Footprint Impacts of BC Hydro Dams On Burbot Populations in the Columbia River Basin, British Columbia

October 2008

Prepared for:
Fish and Wildlife Compensation Program – Columbia Basin
103 – 333 Victoria St.
Nelson, B.C.
V1L 4K3

Prepared by:
Scott Cope, M.Sc., R.P.Bio.
Westslope Fisheries Ltd.
800 Summit Drive
Cranbrook, BC
V1C 5J5

Executive Summary

The Fish and Wildlife Compensation Program (FWCP) has been conducting a 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 as a result of dam construction. The subsequent operational impacts of the dams are considered a separate issue, dealt with in the Water Use Planning (WUP) process.

Over the past 85 years, BC Hydro has constructed eleven dams in the Columbia Basin. Although the dams help control flooding and provide renewable energy, not all the effects have been beneficial. The effects of dam construction on regional ecosystems include the inundation of terrestrial and aquatic habitats, reduced habitat connectivity, disrupted aquatic flow and temperature regimes and altered nutrient cycling and carbon production.

The objective of this report is to summarize burbot (*Lota lota*) population losses and gains, including potential compensation options in the FWCP area (Canadian Columbia River Basin). The report compares the status of burbot populations (increasing, decreasing, stable, unknown) for dam units in the FWCP area before and after construction of dams for flood control and hydroelectric power.

The historic, pre-dam upper Columbia Basin was largely river dominated. Currently, the upper Columbia Basin post-dam is a ‘staircase’ of dams and reservoirs that have transformed most of the riverine ecosystem into a series of large isolated lacustrine depositional basins. Riverine habitats most affected by dam construction (higher order, lower elevation and lower gradient reaches, lower tributary low gradient reaches) are the most productive, richest in terms of the number of native species and tend to have higher fish standing crops as well as larger individuals. Due to known habitat preferences of burbot there is concern these habitat losses may have disproportionately affected burbot populations.

Assessment of the potential footprint impacts of BC Hydro dams on burbot populations in the Columbia Basin is constrained and confounded by; (1) the lack of baseline information (e.g. pre-dam life history and habitat utilization data) within most dam units, (2) potential operational impacts, and (3) significant burbot stock collapses have occurred that are either unrelated to hydroelectric development or confounded by, among other things, habitat alteration, recreational and commercial fisheries, changes in nutrient inputs and introduced species.

Of the 12 dam units where burbot are present within the reservoir, one has likely increased in population abundance, five have probably decreased in abundance and the population status of the remaining six dam units are unknown. General life history and habitat utilization data suggest the spawning, incubation and early rearing life stages of burbot are the most likely to be negatively impacted by changes in aquatic habitat due to inundation. Alternatively, adult burbot probably benefit from the large increase in lake habitat that supports kokanee, a key food source.

Life history and habitat utilization data gaps, particularly in relation to reservoir operational concerns for burbot, should be addressed immediately to assist in prioritizing and planning future restoration or enhancement projects. Priorities include the headwater reservoirs (Koocanusa, Kinbasket, Duncan) and Arrow Lakes that are characterized by extreme water-level fluctuations and burbot populations that appear to have reasonable abundance. Downstream reaches (mid-Columbia below Revelstoke, Kootenay below Libby, lower Duncan) are also of concern for winter spawning migrations and habitat stranding due to the altered hydrograph and the frequency and extent of flow fluctuations.

Operation of reservoirs for power generation and flood control has resulted in reservoirs characterized by extreme annual water level fluctuations. The littoral zone of these reservoirs is severely impaired; frequent desiccation and/or inundation keeps communities in a perpetual state of early succession. Littoral zones provide critical spawning, incubation and early rearing burbot habitat. There are also concerns related to regulation of downstream flows. Higher than normal winter flows appear to have negative impacts on spawning migration and spawning and rearing success in downstream reaches due to the altered hydrograph and thermograph.

Compensation options that are most likely to benefit burbot populations or sub-populations within the Columbia Basin include; continued whole lake nutrient restoration, localized embayment or littoral zone fertilization, operational remedies, experimental burbot culture and stocking programs, and habitat restoration or enhancement.

Table of Contents

List of Tables

List of Figures

List of Appendices

1. Introduction

1.1 Background and Overview

The Fish and Wildlife Compensation Program (FWCP) has been conducting an evaluation of the footprint impacts (*see* Appendix 1 for a definition of footprint impacts) of BC Hydro developments within the Columbia Basin by estimating habitat, primary productivity, and fish and wildlife community changes as a result of dam construction. The subsequent operational impacts of the dams are considered a separate issue, dealt with in the Water Use Planning (WUP) process.

Over the past 85 years, BC Hydro has constructed eleven dams in the Columbia Basin (Figure 1 and Appendix 2). Although the dams help control flooding and provide renewable energy, not all the effects have been beneficial. The effects of dam construction on regional ecosystems include the inundation of terrestrial and aquatic habitats, reduced habitat connectivity, disrupted aquatic flow and temperature regimes and altered nutrient cycling and carbon production (Moody et al. 2007, Thorley 2008).

The FWCP was established in 1995 to offset the impacts resulting from the construction of BC Hydro dams in the Columbia Basin, and works to deliver a wide range of conservation, restoration and enhancement projects for fish and wildlife, on behalf of its program partners BC Hydro, the BC Ministry of Environment (MOE), and the Department of Fisheries and Oceans (DFO) Canada.

The footprint impacts assessment is intended to provide a baseline understanding of the amount, location and significance of ecosystem impacts of dam footprints in the Columbia Basin, and the options and costs for compensation. This will assist the FWCP in developing, prioritizing and monitoring compensation projects. A multi-phase project to estimate footprint impacts of BC Hydro dams has commenced, which includes:

- Existing Data Collection and Compilation (Phase 1);
- Pre-impoundment GIS Habitat Mapping (Phase 2);
- Interpretation and Analysis (Phase 3); and,
- Reporting (Phase 4).

Phase 1 was initiated in 2004 (Ahrens and Korman 2004). Pre-impoundment habitat mapping (Phase 2) has been completed using air photos and base maps circa 1940 (Ketcheson et al. 2005). Phase 3 reports include assessments of terrestrial

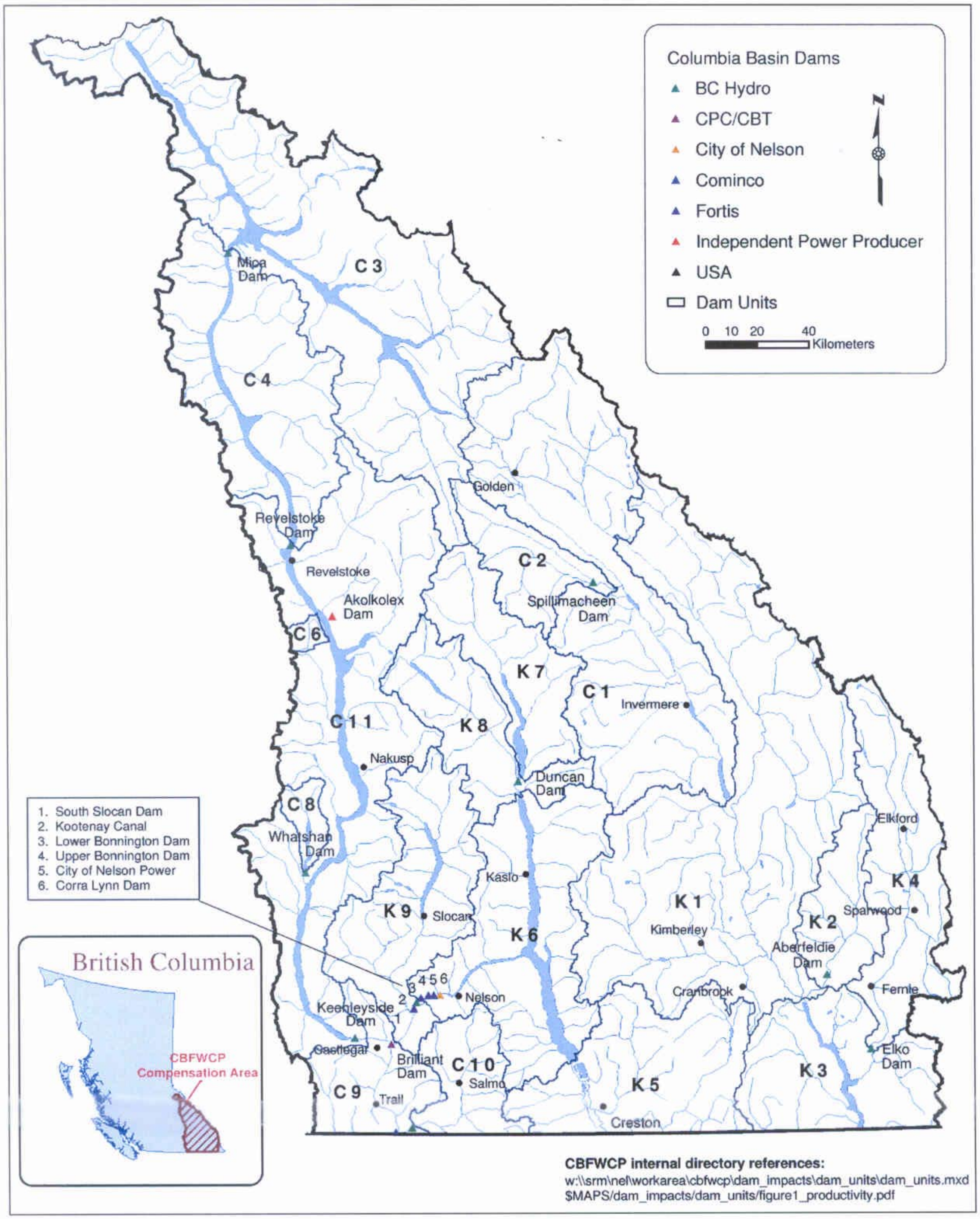

Figure 1: Columbia Basin Fish and Wildlife Compensation Program area with major dams and reservoirs and dam units.

habitat productivity (in prep.), aquatic and wetland primary productivity (Moody et al. 2007) and aquatic habitat losses and gains due to the dams (Thorley 2008). The present report is a component of the Phase 3 assessments.

1.2 Objectives

The objective of this report was to summarize burbot population losses and gains, including potential compensation options in the FWCP area (Canadian Columbia River Basin). Specifically, the objective of this report was to:

- Review the historic and present distribution of burbot in the Columbia Basin;
- Summarize life history traits in relation to potential limiting factors and footprint dam impacts;
- Assess the status (increasing, decreasing, stable, unknown) of individual populations or sub-populations of burbot for each dam unit in the FWCP area before and after construction of dams; and
- Provide compensation options, and if possible, estimated costs for populations that have declined.

The author acknowledges that little historical data exists that would describe the status of burbot during pre and post dam periods. Therefore the conclusions are largely based on historic accounts of fisheries and the relative changes in these fisheries, changes in habitat conditions, and changes in the quantity, distribution, and connectivity of lotic and lentic habitats for not only burbot but also some potential forage species. Together these observations, combined with what is known about burbot habitat requirements in general, from work in the Columbia Basin and elsewhere, are used to derive some conclusions about the state of burbot in the FWCP area relative to periods prior to construction of dams.

1.3 Distribution and Population Status Overview

The burbot or ling (*Lota lota*) is the only freshwater representative of an otherwise marine family (the true cods, Gadidae) and is one of the most widely distributed freshwater fish in the Northern Hemisphere (McPhail 1997). Within the Columbia Basin, burbot occur broadly in most large lakes/reservoirs and rivers (Figure 2).

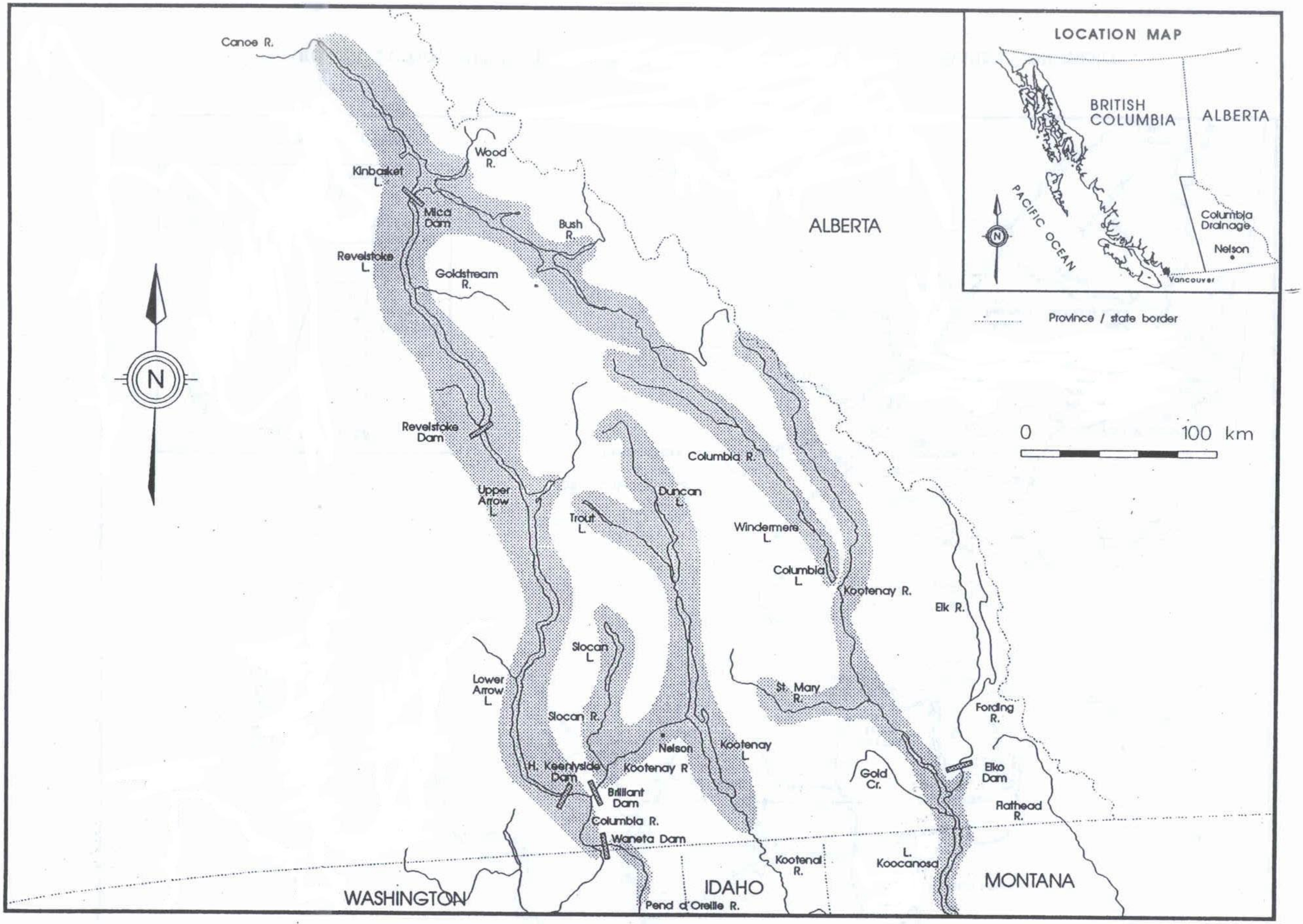

Figure 2. Burbot distribution in the upper Columbia drainage, British Columbia (from Ford et al. 1995).

Burbot in the Columbia Basin FWCP area have long been targeted for food and have a long history as an important and desirable winter food fish for both European settlers and First Nations (Prince 2001, 2008). Burbot have long been a valued sport fish in the Columbia Basin (Martin 1976, McPhail 1997, Ahrens and Korman 2002, Arndt 2004). The majority of fishing occurs in the winter, and it is sometimes related to spawning aggregations.

However, historically in western North America, management agencies and fishermen alike almost universally regarded burbot as either a “coarse” fish, a nuisance fish and/or competitor to important commercial fisheries or more popular recreational fisheries (Scott and Crossman 1973, Ford et al. 1995, McPhail 1997, Quinn 2000). As a result, comparatively little historic information is available for burbot across their range because of their previously low priority to management agencies.

Until recently, recreational fisheries for burbot in Western North America were lightly regulated. In British Columbia, burbot were taken through the ice with setlines and by jigging, but in some areas (East Kootenays) spearing burbot on their spawning grounds was a popular pastime (McPhail 1997). It is generally recognized that some spawning runs were decimated by these practices and the lack of regulation (Andrusak 1998). In general, recreational and commercial fisheries for burbot in the lakes and rivers of southern British Columbia share a similar pattern of exploitation; a period of abundance and “discovery” exploitation that extended into the 1960’s and 70’s, followed by a period of declines in the 1980’s and 90’s (McPhail 1997). In Idaho, Montana and Alaska there is a similar pattern of collapse in the recreational fisheries (Lafferty and Bernard 1993, McPhail 1997, Paragamian et al. 2000).

Burbot can be harvested in great numbers during the winter months when concentrated because of spawning activities. One coarse fish removal operation in Manitoba yielded 50,000 pounds of burbot in 3 days fishing (Scott and Crossman 1973). In Moyie Lake, using conventional recreational fishing techniques, four researchers (i.e. 4 rods ice-fishing) were able to catch 100 burbot in 36 rod-hours (Prince and Cope 2008). Presently, within the FWCP area, setlines and spearing are banned, the region-wide burbot limit has been reduced to 2 fish per day, and burbot harvest is not allowed in areas where conservation concerns have been identified.

This repeated pattern of collapse under intense recreational and commercial harvest suggests that burbot fisheries are susceptible to recruitment over-fishing (McPhail 1997). The decline in burbot size in some fisheries further suggests over-fishing as an important contributor to the declines (Prince 2001). Given burbot life history, susceptibility to recruitment over-fishing is not surprising. Burbot are a relatively late maturing, long-lived species with enormous fecundity, but larval mortality is high and recruitment to the adult population is low (McPhail 1997). They undergo pre- and post-spawning feeding migrations with a tendency to synchronicity and staging aggregations that make them susceptible to high catch rates and over-exploitation (Scott and Crossman 1973, Ford et al. 1995).

Recently, due to concerns over declining burbot populations, burbot have become a species of concern in the Kootenay Region (Columbia Basin in Canada). Populations in Kootenay Lake (British Columbia) and the lower Kootenai (American spelling) River below Kootenai Falls Montana through Idaho and British Columbia are currently near demographic extinction (Paragamian et al. 2002). The B.C. Conservation Data Centre (2008) has red-listed (S1 – Critically Imperiled) this population in Kootenay Lake and the lower Kootenay River in British Columbia. In Idaho, burbot are a species of special concern and an international conservation agreement has been signed by partners in Canada and the United States (Paragamian et al. 2002). Once thriving burbot fisheries on Kootenay, Windermere, Columbia and St. Mary lakes have declined and are now closed to burbot harvest (Andrusak 1998, Prince 2007, MOE data on file). Fluvial fisheries at the confluence areas of the Spillimacheen and Bugaboo rivers with the Columbia River (Prince 2001), and the Goat River, Summit and Corn creeks confluence areas with the Kootenay River have also collapsed (Andrusak 1998).

Fish habitats in the Canadian portion of the Columbia River basin have been impacted substantially by the construction of several large reservoirs from the 1960s through to the 1980s for flood control and hydroelectric power production. While initial conclusions may suggest that hydroelectric development and over-fishing are responsible for these often-dramatic burbot fishery collapses within the Columbia Basin, the causes of declines in specific populations are difficult to assess. Changes in limnology of the lakes, destruction of spawning sites, lakeshore development and stream channelization confound such assessments in most cases.

In other parts of the world and North America, creation of reservoirs has often been accompanied by increased burbot density (McPhail 1997). This appears to be the case for Revelstoke Reservoir. Pre-dam fish habitat assessments suggest burbot were likely rare historically in the fast flowing Mica to Revelstoke reach (Martin 1976, Lindsay 1977). Since inundation, kokanee prey abundance has increased and sturgeon setline by-catch data has identified aggregations of large mature burbot at tributary confluence areas (R.L.&L. 1996). The creation of a large lacustrine environment combined with the remarkable stability in the Revelstoke Reservoir water levels would be consistent with suggestions that increased larval survival and increased adult foraging opportunities may explain possible increases in burbot density after impoundment (McPhail 1997).

However, changes in flow regimes, temperature or nutrient loading due to hydroelectric development and flood control may be detrimental to burbot in or downstream of impoundments (McPhail 1997, Paragamian 2000, Paragamian et al. 2000, Ahrens and Korman 2002, Paragamian and Wakkinen 2008). Consequently, the status of burbot populations is of concern from both footprint and operational hydroelectric perspectives. Despite the concerns for both footprint and operational impacts, the burbot populations in the large Columbia River reservoirs (Arrow Lakes, Revelstoke, Kinbasket), appear to be abundant and healthy, as indicated by high relative CPUE and large size (Arndt and Baxter 2006, C. Spence, MOE, Nelson, B.C., pers. comm.).

1.4 Genetics and Stock Structure

McPhail (1997) hypothesized that Columbia-Kootenay burbot colonized the watershed from the Columbia refugia during the retreat of the last (Wisconsin) ice age and there are genetic and ecological differences between burbot of the Columbia-Kootenay drainage basin and those of other drainage basins to the north and east (McPhail 1997).

The most recent genetic study by Powell et al. (2008) have revealed that burbot from the Kootenay River above Kootenai Falls, Montana a presumed geographic barrier are genetically distinct (Mississippi clade) from Columbia River burbot (primarily Pacific clade). Interestingly, Duncan and Trout lakes are of the Mississippi clade and Moyie Lake of the Pacific clade. Kootenay Lake and the Kootenay River in B.C. and Idaho are the same stock, represented by a mixture of the Pacific and Mississippi clades (see also Paragamian et al. 1999, Paragamian and Whitman 2000).

Hydroelectric development within the Columbia Basin dates back over 85 years. Migratory life history forms would be at a disadvantage where dams have isolated spawning and rearing habitat (BC Hydro 2006). In addition, significant fishery collapses have been documented over the last 30 years (Martin 1976, Andrusak 1998, Prince 2001, 2007). Hammond and Anders (2003) point out that current conditions may not accurately or fully describe historical population structure, relative to the degree that population components have been extirpated.

1.5 Life History Traits and Potential Limiting Factors

Since life history data provide the basic foundation for all management, mitigation and habitat compensation programs, further study of the different life history types and population dynamics within the Columbia Basin sub-populations is urgently required, particularly given the considerable variability of the species basic life history requirements and habitat use (McPhail 1997). Detailed life history and habitat studies for pre-impoundment lakes and streams within the footprint basin do not exist. Historic hydroelectric impact assessments of pre-impoundment lakes and streams (Maher 1961, Peterson and Withler 1965a, 1965b, 1965c, Sinclair 1967, Whately 1972, Andrusak 1976, Martin 1976, Lindsay 1977) focused on quantification of available fish habitat and fish presence/use. These assessments were focused on the popular sportfish species of the day (rainbow trout, bull trout, kokanee), as they were the most abundant, supported regionally significant fisheries, and significant impacts were anticipated for these species. Furthermore, to date, many reservoir and stream populations of burbot within the Columbia Basin have never had any form of directed population, life history or habitat utilization assessment. These baseline data gaps severely constrain the current burbot assessment. Despite these limitations, the following section attempts to summarize the life history and habitat requirements of burbot in the Columbia Basin. Inferences from burbot studies outside the Columbia Basin must be viewed with caution, as there may be genetic and ecological differences between burbot of the Columbia-Kootenay drainage basin and those of other drainage basins (McPhail 1997).

Several recent reviews of burbot life history and habitat use provide the basis for general species life history traits and habitat use (Scott and Crossman 1973, Ford et al. 1995, McPhail 1997, 2007, Paragamian and Willis 2000, Paragamian and Bennet 2008). These reviews of the species basic life history indicate considerable variability. In the Columbia Basin, lacustrine, adfluvial, and fluvial populations occur in the same river system. Presumably, the selection regimes associated with these different life history types also differ, especially in the larval and juvenile stages (McPhail 1997).

1.5.1 <u>Spawning</u>

The age at sexual maturity varies both geographically and with sex. McPhail and Paragamian (2000) note that northern populations of burbot in both Europe and North America reach maturity later (e.g. 4-7 years; Evenson 1990) than southern populations. In the Columbia basin, burbot are usually sexually mature in 3-4 years (males) or 4-5 years (females) (Ford et al.1995, Arndt and Hutchinson 2000). Burbot spawn in both rivers and lakes (Ford et al. 1995, McPhail 1997). Many populations of burbot rear and feed in lakes and return to tributary rivers to spawn, while others rear and spawn within the same habitat type, i.e. river or lakes (Ford et al. 1995).

In lakes, spawning usually occurs over near-shore shallows or over shallow offshore reefs and shoals generally 0.3 to 3 m deep (Ford et al. 1995, McPhail 1997, Spence 1999, Prince and Cope 2008). In rivers and tributaries, burbot spawn in low velocity areas in main channels and in side channels behind depositional bars (McPhail 1997). In many cases, spawning is often associated with tributary confluences or upwelling (Ford et al. 1995, McPhail 1997, Andrusak 1998, Baxter et al. 2002b, Spence and Neufeld 2002, Prince and Cope 2008).

Many lacustrine populations are adfluvial; they live in lakes and migrate to rivers to spawn (Ford et al. 1995, McPhail 1997, Arndt and Hutchinson 2000, Paragamian et al. 2000, Spence and Neufeld 2002). Some adfluvial and fluvial populations within the Columbia Basin are known to migrate long distances (up to 120 km) to specific spawning sites. Tagging and telemetry studies in the lower Kootenay River in B.C. and Idaho have shown that burbot move between Kootenay Lake and the Kootenay River. In addition to spawning tributaries in B.C. (Goat River, Summit and Corn creeks), traditional spawning tributaries in Idaho are 50 to 120 km from Kootenay Lake (Paragamian et al. 2000). In the upper Kootenay River winter migrations of up to 120 km that are assumed to be spawning related have been documented between Koocanusa Reservoir in the U.S. and the St. Mary River in B.C (Hammond and Anders 2003, B. Westover (retired), MOE, Cranbrook, B.C., pers. comm.). In the Tanana River Alaska, upstream movements of adult burbot from November through March associated with spawning averaged 57 km and were as high as 255 km (Breeser et. al 1988 in Ford et al. 1995, Evenson 1993 in McPhail 1997). Ford et al. (1995) report burbot migrations of up to 400 km to tributaries in Lake Baikal, Russia.

Most authors agree that burbot spawn in the winter or early spring, often under ice (December to March), and that the spawning season is relatively short (2 or 3 weeks) and highly synchronized (Boag 1989, Arndt and Hutchinson 2000). In Columbia Lake, peak spawning typically occurs in early February (Arndt and Hutchinson 2000). In Moyie Lake, spawning burbot were observed in mid to late February (Prince and Cope 2008). The timing of spawning for radio tagged burbot in Trout and Duncan lakes appeared to extend into March (Spence and Neufeld 2002, Baxter et al. 2002b). Popular historical food fisheries that were concentrated on known spawning locations or habitat (Bugaboo, Spillimacheen and Goat rivers, Windermere Lake, Dutch, Summit and Corn creeks) suggest late January through early March was the peak spawning period (Prince 2001). Although there is some disagreement, the West Arm Kootenay Lake stock may have been unique in spawning at the later end of this spectrum (e.g. April). The percentage occurrence of mature ripe and spent fish in the 1968 creel data suggests commencement of spawning in the first week of April (Martin 1976).

The preferred spawning substrate appears to be fine gravel, sand or even silt, but coarse gravel and cobbles are used in lakes (Ford et al. 1995, McPhail 1997, Prince and Cope 2008,). Spawning behaviour is unique in that burbot form a large “writhing ball” with one or two females at the centre surrounded by many males (McPhail and Paragamian 2000). There is no site preparation and the eggs are broadcast into the water column well above the substrate. Depending on the current, the semi-buoyant eggs may initially drift but eventually settle into interstices in the substrate (McPhail and Paragamian 2000). Burbot are highly fecund, like other cod, and egg number estimates vary from 6,300 to 3,477,699 (McPhail 1997). Not all fish spawn each year (Arndt and Hutchinson 2000).

1.5.2 Rearing

Eggs are released into the water column and eventually settle to the bottom. They are not adhesive but typically settle into interstices in the substrate. Optimal incubation temperatures for Columbia Lake burbot were between 1.0 and 6.0 ^{0}C, peaking at 3 ^{0}C. (Taylor and McPhail 2000, Taylor 2001).

Burbot eggs are very small (0.53 – 1.7 mm dia.) and produce small larvae that are 3-4 mm in total length (McPhail 2007). Studies suggest burbot numbers are limited by recruitment, as mortality rates of larvae are high (McPhail 1997, Taylor and McPhail 2000). In lakes, newly hatched larvae are pelagic. At first they drift passively in the water column, but as they grow and swimming performance improves, they become more mobile. Observations suggest that in lakes larval burbot undergo a habitat shift in early summer moving inshore (McPhail and Paragamian 2000). Little is known about the larval ecology of fluvial populations. Apparently, in the upper Columbia, quiet water areas are often found downstream of major spawning sites, and these areas could provide nursery sites for larvae (McPhail 1997).

Larvae feed on phytoplankton, rotifers, copepods and cladocerans. At about 30 mm the larvae shift from a schooling, diurnal life to a nocturnal, solitary, benthic life (McPhail

1997). Boag (1989) observed that young-of-the-year burbot sheltered under stones and debris in shallow bays and along rocky shores during the day, but were foraging at night. Others record similar observations including excavated burrows under rocks and debris utilized for cover in 0.5 to 3.0 m depths (McPhail 1997).

Young-of-the year diet shifts with size progression from copepods and cladocerans to larger zooplankton and amphipods, to amphipods and insects. In rivers and streams burbot also shelter in weed beds, under rocks, and debris and feed on amphipods, mayflies, stoneflies and young of the year of other fish (McPhail 1997, Taylor 2002).

Juvenile and sub-adults essentially occupy the same habitat as the young-of-the-year; shallow littoral environments with rocks, weeds or debris for cover. They feed primarily on insects but, as they grow, they progressively shift towards a diet dominated by fish (McPhail 1997).

Burbot are a northern species and at the southern edges of their range, they typically inhabit deep lakes or cool rivers and reservoirs associated with mountainous areas (McPhail 1997). Burbot avoid temperatures above 13 ^{o}C. Thus, in lakes during summer, they are usually below the thermocline and strongly associated with the bottom where they construct extensive burrows in the substrate. In some lakes, burbot move into shallow areas, tributary confluences, or even into rivers in the late fall. These movements are thought to be part of a pre-spawning feeding migration (McPhail 1997).

Habitats used by adult burbot in rivers are unclear. They are a common fluvial species where they are restricted to high altitude cool systems such as the upper Kootenay and Columbia rivers. Adults are associated with main channels and appear to prefer turbid water. Adults are characterized as pisciverous, opportunistic feeders and most authors indicate over 80% of their diet consists of fish (McPhail 1997). A wide spectrum of species is consumed by Koocanusa burbot (Chisholm et al. 1989).

1.5.3 Potential Limiting Factors

McPhail (1997) identifies a series of “bottlenecks” in burbot early life history (e.g. larval stage, transition to demersal life, recruitment to adult population) yet, in British Columbia, information on these critical stages is almost non-existent. For example, during field studies in the Kootenay River between Kootenay Lake and Kootenay Falls Montana that span a 23 year period, only three larval and three juvenile burbot have been collected (Hammond and Anders 2003). On the other hand, one of the most thorough assessments of early life history and ecology of larval and juvenile burbot is provided by the Columbia Lake juvenile burbot studies (Taylor 2001, 2002). The results of Taylor's work correspond closely with information in the literature from other parts of the burbot's natural range (McPhail 1997). This provides some confidence in applying these general inferences to the early life history of Columbia Basin burbot.

In addition, potential limitations to shallow burbot spawning and juvenile rearing habitat are a concern. In most Columbia Basin reservoirs, there are few shallow-water habitats because of the steep-sided slopes of the valley, which limit the amount of suitable habitat in the reservoir for many species of fish. Furthermore, many of the tributaries entering the reservoir are steep, ephemeral or glacial fed and have obstructions in their lower reaches. These characteristics have been exacerbated by inundation and severely limit spawning habitat within most reservoirs for most fish species. In most dam units, it is clear that the loss of the numerous small stream deltas, extensive "flats" and "bottom" lands has resulted in significant losses of salmonid (kokanee, rainbow trout, bull trout) spawning and rearing habitat (Peterson and Withler 1965a, 1965b, 1965c, Sinclair 1967, Whately 1972, Andrusak 1976, Martin 1976, Lindsay 1977). General habitat preferences of burbot suggest these habitats were also utilized by burbot for similar life history functions (spawning and rearing). These habitats would have provided preferred adult burbot feeding habitat in the form of low velocity regions within the main river and medium sized lakes that would provide excellent feeding opportunities by concentrating prey items (Ford et al. 1995). Pre-spawning feeding migrations could be expected into such areas. Existing distribution data suggests burbot in the reservoirs are widely distributed and present in many of these same areas, often in abundance (Prince 2001, 2003, R.L.&L. 2001a, 2001b, Spence and Neufeld 2002, Arndt and Baxter 2006).

The stream and river losses have all occurred at lower elevations (<1,000 m), and larger low gradient rivers have been disproportionately affected (Thorley 2008). Riverine habitats most affected by dam construction (higher order, lower elevation and lower gradient reaches, lower tributary low gradient reaches) are the most productive, richest in terms of the number of native species and tend to have higher fish standing crops as well as larger individuals (Thorley 2008). Due to known habitat preferences of burbot there is concern these habitat losses may have disproportionately affected burbot populations.

In addition to impacts on stream and lake habitats, the reservoirs trap nutrients that would otherwise enter downstream environments. Following the initial boom period from nutrients released in the recently flooded terrestrial habitat, longer water retention times result in increased rates of sedimentation and a reservoir becomes an effective nitrogen (N), phosphorus (P), and carbon (C) sink (Moody et al. 2007). The end result is a reduction in primary production (Stockner et al. 2000 in Moody et al. 2007). The condition is exacerbated by the loss of littoral C production caused by the draw down/flooding cycles that destroy littoral and wetland vascular plant communities (Moody et al. 2007). Loss of aquatic productivity and well documented ecological pathways are of serious concern for potential impacts to burbot early life history stages (Ahrens and Korman 2002). Experimental fertilization of both Kootenay and Arrow lakes has been conducted using an adaptive management approach in an effort to restore lake productivity lost as a result of nutrient uptake in upstream reservoirs (Schindler et al. 2007a, 2007b).

Although outside the scope of this review, operational impacts of several facilities (e.g. Mica, HLK, Duncan and Libby dams) are most likely limiting burbot productivity. The reservoirs formed behind these facilities (Kinbasket Reservoir, Arrow Lakes, Duncan and Koocanusa Reservoirs) are characterized by extreme annual fluctuations in water elevation of 30 m or more due to hydroelectric generation and flood control. Burbot are a species of concern due to the potential negative impact of reservoir operations (winter draw down for hydroelectric power generation and flood control) on spawning success, egg survival, and juvenile stranding.

2. Methods/Approach

This review is the continuation of a multi-phase project to determine the ecological footprint of BC Hydro dams in the Columbia Basin. To a large extent, the current review of footprint impacts of BC Hydro Dams on burbot populations relies on the Phase 2 pre-impoundment habitat mapping as a foundation for analysis of the effects of BC Hydro dams (Ketcheson et al. 2005). Subsequent quantification of ecosystems and water features used to infer productivity and fish use are dependent on the accuracy of the historic mapping.

Similarly, footprint impacts of BC Hydro dams, as they relate to burbot, were inferred from Phase 3 reviews of the footprint impact of BC Hydro dams on aquatic and wetland primary productivity in the Columbia Basin (Moody et al. 2007) and aquatic habitat losses and gains due to BC Hydro dams in the Columbia Basin (Thorley 2008). In these reports, habitat data (by dam unit) are in three broad categories: large lakes/reservoirs (>1,000 ha), small lakes, and streams. Metrics for summarizing lake losses and gains are area and number of lakes. Metrics for summing stream losses are area (footprint only) and length (footprint and non-footprint). Stream habitat may be divided into large river, intermediate and small streams.

Near the beginning of the footprint impacts project a two-day workshop was held in Nelson, British Columbia to review work done to date and form the methods to be used to assess dam footprint impacts (Murray 2005a). Participants were invited based on their knowledge of the basin and its fish habitat to ensure that important aspects would not be missed. Attendees included staff from the BC Ministry of Environment, BC Ministry of Sustainable Resource Management, BC Hydro, Fisheries and Oceans Canada, FWCP and consultants with a history of working in the region.

A key focus of the workshop was to provide direction in regards to what metrics should be considered for assessing impacts, and what performance measures should be used to monitor success of compensation initiatives. Participants emphasized that pre- to post-dam changes should be quantified if possible and provided a list of recommended metrics for assessing fish community impacts. These metrics included: changes in population abundance or escapement, loss of indigenous stocks, introductions of kokanee into new reservoirs, life history changes (e.g., fluvial to adfluvial), and changes in stock diversity or species complexes (complete list in Appendix 3). With regards to performance measures, the participants noted the importance of understanding the limiting factors for populations (e.g. spawning habitat versus lake rearing environment) and encouraged monitoring programs that would test assumptions and resolve uncertainties around population dynamics (Murray 2005b).

2.1 Analysis methods

For management purposes, the afore-mentioned reports divided the Columbia Basin in British Columbia into 18 dam units – not all of which have dams (Figure 1 and Appendix 2). The status (increasing, decreasing, stable, unknown) of burbot populations was evaluated for each dam unit.

Detailed burbot population, life history and habitat studies of pre-impoundment lakes and streams within the footprint basin are almost non-existent and information focused on descriptive observations of available fish habitat and fish presence. These reports are restricted to 'grey' literature (e.g. BC Hydro, Provincial/Federal government, and consultant reports). The majority of these reports are focused on the most dominant and popular sportfish species such as rainbow trout, kokanee, and bull trout (Maher 1961, Peterson and Withler 1965a, 1965b, 1965c, Sinclair 1967, Whately 1972, Andrusak 1976, Martin 1976, Lindsay 1977). These species were the most abundant, supported regionally significant fisheries, and significant spawning and rearing habitat losses were anticipated for these species.

Recently, due to concerns over declining burbot populations in the Kootenay Region, a number of studies have been initiated to assess population abundance and biological characteristics of burbot. These on-going studies were initiated by the Idaho Department of Fish & Game (IDFG) in 1993 (Paragamian 2000, Paragamian et al. 2000, Paragamian and Laude 2007) and by the British Columbia MOE in 1997 (Andrusak 1998, Spence 1999, Baxter and Spence 2001, Ahrens and Korman 2002, Baxter et al. 2002a, 2002b, Spence and Neufeld 2002, Neufeld 2006, Prince 2007, Westover 2007, Prince and Cope 2008,). In addition, a number of FWCP studies have been completed for populations and life-stages of concern within the Columbia Basin (Arndt and Hutchinson 2000, Taylor and McPhail 2000, Arndt 2001, Taylor 2001, 2002, Bisset et al. 2002, Arndt and Baxter 2006,). These study results and progress reports provide the basis for much of the necessary inference and professional judgment required to determine the possible footprint impacts to burbot populations due to BC Hydro dams within the Columbia Basin.

Where pre- and post- dam abundance data were not available, trends in abundance were inferred from local knowledge of Columbia River fisheries in British Columbia (Andrusak 1998, Paragamian et al. 2000, Prince 2001, 2008). Potential footprint impacts were also evaluated based on burbot habitat requirements in general, from work in the Columbia Basin and elsewhere (Scott and Crossman 1973, Bernard et al. 1993, Evenson 1993, Lafferty and Bernard 1993, Ford et al. 1995, McPhail 1997, McPhail and Paragamian 2000), and an evaluation of current habitat conditions in relation to pre-dam habitat conditions reported in historic impact assessment reports (Maher 1961, Peterson and Withler 1965a, 1965b, 1965c, Sinclair 1967, Whately 1972, Andrusak 1976, Martin 1976, Lindsay 1977).

3. Dam Footprint Impacts

The Canadian Columbia River basin has an extensive history of impacts caused by hydroelectric development. Water level fluctuations, water temperatures, water flow regimes, turbidity, sedimentation and productivity have all undergone significant changes. The following sections summarize the various impacts of hydroelectric development and their possible effect, in general, on the burbot resources of the Columbia Basin. Dam specific impacts are identified for each dam unit in Section 4.

3.1 Construction Impacts

Actual construction related impacts would include erosion and sedimentation (turbidity), blasting, increased access, and contaminant spills (e.g. fuel and oil). Although there were probably some burbot killed during blasting, and some burbot may have been driven out of the immediate vicinity due to sensory disturbance, turbidity and/or contaminants, these impacts would have been transitory and limited in their long-term impact when compared to permanent habitat losses and habitat fragmentation.

On the other hand, initial reservoir infilling and the conversion of terrestrial and natural aquatic habitat to reservoir could have been a major shock to burbot populations due to the disruption of spawning and early rearing. This could have resulted in mortality to rearing fish as their habitats were suddenly inundated.

3.2 Habitat Loss

There are three basic types of reservoirs to consider when reviewing potential hydroelectric impacts (Moody et al. 2007):

1. Those created by damming rivers (e.g. Revelstoke, Libby);
2. Those that manipulate the level of existing lakes by damming outflow (e.g. Kootenay); and
3. Those that flood both river and lake (e.g. Kinbasket, Arrow, Duncan).

Although only the most elementary inventory of the fish resources was completed before inundation, it was clear that the loss of the numerous small stream deltas, extensive “flats” and “bottom” lands would result in significant losses of salmonid spawning and rearing habitat and that these losses could result in significant declines in salmonid populations (Maher 1961, Peterson and Withler 1965a, 1965b, 1965c, Sinclair 1967, Whately 1972, Andrusak 1976, Martin 1976, Lindsay 1977). The loss of kokanee would have resulted in a significant indirect impact to burbot. Besides the overall loss of feeding options in the pelagic zone, this would have included loss of the various smaller, dispersed kokanee spawning runs that were replaced by spawning channels in single locations. This would reduce feeding options for burbot as these habitats provide preferred adult burbot feeding habitat in the form of concentrated prey items (Ford et al. 1995). Pre-spawning feeding migrations could be expected into such areas (McPhail 1997). There is some evidence that these habitats were also utilized by burbot for similar life history functions (spawning and rearing). Existing distribution data suggests burbot in the reservoirs are widely distributed and present in many of these same areas, often in abundance.

Prior to construction of the BC Hydro dams and the Bonneville Power Administration's (BPA) Libby dam, the footprint impact area was comprised of over 38,000 km of rivers and streams and over 1,180 km^2 of lakes (Thorley 2008). The losses of riverine habitat due to inundation by dams exceed 1,200 km by length (or 120 km^2 by area), of which, over 1,050 km (or 105 km^2) are due to BC Hydro dams (Thorley 2008). If rivers and streams that were not marked on historical maps and whose presence was inferred from upstream reaches (so called construction lines) is included then the total riverine habitat losses increase by 380 km (Thorley 2008). These estimates may under-estimate the pre-dam side-channel habitat lost due to the limitations of historical map analyses (Moody et al. 2007).

BC Hydro dam construction has resulted in a net increase in lake habitat of over 600 km^2 (Thorley 2008). However, whereas the area of large lakes has increased, the area of medium sized and small lakes has actually declined as medium lakes have been inundated by the newly created reservoirs. It is important to note that the size of a lake defines the importance of pelagic and littoral production, which is considered important drivers of their icthyoecology. Small lakes (<10km^2) are, in general, considered to be dominated by the ecology of their littoral zone, whereas large lakes (>50 km^2) are dominated by pelagic production. In medium size lakes (10 to 50 km^2) both littoral and pelagic production was considered important (Thorley 2008). Olmsted (1994 *in* R.L.&L. 2001a) noted that draw down effects within the littoral zone of Kinbasket Reservoir have resulted in a shift from a littoral-based food web to a plankton-based food web, with the fish community now dominated by kokanee (a planktivore) and bull trout (a predator that feeds upon kokanee).

Total wetland area lost to reservoirs was 160 km^2 and only 13.6% of the historic floodplain areas (Flood and Wetland Habitat Groups) remain within the Columbia Basin footprint (Moody et al. 2007). The most significant losses occurred in the Donald-Mica reach where 89% of these habitats were lost due to impoundment. The Duncan and Koocanusa reservoirs lost in excess of 90% of their historic floodplain habitats. These shifts from pre-dam wetlands, streams and small lakes domination to an overwhelming pelagic domination, carry with it biological implications. There has been a shift from a high-level of aquatic habitat diversity and accompanying biodiversity to a more simple and linear pelagic driven landscape (Moody et al. 2007).

3.3 Habitat Fragmentation

Other than habitat related losses, habitat fragmentation by eliminating migration routes to nursery areas has been an over-riding impact of dams to migratory species in the Columbia system (Ahrens and Korman 2004, Moody et al. 2007). Historical data for migratory burbot stocks within the Columbia Basin is non-existent. However, recent documentation of migrations of up to 120 km in both the upper and lower Kootenay River (Paragamian et al. 2000, Hammond and Anders 2003) suggest habitat fragmentation may be a larger issue for burbot than previously thought.

Habitat fragmentation by the dam itself and the inundation and subsequent destruction of sportfish (kokanee, rainbow and bull trout) spawning habitat (low gradient lower tributary reaches) were two dominant footprint impacts identified in the pre-construction fisheries investigations (Peterson and Withler 1965a, 1965b, 1965c, Sinclair 1967, Whately 1972, Andrusak 1976, Martin 1976, Lindsay 1977). The effect of habitat fragmentation on burbot would depend on the life history (adfluvial, lacustrine, fluvial) of the individual sub-group or population and the geographical influences of habitat availability and distribution within the footprint area. In most Columbia Basin reservoirs, there are few shallow-water habitats because of the steep-sided slopes of the valley, which limit the amount of suitable habitat in the reservoir for many species of fish. In addition, many of the tributaries entering the reservoir are steep, ephemeral or glacial fed and have obstructions in their lower reaches. These characteristics have been exacerbated by inundation and severely limit spawning habitat within most reservoirs for most fish species.

In addition, given the potential limitations to burbot spawning habitat and recent documentation of often lengthy fluvial migrations to spawning grounds, it would not be unreasonable to assume there has been some loss of migratory life history sub-groups;

particularly for the HLK (lower Columbia River/lower Arrow Lake), Duncan (lower Lardeau-Duncan River and Kootenay Lake) and Libby (upper Kootenay River) facilities.

Burbot are opportunistic feeders and pre-spawning feeding migrations suggest burbot most likely follow prey species to areas where they would congregate. The loss of migratory sportfish and decreased food resources would negatively impact burbot populations within reservoirs. This is particularly true of the kokanee situation. As noted earlier, the loss of kokanee with dispersed spawning was “compensated” by building spawning channels, which focused all the prey (kokanee) in a single area.

3.4 Fish Entrainment and Loss of Fish

Fish entrainment is the process by which fish are swept into and through water intakes of generating stations and spillways. Entrainment may result in injury and mortality of fish as they pass through turbines or spillways, or are impinged on physical structures at the dam. In addition to mortality/injury, entrainment may result in fish loss to upstream populations or increased recruitment (gene flow) to downstream populations. Fish entrainment is a known risk of operation of dams and diversion structures; however, there remains considerable uncertainty as to the extent or how to develop and implement a solution (BC Hydro 2006).

Fish entrainment is a site-specific phenomenon depending on site layout, facility operations and the intrinsic characteristics of resident fish populations present in the water bodies adjacent to dams and diversion structures (R.L.&L. 2000, B.C. Hydro 2006). Entrainment rates depend on facility specific seasonal water withdrawal rates, and spatial and temporal patterns of habitat use of fish in relation to the location of water intakes. The probability that a fish is entrained through an intake is dependent on the habitat preferences of a species and life-stage, the physiological characteristics of the species and life-stage (e.g. swimming ability) and the physical and operational characteristics of the intake.

Burbot are known to have low swimming endurance (Paragamian 2000) and this would make the species vulnerable to entrainment. A migratory life history strategy would pre-dispose a population to entrainment. Individual incidents of burbot entrainment have been documented at Duncan Dam (Ord and Olmsted 2000, Spence and Neufeld 2002).

3.5 Nutrient Effects

The effects of the dams on nutrient availability and turbidity are detailed in the primary productivity report (Moody et al. 2007). As previously mentioned, following the initial "boom" period, longer water retention times result in increased rates of sedimentation and a reduction in primary production. This condition is aggravated by the loss of littoral and wetland vascular plant communities due to wide water level fluctuations typical of most large reservoirs in the Columbia Basin (CCRIFC 2007, Moody et al. 2007). Therefore, it comes as no surprise that heterotrophic production is much lower in the present post-dam setting. Furthermore, wetlands are among the world's most productive habitats and only 13.6% of the historic floodplain areas remain within the Columbia Basin footprint (Moody et al. 2007).

The loss of nutrients has been mitigated, to some extent, by increased light penetration due to reduced glacial turbidity in the spring and early summer (Moody et al. 2007). The presence of melting glaciers caused high turbidity in the large rivers and lakes of the Columbia Basin before the dams, especially in the early growing season (Moody et al. 2007). According to Moody et al. (2007), primary productivity was limited by light penetration in these systems prior to dams, and nutrients after dams.

3.6 Water Quality

One predictable outcome from river impoundment is the release of mercury from flooded sediments and its methylated form (MeHg) can bioaccumulate in the food chain, with the highest concentrations occurring in pisciverous fish (Porto 2007). Burbot may be predisposed to high mercury levels because their benthic feeding behaviour may expose them to contaminated sediment and prey items, and because of their position near the top of the trophic chain.

The construction and operation of dams and water storage reservoirs has resulted in the reduction of natural turbidity levels and created clear, oligotrophic systems (Porto 2007). Dams prevent sediment transport to downstream areas and act as settling basins for fine suspended particles. Burbot appear to prefer turbid systems (McPhail 1997) and prevailing low levels of turbidity may result in increased predation on burbot eggs and larvae. For a species already recognized as having high larval mortality and low recruitment to the adult population (McPhail 1997), increased predation at these stages would be a concern.

3.7 Operational (Hydrological) Effects

The construction and operation of dams and water storage reservoirs in the Columbia Basin has resulted in significant changes to the hydrological regime of the aquatic environment. Although fluctuations in river flows and reservoir elevation are considered operational (see Appendix 1) and the focus of this review is on footprint impacts, operational impacts may be limiting burbot productivity at several facilities (e.g. Mica, Revelstoke, HLK, Duncan and Libby Dams). Operational remedies may provide some of the best opportunities for compensation options. Therefore, it was felt an understanding of potential operational impacts and their linkages to burbot populations and footprint areas was critical to this review. The following is a very brief summary of the potential negative impacts of reservoir and river operations on burbot populations in the Columbia Basin.

The reservoirs formed behind these facilities (Kinbasket Reservoir, Arrow Lakes, Duncan and Koocanusa Reservoirs) are characterized by extreme annual fluctuations in water elevation of 30 m or more due to hydroelectric generation and flood control. Operation of these reservoirs is dictated by the need to capture the spring runoff and to fill the reservoir by the end of snowmelt. The reservoir usually reaches its lowest level in April, and fills from May through July. The reservoir is normally near full pool by August. Draw down begins in September when inflows diminish and generation system loads increase, and continues through until May.

Burbot are a species of concern due to the potential negative impact of reservoir operations on spawning success, egg survival, and juvenile stranding. The greatest potential impact of reservoir operations on burbot populations may be the dewatering effect of winter draw down on spawning success and egg survival in sites along the shoreline and in lower sections of tributaries. This species typically spawns between late January and late February, either in shallow lake habitats or low velocity stream habitats, and has an egg incubation period of about 1.5 months (McPhail 1997, Taylor and McPhail 2000). It can be expected that spawning and egg incubation in the reservoirs likely occurs between January and April, which coincides with the period when reservoir water levels can decline by an average of 4 m/month (R.L.&L. 2001b).

Concern has also been expressed that winter draw down of reservoirs may also reduce the productivity of burbot populations by stranding of juvenile fish. Young-of-the year and juvenile burbot (e.g. < 30 cm) essentially occupy the same habitat; shallow littoral environments with rocks, weeds or debris for cover (McPhail 1997, Taylor 2002). In addition to potential stranding, reduced productivity within this draw down zone may also limit productivity for juvenile rearing.

Declining water levels may also interfere with burbot spawning migration and spawning activity. In a radio telemetry study of adult burbot in Duncan Reservoir, the extent of spawning migration into the upper Duncan River appeared to be influenced by reservoir water levels and related impacts on back-flooding and stream velocity (Spence and Neufeld 2002). As back-flooding from Duncan Reservoir declined, burbot tended to move downstream into areas with lower water velocities than the locations they had abandoned. Since stream spawning burbot tend to spawn in low velocity stream habitats (McPhail 1997), the burbot may have been moving downstream to more suitable lower velocity spawning sites.

Similar migratory bottlenecks may be occurring in free-flowing river reaches below these dams (e.g. Libby, Revelstoke, Duncan, HLK). Operation of Columbia Basin dams have created major changes in the seasonal discharge, particularly during the winter when burbot spawn (Paragamian 2000, R.L.&L. 2001b, Paragamian and Wakkinen 2008). Flows in the Kootenay River below Libby Dam are now three to four times higher during winter than in pre-impoundment years but lower in the summer (Paragamian 2000). Burbot are known to have low swimming endurance and biotelemetry results suggest that spawning migrations and spawning success of burbot in the Kootenay River may be disrupted by high flows produced during hydropower production and flood control (Paragamian 2000, Paragamian and Wakkinen 2008). Operational discharge changes at Libby Dam are now required to provide suitable conditions (e.g. flows and temperature) for burbot spawning migration (Paragamian 2000, Paragamian and Wakkinen 2008).

4. Status of Isolated Groups or Sub-Populations within the BC Hydro Dam Footprint Area

The complete distribution and status of burbot populations within the Columbia Basin footprint area is not entirely clear. Table 1 summarizes the dam unit footprint areas and attempts to classify any change in burbot population status after dam construction (e.g. increasing, stable, decreasing, unknown). The following subsections summarize the pre- and post inundation literature in regards to our current understanding of habitat changes, burbot population status and potential footprint impacts by dam unit.

4.1 C1 Columbia Headwaters (Columbia Lake to Donald Station)

There are neither dams nor any known linkage to BC Hydro footprint impacts in this Dam Unit. Nevertheless, this dam unit is notable in that this once renowned burbot fishing area has undergone a fishery collapse. Before construction of Mica Dam in 1973, Columbia River burbot were historically considered abundant and large in size within areas from Kinbasket Lake south to the headwaters (Prince 2001). Specific areas of abundance included the Kicking Horse, Spillimacheen and Bugaboo rivers confluence areas and lower reaches, the Columbia River near Wilmer and Athlemere and Windermere and Columbia lakes and their tributary areas and lower reaches (Prince 2001).

In these locations, burbot were fished year round and were often targeted using jigs, setlines, or spears. These fish were also traditionally speared at night on their spawning beds and the winter spear fisheries on Spillimacheen River, Windermere and Columbia lakes were known for their large catches; both in terms of numbers and fish size. Catches of fish weighing 6-9 kg were common (Prince 2001). Pioneers of these areas told stories of people catching wagonloads of burbot and in the depression (1930’s) many residents commented that their families relied heavily on the burbot as a winter food source. By the 1950’s and 60’s, the upper Columbia River burbot fishery became well known to commercial operations and many burbot were harvested for sale in restaurants south of the border (Prince 2001).

Since the 1970’s, the upper Columbia River burbot fishery south of Kinbasket Reservoir appears to have collapsed. Recent East Kootenay adult burbot population assessments by the MOE (Prince 2007, MOE, Cranbrook, B.C., File Data) and FWCP (Arndt and

Table 1. Changes in burbot population status by dam unit in the Canadian portion of the Columbia River Basin.

Dam Unit	Name	Dam	Population Change [1]	Comments
C1	Columbia – Donald	-	Decrease	Columbia/Windermere Lakes and Spillimacheen fisheries collapse. Suspect decline started before Mica Dam (1973).
C2	Spillimacheen River	Spillimacheen	N/a	Not Present (above dam).
C3	Donald – Mica	Mica	Unknown	Large lentic habitat increase may off-set losses, although reservoir operations may reduce habitat suitability.
C4	Mica – Revelstoke	Revelstoke	Increase	Wide-spread burbot habitat improvements. Relatively stable reservoir improves habitat over previous river gradient.
C6	Cranberry Cr/Walter Hardman	-	N/a	Not present
C8	Whatshan	Whatshan	N/a	Not present
C9	Keenleyside – USA	-	Decrease	Turbidity decrease; Loss of access to Arrow Lakes
C10	Waneta – USA	Seven Mile	N/a	Not present post-dams; pre-dam habitat not suitable.
C11	Arrow Lakes Combined	Hugh Keenleyside	Unknown	Appears relatively abundant and healthy before and after dams. Large lentic habitat increase may off-set losses, although reservoir operations may reduce habitat suitability.
K1	Kootenay – Wardner	-	Unknown	Some utilization by fish from Koocanusa Reservoir
K2	Bull River	Aberfeldie	N/a	Not Present
K3	Wardner – USA	Libby	Unknown	Large lentic habitat increase and increased prey abundance may off-set losses, although reservoir operations may reduce habitat suitability.
K4	Elk River	Elko	N/a	Not Present
K5	USA-Kootenay Lake	-	Decrease	Population near extirpation
K6	Kootenay Lake	-	Decrease	Remnant population in extreme ends of North and South Arms
K7	Duncan River Tributaries	Duncan	Decrease	Habitat Fragmentation and inundation of spawning and rearing habitat
K8	Lower Duncan – Lardeau		Unknown	Possible impacts due to hydrograph and temperature alterations
K9	Corra Linn - Brilliant	Kootenay Canal	Unknown	Impacted area not likely good burbot habitat

[1] – burbot population change since dam construction.

Hutchinson 2000) have documented the low relative abundance and poor condition of Columbia and Windermere lakes adult burbot. Spillimacheen River burbot are considered by the MOE to be extirpated or nearly so (Anon. 2006). In 2001, Columbia Lake burbot catch rates using cod traps for burbot population estimates were approximately one tenth of that expected based on other lakes (Bisset et al. 2002), although the spawning run in one tributary had increased to nearly 1,000 fish the previous winter (Figure 3). In 2006, mean catch per unit effort (CPUE) data was again collected in a standardized manner for comparison among East Kootenay Lakes (North and South Moyie lakes, St. Mary, Columbia and Windermere lakes). CPUE for Windermere Lake and Columbia Lake adult burbot were 0.12 and 0.58 burbot per 48 hr set, respectively. By comparison, CPUE for burbot populations that are thought to be large and stable enough to maintain a productive fishery are much higher. Moyie Lake CPUE during the same 2006 sample session averaged approximately 1.70 burbot per 48 hr set (Prince 2007). The mean Arrow Lakes CPUE using a targeted approach (as opposed to random set locations) was approximately 9.6 burbot per 48 hr set (Arndt and Baxter 2006). The low abundance and low relative weight (e.g. poor condition factor) for Windermere and Columbia lakes populations supported severely restricted harvest regulations. In 2007, the MOE closed the lakes to burbot harvest. Figure 3 illustrates the recent decline in burbot spawner estimates for the inlet groundwater channel at the south end of Columbia Lake. Spawning also takes place in the lake itself and there is evidence that some marked fish switched their spawning location from the tributary to the lake in different years (Arndt 2001b).

There has been some speculation that migratory burbot may have represented a component of the Columbia Lake fishery. Burbot are known to spawn in shallow shoals within Columbia Lake and in two tributaries to Columbia Lake (Baxter 1998, Arndt and Hutchinson 2000). Hutchinson (1996 in R.L.&L. 2001a) speculated that two very large burbot (699 and 852 mm), which were considerably larger than the next largest at 540 mm, may be remnants of original fluvial stocks or possibly now adfluvial stocks (i.e. Kinbasket Reservoir) that historically migrated up the Columbia River to Dutch Creek to spawn. Subsequently, 26 post-spawning Columbia Lake burbot were implanted with radio transmitters and none of the tagged fish were located outside the lake (although they were not of the same large size class; fork length 496 to 579 mm) (Arndt 2001a). Although there is no evidence for migrations in the upper Columbia River, no conclusions should be inferred as significant stock collapses (e.g. Spillimacheen River,

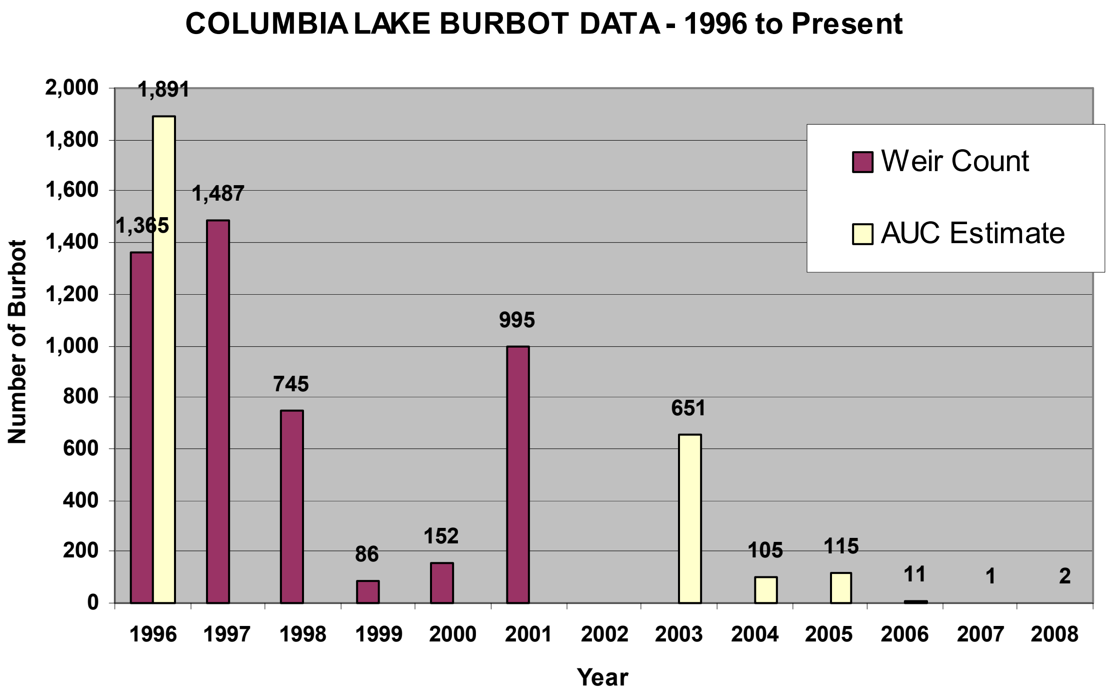

Figure 3. Columbia Lake burbot spawner estimates for the inlet groundwater channel, 1996 to present (MOE, Cranbrook, B.C., File Data).

Windermere Lake, Columbia Lake) suggest current conditions may not fully describe pre-dam historical population structure and life history variability to the degree that some population components have likely been extirpated.

Juvenile burbot catch rates have also shown similar declines in Columbia Lake (Taylor 2002). Juvenile burbot were reportedly found throughout the Columbia headwaters in nearshore habitats and sloughs in 10 to 30 cm depths. In particular, the confluence of the Kicking Horse and the off-channel habitats around Golden such as Milligan Slough were reported as overwintering habitats for juvenile burbot (Prince 2001). In the 1950's and 60's, 12-mile creek and the Bugaboo River were also reputed to support young burbot. In addition, they were often found in the stomachs of char in Kinbasket Lake. Juvenile burbot were further distributed at the mouth of Windermere and Dutch creeks and near the outlet of the Columbia River at Athalmer (Prince 2001).

The primary reason for the loss of the burbot fisheries is believed to be over-fishing and the destruction of spawning and rearing habitat (e.g. lakeshore development and tributary channelization). Many of these locations have undergone significant habitat alteration in the last 85 years. Where burbot have abandoned a traditional spawning site (e.g. Dutch Creek just above Columbia Lake), the loss of the spawning run coincided with human activities that altered the flow and substrate characteristics of the site (McPhail 1997).

Since Grand Coulee Dam on the Columbia River in Washington (completed 1942) prevents the upstream migration of fish species, a run of very large chinook salmon that used to spawn at Athalmeer (Windermere Lake outlet) has been extirpated. In subsequent years, much of the Athalmer gravel beds have been infilled to accommodate urban development. The introduction of kokanee to this dam unit in the 1980's should, at least partially, compensate for the loss of the major food source and the nutrients the chinook spawning run represented.

4.2 C2 Spillimacheen River (Upstream of Dam)

The Spillimacheen Dam was built in 1955 and forms a small, run-of-the-river reservoir on the medium-sized Spillimacheen River. The dam was constructed above upstream fish passage barriers in a canyon with steep valley sides and gradients not suitable for burbot. Burbot are not reported present above the 5 m falls barrier (below the dam; FISS 2008). Reconnaissance (1:20,000) fish and fish habitat inventory sampling supports this determination (Edeburn et al. 2001).

The lower reaches of the Spillimacheen River supported a regionally significant spawning run of mainstem Columbia River burbot (*see C1 Columbia Headwaters*). This burbot fishery collapsed in the 1970's and 1980's and is currently thought to be extirpated or nearly so (Anon. 2006). Although there are no known linkages to the Spillimacheen Dam and downstream footprint impacts have not been identified or implicated in the collapse of the spawning run, the dam is known to trap sediment and there may be unidentified operational impacts. Coincidentally, human activities that altered the flow and substrate characteristics of the Dutch Creek spawning beds in the adjacent dam unit have been implicated in the loss of the spawning run (McPhail 1997).

4.3 C3 Kinbasket Reservoir (Donald to Mica Dam)

Kinbasket Reservoir is 216 km long, and has a maximum surface area of 43,200 ha and a mean depth at full pool of 57 m (R.L.&L. 2001a). Prior to project development, Kinbasket Lake had an area of 2,250 ha and was a 13-km long enlargement of the Columbia River. The reservoir has two reaches: the Columbia Reach, which extends about 100 km from Mica Dam around the Big Bend of the Columbia River to the southeast to Donald Station; and the Canoe Reach, which extends about 90 km in a northwesterly direction (R.L.&L. 2001a).

Kinbasket Reservoir is relatively deep, cold and nutrient poor, which limits biological productivity. It is glacial fed and turbid during spring and summer, further limiting aquatic productivity. There are few shallow-water habitats because of the steep-sided slopes of the valley, which limit the amount of suitable habitat in the reservoir for many species of fish. In addition, many of the tributaries entering the reservoir are steep, ephemeral or glacial fed and have obstructions in their lower reaches. These characteristics have been exacerbated by inundation and severely limit spawning habitat for most species.

Due to the lack of data and information on burbot populations in the Kinbasket footprint area, it has been necessary to use the best available information from the literature, combined with anecdotal local knowledge from anglers, local resource managers and first nations organizations combined with professional judgment, to make general assumptions regarding the likely population trend of burbot sub-groups or populations since dam construction.

The construction of Mica Dam in 1973 resulted in the loss (i.e. inundation) of over 93% of the Columbia River in this dam unit (Thorley 2008). Substantial losses include; 539 km of rivers and streams, five small and medium lakes with a combined surface area of 24 km^2, 5.5 km^2 of shallow water habitat, 499 km or 50.5 km^2 of mainstem and tributary riverine habitat less than 7 percent gradient (i.e. low and moderate gradient), as well as the loss of 89% of the extensive flood plain and wetland habitat present in this dam unit pre-dam (Thorley 2008). The construction of Mica Dam did not include provisions for fish passage. This effectively isolated Kinbasket Reservoir from downstream Columbia River reaches.

The inundation of the mainstem Columbia River, the lower reaches of its major tributaries (i.e. Canoe, Wood, Kinbasket, Sullivan, Bush rivers) and the Bush and Kinbasket lakes may have resulted in significant negative impacts. Tributaries supported significant runs of prey species (whitefish, yellow-fin rainbow trout and bull trout). Before inundation the lower Canoe River was geomorphically similar to the Lardeau River, thus it is likely it contained preferred burbot spawning and juvenile rearing habitat characteristics (high percentage of productive side-channel areas, nutrient enriched by groundwater sources; Moody et al. 2007). Low velocity regions (deep eddies) and confluence areas within the mainstem Columbia River and its large tributaries would provide excellent feeding opportunities by concentrating prey items and pre-spawning migrations could be expected into such areas (Ford et al. 1995).

Historic aquatic habitat assessments of the Kinbasket and Bush lakes suggest these areas likely contained moderate to excellent burbot habitat and spawning aggregations (Peterson and Withler 1965c, Moody et al. 2007). Peterson and Withler (1965c) noted the unique productivity, extensive littoral zone and shoreline spawning gravels of Bush Lakes. Moody et al. (2007) summarize Kinbasket Lake fish abundance in 1964 as unusually high. Peterson and Withler (1965c) note the abundance of prey species (whitefish and whitefish spawning use), and the excellent burbot fishing available at the mouth of the Kinbasket River about October 1 of each year. In addition, juvenile burbot were noted in lower Trident Creek (potential spawning tributary to Kinbasket Lake). A number of additional streams in the area were noted that clearly supported spawning runs of whitefish (Canoe, Gold, Wood, Kinbasket and Bush rivers, Windy Creek), and trout and char (whitefish streams plus Succour, Game, Double Eddy creeks). These spawning streams would also provide the requisite burbot habitat, especially given their proximity to the mainstem Columbia River and Kinbasket and Bush lakes (Peterson and Withler 1965c).

On the other hand, with the completion of Mica Dam, lacustrine habitat increased from 2,250 ha to 43,200 ha at full pool (Thorley 2008). To date, little information has been collected on the status of burbot in Kinbasket Reservoir and it remains uncertain if burbot abundance in this dam unit has increased or decreased. Sampling efforts undertaken on the reservoir have been limited to gill net surveys conducted between 1985 and 1993, and setline sampling in 1995 (RL&L 2001a). Burbot were not captured in gill net sampling in the reservoir between 1985 and 1993, but were captured in 1995 using setlines at two sample locations (Bush River Arm and Sullivan River Arm) on the reservoir (RL&L 1996). In total, 10 burbot were captured, with 9 of these taken at the Sullivan River Arm location. The mean length of the sampled burbot was 67.5 cm. Two burbot were also recorded in the sportfish catch during the 1995 creel survey (Pole 1996).

Of the 28 streams sampled in 1988 (Triton 1990 in R.L.&L. 2001a), burbot were captured only in the Canoe River. Fidler (1994) recorded the downstream movement of three juvenile burbot moving out of Camp Creek, a known trout spawning tributary to the Canoe River, suggesting that some spawning may occur in this creek. Fielden et al.

(1992 in R.L.&L. 2001a) did not capture burbot in any of the 28 streams sampled in 1991.

Little is known regarding the spawning locations of burbot in Kinbasket Reservoir; however, as burbot spawn in shallow water of lakes or rivers during winter (McPhail and Paragamian 2000), it is considered unlikely that they would spawn in the reservoir due to the extensive draw down over the winter (R.L.&L. 2001a). Although outside the scope of this footprint impacts assessment, it is noteworthy that reservoir operations may limit the burbot population productivity for this dam unit. Burbot were identified by the Columbia River Water Use Plan Consultative Committee (WUP CC) as a key fish species of concern in Kinbasket Reservoir because of their importance to the sport fishery, because of the potential for links between reservoir operations and burbot population productivity, and due to the dearth of information regarding burbot biology in the reservoir (BC Hydro 2005). Under the existing water licenses, Kinbasket Reservoir is licensed to operate between a minimum pool elevation of 707.14 m and a maximum elevation of 754.38 m, a vertical draw down of 47.24 m or 154.95 ft. In recent years (1994 – 2006), the reservoir has normally operated between elevation 714 m and full pool (754.38 m), creating an operating range of 40 m or 132 ft.

To summarize, historically and currently, the Kinbasket Reservoir burbot population status is unknown. There are several significant habitat alterations resulting from inundation that would suggest footprint and operational impacts of Mica Dam have negatively influenced burbot populations in the Kinbasket Reservoir dam unit. The impoundment of the Columbia River has resulted in the loss of historically functioning backwater habitats with natural hydrographs. Functioning backwater or off-channel habitat appears to be important habitat for early life history stages and the maintenance of burbot populations in large river systems (Fisher 2000). The suitability of the existing lacustrine habitat is likely limited by operational impacts. Much of the reservoir is largely dysfunctional due to draw down impacts. The typical annual draw down of 40 m results in a reduction in reservoir surface area of roughly 50% limiting littoral productivity and the suitability of littoral habitat for early life history stages and spawning.

4.4 C4 Lake Revelstoke (Mica Dam to Revelstoke Dam)

The construction of the Revelstoke Dam has inundated 100% of the 129 km of the Columbia River within this dam unit. The construction of the Mica Dam and the Revelstoke Dam did not include provisions for fish passage. This effectively isolated the

Revelstoke Reservoir from upstream and downstream Columbia River reaches. Revelstoke Reservoir has a maximum surface area of 11,530 ha and a mean depth at full pool of 46 m (R.L.&L. 2001a). The reservoir is a narrow, deep, cold waterbody with an average width of less than 1 km. Although the reservoir is operated as a run-of-the-river reservoir, with generally less than a 1.5 m fluctuation in water levels, there is little littoral habitat in the reservoir due to the steep-sided nature of the valley.

The historic status of burbot populations within the pre-inundated Columbia River between Revelstoke and Mica Dams is unknown. There were several investigations of fish populations that would be affected by the Revelstoke Dam (Martin 1976, Lindsay 1977); however, there is no mention of burbot; apart from the fact that they were present in the fish assemblage. The absence of burbot data is most likely a result of three factors.

1. Fishery and management priorities of the day were focused on rainbow trout, Dolly Varden (now known to be bull trout in this area) and kokanee. These species supported regionally significant fisheries, and significant spawning and rearing habitat losses were anticipated for these species from the construction of Revelstoke Dam (Martin 1976, Lindsay 1977);
2. Burbot are most often found in low velocity regions or in deep pools in rivers (Ford et al. 1995) and due to their body form, have low swimming endurance (McPhail and Paragamian 2000). Prior to the dams, the Columbia River flowed rapidly between Mica Dam and Revelstoke and contained several points of difficult passage including Steamboat rapids, Little Dalles Canyon, 18 mile, Priest, Death, 12 Mile and Gordon rapids (Figure 4). This reach of the Columbia River was a relatively straight, fast flowing river with an average drop of 4.65 ft per mile. Back eddies, side-channels and deep pools were not prevalent (Martin 1976, Lindsay 1977).
3. As a result of difficult access, and the fact that there were few communities along this stretch of river, there were few people that spent time on the Columbia River upstream of Revelstoke.

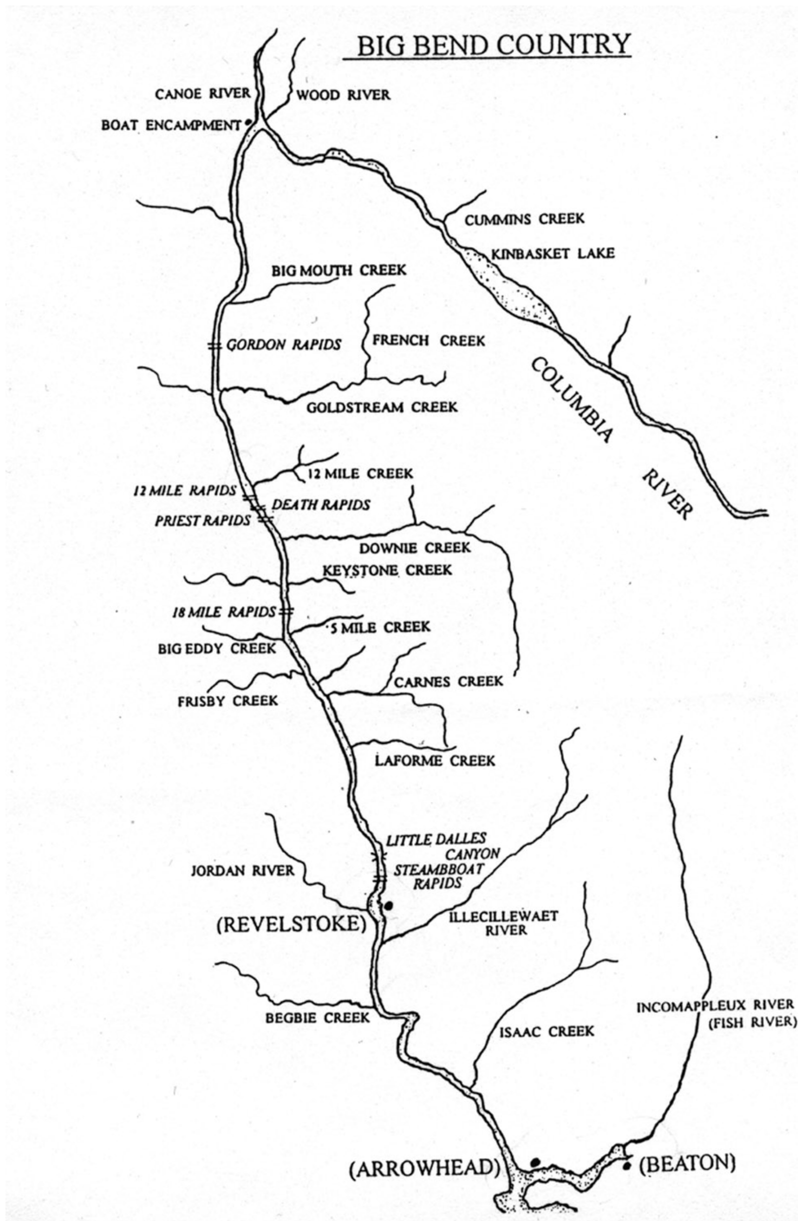

Figure 4. Historical illustration of the Revelstoke and Kinbasket dam units identifying the many rapids and fast flowing nature of the Revelstoke to Mica reach. Reproduced from Parent (1997).

Most likely, burbot were present in low abundance, in isolated sub-populations, that were limited to residing in deep pools and low velocity regions (i.e. deep eddies) within the main river that provide favorable feeding opportunities by concentrating prey items (Ford et al. 1995). The two major salmonid spawning tributaries (Downie and Bigmouth creeks) and several smaller tributaries utilized by kokanee would have provided a seasonal food source for these sub-reach areas.

Unlike most large BC Hydro reservoirs in the Columbia Basin, Revelstoke Reservoir does not undergo a large winter draw down. Under the existing water license, the reservoir is licensed to operate between a minimum elevation of 554.7 m and a maximum elevation of 573.02 m. While the draft limit under normal conditions is 571.5 m, the reservoir level is normally kept within 1 m of the maximum elevation throughout the year (R.L.&L. 2001a). This level is maintained by regulating output at Mica Dam and Revelstoke Dam so that the two facilities are operated in hydraulic balance (i.e. reservoir inflow equals outflow).

Little information is available on the current status of burbot in Revelstoke Reservoir. R.L.&L. (2001a) provides the following review of available data at that time. Small numbers of burbot were captured in gill net sampling in the reservoir in 1985 (0.5 % of total catch), 1987 (3.4 % of the catch) and 1995 (3.6 % of the catch) (R.L.&L. 2001a). RL&L Environmental Services Ltd. (1996) conducted a fisheries survey using setlines at three locations in Revelstoke Reservoir during October 1995 in an attempt to capture white sturgeon. In total, 25 burbot were captured in the reservoir during this program, and an additional two were captured by angling. Two burbot were caught in the Mica Dam tailwater (one with set lines, one angling), 24 were caught at the mouth of Bigmouth Creek (23 with set lines, one angling), and one was caught at the mouth of Downie Creek. The burbot ranged in length from 54 to 87 cm, with the 75 to 80 cm length interval being dominant. The concentration of large burbot at the confluence of Bigmouth Creek may have been related to pre-spawning aggregations.

The inundation of this reach has most likely caused habitat improvements for burbot when compared to the fast-flowing river characteristics of this reach before the construction of Revelstoke Dam in 1984. Kokanee (e.g. prey) abundance has also increased since inundation (Arndt 2008) and would be expected to have a positive influence on burbot abundance. After the construction of the Revelstoke Dam, long-time resident anglers have reported burbot abundance increased in areas upstream of the dam. The mouths of Downie and Bigmouth creeks are now reported to be good areas for burbot fishing (Prince 2001). Winter creel surveys have identified a small burbot fishery with limited catch (McInnis and Bray 2001).

4.5 C6/C8 Cranberry Creek and Whatshan Creek

There is currently no record of burbot presence in either of these watersheds (FISS 2008).

4.6 C9 Columbia River below Keenleyside Dam (HLK Dam to Canada – U.S.A. Border)

The reach from HLK Dam downstream to the international border (56 km) represents the last remaining free-flowing stretch of the Columbia River in the West Kootenays. The construction of the HLK Dam in 1968 did not include provisions for fish passage. This effectively isolated the downstream riverine reach from the historic Arrow Lakes upstream. It is not known if an adfluvial life history form of burbot existed in this area prior to construction of HLK Dam.

A large volume of inventory and assessment data exists for this reach of the Columbia River (see R.L.&L. 2001b). At one point, burbot were red-listed as a conservation concern for this dam unit (R.L.&L. 2001b). Recently, the MOE completed a review of the sport fishery data and inventory data and concluded that burbot in the Columbia River below HLK Dam have likely never been present in large numbers (Anon. 2007). As such, they do not represent a conservation concern. As a result, the population has been removed from the BC Conservation Data Centre Red List and the angling closure has been removed (Anon. 2007).

R.L.&L. (2001b) reported that historically a minor burbot fishery was known to exist below HLK Dam. A number of creel surveys targeting the reaches immediately below HLK Dam date back to 1970 (Andrusak and Withler 1970, Lindsay 1976, Andrusak 1981, Andrusak and Martin 1982, ARA 1992). The 1976 creel census was notable in that it was completed January through March, when burbot are typically targeted. This creel survey did not report any burbot captures (Lindsay 1976). Similarly, the 1970 angler harvest did not report any burbot (Andrusak and Withler 1970). In a 1980-82 creel survey, the burbot fishery between HLK Dam and Trail represented approx 1% of the effort and there were 9 reported captures (Andrusak and Martin 1982). In a more recent creel survey (1992) there were no burbot captures reported (ARA 1992).

Burbot are rarely encountered in inventory work within the area. The abundance of burbot in the study area, as measured by catch rates and percentage composition of the catch, has been very low since the 1980s. During 1980-1981, burbot accounted for 2.2 % (n=125) of the total sportfish catch, and were the third most abundant sportfish species recorded during boat electrofishing surveys in the upper section. Both numerical abundance and relative proportion of the catch declined in 1982-1983 (1.6 %, n=49) and 1983-1984 (1.4 %, n=29). During boat electrofishing surveys in 1990 to 1994, eighteen burbot were captured, which represented only 0.02 % of the total sportfish catch. Low numbers of burbot were recorded in the upper section although the sampling intensity of these surveys was considerably greater than in previous studies (R.L.&L. 2001b).

Recent burbot inventory studies have pointed to a large population in Arrow Lakes Reservoir (Arndt and Baxter 2006) and the Washington Department of Fish and Wildlife also reports that the species is abundant in Lake Roosevelt (Anon. 2007). Therefore, MOE has concluded that the area in question presently supports a few burbot, which stray from large populations in their preferred habitats in the reservoirs upstream and downstream. The loss of habitat connectivity between the Arrow Lakes and the lower Columbia River may have has a significant negative footprint impact if historically an adfluvial or migratory life history form was present. In addition, the literature suggests fluvial burbot populations prefer turbid waters (McPhail 1997) and the effect of reduced turbidity after upstream dam construction on burbot feeding and vulnerability to predation is unknown, but could be significant.

Historical trends in burbot abundance below HLK Dam are likely confounded by significant water quality contamination and subsequent remediation. Overall river health has improved since the early 1990’s, although there are historical legacy issues and occasional problems related to industrial spills (CRIEMP 2005).

Teck-Cominco has operated a smelter in Trail B.C. since 1896. The smelting complex is the largest identified source of metals to the river (EPA 2007). The facility primarily produced lead and silver during the first decade of operation, with zinc production initiated in 1915. Plants for producing nitrogen- and phosphorus-based fertilizers were built in 1930. This facility either produces or has historically produced lead, zinc, cadmium, silver, gold, bismuth, antimony, indium, germanium, arsenic, mercury, sulfuric acid, liquid sulfur dioxide, ammonia, ammonium sulfate, and phosphate fertilizers. The smelter complex has discharged liquid effluent and water-granulated fumed slag into the Columbia River, including a number of accidental spills and releases to the river (EPA 2007). Historical discharges dating back to the late 1800s include an estimated 13 million tons of sand-sized smelter slag, a large volume of liquid effluent, and spills, process bypasses, and emergency releases (EPA 2007). Beginning in 1977 a number of pollution prevention and control measures were implemented including the installation of a liquid effluent treatment plant in 1981. Discharge of slag to the river ceased in 1995. These actions reduced metals loading and Teck-Comino has stated that all Washington State water quality standards for metals are currently being met in the Columbia River at the U.S. border (EPA 2007).

The Celgar pulp mill was completed in 1961, just a few years before HLK was commissioned. In 1992, the Celgar pulp mill was considered functionally obsolescent and assessment of the available data indicated that effluent from the Celgar pulp mill had been negatively altering the water quality of the Columbia River (Butcher 1992). The colour of the Columbia River between the mill and the Kootenay River was degraded by the effluent to dark brown and could reach levels, which impaired the water for downstream recreational use and for drinking water. Surface foaming, taste, and odour problems due to the pulp mill effluent were recurring aesthetic problems. Mill modernization in the early 1990's reduced the discolouration and eliminated the foaming, taste, and odour problems.

In the past, treated sewage effluent from the City of Castlegar was also cited as an important waste discharge affecting water quality (Butcher 1992).

4.7 C10 Pend d'Oreille River

Approximately 98% of the Pend d'Oreille watershed is located in the United States and only the last 22 km of the river, upstream from where it joins the Columbia River at Waneta, is located in B.C. Virtually the entire Pend d'Oreille River from the international border to its confluence with the Columbia River has been inundated by the Seven Mile Dam constructed in 1973 and Tech-Cominco's Waneta Dam built immediately upstream of the Columbia River in 1956.

The Pend d'Oreille River is currently included within the distribution of burbot in the Canadian Columbia River basin (Baxter et al. 2007, FISS 2008). However, burbot have not been confirmed present in either the Waneta or Seven Mile Reservoirs (R.L.&L. 1994, 1995). Based on their reported occurrence in upstream reservoirs (i.e. Boundary Reservoir; B.C. Hydro 1991 in R.L.&L. 1995) they may be present. The absence of this species from setline and gill net catches suggests that if present at all, the number of burbot in Waneta and Seven Mile reservoirs are very low.

The Seven Mile Reservoir is situated in a narrow, steep-sided valley. Historically, this reach was dominated by fast-flowing river characteristics within a confined canyon and limited habitat availability would suggest very low burbot potential. Currently, warm summer water temperatures within the reservoir (>18^{o}C) are inhospitable to burbot during this season (BC Hydro 2003). It is also important to note that the Seven Mile Reservoir receives a steady input of exotic fish species entrained through the Boundary Dam 18 km upstream (BC Hydro 2003). The Seven Mile Reservoir is known to be contaminated by mining tailings (BC Hydro 2003). Furthermore, due to the concern for the exotic species introductions, the low level of productivity of the reservoir, and contamination by mine tailings, the consultative group Seven Mile Dam and Generating Station Water Use Plan decided not to investigate changing operations to enhance reservoir productivity for fish (BC Hydro 2003).

4.8 C11 Arrow Lakes (Revelstoke Dam to HLK Dam)

The original Arrow Lakes were impounded by the construction of the HLK Dam at Castlegar in 1968, which raised the mean water level by 12.5 m (Pieters et al. 1998). The inundation of the Upper and Lower Arrow lakes, which had a combined surface area of 35,000 ha, produced the Arrow Lakes Reservoir which is 230 km long with a surface area of 47,600 ha at full pool (Thorley 2008). Two main basins at the north and south are separated by a shallower narrows section (the Narrows) approximately 30 km long near the midpoint of the reservoir. This resulted in the loss of 151 km of the mainstem Columbia River, 95 km of smaller rivers and streams and 1.03 km^2 of shallow water habitat (Thorley 2008).

The reservoir is located downstream of two other large impoundments (Kinbasket and Revelstoke Reservoirs). The construction of the HLK Dam and the Revelstoke Dam did not include provisions for fish passage. This effectively isolated the Arrow Lakes from upstream and downstream Columbia River reaches. At high Arrow Lakes Reservoir levels, the tailwater of Revelstoke Dam is influenced by the backwater effect of the downstream reservoir. At low Arrow Lakes Reservoir levels, the mid Columbia River below Revelstoke Dam extends approximately 45 km down to Arrowhead, which was the head of the original Upper Arrow Lake prior to impoundment (R.L.&L. 2001b).

Arrow Lakes Reservoir is relatively deep, cold and nutrient poor, which limits biological productivity. There are few shallow-water habitats because of the steep-sided slopes of the valley, which limit the amount of suitable habitat in the reservoir for many species of fish. In addition, many of the tributaries entering the reservoir are steep, ephemeral or glacial fed and have obstructions in their lower reaches. These characteristics severely limit spawning habitat for most species (R.L.&L. 2001b).

In addition, formation of the upstream reservoirs has resulted in nutrient reduction in Arrow Lakes Reservoir (Moody et al. 2007). To address the oligotrophic status, an experimental bottom-up approach was undertaken with additions of nutrients (nitrogen and phosphorus in the form of liquid fertilizer) that commenced in 1999 (Schindler et al.

2007b). Two objectives of the experiment were to replace lost nutrients as a result of upstream impoundments and restore productivity in the Upper Arrow basin that would in turn restore kokanee and other sport fish. Results of the sixth and seventh year of the Arrow Lakes Reservoir fertilization experiment indicate that the bottom up approach to restoring kokanee has been successful by replacing nutrients lost as a result of upstream impoundments (Schindler et al. 2007b).

There are a number of historic assessments of the Arrow Lakes Sport Fishery (Peterson and Withler 1965b, Sinclair 1967, Andrusak 1976). However, due to the anticipated impacts of HLK Dam and management priorities of the day (rainbow trout, bull trout, kokanee), these assessments did not include burbot and there is no historic management data on burbot distribution, population status, or life history characteristics within the Arrow Lakes footprint area. Due to the lack of data and information on burbot populations in the pre-dam Arrow Lakes footprint area, it has been necessary to use the best available information from the literature, combined with anecdotal local knowledge from anglers, local resource managers and first nations organizations combined with professional judgment, to make general assumptions regarding the likely population trend of burbot sub-groups or populations since dam construction.

Peterson and Withler (1965b) identify numerous lower stream reaches that would be inundated and the salmonid spawning potential destroyed. For similar reasons (e.g. depth, sedimentation) burbot spawning potential was also likely destroyed. Some of the most significant potential habitat was located in the lower reaches and confluences of the Illecillewaet, Akolkolex, and Halfway rivers, Tonkawatla, Crawford, Cranberry, Hill, Payne, Fostall, Kuskanax, McDonald, Mosquito, Caribou/Burton, Inonoaklin, Dog and Deer creeks. These tributary reaches consisted of low gradient pool and riffle areas suitable for spawning with spawning runs of prey species (e.g. kokanee, whitefish, rainbow and bull trout). These confluence areas would be expected to represent moderate to excellent burbot feeding and spawning habitat. Additional burbot angling was identified at Montana Slough (Peterson and Withler 1965b).

What is known is that the abundance of Arrow Lakes burbot was substantial enough to be attractive to commercial fishermen in the 1950’s and 60’s (Prince 2001). In the 1940’s, forest rangers stationed at Arrowhead would cross the frozen waters of Beaton Arm to jig for burbot on the mud flats, “There used to be big ling at the mouth of the Fish River. We set night lines for them using red fish as bait.” (Nakusp Historical Archives). Many old-timers confirmed that the Incomappleux River was an area with abundant burbot and fish up to 11 kg were not uncommon. Other areas of abundance were reported at Donnelly point/McDonald Creek, Halfway, St Leon, Kuskanax, and Sherborne rivers, and Galena Bay.

The mid-Columbia reach (e.g. Arrowhead to the Jordan River) was also identified as an area of abundance with plenty of large burbot (Prince 2001). Salmon Rock, the Tonkawatla Creek (a.k.a. Tum-tum) confluence area, and Big Eddy were reportedly good spots to capture burbot. These areas represent low velocity regions (i.e., deep eddies) within the main river that would provide excellent feeding opportunities by concentrating prey items.

The Narrows was also reported as an area of abundance (Prince 2001). The current burbot fishery centers around this area between Burton and Nakusp (Arndt 2004). In addition, there were several reports of juvenile burbot (< 30 cm) rearing in the narrows (Prince 2001).

Incidental catches of burbot during baited set line sampling for sturgeon in 1995 show that the species is widely distributed throughout the reservoir, from the mid-Columbia reach in the north to HLK Dam in the south (Arndt and Baxter 2006). In total, 132 burbot were captured (as incidental catch) in the reservoir during this program. These burbot ranged in length from 43 to 87 cm, with the dominant length-class between 65 and 70 cm total length (R.L.&L. 2001a). Directed sturgeon set line sampling in 2001 to 2003 in the Narrows (Macdonald, Mosquito, Burton Creek confluence areas) and the mid-Columbia reach (Arrowhead to Jordan River) demonstrated that burbot were present in abundance throughout these reaches in June through October (Prince 2003).

Recent creel surveys indicated a small but apparently growing fishery for burbot, most of which occurs in the narrows south of Nakusp (Arndt 2002, 2004). In 2003-2004, FWCP undertook a directed burbot stock assessment for the Arrow Lakes Reservoir (Arndt and Baxter 2006). Sampling confirmed that burbot were still abundant in two widely separated historical areas of abundance (Narrows and Galena Bay) over two years of sampling (Arndt and Baxter 2006). Relative abundance, as indicated by trap CPUE, appeared to be substantially higher than other British Columbia lakes sampled to date. The area south of Nakusp, in which the majority of burbot angling occurs, does not appear to be a single area of highly concentrated fish. Trap CPUE was similarly high in Galena Bay. The targeted study design approach (as opposed to randomly stratified) likely biases these CPUE results as areas of known historical and current abundance were targeted for sampling. Future assessments should incorporate standardized methodology (randomly stratified sampling completed within one month of ice-off or ice-up) to ensure validity of these conclusions.

Based on these results (R.L.&L. 2001a, Prince 2003, Arndt and Baxter 2006), the present Arrow Lakes burbot population can be characterized as follows:

1. Widely distributed within the reservoir;
2. Highest burbot abundance measured in the province thus far; and
3. Large in size relative to other British Columbia lakes.

Despite these data, dam operations may be hampering the productivity of burbot population(s) in Arrow Lakes Reservoir. Although outside the scope of this footprint impacts assessment, it is noteworthy that burbot were identified by the Columbia River Water Use Plan Consultative Committee (WUP CC) and the Revelstoke Unit 5 Core Committee as a species of concern in Arrow Lakes Reservoir because of the lack of data available on their biology and the hypothesized negative impact of reservoir operations on spawning success, egg survival and juvenile stranding.

Although it remains uncertain if the net footprint impact of HLK and Revelstoke Dams on the Arrow Lakes Reservoir burbot population is positive or negative, burbot abundance in this dam unit appears high before and after construction of the dams. Recent data suggests the population is widespread, relatively abundant, and healthy with many large sized, mature fish. The fishery appears stable and catch rate for those who target burbot is also relatively high when compared to other burbot fisheries. There may be operational opportunities for improvement in burbot population productivity, if future operational assessments of habitat use and spawning success can identify recruitment bottlenecks or critical habitat elements.

4.9 K1 Kootenay Headwaters (Kootenay Headwaters to Wardner)

There are no BC Hydro dams within this dam unit. This dam unit is notable in that several tributaries (Bull, St. Mary, Lussier, Skookumchuck, White, Palliser rivers) provide important spawning and rearing habitat for bull trout, westslope cutthroat trout and kokanee resident to Koocanusa Reservoir (Morris and Prince 2004, Manson 2006, Cope 2007).

The current population status of burbot within the Kootenay Headwaters dam Unit is unknown. Burbot are believed to be widely distributed within the Kootenay headwaters, but apparently are rarely captured. There is no known fishery targeting burbot within this dam unit. Most likely, limited numbers of burbot are distributed widely and reside in tributary confluence areas, deep pools and eddies within the mainstem river where prey items are concentrated (Ford et al. 1995). Burbot spawning has been reported in the Kootenay River at Fort Steele (G. Oliver, Oliver and Associates, Cranbrook, B.C. pers. comm. in McPhail 1997) and a single mature burbot was captured exiting the White River (Cope and Morris 2003).

At least some proportion of Koocanusa Reservoir burbot apparently undergo upstream migrations to utilize the upper Kootenay River spawning tributaries for pre-spawning feeding opportunities and spawning. A mature burbot was captured in the winter fishery on St. Mary Lake. This fish was notable as it was previously floy tagged in the American portion of Koocanusa Reservoir by Montana Department of Fish & Game (MDFG; B. Westover, MOE (retired), Cranbrook, B.C., pers. comm.). A second Koocanusa burbot radio tagged not far south of the international border was located near the mouth of Mark Creek, a tributary of the St. Mary River at Kimberley (Hammond and Anders 2003).

In 2006, the MOE closed the St. Mary Lake to burbot harvest due to concerns for the reduced abundance of this population. In 2005, St. Mary Lake CPUE (0.64 burbot per 48 hr set) using a random sampling design for abundance estimation was similar to Columbia Lake in 2006 (0.58 burbot per 48 hr set). By comparison, CPUE for burbot populations that are thought to be large and stable enough to maintain a productive fishery are much higher. Moyie Lake CPUE during the same fall 2005 sample session averaged approximately 4.17 burbot per 48 hr set (Prince 2007). Local anglers interviewed in the Moyie Lake burbot fishery indicated that several decades ago (early 1980's) the St. Mary Lake burbot fishery was as productive as the Moyie Lake fishery (Prince and Cope 2008). The mean Arrow Lakes CPUE using a targeted approach (as opposed to random) was approximately 9.6 burbot per 48 hr set (Arndt and Baxter 2006).

The lowermost 1 km of the Bull River is likely accessible to burbot, as is the lowermost reach of the Elk River. These tributaries are notable in that they provide spawning habitat for Kootenay River fish at the extreme upstream end of Koocanusa Reservoir (Whately 1972). Kokanee spawn in the lowermost reaches of the Bull and Elk rivers in large numbers (Manson 2006). Rocky mountain whitefish are also present and may utilize the lower reaches for spawning. Given the prey base and connectivity, seasonal use by Koocanusa burbot of the lowermost reach of the Bull and Elk rivers for feeding and spawning purposes should be assumed.

4.10 K2 Bull River (Upstream of the Dam)

The Aberfeldie Dam is a small hydroelectric run-of-the-river project built on natural fish barriers in a steep walled canyon approximately 12 km upstream of the confluence with the Kootenay River. Burbot are not present above the Aberfeldie Dam (Cope 2005). A partially destroyed dam (Tie Mill Dam) located approximately 2 km upstream from the confluence with the Kootenay River may represent a barrier to burbot. Upstream of the Tie Mill Dam, the Bull River is generally characterized as a confined, single channel with no side-channel or off-channel habitat (Cope and Rodman 2005). It is unlikely the Bull River above the Tie Mill Dam supports a population of burbot.

The 2 km downstream of the Tie Mill Dam is a depositional environment typical of a low gradient confluence and is notable in that it provides spawning habitat for Kootenay River fish. Kokanee spawn in this reach in large numbers (Manson 2006). Seasonal use of the lowermost reach of the Bull River for feeding and spawning purposes should be assumed.

The Aberfeldie facility is currently being re-developed and provisions for ramping rates and a flow bypass system (e.g. bypass valves) have been incorporated to mitigate for potential downstream dewatering should the generators trip offline (Cope 2005).

4.11 K3 Koocanusa Reservoir (Wardner to Canada – U.S.A. Border)

Although not a BC Hydro facility, Koocanusa Reservoir is a headwater storage and hydroelectric project that is an integral part of the Columbia Basin Hydro-electric network. In 1972, Libby dam was constructed approximately 27 km upstream from the town of Libby Montana; full pool was achieved in June 1974 (Hamilton 1990).

At full pool, this impoundment extends 145 km northward, with the upper 68 km of its length located in British Columbia from the international border to Wardner, B.C. Reservoir elevations are managed primarily for power and flood control purposes. In a year of average runoff, the reservoir is filled by August, and draw down commences in November and continues until April. Annual draw down of up to 52.4 m or 171.8 ft can occur (Chisholm et al. 1989). The full pool surface area is approximately 18,800 ha and the minimum pool area is 5,660 ha. These relative changes are greatest in the Canadian portion of the reservoir.

Unlike downstream reservoirs, the headwater Koocanusa Reservoir receives increased nutrients from the more calcareous rocky mountain trench drainage. Nutrients that used to ‘flush’ out to provide direct benefit to Kootenay Lake downstream now enhance productivity in Koocanusa Reservoir; it is now one of the more productive reservoirs within the Columbia Basin (Moody et al. 2007).

Total riverine habitat losses of 124 km are dominated by moderate elevation, low gradient streams and the Kootenay River (Thorley 2008). Whately (1972) provided the following general description, “The portion of Kootenay River in Canada to be flooded flows rather slowly with very little drop in elevation. Side channels, back eddies, and large, deep pools are interspersed with extensive shallow gravel bars.” In addition, a number of tributaries, principally the Bull and Elk rivers, Sand, Kikomun, Linklater and Gold creeks provide habitat and spawning conditions for Kootenay River Fish (Whately 1972).

There are contradictory reports of historical burbot abundance within the reservoir footprint area. Maher (1961) reports burbot were fished throughout the year in this reach of the Kootenay River before dam construction. Hammond and Anders (2003) report that a relatively productive burbot fishery existed in Montana upstream and downstream from the area now impounded by Koocanusa Reservoir. Due to reduced catch rates since dam construction (1972), historical fishing effort in Montana waters of the Kootenay River have shifted elsewhere (Hammond and Anders 2003). On the other hand, Chisholm et al. (1989) report burbot were considered uncommon in the Kootenay River before impoundment. Given the description of preferred burbot habitat features (Whately 1972, Maher 1961), and the abundant prey base (Whately 1972), the author is inclined to agree with the former assessment. First Nations traditional knowledge of burbot in this reach of the Kootenay River seems to corroborate the assessment that this dam unit supported a relatively productive burbot fishery before dam construction (M. Thomas, CCRIFC, Cranbrook, B.C., pers. comm.).

Historical trends (e.g. post 1950’s) in fish abundance and their relation to hydroelectric footprint impacts are difficult to determine due to significant water quality contamination and subsequent remediation in the late 1960’s and 1970’s. From 1953 to 1973, effluent from the Cominco phosphate fertilizer plant discharged to the St. Mary River. Prior to September 1968, Cominco’s industrial complex at Kimberley discharged to St. Mary River large and toxic amounts of sulphates, phosphates, fluorides, heavy metals and acid wastes (Whately 1972). Consequently, the St. Mary River became uninhabitable to fish and virtually devoid of bottom fauna. After 1968, commencement of pulp mill operations at Skookumchuck resulted in dark brown coloured water, unpleasant odours and foul tasting fish in the downstream reaches of the Kootenay River (Whately 1972). This appears to have resulted in a decline in abundance of Rocky mountain whitefish in the Canadian portion of the Kootenay River during the 1950's and 1960's (Whately 1972). In subsequent years, as Libby Dam and Koocanusa Reservoir became operational (1970's), more stringent pollution control measures have largely restored the "clean water" conditions.

At one time, this reach of the Kootenay River supported a winter mountain whitefish fishery of considerable importance (Whately 1972). In 1966, a creel survey for the months January through February documented over 10,000 Rocky mountain whitefish harvested. The average catch rate was 4.2 fish per hour or 15 whitefish per outing. Subsequently, deteriorating water quality resulting from upstream industrial activity reduced the importance of this winter fishery by reason of unsightly and odorous water conditions, and unpalatable fish flesh (Whately 1972). These confounding effects on fish populations within the Koocanusa Dam Unit illustrate the limitations of any interpretation of fish population monitoring since the 1950's for dam impact monitoring.

The fish species assemblage of Koocanusa Reservoir has undergone significant changes since impoundment in 1974. Before the dam, the fishery of the upper Kootenay River consisted primarily of bull trout, Westslope cutthroat trout, mountain whitefish and burbot (Maher 1961, Whately 1972). Since dam operations (1975 to 1987), the trout species and mountain whitefish have declined in abundance (Hamilton et al. 1990). Three introduced species (Kokanee, rainbow trout, yellow perch) and several native species (peamouth chub, northern pikeminnow, largescale suckers) have undergone large population increases in the 1980's in the reservoir (Chisholm et al. 1989).

Burbot gill net catch gradually increased from 1975 to 1987. Burbot were subsequently classified as common and increasing (Chisholm et al. 1989). Burbot in gill net catches ranged from 269 mm to 1,003 mm total length and 3 to 11 years old (Chisholm et al. 1989). At least 9 fish species were found in the stomachs of burbot (including cannibalism). Largescale suckers (fall and winter) and yellow perch (spring) were the most important food source for adult burbot. The creation of lacustrine habitat (Hamilton et al. 1990) and increased abundance of important prey species may have contributed to the increase in burbot catch rates (Chisholm et al. 1989).

The Montana Department Fish, Wildlife and Parks conducted burbot studies in Koocanusa Reservoir from 1994 to 1997 (Ostrowski et al. 1997 in Hammond and Anders 2003). A total of 16 mature burbot were radio or sonic tagged in the Rexford and

Tobacco Bay areas in Montana. A number of these burbot were tracked moving upstream as far as Wardner, B.C. and one fish was tracked moving upstream to the mouth of Mark Creek, a tributary to the St. Mary River. The recapture of a floy-tagged burbot in the St. Mary Lake winter fishery represented a 120 km migration from Koocanusa Reservoir south of the international border (B. Westover, MOE (retired), Cranbrook, B.C., pers. comm.). The utilization of tributaries and headwater mainstem river with abundant backwater habitat and a natural hydrograph may be an important or even necessary aquatic feature for successful spawning and early rearing by impounded burbot populations (Fisher 2000).

Koocanusa Reservoir has developed into a popular summer (mid-June to mid-September) fishery with anglers mainly targeting kokanee (Hartman and Martin 1987, Parnell 1997). In 1985 to 1987 the summer recreational fishery on Lake Koocanusa tripled in effort and catch (Hartman and Martin 1987). This level of effort and catch has been sustained through to 1996, the last known creel survey (Parnell 1997). Summer angling effort in 1996 was estimated to be 26,928 angler days, which resulted in a catch of 130,659 fish; 113,792 of which were kokanee (Parnell 1997). Kokanee were accidentally introduced into the reservoir between 1970 to 1974 (Manson 2006). In 1987, kokanee were the second most abundant fish species, behind peamouth chub (Chisholm et al. 1989). There was no reported summer burbot catch in these creel surveys.

A limited Ktunaxa First Nation winter food fishery for burbot is known to exist on Koocanusa Reservoir (M. Thomas, CCRIFC, Cranbrook, B.C., pers. comm.). A limited winter recreational fishery targeting burbot is also known to exist on Koocanusa Reservoir (A. Prince, Westslope Fisheries Ltd., Cranbrook, B.C., pers. comm.).

To date, there has been no directed burbot population or life history assessment for burbot within the Canadian portion of Koocanusa Reservoir or the upper Kootenay River. Based on the limited information available, it appears that the burbot population within the Koocanusa Reservoir has increased since inundation. However, this is tempered by the knowledge that the St. Mary Lake winter burbot fishery has collapsed and migratory Koocanusa Reservoir burbot appear to comprise some proportion of this fishery (*see K1 Kootenay Headwaters*).

Reservoir operations may limit the burbot population productivity for this dam unit. In 1972, fluctuating reservoir levels were of concern that they could inhibit spawning whitefish and burbot in the shallows of the reservoir and in the Kootenay River channel

(Whately 1972). The greatest potential impact of reservoir operations on burbot populations may be the dewatering effect of winter draw down on juvenile stranding, spawning success and egg survival in sites along the shoreline and in lower sections of tributaries. In addition, annual winter draw down has resulted in a severely impaired littoral zone eliminating complex and highly productive littoral or foreshore habitat typically utilized by juvenile burbot. There may be opportunities for improvement in burbot population productivity if future operational assessments of habitat use and spawning success can identify recruitment bottlenecks or critical habitat elements for protection.

4.12 K4 Elk River (Upstream of Dam)

Elk River Dam is a small hydroelectric run-of-the-river project built on natural fish barriers (falls) in a steep walled canyon. FISS (2008) does not report burbot present in the Elk River above the barrier and the falls. There are no known footprint impacts or obvious ecological linkages between the run-of-the-river Elk River Dam and possible burbot use of the lowermost reach of the Elk River.

4.13 K5 Kootenay River (U.S.A. Border to Kootenay Lake) and K6 Kootenay Lake

Kootenay Lake with a surface area of 39,400 ha was the largest lake of the Columbia Basin before hydroelectric development. Kootenay Lake has become increasingly regulated due to hydroelectric generation and flood control, beginning with Corra Linn Dam in 1932, Duncan Dam in 1967 and Libby Dam in 1973 (Moody et al. 2007). It has been estimated that 57% of the inflow into Kootenay Lake is regulated. Kootenay Lake levels, which fluctuate over a 2.5 m range, are governed by water releases from Duncan and Koocanusa reservoirs and run-off from unregulated tributaries (Moody et al. 2007). The surface area of Kootenay Lake has remained relatively unchanged by dam construction (Thorley 2008).

Burbot were once an important component of the fish community of Kootenay Lake and the Kootenay River between Kootenay Lake and Kootenai Falls in Montana. Historically, the literature suggests that all three life history forms of burbot (lacustrine, adfluvial, fluvial) often co-exist within the same system (McPhail 1997) and this appears to be the case in the Kootenay River and Kootenay Lake (Andrusak 1998, Spence 1999, Paragamian 2000, Paragamian and Wakkinen 2008).

It has been suggested that two or three sub-populations of burbot likely exist in Kootenay Lake, the stock that utilized the inlet to the West Arm and the stocks that utilized the extreme North and South Arms of Kootenay Lake (Andrusak 1998). There are differing views on the life history and by inference, the genetic and stock structure of the apparently extirpated West Arm burbot (Ahrens and Korman 2004). Hammond and Anders (2003) suggest these fish may have been unique in their late spawning strongly suggesting these fish were reproductively (temporally) isolated from upstream tributary or mainstem spawning fish. Creel data clearly identify ripe fish within the catch in early April (Martin 1976). Alternatively, these fish were staging at the outlet for feeding purposes and spawning elsewhere (i.e. Kootenay Lake tributaries, Kootenay River mainstem and tributaries) and were moving in and out of the area during the fishery. This view is supported by tagged fish from Idaho retrieved at Balfour (burbot and rainbow trout) and, despite extensive beach seining in the West Arm, no juvenile burbot were captured, which one would expect if they spawned at the outlet (H. Andrusak, Redfish Consulting, Nelson, B.C., *pers. comm.*).

Lake dwelling and mainstem river forms of burbot often migrate to streams in the late fall where spawning occurs in the winter months (McPhail 1997). Logical spawning sites would be the mainstem Kootenay River and its tributaries (Goat River, Summit, Boundary and Corn creeks), the Duncan and Lardeau rivers, and their tributaries, and possibly the West Arm of Kootenay Lake (Andrusak 1998). In the 1950's and 1960's, small burbot fisheries existed at the confluences of the Kootenay with the Goat River, and Summit, Boundary and Corn creeks. Tagging and telemetry studies in the Kootenay River in B.C. and Idaho have shown that burbot move between Kootenay Lake and the Kootenay River (Paragamian et al 2000). In addition to spawning tributaries in B.C. (Goat River, Summit and Corn creeks), traditional spawning tributaries in Idaho are 50 to 120 km from Kootenay Lake. Burbot spawning activity and the presence of juveniles have also been identified in the extreme north arm of Kootenay Lake (Spence 1999), although this population remains very small and may simply be a product of entrainment through Duncan Dam (C. Spence, MOE, Nelson, B.C., *pers. comm.*).

Historical burbot abundance before dam construction in these two Kootenay River dam units is unknown but considered abundant. Before European contact, early accounts by missionaries (1845-1846), forest rangers (circa 1900), and ethnography consultants (Turney-High 1941) clearly demonstrate fish comprised the principle diet and economic activity of the lower Ktunaxa “people of the waters” in these dam units. The Lower

Kootenay Band near Creston, B.C. carried out intensive communal fishing for a number of fish species including burbot and sturgeon using weirs, traps, spears, and setlines (Prince 2008). "February was burbot fishing season and the small creeks were full", (Alister Ross, Forest Ranger, paper on "The Lower Kootenay Indians", date unknown, Creston Valley Museum and Archives in Prince 2008). Mr. Ross even mentions fish weirs and traps still in place at Corn Creek, a known spawning tributary.

After European settlement of the area, Kootenay Lake and the Kootenay River in Idaho and B.C. provided a popular sport and commercial winter burbot fishery (Paragamian et al. 2000). This fishery may have been the most robust in North American in the 1950's to 1970's (Paragamian et al. 2000). As early as the 1930's, a tourism marketing pamphlet for the Kootenay and the city of Nelson mention fishing for burbot. This pre-dates the well documented Cominco fertilizer plant enrichment period and the construction of the major dams.

Burbot were the target of a significant sport fishery at the inlet to the West Arm in Kootenay Lake (Martin 1976) and a late summer fishery occurred at the extreme north end of Kootenay Lake in the vicinity of the Duncan River Delta (Andrusak 1998). During the peak of this fishery in the late 1960's and early 1970's, harvest of burbot at the inlet to the West Arm near Balfour ranged from a high of 26,000 fish in 1969 to a low of 20 in 1986 (Martin 1976, Andrusak 1998, Ahrens and Korman 2002). During this same time period, as much as 50,000 lbs of burbot were annually harvested from the Kootenay River in Idaho (Andrusak 1998). In the 1950's and 1960's, small burbot fisheries existed at the confluences of the Kootenay with the Goat River, and Summit, Boundary and Corn creeks. These fisheries were almost exclusively spear fishing at night presumably directed at spawning fish (Andrusak 1998). Modeling results suggest that the Kootenay Lake burbot population before 1967 numbered approximately 200,000 individuals (Ahrens and Korman 2002). It is possible that burbot productivity in these dam units was enhanced during the model period by the input of nutrients during the fertilizer plant era (1953-1970's).

After construction of Libby Dam in 1972, the fishery in both Kootenay Lake and the Kootenay River rapidly declined. The Kootenay River fishery in Idaho was closed in 1992 and the Kootenay Lake fishery in B.C. was closed in 1997 (Paragamian et al. 2000). Currently, the Kootenay Lake population has been red listed (e.g. at risk of extirpation) by the B.C. Conservation Data Centre (CDC 2008) and the West Arm sub-population at Balfour is thought to be extirpated (Neufeld 2006). Remnant populations of burbot remain in the extreme North Arm of Kootenay Lake and the Duncan-Lardeau watershed including Duncan Reservoir and Trout Lake (Neufeld 2006). In the Kootenay River in B.C. and Idaho, the population has been estimated at less than 50 individuals (Pyper et al. 2004 in Neufeld 2006).

The population collapse has been attributed to over harvesting, spawning and early rearing habitat degradation, and the affects of Libby Dam (Andrusak1998, Spence 1999, Ahrens and Korman 2002). Paragamian et al. (2000) analyzed creel data and concluded that over harvest was not the cause of the burbot decline in Kootenay River or Kootenay Lake, but rather habitat changes that prevented successful recruitment. Winter hydropower and flood control flows from Libby Dam upstream have been implicated as the key problem due to their impacts on burbot migrations and reproductive success (Spence 1999, Paragamian and Laude 2007, Paragamian and Wakkinen 2008). These impacts are further compounded by a number of additional factors including extensive dyking and channelization of spawning and early rearing habitat (Andrusak 1998, Cope 2001, Anon. 2002), changes in nutrient loading to Kootenay Lake due to the Cominco fertilizer plant in Kimberley, introduction of mysid shrimp to Kootenay Lake, and shifts in the demersal fish community (Ahrens and Korman 2002).

Oligotrophication of Kootenay Lake during the late 1970s has been well documented by a number of researchers (Moody et al 2007). Since 1992 in the North Arm, and 2004 in the South Arm, experimental fertilization of the lake has been conducted using an adaptive management approach in an effort to restore lake productivity lost as a result of nutrient uptake in upstream reservoirs (Schindler et al. 2007a). Results of the fourteenth year of the Kootenay Lake fertilization experiment (North Arm) indicate that kokanee restoration has been successful by replacing nutrients lost as a result of upstream impoundments. The data illustrates that all trophic levels have responded to the nutrient additions with kokanee numbers reflecting this successful bottom up approach (Schindler et al. 2007a).

However, given the failure to restore the Kootenay Lake burbot population over the last 15 years, it appears nutrient restoration alone will not provide a solution for burbot management. Ahrens and Korman (2002) suggest it seems reasonable to assume that the burbot fishery collapsed as a result of recruitment failure but the collapse was accelerated, substantially, by harvest. Modeling results (Ahrens and Korman 2002) suggested it was likely that changes in the West Arm of Kootenay Lake community structure, most noticeably the increases in mysid densities, resulting from increased productivity (via nutrient loading) caused a substantial reduction in the cladoceran community through competition and predation. The increase and subsequent collapse, in 1964, of the cladoceran community likely resulted in a catastrophic reduction in juvenile burbot food resources resulting in recruitment failure.

Operation of Libby Dam has created major changes in the river's seasonal discharge, particularly during the winter when burbot spawn (Paragamian and Laude 2007, Paragamian and Wakkinen 2008). Flows are now three to four times higher during winter than in pre-impoundment years but lower in the summer. These flows are altered further by containment within flood control dykes. Biotelemetry results suggest that spawning migrations of burbot in the Kootenay River may be disrupted by high flows produced during hydropower production and flood control (Paragamian 2000, Paragamian and Wakkinen 2008). The temperature regime and nutrient supply of the Kootenay River are also thought to be important factors for burbot spawning and recruitment; they too have changed since construction of Libby Dam (Paragamian and Laude 2007).

The construction of Duncan Dam may also have impacted the Kootenay Lake burbot population. Potential impacts include the loss of burbot and kokanee spawning habitat at the lake outlet and the loss of habitat connectivity between rearing areas in the lower Duncan River and the extreme North Arm of Kootenay Lake and potential spawning habitat above the dam. There may be similar operational issues related to high winter flows and interference or disruption of spawning migration. These potential impacts to the North Arm and Duncan Lake burbot population are discussed in the following section (*see* K7 Duncan Lake).

Significant habitat destruction has occurred in the lower reaches of the Kootenay River spawning tributaries, particularly in the 1960's (Andrusak 1998, Cope 2001, Anon. 2002). The Goat River has been subject to major gravel removal operations during the years 1948 to 1985 (Cope 2001). The lower reaches of the Goat River or the Goat River Bottom Lands, as the area is generally known were first subdivided in 1909. Since then the Goat River has had a long and extensive history of severe channelization due to channel diversion, flood control and subsequent settlement (Prince and Cope 2001, Andrusak 1998). The destruction of spawning habitat has not only impacted burbot but also the once numerous kokanee runs to the Goat River that are also on the verge of extirpation (Prince and Cope 2001). The lower reaches of the other two known burbot spawning streams (Summit and Corn creeks) were diverted and channelized in the 1960's and 1970's (Andrusak 1998). The Creston Valley Wildlife Management Act was passed in 1968, after which a network of additional dykes was built to manage the marsh levels for waterfowl (Anon. 2002). Most of the CVWMA area (nearly 7,000 ha) is affected by these dykes. This may have been a major spawning and early rearing area for Kootenay Lake burbot that was inadvertently destroyed.

Based on intensive sample effort, most of the burbot captured in the Kootenay River since 1993 have been in the general vicinity of the Goat River, which appears to support the majority of spawning within this reach of the Kootenay River (Paragamian and Laude 2007). In February 2002, an enumeration fence documented 11 ripe burbot entering the Goat River (Bisset and Cope 2002). During the fall of 1994, one juvenile burbot was sampled in the Goat River and in 1999 one larval burbot was sampled in the Kootenay River in the vicinity of the Goat River (Hammond and Anders 2003).

As mentioned previously, this section of the Kootenay River represents the upper Kootenay River delta and was historically characterized by an extensive floodplain with a diversity of aquatic habitat represented by the mainstem river, small shallow lakes, sloughs, swamps and streams. Not only have the lower reaches of the tributaries been altered, diverted and channelized, so has the mainstem Kootenay River. Starting with the 1909 subdivision and reclamation of the Goat River “bottom lands”, a series of flood control dykes, gates and waterfowl enhancement works have effectively isolated the vast majority of the floodplain from the mainstem river.

Since 1997, the Kootenay Lake burbot population has been the focus of management activity in order to stabilize and rebuild the population (Baxter and Spence 2001). Currently, a conservation strategy for Kootenay River burbot is in the process of being implemented (Paragamian and Laude 2007, Neufeld 2006). Operational discharge changes at Libby Dam are required to provide suitable conditions for burbot spawning migration (e.g. flows and temperature). This population is no longer self-sustaining and a burbot culture program is in the early stages of being developed to provide progeny to enhance the Kootenay River stock. A nutrient restoration experiment has been initiated for the Kootenay River in Idaho by the Kootenay Tribe of Idaho and the Idaho Department of Fish and Game and for Kootenay Lake below Duncan Dam (Schindler 2007a).

4.14 K7 Duncan Lake

The Duncan Dam was constructed in 1967 to provide storage for flood control and optimize energy generation at downstream facilities in Canada and the U.S. (Vonk

2001). Duncan Reservoir has a surface area of 7,140 ha (Vonk 2001). Losses of small streams and small and medium rivers total 42 km, 12 km and 46 km, respectively (Thorley 2008). The medium sized Duncan Lake (2,600 ha) and 172 ha of shallow water habitat was inundated (Thorley 2008). Reservoir operations result in an annual draw down of approximately 30 m resulting in a dewatered area of 5,153 ha. This results in a surface area reduction of 72% from full pool and the minimum pool surface elevation approximates the original Duncan Lake (Vonk 2001).

Before inundation, Duncan Lake divided Duncan River into two portions, the upper and lower Duncan River. Duncan Dam is located on the lower Duncan River. It is situated 1.6 km upstream from the Lardeau River confluence, approximately 5 km downstream from the original Duncan Lake outlet, and 8 km upstream from Kootenay Lake. The upper Duncan River is formed by a large number of small precipitous streams fed by melt-water from snowfields and glaciers, and is highly turbid during spring and summer (Peterson and Withler 1965a). The valley occupied by the reservoir is approximately 1.6 km wide, and is walled by moderately steep mountains (Selkirk and Purcell Mountains). The lower Duncan River is a meandering, braided river with an abundance of side channel and off-channel habitats that culminate in a large silt/sand delta spanning the extreme north end of Kootenay Lake.

The species most affected by the construction of the Duncan Dam are thought to include kokanee, rainbow trout and, to a lesser extent, bull trout. It is also likely that the dam affected migrations of burbot and whitefish; however, there is insufficient information regarding their spatial and temporal distribution in the river to quantify the impact (Vonk 2001).

The footprint impacts of Duncan Dam depend on the life history strategy of resident burbot populations. As there is no pre-dam life history information available for burbot populations in this dam unit, all that can be done is to provide an opinion based on habitat features, other species and other burbot populations. What is known is that before the dam there was habitat connectivity between Kootenay Lake and Duncan Lake and the upper watershed. It is also known that both the lower and upper Duncan River systems supported abundant migratory runs of spawning kokanee, rainbow and bull trout (Peterson and Withler 1965a, Vonk 2001). As with burbot, kokanee are generally not considered strong swimmers. This suggests burbot could have accessed the same habitat for pre-spawning feeding migrations and/or subsequent spawning migrations.

The placement of the Duncan Dam approximately 5 km downstream from the Duncan Lake outlet resulted in the flooding and loss of prime spawning gravel beds in the lower Duncan River and Glacier Creek (Peterson and Withler 1965a). Similarly, the Duncan Dam flooded approximately 25 km of upper Duncan River upstream from the historic Lake inlet. This reach contained much gravel that was probably used for spawning purposes (Peterson and Withler 1965a). Peterson and Withler (1965a) also describe extensive slough areas in the lower Duncan River and immediately upstream of the upper Duncan River inlet. They rated these sloughs as excellent rearing ponds for juvenile game fish. These slough areas were also inundated. Downstream slack water areas are another repeating feature of preferred burbot spawning habitat (McPhail 1997, Fisher 2000).

Following construction of Duncan Dam, migratory runs of sportfish from Kootenay Lake were excluded from historic spawning and rearing areas in both the lower and upper Duncan River system (Peterson and Withler 1965a, Vonk 2001). Although it remains unknown if migratory runs of burbot existed, the potential impacts of the habitat losses due to the Duncan Dam are best illustrated by kokanee. The Duncan-Lardeau River system historically accommodated the largest spawning runs of kokanee from Kootenay Lake. The Duncan run represented about 75% of the kokanee in the system. Construction of the Duncan Dam eliminated access to upstream spawning habitat for this run, which was estimated at 2.8 million fish in 1964. Following dam construction, total escapement to the Duncan-Lardeau system declined to 625,000 fish from an estimated 4.5 million fish in 1964 (Vonk 2001).

It is known that prior to construction of the Duncan Dam, a burbot fishery of some magnitude was lightly exploited in the lower Duncan River and Duncan Lake (Peterson and Withler 1965a), and a late summer fishery occurred at the extreme north end of Kootenay Lake in the vicinity of the Duncan River (Andrusak 1998). Recently, in 2005-06, the Duncan Reservoir burbot population was estimated at 2,983 mature fish (95% C.I. 1,011 – 10,810; Neufeld 2006). Duncan Reservoir burbot are genetically similar to burbot from Kootenay Lake and the Kootenay River in Idaho (Baxter et al. 2002b, Neufeld 2006) suggesting some gene flow between these known burbot concentrations and potential spawning areas.

While the life history and stock status of Duncan Lake burbot before the dam is unknown, recent studies have provided some insight into important habitats, the status of remnant stocks, and impacts of dam operations on burbot in the Duncan system

(Neufeld 2006, Spence and Neufeld 2002, Baxter et al. 2002a, 2002b, Spence 1999, Andrusak 1998). Burbot spawning activity has been identified at the north end of Kootenay Lake near the mouth of the Duncan River (Spence 1999). Burbot spawning activity has also been identified in the reservoir – tributary transition area near the elevation of the original Duncan Lake at two locations; Glacier Creek (e.g. lower Duncan River before impoundment) and in the upper Duncan River (Spence and Neufeld 2002). Both of these locations were previously identified by Peterson and Withler (1965a) as “gravel beds” probably used by sportfish for spawning.

Entrainment of individual burbot has been documented at Duncan Dam in two separate studies (Ord and Olmsted 2000, Spence and Neufeld 2002), and this data lends support to the theory that the small population of burbot at the north end of Kootenay Lake may be Duncan Reservoir fish that are entrained through the dam (Vonk 2001). These fish may or may not have originally been derived from adfluvial stock from Kootenay Lake that were impounded when Duncan Dam was constructed. Given the apparent genetic similarities and habitat fragmentation by Duncan Dam, it is difficult to consider the Duncan watershed burbot in isolation of Kootenay Lake and the Kootenay River.

In summary, it appears that significant footprint impacts may be limiting the productivity of burbot within Duncan Reservoir. Construction of Duncan Dam has resulted in the loss of habitat connectivity between Duncan Lake and the lower Duncan River, the loss of spawning habitat at the outlet of Duncan Lake and the loss of kokanee spawning runs to the lake outlet. Furthermore, the Duncan Reservoir is characterized by extreme annual water level fluctuations of up to 30 m. Operational impacts may also be contributing to spawning and recruitment bottlenecks.

4.15 K8 Lardeau River

There are no dams in this watershed. The only potential linkage to BC Hydro footprint impacts in this dam unit are potential impediments to fish migration and habitat use within the 5 to 6 km reach of the lower Duncan River from the confluence of the Lardeau River to Kootenay Lake. The hydrograph and temperatures of the lower Duncan River have been altered due to Duncan Dam operations.

A burbot population is known to exist in Trout Lake, and young-of-the-year burbot have been captured in the Lardeau River in close proximity to the Trout Lake outlet at Gerrard (Baxter et al. 2002b). The results of a directed stock assessment and radio telemetry study suggest a substantial population of burbot resident to Trout lake with the capture effort comparable to, and potentially higher than Duncan Reservoir. Burbot spawning activity was identified at the outlets of small creeks where they enter Trout Lake.

4.16 K9 Corra Linn to Briliant Dam (Slocan Lake)

There are a total of six hydroelectric facilities within this dam unit; only one, the Kootenay Canal facility, belongs to BC Hydro. Kootenay Canal has a very small footprint (49 ha) and is located at the head of a narrow, steep-sided valley with numerous natural falls and migration barriers. It is unlikely that there are any significant footprint impacts to burbot on the short stretch of river represented by Kootenay Canal. Kootenay Canal is a run-of-the river facility located on a natural barrier to fish passage. This reach is dominated by fast-flowing river characteristics within a confined canyon and limited habitat availability would suggest very low burbot potential.

Brilliant Dam was constructed in 1944 on the Kootenay River 3 km upstream from the confluence with the Columbia River. Although this could have blocked upstream migrations of Columbia River and lower Kootenay River burbot into the Slocan River and Slocan Lake, this would seem unlikely given the low swimming endurance of burbot and the long migration required through several points of difficult passage (e.g. Brilliant Dam site and lower Slocan River).

Slocan Lake (6,929 ha) is relatively deep (mean depth 171 m), cold and nutrient poor, which limits biological productivity. There are few shallow-water habitats because of the steep-sided slopes of the valley, which limit the amount of suitable habitat in the reservoir for many species of fish. Slocan Lake burbot are likely not affected by footprint dam impacts.

Incidental catches of burbot during baited setline sampling for sturgeon in 1995 and 1996 show that the species is abundant in the northern end of the Lake (e.g. Bonanza Creek outlet; R.L.&L. 1997). In total, 51 burbot were captured (as incidental catch) during this program. These burbot ranged in length from 42 to 71 cm, with the dominant length-class between 55 and 60 cm total length (R.L.&L. 1997). Bonanza Creek (a tributary to Slocan Lake) is known to have produced notable catches of large burbot in the fall some 30 years ago (Prince 2001). In 1999 an estimated 30,000 kokanee spawned in Bonanza Creek (Gebhart 2000). These fish would represent a concentrated food source and a pre-spawning feeding migration of burbot would be expected.

5. Compensation Options Related to Footprint Impacts for Burbot.

5.1 Recommendations for Further Study

Limited data, particularly pre-impoundment data, severely constrain the current burbot assessment. In addition, significant burbot stock collapses have occurred that are either unrelated to hydroelectric development or confounded by, among other things, changes in nutrient inputs, mysid shrimp introductions, habitat destruction and over-harvest over the last half century (Martin 1976, Andrusak 1998, Prince 2001, Ahrens and Korman 2004). Furthermore, to date, many reservoir and stream populations of burbot within the Columbia Basin have never had any form of directed population, life history or habitat utilization assessment. Therefore, it is very difficult to definitively assign any burbot population decline to footprint impacts of BC Hydro dams.

The following research needs are required to better understand burbot life history, population dynamics and potential compensation options within the Columbia Basin footprint units;

1. Further study of the different life history types and population dynamics within the Columbia Basin sub-populations is urgently required, particularly given the considerable variability of the species basic life history requirements and habitat use (McPhail 1997). These data gaps, particularly in relation to reservoir operational concerns for burbot need to be addressed. Priorities include the large reservoirs (Koocanusa, Kinbasket, Arrow Lakes, Duncan) that are characterized by extreme annual water level fluctuations and burbot populations that appear to have reasonable abundance.

2. Given the history of collapse in burbot fisheries and populations, some method of assessing adult numbers and recruitment of sub adults to the breeding population is essential. Here the Alaskan experience is invaluable (Bernard et al. 1993), and recently, MOE has taken advantage of these assessment methods in the East Kootenay (Prince 2007). As a first priority, in collaboration with MOE, these methods should be applied in a standardized manner to populations in Arrow, Duncan, Kinbasket, and Koocanusa reservoirs.

3. Collection, compilation and summary of existing burbot life history data (length, weight) and CPUE data (sturgeon set-line by-catch and targeted trapping) from the various individual data sources are recommended.

5.2 Recommendations for Compensation Options

River and creek confluence areas and low gradient tributaries are suspected to be or have been documented as burbot spawning locations in many dam units (McPhail 1997, Andrusak 1998, Prince 2001, Baxter et al. 2002b, Spence and Neufeld 2002, Arndt and Baxter 2006, Paragamian and Laude 2007, Westover 2007). Littoral zones and low gradient spawning tributaries provide critical juvenile rearing habitat and spawning habitat (McPhail 1997, Baxter 1998, Taylor 2002). Functioning backwater or off-channel habitat appears to be important habitat for early life history stages and the maintenance of burbot populations in large river systems (Fisher 2000). These habitats have been the most impacted by dam construction and reservoir operation and should be priorities for mitigation and compensation. Migratory life history forms would be at a disadvantage where hydroelectric or water storage facilities may have isolated spawning and rearing habitat (e.g. HLK, Libby and Duncan dams).

In the case of BC Hydro dams, replacement of 1,700 km of riverine habitat, much of which is large river habitat is simply not possible; regardless of the cost (Thorley 2008). Consequently, for the BC Hydro dam units, "*Compensation options are quite limited within the new 'footprint' and nutrient supplementation has gained pre-eminence over other options that have been precluded due to either low nutrient inputs, or large draw downs and the presence of a non-functional littoral zone*", (Moody et al. 2007). Unfortunately, in the case of burbot, potential recruitment bottlenecks related to the suitability of spawning habitat within reservoirs characterized by winter draw-down, and the reliance of early life stages on low gradient shallow water habitat and the littoral zone, may limit the efficacy of this compensation measure for burbot.

The following compensation options are proposed as most likely to benefit burbot populations or sub-populations within the Columbia Basin dam units;

1. Fertilization or nutrient (P and N) restoration that increases C production in the reservoirs should be continued as an ecosystem recovery approach. The approach of increasing kokanee escapements seems logically to benefit a pisciverous predator such as burbot, particularly given their tendency to pre- and post spawning feeding migrations to areas of prey concentration. Estimated costs are provided in Moody et al. (2007).
2. Pending completion of detailed life history and habitat utilization studies, additional fertilization experiments such as embayment or littoral (shoal) fertilization as proposed in Moody et al. (2007) may have potential to target

habitat and/or life history “bottlenecks”. Estimated costs are provided in Moody et al. (2007).

3. Young-of-the-year and juvenile burbot often concentrate in large rock along the shoreline (Taylor 2001, McPhail 2007). Physical shoreline enhancement structures within littoral areas where burbot young-of-the-year are known to concentrate could present an early life history habitat enhancement option. It might be ideal to couple such works with embayment fertilization. Estimated costs for shoreline enhancement structures (e.g. rock groins) would depend on access for heavy equipment and the distance from the rock source; however, standard metrics for instream habitat restoration likely apply (i.e. $90,000 per km in 1996 Canadian dollars, Slaney and Martin 1997).

4. The feasibility of artificial propagation techniques for Columbia Basin burbot is in the early stages of investigation (Paragamian and Laude 2007, Jensen et al. 2008). Intensive burbot culture techniques are experimental and as yet are untested; however, there may be potential for artificial stocking as an interim management tool to preserve and propagate Kootenai River burbot and genetically related stocks of special concern. Investment in research and development to explore the potential of these techniques is recommended. For interim cost estimates the reader is referred to the funding agencies for the Idaho program (Kootenai Tribe of Idaho, Idaho Fish and Game Department, Bonneville Power Administration).

5. The logical stock recovery option for the Kootenay Lake burbot population is to focus efforts on the remnant populations at the extreme North Arm of Kootenay Lake and in the extreme South Arm of Kootenay Lake and the B.C. portion of the Kootenay River.

    a. Although little is understood on the footprint impact of the BC Hydro dams on the burbot populations, there do appear to be operational mitigative opportunities for improvement in burbot population productivity. One apparent bottleneck has been identified for the Kootenay River and operational discharge changes at Libby Dam are required to provide suitable conditions for burbot spawning migration downstream (e.g. flows and temperature; Paragamian 2000). There may be opportunities for similar operational remedies to improve burbot productivity in the lower Duncan River, the mid-Columbia reach below Revelstoke, and the lower

Columbia reach below HLK. Directed life history and habitat use assessments are required to identify potential recruitment bottlenecks.

b. A floodplain ecosystem recovery plan for the Kootenay River and it's tributaries or "bottom lands" is likely required to restore burbot abundance in the B.C. portion of the Kootenay River. Habitat restoration or "floodplain reclamation" is daunting in scale and options are limited by the long history of flood protection infrastructure and existing private land values behind this infrastructure. The Goat River and in particular the severely degraded south channel of the Goat River, provide a unique opportunity to implement an ecosystem recovery plan on a manageable experimental scale (Prince and Cope 2001). Ideally, this experimental ecosystem recovery plan would include; (1) flow rehabilitation, (2) dyke removal and off-channel/wetland connectivity and restoration, (3) instream fish habitat restoration, (4) nutrient restoration, (5) burbot and kokanee embryo transplanting and donor stocking, and (6) restoration of Kootenay River connectivity. The majority of the land and resources required for such an experiment are located on Lower Kootenay Band (LKB) reserve lands and oral history of the LKB identifies this area as historic burbot, sturgeon and kokanee spawning and rearing habitat. Reliable cost estimates for such a program are not available. Given the requirements for flood control structures, hydraulic assessments, civil engineering, compensation for private land values and donor stocking, standard metrics for instream habitat restoration do not apply (i.e. $90,000 per km in 1996 Canadian dollars, Slaney and Martin 1997). A more accurate estimate may be the $787,000 per km referenced by Thorley (2008). The lower Goat River and South Channel represent approximately 4 km for each channel over a meandering wetland complex. An initial working estimate for proposed works would be in the order of $10 million Canadian dollars, based on $787,000 per km. A multi-disciplinary assessment team would be required to develop a site-specific cost estimate; once clearly defined project scope and terms of reference were identified.

6. Operational remedies may provide some of the best opportunities for compensation options. In addition to operational discharge changes to provide suitable conditions for burbot spawning migration downstream of facilities

mentioned above, altering current water use patterns such as, for example, limiting winter draw down during the burbot spawning and incubation period may provide significant population productivity benefits to burbot populations within the large headwater reservoirs characterized by extreme variation in water elevation. Site-specific life history and habitat utilization data is required to determine the potential benefits for such measures.

7. The best opportunities for compensation options may be in non-impacted dam units. This recommendation has particular relevance for burbot as the burbot populations or sub-groups within several pre-eminent non-impacted dam units (e.g. upper Kootenay and upper Columbia rivers and lakes) are considered to be either severely reduced or threatened. These populations have a long history of utilization by basin residents and first nations and restoration or enhancement provide an excellent opportunity for BC Hydro and FWCP to meet their mandate for conservation and enhancement.

8. Since Grand Coulee dam on the Columbia River in Washington (completed in 1942) prevents the upstream migration of fish species, BC Hydro dams are not considered responsible for the losses of anadromous salmon runs to the FWCP region. Nonetheless, these losses have resulted in the loss of a concentrated prey species, decomposing flesh and a decrease in nutrient inputs to streams, rivers and lakes in the region. The decline of upper Columbia River burbot populations and the disappearance of the very large individuals that were historically captured in places such as the Spillimacheen River, Athalmeer (Windermere Lake outlet) and Dutch Creek were also associated with a run of very large chinook salmon. Thus, there may be a case for further nutrient supplementation in these reaches to enhance productivity, and kokanee runs.

6. Summary

Of the 12 dam units where burbot are present within the reservoir (Table 1), one has likely increased in population abundance, five have probably decreased in abundance and the population status of the remaining six dam units are unknown. General life history and habitat utilization data suggest the spawning, incubation and early rearing life stages of burbot are the most likely to be negatively impacted by changes in aquatic habitat due to inundation (Table 2). Alternatively, adult burbot probably benefit from the large increase in lake habitat that supports kokanee, a key food source.

The historic upper Columbia Basin before dams was largely river dominated. Currently, the upper Columbia Basin is a 'staircase' of dams and reservoirs that have transformed the riverine ecosystem into a series of large isolated lacustrine depositional basins. Flooding of the valley bottoms has inundated the river and creek confluence areas, lower reaches of low gradient tributaries, backwater or off-channel areas and low velocity regions within main rivers. These habitat features represent critical burbot rearing and spawning habitat. These habitat features have been the most impacted by dam construction and reservoir operation and should be priorities for mitigation and compensation.

Although footprint impacts have radically altered the aquatic habitat features of the Columbia Basin and have likely caused some habitat reductions or losses in some dam units, it is very difficult to definitively assign any burbot population decline to footprint impacts of BC Hydro dams. Assessment of the potential footprint impacts of BC Hydro dams on burbot populations in the Columbia Basin are constrained by a lack of data regarding basic burbot life history, distribution, and population status prior to dam construction. Potential impacts are further confounded by significant burbot stock collapses that have occurred that are either unrelated to hydroelectric development or coincide with, among other things, changes in nutrient inputs, mysid shrimp introductions, habitat destruction and over-harvest over the last half century (Martin 1976, Andrusak 1998, Prince 2001). Highly successful and popular burbot fisheries in Kootenay Lake, Kootenay River and the upper Columbia River and lakes were collapsing during the late 1960's and 1970's, immediately prior to or coincident with the construction of most of the Columbia River Treaty Dams.

Table 2. Generalized summary of potential aquatic habitat impacts due to BC Hydro dams by burbot life stage.

Life Stage	Overall Impact	Rationale
Spawning/ Incubation	Negative	For existing lakes, dams have resulted in more seasonal inundation of important lacustrine incubation habitats. Low gradient streams that meet the criteria for this life stage are generally permanently or seasonally inundated. Some key spawning and incubation sites may be dewatered during incubation (largely operational impact). Higher winter flows and altered thermal regime interferes with spawning migration (largely operational impact).
Larval	Negative	The majority of functioning backwater or off-channel habitat has been eliminated and appears to be important habitat for early life history stages. Dams have created more lake habitat, which can be preferred by larval burbot. However, this lake habitat must support appropriate levels of productivity to support larvae, and reservoir productivity may not be enough for good survival. This condition is exacerbated by the severely impaired littoral habitat (largely operational impact).
Juveniles	Mixed	Many low gradient streams that could have provided important rearing for young juveniles are now inundated or otherwise affected by dam operations. Dams have created more lake habitat, which can be used but not necessarily preferred by juvenile burbot. However, this lake habitat, and in particular, the littoral zone must support appropriate levels of productivity to support the juveniles. Potential stranding (operational impact) and elimination of highly productive and complex littoral or foreshore habitat due to frequent desiccation and/or inundation keeps communities in a perpetual state of early succession (largely operational impact). Once juveniles are large enough to shift to eating fish, there may be benefits (i.e. kokanee).
Adults	Positive	Lakes are a preferred habitat for adults and increases in large lake habitat, which supports kokanee, a key food source for adults, may have an overall benefit.

Shallow shoals, littoral zones and the lower reaches of low gradient tributaries provide critical juvenile rearing habitat and spawning habitat. The majority of the large Columbia Basin reservoirs are characterized by extreme annual water level fluctuations, and the current littoral zone of these reservoirs is severely impaired; frequent desiccation and/or inundation keeps communities in a perpetual state of early succession (CCRIFC 2007, Moody et al. 2007). Olmsted (1994 *in* R.L.&L. 2001a) noted that draw down effects within the littoral zone of Kinbasket Reservoir have resulted in a shift from a littoral-based food web to a plankton-based food web, with the fish community dominated by kokanee (a planktivore) and bull trout (a predator that feeds upon kokanee).

In addition to concerns for burbot in reservoirs, there are concerns related to regulation of downstream flows. Higher than normal winter flows appear to have negative impacts on spawning migration and spawning and rearing success in downstream reaches due to the altered hydrograph and thermograph and the timing and severity of habitat dewatering.

These data gaps, particularly in relation to reservoir operational concerns for burbot need to be addressed. Priorities include the headwater reservoirs (Koocanusa, Kinbasket, Arrow Lakes, Duncan) that are characterized by extreme fluctuations and burbot populations that appear to have reasonable abundance. Downstream reaches (mid-Columbia below Revelstoke, lower Columbia below HLK, Kootenay below Libby, lower Duncan) are also of concern for winter spawning migrations and habitat stranding due to the altered hydrograph and the frequency and extent of flow fluctuations.

7. Acknowledgements

Funding for this project was provided by BC Hydro through the Fish and Wildlife Compensation Program (FWCP). The FWCP was established in 1995 to offset the impacts resulting from the construction of BC Hydro dams in the Columbia Basin, and works to deliver a wide range of conservation and enhancement projects for fish and wildlife, on behalf of its Program Partners BC Hydro, the BC Ministry of Environment (MOE), and the Department of Fisheries and Oceans (DFO) Canada.

James Baxter and Steve Arndt (FWCP) provided guidance, advice and invaluable support throughout this project. Steve Arndt is gratefully acknowledged for his review efforts of the early draft version of this report. Previous Phase 3 reports by Moody et al. (2007) and Thorley (2007) were important references for habitat impacts, background, objectives and text.

Colin Spence and Matt Neufeld (MOE) were immensely helpful in sharing their knowledge of burbot within the Columbia Basin and their guidance to various literature sources.

Steve Arndt, Colin Spence, Robert Bison, Alan Caverly (MOE) and Vaughn Paragamian (IDF&G) provided valuable comments to the draft of this report. Being acknowledged as a reviewer does not constitute an endorsement of all aspects of the report.

8. References

Ahrens, R. and J. Korman. 2004. An Evaluation of Available Data to Assess BC Hydro Dam Footprint Impacts in the Columbia River Basin, British Columbia and Phase II Recommendations. Report prepared for the Columbia Basin Fish & Wildlife Compensation Program.

Ahrens, R. and J. Korman. 2002. What happened to the West Arm burbot stock in Kootenay Lake? Use of an age-structured population model to determine the possible causes for recruitment failure. Report prepared for BC Ministry of Water, Land, and Air Protection. Nelson, B.C.

Andrusak, H. 1998. Investigation of burbot in Kootenay Lake. Prepared for B.C. Ministry of Environment by Redfish Consulting Ltd., Victoria, B.C. 22 pp. + 2 app.

Andrusak, H. 1976. Upper Arrow Lake Sport Fishery 1976. Fish and Wildlife Branch.

Andrusak, H. and A.D. Martin. 1982. Angler Use and Harvest of Fish on the Columbia River from the Keenleyside Dam Downstream to Trail: A Summary Report on Creel Census Data Collected from 1976 to 1982. British Columbia Fish and Wildlife Branch, Nelson, BC. 20 pp.

Andrusak, H. and I.L. Withler. 1970. Estimated Angler Use and Harvest in Columbia River areas 2&3. Fish and Wildlife Branch.

Anonymous. 2007. Kootenay Region Angling Regulations Proposed Changes for 2008-09. Ministry of Environment, Fish & Wildlife Branch, Kootenay region, Nelson, B.C. 10 p.

Anonymous. 2006. Kootenay Region Angling Regulations Proposed Changes for 2007-08. Ministry of Environment, Fish & Wildlife Branch, Kootenay region, Nelson, B.C. 10 p.

Anonymous. 2002. Creston Valley Wildlife Management Area Service Plan 2003/2004 to 2005/2006. Available at http://www.gov.bc.ca/cas/agencies/archives/cvwma.html.

The ARA Consulting Group Inc. (ARA). 1992. Lower Columbia River Sport Fishing and Boating Survey. Report prepared for B.C. Hydro, Vancouver, B.C.

Arndt, S. 2008. Footprint impacts of BC Hydro Dams on Kokanee Populations in the Columbia River Basin, British Columbia – *Draft 2*. Columbia Basin Fish and Wildlife Compensation Program Technical Report. Nelson, B.C. 39 p. + appendices.

Arndt, S. 2004. Arrow Lakes Reservoir Creel Survey 2000-2002. Columbia Basin Fish and Wildlife Compensation Program technical report. Nelson, B.C. 23 p. + appendices.

Arndt, S. 2002. Arrow Lakes Reservoir Creel Survey and Contribution of Hatchery Production in 1998 and 1999. Report prepared for Columbia Basin Fish and Wildlife Compensation Program. Nelson, B.C. 33 p. + appendices.

Arndt, S. 2001a. Movements of Burbot in Columbia Lake, British Columbia, for 18 Months After Spawning as Determined by Radio Telemetry. Report prepared for Columbia Basin Fish and Wildlife Compensation Program, Nelson, B.C. 8 pp.

Arndt, S. 2001b. Summary of winter creel surveys for Columbia and Windermere Lakes from 1995 –2001. . Report prepared for Columbia Basin Fish and Wildlife Compensation Program Technical Report, Nelson, B.C. 18 pp.

Arndt, S. and J. Baxter. 2006. Status of burbot (Lota lota) in Arrow Lakes Reservoir. Report prepared for Columbia Basin Fish and Wildlife Compensation Program. Nelson, B.C. 24 pp + 5 app.

Arndt, S.K.A. and J. Hutchinson. 2000. Characteristics of burbot spawning in a tributary of Columbia Lake, British Columbia, over a four-year period. Pages 48-59 In V.L. Paragamian and D.W. Willis, editors. Burbot: biology, ecology, and management. American Fisheries Society, Fisheries Management Section, Publication Number 1.

Ashley, K., and L. Thompson. 1993. Kootenay lake fertilization experiment, year 1 (1992/93) report. BC Environment, Fisheries Branch Research and Development Section, UBC. Fisheries project report no. RD 32. Vancouver, B.C.

Baxter, J.S. 1998. Summary of Juvenile Burbot Sampling in the Upper Columbia River catchment, 1997. Report prepared for Columbia Basin Fish and Wildlife Compensation Program. Nelson, B.C. 9 pp + 2 app.

Baxter, J.S., J.D. McPhail, E.B. Taylor, and J.M. Hagen. 2007. *Draft.* Status Review of Native and Non-Native Fishes in the Canadian Columbia River Basin. Report prepared for Columbia-Kootenay Fisheries Renewal Partnership and Columbia Basin Trust, Cranbrook, B.C. Report prepared by Baxter Environmental, Nelson, B.C.

Baxter, J., C. Spence and M. Neufeld. 2002a. Kootenay Lake burbot studies – Progress 2000 - 2001. Ministry of Environment, Lands and Parks. Nelson, B.C.23 pp. + app.

Baxter, J., C. Spence and M. Neufeld. 2002b. Kootenay Lake burbot studies – Progress 2001 - 2002. Ministry of Environment, Lands and Parks. Nelson, B.C. 32 pp. + app.

Baxter, J. and C. Spence. 2001. Kootenay Lake burbot recovery & Management Plan - *Draft*. Ministry of Environment, Lands and Parks. Nelson, B.C.

B.C. Conservation Data Centre (CDC). 2008. Species Summary: *Lota lota*. B.C. Minist. of Environment. Available: http://a100.gov.bc.ca/pub/eswp/ (accessed Mar 17, 2008).

BC Hydro, 2006. Fish Entrainment Risk Screening and Evaluation Methodology. Report No. E478, July 2006 .

BC Hydro. 2005. Consultative Committee Report: Columbia River Water Use Plan. Prepared by the Columbia River water use plan consultative committee.

BC Hydro 2003. Consultative Report February 2003. Seven Mile Dam and Generating Station Water Use Plan. Prepared on behalf of the Consultative Group for the Seven Mile Dam and Generating Station Water Use Plan.

Bernard, D.R., J.F. Parker, and R. Lafferty. 1993. Stock assessment of burbot populations in small and moderate-size lakes. North American Journal of Fisheries Management 13: 657-675.

Bisset, J.E. and R.S. Cope. 2002. Goat River Burbot Spawner Enumeration Program, Creston, B.C. Prepared for Columbia-Kootenay Fisheries Renewal Partnership, Cranbrook, B.C. by Westslope Fisheries Ltd., Cranbrook, B.C. 23 pp + app.

Bisset, J.E., S.K.A. Arndt, R.S. Cope. 2002. Columbia Lake burbot population estimate program. Prepared for Columbia Basin Fish and Wildlife Compensation Program, Nelson, B.C.

Boag, T.D. 1989. Growth and fecundity of burbot, Lota lota L., in two Alberta Lakes. MSc. Thesis, Dept. of Zoology, Univ. of Alberta, Edmonton.

Butcher, G.A. 1992. Ambient water quality objectives for the lower Columbia River, Hugh Keenleyside Dam to Birchbank. Overview Report. Report prepared by Water Management Branch, Environment and Resource Division, Ministry of Environment, Lands and Parks.

Canadian Columbia River Inter-tribal Fisheries Commission (CCRIFC). 2007. CLBWORKS-23 Kinbasket Reservoir Debris Removal Environmental Review (BC Hydro Reference No. Q7-7122). Prepared for Columbia Water Use Plan, BC Hydro, Castlegar, B.C. 60 pp. + app.

Chisholm, I., M.E. Hensler, B. Hansen, and D. Skaar. 1989. Quantification of Libby Reservoir Levels Needed to Maintain or Enhance Reservoir Fisheries. Prepared for Bonneville Power Administration, Portland, Or.

Columbia River Integrated Environmental Monitoring Program (CRIEMP). 2005. Environmental Status Report – Public Update on the Environmental Health of the Columbia River from Hugh Keenleyside Dam to the border. 15 p.

Cope, R.S. 2007. Upper Kootenay juvenile bull trout and fish habitat monitoring program: 2000-2005 summary. Prepared for Ministry of Environment, Cranbrook, B.C. Prepared by Westslope Fisheries Ltd., Cranbrook, B.C. 46 pp. + 2 app.

Cope, R. S. 2005. Environmental Impact Assessment of the Aberfeldie Dam Redevelopment Project, Bull River, British Columbia. Prepared for BC Hydro, Burnaby, B.C. Prepared by Westslope Fisheries Ltd., Cranbrook, B.C. 82 pp. + 1 app.

Cope, R.S. 2001. Fish and Fish Habitat Assessment for the lower Goat River, Creston, B.C. Prepared for Columbia-Kootenay Fisheries Renewal Partnership, Cranbrook, B.C. by Westslope Fisheries Ltd., Cranbrook, B.C. 51 pp + app.

Cope, R.S. and R. Rodman. 2005. Aberfeldie Redevelopment Project River Stage and Flow Study. Prepared for BC Hydro, Burnaby, B.C. Prepared by Westslope Fisheries Ltd., Cranbrook, B.C. and Klohn Crippen Consultants Ltd. 32 pp. + 2 app.

Cope, R.S. and K.J. Morris. 2003. Summary of the White River Bull Trout Enumeration Project (2003). Prepared for Ministry of Environment, Cranbrook, B.C. Prepared by Westslope Fisheries Ltd., Cranbrook, B.C. 19 pp.

Edeburn, A., J. Wright and D. Michel. 2001. Reconnaissance (1:20000) Fish and Fish Habitat Inventory of TFL 14 in the Spillimacheen River (390-) Watershed and Columbia River (300-) Tributaries Phases IV to VI. Prepared for Tembec Industries Inc., Parson Division, Cranbrook, B.C. Prepared by Interior Reforestation Co. Ltd., Cranbrook, BC.

Environmental Protection Agency – United States (EPA). 2007. Memorandum – Contaminated Sediments Technical Advisory Group Recommendations for the Upper Columbia River Site. 7 p.

Evenson, M.J. 1993. Seasonal movements of radio implanted burbot in the Tanana River, Alaska. Alaska Dept. Fish and Game, Fishery Data Series No. 93-47, 27 pp.

Fisher, S.J. 2000. Early life history observations of burbot utilizing two Missouri River backwaters. Pages 96-101. In V.L. Paragamian and D.W. Willis, editors. Burbot: biology, ecology, and management. American Fisheries Society, Fisheries Management Section, Publication Number 1.

Fisheries Inventory Summary System (FISS). 2008. Fisheries Inventory Data Queries – Report Server. www.env.gov.bc.ca/fish/**fiss**/index.html - accessed March 2008.

Ford, B.S., P.S. Higgins, A.F. Lewis, K.L. Cooper, T.A. Watson, C.M. Gee, G.L. Ennis, and R.L. Sweeting. 1995. Literature reviews of the life history, habitat requirements and mitigation/compensation strategies for selected fish species in the Peace, Liard and Columbia river drainages of British Columbia. Prep. for Habitat and Enhancement Branch, Department of Fisheries and Oceans, Vancouver, B.C. by Triton Environmental Consultants Ltd.

Gebhart, D.J. 2000. Kokanee Spawner Assessment in Bonanza Creek Watershed Fall 1999. Prepared for Hills Recreation Society and Watershed Committee by Aquatic Resources Ltd., Vancouver, B.C.

Hamilton, H.R., L.R. Linton, P. Chow-Fraser, B. Taylor and D. Fernet. 1990. Koocanusa Reservoir State of the Aquatic Environment; 1972 – 1988. Prepared for B.C. Ministry of Environment, Cranbrook, B.C. 130 pp. + app.

Hammond, R.J. and P.J. Anders. 2003. Population biology and population genetics review of Kootenai Basin burbot upstream from Bonnington falls, British Columbia. Report prepared for U.S. Department of Energy, Bonneville Power Administration by Idaho Department of Fish and Game, Boise, ID by Golder Associates Ltd, Burnaby, B.C.

Hartman, L. and A.D. Martin. 1987. Lake Koocanusa Creel Census 1987. Manuscript Report Prepared for B.C. Ministry of Environment and Parks Job Trac Program by the B.C. Conservation Foundation. 12 p.

Hutchinson, J. 1996. Upper Columbia burbot study 1996. Technical report prepared for B.C. Ministry of Environment and Columbia Basin Fish and Wildlife Compensation Program 29 pp.

Jensen, N.R., S.R. Williams, S.C. Ireland, J.T. Siple, M.D. Neufeld and K.D. Cain. 2008. Preliminary captive burbot spawning observations. Pages 155-165 *in* V.L. Paragamian and D. Bennett, editors. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, Maryland.

Ketcheson, M.V., K. Misurak, V. Lipinski, G. Kernaghan, K. Lessard, T. Dool, L. Bradley and E. White. 2005. Columbia Basin BC Hydro Footprint Mapping: BC Hydro Reference Number DFIM040. Report prepared for Columbia Basin Fish & Wildlife Compensation Program.

Lafferty, R. and D.R. Bernard. 1993. Stock assessment and biological characteristics of burbot in Lake Louise, Moose, and Tolsona lakes, Alaska, 1992. Alaska Dept. Fish and Game, Fishery Data Series No. 92-20, 71 p.

Lindsay, R.A. 1977. Investigations on Fish Populations That Will Be Affected by the Revelstoke 1880 Dam, Volume II. Report prepared by Fish and Wildlife Branch for B.C. Hydro and Power Authority. 71 pp.

Lindsay, R.A. 1976. Castlegar Ferry – Keenleyside Dam Creel census. Report prepared by Fish and Wildlife Branch.

Maher, F.P. 1961. A preliminary report on the effects on fisheries of four dams proposed for the Columbia and Kootenay Rivers in British Columbia. Prepared by Fish and Game Branch, Department of Recreation and Conservation. 52 pp.

Manson, H. 2006. Koocanusa Reservoir Kokanee Spawner Index 2005. Prepared by Columbia Basin Fish & Wildlife Compensation Program, Nelson, B.C.

Martin, A.D. 1976. Interim Report of Investigations of Fish Populations That Will Be Affected by the Revelstoke 1880 Dam. Fish and Wildlife Branch, Nelson, BC. 49 pp.

McInnis, S. and K. Bray. 2001. Lake Revelstoke Reservoir Winter Creel Survey 2000:2001. FWCP Report. 8 p. + 3 app.

McPhail, J.D. 2007. Freshwater Fishes of British Columbia (The). The Univeristy of Alberta Press.

McPhail, J.D. 1997. A review of burbot (Lota lota) life history and habitat use in relation to compensation and improvement opportunities. Can. Manuscr. Rep. Fish Aquat. Sci. 2397: viii+37 p.

McPhail, J.D. and V. L. Paragamian. 2000. Burbot biology and life history Pages 11-23 in V.L. Paragamian and D.W. Willis, editors. Burbot: biology, ecology, and management. American Fisheries Society, Fisheries Management Section, Publication Number 1.

Moody, A., P. Slaney and J. Stockner. 2007. Footprint Impact of BC Hydro Dams on Aquatic and Wetland Primary Productivity in the Columbia Basin. *Final Draft – April 2007*. Report prepared for the Columbia Basin Fish & Wildlife Compensation Program by AIM Ecological Consultants Ltd. in association with Eco-Logic Ltd. and Pslaney Aquatic Science Ltd.

Morris, K.J. and A. Prince. 2004. St. Mary River Westslope Cutthroat Trout Radio Telemetry Study 2001-2004. Prepared for Columbia-Kootenay Fisheries Renewal Partnership, Cranbrook, B.C. by Westslope Fisheries Ltd., Cranbrook, B.C. 39 pp. + 5 app.

Murray, C. 2005a. BC Hydro Dam Footprint Impact Workshop January 5-6, 2005: Workshop Report. Prepared for Fish and Wildlife Compensation Program, Nelson, BC. 20 p.

Murray, C. 2005b. BC Hydro Dam Footprint Impact Study Draft Terms of Reference for Services and Deliverables. Prepared for Fish and Wildlife Compensation Program, Nelson, BC. 21 p.

Neufeld, M.D. 2006. Kootenay Burbot Recovery Projects in British Columbia, 2005-06. B.C. Ministry of Environment, Nelson, B.C.24 pp. + app.

Ord, S. and R. Olmsted. 2000. Juvenile bull trout (Salvelinus confluentus) downstream trapping study, Duncan Dam tailrace, 2000. Prepared for Ministry of Environment, Lands and Parks, Nelson, B.C. by BC Hydro, Environmental and Social Issues Department, Kootenay Generation Area, Castlegar, B.C. 9 pp.

Ostrowski, T., B. Marotz, C. Muhlfeld, S. Snelson, and W. Young. 1977. Draft Summary Report 1994 – 1997. Mitigation for excess drawdowns at Hungry Horse and Libby Reservoirs. Project 94-10: MFWP 3180-1.

Paragamian, V.L. 2000. The Effects of Variable Flows on Burbot Spawning Migrations in the Kootenai River, Idaho, USA, and Kootenay Lake, British Columbia, Canada, After Construction of the Libby Dam. Pages 111-126 In V.L. Paragamian and D.W. Willis, editors. Burbot: biology, ecology, and management. American Fisheries Society, Fisheries Management Section, Publication Number 1.

Paragamian, V.L. and D. Bennett [editors]. 2008. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, Maryland. 270 p.

Paragamian, V.L. and V.D. Wakkinen. 2008. Seasonal movement of burbot in relation to temperature and discharge in the Kootenai River, Idaho, USA and British Columbia, Canada. Pages 55-77 *in* V.L. Paragamian and D. Bennett, editors. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, Maryland.

Paragamian, V.L. and D.C. Laude. 2007. Kootenai River Fisheries Investigation: Stock Status of Burbot – Annual Progress Report April 1, 2006 – March 31, 2007. Prepared for U.S. Department of Energy, Bonneville Power Administration by Idaho Department of Fish and Game, Boise, ID. IDFG Report Number 07-56.

Paragamian, V.L., S. Yundt, J. Hammond, C. Spence, S.C. Ireland, G. Hoffman, and J. Laufle. 2002. Development of an international conservation strategy for burbot in Idaho and British Columbia. Intermountain Journal of Sciences. 8(3): 178-190.

Paragamian, V.I. and V. Whitman. 2000. Kootenai River Fisheries Investigation: Stock Status of Burbot. Annual Progress Report, January 1, 1999 to December 31, 1999. Project no. 88-65, Idaho Department of Fish and Game, Couer d'Alene.

Paragamian, V.L. and D.W. Willis (Editors). 2000. Burbot Biology, Ecology, and Management. American Fisheries Society, Fisheries Management Section, Publication Number 1.

Paragamian, V.L., V. Whitman, J. Hammond, and H. Andrusak. 2000. Collapse of burbot fisheries in the Kootenai River, Idaho, USA, and Kootenay Lake, British Columbia, Canada. Pages 155-164 In V.L. Paragamian and D.W. Willis, editors. Burbot: biology, ecology, and management. American Fisheries Society, Fisheries Management Section, Publication Number 1.

Paragamian, V.L., M.S. Powell and J.C. Faler. 1999. Mitochondrial DNA analysis of burbot stocks in the Kootenai River basin of British Columbia, Montana, and Idaho. Transactions of the American Fisheries Society 128:868-874.

Parent, M. 1997. Silent Shores and Sunken Ships. Produced by the Arrow Lakes Historical Society, Nakusp BC.

Parnell, S.C. 1997. Lake Koocanusa Creel Survey 1996. Report Prepared for Columbia Basin Fish and Wildlife Compensation Program, Nelson, B.C.

Pieters, R., L. C. Thompson, L. Vidmanic and 10 other authors. 1998. Arrow Reservoir limnology and trophic status - year 1 (1997/98) report. Province of British Columbia Fisheries Project Report No. RD 67.

Petersen, G.R. and I.L. Withler. 1965a. Effects on Fish and Game Species of Development of Duncan Dam for Hydro-electric Purposes. B.C. Fish and Wildlife Branch, Fisheries Management Publication 8. 72 pp.

Petersen, G.R. and I.L. Withler. 1965b. Effects on Fish and Game Species of Development of Arrow Lakes Dam for Hydro-electric Purposes. B.C. Fish and Wildlife Branch, Fisheries Management Publication 9. 43 pp.

Petersen, G.R. and I.L. Withler. 1965c. Effects on Fish and Game Species of Development of Mica Dam for Hydro-electric Purposes. B.C. Fish and Wildlife Branch, Fisheries Management Publication 10. 67 pp.

Porto, L. 2007. White sturgeon populations in the BC Hydro dam footprint impacts area. Columbia Basin Fish and Wildlife Compensation Program.

Powell, M., V.L. Paragamian and J. Dunnigan. 2008. Mitochondrial variation in Western North American burbot with special reference to the Kootenai River in Idaho and Montana. Pages 3 – 27 *in* V.L. Paragamian and D. Bennett, editors. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, Maryland.

Prince, A. 2008. Kootenay River white sturgeon traditional knowledge habitat assessment near Creston, B.C. Prepared for Canadian Columbia River Intertribal Fisheries Commission, Cranbrook, B.C. by Westslope Fisheries Ltd., Cranbrook, B.C.

Prince, A. 2007. East Kootenay burbot population assessment. Report prepared for British Columbia Ministry of Environment, Nelson, B.C. Prepared by Westslope Fisheries Ltd., Cranbrook, B.C. 26 p. +3 app.

Prince, A. 2003. Arrow Reservoir White Sturgeon Assessment 2001-03. Report prepared by Westslope Fisheries Ltd., Cranbrook, B.C. Report prepared for Canadian Columbia River Intertribal Fisheries Commission, Cranbrook B.C. 26 pp. + 3 Appendix.

Prince, A. 2001. Local knowledge of Columbia River fisheries in British Columbia, Canada. Report prepared for Columbia-Kootenay Fisheries Renewal Partnership, Cranbrook, B.C. Prepared by Westslope Fisheries Ltd., Cranbrook, B.C. 50 p. +1 app.

Prince, A. and R.S. Cope. 2008. North Moyie Lake Creel survey (January – March 2008). Prepared for Ministry of Environment, Environmental Stewardship Division, Fish and Wildlife Section, Cranbrook, B.C. by Westslope Fisheries Ltd., Cranbrook, B.C.

Prince, A. and R.S. Cope. 2001. Investigations to determine fish use of the lower Goat River, Creston, B.C. Prepared for Columbia-Kootenay Fisheries Renewal Partnership, Cranbrook, B.C. by Westslope Fisheries Ltd., Cranbrook, B.C. 46 pp + app.

Pole, M. 1996. Kinbasket Reservoir creel surveys, 1995. Prepared for Columbia Basin Fish and Wildlife Compensation Program, BC Hydro and B.C. Environment. Nelson, B.C. 43 p.

Pyper, B.J., M.J. Daigneault, V.L. Paragamian, and S.C. Ireland. 2004. Population Dynamics and Extinction Risk of a Burbot (Lota lota) Stock in Decline. S.P. Cramer and Associates, Gresham, OR. Draft report prepared for the Kootenai Tribe of Idaho. 46 pp.

Quinn, S. 2000. The status of recreational fisheries for burbot in the United States. Pages 128-135 in V.L. Paragamian and D.W. Willis, editors. Burbot: biology, ecology, and management. American Fisheries Society, Fisheries Management Section, Publication Number 1.

RL&L Environmental Services Ltd. 2001a. Water Use Plans – Environmental information review and data gap analysis. Volume 1: Upper Columbia – Mica and Revelstoke Projects. Prepared for BC Hydro, Burnaby, B.C. by RL&L Environmental Services in Association with Robertson Environmental Services Ltd., Pandion Ecological Research Ltd., Bruce Haggerstone Landscape Architect, Pomeroy & Neil Consulting Inc. and DVH Consulting. RL&L Report No. 858V1-F: 498 p.

RL&L Environmental Services Ltd. 2001b. Water Use Plans – Environmental information review and data gap analysis. Volume 2: Lower Columbia –Keenleyside Project. Prepared for BC Hydro, Burnaby, B.C. by RL&L Environmental Services in Association with Robertson Environmental Services Ltd., Pandion Ecological Research Ltd., Bruce Haggerstone Landscape Architect, Pomeroy & Neil Consulting Inc. and DVH Consulting. RL&L Report No. 858V2-F: 482 p.

RL&L Environmental Services Ltd. 2000. Resident Fish Entrainment Information Review and Analysis – Draft. Prepared for the Canadian Columbia River Inter-tribal Fisheries Commission. RL&L Report No. 872D.

R.L. & L. Environmental Services Ltd. 1997. The status of white sturgeon in Slocan Lake, B.C., 1996 study results. Report prepared for B.C. Ministry of Environment, Lands and Parks. R.L. & L. Report No. SL-515F: 12 p. + 2 app.

R.L.&L. Environmental Services Ltd. 1996. Investigations of White Sturgeon Populations in Revelstoke and Kinbasket Reservoirs 1995 Data Report. Report prepared for British Columbia Ministry of Environment.

R.L.&L. Environmental Services Ltd. 1995. Seven Mile Unit 4 Study: Fish and Aquatic Investigations, September 1994 to June 1995 - Study Results and Impact Discussion. Report prepared for BC Hydro. R.L.&L. Report No. 434-95D: 161 p. + 87 plates + 6 app.

R.L.&L. Environmental Services Ltd. 1994. Waneta expansion feasibility study. 1992 Fisheries study results and preliminary impact assessment. Report prepared for BC Hydro. R.L.&L. Report No. 380D: 51 p. + 5 app.

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada. Bulletin 184. 966 p.

Sebastian, D., H. Andrusak, G. Scholten and L. Brescia. 2000. Arrow Reservoir Fish Summary. B.C. Ministry of Fisheries, Stock Management Report. 106 pp.

Schindler, E.U., H. Andrusak, K.I. Ashley, G.F. Andrusak, L. Vidmanic, D. Sebastian, G. Scholten, P. Woodruff, J. Stockner, F. Pick, L.M. Ley and P.B. Hamilton. 2007a. Kootenay Lake Fertilization Experiment: Year 14 (North Arm) and Year Two (South Arm) – 2005. B.C. Ministry of Environment, Fisheries Project Report No. RD 122.

Schindler, E.U., L. Vidmanic, D. Sebastian, H. Andrusak, G. Scholten, P. Woodruff, J. Stockner, K. I. Ashley and G. F. Andrusak. 2007b. Arrow Lakes Reservoir Fertilization Experiment, Years 6 and 7 (2004 and 2005) Report. B.C. Ministry of Environment, Fisheries Project Report No. RD 121.

Sinclair, D. 1967. Arrow Lake Stream Survey. B.C. Fish and Wildlife Branch.

Slaney, P.A. and A.D. Martin. 1997. Planning fish habitat rehabilitation: Linking to habitat protection. Pages 1-1 to 1-23 in Slaney, P.A. and D. Zaldokas (eds.). Fish habitat rehabilitation procedures. Watershed Restoration Technical Circular No. 9, Ministry of Environment, Lands and Park, Vancouver, B.C.

Spence, C. 1999. Kootenay Lake Burbot Studies Progress 1998-99. B.C. Ministry of Environment, Nelson, B.C. 42 pp. + 2 app.

Spence, C., and M. Neufeld. 2002. Radio telemetry studies of Duncan Reservoir burbot. Report prepared by the Ministry of Water, Land and Air Protection, Nelson, BC, for the BC Habitat Conservation Trust Fund and the Bonneville Power Administration.

Taylor, J. 2002. Juvenile Burbot Sampling in Columbia and Windermere Lakes, Summer 2002. Report prepared for Columbia Basin Fish & Wildlife Compensation Program. 12 p. + 3 app.

Taylor, J.L. 2001. The early life history and ecology of Columbia Lake Burbot. M.Sc. Thesis, Department of Zoology, University of British Colubia, Vancouver, B.C. 70 pp.

Taylor, J. L. and J. D. McPhail. 2000. Temperature, development and behaviour in the early life history of burbot from Columbia Lake, British Columbia. Pages 30-37 *in* V. L. Paragamian and D. W. Willis, editors. Burbot biology, management, and ecology. Fisheries Management Section, Special Publication 1, American Fisheries Society.

Thorley, J.L. 2008. Aquatic Habitat Losses and Gains due to BC Hydro Dams in the Columbia Basin. *Draft3 – December 2007*. Report prepared for the Columbia Basin Fish & Wildlife Compensation Program by Poisson Consulting Ltd.

Turney-High, Harry Holbert. 1941. Ethnography of the Kutenai. American Anthropological Association, Memoirs, No. 56. Menasha, Wisconsin.

Vonk, P. 2001. Status of Knowledge Report Duncan Dam – A Fisheries Assessment and Planning study. Prepared for Bc Hydro, Castlegar, B.C. Prepared by DVH Consulting, North Vancouver, B.C. 108 pp.

Westover, W.T. 2007. Moyie Lake Creel and Burbot Spawning Survey (January – March 2007). Prepared by Ministry of Environment, Environmental Stewardship Division, Fish and Wildlife Section, Cranbrook, B.C. 22 p.

Whately, M.R. 1972. Effects on Fish in Kootenay River of Construction of Libby Dam. B.C. Fish and Wildlife Branch, Fisheries Management Report 65. 49 pp. + 3 app.

Appendix 1

Definition of Footprint Impacts

These definitions of operational and footprint impacts associated with BC Hydro's hydroelectrical facilities in B.C. have been proposed to provide clarification to the Fisheries Technical Committees as well as committees involved in Water-Use Planning (WUP) and the BC Hydro Fish & Wildlife Bridge Coastal Restoration Program.

Footprint Impacts:
These impacts would occur primarily as a result of inactive storage and construction of dam structures, and are largely irreversible. Some impacts are re-occurring but the causative agent is usually a one-time action or event. Any footprint impacts should be considered when reservoir is at full pool.

1. Construction impacts (e.g. sediment, water quality) temporary events associated with building and construction.
2. Habitat loss from facilities or structures (e.g. habitat inundation by reservoir): includes loss of riparian area for LWD recruitment and permanent lotic - lentic habitat change and impact.
3. Permanent loss of upland and riparian terrestrial habitats within the full pool footprint and their associated impacts on biodiversity.
4. Fragmentation and loss of habitat connectivity at landscape scale.
5. Changes in the amount and spatial extent of aquatic-terrestrial species interactions due to loss of seasonal habitats, shifts in primary productivity or habitat fragmentation.
6. Nutrient or contaminant effects (e.g. trapping, downstream release, methylation) related to flows released from the reservoir.
7. Water quality in reservoir (e.g. temperature, TGP, DO) related to water quality within the water column of the reservoir.
8. Erosion, sediment transport, erosion and morphological change due to reservoir could include effects of interception of bed load and increased earth slides and instabilities caused by reservoir draw downs.
9. Impacts to fish movement and migration often due to structures like dams or barriers exposed during reservoir draw down.
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. draw down zones, exposed creek fans)
8. Ice regime impacts: ice effects due to operational changes such as flows and temperature
9. Local hydrological effects: includes seasonal groundwater effects, flooding and seasonal inundation

Appendix 2

Reservoir Units and Footprint Areas

Appendix 2. Reservoir Units and Footprint Areas (source Moody et al. 2007).

Dam Unit	Reservoir Unit	Reservoir Unit Area (ha)	Dam	Year Completed	Reservoir Age	BC Hydro Footprint Area (ha)	% of Total Footprint
C1	Columbia-Donald	865,932					
C2	Spillimacheen River	145,719	Spillimacheen Dam	1955	50	1	0.0%
C3	Donald - Mica	1,103,953	Mica Dam	1973	32	42,045	34.8%
C4	Mica - Revelstoke	525,489	Revelstoke Dam	1984	21	11,450	9.5%
C6	Cranberry Creek-Walter Hardman	14,898	Walter Hardman	1965	43	<1-	0.0%
C8	Whatshan	39,344	Whatshan Dam	1952	53	1,764	1.5%
C9	Keenleyside-USA	180,542				-	
C10	Waneta - USA	141,307	Seven Mile Dam	1973	33	428	0.4%
C11	Arrow Lakes Combined C5 &	972,795	Hugh Keenleyside	1968	37	47,131	39.0%
K1	Kootenay-Wardner	1,201,720				-	
K2	Bull River	151,424	Aberfeldie Dam	1922	83	12	0.0%
K3	Wardner - USA	342,712	Libby Dam*	1972	33	6,649	5.5%
K4	Elk River	351,893	Elko	1924	81	18	0.0%
K5	USA-Kootenay Lake	387,033				-	
K6	Kootenay Lake tributaries	492,923					
K7	Duncan River tributaries	243,000	Duncan Dam	1967	38	7,299	6.0%
K8	Lower Duncan - Lardeau	233,223					
K9	Corra Lynn - Brilliant	363,843	Kootenay Canal	1932	73	49	0.0%

* Dam operated by Bonneville Power Administration.

Appendix 3

Potential Candidate Metrics for Quantifying Fish Losses and Gains

Appendix 3. Potential candidate (and some required) metrics for quantifying fish losses and gains related to BC Hydro dam footprint impacts as recommended by participants at the BC Hydro Dam Footprint Impact Workshop in Nelson, BC, January 5-6, 2005 (from Murray 2005b).

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

Impacts	Potential candidate metrics (required metrics are in bold)
Productivity Impacts (continued)	▪ Note that two habitats are subject to productivity impacts: ▪ Littoral zone production (impacted by water level fluctuation) – could be restored through the growing season ▪ Pelagic habitat
Other	▪ Effects of fish impacts on wildlife. ▪ Climate change. Local micro climatic impacts (change in air temperature, stream temperature, snowfall, precipitation) due to reservoir inundation ▪ Temperature change (maximum, minimum, duration) resulting from impoundments/storage ▪ Change in aquatic vegetation and invertebrates (change in species abundance and composition) ▪ Entrainment, upstream and downstream (number of fish per year) ▪ Change in biogenic and abiogenic turbidity (TSS, NTUs, or secchi disk) ▪ Hydrological changes ▪ Ice regime changes