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White Sturgeon Populations in the BC Hydro Dam Footprint Impacts Area

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Fish and Wildlife Compensation Program – Columbia Basin
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EXECUTIVE SUMMARY

Sturgeon productivity in both the Columbia and Kootenay rivers has declined due to the construction of dams within the basin. The construction of dams has played a large role in the loss and degradation of critical white sturgeon habitat, which has resulted in decreased productive habitat capacity and ultimately to population decline. Based on Federal regulations for BC Hydro's existing dams, DFO may require compensation for losses to white sturgeon populations within the Columbia Basin.

In the BC Hydro dam footprint impact area, eight sub-populations of white sturgeon are isolated between six BC Hydro dams. White sturgeon in these eight sub-populations are likely impacted by the following footprint impacts: i) construction impacts related to sediment and water quality; ii) habitat loss; iii) nutrient and/or contaminant effects related to flows released from the reservoir; iv) reduction in natural turbidity levels due to interception of sediment in reservoirs; v) fragmentation and loss of habitat connectivity at the landscape level (barriers to fish movement and migration); and, vi) fish entrainment and loss of fish (mostly an operational impact).

Since it is difficult to directly quantify with accuracy white sturgeon habitat losses and losses to productive capacity due to dam footprint impacts, the Upper Columbia White Sturgeon Recovery Initiative's (UCWSRI) Recovery Plan is more appropriate to consider when reviewing compensation options for the white sturgeon population. Recovery Team members for the UCWSRI have developed a set of 12 recruitment failure hypotheses to direct white sturgeon research and conservation. These recruitment failure hypotheses were presently reviewed to compile and prioritize dam footprint-related compensation options. A review of relevant compensation options and costs for white sturgeon footprint impacts are provided. Current conservation aquaculture programs to restore white sturgeon should be maintained to help restore populations to naturally reproducing levels. The Fish and Wildlife Compensation Program's contribution to the aquaculture program is a cost effective option for compensation, in terms of feasibility and direct supplementation of the population, compared to other compensation measures. The highest compensation priorities ranked by the UCWSRI related to footprint impacts causing the observed recruitment failure included substrate addition and turbidity augmentation below Hugh L. Keenleyside Dam. However, these options are in the millions of dollars and feasibility studies are required before these measures can be undertaken. Coordinated efforts between agencies in Canada and the U.S. are imperative for the recovery of white sturgeon stocks regardless of which compensation measures are undertaken.

1.0 INTRODUCTION

In the Columbia Basin, the once contiguous white sturgeon (*Acipenser transmontanous*) population was separated into two distinct populations (i.e., Columbia and Kootenay) with the formation of a natural barrier at Bonnington Falls during the last glaciation period (approximately 10,000 years ago) (Northcote 1973, Ptolemy and Vennesland 2003). These two white sturgeon populations are genetically different (Nelson et al. 1999) and represent biologically significant units (Ptolemy and Vennesland 2003). Historically, the Columbia white sturgeon population was likely distributed throughout the Columbia River and lower Kootenay River (below Bonnington Falls) and may have accessed the Pacific Ocean. The Kootenay population was distributed above Bonnington Falls throughout Kootenay Lake most likely to Kootenai Falls, a natural barrier located in the United States (Ptolemy and Vennesland 2003). In British Columbia, historical ranges of the Columbia and Kootenay white sturgeon populations have been estimated at 17,380 km^2 and 7,930[1] km^2, respectively (Ptolemy and Vennesland 2003).

With the construction of large hydroelectric dams on the Columbia and Kootenay rivers over the past century, white sturgeon populations have become fragmented and the extent of occurrence in BC has been reduced to an estimated 12,190 km^2 and 6,780 km^2, respectively (Ptolemy and Vennesland 2003). In the BC Hydro dam footprint impact area (AIM 2007) alone, six dams have isolated these two populations into eight groups or sub-populations (Figure 1), which experience reduced production due to recruitment failure, lowered food resources (i.e., dams also decreased kokanee, rainbow trout, and bull trout populations), and degradation or lack of access to suitable habitats. Preliminary genetic analyses indicated that some sub-structuring may have been present prior to the construction of dams among a few of these groups (Nelson et al. 1999, Ptolemy and Vennesland 2003). More recent mitochondrial DNA analyses may provide insight into how white sturgeon may have been impacted by dam developments (S. McAdam, Senior Hydroelectric Impacts Biologist, Ministry of Environment (MOE), pers. comm., 2008).

Although estimates are not available for the pre-dam period, white sturgeon populations in the Columbia and Kootenay rivers were likely abundant and healthy based on historical catch records, interviews with First Nations, and other anecdotal information (Prince 2001, Ptolemy and Vennesland 2003, BC Ecosystem Explorer 2008). Presently, wild white sturgeon populations in the Columbia and Kootenay rivers are mainly comprised of older individuals and their populations are in decline due to the lack of recruitment of juveniles since the mid-1980's and mid-1960's, respectively (e.g., Ptolemy and Vennesland 2003, Paragamian et al. 2005, Golder 2006a).

[1] This estimate of Kootenay River historical range does not include the area between Canal Flats and the US border, since information has not been verified and therefore may be an underestimate. Including this area brings historical extent of occurrence to 18,358 km^2 (Ptolemy and Vennesland 2003).

It has been recognized that white sturgeon are prone to changes in the environment since they are long-lived, mature at a late age (i.e., approximately 22 to 26 years for females and 16 years for males), and have longer spawning intervals (2 to 11 years for females) than most other freshwater fishes (e.g. Ptolemy and Vennesland 2003, BC Ecosystem Explorer 2008). Further concern occurred when white sturgeon populations in the Columbia River and Kootenay River began experiencing recruitment failure. Initially fishing regulations were changed, but when it was obvious that population levels were critically low, fisheries were closed, and recovery actions and legislative measures were undertaken to conserve this species. Both the Columbia River (i.e., lower Columbia River in Canada) and Kootenay River white sturgeon populations are listed under as Endangered under Schedule 1 of the Federal Species At Risk Act (SARA; 2002; c.29). In the United States, the Kootenay River white sturgeon population is also federally listed under the U.S. Endangered Species Act. Recovery programs, that include conservation aquaculture and flow manipulations (presently only in Idaho, US from Libby Dam), are in place to address the lack of recruitment and overall population decline.

This report will discuss BC Hydro footprint impacts (see Appendix A) on white sturgeon populations within the Columbia Basin, as well as provide compensation options for these impacts that may be required by the regulatory agencies.

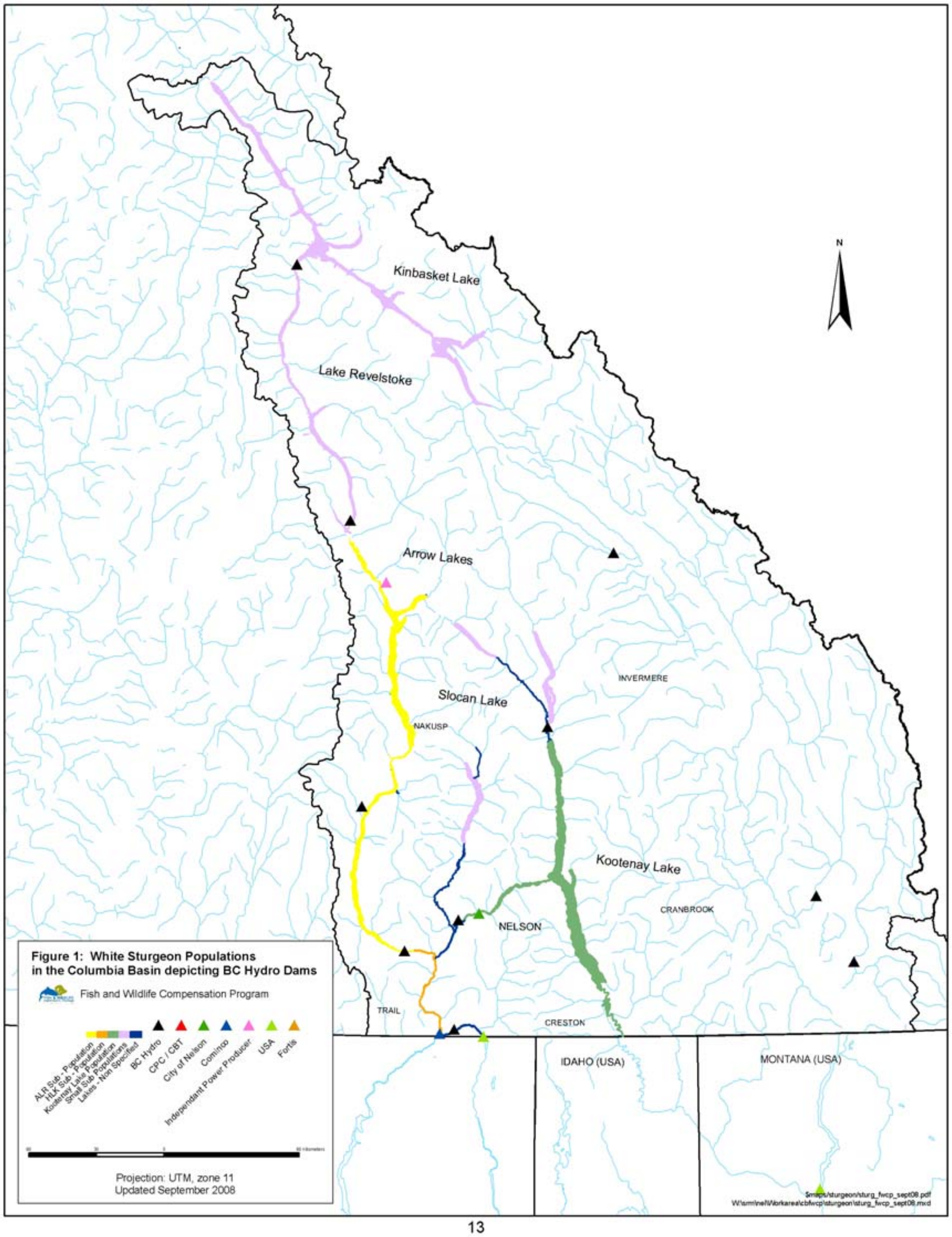

Figure 1 White sturgeon populations in the Columbia Basin depicting BC Hydro Dams

2.0 DAM FOOTPRINT IMPACTS AND WHITE STURGEON POPULATIONS

It is widely known that white sturgeon populations throughout the Columbia Basin (Canada and U.S.) have been negatively impacted by hydroelectric developments (e.g., Beamesderfer et al. 1995, DeVore et al. 1995, Duke et al. 1999, Hildebrand et al. 1999, Ptolemy and Vennesland 2003) and are now found in isolated populations due to dam construction. In order to remain viable and self-sustaining, these isolated populations require access to adequate habitats to support all of their life history stages from spawning and egg incubation, through the larval and juvenile stages to adult maturity. In the BC Hydro dam footprint impact area, white sturgeon are likely impacted by the following footprint impacts (as defined in Appendix A): i) construction impacts related to sediment and water quality; ii) habitat loss; iii) nutrient and/or contaminant effects related to flows released from the reservoir; iv) reduction in natural turbidity levels due to interception of suspended sediment in reservoirs; v) fragmentation and loss of habitat connectivity at the landscape level (barriers to fish movement and migration); and, vi) fish entrainment and loss of fish (mostly an operational impact). Habitat created from the infilling of the reservoir behind dams may also encourage the proliferation of exotic species and predation on native fish stocks. These impacts are discussed further below.

2.1 Construction Impacts Related to Sediment and Water Quality

Besides eliminating potential white sturgeon habitat directly on-site, the construction of dams also caused short-term increases in sedimentation (and the subsequent long term infilling of substrate with the reduction of freshet flows) and potential degradation of water quality. The type of dam constructed may also play a role in sedimentation of downstream habitats. For example, the construction of earth-filled dams, such as Hugh L. Keenleyside (HLK) dam, may have the potential to release sediments and change downstream habitats both short- and long-term depending upon construction methods used. Evidence linking initial dam construction and reservoir-filling to reduced production potential (e.g., Beamesderfer et al. 1995, DeVore et al. 1995) and recruitment failure (no significant survival past the egg stage) has been observed in white sturgeon populations throughout the Kootenay River (e.g., Paragamian et al. 2005) and Columbia River in Canada and the U.S. (e.g., Hildebrand et al. 1999). However, recruitment failure is likely related to longer-term impacts such as habitat loss, the elimination of freshet flows, and the reduction of natural spring turbidity levels (see Section 2.4) as opposed to short-term losses from actual construction.

2.2 Habitat Loss

White sturgeon tend to group themselves together and distribute themselves in suitable habitats depending upon the season and their life-history stage (e.g., Ptolemy and Vennesland 2003, Golder 2006d). Seasonal movements of white sturgeon usually occur around the same time each year between and within important spawning, rearing, overwintering, and feeding habitats. In addition to providing suitable characteristics for white sturgeon life history, important habitats in the Columbia Basin most likely have a historical component to their use. That is, white sturgeon may still use the same locations that they did historically, even if suitability has been degraded by dams.

Modification of habitat due to construction of dams has altered spawning, egg incubation and rearing habitats and reduced overall biological productivity (USFWS 1999). The footprint impact of dams on white sturgeon habitat may include changes in channel morphology, substrate composition, water depth and velocity, turbidity, altered temperature regimes, as well as the complete elimination of critical habitat at the dam site and lack of access to important habitats between dams (see *Section 2.5*). Direct habitat loss may have affected spawning, rearing, overwintering and feeding as detailed below.

2.2.1 Spawning

Several populations of white sturgeon throughout the Columbia Basin, both in Canada and the United States have been observed to spawn below hydroelectric dams (e.g., Parsley et al. 1993, McCabe and Tracy 1994, R. L. & L. 1994, R. L. & L. 1999, Golder 2003b, Golder 2004, Golder 2006a). Spawning characteristics below hydroelectric dams include depths between 4 m and 24 m, mean column water velocities ranged from 0.8 m/s to 2.8 m/s, and substrates consisting mostly of cobble and boulder (e.g., Parsley et al. 1993). Populations spawning below dams may be responding to natural imprinting from historical spawning areas, but many of these habitats have most likely been degraded or eliminated due to dam construction (and operations).

Many researchers suggest that “zones of hydraulic complexity” are used for spawning within confined river channels, such as those observed at dam tailraces in regulated rivers (e.g., Parsley et al. 1993, Parsley and Beckman 1994, Parsley et al. 2006), and at river confluences in free-flowing rivers (Perrin et al. 2003). Studies conducted in unregulated rivers, such as the Fraser River (Perrin et al. 2003) indicate that white sturgeon spawning may occur over a wider range of habitat conditions than previously reported for impounded areas (e.g., Parsley et al. 1993). For example, shallow (depth: 1.5 m to 4.0 m), low velocity (mean near-bed velocity: 0.8 m/s to 2.1 m/s) side channel habitats with sand/gravel substrates were more commonly used in the Fraser River, compared to confined sections (Perrin et al. 2003). Side channel habitats may be preferred when seasonally higher turbidity levels provide cover allowing habitats of relatively shallow depth to become suitable for spawning (Perrin et al. 2003).

Although annual spawning has been observed in white sturgeon populations within the BC Hydro footprint area, it has largely been unsuccessful and minimal survival past the egg/larvae stage has been observed (e.g., UCRWSRI 2002, Paragamian et al. 2005, Irvine et al. 2007). Known spawning locations within the Canadian portion of the Columbia River have been documented downstream of Waneta (Golder 2004 and 2006a) and Revelstoke (R.L. &L. 1999 and Golder 2006b) dams, and below the confluence of the Kootenay River (Golder 2008) and are within “zones of hydraulic complexity.” White sturgeon are broadcast spawners and areas of higher water velocities may be important for dispersing embryos downstream to appropriate developmental habitats, as well as assist in reducing predation effects. However, the construction of, and flooding caused by dams may have eliminated other types of spawning habitats that are required for successful recruitment as observed in the Fraser River (e.g., Perrin et al. 2003). Historical spawning areas within the BC Hydro dam footprint impact area have only been documented based on interviews with locals and First Nations elders (e.g., Prince 2001) and are described below under each sub-population, where applicable.

2.2.2 Rearing

Several studies conducted throughout the Columbia River indicate that suitable habitats for juvenile white sturgeon consist of depths between 5 and greater than 25 meters, water velocities less than 0.5 m/s, as well as bottom types consisting of sand, sand/silt, or small gravels (e.g., McCabe and Tracy 1994, Parsley and Beckman 1994, Golder 2006c). Other studies suggest that eggs, free embryos, and larvae can be found within substrate interstices in shallow, inundated riparian habitats downstream of spawning areas (van der Leeuw et al. 2006) and directly within low velocity, shallow side channels (Perrin et al. 2003). White sturgeon spawning and rearing habitats may be are similar in some cases, especially in lower velocity areas where dense eggs can sink (Perrin et al. 2003). However, drifting larvae are typically mobile post-hatch and use river currents as a means of dispersement from spawning areas to downstream rearing habitats. Larvae have been observed as far as 194 km from the spawning site (e.g., McCabe and Tracy 1994).

Similar to spawning habitats, dam construction and reservoir filling may have eliminated juvenile rearing areas within the BC Hydro footprint area. The construction of dams fragmented habitats into smaller segments that may preclude the presence of accessible rearing habitats depending upon the size of the reservoir or dam unit area. For example, shorter dam units may not contain adequate rearing habitats, and drifting larvae may either settle in inadequate areas or get entrained through a dam, resulting in reduced survival or mortality. Increased water clarity and lack of seasonally high turbidity during spawning and rearing periods due to the presence of a dam may reduce the use of potentially suitable rearing habitats within the BC Hydro footprint impacts area. For example, high turbidity levels were a natural occurrence in the Columbia River, but dams increased water clarity and reduced the seasonal pulses of turbidity that white sturgeon larvae may have used for cover from predation (UCRWSRI 2002). Side channel habitats may be important rearing habitats for white sturgeon as observed on the Fraser River (Perrin et al. 2003), but due to the photophobic nature of white sturgeon, spawning in these areas may not occur due to increased water clarity.

2.2.3 Overwintering

Overwintering habitats are usually deep, stable habitat areas with low water velocities, and are likely used by prey (Golder 2006d). Juvenile and adult white sturgeon have been observed to use similar habitats for overwintering throughout the Columbia River (e.g., Golder 2003a, Golder 2005a, and Golder 2006 d). Stable overwintering areas within the BC Hydro dam footprint impact area most likely have not been directly impacted, unless the construction of the dam completely eliminated this habitat. However, fragmented populations that once moved freely within the original Columbia River and Kootenay River populations may have lost access to some important overwintering areas.

2.2.4 Feeding

Feeding habitats have been observed at tributary mouths where prey may be migrating to spawn, as well as in habitats used by white sturgeon for spawning, rearing, and overwintering. The flooding of reservoirs may have eliminated (or created) important spawning areas for prey species and may have created more suitable habitats for predator species of juvenile sturgeon (including introduced species). Older juvenile and adult white sturgeon are opportunistic feeders (see *Section 2.3*) and most likely had access to several different feeding habitats throughout the Columbia Basin. The fragmentation of the basin into several sub-populations prevented spawning access to many prey species, which could have fed older juvenile and adult white sturgeon. Feeding areas may also be limited within each sub-population, since white sturgeon may have accessed the entire drainage to feed opportunistically in more productive areas that housed larger concentrations of prey that no longer exist, or that they not longer have access to.

2.3 Nutrient and/or Contaminant Effects

Nutrient levels and the resulting water quality following the trophic upsurge that occurs in newly formed reservoirs is unpredictable and depends upon several factors including the biological community (Prowse et al. 2006). However, one predictable outcome from river impoundment is the release of mercury (Hg) from flooded sediments, and its methylated form (MeHg) can bioaccumulate in the food chain, with highest concentrations occurring in piscivorous fish (Prowse et al. 2006). Tremblay and Lucotte (1997) found that concentrations of MeHg in aquatic insect larvae can be 3 to 5 times higher in hydroelectric reservoirs compared to their counterparts from natural lakes. Aquatic insects were found to be an important source of total Hg and MeHg for higher trophic levels since they constitute a major part of the diet of fish (Tremblay and Lucotte 1997). Mercury is a non essential metal that is embryotoxic, teratogenic and can affect behaviour, biochemistry, growth, reproduction, development and survival in fish (Kruse and Webb 2006). Concentrations of muscle Hg in the range of 6 to 20 µg/g have been found to adversely affect reproduction and developmental growth in fishes (Kruse and Webb 2006).

White sturgeon are predisposed to high Hg levels because their benthic feeding behaviour may expose them to contaminated sediment and prey items, and because of their position at the top of the trophic food chain. Besides feeding on benthic invertebrates and clams, predaceous adults are known to aggregate and voraciously feed on fish. For example, 12 whole mountain whitefish were found in the stomach of a Columbia River white sturgeon during a necropsy (personal observation). The diets of juvenile white sturgeon include

Amphipods, Chironomids, Emphemoptera nymphs, snails, Dipterans, Gammarids, Hemipterans, Plecopterans, freshwater clams, and small fish, whereas white sturgeon larvae feed mostly on Amphipods, Chironomid larvae, and cyclopoid copepods (McCabe and Tracy 1994, Muir et al. 2000 as cited in Westslope 2005, Golder 2006c). In the Columbia River below HLK dam, 93% of the prey items in the stomachs of hatchery-released juveniles (age-1 to 3 fish) were primarily the opossum shrimp, *Mysis relicta*, entrained from Arrow Lakes Reservoir (Golder 2006c, Golder 2006d).

Mercury has been found in adult white sturgeon tissues, eggs, and naturally spawned juveniles in a small number of individuals sampled below HLK dam (Kruse and Webb 2006). Hatchery-reared juvenile white sturgeon and sampled sperm did not contain detectable levels of Hg (Kruse and Webb 2006). The concentrations of Hg in the tissues of these fish (mean=0.23 µg/g) were well below levels that would affect growth and reproduction, but they exceeded Canadian Council of Ministers of the Environment (CCME) diet standards (0.033 µg/g). Kruse and Webb (2006) indicated that the production of steroids in white sturgeon may be affected at threshold Hg concentrations of 0.187 µg/g in muscle, 0.093 µg/g in liver, and 0.074 µg/g in gonad. Kruse and Webb (2006) indicated that only one study has been found with Hg concentrations within the range found in the eggs of white sturgeon sampled below HLK dam, and this study revealed a decrease in survival of embryos and larvae.

Even though evidence indicates that Hg contamination from reservoir flooding may also be transported far downstream (Johnston et al. 1991 in Tremblay and Lucotte 1997), contaminant inputs to the Columbia River below HLK dam have been exacerbated by the presence of Teck Cominco and Celgar, major contributors to Hg levels in this area (Kruse and Webb 2006). Further sampling is required, especially in fish known to inhabit upstream areas of HLK and other dams to determine contamination impacts due to impoundment. In the U.S. portion of the Columbia River, researchers have observed that white sturgeon in reservoirs behind older dams have high concentrations of contaminants (Schreck and Feist 2006). The tissue burden in parental stock has the potential for reproductive and developmental effects in progeny (Kruse and Webb 2006). However, no direct link between contaminants, such as Hg, has been made to white sturgeon recruitment failure in the Columbia Basin.

2.4 Turbidity

Historically, turbidity in the Columbia River was high particularly in spring and early summer due to glacial runoff (AIM 2007). Ktunaxa elders indicated that sturgeon spawned in areas of high turbidity, which included the Spillimacheen area of the Columbia River, and in the Kootenay River near Bonner’s Ferry (Westslope and CCRIFC 2005).

The construction and operation of dams and storage reservoirs has resulted in the reduction of natural turbidity levels and created clear, oligotrophic systems both upstream and downstream of dams (UCWSRI 2002). Dams prevent sediment and substrate transport to downstream areas and their reservoirs act as settling basins for fine suspended particles

(UCWSRI 2002). In the Columbia River below HLK Dam turbidities have been observed to range from 1 to 3 NTU's, whereas observed turbidity in systems with successful white sturgeon spawning and recruitment range from > 2 to 92 NTU's (UCWSRI 2002). In the Fraser River, average turbidity during the spawning period was 42 NTU's and notably higher than in regulated rivers (Perrin et al. 2003).

Predation on white sturgeon eggs and larvae may be high at the prevailing low levels of turbidity within the Columbia Basin (UCWSRI 2002). Bottlenecks at the egg and/or larval stages have been cited as a cause of recruitment failure in the upper Columbia River and Kootenay River white sturgeon populations, which may likely reflect increased predation at these stages due to water clarity (UCWSRI 2002). Higher predation levels have been observed on white sturgeon yolk-sac larvae by prickly sculpin (*Cottus asper*) at low turbidities between 0 and 20 NTU, and the highest proportion of larvae were ingested at 20 NTU (Gadomski and Parsley 2005a). Egg predation studies conducted on the Columbia River indicated that resident fish, such as largescale suckers (*Catostomus macrocheilus*), using Waneta Eddy may occasionally feed on newly spawned white sturgeon eggs (Golder 2006a). Water clarity at this time was relatively high, since turbidity measurements taken during the spawning period in July did not exceed 1.1 NTU in the Columbia and Pend d'Oreille rivers (Golder 2006a). Laboratory studies conducted on the vulnerability of age-0 white sturgeon to predation by adult northern pikeminnow (*Ptychocheilus oregonensis*) and prickly sculpin, and juvenile walleye (*Stizostedion vitreum*) indicate that predation may be contributing to the year-class failures that have been observed (Gadomski and Parsley 2005b).

In addition to predation effects, lowered turbidity levels may preclude photophobic adults from using shallower habitats to spawn, since light attenuation may be an important factor affecting spawning depth (Perrin et al. 2003). White sturgeon have been observed to spawn in side channel habitats in the unregulated Fraser River, which experiences naturally high turbidity levels during the spawning and rearing season (Perrin et al. 2003). Spawning habitats observed in the Fraser River were shallower compared to those reported in regulated rivers (e.g., Parsley et al. 1993, Paragamian and Kruse 2001); with turbidities at least four times higher (Perrin et al. 2003).

2.5 Habitat Fragmentation

Movements and/or migrations to spawning, rearing, overwintering, and feeding habitats are important for white sturgeon to carry out their life history. Historically, white sturgeon likely migrated occasionally to and from the Pacific Ocean to the Columbia and lower Kootenay rivers, although freshwater resident populations were also likely distributed and moved freely within the upper Columbia Basin.

Fragmentation within the BC Hydro dam footprint impact area has blocked movements (see Section 2.6) and created eight, isolated sub-populations of white sturgeon in reservoirs or river fragments that in some cases no longer provide the full array of habitats or conditions necessary to complete their life cycle (Ptolemy and Vennesland 2003). The extent of impact and the status of each sub-population varies depending upon the locale and size of the fragment (see Section 3.0), as well as the remaining habitat availability. For example, white sturgeon within Arrow Reservoir have access to one known spawning area within their sub-population (i.e., below Revelstoke Dam; R. L. & L. 1999). However, several spawning locations downstream of HLK Dam both within Canada and the US have been documented (Golder 2006d and 2008), but may only be accessible to white sturgeon within the residing HLK sub-population. Some of these spawning areas have been observed to have sub-optimal temperature conditions required for normal embryo development during a portion of the spawning period (Golder 2003b, Golder 2004).

In general, blocked movement causes a disruption of natural migration and spawning behaviour. Spawning can be delayed, which may cause stress, egg re-absorption (lowers fecundity) and even atresia (egg degeneration and cessation of spawning). If habitats are unsuitable, spawning may not occur at all (e.g., R. L. & L. 1998a), or the survival of white sturgeon larvae is reduced since adequate habitat and variables for development are not present (e.g., Golder 2004). Observations have also indicated that reproductively mature individuals may have a difficult time finding suitable mates in isolated areas (e.g., R. L. & L. 1998a). Isolated sub-populations of white sturgeon may not be able to access important feeding and overwintering habitats used historically by the population, and these areas may be limited within the reservoir or river fragment (see Section 2.2). Telemetry studies in the Columbia River indicate that while white sturgeon remain in preferred high use areas throughout the year, some also move between these areas for spawning and/or feeding (Golder 2006d, Neufeld 2008). Long distance migrations (>1000 km) have been observed in few individuals that have access to the ocean (e.g., Welch et al. 2006). However, movement observations and tagged individuals are limited.

2.6 Fish Entrainment and Loss of Fish

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." (BC Hydro definition). The construction of BC Hydro dams eliminated access to spawning grounds and subsequently reduced the productivity of sport fish species such as kokanee, rainbow trout, and bull trout (e.g., MOE 1984, Ahrens and Korman 2004). White sturgeon are opportunistic feeders and most likely followed prey species to areas where they would congregate. Decreased food resources would negatively impact white sturgeon populations (see Section 2.2.4).

Entrainment can occur during all life phases (i.e., larval, juvenile, adults) and has been well-studied for salmonids (e.g., Coutant and Whitney 2000), but information is sparse for white sturgeon. White sturgeon that have been sonically tagged from Arrow Lakes Reservoir have been observed below HLK dam, and it is likely that some of these attempted movements have resulted in mortality. Dead sturgeon are occasionally found downstream of HLK, with injuries consistent with some interaction with the facility. Since 1999, five such mortalities have been confirmed (Wood et al. 2007).

Studies conducted on larvae and juveniles indicate that smaller sized larvae of some sturgeon species have been observed to experience higher mortality through turbine forces compared to larger larvae and/or juvenile fish (Killgore et al. 2001). Post-hatch larvae typically use river currents as a means of dispersal from spawning areas to downstream rearing habitats and have been observed as far as 194 km from the spawning site (e.g., McCabe and Tracy 1994), which may make them prone to entrainment through dam turbines. High mortality of larvae and juveniles may subsequently result in a decrease in adult recruitment (Killgore et al. 2001). Since natural recruitment is lacking in populations within the BC Hydro footprint impact area, larval and juvenile entrainment is not a concern (UCWSRI 2002).

3.0 STATUS OF ISOLATED GROUPS OR SUB-POPULATIONS WITHIN THE BC HYDRO DAM FOOTPRINT AREA

As mentioned previously, eight sub-populations of white sturgeon are isolated between six BC Hydro dams (Figure 1). Different locations within the BC Hydro dam footprint impacts area were delineated to represent a dam unit (DU) (Ahrens and Korman 2004). White sturgeon sub-populations within the DU areas are discussed further below.

3.1 Upper Columbia River (HLK Dam to Canada-U.S.A border- C9)

The upper Columbia River white sturgeon population (referred to herein as the HLK sub-population) is located in approximately 56 km of riverine habitat located between HLK Dam (1968) and the U.S.A border (Figure 1). However, white sturgeon have access to approximately 180 km from HLK dam to Grand Coulee dam, Washington, which includes Roosevelt Lake.

The HLK sub-population consists of older, adult fish that are in severe decline due to recruitment failure (Hildebrand et al. 1999, UCWSRI 2002). Studies conducted on this sub-population in Canada since 1990 indicate that recruitment has not occurred for the past 30 years despite annual observations of spawning at Waneta (i.e., confluence of the Pend d'Oreille and Columbia rivers) since 1993 (UCWSRI 2002, Golder 2004, Irvine et al. 2007), and more recent observations of spawning in Northport, Washington (Golder 2006d) and potentially near the confluence of the Kootenay River (based on the capture of one larval fish; Golder 2008). Some low, but measurable recruitment to the HLK sub-population has been observed intermittently over the past 30 years, but is insufficient to maintain the population (Irvine et al. 2007). Recruitment failure and population decline for white sturgeon in the HLK sub-population have been attributed to the construction of HLK dam in 1968 (Hildebrand et al. 1999, Ptolemy and Vennesland 2003), which "isolated sturgeon populations in the former Arrow Lakes, and cut off access by fish in the transboundary reach to spawning, rearing and feeding areas in the upper basin" (UCWSRI 2002).

The estimated 2004 abundance of adult (fish greater than 1 m in length) white sturgeon in this sub-population was 1157 (95% CI: 414 to 1900; Irvine et al. 2007). Projections of the HLK sub-population estimate that the population will decline to under 400 individuals by 2025 (not accounting for any hatchery-released juveniles surviving to adulthood), which may cause a severe genetic diversity bottleneck (UCWSRI 2002, Golder 2003b, Golder 2005b), and to fewer than 50 individuals in 25 years (Irvine et al. 2007). Causes of population decline related to footprint impacts may also include loss and degradation of habitat, blocked movement/migration (i.e., habitat fragmentation), altered nutrient inputs and higher contaminants, reduced turbidity, and water quality issues (Hildebrand et al. 1999, UCWSRI 2002). Although there is little agreement on the exact mechanisms linked to dams that are limiting sturgeon populations, there is agreement that dams have created an impact because of the timing of recruitment failure (UCWSRI 2002). Evidence to date indicates that the HLK white sturgeon population will continue to decline, unless natural recruitment is re-established (e.g., Irvine et al. 2007) or conservation aquaculture practices are put in place for the long-term (UCWSRI 2002).

Even though spawning occurs on a yearly basis below Waneta Dam (confluence of the Pend d'Oreille and Columbia rivers above the Canada-U.S. border) and successful egg incubation has also been recorded (Golder 2004), natural recruitment is limited. More recently, additional spawning habitats have been identified in Northport, Washington (Golder 2006d) and near the confluence of the Kootenay River (Golder 2008). Spawning movements have been recorded between the spawning locations at Waneta and Northport (Golder 2006d). Studies conducted at Waneta since 1990 indicate that spawning usually occurs in water temperatures of approximately 14°C or more, during a period of declining discharge (Golder 2003b, Golder 2004). Some spawning events have been observed in temperatures that are sub-optimal (i.e., >20°C) for normal embryo development during most years (Golder 2004, Golder 2006a). Analyses also indicate that spawn timing has been progressing to later in the season, which has implications for embryo survival since increased water temperatures occur later in the spawning season (Golder 2003b, Golder 2004). However, more recent evidence suggests that this pattern is not consistent; in 2005 later spawn timing at Waneta did not occur (Golder 2006a).

Movements of white sturgeon between Canada-U.S. have been observed (Golder 2006d), but white sturgeon within the HLK reach (HLK to U.S. border) tend to remain within fairly localized areas and tend to make larger movements related to spawning activity (Golder 2006d). Habitats within this reach include large, deep, eddy areas that are "preferred" areas for both white sturgeon and their prey items (Golder 2006d). Overwintering aggregations of adult white sturgeon have been observed mostly between HLK dam (i.e., in HLK eddy) and Sullivan Creek (6.5 km downstream of HLK dam), and to a lesser extent near Sullivan Creek, Fort Shepherd eddy, Waneta eddy, and in the lower portion of the Kootenay River below Brilliant dam (i.e., Kootenay eddy, near Brilliant bridge, Brilliant dam plunge pool; Golder 2006d).

Recovery plans for the HLK white sturgeon population include conservation aquaculture programs that have released juveniles into the HLK reach since 2002 (UCWSRI 2002). Monitoring studies indicate that hatchery-released juveniles are foraging and overwintering in suitable areas of the HLK reach (Golder 2006d). Habitats for juveniles age-1+ seem to be present below HLK Dam. However, habitats for successful recruitment of eggs and larvae seem to be limited. It is hoped that the causes of recruitment failure can be determined and important egg/larval habitats be restored in order to enable white sturgeon to spawn and reproduce naturally in this portion of the river. If the situation cannot be improved, severe population bottlenecks are predicted to occur which, in the absence of ongoing conservation aquaculture, will result in the population becoming functionally extinct (UCWSRI 2002).

3.2 Arrow Lakes Reservoir (Revelstoke Dam to HLK Dam - C11)

The Arrow Lakes Reservoir (ALR) white sturgeon sub-population has access to approximately 230 km of riverine and lacustrine habitat located from Revelstoke Dam (built in 1984) to HLK Dam (Figure 1). Even though this population has a large area to reside in "Revelstoke Dam (1984) effectively eliminated the 130 km section of flowing river between Mica Dam and the Arrow Lakes Reservoir and sealed the fate of sturgeon in this segment of the river by eliminating and cutting off access to the upper riverine habitat that may have served as a sturgeon spawning area" (UCWSRI 2002). The construction of Revelstoke Dam also eliminated spawning habitat for kokanee and bull trout that could have been a large food resource for white sturgeon in the area (MOE 1984, Ahrens and Korman 2004, C. Spence, pers. comm., 2006).

A relatively small population of white sturgeon, estimated between 37 and 92 older adults is present in ALR (Golder 2006b). It is likely that all white sturgeon present in ALR were produced prior to construction of HLK Dam (Golder 2006b). Originally, the ALR sub-population would have been part of the larger HLK population but were trapped in the reservoir following the construction of HLK Dam (UCWSRI 2002). These fish may have also moved into ALR post-dam construction via the HLK boat lock (UCWSRI 2002). However, no telemetry evidence exists indicating that upstream movements through HLK dam occur, and observed attempts to migrate downstream of the dam, perhaps to join the larger spawning population, have been fatal (personal observations, Golder 2006b). Historical accounts indicate that white sturgeon were present in ALR since the early 1900's and possible capture locations reported by anglers include: Burton, West Demares, Galena Bay, Eagle Bay, Shelter Bay, Donnelly Point (near McDonald Creek), St. Leon, Arrowhead, Beaton, and Big Eddy (Prince 2001).

Similar to the HLK sub-population, white sturgeon in ALR presently consist of older adults, spawned prior to 1969 (Golder 2006b). Juveniles have not been observed within ALR even though natural spawning was observed in 1999 and 2003 in the flowing section of the

Revelstoke Dam tailrace (Golder 2006b). The cause of recruitment failure has not been determined, but recruitment failure hypotheses recently developed by the UCRWSRI (Section 5.0) indicate that habitat changes due to the back flooding behind HLK dam in Arrow Lakes Reservoir may be a main footprint impact, whereas other issues identified are operational (C. Spence, pers. comm., 2008).

White sturgeon in ALR are distributed mainly in upper Arrow Lake, with concentrations near Beaton Flats, Galena Bay, Beaton Arm, Big Eddy, and Revelstoke (Golder 2006b). Suitable adult habitats are present for feeding and overwintering, and rearing habitats for juveniles past the YOY and/or larval stages may also be available based on habitat preference studies (Golder 2006b). White sturgeon in ALR are relatively inactive from October to early March and remain in Beaton Flats, an important overwintering area (Golder 2006b). Feeding aggregations have been observed from spring through fall near the mouths of tributaries, with fall aggregations likely the result of following spawning kokanee (Golder 2006b).

Spawn timing in ALR has also been the latest recorded for this species throughout its range, and water temperatures are at the lower end of that recorded for the Kootenai population (Golder 2006b). Even though low water temperatures did not seem to impact egg development below Revelstoke Dam (Golder 2006b), survival is most likely limited (or eliminated altogether) because of the shortened growing season. However, low water temperatures may not be related to recruitment failure since incubated larvae from collected eggs hatched within time required for normal embryo development (Golder 2006b). It is more likely that low numbers of spawners (and hence low numbers of eggs/larval) limit the spawning potential of this sub-population. Mature, pre-spawning females are limited in ALR, since the population is mostly dominated by males (sex ratio=1.6:1 in favour of males) and female maturation intervals are much larger compared to males (Ptolemy and Vennesland 2003, Golder 2006b). Reproductive white sturgeon from the HLK and/or Revelstoke sub-populations cannot contribute to the ALR sub-population because they no longer have access to ALR due to the presence of the respective dams.

The ALR population is known to be functionally extinct (UCWSRI 2002), since numbers are extremely low and the possibility of a self-sustaining population was rated as having low to moderate level of feasibility due to availability and suitability of spawning and early life-stage rearing habitats (Golder 2006b). The re-establishment of this population with HLK stock may be a possibility and in 2007 and early 2008, approximately 4,000 and 7,000 sub-yearling white sturgeon were released below Revelstoke Dam (K. Bray, Biologist, BC Hydro-Revelstoke, pers. comm., 2008). There are also plans to release an additional half-million larvae in July 2008, which will aid in future research on recruitment bottlenecks, habitat availability and use, as well as juvenile growth and survival within the ALR (K. Bray, pers. comm., 2008). BC Hydro's Water Licensing Requirements (WLR) will include directed research within the ALR to determine whether this location is adequate for a recovery or failsafe population of white sturgeon.

3.3 Revelstoke Reservoir (Mica Dam to Revelstoke Dam – C4)

The presence of white sturgeon between Mica and Revelstoke dams is relatively unknown and the population is believed to be functionally extinct (UCWSRI 2002). "Mica Dam (built in 1973) further fragmented the river ecosystem above Arrow Lakes Reservoir, flooded over 250 km of the Columbia River mainstem that may have provided spawning and feeding habitats, reduced productivity by trapping nutrients, and increased water clarity by trapping sediments" (UCWSRI 2002).

Historical and recent sightings of white sturgeon have been made in Bush River Arm, at the confluence of Big Mouth and Downie creeks, and in the spillway plunge pool of Mica Dam (R. L. & L. 1996, Prince 2001). Construction workers on the Mica Dam also recalled moving several white sturgeon, but they were not sure if they were placed upstream or downstream of the dam site (Prince 2001, CCRIFC 2005). In 1995, studies conducted in Revelstoke Reservoir failed to capture white sturgeon even though set lines were deployed in areas where sturgeon were previously sighted (R. L & L. 1996). However, limited sampling effort was expended in a relatively large area (R. L. & L. 1996).

Specific habitat information regarding the presence of suitable overwintering, spawning, feeding, and rearing areas in Revelstoke Reservoir is lacking, except for the fact that forage fish such as kokanee were present prior to the dam and remain in the area today (C. Spence, pers. comm., 2008). Historical observations, made by construction workers at Mica Dam, indicated that sturgeon were present in a deep hole at this location (Prince 2001). Therefore, a potential overwintering area may have been present at the Mica Dam site. Potential spawning areas may have also been located in the area immediately upstream of Downie Creek, where several rapids were historically present prior to reservoir flooding (Prince 2001). Hence, the presence of Revelstoke Dam presents a possible obstacle to a variety of important habitats for sturgeon currently residing in downstream locations.

The re-establishment of white sturgeon in the Revelstoke Reservoir may not be a plausible option, since it is doubtful that remaining habitats are suitable for completing all components of their life history.

3.4 Kinbasket Reservoir (C3)

Sturgeon likely did not reside year-round in the area located between Mica Dam and Columbia Lake based on interviews with Ktunaxa/Kinbasket elders and anecdotal information collected from area residents (Prince 2001, CCRIFC 2005). However, several sightings of sturgeon using areas within the original Kinbasket Lake indicate that they were likely present in this area in autumn to feed on anadromous salmon runs prior to the construction of Grand Coulee dam (Prince 2001, CCRIFC 2005). Historical and recent sightings include areas near the Spillimacheen River, confluence of the Columbia River and Bugaboo Creek, and in Kinbasket Reservoir near Windy Creek and Sullivan River (Prince 2001). Spawning has also been observed by area residents at Surprise Rapids (between historic Kinbasket Lake and Golden), and a sturgeon may have been angled in Lake

Windermere (outside of this dam unit) in the early 1920's; this fishing story has never been authenticated (Prince 2001, CCRIFC 2005).

The only study conducted in Kinbasket Reservoir, in 1995, failed to capture white sturgeon, but limited sampling effort was expended in this large area (R. L. & L. 1996). Sample sites were located in areas with spawning kokanee (e.g., mouth of Bush and Sullivan rivers), as well as in areas where sturgeon had been previously sighted (R. L. & L. 1996).

Kinbasket Reservoir and its associated tributaries are glacier fed and water temperatures remain low throughout the year (Westslope and CCRIFC 2005). The habitat upstream of Mica Dam is thought to have important attributes for juvenile white sturgeon such as a natural hydrograph, turbid water, and availability of side channels, sloughs and backwaters that could serve as nursery areas (Perrin et al. 2003 as cited in Westslope and CCRIFC 2005). Water temperatures may limit successful recruitment in this reservoir, but incubation studies indicate that low water temperatures may not limit larval growth and natural development (Westslope and CCRIFC 2005). As well, recent direct observations of water temperature suggest temperatures may be more favourable than earlier studies have suggested (G. Birch, Technical Advisor and Manager, EMS, BC Hydro, pers. comm., 2008).

The stocking of juvenile white sturgeon in Kinbasket Reservoir to develop a recovery or failsafe area is under consideration (Westslope and CCRIFC 2005). Risk assessments determined that juvenile habitats are available and the associated risk of stocking on valued non-target taxa was relatively low, with the exception of burbot, which likely will be consumed by and compete with sturgeon (Westslope and CCRIFC 2005). A low risk of introducing pathogens to the study area was also assigned, provided established rearing and health protocols are followed (CCRIFC 2005). Studies planned under BC Hydro's WLR will further assess the risks associated with stocking sturgeon into Kinbasket Reservoir, as well as investigate habitat availability and use, and conduct more thorough inventories to capture white sturgeon (K. Bray, pers. comm., 2008). Future research will help direct the use of Kinbasket Reservoir as a recovery area or location for a failsafe population; no decisions will be made until 2010, when studies in ALR and Kinbasket have been completed (K. Bray, pers. comm., 2008).

3.5 Kootenay Lake (Corra Lynn Dam to Duncan Dam to U.S. border) and Trout Lake (K6, K5, and K8)

The Kootenay River white sturgeon population (referred to as Kootenai in the United States) is located in river and lake habitats that extend from Corra Lynn Dam to Duncan Dam to the Canada-U.S. border (Figure 1). The estimated total linear occupancy is 173 km without including U.S. habitats (BC CDC 2005). Kootenay Lake white sturgeon also have access to the U.S. portion of the Kootenay River to Kootenai Falls (Montana) and may also use habitats located within Trout Lake, since no barriers exist, but their presence in this lake is unknown (R. L. & L. 1998b).

The Kootenay River white sturgeon population was once abundant, and Ktunaxa Nation elders have historically observed juveniles in seasonally flooded wetland areas in Indian Creek near its confluence with the Goat and Kootenay rivers (Failing and Gregory 2003 as cited in Ptolemy and Vennesland 2003). Historical observations and angler reports from B.C. indicated that areas abundant with white sturgeon included the area where the Kootenay River joined Duck Lake and at the mouth of Summit Creek, near Creston, B.C.; sturgeon were numerous and weighed up to 350 lbs (Prince 2001). Studies indicate that high and medium use areas for white sturgeon in British Columbia include Creston Delta, Duncan Delta, and Crawford Bay (BC CDC 2005). White sturgeon may also occasionally use the West Arm of Kootenay Lake (R. L. & L. 1998b). Recent telemetry studies conducted on older hatchery-released juveniles indicate that the Creston Delta in Kootenay Lake is used extensively and provides preferred juvenile winter habitat (Neufeld 2006). The only known spawning area for this population is near Bonners Ferry, Idaho below Kootenai Falls.

The Kootenay River white sturgeon population was in decline prior to the construction of Libby Dam (1972) due to habitat alterations such as dyking, but consistent recruitment failures occurred after completion of the dam (Apperson and Anders 1991, Paragamian et al. 2005). The changes in the hydrograph (flow and sediment transfer) from the construction and operation of Libby Dam have been postulated as a main factor for this population's decline and it is expected that the wild population will be as low as 50 by 2030, without hatchery intervention (Ireland et al. 2002, Berenbrock and Bennett 2005, Paragamian et al. 2005). The wild population has been estimated at 760 adults (95% CI: 430 to 1090) and is declining by approximately 9% per year (Paragamian et al. 2005), despite conservation aquaculture, which began in 1990 and has added thousands of hatchery fish to the population since 1992 (Paragamian and Hansen 2008). Discharge mitigation has been used every year since 1994 and spawning and egg deposition was observed in most years, but poor egg and larval survival precluded measurable natural recruitment (Paragamian and Hansen 2008). Wild recruitment is very low and is estimated at approximately 10 fish per year (Paragamian et al. 2005).

Hatchery intervention is seen as the only viable option for stabilizing this population and preserving genetic diversity over the short term (Ireland et al. 2002), and is critical since data indicate that the population declines by half every 7.4 years (Paragamian et al. 2005). Hatchery-reared juveniles have had success in the wild (Ireland et al. 2002) and some have been observed to migrate long distances, travelling as far as 60 km upstream to a maximum of 127 km downstream (Neufeld 2007). Rearing habitats have been observed in the Canadian portion of Kootenay Lake, especially at the Creston, BC delta. Hatchery-reared juveniles captured at the Creston delta were significantly larger in weight and length compared to those of similar age captured in the river in BC and Idaho (Neufeld 2007).

Impacts from BC Hydro dams on this sub-population are likely related to fragmentation and impeded movements to feeding and overwintering areas within Duncan Reservoir.

However, the importance of movements and presence of required habitats outside current population boundaries are unknown.

3.6 Duncan Reservoir (K7)

In 1964, two 70 kg white sturgeon were captured on set lines set by the BC Fish and Wildlife Branch (AIM 2007). Since the construction of Duncan Dam in 1967, five older, adult white sturgeon have been captured during investigations conducted in 1995 and 1996, indicating that a remnant population is present in Duncan Reservoir (R. L. & L. 1998b). All fish were spawned prior to 1948 (R. L. & L. 1998b). Based on the age of the five captured white sturgeon and a lack of juveniles, it is likely that this group is not reproducing at levels to sustain the population (R. L. & L. 1998b).

White sturgeon in this area may have been part of the larger Kootenay Lake population that used Duncan Lake for feeding, but were trapped behind Duncan Dam during its construction (R. L. & L. 1998b). Wetland habitats were abundant prior to the construction and flooding of Duncan Dam (AIM 2007). However, it is unknown as to whether these habitats were utilized as rearing areas for the Kootenay Lake white sturgeon population. Potential feeding areas may be present where the five fish were captured in 1995 (i.e., Glacier Creek, between Little Glacier Creek and Howser Creek, and near Reno Creek) (R. L. & L. 1998b). However, potential spawning habitats for white sturgeon in Duncan Reservoir are lacking (C. Spence, pers. comm., 2008), and rearing, and overwintering areas within the reservoir are unknown. Since Duncan Dam blocks the movement of white sturgeon between Duncan Reservoir and Kootenay Lake, it was proposed that the remaining white sturgeon be captured and transferred from Duncan Reservoir to Kootenay Lake (R. L. & L. 1998b), since these individuals are recognized as being important to the persistence of a declining Kootenay Lake population (Neufeld and Spence 2004). In 2003, one female white sturgeon, a recapture from 1995, was moved from Duncan Reservoir to the North Arm of Kootenay Lake and travelled approximately 120 km to Creston Delta (Neufeld and Spence 2004). This fish was subsequently tracked to Bonners Ferry, where it was suspected to have spawned the next spring following its transplant (C. Spence, pers. comm., 2008).

3.7 Slocan Lake (K9)

Slocan Lake is included in the K9 dam unit. Movements of white sturgeon between the lower Kootenay River and Slocan Lake are directly impeded by several non-BC Hydro dams, located below lower Bonnington Falls (Figure 1). Slocan Lake was included in the K9 footprint impacts area because it is potentially impacted by BC Hydro owned Kootenay Canal. A remnant group of white sturgeon is present in Slocan Lake based on the capture of two older, adult fish in 1995 and 1996 and reports from anglers (R. L. & L. 1996). The fish were spawned prior to 1958 (R. L. & L. 1996). Since the age of these fish are younger than Brilliant Dam, this population may have been entrained from the Kootenai population and subsequently moved into Slocan Lake (R. L. & L. 1996, R. L. & L. 1997). It is unlikely that fish in Slocan Lake represent a lake dwelling sub-population (originally from the larger

Columbia River population), since they would have been spawned in the Slocan system or between the dams on Kootenay River, a highly unlikely scenario (C. Spence, pers. comm., 2006). The presence of white sturgeon in other portions of the lower Kootenay River between Brilliant and Corra Lynn dams has not been confirmed; no captures were made during sampling conducted in 1995 (R. L. & L. 1996).

Based on observations of one sonic tagged female (in pre-spawning condition), overwintering areas in Slocan Lake may be present near Wragge Creek and near Nemo Creek (R. L. & L. 1997). Suitable spawning areas (or suitable mates) are not likely present in Slocan Lake, since this female was observed to make many exploratory-type movements mostly to tributary mouths during the early spawning season in 1997 (R. L. & L. 1998a).

The Slocan Lake remnant population of white sturgeon is also not successfully reproducing based on the small number of fish captured over a three year period, a lack of juveniles, and the limited presence of spawning habitats (R. L. & L. 1997). The re-establishment and further study of white sturgeon in Slocan Lake is a low priority (C. Spence, pers. comm., 2006).

3.8 Koocanusa Reservoir (K3)

The Canadian portion of the Koocanusa Reservoir is located from Wardner to the U.S. border (K3). The presence of Kootenai Falls (a natural barrier located in the U.S.) either partially blocked or completely blocked upstream migration of white sturgeon into upstream reaches in Montana and B. C. (C. Spence, pers. comm., 2008). The construction of Libby Dam prevented any further movements into Koocanusa Reservoir (that is, if Kootenai Falls was a partial barrier). During the mid-1970's, Montana Fish, Wildlife & Parks introduced five adult white sturgeon into Koocanusa Reservoir (C. Spence, pers. comm., 2008). One of these five white sturgeon was captured at Wardner Bridge in 1980, but the fate of the remaining sturgeon are unknown (C. Spence, pers. comm., 2008). It is hypothesized that some or all of these fish may have been captured by anglers (C. Spence, pers. comm., 2008).

Mitigation/compensation measures may not be applicable for this reservoir, since it is unknown if the area was used by sturgeon prior to Libby Dam. Further studies to determine the habitat potential and presence of other individuals may be warranted if the Koocanusa Reservoir were to be used as a fail-safe[2] area for the Kootenai River white sturgeon recovery program. The Kootenai White Sturgeon Recovery Team have had some preliminary discussions regarding stocking white sturgeon in Koocanusa Reservoir, and this work is ongoing (C. Spence, pers. comm., 2008).

[2] The establishment of another group or sub-population of white sturgeon in a location separate (i.e., Kinbasket) from the main group (i.e., HLK). This would enable separate groups of sturgeon to persist in the event that one sub-group experiences a catastrophic die-off.

4.0 REGULATORY CONTEXT FOR COMPENSATION FOR DAM FOOTPRINT IMPACTS AND WHITE STURGEON POPULATIONS

There are two main pieces of Federal legislation concerning white sturgeon compensation for BC Hydro dam footprint impacts within the Columbia Basin. These include: i) Species At Risk Act (SARA); and, ii) Fisheries Act. Both pieces of legislation are described briefly below with respect to BC Hydro dams.

4.1 Species At Risk Act (2002; c.29)

In 2006, both the Columbia River and Kootenay River white sturgeon populations were listed under Schedule 1 (Subsections 2(1), 42(2) and 68(2)) as Endangered. Responsibility for the protection of white sturgeon under SARA sits with Fisheries and Oceans Canada (DFO). The pertinent prohibitions under SARA include: Section 32 - can not kill, harm or harass a species at risk; Section 33 - can not damage or destroy the residence of a species at risk; and, Section 58 - can not destroy the critical habitat of a species at risk. Existing facilities, such as BC Hydro dams, impacting any of the above provisions under SARA cannot be ‘grandfathered’ and will require a permit or exemption to be in compliance with the legislation (T. Coopper, Habitat Biologist, DFO SARA Policy, Nelson, B.C., pers. comm., 2008).

Once a species is listed as *extirpated, endangered, and threatened*, SARA legislation requires that a Recovery Strategy be created, which consists of Action Plans and Management Actions. DFO ensures that recovery planning is consistent with federal acts, policies, and regulations, whereas the administrative responsibility for the management of the white sturgeon (and other freshwater species) belongs with the BC Ministry of the Environment. In 2000, an agreement between provincial and federal governments in Canada and the United States and BC Hydro was made to address the upper Columbia River white sturgeon (i.e., populations residing above Grand Coulee Dam). This agreement defined strategies for recovery, initiated a recovery program, and involved First Nations and the public. In 2002, the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI) completed a Recovery Plan that identified goals and recovery measures for rebuilding the white sturgeon population, which is still ongoing.

4.2 Fisheries Act (R.S.C., 1985, c. F-14)

Most BC Hydro dams within the Columbia Basin were constructed and commenced operation prior to the enactment and widespread application of the Federal Fisheries Act. Responsibility for the administration and enforcement of this Act also sits with DFO. “DFO takes the position that sections 20, 22, 32, 35, and 36 of the Fisheries Act apply to the continued operation, modification or maintenance of a facility even though the facility in question was constructed prior to the enactment of those sections” (DFO 2006).

The following sections of the Fisheries Act are the most applicable to dam footprint impacts on white sturgeon in the Columbia Basin: Section 20 – requirement of fish passage; Section

32 – prohibits the destruction of fish; Section 35 – prohibits the harmful alteration, disruption or destruction (HADD) of fish habitat; and, Section 36 – prohibits the deposit of deleterious substances. Section 22 mentioned above is mainly related to the operation of BC Hydro dams to provide sufficient flow of water for the safety of fish, flooding of spawning grounds, and safe fish passage. Also, Section 32 deals with entrainment of fish through dams and is mostly an operational impact that will be covered by the BC Hydro-DFO Entrainment Strategy.

4.2.1 Habitat Protection Provisions of the Fisheries Act (Subsection 35(1))

The majority of DFO's policy has been derived for Subsection 35(1) of the Fisheries Act which is a general prohibition of Harmful Alteration, Disruption or Destruction (HADD) of fish habitat. This means that any work or undertaking that results in a HADD is a contravention of Subsection 35(1). The only relief from this general prohibition is when a Subsection 35(2) Authorization is issued for the HADD. DFO's main policy related to Subsection 35(1) is the overall *net gain* of the productive capacity of fish habitats and is to be achieved by meeting three goals: i) conservation of existing habitats; ii) restoration of damaged habitat; and, iii) development of new habitats (DFO 1986). "The conservation goal requires that the current productive capacity of existing habitats is maintained by applying the *No Net Loss* (NNL) *of the productive capacity of fish habitat* guiding principle. When fish habitat losses are unavoidable, the productive capacity may be compensated by replacing or enhancing fish habitat" (DFO 2006).

The use of compensation to achieve NNL is only considered after it proves impossible or impractical to avoid a HADD of fish habitat through project relocation, redesign, or mitigation. DFO's Hierarchy of Compensation Options includes (DFO 2006):

1. Create or increase the productive capacity of like-for-like habitat in the same ecological unit;
2. Create or increase the productive capacity of unlike habitat in the same ecological unit;
3. Create or increase the productive capacity of habitat in a different ecological unit; and,
4. As a last resort, use artificial production techniques to maintain a stock of fish, deferred compensation or restoration of chemically contaminated sites.

While the Hierarchy of Compensation Options should normally be followed, there are circumstances under which exceptions may be required such as: i) situations where site-specific issues are well understood and may include circumstances where limitations to productive capacity are known, and local management plans contain clear objectives for the fishery may have been prepared; ii) where a better opportunity for maximising the amount of habitat gained, particularly where there are known limitations (or bottlenecks), then moving down the hierarchy may be justified (DFO 2006).

5.0 COMPENSATION FOR WHITE STURGEON POPULATION LOSSES DUE TO FOOTPRINT IMPACTS

White sturgeon productivity in both the Columbia and Kootenay rivers has declined due to the construction of dams within the basin. Permanent losses of critical habitats and the degradation of those habitats are major contributors to reducing the productive capacity of white sturgeon habitat and to the overall decline of white sturgeon populations.

Based on Federal regulations for BC Hydro's existing dams, DFO may require compensation for losses to white sturgeon populations within the Columbia Basin. "The goal with existing facilities that can not, or are not going to be, removed or shut down is to make sure everything feasible is being done to mitigate and avoid the impacts and then if there are residual impacts that can not be avoided then work with the facility to get involved with recovery and compensation to offset those impacts" (T. Coopper, pers. comm., 2008).

5.1 Quantifying Dam Footprint Losses on White Sturgeon Populations

Quantifying permanent losses of white sturgeon habitat and population(s) productive capacity from the construction of BC Hydro dams is difficult, especially when historical use and productivity of white sturgeon habitats cannot be accurately defined. Methods to quantify losses of habitat and its potential productive capacity due to developments are available and have been used for environmental assessments prior to construction. For example, the Habitat Evaluation Procedure (HEP; USFWS 1981) considers the availability and use of fish habitats in the proposed area of impact and applies Habitat Suitability Indices (HSI) to each life stage of a fish species. However, detailed habitat surveys are required to quantify fish habitat and use of this habitat in areas both directly and indirectly impacted. Also, HSI models are not available across the range of distribution of white sturgeon in the Kootenay and upper Columbia systems.

For existing facilities, such as BC Hydro dams, quantification of impacted habitats on an areal basis may also not be a useful method, since it is difficult to ascertain the level of impact and habitat use by sturgeon. For example, five DU's (i.e., C4, C11, C9, and K7) are directly impacted by BC Hydro dams, but the populations within the other DU's are either partially impacted (i.e., C3, K5, K6, and K9) or the use of the area historically by white sturgeon is largely unknown (i.e., K3). Additionally, total habitat loss within C4, C11, C9, and K7 is not an appropriate measure, since impoundments actually increased the total area available and may provide useful white sturgeon habitat. However, access to this newly created habitat may be unavailable due to blocked movements at dams. Also, critical habitats for white sturgeon are still present and functional within the impacted DU's, although productive capacity is reduced to some extent.

5.2 White Sturgeon Recovery Planning & Compensation

Since it is difficult to directly quantify with accuracy white sturgeon habitat losses and losses to productive capacity due to dam footprint impacts, the UCWSRI's Recovery Plan is more appropriate to consider when determining compensation options for the white sturgeon population. Recently, Recovery Team members have outlined white sturgeon recruitment failure hypotheses, that incorporate operational and footprint constraints on the white sturgeon population (C. Spence, pers. comm., 2008), which are discussed further below.

5.2.1 Recruitment Failure Hypothesis (RFH) Review

In 2008, various members of the Recovery Team as well as outside experts attended approximately six workshops to discuss several recruitment failure hypotheses (G. Birch, pers. comm., 2008). At the time of this writing, 100 hypotheses were refined and distilled to twelve, which were further prioritized and a list of research and mitigation measures were developed (G. Birch, pers. comm., 2008). A detailed report on the outcome of the workshops and recruitment failure hypotheses is currently in preparation, but was not available for this review.

The 12 hypotheses were provided by the Recovery Team in draft form during the development of this report to assist in compiling a list of compensation options and associated costs pertinent to the white sturgeon population recovery. Of these 12 hypotheses, two are operational and the remaining 10 hypotheses are potential footprint impacts intermixed with operational issues. All 12 hypotheses are listed below and reference numbers used by the Recovery Team are provided in parenthesis; LC and MC refer to Lower Columbia (below HLK Dam) and Middle Columbia (upstream of HLK Dam), respectively. Those hypotheses directly related to BC Hydro dam footprint impacts have been highlighted in yellow, whereas those highlighted in green are potentially related to footprint impacts.

1. Changes in flow patterns (magnitude and timing) and reduction in turbidity reduce the survival of young sturgeon (LC1/LC3).

2. Diminished suitability and availability of habitat (primarily related to substrate conditions) downstream of spawning areas has led to reduced survival of early life stages (LC2/LC4).

3. Changes to the fish community have resulted in increased predation on eggs, free embryos, larvae and juvenile sturgeon and significantly reduced survival (LC5/LC6).

4. Contaminated effluent from smelter and pulp mill sources leads to direct or indirect toxicity, impacted health, reduced spawning success, and reduced habitat and prey availability (LC7/LC8).

5. Food of the appropriate type and size is not available at the right time and place to promote survival of young sturgeon (LC9/LC10).

6. Changes in flow and temperature patterns (magnitude and timing) reduce the success of or delay spawning, egg development, and post-hatch embryo growth and development. As a result, the over-wintering fitness of post-hiding phase juveniles is impacted and survival significantly reduced (MC1/MC2/MC5).

7. Changes in flow patterns (magnitude and timing) and reduction in turbidity reduce the survival of eggs and young sturgeon (MC3/MC4/MC6).

8. The suitability and availability of habitat (primarily related to substrate conditions) downstream of spawning areas has led to reduced survival of eggs and early life stages (MC7/MC8).

9. The installation of HLK dam eliminated the ability of mature adults from below the dam to access spawning habitat in the mid-Columbia reach upstream of Arrow Lakes resulting in lost recruitment (MC9).

10. The installation of HLK dam eliminated access to feeding areas in the Arrow Lakes and upstream river-lake interface area for juveniles to pre-mature adults impacting growth and survival (MC13).

11. Changes to the fish community have resulted in increased predation on eggs, free embryos, larvae and juvenile sturgeon and significantly reduced survival (MC10/MC11).

12. Food of the appropriate type and size is not available at the right time and place to promote survival of young sturgeon (MC12).

5.3 Priorities & Preferred Compensation Options

Compensation options were considered mostly for the HLK subpopulation, since this group has been the main focus of recovery efforts. Compensation options deemed suitable by Recovery Planning efforts for footprint-related impacts to the white sturgeon population are presented below. Options are listed with their priority ranking as discussed with the Recovery Team and provided by unpublished data from the RFH review. Compensation options presented may be relevant for more than one footprint RFH listed above and were thus grouped accordingly. It is assumed that mitigation measures taken to lessen the operational impacts of BC Hydro dams on the white sturgeon population will be covered by BC Hydro's Water Licensing Requirements (WLR).

5.3.1 RFH Compensation Priorities

The following RFH compensation options were identified and ranked by the UCWSRI's Technical Working Group (TWG):

1. Flow Manipulation – operational
2. Backwater Timing Manipulation – operational
3. Substrate Addition
4. Turbidity Augmentation
5. Embayment Fertilization
6. Substrate Cleaning
7. Seeding of Varial Zones
8. Walleye Reduction program
9. Fertilize Transboundary Reach
10. General Predator Control Program

RFH compensation options related to footprint impacts only are discussed further below.

5.3.1.1 Substrate Addition Below HLK Dam

RFH Reference: LC1/LC3; LC2/LC4; LC9/LC10 – Turbidity
Priority Ranking: 3
Substrate preference and use by white sturgeon early life stages form much of the emerging research by biologists involved in white sturgeon recovery (e.g., Berenbrock and Bennett 2005, McAdam et al. 2005, C. Spence, pers. comm., 2008). It is hypothesized that substrate suitability has been adversely affected by dam construction and operation, perhaps in combination with other natural and/or industrial influences (e.g., smelting slag). For example, construction of HLK dam may have created a large sediment plug that was subsequently released to downstream areas. Sediments released due to dam construction may have in-filled substrate interstices or overlain substrates rendering them unsuitable for use by early life stages (UCWSRI, unpublished). Juveniles would be prone to a reduction of food availability (impacting growth) and predation (during search for food and habitat).

The addition of new substrates has been proposed to compensate for the initial sediment plume and degradation of substrates below HLK dam. Research requirements to further investigate the feasibility of substrate addition include (UCRWSRI, unpublished):

1. Pre- and post-construction sediment condition comparisons;
2. Comparison to substrate and sediment conditions in other river systems with white sturgeon;
3. Behavioural studies on juvenile habitat use and substrate requirements;
4. Substrate preferences by age;
5. Relationships between substrate composition and drift/hiding phases of early life stages; and,

6. Scale of activity required (i.e., size of substrate patch).

The overall estimated cost to conduct feasibility studies is $1.7 million. Table 1 provides a summary of each research item and its estimated cost.

Prior to substrate addition below HLK dam, investigations (in addition to feasibility studies listed above) are required to determine the type of substrates to be added, which areas will be added to and how, and the size of the area required. Also, the process used to add the substrate (e.g., machinery) may trigger an environmental assessment review, either in Canada and/or the United States. In Canada, any work or undertaking that causes a HADD under the Fisheries Act (and the requirement of a Fisheries Authorization) must undergo a review under the Canadian Environmental Assessment Act (CEAA). Other requirements for this compensation option would include design plans for substrate additions, as well as monitoring programs (biological and physical); these would also be required for the CEAA review. Substrate addition has been successfully employed to increase spawning success for lake sturgeon and may have similar benefits for white sturgeon (UCWSRI 2002). Substrate augmentation in the white sturgeon spawning reach at Bonner's Ferry was piloted in 2006 and rip rap was placed on sandy substrates within the current white sturgeon spawning area (M. Neufeld, Biologist, MOE, Nelson, B.C., pers. comm., 2008). However, the success of this rock addition in terms of a biological response has not been completed to date (M. Neufeld, pers. comm., 2008). More detailed research with smaller substrates is ongoing in the lab and field (S. McAdam, pers. comm., 2008). The cost of adding substrates to areas below HLK dam is estimated at $1.5 million; costs are also provided in Table 1.

Table 1 Cost estimates for white sturgeon compensation option of substrate modification below HLK dam to provide more suitable habitat for early life stages of white sturgeon

Component	Estimated Cost
Apriori Research Feasibility	
Pre and post-construction sediment condition comparisons	$100,000
Comparison to substrate and sediment conditions in other river systems with white sturgeon	$200,000
Behavioural studies on juvenile habitat use and substrate requirements	$300,000
Substrate preferences by age	$300,000
Relationships between substrate composition and drift/hiding phases of early life stages	$300,000
Scale of activity required (i.e., size of substrate patch)	$500,000
Subtotal	***$1,700,000***
Substrate Addition/Cleaning[b]	
Background studies (methods, area, costs, options)	$600,000
Environmental Assessment (if required)	$300,000
Design Plan for cleaning substrate	$100,000
Monitoring - Biological Response	$250,000
Monitoring - Physical Response	$250,000
Subtotal	***$1,500,000***
Total[c]	***$4,700,000***

[a]Cost estimates based on UCWSRI (unpublished data).
[b]Costs presented are the same for either cleaning or addition.
[c]Total cost estimate includes costs for both substrate addition and substrate cleaning.

5.3.1.2 Turbidity Augmentation

RFH Reference: LC1/LC3
Priority Ranking: 4

The construction of dams and reservoirs in the Columbia Basin has changed a once relatively turbid river system to clear, oligotrophic lakes. The addition of turbidity-inducing substances may aid in reducing predation on white sturgeon eggs and larvae (UCWSRI, unpublished).

Prior to conducting any turbidity augmentation below HLK dam, investigations are required to determine the material type to be used and how it will be delivered into the system, as well as its effectiveness for recovery of the stock. Also, the addition of any turbidity producing substance may fall under a “deleterious substance” under the Federal Fisheries Act (Subsection 36), which may trigger an environmental assessment review, either in Canada and/or the United States. Other requirements for this compensation option would include permits and approvals, communications between levels of government, local industry and the public, as well as monitoring programs (biological and physical); these would also be required for the CEAA review. The overall estimated cost to conduct feasibility studies is $860,000. Table 2 provides a summary of each research item and its estimated cost. The costs for turbidity augmentation studies and application below HLK dam is estimated at $2.0 million.

Table 2 Cost estimates for white sturgeon compensation option of turbidity augmentation below HLK dam to reduce predation on early life history stages.

Component		Estimated Cost
Apriori Research Feasibility		
Pre- and Post-construction comparisons		$30,000
Comparison to substrate and sediment conditions in other river systems with white sturgeon		$30,000
Behavioural studies on early life stages and requirements		$500,000
Determining minimum acceptable turbidity for reducing predation		$300,000
	Subtotal	***$860,000***
Turbidity Augmentation		
Background studies (material type, delivery, effectiveness for recovery success)		$400,000
Environmental Assessment (if required)		$500,000
Permits/Approvals		$100,000
Communications		$200,000
Monitoring - Biological Response		$500,000
Monitoring - Physical Response		$300,000
	Subtotal	***$2,003,000***
	Total	***$2,863,000***

[a]Cost estimates based on UCWSRI (unpublished data).

5.3.1.3 Fertilization Below HLK

RFH Reference: LC9/LC10
Priority Ranking: 5, 7, 9

The addition of fertilizer to areas below HLK dam has also been proposed increase food availability to early life stage white sturgeon. Substrates below HLK dam have been altered and invertebrate prey species are unable to find suitable substrate and die (UCWSRI, unpublished). Sub-yearling white sturgeon cannot find suitable or sufficient prey, and they starve or their growth is reduced and they succumb to predation (UCWSRI, unpublished).

The addition of fertilizer to below HLK dam within embayments (Section 5.3.1.3.1), within specific sections (Section 5.3.1.3.2), or in its entirety (Section 5.3.1.3.3), requires further research to demonstrate the feasibility of this compensation option. Large-scale fertilization projects in Kootenay Lake and Arrow Lakes Reservoir within the Columbia Basin have been successful to improve kokanee stocks (and in turn their predators; e.g., Schindler et al. 2006) and may have some application for the white sturgeon population.

Research requirements to further investigate the feasibility of fertilization include (UCRWSRI, unpublished):

1. Juvenile stomach contents study (histology, evidence of starvation);
2. Starvation dynamics and physiology;
3. Prey availability and abundance in settlement areas;
4. Historical review of nutrients pre-reservoir (see also AIM et al. 2007);
5. Comparison with other white sturgeon populations (recruiting or not);
6. Investigation of food enhancement opportunities (site surveys, design options, cost); and,
7. Confirmation of prey preferences.

The overall estimated cost to conduct feasibility studies is $3.1 million. Table 3 provides a summary of each research item and its estimated cost.

5.3.1.3.1 Embayment Fertilization

Priority Ranking: 5

The fertilization of an embayment test area was proposed as a pilot project and given the highest priority within all of the fertilization options provided (UCWSRI, unpublished). The estimated cost associated with this option is $2.2 million (Table 3).

5.3.1.3.2 Seeding of Juvenile Rearing Areas

Priority Ranking: 7

As a pilot project, the fertilization of one juvenile rearing area was proposed for a three year period (UCWSRI, unpublished). The total estimated cost for this option, including feasibility studies, environmental assessment, permitting/approvals, design, implementation, and monitoring studies is $2.6 million (Table 3).

5.3.1.3.3 Transboundary Fertilization

Priority Ranking: 9

One option that has been proposed is to fertilize the transboundary area below HLK dam to Grand Coulee dam (Washington, USA), which is approximately 250 km in length. However, this was the second lowest priority identified by the UCWSRI. The practicality of fertilizing such a large area in a dynamic river is unknown. However, the UCWSRI has estimated that the costs of this task may be well over $ 5.0 million (Table 3). Similar feasibility and implementation studies would be required as for substrate addition; cost estimates for each are also provided in Table 3. Estimated costs would have to be proportionally shared between Canada and the United States.

Table 3 Cost estimates for white sturgeon compensation option of fertilization below HLK dam to increase food availability for early life stages of white sturgeon

Component		Estimated Cost[a]
A priori Research Feasibility		
Juvenile stomach contents study		$500,000
Starvation dynamics and physiology		$300,000
Prey availability and abundance in settlement areas		$500,000
Historical review of nutrients pre-reservoir[b]		$100,000
Comparison with other white sturgeon populations		$600,000
Investigation of food enhancement opportunities		$750,000
Confirmation of prey preferences		$300,000
	Subtotal	***$3,050,000***
Embayment Fertilization		
Background & feasibility studies		$100,000
Environmental Assessment (if required)		$200,000
Design and Develop Plan for Delivery		$-[d]
Permitting/Approvals[c]		$100,000
Communications/Outreach		$200,000
Implement Strategy		$1,000,000
Monitoring - Pre-fertilization		$300,000
Monitoring - Post-Fertilization		$300,000
	Subtotal	***$2,200,000***
Seeding of Juvenile Rearing Area		
Background & feasibility studies		$200,000
Environmental Assessment (if required)		$200,000
Design and Develop Plan for Delivery		$100,000
Permitting/Approvals[c]		$100,000
Communications/Outreach		$200,000

Component		Estimated Cost[a]
Implement Strategy		$600,000
Monitoring - Pre-fertilization		$600,000
Monitoring - Post-Fertilization		$600,000
	Subtotal	***$2,600,000***
Transboundary Fertilization		
Background studies (methods, quantity, costs, options)		$200,000
Environmental Assessment (if required)		$150,000
Permitting/Approvals[c]		$100,000
Implement Strategy		$3,000,000
Monitoring - Pre-fertilization (productivity of target food source etc.)		$600,000
Monitoring - Post-Fertilization (water quality; response to sturgeon and other species)		$600,000
	Subtotal	***$4,750,000***
	Total	***$10,000,000***

[a] Cost estimates based on UCWSRI, unpublished data.
[b] Costs for this component may be reduced or eliminated based on AIM et al. (2007).
[c] Costs for this component may be covered by the EIA (or are in addition to the EIA).
[d] Costs for this component are not required, since designs and plans for delivery can be utilized from ongoing fertilization programs.

5.3.1.4 Substrate Cleaning

RFH Reference: LC1/LC3; LC2/LC4; LC9/LC10 – Turbidity
Priority Ranking: 6

The cleaning of substrates below HLK dam was also deemed a compensation option for white sturgeon recovery. However, this option was ranked lower than substrate addition. Prior to substrate cleaning below HLK dam, investigations are required to determine the type of substrates to be cleaned, which areas will be cleaned and how, and the size of the area required. Also, the process used to clean the substrate (e.g., removal, treatment, replacement) may trigger an environmental assessment review, either in Canada and/or the United States. Research requirements and substrate cleaning feasibility studies are similar to that listed for substrate addition (Section 5.3.1.1). Other requirements for this compensation option would include design plans for cleaning, as well as monitoring programs (biological and physical); these would also be required for the CEAA review. The estimated costs for each component related to substrate cleaning are similar to substrate addition and provided in Table 1. Overall, costs for substrate cleaning are estimated at $1.5 million.

5.3.1.5 Predator Control

RFH Reference: LC5/LC6
Priority Ranking: 8, 10
It was hypothesized that dam installation and operations, combined with fish introductions have altered the fish community and increased the number of predators (UCWSRI, unpublished). Increased predation on early life stages would therefore reduce white sturgeon survival, especially since juvenile growth is reduced and habitat refugia may not be available (UCWSRI, unpublished). Research requirements to further investigate the feasibility of predator control include (UCRWSRI, unpublished):

1. Species that prey on white sturgeon (literature review and field studies);
2. Predator population profiles;
3. Measures for reducing/eliminating exotic introductions into Canada and US;
4. Historical review of predators pre- and post-regulation;
5. Impacts of predator reduction/controls to overall fish community; and,
6. Predator reduction techniques/effectiveness.

The overall estimated cost to conduct feasibility studies is $1.7 million. Table 4 provides a summary of each research item and its estimated cost.

5.3.1.5.1 Walleye Reduction Program

Priority Ranking: 8
Walleye are suspected to have been originally introduced into Lake Roosevelt, Washington, and have migrated upstream into the HLK reach in B. C. Studies conducted in the HLK reach indicated that walleye have been abundant since 1990 and although fluctuations in the population have been observed, their population is steadily increasing (Golder 2002, Golder 2007). Costs associated with a walleye reduction program are estimated at $1.1 million, but this was not highly ranked by the UCWSRI (Table 4).

5.3.1.5.2 General Predator Control Program

RFH Reference: LC5/LC6
Priority Ranking: 10
Other predators, besides walleye, may also be impacting the white sturgeon population. However, studies are required to determine which species have an impact within the HLK reach. A general predator control program for the HLK population was given the lowest priority of all RFH rankings. Costs associated with this type of program are estimated at $1.4 million (Table 4).

Table 4 Cost estimates for white sturgeon compensation option of predator control below HLK dam to increase survival for early life stages of white sturgeon

Component		Estimated Cost[a]
A priori Research Feasibility		
Species that prey on white sturgeon		$500,000
Predator population profiles		$500,000
Measures for reducing/eliminating exotic introductions		$-[b]
Historical review of predators pre- and post-regulation		$100,000
Impacts of predator reduction/controls to overall fish community		$500,000
Predator reduction techniques/effectiveness		$-[b]
	Subtotal	***$1,600,000***
Walleye Reduction		
Reduction Strategy		$100,000
Permitting/Approvals		$-[b]
Communications/Outreach		$50,000
Implement Strategy		$300,000
Monitoring – Effectiveness of Control on Predator Species		$300,000
Monitoring – White Sturgeon Response		$300,000
	Subtotal	***$1,050,000***
General Predator Control		
Environmental Assessment (if required)		$300,000
Develop species-specific reduction strategy		
Permitting/Approvals		$-[b]
Communications/Outreach		$50,000
Implement Strategy		$300,000
Monitoring – Effectiveness of Control on Predator Species		$300,000
Monitoring – White Sturgeon Response		$300,000
	Subtotal	***$1,350,000***
	Total	***$4,000,000***

[a] Cost estimates based on UCWSRI, unpublished data.
[b] Costs for this component were not available.

5.4 Current & Ongoing Compensation Priorities

5.4.1.1 Artificial Propagation/Conservation Aquaculture

DFO's Hierarchy of Compensation Options indicates that artificial propagation may be undertaken as a measure of last resort to compensate for lost productive capacity. The UCWSRI Recovery Strategy indicates that "immediate hatchery intervention is necessary to preserve the remaining population diversity in the face of almost complete collapse of recruitment of young sturgeon" (UCWSRI 2002). A conservation aquaculture program was initiated in 2001 to supplement the white sturgeon population below HLK Dam. Hatchery-reared juveniles are released to supplement the existing population until natural recruitment can be restored, at such time hatchery-releases will cease (UCWSRI 2002). The UCWSRI projects that a stable adult population may be reached in 50 years (UCWSRI 2002). However, the next 5 to 20 years was emphasized as the "most critical period in recovery of upper Columbia River sturgeon because of the current lack of juvenile and subadult fish and the corresponding decline in numbers of potential female spawners" (UCWSRI 2002). The conservation aquaculture program has been successful in providing hatchery-reared juveniles annually below HLK. In 2007, the program was extended to provide hatchery-reared juveniles and larvae below Revelstoke Dam for future research programs.

5.4.1.1.1 Annual Costs and Contributions

The total cost for the lower Columbia River white sturgeon conservation aquaculture program is approximately $500,000, not including costs for the mid-Columbia River (fiscal 2008-2009; B. Ludwig, Freshwater Fisheries Society BC, pers. comm., 2008). Including costs for the added sturgeon culture required for Arrow Lakes Reservoir (i.e., releases below Revelstoke Dam) increase costs to approximately $1.0 million. In addition to aquaculture operations at the Kootenay Sturgeon Hatchery, costs also include approximately 16,000 PIT tags each year ($2 each), Broodstock Collection activities ($87,000/yr), and the release of juveniles (C. Spence, pers. comm., 2008). For 2008-2009, the FWCP's contribution is approximately $225,000 of the total conservation aquaculture budget (B. Ludwig, pers. comm., 2008). This contribution makes up approximately half of the total contribution to the lower Columbia River white sturgeon culture operations (or approximately 23% of the total for projected expenses required); the remainder comes from WLR funding.

5.5 Additional Compensation Options

RFH Reference: MC9 – Habitat Fragmentation & Fish Passage
Priority Ranking: Not Applicable

The following compensation options were also identified by the UCWSRI for footprint impacts, but were not part of their priority ranking. They are provided here for consideration, since they are directly related to footprint impacts (i.e., habitat fragmentation and fish passage).

5.5.1 Fish Passage Options between Lower and Mid-Columbia Sub-populations

The construction of HLK dam, without suitable passage facilities, eliminated the ability of white sturgeon to access upstream areas for spawning and/or foraging (UCWSRI, unpublished). Upstream adult migration is impeded either seasonally or during the interval between spawning events into Arrow Lakes and upstream to the Columbia River. This results in reduced spawning success (UCWSRI, unpublished). Also, impeded passage to upstream areas eliminated the ability of foraging juveniles and older sub-adults and pre-mature fish to access feeding areas in Arrow lakes and the upper river. The loss of this productive foraging habitat has impacted growth and survival of the remaining population (UCWSRI, unpublished). Compensation options for impeded fish passage include transporting fish and building passage facilities, which are discussed further below.

5.5.1.1 Transport Wild Adults Upstream of HLK

Transporting wild adults from the HLK sub-population to the Arrow Lakes Reservoir has been proposed to help supplement the adult spawning population in the mid-Columbia River (UCWSRI, unpublished). Costs associated with this compensation option depend upon the number of fish transported upstream. However, if a few fish each year are moved into the Arrow Lakes sub-population, then this may be added to the Broodstock Collection program for less than $10,000 (C. Spence, pers. comm., 2008). This is a low priority project in the near term, but could become a possibility when and if numbers of wild fish are increased as a result of recovery efforts in the HLK reach (C. Spence, pers. comm., 2008).

5.5.1.2 Transport Juveniles Upstream of HLK

The transport of white sturgeon juveniles (>1 year old) and sub-adults was also proposed to make alternative habitats available and increase gene flow in upstream areas that were once available to the HLK sub-population prior to dam construction (UCWSRI, unpublished). The cost to conduct five days of gill netting and transporting juveniles is estimated at $17,700 per event. This does not include any reporting options (Table 5). However, as described earlier, juvenile and larval white sturgeon were released in early 2008 to aid in operational studies under the BC Hydro WLR and may address this issue.

Table 5 Cost estimates for fish passage compensation option of gill netting and transporting juveniles from the HLK sub-population to Arrow Lakes Reservoir

Component	Estimated Cost[a]
Personnel Costs - 5 days[b]	
Crew of 3 (1 biologist or senior technician, 2 technicians); 1 additional technician for transporting catch	$10,000
Equipment Costs	
Capture (boat, truck, sample kit, gill nets, camera, phone, PIT tag reader; includes boat and truck gas)	$7,000
Transport to Revelstoke (based on 2 trips)	$700
Subtotal	***$7,700***
Total	***$17,700***

[a]Cost estimates based on average 2008 consulting rates for medium to large-sized firms.
[b]Based on 5 days of gill net sampling and 2 separate days for transport; 10 hour day.

5.5.1.3 Build Fish Passage Structure

The construction of a volitional fish passage structure with attraction flow facilities is another option to allow the passage of adult and juvenile white sturgeon (depending on the design of the facility). Investigations into the type and design of a fish ladder to pass white sturgeon is required, since sturgeon tend to stay near the bottom of deep pools and are too large to use some fish ladders that are designed to pass salmonids (Warrren and Beckman 1993 as cited in Jager et al. 2001). The cost for building a fish ladder at HLK dam is estimated in the hundreds of millions of dollars, based on fish passage projects undertaken by the U.S. Army Corps of Engineers (2008). Clay (1995) indicates that the best way to apply costs derived from previously built fishways is to use costs per unit of volume. However, the cost of the fishway structure alone can only be considered as a base cost, since other structures such as auxiliary water supply, powerhouse collection system, and operating and maintenance costs (among others) also need to be factored in (Clay 1995). It is estimated that total operation and maintenance charges on a large fishway installation should average between 1% and 2% of the capital cost (Clay 1995).

5.5.1.4 Transfer All Adults from Mid-Columbia to HLK Sub-population

The capture and transfer of all adult white sturgeon from the Arrow Lakes Reservoir was proposed, should this area not be suitable for recovery (i.e., no success for spawning and rearing; see Section 3.2). Studies under BC Hydro's Water Use Planning process may determine if hatchery-released juveniles and larvae are able to survive within the Arrow Lakes Reservoir. If mid-Columbia River white sturgeon are to be transferred to the HLK sub-population, the cost to capture adults from the Beaton Flats area (main overwintering area) over a three week period is estimated at $50,500 per year; this does not include any reporting options (Table 6). If this program is carried out for approximately five years, the total estimated cost is $300,000.

Table 6 Cost estimates for fish passage compensation option of set lining and transporting adults from the Arrow Lakes Reservoir sub-population to the HLK sub-population

Component	Estimated Cost[a]
Personnel Costs - 3 weeks[b]	
Crew of 3 (1 biologist or senior technician, 2 technicians); 2 additional technicians for transporting catch	$25,500
Equipment Costs	
Capture (boat, truck, sample kit, set lines, bait, camera, phone, PIT tag reader; includes boat and truck gas)	$40,000
Transport to Revelstoke (based on 2 trips)	$1,500
Accommodation and Meals	$9,000
Total	***$50,500***
5 year Total[c]	***$300,000***

[a]Cost estimates based on average 2008 consulting rates for medium to large-sized firms.
[b]Based on 3 weeks of set line sampling and 5 separate days for transport; 10 hour day.
[c]Includes inflation.

6.0 CONCLUSIONS

Overall, the construction of BC Hydro dams fragmented the Columbia white sturgeon population into four sub-populations or remnant groups and potentially isolated four other groups from the larger Kootenay Lake white sturgeon population. In addition, the dams also changed primary production (AIM 2007) and blocked thousands of prey, such as kokanee, from migrating to natal spawning areas. As a result, a large decline in fish productivity occurred, which impacted predator species such as white sturgeon.

The eight fragmented sub-populations of white sturgeon do not have access into other areas of the basin, unless they are entrained to downstream areas. However, adult entrainment is most likely fatal based on observations at HLK dam. Because white sturgeon are severely in decline, entrainment mortality of even one adult eliminates spawning contributions to the overall population and reduces the amount of genetic diversity available for conservation aquaculture programs.

The physical presence of BC Hydro dams blocks movements of white sturgeon to important habitats necessary for them to carry out their life history. For example, white sturgeon from the pre-dam Columbia River population had access to many spawning areas that may no longer be available or accessible. Reproductive male white sturgeon often move more frequently to and from spawning areas during the spawning season. Perhaps in a larger area with several spawning grounds, fish could move between locations and reproduce with others using each area and therefore, contribute more to the population (evidenced at Newport, WA; Golder 2006d). Feeding areas may also be limited within each sub-population, since they may have accessed the entire drainage to feed opportunistically on concentrations of prey that no longer exist.

The construction of BC Hydro dams also altered or flooded spawning, overwintering, and rearing areas in the basin. The habitats lost vary between each area and depend upon the original configuration of the channel and the presence of historical use areas. The presence of important white sturgeon habitats in some reservoirs historically and presently are unknown, which makes the importance of these areas for white sturgeon difficult to ascertain.

White sturgeon populations in the Columbia Basin currently experience recruitment failure. Factors that have contributed to recruitment failure may include both footprint (e.g. reduced turbidity, loss of wetland and side channel habitats) and operational (e.g., altered hydrograph, temperature, and sediment deposition regimes) effects. Evidence suggests that loss or modification of larval and early juvenile rearing habitats is likely the most critical factor limiting successful natural reproduction in the remaining populations. Sediment released as a result of the construction of HLK dam is hypothesized as a large contributor to recruitment failure in this sub-population, which degraded spawning and rearing habitats, reduced invertebrate productivity (juvenile prey species), and increased predation on juvenile white sturgeon that now have to more actively search for food, thereby increasing their susceptibility to predation (UCWSRI, unpublished). The physical presence of HLK dam is also postulated as a main impact to recruitment success for both the HLK and Arrow Lakes Reservoir sub-populations because access to multiple spawning and foraging areas is limited, which may be important for successful reproduction (UCWSRI, unpublished, Jager et al. 2001). Jager et al. (2001) indicate that the extinction risk of white sturgeon increases when unbalanced migration (i.e., occasional downstream migration without upstream migration) is present and outweighs the isolation of populations.

Conservation aquaculture programs have been implemented to restore white sturgeon in the HLK and Kootenay River populations to naturally reproducing levels. The continued stocking of juveniles is required to prevent white sturgeon from being extirpated in the Columbia Basin and may be one cost effective option, in terms of feasibility and direct supplementation of the population, compared to other compensation measures. Substrate addition and turbidity augmentation were the two highest ranking footprint impact compensation options by selected by the UCWSRI (RFH). Other compensation options prioritized by the UCWSRI included habitat fertilization, substrate cleaning, and predator control programs. However, most RFH compensation options are in the $millions and feasibility studies are required before any of these measures can be undertaken. Additional compensation options directly related to footprint impacts concerning habitat fragmentation and fish passage are not currently a priority for white sturgeon recovery initiatives. Should this become a priority, then the transport of juveniles and adults from the HLK sub-population to the Arrow Lakes Reservoir sub-population is relatively inexpensive when compared to the construction of fish passage facilities at HLK dam. Coordinated efforts between agencies in Canada and the U.S. are imperative for the recovery of white sturgeon stocks regardless of which compensation measures are undertaken.

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APPENDIX A
Definition of Footprint Impacts

Definition of Footprint Impacts

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

Footprint Impacts:

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

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

11. Ice regime impacts due to reservoir and effects on tributary systems and ice effects within the reservoir or due to the thermal action of the stored water.
12. Local hydrological effects increased snow or precipitation due to thermal effects of reservoir, evaporative water losses, long-term groundwater effects, greenhouse gas release, and cumulative effects from other uses (i.e. increased water withdrawal due to proximity to reservoir).

Operational Impacts:

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

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