for bull trout in the upper Columbia Basin.

Moody et al. (2007) conducted a review of compensation options potentially applicable in the upper Columbia Basin for the FWCP, and recommended a strategy incorporating a high diversity of compensation measures, applied equally to both stream and reservoir environments. The strategy is likely to benefit bull trout in that ecosystem productivity is a focus. However, bull trout have a unique early life history and adaptations. Little research has been done on the suitability of typical compensation measures for bull trout specifically, so in the following sections of this report compensation options identified in Moody et al. (2007) are presented and discussed. In this discussion, consideration is given to how the unique biology of the species should affect the priority of each as a compensation approach for bull trout losses. Realistically speaking, cost estimates for individual projects are beyond the limitations of this analysis, as the necessary biophysical surveys have not been conducted. Where applicable, however, estimated costs per unit of compensation are presented in Moody et al. (2007).

7.3 Reservoir fertilization

As discussed in Section 3.2, experimental fertilization of Kootenay Lake and the Arrow Lakes Reservoir appear to have been successful at mitigating kokanee losses resulting from oligotrophication due to nutrient retention in reservoirs upstream, and this appears to have resulted in increased bull trout abundance. The assertion of Moody et al. (2007), that reservoir habitat is a poor replacement for the productivity of river environments, is probably not true for bull trout when measured merely in terms of production of adults (losses of genetic diversity notwithstanding). Bull trout are known to do well in cold reservoirs (McPhail and Baxter 1996; Ratliff 1992), likely due to good growth efficiency and survival associated with the lacustrine environment and the presence of a pelagic prey fish base. The productivity of Koocanusa Reservoir for bull trout appears to be extremely high, with redd densities in the Wigwam River being the highest to have been observed in the upper Columbia Basin (Section 3.2). Abundance also appears to be very high in Kinbasket Reservoir, based on reports of catch rates exceeding all other lacustrine fisheries in the Kootenays (Pole 1996). Fertilization of Kinbasket Reservoir, as proposed by Moody et al. (2007), will have ecosystem benefits beyond those to just bull trout, and bull trout production is likely to respond positively. However, the cost of Kinbasket Reservoir fertilization is expected to be high, given the large size of the reservoir and its remoteness. Fertilization of a portion of the reservoir has therefore been presented as a second alternative (Moody et al. 2007). Given the high projected cost, and evidence that bull trout production in Kinbasket Reservoir already appears to be high already, higher priorities for bull trout compensation can probably be found.

Run-of-river reservoirs are thought to be particularly unproductive, and Revelstoke Reservoir is estimated to be of lower primary productivity than the Arrow Lakes Reservoir (Moody et al. 2007). In Section 6.4 it has been suggested that survival and growth for adfluvial bull trout in dam unit C4 may be lower relative to their survival and growth in the Arrow Lakes Reservoir, which they would have utilized prior to impoundment. Fertilization of embayments within Revelstoke Reservoir, in which water residence times would be higher, was suggested by Moody et al. (2007) as a relatively cost-effective means of increasing production. Production of bull trout wholly within dam unit C4 has probably increased greatly, given the establishment of a lacustrine environment and a kokanee prey fish base, in addition to recruitment that would have formerly been destined for the ALR (Table 5). The rationalization for fertilization of Revelstoke Reservoir would be therefore be as a means of compensating bull trout populations for cut off access to the ALR, and would address net losses in dam unit C11 (Table 5).

Embayment fertilization was also suggested for Duncan Reservoir, and may benefit bull trout populations there, but in my analysis the need is not acute, given that connectivity exists between Duncan Reservoir and Kootenay Lake where compensation for tributary losses has occurred (Table 5), and pre- and post-impoundment estimates of productivity for the reservoir are comparable (Moody et al. 1007).

7.4 Stream fertilization

Stream fertilization in British Columbia has been evaluated during two decades of its application in the province, and significant positive benefits appear to be possible (Moody et al. 2007 and references therein). Specific stream fertilization proposals in Moody et al. (2007), if effective, could be utilized to address production and conservation impacts identified in Section 6, but existing patterns of bull trout habitat use must be taken into account to ensure that benefits extend to this species. Fertilization was proposed for reaches utilized by remaining fluvial populations, by fertilizer application to rearing tributaries, as compensation for reaches inundated by reservoirs. With respect to potential bull trout benefits, the highest priority watersheds for trials should be those of high conservation and compensation value. The Salmo River, where benefits would also extend to rainbow trout and where the bull trout population is of serious conservation concern, is already listed as an example in Moody et al. (2007).

A second proposal is stream fertilization in tributaries to Revelstoke Reservoir, where benefits would also extend to embayments they enter. It is important to note that glacial inputs to some tributaries may be a factor limiting the effectiveness of fertilization in these streams. It was suggested that suitable streams would be those that clear by mid summer at the latest (Moody et al. 2007), so biophysical assessments of tributaries in Triton (1992) should be referred to as a first step in identifying candidate streams, in advance of a detailed study to identify the extent of core rearing areas.

The third proposal was for stream fertilization of accessible reaches of non-glacial tributaries to Arrow Lakes Reservoir. Results from Decker and Hagen (2007) identify bull trout rearing streams that are both non-glacial and contain high densities of rearing juveniles. These are: Halfway River, MacDonald Creek, and Caribou Creek. Advantages to the use of these streams for a fertilization experiment are that key rearing areas have been delineated, important populations of adfluvial rainbow trout utilize downstream reaches, and a methodology for quantitative population assessment has been developed. This is consistent with the prioritization in this report of populations of conservation concern as recipients for compensation activities, as these streams include major rearing habitats for 'southern' genotype bull trout, which are of greater conservation concern than 'northern' genotype populations. It should be noted that slow release fertilizer is probably more desirable for bull trout rearing streams because of typically poor access.

Tributaries that flow directly into the reservoir appear to be the most important for Kinbasket Reservoir bull trout. Two systems thought to contain high density bull trout use, are relatively clear, and have access facilitating monitoring are Hugh Allan Creek in Canoe Reach and Windy Creek on Columbia Reach (Oliver 2001). These may present the best opportunities for a fertilization experiment in dam unit C3, where losses of rearing streams have been greatest.

Moody et al. (2007) suggested that stream fertilization may be of broad potential application in the upper Columbia Basin. The unique early life history of bull trout, however, where core rearing areas are often the coldest and least productive within a watershed, suggest that the technique must be evaluated for bull trout specifically. Although preliminary results from the fertilization experiment on Sheep Creek in the Salmo watershed are promising, showing increased bull trout growth and abundance (S. Decker and Associates, Kamloops, data on file 2008), most tributaries of Revelstoke and Kinbasket reservoirs have at least some degree of glacial influence, which may affect potential benefits. It is important, therefore, that the development of a stream fertilization program for bull trout occur at a modest rate, which permits adaptive management, and monitoring be of a standard that permits quantitative assessment of the effects.

7.5 Fish access improvement

If high quality, coldwater habitats exist upstream of an existing migration barrier, the modification of the obstruction to permit fish passage can be an extremely cost-effective mitigation measure, which has the desirable attribute of not requiring artificial manipulations to healthy stream reaches. Approximately 2,400 adult bull trout now spawn above breached barriers on the Kaslo, Halfway, and Illecillewaet rivers. These measures have been extremely significant for the Arrow Lakes Reservoir in particular, where spawning habitat for an estimated 1,950 adult bull trout (Section 6.6.2) was cut off by the Revelstoke Dam. Breaching of natural migration barriers, however, allows adfluvial bull trout access into areas that are likely to be inhabited by resident bull trout, unless the reach is barren of fish. Resident bull trout populations are highly invasible by adfluvial genotypes (Latham 2002), meaning that production benefits are offset by a loss of genetic diversity. A significant amount of the total bull trout genetic diversity of the upper

Columbia Basin exists above current migration barriers (Latham 2002; Costello et al. 2003), suggesting that these populations are of high conservation value. Considering that genetic diversity loss is a primary footprint impact in the upper Columbia Basin, the presence of a resident population above a migration barrier should preclude barrier removal, and it should be considered only when the below-barrier population is facing a serious conservation situation.

Barrier removal has been identified as a potential compensation measure on Nagel, Downie, Hoskins, and Park creeks in dam unit C4, and are likely to have particularly high production benefits on Downie and Nagel creeks (Triton 1992). Barrier removal on the Beaver and Cummins systems in dam unit C3 was considered feasible and recommended as a compensation measure by Fielden et al. (1992), which would allow access to 60 km of stream. Resident populations exist above all of these migration barriers. Extensive areas of low gradient were noted above migration barriers on Prattle Creek and the Valenciennes and Kinbasket rivers, also tributaries to Kinbasket Reservoir (Fielden et al. 1992). Fish were not sampled from these areas, and barriers are not high, suggesting that they may be breached by blasting. A more thorough biophysical survey of these systems is required before they can be identified as potential enhancements. This should be conducted, given the proven effectiveness of barrier removal as a stream compensation measure. Breaching of migration barriers on Cranberry Creek (dam unit C6) has been identified as a potential enhancement now that minimum flows have been guaranteed by BC Hydro (Moody et al. 2007), although bull trout may not use the enhanced reach unless maximum summer temperatures in accessible reaches are less than 14ºC.

Cost-effective, and consistent with the goal of conserving genetic diversity, is the re-establishment of access blocked by anthropogenic structures such as small dams, culverts, or logging debris. The removal of dams on the Illecillewaet and Kaslo Rivers, which provided habitat for more than 2,000 spawning adults, are compensation measures of this kind. In streams where bull trout and rainbow trout both occur, consideration should be given to whether the presence of a barrier is an important habitat feature restricting rainbow trout access. This is likely to be the case in several tributaries of the Arrow Lakes Reservoir (Section 3.1). Assessments of road crossings and debris jams, and remediation measures where appropriate, has been a focus of stream compensation activities conducted by the FWCP to date (Fielden et al. 1992; Triton 1992; Aspen Applied Science 1993; Golder Associates 1998a, 1998b; Hendricks et al. 2003). Given the ephemeral nature of smaller barriers, the low cost associated with remediation, and potential for public involvement, connectivity should be assessed periodically rather than just once, and annual remediation may we warranted when cost-effective.

7.6 Side channel developments

Side channels have been found to be highly productive for juvenile bull trout production. Mean parr abundance for side channels along the mainstem of Kemess Creek, in the Thutade watershed, averaged 11.8/100 m^2 (derived from Bustard 2004), higher than the most productive mean reach densities observed in other streams (Table 2) and twice the density of adjacent mainstem areas. Side channel developments are typically located in old side channel tracks, which receive habitat structures, then are armoured and excavated at their top end to provide year-round flow (Moody et al. 2007). It is important to note that side channel developments require careful design and regular maintenance (considerations for which are summarized in Moody et al. 2007), which probably limits their deployment to road accessible sites. Although the range of juvenile fish densities attained for other species probably cannot be assumed for bull trout, a side channel development in the Thutade watershed averaged 13 age-1+ and older juveniles /100 m^2 over the five years since its construction (Bustard 2007), and this may be a realistic target.

An advantage of side channel developments is that projects are manageable relative to those in high-energy mainstems, suggesting they may be feasible within the generally steep, high energy systems utilized by bull trout in the upper Columbia Basin. They are probably not suited for glacial systems with high bedload movement, in which intake structures have a high likelihood of being buried or stranded, as occurred for a rearing channel development adjacent to Tenderfoot Creek in the Lardeau system (H. Andrusak, Redfish Consulting, Nelson, pers. comm. 2006). Floodplains of the Bush, Sullivan, and Wood Rivers of dam unit C3 have been identified as having potential for side channel development (Fielden et al. 1992), although a high degree of channel instability was indicated, as was Carnes Creek in dam unit C4 (Triton 1992).

7.7 Instream structures

Fish production increases from the introduction of large wood structures into stream channels can be significant, but bull trout in streams of the upper Columbia Basin may be less likely to benefit from this enhancement technique. Bull trout distribution in the basin is typically associated with relatively high gradient stream sections where cobble and boulder substrates and associated pocket pools are preferred cover forms. Unembedded boulder and cobble appears to be preferred generally by bull trout, with wood debris being utilized in its absence in lower gradient stream sections (Section 2.2). Recognizing that the production benefits from large wood debris placements in steeper, boulder-laden streams are generally less, Moody et al. (2007) recommended that large woody debris placements occur in streams ≤ 2 % gradient. The widespread use of instream structure placements in bull trout streams of low gradient may not be advisable either. In the upper Columbia Basin, core bull trout rearing reaches that are of low gradient and small bed material are frequently in larger, glacial tributaries, where high peak flows and bed load transport are likely to eventually result in structure failure or the loss of its function.

Reviews of instream structure performance suggest that installations in large streams are more prone to failure (Roper 1998), and that structures are unlikely to be durable or function properly over the longer term in streams with high or elevated sediment loads, high peak flows, or highly erodable bank material (Frissell and Nawa 1993). In streams of northern dam units of the upper Columbia Basin where bull trout rearing stream losses are greatest (C3 Kinbasket, C4 Revelstoke, K7 Duncan), high water events associated with snowmelt, glacial runoff, and frequent heavy rainfall are amplified since watersheds are relatively steep, and few lakes are present to moderate flows (Triton 1992). This suggests that instream structures may be inappropriate as long-term compensation. For example, wood debris structures placed in the glacial bull trout streams Bluewater Creek and the Bull River experienced a very high rate of failure (Hagen 1993; R.L. and L. 1997) within a relatively short time period following their installation. Of 47 habitat treatments in non-glacial Camp Creek, 12 (26%) had failed completely, 17 (36%) had impaired function, and 18 (38%) were considered to be functioning well less than ten years after their installation in 1994. Although boulder placements were more durable than wood structures, they were frequently filled in with sediment instead of creating scour as intended. With the exception of rainbow trout at one enhanced site, all other species and life stages appear to either decline at treated versus control sites (rainbow trout 0+ and cottids) or show very little difference (bull trout 0+ and juveniles; Bray and Mylechreest 2003).

Contrary to Moody et al. (2007), Thompson (2002) indicated that a risk of locally degraded habitats, including localized channel widening and associated bank erosion, loss of streamside vegetation, and loss of overhead and undercut bank cover, also accompanies structure deployment when evaluated over longer time horizons. Recently a consensus appears to have emerged among scientists evaluating structure performance, which is that structures can be effective in appropriate settings at enhancing fish production, but that their appropriate role is as a short-term restoration to be applied while natural ecosystem processes re-establish themselves (Kauffman et al. 1993, 1997; Roni et al. 2002; Binns 2004). The proposed application within the upper Columbia Basin, as in-perpetuity additions to streams that may already be in good ecological condition, exceeds the scope of this recommended role for instream structures except in cases where remaining stream habitats are degraded, are of low gradient, and experience low bed material transport.

7.8 Riparian restoration

Riparian restoration is accorded a high priority by stream restoration scientists (Frissel and Nawa 1992; Roni et al. 2002), and may have the highest potential for salmonid habitat restoration among existing techniques (Kauffman et al. 1993). In the upper Columbia Basin, bull trout production, and even the continued existence of populations, is probably threatened more by water temperature increases that reduce habitat suitability and favour other species than any other factor. In three small basins in the western Cascade Mountains, Oregon, removal of riparian vegetation resulted in increases of maximum stream temperature of 7ºC, and diurnal temperature fluctuations from 2ºC to 8ºC (Johnson and Jones 2000). In British Columbia, logging of 41% of the Carnation Creek watershed resulted in an increase of 3.2ºC in August over previous conditions (Holtby 1988).

Riparian restoration methods include planting and maintenance of conifers at disturbed locations, livestock exclosure fencing (where applicable), and accelerating rates of growth of existing immature and young forests in riparian areas (Koning 1999, as cited in Moody et al. 2007). Riparian restoration methods are of low risk to bull trout and likely to have broad potential application in the upper Columbia basin. Lower Downie and Bigmouth creeks in dam unit C4 (Revelstoke Reservoir) were identified by Triton (1992) as being in need of riparian restoration, and degradation caused by riparian vegetation removal has also been noted for tributaries to Kinbasket Reservoir (Fielden et al. 1992) and the Arrow Lakes Reservoir (Decker and Hagen 2007). However, the timelines of the older studies, which precede BC's Forest Practices Code and Watershed Restoration Program (Slaney and Martin 1997), suggest that more recent assessments are necessary. Residential and agricultural developments in the Salmo system suggest that riparian restoration should be a priority in this temperature-sensitive watershed as well.

7.9 Preservation

Simplistic thinking about losses and benefits of habitat alteration may prevent us from directing our attention to the most urgent threats to bull trout production and persistence, with biologically costly results. When considered from a North America-wide perspective, watershed restoration has evolved from an emphasis on installations of instream structures favouring individual species to watershed-scale re-establishment of biophysical processes that lead to ecosystem recovery. The most effective and efficient technique that restoration scientists can employ to attain the overarching goals of habitat restoration programs is to preserve existing, high quality habitats and their populations (Roni et al. 2002). Although such preservation is the top priority identified in DFO's "no net loss" principle (Section 7.1), off-site preservation is not explicitly mentioned as a suitable compensation activity, as increases in the environment's productive capacity do not occur to offset losses. Other reasons for not including prevention/preservation in restoration activities appear to have been difficulty in quantifying the benefits, and determining the appropriate scale for compensating for losses (Chapman and Julius 2005).

Because of likely difficulty in locating suitable sites for long-term enhancement of bull trout production in streams, prevention of damage to existing, high quality habitats has been suggested previously as an appropriate focus for the FWCP (Triton 1992). Core bull trout rearing areas in southern upper Columbia Basin streams without glacial influence currently have water temperature regimes that approach thresholds for bull trout suitability, and are highly vulnerable to increases resulting from land management practices. Without thoughtful preservation of riparian and watershed processes that result in cool streams, losses resulting from water temperature changes may outweigh benefits from stream enhancements, and would occur in the same southern areas where conservation status is most serious. Water temperature changes of even 1-2ºC may shift habitat suitability within key bull trout rearing areas in the Arrow Lakes Reservoir basin in favour of rainbow trout (Decker and Hagen 2007), suggesting that extirpations are possible even in watersheds managed according to Forest Practices Code guidelines.

Prevention of temperature-related community shifts requires first that important rearing reaches be identified, and temperature sensitivity predicted based on existing thermal regimes plus predictions of temperature changes resulting from land use prescriptions for the watershed, noting a threshold of maximum water temperature of 13-14ºC for bull trout dominance. It is important to note that such analysis is beyond the scope and ability of current Forest Practices Code requirements, and would therefore require facilitation by FWCP. Actual preservation steps may include the designation of the reach as a Temperature Sensitive Stream (BC Wildlife Act, Section 15) or Fisheries Sensitive Watershed (BC Forest Practices and Range Act, Section 14), or direct steps to mitigate temperature increases such as prescriptions for riparian leave strips to provide shading even in non-fish bearing reaches upstream, or watershed-specific guidelines for the maximum percentage of the watershed that can be in cut blocks at any point in time.

Preservation is likely to be a cost-effective means of preventing further losses of production among stream rearing reaches, and even if it does not fit definitions of 'compensation,' it is probably the most direct method left available for addressing losses of genetic diversity likely to have occurred due to the construction of BC Hydro dams in the upper Columbia Basin. At the very least, preservation should be incorporated as a goal when identifying candidate reaches for stream habitat enhancement.

7.10 Monitoring

Our ability to predict the outcomes of stream enhancement measures for bull trout in streams is limited at this point in time, partially because of the unique physical and hydrological setting of the upper Columbia Basin relative to other areas where enhancement has been attempted, and partially because of the unique biology of the species. This necessitates that enhancements targeting bull trout specifically be initiated on a small scale and treated as experiments, until the basis for confident predictions of benefits has been established and peer reviewed. Monitoring requirements for these projects therefore exceed those typically specified for BC restoration programs, as specified in Moody et al. (2007). Instead, monitoring requirements for compensation activities should be those associated with management research, so that peer review and publication of results can occur. Such information would be highly valuable to the management and scientific communities.

To ensure that stream mitigation measures effectively benefit bull trout and are adequately evaluated, several monitoring steps are required. Given that bull trout distribution is often patchy within a basin, systematic fish sampling utilizing reliable, quantitative assessment methodologies is required to identify core rearing reaches. Benefits of compensation activities will be limited or go to other species if larger-scale factors determining distribution and abundance are not taken into account. This step will be of conservation value in itself, as it can provide necessary information required for the effective preservation of remaining habitat capability and genetic diversity. Specific prescriptions for preservation or enhancement measures will follow from this initial step. For mitigation measures where substantial levels of uncertainty exist about potential outcomes, such as stream fertilization, the quantification of results will be of high value to the scientific and fisheries management communities. Monitoring study designs will have to be considered on a case-specific basis, but monitoring of both control and treatment reaches prior to and during treatments should occur as resources permit.

With respect to lacustrine mitigation measures, current levels of adult bull trout stock assessment, outside the East Kootenay region, are inadequate for assessing the relationship between lacustrine conditions and production of adult bull trout. Insufficient information is available, therefore, with which to quantify benefits of fertilization or gain insight into the relative roles of stream and fluvial/adfluvial environments for regulating bull trout production (or the role of piscivory in regulating lower trophic levels from the top down). The feasibility of monitoring adult bull trout abundance should therefore be investigated in tributaries to each of Revelstoke and Kinbasket reservoirs and Kootenay Lake.

Adult bull trout stock assessment is efficiently conducted using redd counts (Decker and Hagen 2007), which can cover numerous reaches without sub-sampling and can be conducted in areas without good road access. The identification, using redd count data, of the total distribution of bull trout production among tributary streams, and the relative importance of each, would be highly valuable information facilitating preservation and effective mitigation. This has been accomplished by FWCP in the Arrow Lakes Reservoir basin (Decker and Hagen 2007), but assessments in the Revelstoke, Kinbasket, and Kootenay Lake basins will require a more significant allocation of effort and a longer time horizon.

8.0 CONCLUSIONS

Despite the best efforts of many investigators, substantial uncertainty remains with respect to the impacts of dam construction within the upper Columbia Basin on bull trout populations, as production changes in environments used in both juvenile rearing and migratory adult portions of the life cycle must be integrated into inferences. Bull trout have probably fared better than most other species, sport or non-sport, in the flooded valleys of the upper Columbia Basin, due to the great efficiency with which they can exploit a cold, lacustrine environment, even one which is of extraordinarily low primary productivity, once a prey fish base is established. Negative footprint impacts on bull trout production associated with BC Hydro dams are nonetheless likely to be significant. By far the most significant loss of potential bull trout spawning and rearing habitat was the 142 km estimated to have been inundated due to the construction of the Mica Dam. When integrated over the entire life cycle, however, these losses appear to be mitigated in large part by good growth and survival in Kinbasket Reservoir, and bull trout in the dam unit under post-impoundment conditions are large and abundant. Fluvial populations rearing in accessible tributaries to Revelstoke Reservoir now have adopted an adfluvial life history or have been replaced by/amalgamated with adfluvial populations, which probably experience greater growth and survival than in the pre-impoundment Columbia River. Although significant tributary habitat losses (29 km) also occurred, production of adult bull trout from wholly within the dam unit has increased because of recruitment from adfluvial populations with natal streams above the Revelstoke Dam but that would have recruited to the Arrow Lakes prior to dam construction. This recruitment, however, has been permanently cut off from the Arrow Lakes Reservoir. Although the breaching of barriers on the Illecillewaet and Halfway rivers has compensated for much of this lost recruitment, the estimated shortfall remaining is 19,300 age-1+ and older juvenile bull trout, equivalent to 770 spawners annually. Bull trout rearing habitats (8.9 km) were also inundated by Duncan Reservoir. Because connectivity remains with Kootenay Lake, however, 30 km of access above a breached barrier on the Kaslo River has mitigated these tributary losses. Pend d'Oreille system bull trout, which are now isolated within the Salmo River, have been most severely affected by dam construction, with the Seven Mile Reservoir now being too warm for bull trout production and not allowing passage into productive habitats in the Columbia River mainstem.

Probably the gravest effect of the dam construction and flooding, from the perspective of those who are entrusted with the conservation of the species, has been the compromised relationship between diverse natural environments, adaptations within bull trout populations to these environments, and genetic diversity. Genetic diversity within upper Columbia Basin appear already to have been lost as a result of amalgamation of diverse adult and subadult rearing habitats into single reservoirs, and, to some degree, compensation efforts to date in the ALR basin. The deteriorated conservation status of two southern populations in the upper Columbia Basin, the isolated, small populations in the Blueberry Creek and Salmo River watersheds, are directly the result of dam construction, and the requirement for mitigation measures in these watersheds may be urgent even if restoration of populations to pre-impoundment levels is no longer possible.

A great deal of uncertainty will remain about the potential benefits of compensation measures for bull trout as well, and wisdom and creativity will be required in equal measure to ensure that compensation results in the security of remaining populations, and that net improvements of fish production in the upper Columbia Basin occur. Given the attendant uncertainty, the need to be seen as 'doing something' must not override the obvious requirement for cautious beginnings, adaptive management, and rigorous population-level assessments. The discussion of how to proceed with compensation for bull trout losses should therefore remain open, and an experimental approach should be employed where monitoring requirements surpass those typically associated with restoration efforts.

A consensus appears to be growing about the necessity of continuing with existing reservoir fertilization to compensate for fish population declines in Kootenay Lake and the Arrow Lakes Reservoir. It is inevitable, however, that it will be difficult to find locations suitable for bull trout compensation activities in streams, due to unique biology of the animal, and also the fact that important bull trout rearing reaches are frequently inaccessible, steep, and have glacial influence. Hence, alternative, outside-the-"no net loss"-box ideas about how to compensate the environment and society in the upper Columbia Basin must be considered as well. The preservation of existing bull trout rearing reaches that are in good ecological condition may be the best and most cost-effective of these alternatives. The facilitation of this preservation by the Columbia Basin Fish and Wildlife Compensation Program, by identifying core habitats and their requirements for special habitat management, may be the best approach available for ensuring that continued genetic diversity and production losses, associated with 'normal' land management practices and climate change, do not hopelessly outweigh benefits from artificial alterations to streams where bull trout conservation status is already secure.

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TABLES AND FIGURES

Table 1. Dam units and reach descriptions for the upper Columbia Basin

Dam unit	Reach description
Columbia River dam units	
C1	Columbia Lake to Donald Station
C2	Spillimacheen
C3	Donald Station to Mica Dam (including Canoe Reach)
C4	Mica Dam to Revelstoke Dam
C5	Revelstoke Dam to Arrowhead
C6	Cranberry Creek
C7	Arrowhead to Keenleyside Dam
C8	Whatshan River
C9	Keenleyside to US border
C10	Pend d'Oreille (US border to Waneta Dam)
C11	Arrow Lakes Reservoir (C5+C7)
Kootenay River dam units	
K1	Headwaters to Wardner
K2	Bull River
K3	Wardner to US border
K4	Elk River
K5	US Border to Kootenay Lake
K6	Kootenay Lake and tributaries
K7	Upper Duncan and Duncan Reservoir
K8	Lower Duncan and tributaries
K9	Corra Linn Dam to Brilliant Dam

Table 2. Observed densities of juvenile bull trout across their geographic range

Drainage	Region	Source	Comment	Average Reach Density	
				parr/100m^2	parr/100 m
ALR tributaries	West Kootenay, British Columbia	Decker and Hagen (2007)	Core bull trout rearing areas only	1.1 – 10.2	13 – 101
Lake Pend Oreille tributaries	Northern Idaho	Saffel and Scarnecchia (1995)	Best rearing tributaries	3.9 – 11.2	-
East side Cascades streams	Washington	Sexauer (1984)		0.2 – 1.9	-
Flathead River tributaries	Montana	Fraley and Shephard (1989)	Range observed at index sites	-	41 – 113
Line Creek in Elk River drainage	East Kootenay, British Columbia	Allan (2001)		0.45 – 3.19	-
Salmo River, Pend d' Oreille tributary	West Kootenay, British Columbia	S. Decker, data on file	4-8 parr/100m^2 in the best upstream sites	0.2 – 4.8	-
Goathorn Creek, Telkwa drainage	Skeena system, British Columbia	D. Bustard, Smithers, data on file	6-7 parr/100m^2 in the best upstream reaches	6.2 - 7.4	-
Thautil/Gosnell system, Morice watershed	Skeena system, British Columbia	Bustard and Schell (2002)	6-8 parr/100m^2 in the best reaches	2.0 - 8.0	-
East Starr Creek, Morice watershed	Skeena system, British Columbia	Bustard and Schell (2002)	Resident population isolated above waterfall	>25	-
Thutade watershed	Peace River system, Britsh Columbia	Bustard (2004)	7.0-8.4 parr/100m^2 in the best reaches	1.8 - 8.4	-

Table 3. Stock assessment data for biostandards used to estimate standing stock losses in the upper Columbia Basin (from Decker and Hagen 2007)

Study stream	Accessible stream length (km)	Bull trout parr standing stock	% of total	Redd count	Estimated spawners	% of total
Illecillewaet	45	23,276	48.8%	449	898	47.1%
Incomappleaux	47	12,524	26.3%	165	330	17.3%
Halfway	33	6,376	13.4%	141	282	14.8%
MacDonald	12	3,256	6.8%	112	224	11.8%
Caribou	5.9	2,089	4.4%	49	98	5.1%
Kuskanax	8.5	183	0.4%	37	74	3.9%
Total of above	151	47,704		953	1906	

Table 4. Footprint impacts to bull trout production in the upper Columbia Basin

Dam unit	Lost fluvial adult habitats	Survival/growth in large natural lakes	Inundated rearing tributaries	Lost tributary production	
				Spawners (low-high)	Age-1+ and older juveniles (low-high)
Columbia River dam units					
C1	No impact	No impact	0	0	0
C2	Negligible	N/A	0	0	0
C3	340 km	Increased relative to pre-impoundment river	142 km	1,800 (1,500-2,070)	44,900 (36,400-53,800)
C4	141 km	Increased relative to pre-impoundment river	29 km	370 (305-424)	9,200 (7,440-11,000)
C5+C7 (C11)	42 km	Negative impacts	0	1,950* (1,620-2,250)	49,000* (39,500-58,400)
C8	Neutral	Neutral	0	0	0
C9	68 km	N/A	0	0	0
C10	18 km	N/A	0	0	0
Kootenay River dam units					
K1	No impact	N/A	0	0	0
K2	3 km	N/A	0	0	0
K3	85 km	N/A	0	0	0
K4	1 km	N/A	0	0	0
K5	Unknown	N/A	0	0	0
K6	No impact	Negative impacts	0	0	0
K7	46 km	Neutral	8.9 km	110 (99-130)	2,800 (2,280-3,370)
K8	No impact	N/A	0	0	0
K9	23 km	N/A	0	0	0

*Includes tributary production cut off by the Revelstoke Dam and now contributing to Revelstoke Reservoir

Table 5. Existing mitigation and net footprint impacts to bull trout production

Dam unit	Current mitigation: Adult/subadult rearing	Current mitigation: Tributary production	Net impact on bull trout production
Columbia River dam units			
C1	Kokanee spawners introduced	None	Probable net increase in production for fluvial populations related to kokanee
C2	None	None	Neglibible loss in production
C3	Reservoir survival/growth increased over pre-impoundment rivers	None	Lost tributary rearing mitigated in part by increased suvival/growth in reservoir
C4	Reservoir survival/growth increased over pre-impoundment river	Minor	Lost tributary rearing mitigated by increased suvival/growth in reservoir, recruitment from former ALR migrants
C5+C7 (C11)	Fertilization: increased ALR growth/survival to mitigate impacts	Illecillewaet+Halfway: 1,190 spawners/ 29,700 parr	Net loss of 770 adult bull trout, 19,300 parr cut off by Revelstoke Dam; reservoir changes neutral
C8	None	None	Neutral
C9	None	None	Loss of reach to all but one remnant population in Blueberry Creek.
C10	None	Sheep Creek fertilization	Severe reduction in fluvial growth and survival and overall production
Kootenay River dam units			
K1	Kokanee spawners introduced	None	Probable net increase in production for fluvial populations related to kokanee
K2	Losses mitigated to degree headpond utilized by bull trout	None	Minor
K3	Reservoir survival/growth increased over pre-impoundment rivers	Minor	Substantial net increase in bull trout production
K4	Losses mitigated to degree headpond utilized by bull trout	None	Minor
K5	None	None	No information, but habitat capability for fluvial bull trout probably reduced
K6	Fertilization: increased Kootenay Lake growth/survival	Kaslo River: 30 km, 1,170 adfluvial adults	Neutral: Fertilization, Kaslo River production successful mitigation
K7	None	None	Kaslo River.production mitigates inundated/lost Duncan production
K8	None	None	Neutral - see K6, K7
K9	None	None	Reduction in fluvial growth and survival and overall production due to lost connectivity with C9, K10 (Brilliant Dam)

Table 6. Footprint impacts of Columbia Basin dams on conservation status and fisheries

Dam unit	Footprint impacts on conservation status	Current conservation status	Fisheries impacts
Columbia River dam units			
C1	None	Secure	Small production increase over pre-impoundment conditions
C2	None	Degraded due to presence of brook trout	Negligible
C3	Genetic diversity loss likely	Secure	340 km river fishery lost; very good reservoir fishery
C4	Genetic diversity loss likely	Secure	140 km river fishery lost; good reservoir fishery catches possible
C5+C7 (C11)	Some genetic diversity loss	Northern': secure; 'Southern': status assessment required	Fishery losses partially mitigated by fertilization, Illecillewaet and Halfway barrier removal
C8	Minor	Genetically unique, high conservation value	n/a
C9	Major	Blueberry Creek: serious conservation concern	Significant reduction in bull trout catch/effort
C10	Major	Salmo River: serious conservation concern	Loss of Pend d'Oreille and Salmo fisheries
Kootenay River dam units			
K1	Minor	Secure	Probably net positive effect over pre-impoundment conditions
K2	Minor	Genetically unique, high conservation value	Loss of 3km of river angling opportunity
K3	Genetic diversity loss in Koocanusa tributaries	Secure	Loss of 75 km of river angling; mitigated in part by high quality fishery on remaining stream sections
K4	Minor	Genetically unique, high conservation value	Minor
K5	Unknown	Unknown, but connectivity remains	Unknown, but probably negative
K6	Minor	Secure	Potential fishery losses mitigated by fertilization, Kaslo R. barrier removal
K7	Genetic diversity loss in Duncan tributaries	Secure	Tributary production losses mitigated by Kaslo R. barrier removal
K8	Minor	Secure	10 km of lower Duncan River closed to bull trout fishing
K9	Loss of connectivity with C9	Unknown, but degraded	Slocan River closed to bull trout fishing

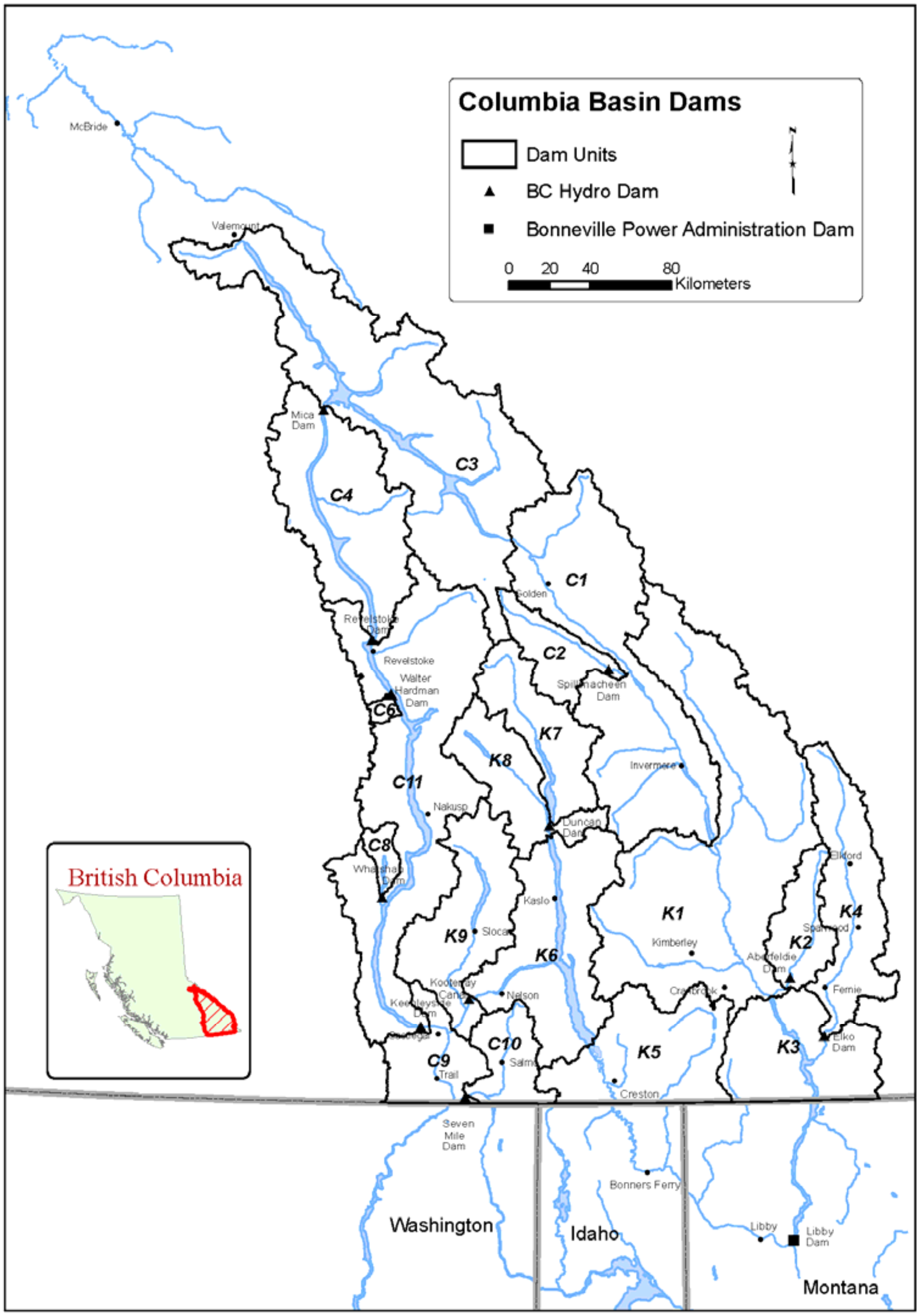

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Figure 1. The upper Columbia Basin showing dam units referred to in the report

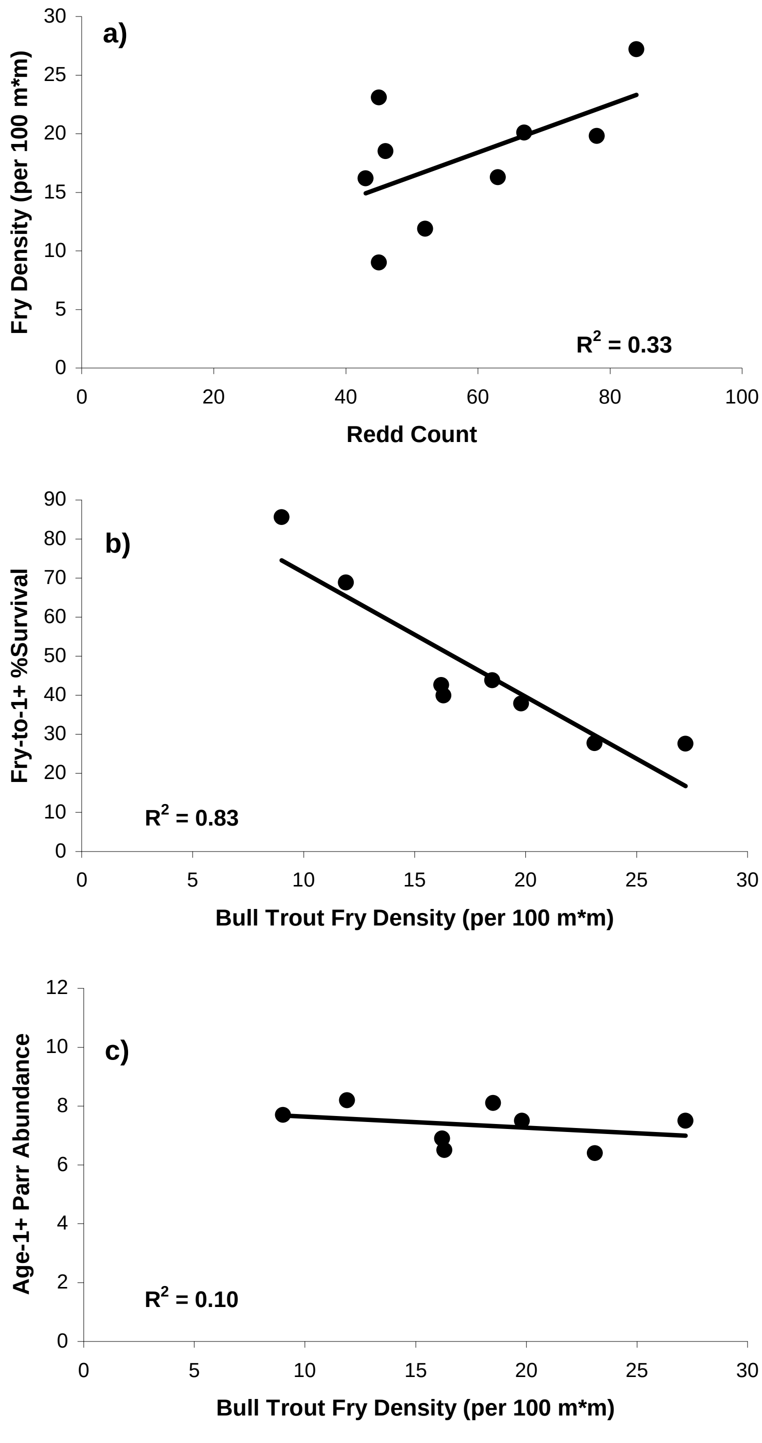

Figure 2. Bull trout stock assessment data from Kemess Creek (derived from Bustard 2004), exhibiting: a) a positive and variable relationship between brood spawner abundance and fall fry density; b) a negative relationship between fall fry abundance and their survival to age-1+; and c) relatively stable age-1+ parr abundance over a range of previous-year fry abundance levels.

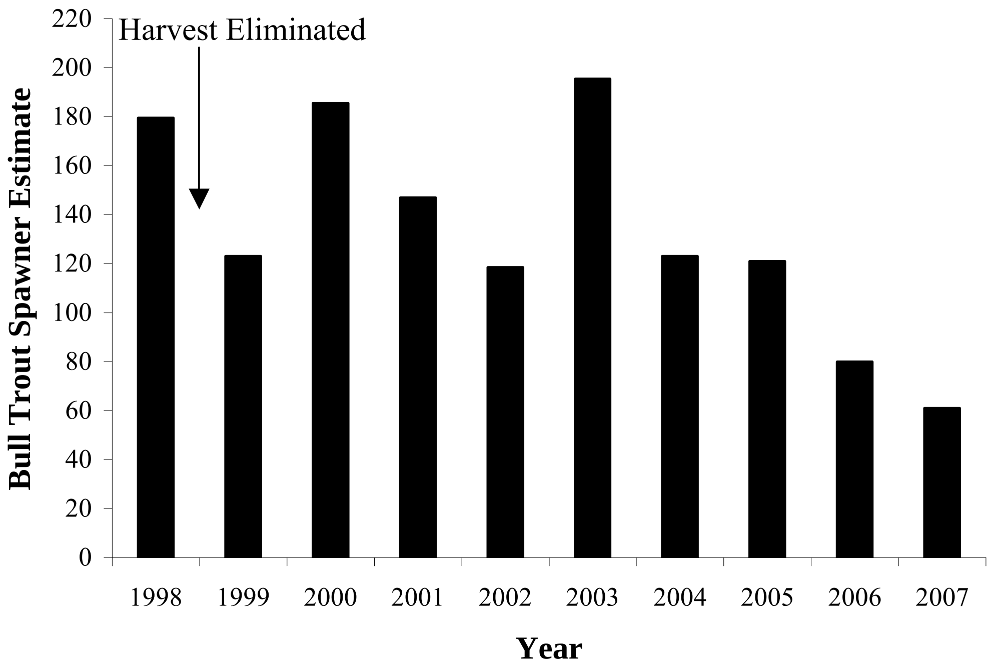

Figure 3. Adult bull trout population estimates for the Salmo River system, Pend d'Oreille watershed, from 1998 to 2007.

APPENDIX 1 – Definition of footprint impacts

These definitions of operational and footprint impacts associated with BC Hydro's hydroelectrical facilities in British Columbia 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