Dam Footprint Impact Summary

BC Hydro Dams in the Columbia Basin

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Executive Summary

The Columbia River has been extensively altered by dams built for flood control and hydroelectric power production in both Canada and the United States. The Fish and Wildlife Compensation Program: Columbia Basin (FWCP:CB) was established to offset footprint impacts of BC Hydro dams and reservoirs on fish and wildlife in the basin. Objectives of the FWCP:CB are to: 1) meet BC Hydro water license obligations with regard to compensation of fish and wildlife impacted by dam construction in the Columbia Basin, and 2) to sustain and enhance fish and wildlife populations by undertaking projects with potential to mitigate impacts resulting from BC Hydro projects. The FWCP:CB program area includes the BC portions of the Kootenay and Columbia drainages, east of the Monashee Mountains. The program addresses impacts related to 12 dams and associated reservoirs, including impacts on Kootenay Lake.

At the time of dam construction, the amount and quality of impact assessments for fish and wildlife were not sufficient to fully assess the significance of potential impacts to ecosystems and species, particularly poorly understood species. The lack of this information has made it difficult for agencies, program sponsors and stakeholders to assess the progress toward compensation for the range of dam impacts.

In 2005 the FWCP:CB undertook this project to update our understanding of the impacts of the dams, to support ongoing strategic and program planning, to assist in prioritization of compensation options, and to facilitate reporting the progress of addressing impacts. Study objectives included: improved quantification and increased understanding of the significance of the impacts to fish and wildlife, their habitats, ecosystem function and fish-wildlife interactions, and the identification of the range of compensation options.

The project is composed of five broad elements: 1) mapping of basic aquatic and terrestrial ecosystems within the dam footprints; 2) assessing changes in primary productivity; 3) assessing changes to aquatic and terrestrial habitats; 4) assessing impacts on individual fish and wildlife species; and 5) the identification of compensation options. This report is a summary of thirteen previous reports that document individual components of the five elements.

Pre-dam aquatic, wetland/floodplain and terrestrial ecosystems were mapped from pre-dam information sources, including aerial photographs, topographic maps and land class mapping. The ecosystem mapping demonstrated that each reservoir was unique with regard to the types, amounts and proportions of ecosystems impacted. The Arrow and Kinbasket Reservoirs occupy the largest footprints at 51,270 and 42,650 ha respectively. The Revelstoke (11,450 ha), Duncan (7,300 ha) and Koocanusa (6,685 ha) reservoirs are also fairly extensive. The Whatshan (1,770 ha) and Pend d'Oreille (430 ha) are somewhat smaller, and Kootenay Canal, Aberfeldie, Elko, Cranberry, and Spillimacheen reservoirs are less than 50 ha each (because of lack of data, footprint impacts of Aberfeldie, Elko and Cranberry are not discussed in the report). The pre-dam ecosystem composition of the Arrow and Whatshan Reservoirs were dominated by pre-existing lakes, while the Kinbasket, Revelstoke, Koocanusa, Pend d'Oreille, and Spillimacheen were dominated by forested ecosystems and large river systems, and the Kootenay Canal by forested ecosystems. The Duncan footprint included a complex mix of lakes, forests and wetlands. All footprints included varying lengths of river and/or stream ecosystems.

Primary productivity was calculated for the pre-dam aquatic, wetland/floodplain and upland ecosystems, and for the new reservoirs. Methods for determining primary productivity varied depending on the type of ecosystem; however, most pre-dam calculations relied on modeling and/or comparisons with other similar ecosystems in BC due to the lack of pre-dam information. Overall pre-dam gross primary productivity within the dam footprints was estimated at approximately 870,000 tons of C/yr, with approximately 95% of that from forested ecosystems. Post-dam reservoirs have an estimated gross primary productivity of about 29,600 tons of C/yr, resulting in a net loss of over 840,000 tons of C/yr. Variation in primary productivity changes between reservoirs was principally dependent on footprint area and the proportion of forested ecosystems.

Impacts on aquatic habitats were assessed by comparing the pre-dam habitats within the footprints with the total aquatic habitats within the Columbia Basin. Significant areas of lotic (riverine) habitats were lost because of

flooding (1600 linear km or 12,000 ha), with low elevation, low gradient rivers having the most significant losses. Lentic (lake/reservoir) habitat has been significantly increased in area, from 41,450 ha to 110,800 ha. However, the diversity and type of lentic habitats has been altered, with 12 lakes being replaced by 12 reservoirs. Changes in littoral habitats vary from reservoir to reservoir. Littoral habitats within storage reservoirs are subjected to larger variations in water levels than natural lakes, while most of the run of the river reservoirs and regulated Kootenay Lake, have water level stability similar to or more than that of comparable natural lakes in the region, including some lakes that were inundated. A risk assessment, based on losses as a proportion of similar terrestrial habitats available in the Columbia Basin, demonstrated that across the various dam units, loss-induced risks were: very high for very wet forests (4780 ha, 19%), wetlands (7700 ha, 26%) and gravel bars (3660 ha, 53%); high for wet forests (28,760 ha, 10%), cottonwoods (5530 ha, 21%) and shallow water/ponds (1070 ha, 31%); and medium high for intermediate forests (15,660 ha, 2%). Losses of lake and river shoreline habitats were rated high for Kinbasket (980 km) and Arrow (680 km) reservoirs, while Revelstoke (350 km), Duncan (200 km) and Koocanusa (310 km) were rated medium high. Within the drawdown zones of some reservoirs there have been new ecosystems established, especially in the Revelstoke Reach of the Arrow Reservoir. Even though some of these simplified communities produce large quantities of vegetation, their value for higher trophic levels is limited.

Fish species impact assessments described a wide range of impacts, although the significance of particular impacts on individual species varied considerably depending on the life history of the species. Impacts were assessed in detail for 5 fish species, and to a lesser extent for 19 other species. The major impacts reported include loss of riverine habitat affecting some stage of the life history (e.g., kokanee, rainbow trout, bull trout, sculpins, dace, minnows, suckers), nutrient losses (e.g., kokanee, piscivorous rainbow trout, bull trout, sculpins, chubs), changes in flow regimes (e.g., white sturgeon), changes in water quality/turbidity (e.g., white sturgeon, rainbow trout, kokanee, mountain whitefish, sculpins), habitat/population fragmentation (e.g., white sturgeon, bull trout, rainbow trout), and entrainment (e.g., kokanee). In contrast, species that were able to take advantage of the extensive increases in lentic habitat, may have benefited from reservoir establishment in some situations (e.g., kokanee, burbot, lake chub, bull trout).

Wildlife impacts were evaluated for 289 vertebrate species using habitat loss information and species-habitat associations. Sixty-four Priority 1 species including: 3 amphibians, 1 reptile, 45 birds and 15 mammals had high habitat impacts, and agency emphasis for conservation and/or management. Forty-six Priority 2 species including 38 birds and 8 mammals had high habitat impacts, but were low agency conservation or management priority. Species with the highest habitat impacts were wetland and riparian specialists such as amphibians, waterbirds, waders, songbirds, bats and aerial insectivores. Overall species impacts mirrored substantial habitat losses, particularly in Kinbasket, Arrow and Duncan dam units.

In addition to direct habitat and species impacts, the dams have also had significant impacts on ecological functions and processes. These include altered annual hydrologic regimes and floodplain processes, as well as disrupted biological processes such as natural disturbance regimes, trophic dynamics and nutrient cycling. The dams and reservoirs have impacted functions for individual species and populations, including seasonal migrations, genetic exchange, predator/prey relationships, reproduction and dispersal. These impacts can extend into non-impacted watershed units, especially those downstream of dams and reservoirs (e.g., Kootenay Lake, lower Columbia River).

Potential compensation opportunities identified in the series of impact assessment reports are summarized. Compensation options included various projects for both aquatic and terrestrial ecosystem restoration and creation (e.g., stream channel works, lake fertilization, stand structure treatments, restoration of connectivity); habitat securement, stewardship and management (mainly off-site); and species-specific projects for inventory, research, predator/prey manipulation and artificial population/habitat enhancement (e.g., spawning channels, hatchery production, captive rearing, re-introductions, nest boxes). Long-term investments in these activities will contribute to meeting the water license conditions that gave rise to the FWCP:CB, and provide valuable support to maintaining the biodiversity of the Columbia Basin.

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1 INTRODUCTION

1.1 Background and History of Fish and Wildlife Compensation Program

The Columbia River has been extensively altered by dams built for flood control and hydroelectric power production in both Canada and the United States. In the Canadian portion of the basin, there are 19 facilities which generate about 50% of the total hydroelectric power produced in British Columbia. Eleven of these facilities are operated by BC Hydro. The Fish and Wildlife Compensation Program: Columbia Basin (FWCP: CB) was established to offset footprint impacts[1] of BC Hydro dams and reservoirs on fish and wildlife in the basin. Objectives of the FWCP:CB are to: (1) meet BC Hydro water licence obligations with regard to compensation of fish and wildlife impacted by dam construction in the Columbia Basin, and (2) to sustain and enhance fish and wildlife populations by undertaking projects with potential to mitigate impacts resulting from BC Hydro projects.

Conditional Water Licenses on most Columbia Basin dams require BC Hydro to undertake “Programs for the protection or enhancement of fish and wildlife habitat and for the mitigation of losses of habitat”. The term “compensation” has been applied to the broad suite of protection, enhancement, and mitigation measures intended in the original water license conditions.

The FWCP:CB, originally named the Columbia Basin Fish and Wildlife Compensation Program (CBFWCP), was established in 1995 as an amalgamation of several pre-existing programs related to water licence requirements for Arrow, Duncan, Mica, Seven Mile, and Revelstoke dams. The programs included:

- Meadow Creek spawning channel and hatchery;
- Hill Creek spawning channel and hatchery;
- Kootenay Lake fertilization program;
- Pend d’Oreille fish and wildlife compensation program;
- Lower Arrow fish and wildlife compensation program;
- Mica fish and wildlife compensation program; and,
- Revelstoke fish and wildlife compensation program.

These programs had been established for defined impacts of specific dams, and were delivered directly by the BC Ministry of Environment, Lands and Parks with funding provided by BC Hydro under separate agreements. The focus of these programs was almost entirely on maintaining and enhancing harvested fish and game species impacted by the dams. Funding levels were linked to estimates of lost angling and hunting opportunities, and the economic value of these recreational days to the province in terms of daily expenditures and licence fees. Compensation targets were in some cases very specific (e.g., 500,000 kokanee and 4,000 bull trout for the Arrow Reservoir and Revelstoke Dam impacts).

With the creation of the FWCP:CB, the facilities to be addressed by the fund were expanded to include impacts from Duncan Dam, Kootenay Canal and smaller BC Hydro facilities such as Whatshan, Aberfeldie, Walter Hardman, Elko and Spillimacheen; these projects did not have their own compensation funds before the FWCP:CB. The program area was also expanded to include the whole basin rather than the specific areas of the

[1] A definition of footprint impacts as used in this review is provided in Appendix A.

previous agreements. In addition, the mandate for the amalgamated program was broadened to "fish and wildlife populations", and hence the scope of projects funded in subsequent years has expanded to include many non-harvested species of conservation concern such as leopard frogs and white sturgeon that were not targeted by the previous programs. Another largely unforeseen development that has had major funding impacts for the FWCP:CB is the expansion of large lake nutrient restoration to Arrow Reservoir in 1999 (due to declining kokanee returns), and the rapid increase in the costs of fertilizer purchase for both the Kootenay Lake and Arrow Reservoir nutrient restoration programs in subsequent years.

Funding for the new program was also increased. The previously existing programs totalled about $2.2 million and $1.0 million was added to provide an annual fund of $3.2 million (1994 purchasing power indexed to inflation). This figure took into account the estimated costs of three major ongoing fisheries projects in the basin, other existing compensation activities, and new compensation projects expected to be established in the near future.

1.2 Vision and Principles

The FWCP's provincial vision is:

"Thriving fish and wildlife populations in watersheds that are functioning and sustainable."

While the program operates in basins and landscapes that have been significantly altered by hydro-electric development, the vision recognizes that an effective program can support the maintenance of healthy fish and wildlife populations that will meet both conservation and sustainable use objectives. Actions focussed on conserving, and where possible restoring ecosystem function, will help species be more resilient to emerging pressures such as climate change.

The program principles include:

- **Approach** –The program has a forward-looking, ecosystem-based approach that defines the desired outcomes and takes actions to restore, enhance and conserve priority species and their habitats.
- **Decision Making** – The program efficiently uses its resources and works with its partners to make informed and consensus-built decisions that enable the delivery of effective, meaningful and measurable projects that are supported by the impacted communities.
- **Geographic Scope** - Within the watersheds, basins and ranges of the populations of species affected by generation facilities owned and operated by BC Hydro.
- **Objectives** – The program defines and delivers on compensation objectives that reflect the partnership's collective goals and align with provincial and federal fish and wildlife conservation and management objectives in the areas where we work.
- **Delivery** – The program strives to be a high performing organization with skilled and motivated staff and partners delivering efficient, effective and accountable projects.

1.3 Partners and Program Delivery

The program is a partnership between BC Hydro, the BC Ministry of Environment, Fisheries and Oceans Canada, First Nations and public stakeholders. The goal is to have engagement and participation of all the partners in priority setting, approval, review and delivery of the program.

The program is coordinated at a provincial level through a provincial secretariat and the Policy Committee made up of the three agency partners. Project approval occurs at the basin level through Regional Steering Committees or Regional Boards advised by Technical Committees. Project development and delivery is carried out through FWCP regional staff and project applicants.

1.4 Program Area Description

The FWCP consists of 3 broad program areas; Peace, Coastal, and Columbia. The FWCP:CB area includes the parts of the Kootenay and Columbia drainages shown in Figure 1, an area roughly equivalent to the Kootenay Region of British Columbia.

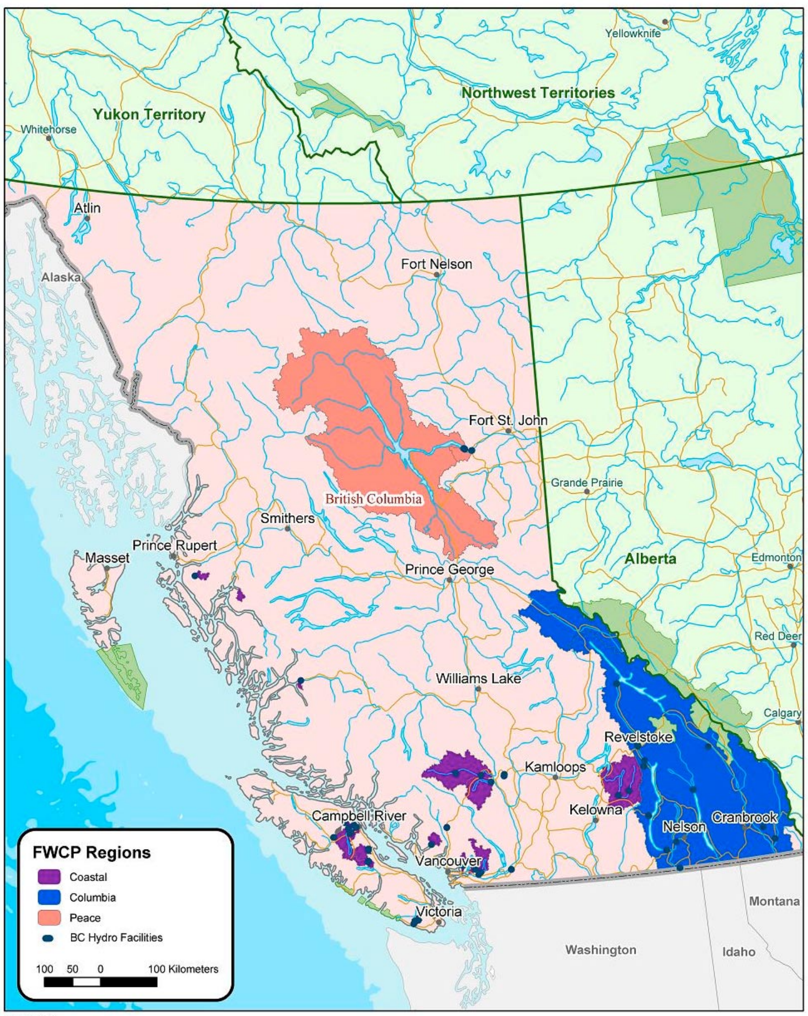

Figure 1: Fish and Wildlife Compensation Program regions in British Columbia. Blue shaded area is the Columbia Basin compensation area.

2 DAM IMPACTS SUMMARY

2.1 Context

Over the 60 year period (1922-1982) that the dams were constructed, the amount and quality of fish and wildlife information available for the affected lands was highly variable, and often focused on game species. Short timeframes, limited budgets and poor access limited impact assessments of the pre-dam environment, often leading to “best guess” approaches to species and habitat analyses. The baseline conditions described were in most cases not sufficient to identify, assess significance of, or prioritize the potential impacts to ecosystems and species, particularly poorly understood species. With these elements lacking, it has been impossible for agencies, program sponsors and stakeholders to determine the progress made toward compensation as identified in the water license conditions. In 2005 the FWCP:CB began a project to update the understanding of the footprint impacts of the Columbia Basin Dams to enable a renewed focus on priority compensation options, and facilitate more quantitative reporting on progress made in addressing impacts.

To initiate the project, the FWCP:CB Steering Committee directed the program to undertake a study to:

a) establish and/or update understanding of original footprint impacts from BC Hydro dams in the Canadian portion of the Columbia River Basin;

b) identify the full range of compensation opportunities;

c) provide a summary of approximate costs to implement the compensation opportunities identified in “b” above; and,

d) identify performance measures for program monitoring and evaluation.

The project is focused on “footprint” impacts (losses and gains) related to the construction and ongoing presence of BC Hydro dams, as BC Hydro operational impacts are being addressed through the Water Licence Requirement program (see Appendix A for a definition of “footprint” impacts used for this study). The project does not include collection of new field data, but utilization of existing data collected before dam construction, as well as subsequent studies of post-dam populations and compensation initiatives. The results of the Dam Impacts Project are intended to support ongoing strategic and program planning, and assist in identification of funding and capacity requirements.

Although this report is limited to footprint impacts, there are numerous other changes that have impacted both terrestrial and aquatic ecosystems throughout the Columbia Basin. The construction of the Grand Coulee Dam downstream on the Columbia River in 1941 was probably one of the most significant. It is estimated that historically, over one million anadromous salmon and steelhead seasonally returned to the upper Columbia Basin[2]. These losses had substantial productivity implications for both aquatic and terrestrial ecosystems, especially in riparian ecosystems adjacent to spawning areas, where nitrogen from the returning salmon has been reported to increase terrestrial productivity by up to 30%. Numerous species such as grizzly bears and eagles that utilized the fish were also directly affected.

Forested landscapes have been fragmented by extensive harvesting and linear developments, including railroads, highways, resource extraction roads and utility corridors. Accompanying urban and rural development

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[2] Scholz, A. et al. 1985. Compilation of information on salmon and steelhead run size, catch and hydropower related losses in the Upper Columbia River Basin, above Grand Coulee Dam, Fisheries Technical Report No. 2, Upper Columbia United Tribes Fisheries Center. Department of Biology, Eastern Washington University. Cheney, WA.

and increased recreational use has also displaced species, particularly from low elevation habitats. These corridors have acted as vectors for dispersal of alien invasive species such as knapweed. Linear developments have also impacted stream habitats through sedimentation and the creation of movement barriers in some crossings. Changes in forest age class distribution and hunting pressures have altered foundation species populations and distributions (e.g., deer, elk), as well as predator-prey relationships (e.g., wolves/cougar – mountain caribou). East Kootenay grassland and open-forest ecosystems have also been affected by cattle grazing and changes to historical fire regimes. Over-harvesting may also have contributed to the decline of some fish and wildlife populations.

Agricultural development has altered ecosystems along the main river valleys throughout the basin. At the southern end of Kootenay Lake, diking has converted extensive riparian forests and wetlands to agricultural croplands. The aquatic environment of Kootenay Lake has been further altered through the addition of nutrients from mining and industrial activities and the intentional introduction of an alien species (mysid shrimp).

The geographic scope of the study area is illustrated in Figure 2. The delineated Dam Impact Units are based on the locations of reach breaks on the Kootenay and Columbia Rivers, the locations of dams on the system, environmental gradients, and watershed boundaries that are applicable to each of the individual reaches. For completeness, the Dam Impact Units span the whole Columbia Basin, and include both impacted and un-impacted units. The identifying letters and numbers are used as references throughout the summary to indicate both facility and impacted watershed.

The impacted dam units discussed in this report include: C2 – Spillimacheen, C3 – Kinbasket, C4 – Revelstoke, C6 – Cranberry, C8 – Whatshan, C10 – Pend d'Oreille, C11 – Arrow, K2 – Aberfeldie, K3 – Koocanusa (Canadian portion), K4 – Elko, K7 – Duncan, and K9 – Kootenay Canal and K6 – Kootenay Lake. Due a lack of pre-dam information, terrestrial footprint impacts of Cranberry, Aberfeldie and Elko are not discussed in this report (these are all small reservoirs/headponds <25 ha in area). Discussions on Kootenay Lake (K6) are focussed on fisheries and aquatic habitat, as the impacts to Kootenay Lake are primarily related to downstream impacts from other dams.

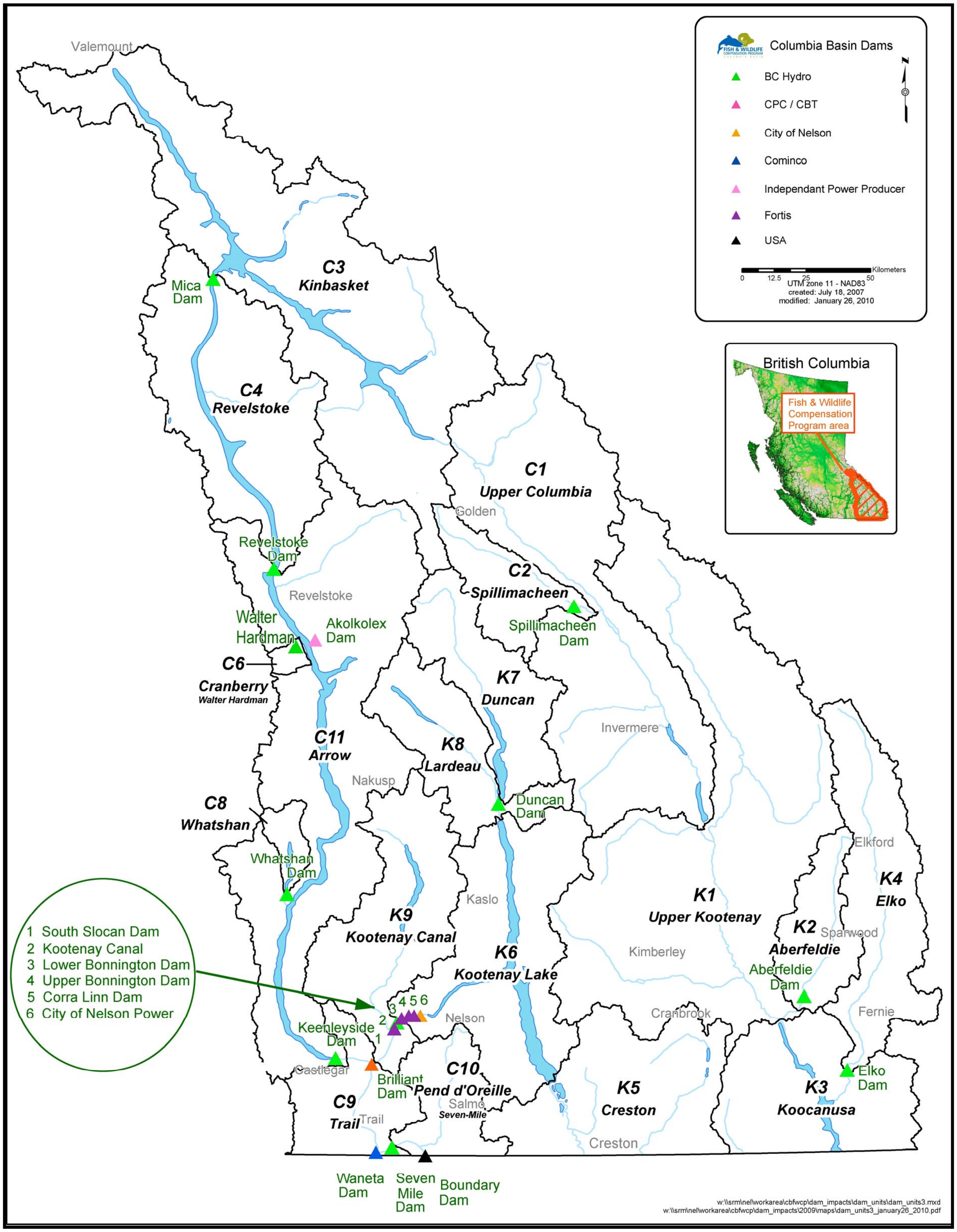

Figure 2: Fish and Wildlife Compensation Program: Columbia Basin area showing Dam Units, major dams and reservoirs.

The Dam Impacts Project includes a series of components that are summarized in Table 1. The results of these components are summarized in the following sections. For original sources and references please refer to the individual component chapter reports.

Table 1: Component Chapters of FWCP:CB Dam Impacts Project.

Number	Component	Reference	Content
1	Pre-dam Aquatic and Terrestrial Habitat Mapping	Ketcheson et al. 2005	GIS dataset of streams, lakes, wetlands and uplands within Columbia Basin reservoir footprints
2A	Impacts on aquatic and wetland primary productivity	Moody et al. 2007	Estimated Net Primary Productivity and Net Ecosystem Productivity changes in wetland and aquatic habitats following dam construction
2B-1	Terrestrial primary productivity modeling	MacKillop and Utzig 2005	Modeled NPP in terrestrial habitats for the basin
2B-2	An evaluation of terrestrial and wetland primary productivity impacts	Utzig and Holt 2008	Determined change in NPP for terrestrial and wetland habitats following dam construction
3A	An assessment of aquatic habitat impacts	Thorley 2008	Summary of aquatic fish habitat loss within and among reservoir units
3B	Impact of BC Hydro dams on Terrestrial and Wetland Habitat	MacKillop et al. 2008	Summary of terrestrial and wetland ecosystem loss within and among reservoir units
4A-1	Fish Species Impacts: Sturgeon	Porto 2008	Species-specific review
4A-2	Fish Species Impacts: Kokanee	Arndt 2009a	Species-specific review
4A-3	Fish Species Impacts: Bull Trout	Hagen 2009	Species-specific review
4A-4	Fish Species Impacts: Rainbow Trout	Arndt 2009b	Species-specific review
4A-5	Fish Species Impacts: Burbot	Cope 2008	Species-specific review
4A-6	Fish Species Impacts: Biodiversity	Ladell et al. 2009	Multi-species review
4B	Wildlife Species and Population Impacts	Manley and Krebs 2010	Species-habitat assessment of non-fish vertebrates
5	Dam Impacts Summary	This report	Synthesis of Component Chapters

2.2 Footprint Mapping

2.2.1 Methodology

Reservoir footprint was determined from TRIM mapping. A BC Government MS Map Series that was hand-drawn prior to the construction of most of the dams (1946 -1958; 1:31,680) provided the base maps for the ecosystem mapping within the footprint. The MS map series included spatial information on the location of terrestrial and aquatic features, as well as contours and a generalized land cover classification. The MS Series base maps were geo-rectified, digitized and combined with the TRIM mapping to create a digital file with spatial representation of terrestrial/aquatic boundaries prior to dam construction (Ketcheson et al. 2005).

Stream reaches were mapped according to BC standards for fish habitat inventory standards, using additional pre-dam aerial photography and gradients calculated from the MS Series maps. Stream reach breaks were determined by noting features such channel pattern, confinement, gradient and bank and streambed materials. Barriers to fish movement were also identified. Reach gradients and length were incorporated attributes for each defined reach.

Terrestrial ecosystems, including wetlands, were mapped within the reservoir footprints, and the area within 200 m adjacent to the reservoirs. The terrestrial ecosystem mapping delineated wetland types, site series, and structural stages from pre-reservoir aerial photographs based on modified Terrestrial Ecosystem Mapping (TEM) standards and commonly employed ecosystem classification systems. Each mapped polygon was also assigned attributes for slope class, aspect class, forest type and a cottonwood cover rating.

Subsequent work reported by Moody et al. (2007) and Utzig and Holt (2008) has further refined the transition between terrestrial and aquatic ecosystems by defining breaks between wetlands, floodplains and forests. The category of floodplains has been added to those defined in the original footprint mapping, and reported in the subsequent tables and figures below. Differences in approach between the various chapter authors have resulted in some inconsistencies in reference to the terms wetlands, forested wetlands and very wet forests in various chapters of the dam impacts project (Ketcheson et al. 2005, Moody et al. 2007, Utzig and Holt 2008, MacKillop et al. 2008, Manley and Krebs 2009). Utzig and Holt (2008) provide a cross-reference between Ketcheson et al. 2005, Moody et al. (2007) and MacKillop et al. (2008). In MacKillop et al. (2008) and Manley and Krebs (2010), forested wetland is equivalent to very wet forests in Utzig and Holt (2008). This report follows the nomenclature in Utzig and Holt (2008).

2.2.2 Results and Discussion

The footprint mapping results are summarized in Table 2 and Figure 3. The largest footprints are associated with the Kinbasket and Arrow reservoirs; however, the percentages of ecosystems affected by each reservoir are quite variable, with some dominated by aquatic habitats and others by terrestrial habitats.

Table 2: Area (ha) of various pre-dam aquatic and terrestrial ecosystems inundated by reservoirs, based on full pool reservoir elevation (from Ketcheson et al. 2005, Moody et al. 2007, Utzig and Holt 2008).

	Kinbasket C3	Arrow C11	Revelstoke C4	Koocanusa K3	Duncan K7	Pend d'Oreille C10	Whatshan C8	Kootenay Canal K9	Spillimacheen C2	Total
Lakes	2,343.0	34,992.3	0.0	0.0	2,583.9	0.0	1,528.9	0.0	0.0	**41,448.1**
Rivers	4,896.6	2,021.9	2,654.4	1,490.1	424.5	179.0	14.6	0.0	0.3	**11,681.4**
Streams	192.1	50.6	53.4	10.3	17.7	1.5	0.5	0.0	0.0	**326.1**
Shallow ponds	555.1	102.9	26.9	210.6	172.3	0.0	4.9	0.0	0.0	**1,072.7**
Gravel Bars	235.6	3,262.8	56.9	80.4	22.0	0.4	0.0	0.0	0.0	**3,658.1**
Wetlands	5,862.6	3,431.6	456.0	1,071.9	1,824.5	1.8	1.5	0.9	0.0	**12,650.8**
Floodplains*	15,526.5	3,563.5	4,004.7	2,173.1	1,396.6	6.0	14.5	0.7	0.0	**26,685.6**
Upland Ecosystems	13,035.7	3,844.3	4,199.1	1,646.8	860.0	241.7	204.6	47.1	0.8	**24,080.1**
Total	**42,647.2**	**51,269.9**	**11,451.4**	**6,683.2**	**7,301.5**	**430.4**	**1,769.5**	**48.7**	**1.1**	**121,602.9**

*Riparian forests and some wetlands as described in Moody et al. (2007) and Utzig and Holt (2008).

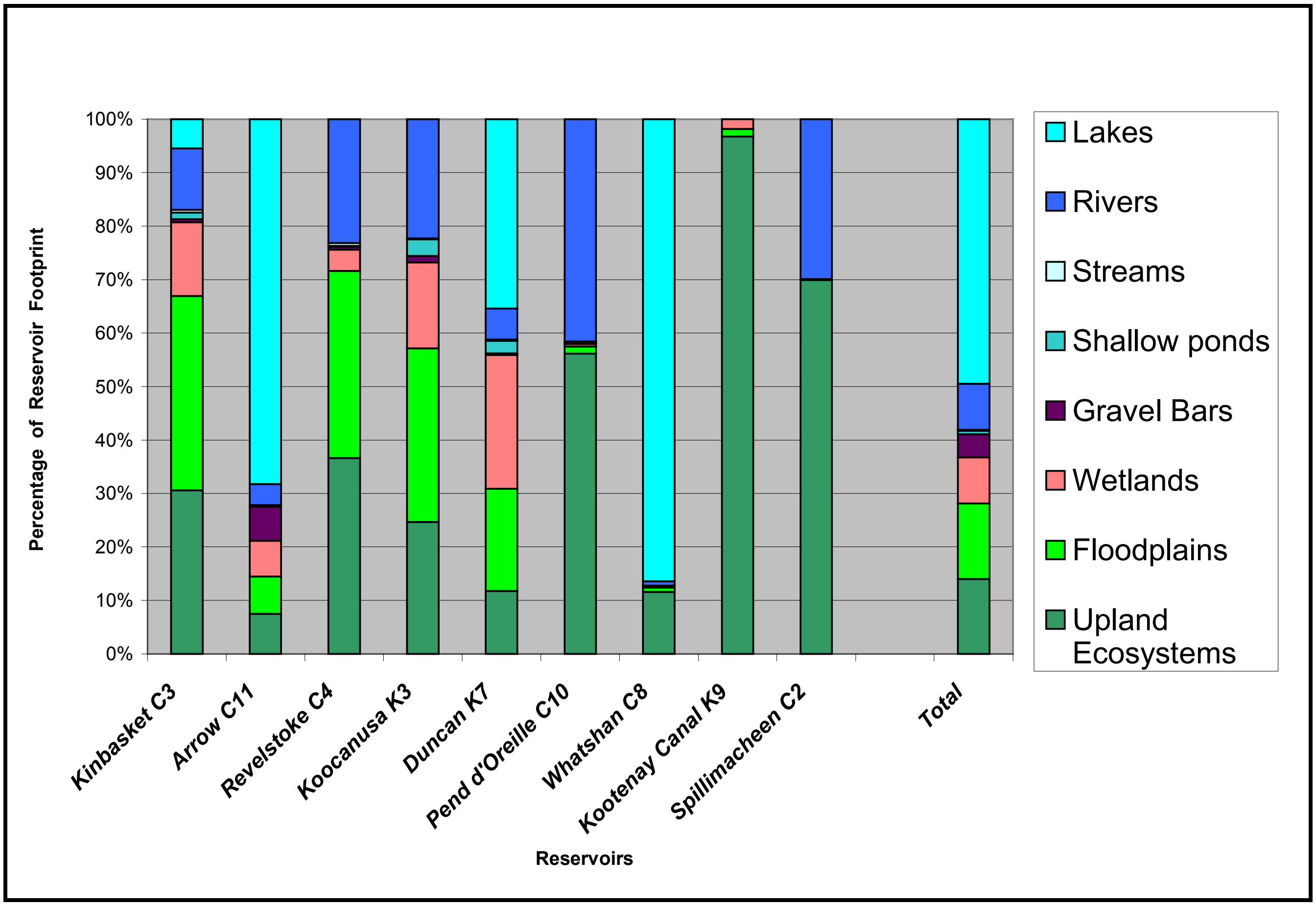

Figure 3: Percentages by area for various pre-dam aquatic and terrestrial ecosystems by reservoir (from Ketcheson et al. 2005, Moody et al. 2007, Utzig and Holt 2008). Floodplains include riparian forests and some wetlands as defined by Moody et al. (2007) and Utzig and Holt (2008).

2.3 Productivity Impacts

Primary production is the conversion of solar energy into organic carbon by plant photosynthesis over time. Primary productivity is reported in various ways, depending on the type of ecosystems under scrutiny and the objectives for the calculations. Gross primary productivity (GPP) refers to the total amount of carbon fixed per unit time, while net primary productivity (NPP) refers to GPP minus the amount of carbon lost through autotrophic respiration. In practical applications, NPP is often used for describing primary productivity in terrestrial ecosystems, as it is generally correlated with common measures such as mean annual increment in trees or annual biomass production in other plants. In aquatic systems GPP is the more common tool for reporting primary production because of the methods for measuring primary production (e.g. light/dark bottle). Both GPP and NPP are generally reported as the weight of carbon per unit area per year.

The estimates of primary production calculated in the dam impacts studies followed the well established trends, with terrestrial primary production being reported as NPP (MacKillop and Utzig 2005; Utzig and Holt 2008), aquatic primary production being report as GPP (Moody et al. 2007).

2.3.1 Methods

Both terrestrial and aquatic primary productivity calculations for pre-dam conditions were based on historic aerial photographs and maps that depicted conditions prior to dam construction, correlations with measured GPP from other similar ecosystems, theoretical or modeled GPP relationships, and discussions with scientists and local residents who were familiar with the areas at that time. Digital mapping used in the primary productivity analysis was produced in the earlier footprint mapping phase of the project.

To prepare a complete summary of primary production changes with reservoir flooding it was necessary to convert the terrestrial and aquatic estimates to compatible values. Given the general lack of information on NPP for aquatic systems, and the recent developments in assessing NPP/GPP ratios in terrestrial ecosystems, the decision was to convert the terrestrial values from NPP to GPP. Following a review of relevant literature, a series of NPP/GPP ratios were assigned to each of the terrestrial ecosystem types (see Appendix 2 for details).

2.3.2 Terrestrial

Historic pre-dam terrestrial NPP was calculated based on estimated NPP for each of the Site Series that were identified during the footprint mapping. The methodology was a multi-step process involving utilization of Biogeoclimatic Ecosystem Classification guidebooks to identify appropriate tree species for each Site Series, BC Ministry of Forests (MoF) site index relationships (SIBEC) to determine site index for each tree species/site combination, MoF's Variable Density Yield Prediction Model (VDYP) to estimate yield curves for each of the site/species combinations and the Canadian Forest Service Carbon Budget Model to calculate NPP values based on the growth and yield outputs (MacKillop and Utzig 2005). Non-forested Site Series were estimated using NPP values for early seral stages of similar forest sites. Outputs were verified by comparing the predicted values with measured values derived from a literature review of relevant NPP studies.

Further analysis then combined the NPP estimates for each site series with the footprint mapping to derive total NPP estimates for each dam unit (Utzig and Holt 2008). Values of NPP were presented for three conditions:

- mapped NPP - based on structural stage conditions approximating the time of flooding (i.e. the time of aerial photography just prior to flooding used for the footprint mapping),
- maximum NPP – based on structural stage conditions that maximize NPP (similar to culmination age in forest yield modeling), and
- long-term average NPP – based on structural stage distribution that would represent the "average" conditions associated with a natural disturbance regime defined by the Range of Natural Variation (RONV).

2.3.3 Floodplains and Wetlands

Literature reviews revealed that there was little relevant information available on NPP or GPP for wetland ecosystems within the Columbia Basin. Based on the limited literature available and expert opinion, Moody et al. (2007) estimated NPP values for non-forested wetlands and forested wetland/ floodplains. Forest site series that were identified as floodplain ecosystems based on moisture regime and structural stage were assumed to provide wetland carbon to the aquatic realm from foliar materials and understory components during flood events. This resulted in partitioning of the NPP of these ecosystems, where part was assigned to "forested wetlands", and the remainder to the upland terrestrial realm (see Moody et al. 2007 and Utzig and Holt 2008 for more details).

2.3.4 Aquatic – Lacustrine and Fluvial

Most of the pre-dam limnological information for the lakes that existed prior to flooding in the affected dam units was anecdotal, and mainly related to fisheries habitat. Therefore, the pelagic Gross Primary Productivity (GPP) estimates for lakes were primarily derived from expert opinion and analysis of a database of primary production measurements from over 50 lakes in BC. Additional information on seasonal sediment patterns, flow regimes and turbidity was also derived from examination of pre- and post-dam sediment core data, and discussions with scientists and local residents who were familiar with pre-dam conditions.

Because of the lack of information on periphyton littoral production from the impacted dam units, Moody et al. (2007) had to rely on estimates of percentages of pelagic C production from the literature. Primary productivity estimates for pre-dam rivers and streams were primarily based on a regression equation relating stream order and GPP. The regression equation outputs were adjusted based a review of BC benchmark stream characteristics, including factors such as: chlorophyll *a* concentrations, soluble reactive phosphorus concentrations, bryophyte and macrophyte presence, glacial meltwater and/or high sediment load impacts on turbidity, flow variations, kokanee carcass inputs, incidence of large woody debris, known fish species use/abundance, and the distribution of higher quality side-channel environments. The estimates for rivers should be considered conservative, as there were likely significant areas of side-channels that were not accounted for.

Post-dam Arrow Reservoir and Kootenay Lake GPP estimates were based on measured daily C production. Kinbasket Reservoir GPP values were taken from published literature. Estimates for Revelstoke Reservoir GPP were derived from chlorophyll measurements made in 2003. Professional judgment was used to provide GPP estimates for Duncan, Koocanusa and other smaller reservoirs.

2.3.5 Results and Discussion

Based on the results of the earlier primary production studies, and conversion of terrestrial NPP values to GPP, a summary of total historic pre-dam and post-dam GPP values are provided in Figures 4 and 5, and Table 3. The values for terrestrial NPP pre-dam baseline are taken from the “long-term average” scenario, and aquatic values for the post-dam Arrow Reservoir and Kootenay Lake are without fertilizer treatments. The region-wide losses of primary production are mainly related to the loss of forested ecosystems in the big three reservoirs, Kinbasket, Revelstoke, and Arrow. The only gains in terrestrial GPP have been associated with the minor amount of vegetation in the drawdown zones of some reservoirs. Large rivers, lakes, and tributary streams have been replaced by a larger area of reservoir aquatic ecosystems. Overall aquatic production has increased, because of the extensive area of reservoirs, and increased water clarity in some cases.

Although Kootenay Lake was affected by dams upstream, no changes in GPP for terrestrial, river or stream ecosystems are shown, as no areas in that dam unit were directly flooded by BC Hydro dams. Because of the conflicting effects of reduced nutrients and increased water clarity, Moody et al. (2007) estimated that the Duncan and Libby dams have produced a negligible change in GPP for the North and South Arms of Kootenay Lake (Table 3 and Figure 4). Over the last century, changes in GPP for the North and South Arms of Kootenay Lake have been quite complex, including those from upstream and downstream[3] dam construction. The Libby dam has significantly blocked sediment inputs from the upper Kootenay River, which has had potentially offsetting positive and negative impacts on the South Arm productivity – decreased turbidity and decreased nutrient inputs, respectively (Moody et al. 2007). The Duncan dam has had similar types of impacts on the North

[3] The Corra Linn Dam was built downstream of Kootenay Lake in the 1930s, however its impacts are not considered in this report, nor were they assessed by Moody et al. 2007.

Arm, but of less significance because the Duncan River drainage is smaller, and Duncan Lake had previously acted as a partial sediment trap. Other factors such as fertilizer plant pollution, introduction of mysids, fisheries management and present-day fertilization have also periodically impacted GPP, and its redistribution among higher trophic layers.

Primary production within the reservoir footprints has been reduced by over 90%, moving from riverine, lake,,wetland and terrestrial systems of primary production, to a reservoir ecosystem and low diversity drawdown vegetation communities, some of which include introduced exotic species.

A complex system of terrestrial primary production that included trees, shrubs, herbs, mosses, lichens and micro-organisms has been lost from the reservoir footprints. These ecosystems accounted for the largest percentages of pre-dam primary productivity. Primary productivity of the pre-dam wetlands and floodplain ecosystems has also been significantly reduced. The transfer of carbon and nutrients between floodplain and wetland ecosystems, and the aquatic system, has also been altered.

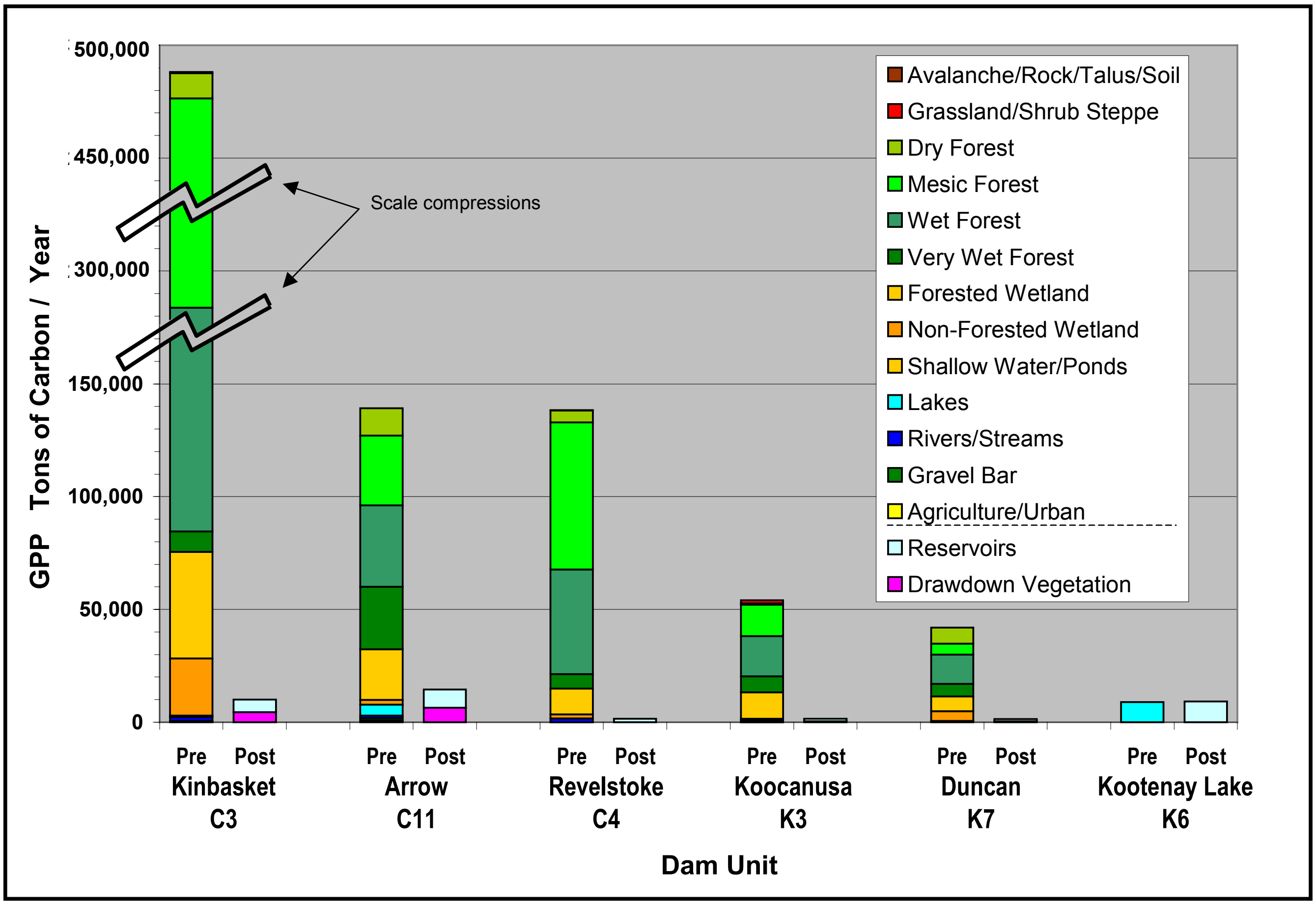

Figure 4: Gross primary productivity (GPP) before and after flooding for each of the larger reservoirs and Kootenay Lake (from Moody et al. 2007 and Utzig and Holt 2008). Note scale compressions on Kinbasket values.

River and stream productivity in the footprint areas has been also been lost, except for short segments that are exposed seasonally during drawdown periods. In dam units where lakes with relatively stable water levels were present, littoral primary productivity has been severely decreased, especially the macrophyte contributions, due to the fluctuations in water levels in most of the reservoirs. The exceptions are run of the river reservoirs with more stable water levels, such as the Revelstoke, where littoral productivity is estimated to be significant, and pre-dam lakes with significant water level fluctuations such as Arrow Lakes and Kootenay Lake.

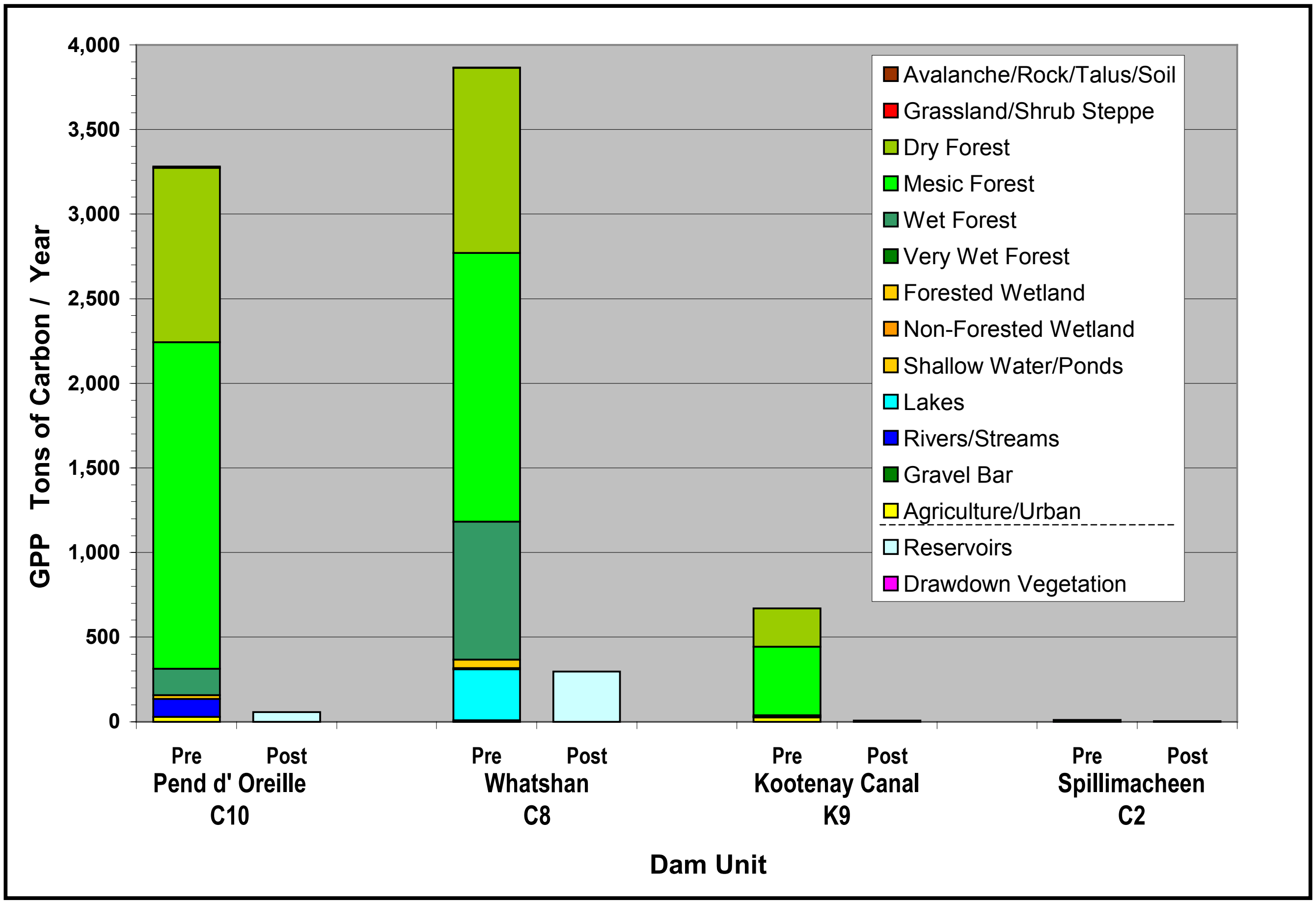

Figure 5: Gross primary productivity (GPP) before and after flooding for each of the smaller reservoirs (from Moody et al. 2007 and Utzig and Holt 2008). Note the scale difference from Figure 4.

Because of the large flooded areas, reservoir pelagic productivity has become the dominant source of primary productivity within the flooded portions of the dam units. Arrow Lakes and Kootenay Lake were large pelagic producers prior to dam construction. The degree of change in pelagic primary productivity is dependent on the specific conditions of each reservoir, including area and character of lakes prior to flooding, character and area of reservoir post-flooding, water retention rates, sediment and nutrient inputs, turbidity, water temperatures and water level fluctuations.

Table 3: Gross primary productivity (tons C/year) by ecosystem type before and after reservoir flooding for each dam unit (from Utzig and Holt 2008 and Moody et al. 2007).

Terrestrial and Aquatic Ecosystems	C3 Kinbasket	C11 Arrow	C4 Revelstoke	K3 Koocanusa	K7 Duncan	K6 Kootenay Lake	C10 Pend d'Oreille	C8 Whatshan	K9 Kootenay Canal	C2 Spillimacheen	Total
Avalanche/Rock/Talus/Soil	530	11	99	6	9	0	6	0	0	0	661
Grassland/Shrub Steppe	0	3	0	1,447	0	0	0	0	0	0	1,450
Dry Forest	11,234	12,100	5,411	584	7,207	0	1,032	1,096	227	0	38,891
Intermediate Forest	192,613	30,974	65,016	13,898	4,904	0	1,931	1,586	405	9	311,337
Wet Forest	199,201	35,967	46,503	17,919	12,899	0	154	816	8	0	313,467
Very Wet Forest	9,023	27,698	6,371	7,012	5,573	0	0	0	0	0	55,677
Forested Wetland/Floodplain	47,184	22,479	11,353	11,797	6,609	0	24	49	2	0	99,497
Non-Forested Wetland	25,384	2,001	1,906	498	4,209	0	0	7	4	0	34,008
Gravel Bar	65	899	16	22	6	0	0	0	0	0	1,008
Shallow Water/Ponds	154	29	7	58	48	0	0	1	0	0	297
Rivers/Streams*	1,676	1,161	1,566	877	127	0	106	6	0	0	5,519
Lakes*	586	4,931	0	0	413	9,038	0	302	0	0	15,270
Agriculture/Urban	505	917	92	47	35		28	2	25	0	1,650
Total Before Flooding	**487,626**	**139,163**	**138,240**	**55,474**	**42,029**	**9,038**	**3,275**	**3,865**	**670**	**10**	**878,733**
Reservoirs (and Kootenay Lake)	5,435	8,043	1,639	1,057	1,025	9,220	56	296	7	3	26,782
Drawdown Vegetation	4,550	6,516	0	532	402	0	0	0	0	0	12,000
Total After Flooding	9,985	14,559	1,639	1,589	1,427	9,220	56	296	7	3	38,782
Net Change After Flooding	**-478,171**	**-124,611**	**-136,700**	**-52,575**	**-40,611**	**182**	**-3,224**	**-3,570**	**-663**	**7**	**-839,951**

* Primary productivity values for pre-dam rivers and lakes are likely underestimated because of the lack of data for river side channels and associated oxbow lakes, especially in Kinbasket and Arrow (Moody et al. 2007, p85 & 87).

2.4 Habitat Impacts

Aquatic habitat losses and gains were addressed based on the areal coverage of various habitats by Thorley (2008). A terrestrial habitat impacts project grouped the forested and non-forested ecosystem map units from the footprint mapping into more generalized "ecosystem types" for an analysis of the significance of habitat losses within a risk assessment framework (MacKillop et al. 2008). Changes to habitat value (as opposed to quantity) such as habitat fragmentation and nutrient changes are discussed later in sections on species impacts and ecological function and process impacts.

2.4.1 Methods

The aquatic physical habitat has been quantified through estimates of pre and post impoundment area, or in the case of riverine habitat, both the length and the area of the streams inundated when reservoirs are at full pool

(Thorley 2008). Thorley (2008) classified habitat as lotic (riverine) and lentic (lake), including reservoirs in the lentic habitat type. In the productivity study, Moody et al. (2007) interpreted lakes and reservoirs separately and classified riverine habitat loss based on area. Thorley's (2008) areas for lentic habitat in reservoirs differ from the terrestrial impact reports because he followed Moody et al. (2007), and used the average surface area during the growing season to estimate "productive" lentic habitat. We used Thorley's tabulations in this section of the summary. Thorley (2008) also reports on ten reservoirs, rather than the nine in other sections of this report. He includes Elko and Aberfeldie, and excludes Cranberry and Kootenay Canal. The decision as to how to summarize the different large waterbodies is somewhat complicated, as the predam Arrow Lakes and Duncan Lake have been enlarged into reservoirs, but Kootenay Lake which has not been inundated has also been impacted, and is now regulated by the Corra Linn Dam. The Kinbasket Reservoir inundated a series of medium sized lakes. All of these lakes and reservoirs now support kokanee populations which support piscivorous fish and wildlife species, but with many of the reservoirs having reduced quality of littoral zone habitat because of the large annual variations in water levels. See Thorley (2008) for a full description of the methods used to calculate aquatic habitat impacts.

To establish the significance of terrestrial habitat losses, the areas of habitats lost during reservoir flooding were compared to present-day availabilities of those habitats within the relevant catchments for each of the reservoirs. Present-day distribution of ecosystem types within the catchments were based on Terrestrial and Predictive Ecosystem Mapping (TEM/PEM), Terrain Resource Inventory Mapping (TRIM), Thematic Mapping of Present Land Use (BTM) and a mapping project on the distribution of deciduous stands in the Columbia basin[4]. The level of environmental risk associated with changes in availability for each of the ecosystem types was determined using three factors: the area impacted, the impacted proportion of total area available within the relevant catchment and/or the Columbia Basin, and the rarity of the type within the Columbia Basin (see MacKillop et al. 2008 for more details on the methodology).

2.4.2 Aquatic Habitat Impacts

Thorley (2008) stratified streams within the dam units by stream order, gradient, and elevation, and then summarized stream loss based on length and area of stream inundated in each of those classes (Figure 5). Each of the classes was assigned a risk rating based on the proportion of the particular habitat type that was lost in the basin. Thorley (2008) generally evaluated higher order rivers at lower elevation as having increased value because of greater productivity and biodiversity, although river systems dominated by glacial meltwaters were an exception to this trend (Moody et al. 2007).

Table 4 describes the loss of riverine (lotic) habitat by stream gradient, elevation, and order as linear km for the entire basin. Table 5 describes the losses and gains of lake and reservoir habitat (lentic) as km^2.

The total length of pre-dam lotic habitat (i.e. rivers and streams) in the entire basin was over 38,000 km. The majority of the riverine systems were higher elevation streams and small rivers. The region-wide losses of rivers and streams due to dams exceeds 1,600 km when reservoirs are at full pool. Of these, over 1,200 km are attributable to BC Hydro facilities. Furthermore, an additional 400 km of river and stream losses were also

4 Jamieson, B., E.B. Peterson, N.M. Peterson and I. Parfitt. 2001. The conservation of hardwoods and associated wildlife in the CBFWCP area in southeastern British Columbia. Prepared for: Columbia Basin Fish and Wildlife Compensation Program, Nelson, B.C. By: BioQuest International Consulting Ltd., Western Ecological Services Ltd. and I. Parfitt. 98p.

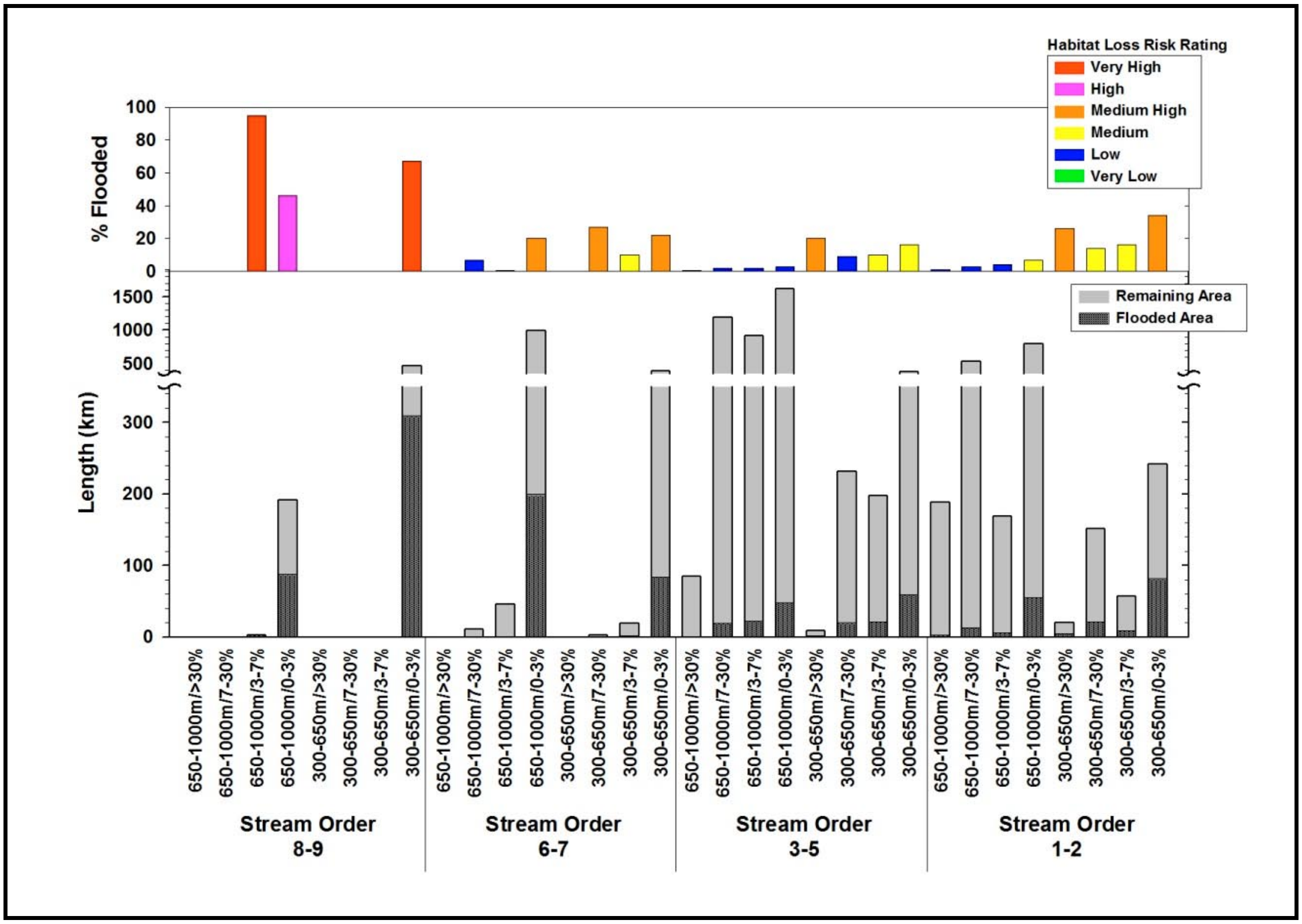

Figure 6: Total length and significance of aquatic stream losses by stream order, elevation and gradient, across all affected Dam Units (derived from Thorley 2008). Percent flooded relates to the pre dam baseline.

Table 4: Summary of length of lotic (riverine) habitat lost (linear km) due to inundation*. Summarized by elevation, stream gradient, and stream order throughout the study area (from Thorley 2008).

		Stream Order				
Elevation	**Slope**	**1-2**	**3-5**	**6-7**	**8-9**	**Total**
moderate (650-1000m)	barrier (>30%)	26	<1	0	0	26
moderate (650-1000m)	high (7-30%)	161	27	<1	0	189
moderate (650-1000m)	moderate (3-7%)	29	25	<1	3	59
moderate (650-1000m)	low (0-3%)	118	<1	218	158	548
low (300-650m)	barrier (>30%)	35	3	0	0	38
low (300-650m)	high (7-30%)	94	23	<1	0	117
low (300-650m)	moderate (3-7%)	39	22	2	0	62
low (300-650m)	low (0-3%)	110	62	84	309	565
Total		**612**	**162**	**304**	**470**	**1604**

* The table includes Aberfeldie and Elko dam units, but excludes Kootenay Canal and Cranberry.

Table 5: Gains and losses of lentic habitat (lakes/reservoirs) in km^2 (fromThorley 2008). The lentic habitat is classified by elevation and size. The number of lakes and reservoirs in each class are shown in parentheses.

Elevation	Size	Prior	Loss	Gain*	Current	Change
alpine (>1700m)	small (<10km^2)	85 (1873)	0 (0)	0 (0)	85 (1873)	0%
high (1000-1700m)	small (<10km^2)	53 (486)	0 (0)	0 (0)	53 (486)	0%
moderate (650-1000m)	large(>50km$^{2)}$	0 (0)	0 (0)	430 (2)	430 (2)	Inf
moderate (650-1000m)	medium(10-50km^2)	88 (4)	20 (1)	0 (0)	68 (3)	-23%
moderate (650-1000m)	small (<10km^2)	88 (686)	3 (4)	<1 (3)	85 (685)	-3%
low (300-650m)	large (>50km^2)	809 (4)	350 (2)	656 (3)	1115 (5)	38%
low (300-650m)	medium(10-50km^2)	50 (3)	38 (2)	18 (1)	30 (2)	-40%
low (300-650m)	small (<10km^2)	13 (73)	4 (3)	4 (1)	14 (71)	6%
Total		**1187 (3129)**	**415 (12)**	**1108 (10)**	**1880 (3127)**	**58%**

*Note that area for reservoirs in this table is not total footprint area, but area based on mean growing season water levels, a better indicator of effective lentic habitat extent. The table includes Aberfeldie and Elko dam units, but excludes Kootenay Canal and Cranberry.

stimated indirectly using “construction lines” to account for lengths of stream not mapped, of which over 380 km are attributable to BC Hydro dams. This brings the total stream and river losses attributable to BC Hydro dams to 1,604 km, and all of the losses have occurred in areas below 1,000 m in elevation.

The total areas of the lakes and reservoirs in the region prior to and after dam construction are summarized in Table 5. For the purposes of this comparison, reservoirs are considered to be equivalent to lakes in that “lentic habitat” is pervasive in both. Before 1922, just over 1,180 km^2 of lake habitat existed in the region. A total of 12 lakes, with a combined surface area of 415 km^2 have been inundated whereas 12 reservoirs (10 that were included in the analysis), with a combined area of 1,108 km^2, have been created, representing a 58% increase in the total area of lentic habitats. The pre-dam total lake surface area was dominated by just four lakes, Upper and Lower Arrow, Kootenay and Slocan lakes, which had a combined area of just over 800 km^2 and represented 68% of the total area. Although Slocan Lake has not been impacted by dam construction and the area of Kootenay Lake has remained relatively unchanged, Upper and Lower Arrow lakes were inundated by construction of Keenleyside Dam to produce Arrow Reservoir. In addition, Mica, Revelstoke, Libby and Duncan dams have all resulted in the creation of large reservoirs.

Based on the information provided by Thorley (2008), the net gain in lentic habitat was ~700 km^2 with the corresponding loss to 1600 linear km of lotic habitat at full pool. This section only provides information on the alteration in aquatic habitat, while species impacts are described in subsequent sections.

2.4.3 Terrestrial Habitat Impacts

The results of the terrestrial habitat loss analyses (MacKillop et al 2008) are summarized in Figure 6 and Table 6. Kinbasket Reservoir accounts for the largest area of terrestrial ecosystems flooded - over 50% of the total (~35,000 ha). The next largest are the Arrow and Revelstoke reservoirs, accounting for roughly 20% (~14,000 ha) and 13% (~9,000 ha) respectively. The terrestrial ecosystem type most impacted on an area basis was Wet Forest, accounting for 42% of the area lost, while Intermediate Forest accounted for 23% of the area. However, when the proportion of the area impacted and rarity are taken into account, Very Wet Forest, Wetlands and Gravel Bars have the highest risk ratings, followed by Shallow Water/Ponds, Cottonwood Stands and other Wet

Forests (see Figure 6). The trends are similar whether the impacts are examined across affected Dam Units only, or across the whole Columbia Basin planning area.

Habitat Loss Risk Ratings (HLRR's) for the Rock/Talus Ecosystem Type were low or very low in all of the dam units except for Koocanusa and Spillimacheen, where the ratings were medium and medium high. The rating for the Columbia Basin as a whole is very low. Habitat loss ratings for Avalanche Features were also low or very low for all affected dam units and very low across the basin as a whole. Grasslands and Shrub-Steppe Ecosystem Types were limited to the Dry Climatic region, with the Koocanusa Reservoir being the only dam unit to have impacts for these types. The HLRR's were medium for Grasslands and very low for the Shrub-Steppe type. Dry Forest habitat losses were an insignificant percentage of the total Dry Forest area in the Columbia Basin. The HLRR's for Dry Forest in the Moist Climatic Region for the Arrow, Kinbasket and Duncan Dam Units were medium, while all the other units were low to very low. Although percentage losses of Intermediate Forest were low across the Columbia Basin as a whole (~2%), HLRR's were high for the Kinbasket, Revelstoke and Duncan Dam Units for individual climatic regions. Medium high ratings were also determined for the Arrow and Koocanusa Dam Units, and other climatic regions of the Kinbasket and Revelstoke units.

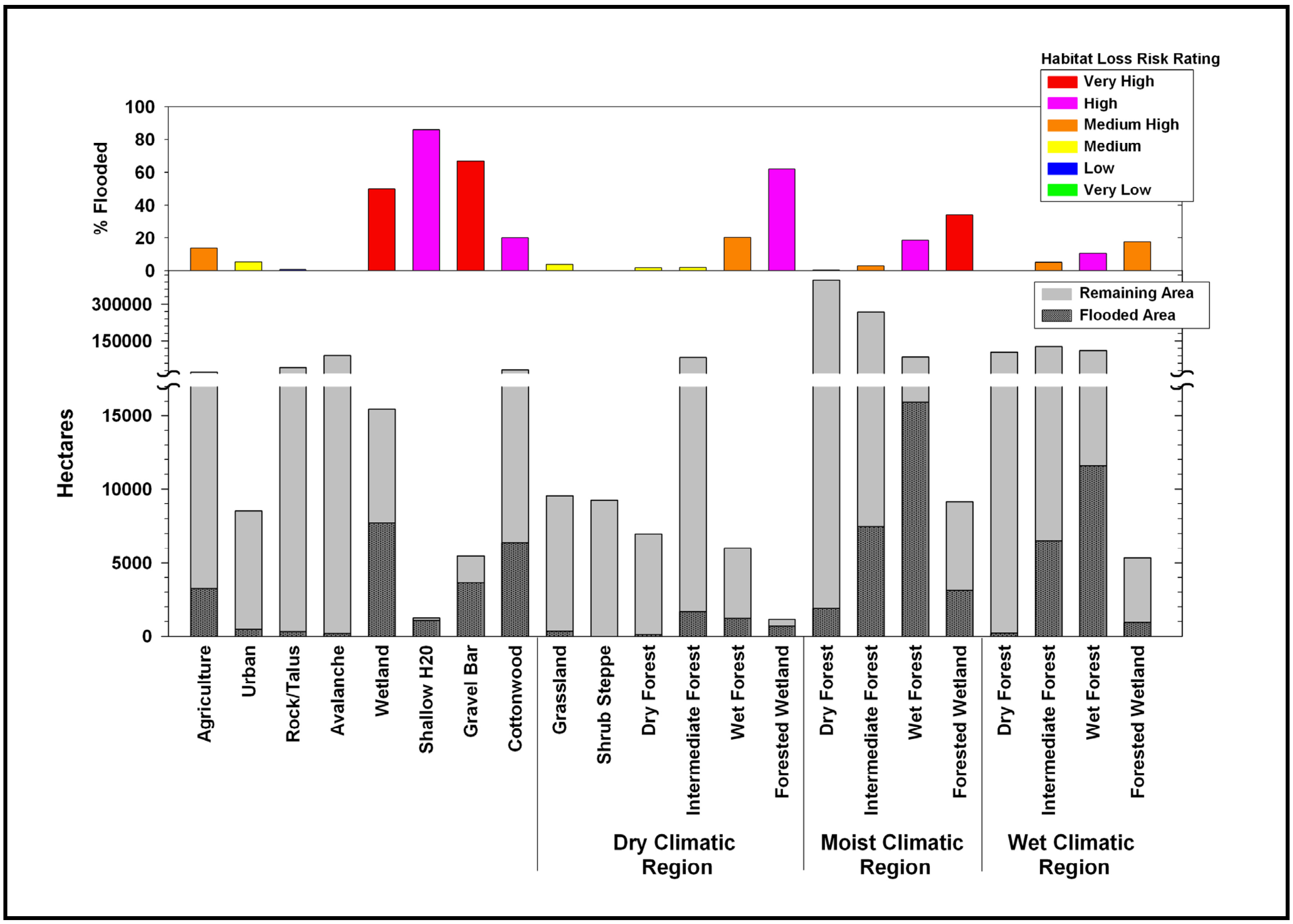

Figure 7: Significance of terrestrial habitat losses, by Ecosystem Type, summed for affected Dam Units (from Manley and Krebs 2010.Note that "Forested Wetland" in this graphic is equivalent to "Very Wet Forest."

Table 6: Summary of terrestrial habitat types lost (hectares) by Ecosystem Type and Dam Unit (from Ketcheson et al. 2005, Moody et al. 2007, MacKillop et al. 2008, Utzig and Holt 2008).

Climatic Region	Ecosystem Type	Kinbasket	Arrow	Revelstoke	Duncan	Koocanusa	Pend d'Oreille	Whatshan	Kootenay Canal	Spillimacheen	Total
Dry	Dry Forest	…	25	…	…	39	64	0	0	0	128
	Grassland	…	1	…	…	353	0	0	0	0	354
	Intermediate Forest	…	123	…	…	1529	22	0	0	0.7	1675
	Wet Forest	…	64	…	…	1159	6	0	0	0	1228
	Very Wet Forests	…	…	…	…	709	…	…	…	…	709
Moist	Dry Forest	600	691	141	382	…	16	58	13	…	1902
	Intermediate Forest	4218	1733	1051	294	…	98	95	24	…	7472
	Wet Forest	10686	3319	279	1837	…	6	58	1	…	15938
	Very Wet Forests	563	1951	370	487	…	…	…	…	…	3130
Wet	Dry Forest	58	…	155	1	…	…	…	…	…	213
	Intermediate Forest	4416	32	2027	…	…	…	…	…	…	6515
	Wet Forest	7472	4	3869	…	…	…	…	…	…	11592
	Very Wet Forests	513	…	188	…	…	…	…	…	…	940
All (summary)	Dry Forest	658	716	296	383	39	80	58	13	0	2243
	Intermediate Forest	8634	1888	3078	294	1529	120	95	24	1	15663
	Wet Forest	18158	3387	4148	1837	1159	12	58	1	0	28760
	Very Wet Forests	1076	1951	558	487	709	0	0	0	0	4781
All	Agriculture	30	2212	0	53	964	2	…	…	…	3260
	Avalanche Features	200	…	3	3	…	…	…	…	…	205
	Gravel Bar	236	3263	57	22	80	…	…	…	…	3658
	Rock/Talus	22	64	142	34	17	27	7	…	0.1	313
	Shallow Water	555	103	27	172	211	…	5	…	…	1073
	Shrub Steppe	…	…	…	…	7	…	…	…	…	7
	Urban	188	194	34	2	18	11	1	9	0	457
	Wetland	5653	479	456	1007	108	…	1	1	0	7705
	Cottonwood*	1651	1709	83	1426	655	…	6	…	0	5530
Grand Total	Terrestrial	35410	14258	8882	4294	5194	252	225	48	0.8	68474

*Cottonwood values are based on different data sources than the other Ecosystem Types and do not contribute to the total value for each Dam Unit. Most Cottonwood stands mapped correspond to Wet Forests or Very Wet Forests.

In contrast to Intermediate and Dry Forests, losses of the Wet Forest Ecosystem Type were significant, even as a percentage of occurrences across the whole of the Columbia Basin Study Area (~10%). Overall HLRR's were high for some climatic regions of the Kinbasket, Arrow, Duncan and Koocanusa Dam Units. Medium high ratings were also determined for two climate regions of the Revelstoke Unit. Cottonwood Forests were assessed separately from other wet forests (stands with a >10% cottonwood component). Across the affected dam units, 21% of the cottonwood stands were lost to reservoir flooding. Habitat Loss Risk Ratings were very high in the Duncan Dam Unit, high in the Kinbasket and Koocanusa units and medium high in Arrow. Very Wet Forests were one of the most heavily impacted ecosystem types, with an overall loss of 19% of the pre-dam distribution, with some individual dam units recording 60-80% losses. HLRR's were very high for Kinbasket and Arrow Dam Units and high for the Koocanusa, Revelstoke and Duncan units.

Wetlands were also heavily impacted by reservoir creation (primarily fens with lesser amounts of shrub-dominated swamps and marshes). Within impacted dam units the overall loss was 26%, with some individual units losing 60-90%. Risk ratings were very high for the Kinbasket and Duncan Dam Units, and medium high for the Arrow and Revelstoke units. Losses of Gravel Bars due to reservoir flooding were rated very high across the Columbia Basin as a whole. Within individual dam units, they were rated very high in the Arrow, high in the Revelstoke, and medium high in Kinbasket, Koocanusa and Duncan units. The HLLRs for losses of Shallow Water/Ponds were high across the basin as a whole, with the majority of losses in the Kinbasket Dam Unit. Risk ratings for individual Dam Units were very high for the Kinbasket, high for Arrow, Duncan and Whatshan, and medium high for Revelstoke and Koocanusa. Losses of lake and river shoreline habitats were also assessed as part of the terrestrial species assessment (Manley et al. 2009). Habitat loss risk ratings were assigned based on the magnitude of loss, with Kinbasket and Arrow being rated high, Revelstoke, Duncan and Koocanusa medium high, and Whatshan and Pend d'Oreille low.

In addition to ecosystem type, the losses for forested ecosystems were also analyzed for changes in structural stage distribution. Approximately 40% of the flooded forest ecosystems were late seral forests (structural stages 6 and 7), with the vast majority being in the Kinbasket and Revelstoke Dam Units, on Wet Forest types. Mid seral stands accounted for 40% of the flooded forested ecosystems, and the remaining 20% were early seral.

Within the drawdown zones of some reservoirs there have been new ecosystems established, especially in the Revelstoke Reach of the Arrow Reservoir. These are generally simplified ecosystems, sometimes dominated by planted exotic species. Even though some of these communities produce large quantities of vegetation, their value for higher trophic levels is limited, because of the operational effects of the reservoir (e.g., flooding of waterfowl nests prior to fledging, benthic invertebrate production limited by timing and duration of inundation).

2.4.4 Summary of Terrestrial and Aquatic Habitat Impacts

Although impacts varied by the Dam Units, generally large rivers ecosystems were replaced with reservoirs, resulting in a loss of over 1600 linear km (10 km^2) of riverine habitat and inundation of 400 km^2 of lakes with a net gain of ~700 km^2 of reservoir (lentic) habitat. On the terrestrial side, the loss was approximately 690 km^2 of primarily wet and intermediate forested ecosystems and wetlands. The drawdown zone within the reservoir pool area has created some vegetated areas but of limited wildlife value because of periodic re-flooding. The value of the lost habitats for terrestrial and aquatic species varies significantly dependent upon the habitat type impacted. The impact of the dams' footprint on individual species is addressed in fish and wildlife species sections of this summary report.

2.5 Fish Species Impacts

There have been dam impacts documented for many of the fish species identified within the Columbia Basin. During the FWCP:CB dam footprint impacts review, impacts to 24 species were described. Impacts associated with dam operations, or from other industry/development are not assessed under this review unless there is relevance to a BC Hydro dam impact upstream or downstream. The FWCP:CB Dam Impact Project chapter reports 4A1-6 reviewed species-specific impacts across the basin that are summarized in this section.

2.5.1 Methods

The individual reports developed for FWCP:CB include white sturgeon, burbot, bull trout, rainbow trout, kokanee, and whitefish, westslope cutthroat trout, cottids, cyprinids, and catostomids. Each of the authors reviewed available fish species life history information and potential limiting factors, as well as potential footprint impacts including: 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. Fish species population status was subsequently assessed for each relevant dam unit. In addition, we have included information on other species in the basin not described in the reports as well as their respective conservation status to assist FWCP:CB committee members in making species-specific impact mitigation decisions.

2.5.2 Results and Discussion.

The impact of creation of dams and their subsequent footprint impacts in the study area has influenced one or more life history stages of the fish species listed in Table 7 below. Many of the species have genetically distinct forms that have highly variable life histories. The adfluvial piscivorous rainbow trout (Gerrard and Yellowfin) and adfluvial piscivorous bull trout are of much interest within the region. As these forms are dependent upon kokanee populations in large lakes and reservoirs, their viability is tied to maintenance of the primary productivity of the pelagic habitat associated with lakes and reservoirs. Other species have special status because of failing reproduction or habitat destruction, such as SARA-listed white sturgeon (endangered) and the recently SARA-listed westslope cutthroat (species of special concern, 5 Dec, 2009). The listing includes all of the ecotypes found in the FWCP:CB study area (Pers. Comm. Robert Westcott, Golder Associates Ltd, 2009), including those not addressed by the authors of the individual reports. Introduced species are of particular interest as dams may both enhance and limit their populations within the study area. The following sections describe the general status and impact summaries for each of these species reports.

White Sturgeon

Recruitment failure prior to age 1+ is the primary issue of concern for white sturgeon populations in the Columbia Basin. 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 are all considered to have an impact on sturgeon population recruitment success. In general, habitat quality, egg/fry survival and access to feeding areas (and reduced food fish populations) have been noted as negatively influenced by dam creation. Water temperatures, available rearing habitat for age 1+ fish, as well as overwintering habitat are not hypothesized to limit sturgeon production in the basin.

Table 7: Species specific impacts for fish found in the FWCP:CB area, with status and impact narrative (from Arndt 2009a, 2009b. Cope 2009, Hagen 2009, Ladell et al. 2009, Porto 2008).

Species	Type and Distribution	Conservation Status	CB Dam Impacts
Bull trout (*Salvelinus confluentus*)	Present throughout Columbia and Kootenay watersheds.	Blue Listed (S3 Vulnerable) by BC CDC. Conservation Framework Priority 2 Persistence secure for most dam units. Conservation status in Salmo River, Blueberry Creek, and Arrow Lakes south of Nakusp of concern.	Inundation of fluvial habitat, habitat fragmentation, nutrients, food availability.
Lake trout (*Salvelinus namaycush*)	Introduced and found in Kootenay Lake and lower Columbia River.	Exotic	Not described
Rainbow trout insectivorous (*Oncorhychus mykiss*)	Indigenous to Columbia Basin and Kootenay watershed below Kootenai Falls. Stocking using a variety of stocks has occurred in many areas of basin.	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6. Conservation status is not currently evaluated for individual ecotypes, but adfluvial piscivore and large river fluvial fish are relatively rare provincially. Yellow Fin from Arrow Lakes considered extirpated.	Inundation of fluvial habitat, habitat fragmentation, nutrients, food availability, reduced turbidity.
Rainbow trout piscivorus (*Oncorhynchus mykiss*)	Indigenous to Columbia Basin and Kootenay watershed below Kootenai Falls. Gerrard stock has been introduced in some other areas of basin.		Inundation of fluvial habitat, habitat fragmentation, nutrients, food availability, reduced turbidity.
Brook trout (*Salvelinus fontinalis)*	Introduced and present throughout basin	Exotic	Not described
Brown trout (*Salmo trutta*)	Introduced and present in Kootenay Lake, lower Columbia River, and Pend d'Oreille River.	Exotic	Not described
Kokanee (*Oncorhynchus nerka*)	Indigenous to Kootenay (3 stocks), Duncan, Trout, Upper and Lower Arrow, and Slocan lakes. Species introduced to Kinbasket, Koocanusa, Revelstoke Reservoirs. Widely enhanced through stocking and spawning channels.	Yellow Listed S5 (Abundant and Secure) by BC CDC.	Habitat loss and gain, habitat fragmentation, nutrient and turbidity changes, entrainment.
White sturgeon (*Acipenser transmontanus*)	Two populations: Columbia River and lower Kootenay River to Bonnington Falls. Kootenay population through lower watershed to Kootenai Falls.	SARA (Schedule 1). COSEWIC (Endangered). Red Listed by BC CDC. Conservation Framework Priority 2.	Sediment and water quality impacts, habitat loss, habitat fragmentation, entrainment.
Burbot (*Lota lota*)	Occur broadly within most large lakes, reservoirs and large rivers in the Columbia Basin.	Red Listed (S1 – Critically imperilled) in Kootenay Lake by BC CDC and Species of Special concern in Idaho.	Mixture of population increase, decrease and unknown associated with the various dam units.
Mountain whitefish (*Prosopium williamsoni*)	Found throughout Columbia and Kootenay Rivers.	Yellow Listed S4(Apparently Secure) by BC CDC. Conservation Framework Priority 4.	Habitat fragmentation, fish entrainment, water quality (temperature, DO, TGP), fluvial habitat loss
Pygmy whitefish (*Prosopium coulterii*)	Indigenous and widely distributed throughout the Columbia Basin.	Lacustrine population Yellow Listed (S4S5 secure, widespread, abundant, secure) by BC CDC. Conservation Framework Priority 4. Fluvial populations rare.	Habitat Fragmentation, fish entrainment, water quality. (temperature, DO, TGP), fluvial habitat loss
Lake whitefish (*Coregonus clupeaformis*)	Introduced to Kootenay and Arrow Lakes from Eastern Canada.	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6.	Not described

Species	Type and Distribution	Conservation Status	CB Dam Impacts
Westslope cutthroat trout (*Oncorhynchus clarki lewisi*)	Occurs in upper Kootenay River drainage and isolated populations above barriers in upper Columbia and lower Kootenay River systems.	Blue listed (Special concern) by BC CDC or no status S4. Conservation Framework Priority 4. SARA (Schedule 1 Listing under review).	Habitat loss, habitat fragmentation, and fish entrainment.
Walleye (*Sander vitreus*)	Introduced. Present in lower Columbia River, Pend d' Oreille River, and may be in Arrow Reservoir.	Exotic	Not described
Yellow perch (*Perca flavescens*)	Introduced. Present in Arrow, Kootenay and Pend d'Oreille systems.	Yellow Listed S4 (Apparently secure). Conservation Priority 4 or Exotic for Columbia (Uncertain).	Not described
Prickly sculpin (*Cottus asper*)	Distributed in Columbia River to site of Mica dam and Kootenay River to Bonnington Falls'	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 5.	Habitat loss, nutrient effects, reduction in turbidity levels, habitat fragmentation and fish entrainment.
Slimy sculpin (*Cottus cognatus*)	Dominant stream dwelling species widely distributed throughout Columbia and Kootenay and Pend d'Oreille basins. Absent from Lower Columbia below Keenleyside Dam and Kootenay River below Bonnington falls.	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6.	Habitat loss, nutrient effects, reduction in turbidity levels, habitat fragmentation and fish entrainment.
Shorthead sculpin (*Cottus confuses*)	Lower Columbia River below Keenleyside Dam and Kootenay River below Bonnington Falls – rare in mainstem and present in tributaries.	COSEWIC (Threatened). Blue Listed S2S3 (imperilled, special concern) by BC CDC.	Habitat loss, nutrient effects, reduction in turbidity levels, habitat fragmentation.
Columbia sculpin (*Cottus hubbsi*)	Lower Columbia River below Keenleyside Dam and Kootenay River below Bonnington Falls.	COSEWIC (species of concern). SARA (Schedule 1 Special Concern).Blue Listed S3 (rare or uncommon) by BC CDC. Conservation Framework Priority 2.	Habitat loss, nutrient effects, reduction in turbidity levels, habitat fragmentation.
Torrent sculpin (*Cottus rhotheus*)	Widely distributed throughout Columbia and Kootenay basins.	Yellow Listed S4 (Apparently Secure) by BC CDC. Conservation Framework Priority 2.	Habitat loss, nutrient effects, habitat fragmentation, reduction in turbidity levels, water quality, and fish entrainment.
Malheur mottled sculpin (*Cottus bendieri*)	Not confirmed present in basin, but may be present based on record from Little Slocan.	Not assessed but will likely be listed as threatened or endangered.	Not described
Longnose dace (*Rhinichthys catarctae*)	Widely distributed throughout Columbia and Kootenay basins.	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6.	Riverine habitat loss, habitat fragmentation, fish entrainment, water quality.
Leopard dace (*Rhinichthys falcatus*)	Lower Arrow Lake to US Border and Kootenay River below Bonnington Falls. Associated with larger mainstem reaches	Yellow Listed S4 (Apparently secure) by BC CDC. Not at Risk COSEWIC. Relatively rare in Columbia BCH dam footprint area. Conservation Framework Priority 4.	Riverine habitat loss, habitat fragmentation, fish entrainment, water quality.
Umatilla dace (*Rhinichthys Umatilla*)	Endemic to Columbia Basin found from Keenleyside Dam to the Border and Kootenay River below Bonnington Falls.	COSEWIC (Special Concern). Red Listed S2 (endangered or threatened) by BC CDC. Conservation Framework Priority 2.	Riverine habitat loss, habitat fragmentation, fish entrainment, water quality.
Lake chub (*Couesius plumbeus*)	Populations scattered and in southern portion of range in the Columbia Basin	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6.	Riverine habitat loss lacustrine habitat gains, habitat fragmentation, fish entrainment, water quality impacts may be beneficial.
Peamouth chub (*Mylocheilus caurinus*)	Occur throughout Columbia, Kootenay and Pend d'Oreille drainages	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 5.	Riverine habitat loss, lacustrine habitat gains, habitat fragmentation, fish entrainment,

Species	Type and Distribution	Conservation Status	CB Dam Impacts
			water quality changes may be beneficial.
Northern pikeminnow (*Ptychocheilus oregonensis*)	Common throughout Columbia Kootenay and Pend d'Oreille River systems.	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6.	Riverine habitat loss, lacustrine habitat gains, habitat fragmentation, fish entrainment, water quality changes may be beneficial.
Redside shiner (*Richardsonius balteatus*)	Widely distributed and abundant throughout Columbia, Kootenay and Pend d'Oreille River systems.	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6.	Riverine habitat loss, habitat fragmentation, fish entrainment, water quality changes may be beneficial.
Longnose sucker *Catostomus catostomus*)	Widely distributed throughout Columbia Basin. Normal and dwarf populations.	Yellow Listed S5 (Abundant and Secure) by BC CDC Conservation Framework Priority 6.	Habitat loss, habitat fragmentation, fish entrainment.
Bridgelip sucker (*Catostomus columbianus*)	Lower Arrow Lake, Lower Columbia River (Keenleyside Dam to Border), Pend d'Oreille and lower Kootenay River below Bonnington Falls. Occurs in warmer, nutrient rich systems	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6.	Habitat loss, habitat fragmentation, fish entrainment.
Largescale sucker (*Catostomus macrocheilus*)	Widely distributed throughout Columbia and Kootenay River systems.	Yellow Listed S5 (Abundant and Secure) by BC CDC. Conservation Framework Priority 6.	Habitat loss, habitat fragmentation, fish entrainment.
Mountain sucker (*Catostomus platyrhychus*)	One unconfirmed record in the Columbia Basin near the Pend d'Oreille-Salmo River confluence.	Blue Listed S3 (Special concern) by BC CDC.	Habitat loss, habitat fragmentation.
Northern pike (*Esox lucius*)	Introduced into US portion of Columbia system. Captured 2009 in lower Columbia River near Zellstoff Celgar pulp mill.	Exotic	Not described
Smallmouth bass (*Micropterus dolomieu*)	Introduced. Moyie Lake on Kootenay River, Pend d' Oreille reservoirs, lower Salmo River.	Exotic	Not described
Largemouth bass (*Micropterus salmoides*)	Introduced and known presence in Duck Lake. May be found elsewhere in the basin.	Exotic	Not described
Pumpkinseed (*Lepomis gibbosus*)	Introduced and known presence in Duck Lake. May be found elsewhere in the basin.	Exotic	Not described
Black Bullhead (*Ameiurus melas*)	Introduced and known presence in Duck Lake and Kootenay River. May be found elsewhere in the basin.	Exotic	Not described
Black Crappie (*Pomoxis nigromaculatus*)	Introduced and known presence in Pend d'Oreille Reservoir. May be found elsewhere in the basin	Exotic	Not described
Common carp (*Cyprinus Carpio*)	Introduced. Found in the lower Columbia River below Keenleyside Dam and Kootenay River below Bonnington Falls.	Exotic	Not described
Tench (*Tinca tinca*)	Introduced. Present in Pend d'Oreille and lower Columbia River.	Exotic	Not described

Six dams have isolated the two populations of white sturgeon (Kootenay and Columbia) into eight groups or sub-populations. Wild white sturgeon populations (non-hatchery) in the Columbia and Kootenay rivers are mainly comprised of older individuals and their populations are in decline because of the lack of recruitment of juveniles since the mid-1980's and mid-1960's respectively.

Porto (2008) stated that for existing 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. She further stated that populations within four DU's (i.e., Trail, Arrow, Revelstoke and Duncan) are directly impacted by BC Hydro dams, but the populations within the other DU's are either partially impacted (i.e., Kinbasket, Kootenay Canal, Kootenay Lake and Creston) or the use of the area historically by white sturgeon is largely unknown (Koocanusa). In addition she added that total habitat loss within Trail, Arrow, Revelstoke, and Duncan DUs 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 because of blocked movements at dams.

Burbot

The presence of dams in the Columbia Basin has been identified to have a range of influences on burbot habitat and populations from negative through positive. The footprint factors influencing burbot populations in the CB are mainly concentrated in the earlier life stages, including: loss of riverine habitat for spawning, incubation and rearing, blockage of movement (habitat fragmentation), loss to the dam unit through entrainment, and productivity impacts associated with nutrient retention and/or water quality.

Burbot larvae in lakes/reservoirs are pelagic, limiting impacts of reservoir operations on fish stranding during this life stage. At the juvenile stage they are more mobile, but still may have some vulnerability to stranding within the littoral zone of lakes. Alternatively, adult burbot probably benefit from the large increase in lake habitat that supports kokanee, a key food source (Cope 2009). There is a general concern with habitat fragmentation leading to a long-term decrease in genetic diversity.

The larger reservoir populations tend to be relatively healthy; however, other anthropogenic effects (species introduction, harvest, etc.) have likely contributed to a decline in some burbot populations. Burbot are a popular sportfish and can be subject to intensive fishing pressure. The conservation status of burbot varies throughout the Columbia Basin and they are currently red-listed in Kootenay Lake and the lower Kootenay River.

Bull Trout

Bull trout of both fluvial and adfluvial life histories exist in the Columbia Basin. The conservation status of bull trout in British Columbia indicates they are blue-listed as a species of special concern by the BC Conservation Data Center (BC CDC) since 1994.

Bull trout spawning and juvenile rearing habitats are located well above reservoir full pool elevations in most dam units. Extensive fluvial rearing habitat losses were likely in the coldwater streams inundated by Kinbasket, Revelstoke, and Duncan reservoirs. An estimated 180 km of inundated stream habitat was likely to have been utilized by bull trout for spawning and juvenile rearing in these dam units, which equates to estimates of 57,000 age 1+ and older juveniles (low: 46,200; high: 68,200 = 50% confidence limits) and 2,300 adult spawners (low: 1,900; high: 2,630) using biostandards for predicting mean fish density (Hagen 2009). Conservation status for remaining bull trout, with respect to the likelihood of long-term persistence of multiple, interconnected populations, appears to be secure for most dam units. The Salmo River watershed population is a conservation concern as a result of dam construction and the loss of connectivity to larger rivers downstream. Populations in Blueberry Creek and Slocan River watersheds, and the Arrow Lakes Reservoir south of Nakusp, may also be of conservation concern.

Rainbow Trout

Prior to dams, rainbow trout were indigenous throughout the Columbia River drainage, and in the Kootenay River drainage below Kootenai Falls, Idaho. Introductions of rainbow trout in recent years, primarily into Koocanusa Reservoir (Montana) have resulted in an expansion into the upper Kootenay River drainage. Arndt (2009b) provides an impact assessment for rainbow trout, segregating the species into five rainbow trout ecotypes in the basin (small-stream resident, fluvial, small lake adfluvial, large lake insectivorous, large lake piscivore). Conservation status is not currently evaluated for individual ecotypes, but the adfluvial piscivore and large river fluvial fish are relatively rare provincially. Major habitat losses affected trout from Arrow and Kootenay Lakes, the two most important large lake habitats in the basin. In the Arrow Lakes, a unique indigenous "yellowfin" rainbow trout was extirpated. These fish are believed to have spawned in Camp Creek above Mica Dam; access to their historical adult habitat was blocked, and Kinbasket Reservoir apparently was not suitable for their survival at least in the early years. In Kootenay Lake, an important spawning area for piscivorous adfluvials was lost because of the creation of Duncan Dam. Several small-lake adfluvial populations were also lost because of inundation of their habitats. The distribution and abundance of the fluvial ecotype of rainbow trout has been diminished because of a reduction in post-dam riverine habitat.

The most important density-independent factors determining habitat quality for juvenile rainbow trout are likely temperature, flow regime, and food availability. In stream reaches downstream of dams, dam footprint impacts can directly affect these factors. In reaches upstream of dams and reservoirs, the impact of dams is more likely to be on habitat quantity (i.e., inundation of stream habitat by reservoirs). For most populations of large and small lake adfluvials, and large stream migratory fluvials, rearing habitat rather than the spawning habitat would be most likely to limit recruitment to the adult population.

Kokanee

Prior to dam construction, kokanee in the Columbia Basin were indigenous to lentic habitats in Kootenay, Duncan, Trout, Upper and Lower Arrow, and Slocan Lakes. In general, kokanee habitats in the FWCP:CB area can be grouped into three categories: 1) non-impacted lakes, 2) new reservoirs or greatly enlarged lakes, and 3) impacted historic lakes. Reservoirs such as Whatshan, Kinbasket, Revelstoke, and Koocanusa support robust populations of introduced kokanee. Introduced kokanee populations in Kinbasket and Koocanusa reservoirs utilize suitable upper Columbia and Kootenay drainage spawning habitat that previously was inaccessible. Duncan Reservoir has an expanded lentic area that may support more kokanee than the historic lake, if remaining spawning habitat or drawdown reservoir volume are not limiting. Limited information is available on the Duncan population.

Footprint dam impacts affecting kokanee include habitat loss (spawning) and habitat gain (lentic), habitat fragmentation, nutrient and turbidity changes, entrainment, and changes in aquatic-terrestrial interactions. Construction of dams expanded lentic habitat in the basin by approximately 700 km^2, including new reservoirs and increased surface area in previously-existing lakes.

Historic spawning habitat for key indigenous populations was reduced by inundation. The inundated spawning areas included much of the quality habitat ideal for kokanee spawning such as alluvial fans and low gradient reaches, which were typically in the flooded lower reaches of inundated tributaries..

Within Kootenay Lake and Arrow Reservoir, spawning channels and fertilization programs have been developed to maintain populations at or above pre-dam levels. There is debate as to what life history segment determines population abundance and size of kokanee produced in these and other systems, although it is generally accepted that the early pelagic rearing phase during the first year of life positively correlates with year class strength, and both increased growth and recruitment are related to nutrient status in the reservoir/lake.

Assessment of changes in population status in relation to footprint impacts was hampered by substantial uncertainty in regards to pre-dam kokanee abundance, and potential causes of declines. The quantity of spawning habitat actually used by kokanee prior to inundation is not known; however, low gradient, low elevation stream losses quantified by Thorley (2008) likely included habitat with good potential for kokanee spawning.

Biodiversity: Whitefish, Westslope Cutthroat Trout, Cottids, Cyprinids, Catostomids

The Columbia Basin is home to representatives of over half of British Columbia's freshwater fish species. This region contains a total of 43 fish species of which 27 are native to the area and 9 are endemic. In general very little is known about the impacts on these relatively unstudied species. At the very least, a significant amount of river and stream habitat was inundated with dam construction. Distribution, inventory, and life history work will allow for more informed decisions about future management of these fish species, particularly those at risk.

2.6 Wildlife Species Impacts

Terrestrial species impacts were analyzed by Manley and Krebs (2010). Recognizing that loss of habitat is the primary driver in species impacts, the wildlife species impacts assessment focused on identifying the severity of habitat loss for each species that were predicted to have been resident within the dam footprints at the time of flooding. Because of the presence of wetlands that were important stopover habitats for migratory birds, impacts to some migratory species were also assessed. Because of paucity of pre-dam information related to what species were present, and population sizes, it was deemed impractical and imprecise to assess quantitative losses by species. The assessment did not consider impacts to plants, fungi, or invertebrates.

2.6.1 Methods

The approach included: preparing wildlife species lists for each dam unit, linking each identified species with mapped habitats affected by reservoir flooding through a modified version of the BC Columbia Basin Data Base for Terrestrial Vertebrate Species (CBDB) habitat associations, and then rating the estimated impact to individual wildlife species based on the habitat associations from the CBDB and habitat losses described by MacKillop et al. (2008) and Thorley (2008). Provincial standard approaches using Terrestrial Ecosystem mapping units linked to Wildlife Habitat Ratings were not applicable to the species and scale of the assessment.

Species considered included both resident/breeding species and migratory bird species that use habitat within the basin during spring/fall migration. Many of the Habitat Types defined in the CBDB could be correlated directly with the Ecosystem Types from MacKillop et al. (2008), while some had to be cross-walked from the Ecosystem Association map units from the original footprint mapping (Ketcheson et al. 2005). In addition, four new Habitat Types for analysis were defined based on additional Ecosystem Types from MacKillop et al. (2008). New species/ habitat associations were added to the CBDB to match species to the new Habitat Types, based on species use of habitat elements associated with the new types (e.g., coarse woody debris and hollow live trees with Wet Forests, deciduous trees and Cottonwood stands).

A Wildlife Species Impact Rating (WSIR; Range 0 [nil] to 5 [very high]) was calculated for each species in each dam unit it occurred, based on a summation of the Habitat Loss Risk Ratings (HLRR) for each of the Habitat Types associated with that species. The WSIR's were then combined with further information from the BC

Conservation Framework, BC MoE regional management priorities for mammal species, and the list of focal species birds of significance for the Columbia Basin prepared by the Canadian Intermountain Joint Venture. Based on those combined criteria, priority ratings were determined for each resident/breeding vertebrate species in each impacted dam unit (a total of 289 species for the Columbia Basin Study Area). Priority 1 species had both high or very high impact ratings (WSIRs), as well as high priorities for management, as determined by other agencies/processes. Priority 2 species had high or very high impact ratings, but were not designated as a high priority for management by the other agencies/processes.

Because of their transitory nature, ratings for migratory species were determined for the whole basin rather for individual dam units.

2.6.2 Results and Discussion

Wildlife Species Impact Rating (WSIR) results are summarized for the major dam units in Figure 7. As indicated, the most significant species/habitat impacts were associated with the Kinbasket Dam Unit, with a mean WSIR of 2.96, and a number of species with WSIRs over 4. The Duncan and Arrow Dam Units also had relatively high species/habitat impacts, with mean WSIRs of 2.49 and 2.37 respectively.

From the total of 289 species examined, 64 resident/breeding species were assigned to Priority 1 and 46 species were assigned to Priority 2, based on the criteria described above. In addition, 9 migratory species were also assigned to Priority 1, and two to Priority 2 (see Table 8).

As shown in Table 8, the highest numbers of species impacted were bird species, mainly from the waterbird and flycatcher-vireo guilds, followed by the warbler-sparrow guild. Some of the highest mean and maximum WSIRs in Priority 1 were associated with the waterbird, wader and amphibian guilds, while the shorebird-gull-tern and reptile guilds also had higher mean WSIRs (however species numbers were low).

Within Priority 2 species, the highest mean and maximum WSIRs were associated with the shorebird-gull-tern and wader guilds, but species numbers were low (n=1 for both). The waterbird and flycatcher-vireo guilds also had higher maximum WSIRs. There were two additional guilds represented in Priority 2 species: corvids and small mammals.

The results of the CBDB analysis outputs were also used to examine the degree to which species with key ecological functions were impacted. Primary and secondary cavity nesters and aerial insectivores were the most significant functional groups impacted. However, species that create large burrows were also found to be significantly impacted.

The significant losses of Floodplain Forest, Wetlands, Shallow Water/Ponds and Shoreline are all reflected in the types of species that are impacted, including: songbirds, shorebirds, waterbirds, waders and amphibians. These are all guilds that are associated with older forests, lowland aquatic features and/or the terrestrial/aquatic interface.

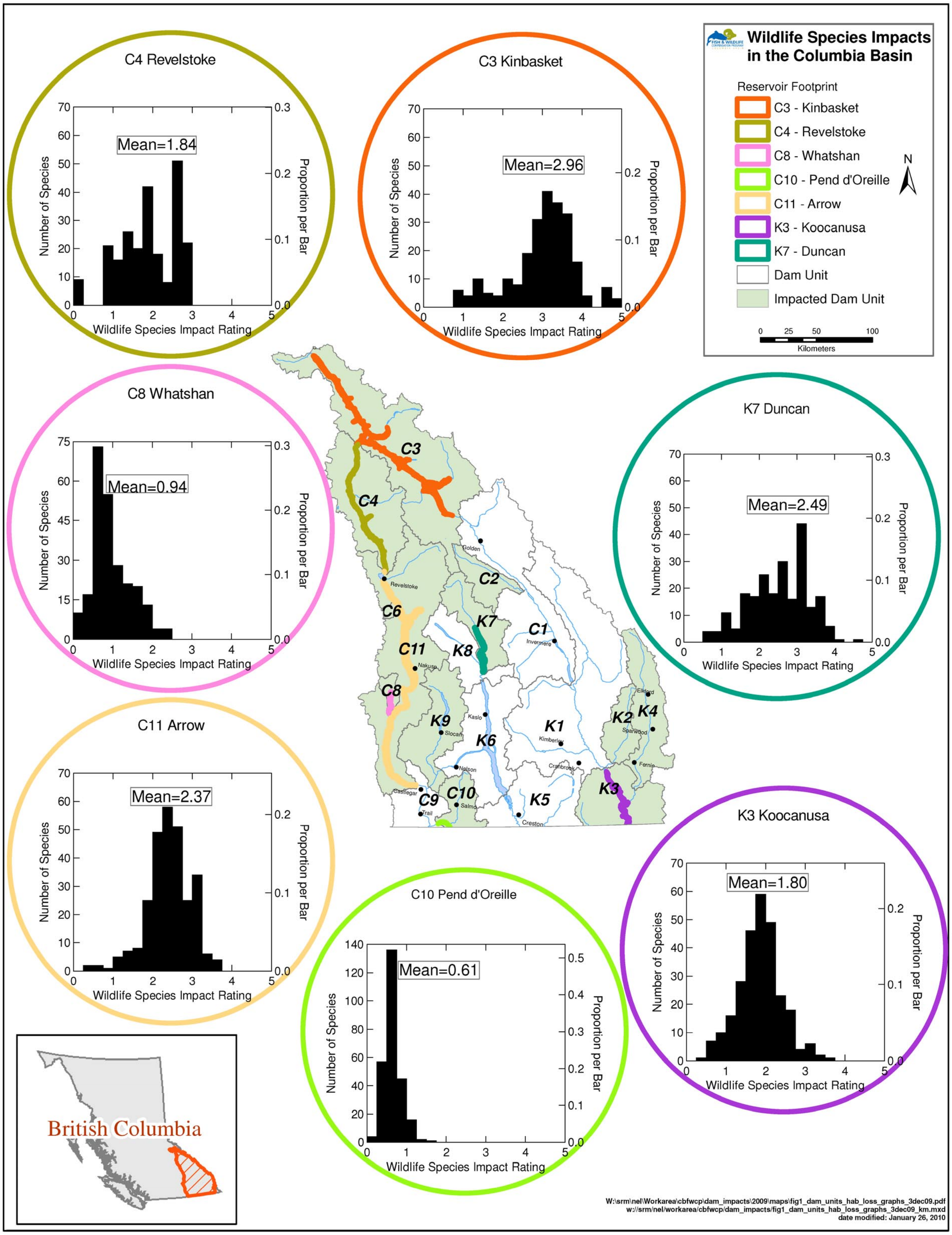

Figure 8: Species impacts by dam unit for the larger reservoirs (from Manley and Krebs 2010). Graphs indicate the frequency and proportion of species in the range of WSIR impact ratings (each bar represents a 0.25 increment of rating value).

Table 8: Priority 1 and 2 wildlife species impacted by dams in the Columbia Basin (from Manley and Krebs 2010); w= wetland/ riparian species and u= upland species. Species are coloured by Wildlife Species Impact Rating (Very High, High, Medium Low, Very Low).

Guild	Priority 1 Wildlife		Priority 2 Wildlife	
Amphibians/ Reptiles	Northern Leopard Frog	w		
	Western Toad	w		
	Wood Frog	w		
	Painted Turtle	w		
Waterbirds	Harlequin Duck	w		
	American Coot	w	Common Goldeneye	w
	Barrow's Goldeneye	w	Common Loon	w
	Belted Kingfisher	w	Eared Grebe	w
	Blue-winged Teal	w		
	Canvasback	w	Horned Grebe	w
	Cinnamon Teal	w	Red-necked Grebe	w
	Lesser Scaup	w	Ring-necked Duck	w
	Northern Pintail	w	Bufflehead	w
	Pied-billed Grebe	w	Hooded Merganser	w
	Redhead	w		
	Western Grebe	w		
	Wood Duck	w		
Waders	American Bittern	w	Sora	w
	Great Blue Heron	w		
	Virginia Rail	w		
Raptors	Northern Harrier	w	Cooper's Hawk	u
Shorebirds	Common Snipe	w	Black Tern	w
	Killdeer	w		
Game birds	Dusky Grouse			
	Ruffed Grouse			
Owls	Northern Pygmy-owl	u	Barred Owl	u
	Short-eared Owl	w		
	Western Screech-owl	w		
Hummingbird	Rufous Hummingbird	u		
Woodpeckers	Lewis' Woodpecker	w	Downy Woodpecker	u
			Pileated Woodpecker	u
			Red-naped Sapsucker	u
Aerial Insectivores	Barn Swallow	w	Tree Swallow	w
	Black Swift	w		
	Cliff Swallow	w		
	Northern Rough-winged Swallow	w		
	Violet Green Swallow	w		
	Vaux's Swift	w		
Corvids			Steller's Jay	u

Guild	Priority 1 Wildlife		Priority 2 Wildlife	
Songbirds Flycatcher-Vireo	Brown Creeper	u	Red-eyed Vireo	u
	Chestnut-backed Chickadee	u	American Dipper	w
	Eastern Kingbird	u	White-breasted Nuthatch	u
	Olive-sided Flycatcher	u	Alder Flycatcher	u
	Pacific-slope Flycatcher	u	American Pipit	u
	Veery	w	Black-capped Chickadee	u
	Western Wood-pewee	u	Golden-crowned Kinglet	u
	Willow Flycatcher	w	Gray Catbird	u
			Hammond's Flycatcher	u
			Least Flycatcher	u
			Marsh Wren	w
			Winter Wren	w
			Northern Mockingbird	u
Songbirds Warblers-Sparrows	Yellow Warbler	w	American Redstart	w
			Black-headed Grosbeak	u
	Purple Finch	u	Blackpoll Warbler	u
	Yellow-headed Blackbird	w	Brown-headed Cowbird	u
			Common Yellowthroat	w
	Bobolink	w	Magnolia Warbler	u
	Yellow-breasted Chat	u	Nashville Warbler	u
			Northern Waterthrush	w
Bats	California Myotis	u		
	Hoary Bat	w		
	Long-eared Myotis	u		
	Long-legged Myotis	u		
	Northern Myotis	w		
	Silver-haired Bat	u		
Small Mammals			American Beaver	w
			Dusky Shrew	u
			Meadow Vole	u
			North American Water Vole	w
			Western Jumping Mouse	w
			American water shrew	w
Carnivores	Fisher	w	American Badger	u
	Northern River Otter	w	American Marten	u
	Grey Wolf	u	American Mink	w
	Grizzly Bear	u		
Ungulates	Caribou	u	Bighorn Sheep	u
	Moose	w		
	White-tailed Deer	u		
	Mule Deer	u		
	Elk	u		

2.7 Ecological Function and Process Impacts

Construction of dams and the flooding of a significant portion of the valley bottoms of the Columbia basin have not only significantly altered habitats, impacted individual species and reduced primary productivity by trapping nutrients behind dams, but have also had significant impacts on ecological functions and processes. The dams themselves have disrupted geomorphic processes including annual hydrologic regimes, erosional patterns, sediment transport, channel formation, flooding and sediment deposition. These changes, combined with habitat alterations due to reservoir flooding, have in turn altered environmental and biological processes such as natural disturbance regimes, seasonal variation in microclimates, aquatic and terrestrial primary productivity, trophic dynamics, nutrient cycling and soil formation. The dams and reservoirs have also impacted functions for individual species and populations, including seasonal migrations, connectivity, genetic exchange, predator/prey relationships, reproduction and dispersal. Although relevant to overall ecosystem function, impacts associated with seasonal dam operation and anthropogenic impacts such as species introductions (i.e. mysids and kokanee), are not included in this discussion.

The impacts of the dam creation on ecological function and processes are most acute in the dam impact units themselves, but they can also extend into non-impacted units, especially those downstream of dams and reservoirs (e.g., Kootenay Lake, lower Pend d'Oreille River). In river systems where fish species had previously migrated upstream from current dam locations, ecosystems upstream of the dam units have also been impacted[5]. The following sections describe the potential impacts of dam creation on ecological processes associated with aquatic, wetland, riparian and upland terrestrial habitats.

Although other anthropogenic activities have impacted aquatic habitats and ecological processes in the Columbia Basin (e.g., pollution from pulp mills/smelters/sewage plants, dam operations, forest harvesting, residential/industrial development, species introductions), impacts from these activities are not discussed here. A lack of pre-dam baseline data limits the ability to quantify many of these impacts, and therefore professional judgement is often relied on to describe potential impacts.

2.7.1 Aquatic

In the terms of the FWCP:CB Footprint Impacts review, aquatic habitat is defined as the area of river/stream (lotic) and lake/reservoir (lentic) area. The following sections describe the ecological function and process impacts associated with dam creation.

Impacts to Fish Movement and Migration Due to Dam Presence

The construction of dams in the Columbia Basin within Canada provides multiple barriers to upstream fish migration. Following the construction of the Grand Coulee Dam in the US, which blocked anadromous fish migration into Canada in 1941, fish passage facilities were not built into dams in Canada. The exceptions to this general statement include the lock at Hugh Keenleyside dam that allows fish to pass opportunistically, Also a fish transfer procedure has been established at Duncan Dam to pass a spawning population of adult bull trout. In total, eight of eleven BC Hydro dams in the Columbia Basin are thought to influence upstream fish migration – the remaining three (Aberfeldie, Elko, and Spillimacheen) all exist beside falls that were historic barriers to fish migration. Downstream passage past dams (through generating units, water passage ports, or spillways) is referred to as entrainment, and is generally considered an operational impact, and therefore not discussed here.

[5] Although not a direct effect of BC Hydro dams, the loss of Pacific salmon runs that extended into the upper reaches of the Columbia River due to the Grand Coulee Dam on the lower Columbia have impacted many ecosystems throughout the Columbia River Basin in British Columbia.

Fish migration barriers influence reproductive success by blocking access to spawning tributaries, as well as genetic diversity of fish populations as a result of population isolation. Arrow Lakes' rainbow trout, bull trout, kokanee, and white sturgeon (spawning and early rearing habitat) and Duncan Lake rainbow trout, bull trout and kokanee were directly impacted by fish barriers from dams. In several instances, restricted access to spawning habitat was offset by flooding of historic barriers (due to increased reservoir levels) or man-induced changes to barriers (Kaslo River barrier removal on Kootenay Lake), and/or creation of spawning channels to increase reproductive success. Fish species, such as kokanee and Gerrard Rainbow, have been intentionally introduced into the newly created reservoirs on the Columbia to provide enhanced value to these habitats. They would have likely arrived eventually, but barriers formed by the dams would have reduced the probability of these habitats being colonized in a short time frame and have provided enhanced value to these reservoirs. In some cases (e.g., Salmo River bull trout), a downstream dam has isolated the population from historical connections to larger adult habitats, thereby increasing vulnerability.

The reservoirs have also altered geomorphology at the mouths of tributaries so that in certain instances spawning migration of fish is restricted, preventing the use of spawning habitat by the species. If the altered stream mouth is dewatered during periods when juveniles are migrating downstream, a barrier fomed at the same location could lead to stranding of outmigrants. This impact is related in part to the footprint of the reservoir and in part to operations.

The barriers also serve a positive function by preventing the spread of introduced species, such as walleye, northern pike, and other introductions. In other jurisdictions, introduced species may spread more easily, potentially resulting in a complete alteration of the food web and/or in extirpation of native species.

Water Quality

Dams often result in changes to water quality both within and downstream of the reservoir. Reservoirs, especially those with larger storage volumes, result in a more stable temperature regime – warmer in winter, cooler in summer. In addition, large volumes of water stored behind dams can result in thermal stratification, depending on water residence time, and influence fish species presence. Turbidity is also impacted by reservoirs. Previous to dam construction, seasonal peak flows resulted in bank erosion and significant sediment transport. In some systems, sediments associated with glacial meltwaters further increased the sediment loads and duration of turbid waters. Reservoirs act as settling ponds, trapping much of the sediment. The resulting decrease in turbidity contributes to increased primary productivity in some reservoirs and river reaches downstream of the dams. Turbidity decreases also change the habitat quality for certain species, such as white sturgeon, and may be a major factor in their reproductive failure.

Productivity gains caused by turbidity decreases are somewhat offset by nutrient losses in the lakes, reservoirs and rivers downstream of the dams. The overall change in trophic status is complex, and depends on the specific characteristics of the system and the species present.

The loss of productive, functional littoral and shoreline ecosystems in most reservoirs has constrained total basin C production (Moody et al 2007). Mercury methylation associated with inundation of new soils is also a known impact of reservoir creation that can bio-accumulate in both aquatic and terrestrial species, and influence health and reproduction. Impacts on dissolved oxygen are often associated with reservoir formation but the oligotrophic nature of the reservoirs in this region has limited these types of impacts. Total Dissolved Gas pressure is often elevated below spillways and some powerplants. As these impacts are primarily operational, they are not included as a footprint impact.

Habitat Changes from Lotic to Lentic Habitat

From an aquatic perspective, reservoir creation inundates stream habitats (lotic) and creates additional lake (lentic habitat). For example, the Duncan and Koocanusa reservoirs lost in excess of 90% of their historic floodplain habitats, which included pre-dam wetlands, streams and small lakes. For these two systems, there has been a shift from highly diverse aquatic habitats and accompanying biodiversity, to a pelagic driven landscape (Moody et al. 2007). Reservoir creation may, in some cases, reduce the littoral productivity, but also benefit species that rely on pelagic production (kokanee, burbot, bull trout).

Seasonal water level changes in reservoirs can result in the seasonal exposure of stream habitat. The value of stream habitat exposed during reservoir drawdown is site specific, depending on factors such as sediment deposition, channel configuration and gradient. Some of the reservoirs have more stable water levels, with minimal seasonal changes in habitat, and act more like run-of-river facilities (Revelstoke, Cranberry, Spillimacheen, Elko, Aberfeldie, Kootenay Canal, and Pend d'Oreille).

Changes to fish species assemblages can also occur as a result of changes in habitat. The flooding of rivers and streams has resulted in losses of habitats important for specific life-cycle requirements for some species. Fish species have lost important spawning and rearing habitat, and other species such as burbot have lost important off-channel or backwater habitats for rearing.

2.7.2 Changes in Aquatic-Terrestrial Interactions

Many of the wetlands and shallow water/pond habitats within the reservoir footprints and other areas within the Columbia Basin were located on the floodplains. Their functioning and production were based on inputs from seasonal flooding, as well as these areas producing organic matter and other nutrients that were transported to downstream river and lake habitats. The loss of these wetlands also had wider implications on a continental scale as they provided important resting and feeding habitats for migratory waterfowl and upland birds.

High water tables on floodplains and other riparian zones increased productivity of the terrestrial ecosystems on those sites by limiting seasonal water deficits, while the floodplain vegetation itself provided bank stability, large woody debris inputs and moderated sediment inputs for the adjacent aquatic environments. The lost floodplains of the footprint areas also played key roles in the functioning of downstream floodplain forests, wetlands, lakes and rivers. Floodplains provided nutrient inputs to aquatic systems, while stream spawning by salmonids provided a vector for the transfer of nutrients from downstream lakes, and prior to the Grand Coulee Dam, from the Pacific Ocean to floodplains and upland sites throughout the basin. In addition, many terrestrial species that may not be limited to riparian sites, may still utilize riparian sites, or at least other resources generated on those sites, to meet their life requisites or to complete a portion of their life cycle (e.g., bears, ungulates).

By altering the seasonal timing of flows of the dammed river system, and by changing the biological and physical characteristics of the waters, the dams and reservoirs also affect wetlands, floodplain forests, and downstream aquatic environments that have been missed by the reservoir flooding itself (e.g., cottonwood ecosystems on the Duncan and Columbia Rivers below the dams).

Aquatic/ terrestrial species interactions can also be changed by dam creation. The increase in water volume can result in an increase in pelagic species populations that, depending upon the species, may be more or less vulnerable to terrestrial predators compared to a riverine population. Fish entrainment from dams and the increase in downstream water temperatures in winter (reduced ice cover) can lead to year-round habitats for piscivorous water-based species (e.g., mergansers, otters). Change in the amount and/or distribution of kokanee carcasses within stream and riparian ecosystems can impact an important food base for piscivorous terrestrial animals (e.g., bears, eagles). This impact may be positive where kokanee have been introduced, or potentially negative where spawning is concentrated in artificial spawning channels (e.g., Kootenay Lake and Arrow Reservoir).

2.7.3 Upland Terrestrial

Some upland terrestrial species were also impacted by the barriers to movement imposed by large reservoirs, resulting in habitat fragmentation. The formation of large reservoirs created disjunct seasonal habitats, limiting dispersal and population recovery, or limiting genetic exchange between populations. Fragmentation often operates subtly, potentially impacting population dynamics, genetic population structure, distribution and population persistence. These phenomena were not studied in detail as part of the dam impacts assessments, but other studies have noted potential impacts on the following species: Grizzly Bear, Mountain Caribou, Fisher, Badger, Bighorn Sheep, Painted Turtle, Northern Leopard Frog, Western Toad and Western Screech Owl. Although not defined as a footprint impact, powerlines associated with the dams have further amplified habitat fragmentation impacts.

3 CONCLUSIONS/COMPENSATION OPTIONS

Conditional Water Licenses on most Columbia Basin dams require BC Hydro to undertake “Programs for the protection or enhancement of fish and wildlife habitat and for the mitigation of losses of habitat”. The term “compensation” has been applied to the broad suite of protection, enhancement, and mitigation measures intended in the original water license conditions. This section provides a general overview of the broad categories of compensation options that link the increasing understanding of the terrestrial and wetland habitat losses reported in the various dam impact reports to potential actions for addressing those impacts. As shown in the preceding sections, the significance and nature of the habitat loss impacts vary substantially between dam units. Compensation options therefore also vary accordingly and are discussed more specifically by dam unit in the individual dam impact reports (see Table 1).

The individual dam impact reports describe compensation options targeted towards a specific subset of impacts. For example, aquatic, wetland and terrestrial primary productivity compensation options are described in Chapters 2A and 2B-2, aquatic habitat loss compensation options are outlined in Chapter 3A and terrestrial habitat loss options are described in Chapter 3B (Table 1). The compensation options for various fish species are outlined in Chapters 4A1 to 4A6, and for terrestrial species in Chapter 4B. Many of the compensation options recommended for addressing one type of loss can also compensate for other types of losses. Overlapping compensation options reinforce and acknowledge the relative importance of how compensation activities can address multiple impacts. For example, creation of functional wetlands within a dam footprint could simultaneously increase primary production, restore a highly impacted habitat, and provide fish and wildlife habitat.

BC Hydro is also actively developing projects to address environmental impacts associated with operation of Columbia Basin dams identified in the Water Use Planning (WUP) process. Projects arising from the WUP initiative may also overlap with those identified here in the Dam Impact assessment. Multiple footprint and operational impact benefits from some projects are possible and desirable, and will require ongoing co-ordination between the FWCP:CB and the BC Hydro Water License Requirements (WLR) group.

The concept of 'No Net Loss' (NNL) is central to current policy from the Department of Fisheries and Oceans (DFO) concerning fisheries habitat compensation. The hierarchy of compensation options framed by the DFO policy begins with creating or increasing productive capacity of like-for-like habitat in the same ecological unit; if this is not possible, either replacing like-for-like habitat off-site or increasing the productivity of existing habitat are considered; finally if none of the above are possible, artificial production techniques (e.g., hatcheries), deferred compensation, or restoration of contaminated sites are possible options. No such NNL policy guides terrestrial habitat compensation.

Other authors emphasize the need to address primary limiting factors when attempting to maintain productive capacity, rather than having a strict focus on habitat loss. For example, replacement of lost spawning habitat will result in minimal population increase if factors later in the life history are more limiting. They also note that compensation approaches should have a goal of maintaining the habitat required to provide broad life history diversity, and recognize that evaluation of project success should be based on meeting objectives that reflect clearly defined and measurable sustainable population increases rather than easily measured outputs such as funds spent or the number of fish stocked.

Clearly, re-creating the total amount and composition of habitats lost within the footprint of the reservoirs is not a practical consideration as this would require removal of the dams themselves. In practice, where impacts are extensive and varied, compensation approaches also need to be multifaceted and acknowledge that NNL may not be achievable.

Within some reservoir footprints, it is potentially feasible to re-create functioning fish and wildlife habitats to a fraction of pre-dam distribution (e.g., pelagic habitats, non forested wetlands); however, most opportunities for compensation (e.g., habitat restoration) occur 'off-site' or in 'unaffected-dam-units'. In addition, opportunities for habitat protection through acquisition, covenant, or stewardship agreement (e.g., preservation), do not neatly fit into the concept of NNL but arguably provide the greatest environmental benefit into the future. In concert with other compensatory approaches, preservation is a recognized tool and is considered here alongside the generally accepted compensation options of habitat conversion/creation and restoration.

Knowledge of species, ecosystems, and their functions continues to expand as new information is gathered through inventory, research, and new analytical techniques. Where the majority of the land base is Crown owned and managed (as is the case in the Columbia Basin), provision of new information supporting effective protection and/or restoration of remaining highly-impacted habitats can also be considered a viable compensation option. For example, 'Integrated Management Planning' information that assists designation of Protected Areas, Watershed and Riparian Reserves, Old Growth Management Areas, Wildlife Habitat Areas, and Ungulate Winter Ranges can provide incremental benefit to species and ecosystems affected by footprint impacts.

On-site compensation options for some lake habitats and fish species are present, but for stream and terrestrial habitats and species compensation, on-site compensation options are generally limited to the upper elevations of reservoirs where water levels can allow for development of some habitat types (e.g., wet meadows, mud flats/ sand bars and limited shrub habitat). These created habitats may have severely limited seasonal function, depending on reservoir water level fluctuations. In addition, wildlife use of 'on-site' habitats requires further study to determine the conditions where these re-created habitats act as production 'sources' or 'sinks'. Forest and stream habitats cannot be developed within the reservoir footprints, so compensation opportunities for these habitats will only occur off-site or in unaffected dam units. Floating islands offer the opportunity to create additional wetland or herbaceous habitat within the dam footprints. Because of the combination of limited area, site-specific habitat types, and potential habitat function that can be achieved on-site, the majority of terrestrial and stream habitat compensation options will occur off-site.

Off-site compensation options depend heavily on the availability of low elevation habitats. In many cases, limited opportunities remain in the affected dam units, and unaffected dam units may provide some of the only remaining low elevation habitat types. Free flowing sections of the Columbia River are rare in the Basin, consequently these areas have value both as a benchmarks and potential concentration areas for fish and wildlife in remaining low elevation habitats.

The range of potential compensation activities recommended by the various dam impact reports that FWCP:CB could undertake to fulfill BC Hydro's license requirements are summarized in Table 9, including their potential benefits. Land acquisition combined with subsequent management for enhancement of specific habitats that have been lost due to flooding is one of the compensation options from Table 9 that has clear benefits. This option has been successfully pursued in cooperation with other conservation agencies in the East Kootenays, along the lower Columbia River, the Lardeau Valley and other areas. The primary limitations of this option are the minimal amount of low elevation lands available and high acquisition costs. When the acquired lands include riparian areas, shorelines, ponds and/or wetlands, they can have aquatic as well as terrestrial benefits (e.g., the Lardeau, lower Columbia River, East Kootenay). In areas where existing landowners are motivated to cooperate on conservation actions, stewardship agreements can be a more cost-effective alternative.

Specific habitat enhancements within reservoirs and lakes, such as fertilization of Kootenay Lake and Arrow Reservoir, have been successful in directly mitigating the nutrient blockages associated with dams upstream of those water bodies. However, realizing the full potential benefits of these also depends on coordination with other activities such as spawning channels, spawning and rearing habitat enhancements, and riparian land acquisitions on associated rivers and streams. The installation of structures to restore habitat within stream channels has also been utilized (e.g., the Salmo River, Sproule Creek). Terrestrial habitat projects such as restoration of grasslands and open forest ecosystems, wildlife tree recruitment and increasing the amount of shrub and deciduous habitats can benefit a range of terrestrial species.

For many species that have been impacted, there is presently insufficient information available to adequately design appropriate mitigation options. For species such as Great Blue Heron, Harlequin Duck, and the Painted Turtle, inventories have proven important in identifying specific stewardship and restoration opportunities, as well as increasing the knowledge base needed for designing management actions on Crown lands (e.g. designation of Wildlife Habitat Areas).

Translocations, re-introductions or assisted migration of species have proven useful for enhancing populations of some species (e.g., Mountain Caribou, Bighorn Sheep, White Sturgeon, Northern Leopard Frogs), however, they are generally costly, and require detailed planning to maximize success. Successful translocations will require addressing any threats that may face the target population such as unsuitable habitat, predators, or disease. Species interactions must also be carefully assessed to avoid unintended consequences.

In general, carefully designed habitat restoration/ enhancement projects combined with securing critical lands through acquisition or stewardship agreements appear to provide broader benefits with fewer risks of negative impacts. However, providing assistance to help restore species-at-risk may require more focused activities where immediate action is required. Projects that involve restoration of ecosystem processes tend to minimize requirements for long-term operating and maintenance costs, and are generally more cost-effective over the long term (e.g., installing instream structures, but also restoring riparian functions so the structures will eventually be renewed naturally).

Table 9: A summary of the types of compensation options recommended by the various impact reports and their potential benefits: 1) Major direct benefit; 2) Moderate indirect benefit; 3) Minor indirect benefit; P) Possible benefit or negative impact, depending on location and details of treatment; and (-) Negative impact, often depending on location and detail of treatment.

Compensation Option	Chapter Source (Table 1)	Range of Potential Benefits										Comments/ Examples
		Primary Product'n		Aquatic Habitat		Terrestrial Habitat		Species (incl. spp. @ risk)			Frag-men-tation	
		Aquatic	Terrest.	Lakes	Stream	Wetlnd/fldpln	Upland	Fish Species	Wetlnd/fldpln	Upland		
Ecosystem Restoration/ Enhancement												
Nutrient Addition-Lakes/Reservoirs	2A, 4A2, 4A3, 4A5	1	3	1	2	3		1	2	3		Could be focused on littoral areas or embayments; downstream benefits
Nutrient Addition-Streams	2A, 4A1, 4A3, 4A4, 4A5	1	3	2	1	3		1	2	3		Downstream benefits
Reservoir operation/ flow management	1A, 3B, 4A1, 4A2, 4A4, 4A5	1P	2P	2P	3P	2P	3P	1P	3P	3P	1P	Change in draw-down timing for shoreline veg. and spawning
Streamflow mgmt.	4A3,4A4	1			1	2		1P–3P	2		1	Maintain flows
River/ stream substrate/ structure	2A, 3A, 3B, 4A1, 4A2, 4A4, 4A5	2P			1	2		1	2			LWD, gravel bars, substrate mgmt.
Turbidity augmentation	4A1	(-P)		-P	1P			1P	3P			Sturgeon
Lakeshore structure	4A5			1				1				Rock groins
Small lake restoration/ enhancement	4A4			1		3P		1	3P			
Wetland	2A, 3B, 4A5	2	1	3	3	1		2P	1	3		Water controls
Upland	2B, 3B, 4B		2P		3		1			2	3P	Fire,shrub/ grassland habitat
Floodplain/riparian	2A, 3B, 4A3, 4A4, 4A5	3	1		2	1	3	2	1	3	2	Flooding – Ac, fish carcasses
Stand/site level structure	2B, 3B			3P	3P	1	1	3P	1	1		CWD, wildlife trees; LWD

DAM FOOTPRINT IMPACTS SUMMARY: COLUMBIA BASIN

Compensation Option	Chapter Source (Table 1)	Range of Potential Benefits: Primary Product'n – Aquatic	Primary Product'n – Terrest.	Aquatic Habitat – Lakes	Aquatic Habitat – Stream	Terrestrial Habitat – Wetlnd/fldpln	Terrestrial Habitat – Upland	Species (incl. spp. @ risk) – Fish Species	Species – Wetlnd/fldpln	Species – Upland	Frag-men-tation	Comments/ Examples
Improve Connectivity	2A, 4A1, 4A2, 4A3, 4A4, 4A5, 4B	3P		1	1	1	1	1P(-P)	1P(-P)	1P(-P)	1	fish ladders, barrier removal, mature forest, road crossings; invasive spp.
Control invasive/ introduced spp.	2B, 3B, 4A6	3P	3P	3P	3P	1P	2P	2P	2P	1P		Plants, fish
Erosion control	2A, 3B				1	1	1	2P	2P	3P		Bank stabilization, road deactivation
Grazing mgmt.	3B				1	1	1	2	1	1		
Ecosystem/ Habitat Creation												
Side channel habitat	2A,4A3	2			1	2		1	2	3P		
Wetland	2A, 2B, 3B	2	1	2P	3P	1		3	1	3		Drawdown wetlands & other
Shoreline/Littoral	2A, 2B, 3B	3		2P		3		2	3P	3		Drawdown seeding
Floating Islands	2B	(-)	1	3		1	2P	3	2P			Floating wetlands and/or upland
Stand/ site level	3B, 4B					1	1		1	1		Enhance cavity/burrow spp.
Maximum productivity plantations	2B		1			3P(-P)	3P(-P)		3P(-P)	3P(-P)	3P(-P)	Hybrid poplar
Habitat Securement												
Acquisition of private land	2A, 2B, 3A,3B		3P	3P	2P	1	1	3P	1	1	2P	
Stewardship/ Covenants on private land	2B, 3B		3P	3P	3P	1P	1P	3P	1P	1P	2P	
Stream Habitat/ Full Watershed Protection	3A, 4A3, 4A6			3P	1P	1P	1P	1P	1P	1P	1P	
Integrated Habitat Planning	3B				2P	1P	1P	3P	1P	1P	1P	

DAM FOOTPRINT IMPACTS SUMMARY: COLUMBIA BASIN

Compensation Option	Chapter Source (Table 1)	Range of Potential Benefits										Comments/ Examples
		Primary Product'n		Aquatic Habitat		Terrestrial Habitat		Species (incl. spp. @ risk)			Frag-men-tation	
		Aquatic	Terrest.	Lakes	Stream	Wetlnd/fldpln	Upland	Fish Species	Wetlnd/fldpln	Upland		
Species Specific												
Inventory/ Monitoring/ Research	4B, 4A3, 4A6			**3P**	**3P**	**3P**	**3P**	**3P**	**3P**	**3P**	**3P**	
Pred/prey manipulation	4A1, 4A2, 4A4, 4A5, 4B							**1P**	**3P**	**1P**		kokanee/trout, mysids; caribou, wolves, ungulates
Alternate spp. enhancement	4A4							**1**				Fluvial cutthroat/ rainbow trout tradeoff; off-site
Artificial Production												
Spawning channel	4A2,4A4				**1P**			**1**	**3P**			
Hatchery	4A1, 4A4							**1**				Sturgeon, rainbow trout in small lakes
Captive rearing	4B							**3P**	**1P**	**3P**		Leopard frogs
Re-introduction	4A2, 4B							**2P**	**1P**	**1P**		Kokanee eggs, caribou
Nest boxes	3B								**1**	**1**		

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Appendix 1

Definition of Footprint Impacts

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

1. Construction impacts (e.g. sediment, water quality) temporary events associated with building and construction.

2. Habitat loss from facilities or structures (e.g. habitat inundation by reservoir): includes loss of riparian area for LWD recruitment and permanent lotic - lentic habitat change and impact.

3. Permanent loss of upland and riparian terrestrial habitats within the full pool footprint and their associated impacts on biodiversity.

4. Fragmentation and loss of habitat connectivity at landscape scale.

5. Changes in the amount and spatial extent of aquatic-terrestrial species interactions due to loss of seasonal habitats, shifts in primary productivity or habitat fragmentation.

6. Nutrient or contaminant effects (e.g. trapping, downstream release, methylation) related to flows released from the reservoir.

7. Water quality in reservoir (e.g. temperature, TGP, DO) related to water quality within the water column of the reservoir.

8. Erosion, sediment transport, erosion and morphological change due to reservoir could include effects of interception of bed load and increased earth slides and instabilities caused by reservoir drawdowns.

9. Impacts to fish movement and migration often due to structures like dams or barriers exposed during reservoir drawdown.

10. Fish entrainment and loss of fish includes loss of fish from reservoir populations with the inability to return to natal areas resulting in a loss of fishing potential or damage to the population numbers, dynamics, etc.

11. Ice regime impacts due to reservoir and effects on tributary systems and ice effects within the reservoir or due to the thermal action of the stored water.

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

Appendix 2

NPP/GPP Ratios

Based on a web search, review of relevant literature and professional judgement, the following NPP/GPP ratios were assigned to each of the terrestrial ecosystem types to convert NPP to GPP for comparison with aquatic ecosystems.

Ecosystem	Ratio
Avalanche/Rock/Talus/Soil	0.55
Grassland/Shrub Steppe	0.5
Dry Forest	0.35
Mesic Forest	0.4
Wet Forest	0.45
Very Wet Forest	0.45
Forested Wetland	0.5
Non-Forested Wetland	0.5
Gravel Bar	0.5
Agriculture/Urban	0.55
Drawdown Vegetation	0.5

Example References

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