Terrestrial Productivity
in the
Flooded Terrestrial Ecosystems of the Columbia Basin: Impacts, Mitigation and Monitoring

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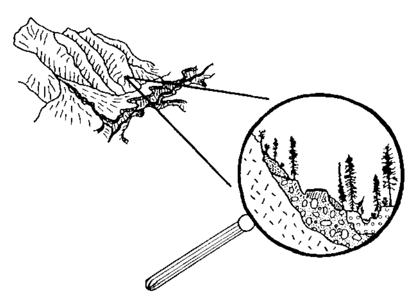

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Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION AND BACKGROUND

A suite of different terrestrial ecosystem impacts are associated with the construction of the BC Hydro dams on the Columbia/ Kootenay River system. From an ecological perspective, these include loss of habitat and/or ecosystems, loss of connectivity between remaining ecosystems, loss of associated wildlife populations and loss of the associated productivity relating to those ecosystems. The Fish and Wildlife Compensation Program (FWCP) is conducting a multi-phase project to evaluate the footprint impacts of BC Hydro developments within the Columbia Basin by determining the extent of habitat, primary productivity, and fish and wildlife community changes that result from dam construction. The footprint impacts project will provide a baseline understanding of the amount, location and significance of ecosystem impacts of dam footprints in the Columbia Basin, as well as assist FWCP to develop, prioritize and monitor compensation projects.

Phase 1, collection and compilation of existing data, was completed in 2004. Pre-impoundment habitat mapping (Phase 2) has also been completed using air photos and base maps circa 1940 (Ketcheson et al. 2005). Phase 3 reports include an approach for deriving terrestrial primary productivity losses (MacKillop and Utzig 2005), an assessment of aquatic/ wetland primary productivity impacts (Moody et al. 2007) and analysis of terrestrial habitat losses (MacKillop 2008, in progress).

This document reports on the overall losses in terrestrial primary productivity resulting from dam construction and associated flooding. This report has three main objectives:

- identifying the terrestrial ecosystem productivity impacts associated with inundation,
- identifying potential mitigation options, relating to terrestrial productivity losses, and
- identifying a monitoring framework to assess effectiveness of these options.

Why are terrestrial productivity losses significant?

Productivity lost during inundation of ecosystems is an important variable to quantify because primary productivity is the fundamental process. This ‘energy cycle’ - capturing energy from the sun and turning it to biomass is the basis for all other processes. However, productivity losses per se are often overlooked when quantifying impacts of activities. Quantification of this primary process is therefore an important aspect of understanding the effects of the dams on terrestrial ecosystems.

Ecosystems in general differ in terms of their average productivity per unit area. On a global scale, average ecosystem productivity from highest to lowest is: estuaries, swamps/ marshes, tropical rainforest, temperate forest, taiga, savanna, agricultural land, woodland, temperate grassland, lakes/streams, continental shelf, tundra, open ocean, desert scrub, extreme desert (Pidwirny 2007). The ecosystems under consideration here – temperate rainforests to temperate grasslands – have relatively high productivity levels, so losses within these ecosystems can be significant.

In addition, productivity itself reflects a number of different indicators of concern including:

- **Biodiversity:** Within a particular type of ecosystem (e.g., within forests or grasslands) higher productivity ecosystems tend to have higher biodiversity values (Hansen et al. 2000). This is likely directly linked to the availability of energy produced by primary producers and made available for consumers. This relationship between productivity and species richness has been hypothesised for many years, and has now been demonstrated in a number of ecosystems (van Rensburg et al. 2002).
- **Carbon storage:** Productivity and carbon sequestration are linked. Mitigation of carbon releases is especially relevant in the face of a rapidly changing global climate primarily caused by accelerated accumulation of carbon in the atmosphere (e.g., Kurtz et al. 2002).

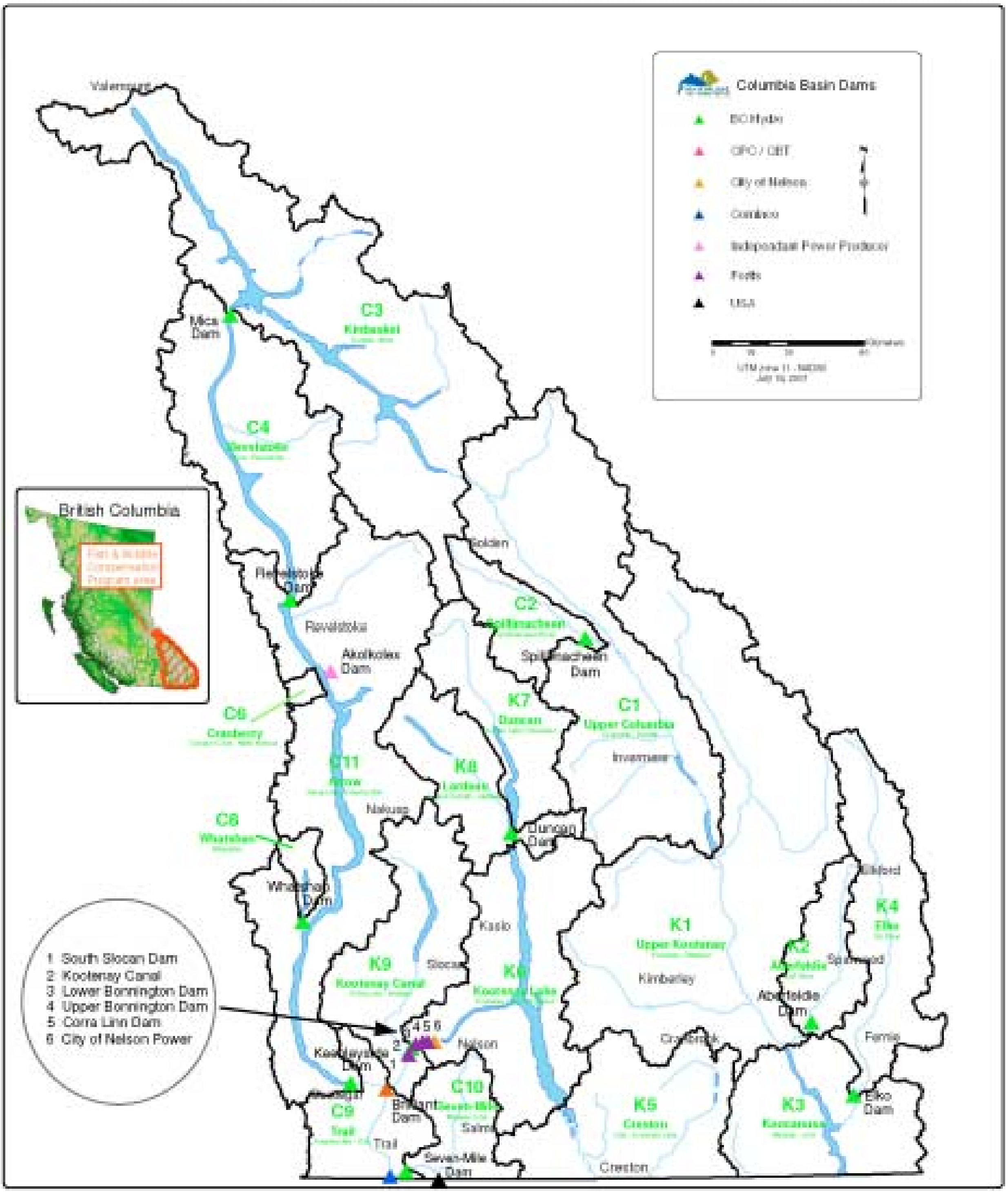

Figure 1.1. Dams, reservoirs and dam units for the BC Hydro dams on the Kootenay/ Columbia River system.

Depending on the specific rationale for mitigation, different aspects of productivity may be appropriate to maximise and measure. In this report, we will focus on the importance of productivity as a fundamental process of ecosystems, but refer to other values where relevant.

What is Productivity?

Primary productivity is the production of organic compounds resulting predominantly from photosynthesis[1] (e.g., Peng and Apps 1999). Terrestrially this relates to plant growth, whereas aquatically the predominant primary producer is algae. This report deals only with terrestrial productivity changes resulting from dam construction, and another report deals with aquatic/ wetland productivity (Moody et al. 2007). The following paragraphs provide a brief summary of the main concepts related to primary productivity. For a more in-depth discussion of terrestrial primary productivity, see a previous report on the approach used to determine primary productivity measures for each impacted terrestrial ecosystem (MacKillop and Utzig 2005).

Primary productivity can be measured or estimated in a number of different ways. The most direct approach is to measure gross, or net production. Gross primary productivity (GPP) is the total amount of energy fixed by primary producers in a given area or ecosystem over a given period of time. This gross production does not consider the losses of production that result from internal activities such as cellular respiration within the plant. Net primary productivity (NPP) is gross production minus losses to respiration, and as a result is more complex to measure. Net primary productivity (NPP) is therefore a better measure of the rate at which new biomass accrues in an ecosystem. Both GPP and NPP are measured in units of mass/ area/ time (typically kg/m2/year or tons/ha/yr). Note that this measure focuses only on accumulation during a year, and does not reflect overall storage of carbon with an ecosystem.

Net Ecosystem Productivity (NEP) is a measure of overall carbon uptake or release for the ecosystems as a whole, minus losses to respiration at multiple scales. It differs from NPP by including a measure of heterotrophic respiration (mostly bacterial), and also includes overall losses due to decomposition and disturbance (e.g., combustion). It is therefore a more full accounting of the total carbon cycle, and can reflect whether the ecosystem as a whole is a sink or a source for carbon. Ecosystems may be an overall carbon source if disturbance (e.g., fires) create more release of carbon than is otherwise sequestered.

Carbon pools also reflect net primary productivity for the ecosystem as a whole, but usually reflect accumulation over a longer period than a single year. Ecosystems or groups of ecosystems are often classified according to their capacity to accumulate or release carbon. Carbon pools reflect the biomass[2] in a system and can be used to reflect whether the site is a carbon sink (sequestering carbon overall), or carbon source (releasing carbon overall). Carbon pools are typically classified into various types, for example living biomass, dead biomass, soils, coarse woody debris and litter.

A number of surrogates for productivity are also used. In forest applications, these often include site index[3] and the rate of mean annual increment[4].

[1] Or much less commonly chemosynthesis.
[2] Total mass of living organisms in an area (above and below ground).
[3] Based on average height of dominant and codominant trees at age 50.
[4] Average increase in volume / year, of a tree or more commonly a stand of trees (m3/ha/yr).

2.0 ESTIMATED TERRESTRIAL NET PRIMARY PRODUCTIVITY (NPP) CHANGES

2.1 Background

Based on ecosystem mapping by Ketcheson et al. (2005) and productivity estimates in MacKillop and Utzig (2005), estimated Net Primary Productivity (NPP) was calculated for terrestrial ecosystems for each reservoir flood zone. For transitional wetland and floodplain ecosystems that were assigned wetland NPP values in the wetland productivity report (Moody et al. 2007, see pages 64-72 and 87-92), the total estimated NPP values for those ecosystems were partitioned into wetland and terrestrial components, and only the terrestrial component is included in this report (i.e. generally tree productivity *vs.* understory and litterfall that constribute to wetland/aquatic productivity via annual flooding transfers).

As forests grow following a disturbance, NPP changes over time. Therefore the seral stage, structural stage or age of a forest will affect the NPP value for a particular forest. In general, NPP is very low at early seral stages and rapidly increases to a maximum at maturity (culmination age) and then declines slightly to a generally stable level at old seral stages (see MacKillop and Utzig 2005 for a more detailed discussion). Because the dam footprint ecosystem mapping represents only one point in time we have provided three scenarios of NPP:

- **Mapped NPP**: an estimate of NPP for the structural stages present shortly prior to flooding (i.e. at the time of aerial photographs used for ecosystem mapping)
- **Long-term Average NPP**: an approximation of the long-term average NPP based on the estimated average structural stage distribution that would be associated with an estimated mean for the range of natural variability (RONV, i.e. assuming “natural” disturbance regimes)
- **Maximum NPP**: an estimate of the maximum potential NPP, based on assigning each site the structural stage (or stand age) where annual NPP is maximized

2.2 Methods

Building on earlier phases of the overall footprint impacts project, and other components of this phase, this component has included two groups of activities:

- clearly distinguishing terrestrial ecosystems from aquatic and wetland ecosystems – to prevent double-counting between this and other productivity reports, and
- estimating NPP for each terrestrial ecosystem, using three scenarios.

2.2.1 Definition of Terrestrial, Aquatic and Wetland Ecosystems

To ensure that there was no overlap and potential double-counting of primary production between aquatic, wetland and terrestrial ecosystems, it was first necessary to establish what was accounted for in each realm.

Lakes and larger rivers were designated and identified as individual polygons in the mapping database, and therefore were clearly accounted for in the aquatic/wetland productivity report (Moody et al. 2007). Streams, being mapped as single-line features, were not assigned an area in the mapping database. The aquatic report assigned the single-line stream features channel widths based on regression equations applied to accumulated upstream length, and then summed the resulting areas to determine total stream area for each reservoir (Moody et al. 2007 pp.61 and 86). This area was deducted from terrestrial ecosystems that were mapped as "Wet and Mesic Forest" in the GIS database[5].

Although they generally occurred within the river channels, areas mapped as gravel bars were not accounted for in the aquatic/wetland productivity assessment, and were therefore included here as a part of the terrestrial assessment.

Throughout the footprint assessment, wetlands have been defined according to various classification systems depending on the objectives of the authors (Ketcheson et al. 2005, MacKillop 2008, in progress, Moody et al. 2007). To ensure seamless coverage between the aquatic/wetland productivity measurements and the terrestrial analysis, this report has adopted the classification system utilized in the aquatic/wetland report (Moody et al. 2007). The aquatic/wetland report has opted for a functional definition of wetlands that includes both wetlands *per se*, and forested riparian floodplains that periodically supply nutrients to aquatic/wetland systems during flood events (Moody et al. 2007 pp.87-92). Using structural stage criteria (structural stage <4 and $\geq$4), the wetland/riparian ecosystem mapping units were divided into what they called forested and non-forested[6] wetland areas (see Moody et al. 2007, Table 21, p.90). The aquatic/wetland report assigned average primary productivity contributions to each of these classes[7]: 2.1 t/ha/yr C for wetlands and 1.4 t/ha/yr C for forested-wetland understory and litter.

In this report, terrestrial NPP was estimated for all terrestrial ecosystems, including riparian floodplain ecosystems and some wetland ecosystems that were forested or potentially forested. For wetland ecosystems and riparian floodplain ecosystems for which Moody et al. (2007) had calculated a wetland NPP contribution, their NPP values were subtracted from the estimated total terrestrial values to ensure there was no double-counting of NPP. Where the NPP values provided for wetland contributions exceed the terrestrial estimates, the areas are considered wetlands, where the terrestrial NPP estimate exceed the wetland estimates, the areas are classed as floodplain ecosystems – areas contributing to wetland productivity and terrestrial productivity.

The area of overlapping floodplain ecosystems varies depending on the terrestrial NPP calculation scenario (i.e. mapped NPP, estimated long-term average, and maximum NPP – see following sections). The area of overlap is greatest under the maximum NPP scenario, as the estimated total NPP for sites is more likely to exceed the calculated wetland portion of NPP. The differences in area of overlap for the mapped and estimated long-term average scenarios varies depending on how close a given reservoir was to RONV at the time of the aerial photography used for mapping, and how close the estimated long-term average NPP is to the maximum NPP.

2.2.2 Mapped NPP

Using the estimated NPP values for each structural stage for each terrestrial ecosystem from MacKillop and Utzig (2005), estimated NPP was assigned to each decile portion of each map polygon based on their mapped site series and structural stage. Minor adjustments included the addition of NPP values for Grassland and Shrub steppe ecosystem groups that were 2.0 and 2.5 tons of C/ha/yr respectively. These values were then multiplied by the appropriate area, and summarized by ecosystem group and reservoir.

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[5] Some of the streams certainly occur in the floodplain ecosystems, but deducting the areas from the floodplain ecosystems would require revising the areas and productivity values in the aquatic/wetland report. Given their relatively small aggregate area, for simplicity all streams were deducted from terretrial map area.
6 This correctly classifies shrub and herb dominated wetlands, but may also misclassify some forest ecosystems that were only temporarily in a non-forested state due to recent disturbance (e.g., early seral stages that resulted from logging, bank-erosion or fire).
[7] As recommended by Moody et al. (2007), dry matter biomass measurements were converted to Carbon using a factor of 47.5%.

2.2.3 Long-term Average NPP

Generalized ecosystem groups defined for each BEC unit within the reservoir footprint (MacKillop 2008, in progress) were assigned to two types of disturbance regimes: those with periodic stand-replacing disturbances (generally closed forests with periodic high intensity disturbances), and those with relatively constant vegetation conditions (generally disclimax types – e.g. snow avalanche tracks, rock outcrops, low intensity high frequency fire climaxes).

Based on a review of applicable literature (e.g., Wong et al. 2003, Pollack et al. 1997) and expert opinion, return intervals for stand-replacing disturbances were estimated for each BEC unit/ ecosystem group combination in the first type. By applying the exponential equation to these estimated return intervals, average percentage distributions for the various structural stages were calculated for each BEC unit/ ecosystem type combination (see Appendix for individual return intervals and structural stage distributions). These estimated structural stage distributions were then assigned to each applicable decile portion of each map polygon. The estimated NPP values for each structural stage of each ecosystem group from MacKillop and Utzig (2005) were then used to calculate the average long-term NPP that would be associated with a natural disturbance regime (i.e. RONV) for each decile portion of each mapping polygon. Total NPP for each map unit was then calculated by multiplying by the appropriate area.

Ecosystem groups with relatively constant structural stages (i.e. where stand-replacing disturbances were not a factor), were assigned a single value of estimated NPP based on those reported in MacKillop and Utzig (2005). Minor adjustments included the addition of NPP values for Grassland and Shrub steppe ecosystem groups that were 2.0 and 2.5 tons of C/ha/yr respectively. Agriculture and urban ecosystem groups were assumed to be equivalent to Mesic Forest groups within applicable BEC units for the RONV calculations. The results of these calculations were then summarized by ecosystem group and reservoir.

2.2.4 Maximum NPP

Maximum NPP was calculated by assigning the appropriate estimated maximum NPP value from MacKillop and Utzig (2005) to each site series decile portion of each map polygon and multiplying by the appropriate area. Minor adjustments included the addition of NPP values for Grassland and Shrub steppe ecosystem groups that were 2.0 and 2.5 tons of C/ha/yr respectively. The results of these calculations were then summarized by ecosystem group and reservoir.

2.3 Results

2.3.1 Classification and Correlation of Terrestrial, Aquatic and Wetland Ecosystems

As discussed in the methods section, use of differing wetland classifications by various phases of the project has led to the need to correlate the various systems. Table 2.1 and Figure 2.1 provide a summary of the distribution of the various ecosystem classes employed for reporting on NPP. The areas are based on the long-term average NPP scenario. The areas for lakes, rivers, shallow ponds and gravel bars are common to all of the studies and scenarios. The remaining areas have been calculated based on the methods outlined above. Wetlands and floodplains combined in Table 2.1 and Figure 2.1 are equivalent to the combined forested and non-forested wetlands in the aquatic/wetland report (Moody et al. 2007). Similar tables and figures for the maximum NPP scenario can be found in Appendix 2.

Table 2.1. Area (ha) of various aquatic and terrestrial ecosystems by reservoir. Data from ecosystem mapping (Ketcheson et al. 2005 and the aquatic/ wetland report (Moody et al. 2007) and findings of this report (long-term average NPP scenario).

	Arrow C11	Revelstoke C4	Kinbasket C3	Duncan K7	Koocanusa K3	Seven-Mile C10	Whatshan C8	Kootenay Canal K9	Spillimacheen C2	Total
Lakes	34,992.3	0.0	2,343.0	2,583.9	0.0	0.0	1,528.9	0.0	0.0	**41,448.1**
Rivers	2,021.9	2,654.4	4,896.6	424.5	1,490.1	179.0	14.6	0.0	0.3	**11,681.5**
Streams	50.6	53.4	192.1	17.7	10.3	1.5	0.5	0.0	0.0	**326.1**
Shallow ponds	102.9	26.9	555.1	172.3	210.6	0.0	4.9	0.0	0.0	**1,072.7**
Gravel Bars	3,262.8	56.9	235.6	22.0	80.4	0.4	0.0	0.0	0.0	**3,658.1**
Wetlands	3,431.5	456.0	5,862.6	1,824.5	1,071.9	1.8	1.5	0.9	0.0	**12,650.8**
Floodplains (overlap)	3,563.5	4,004.7	15,526.5	1,396.6	2,173.1	6.0	14.5	0.7	0.0	**26,685.6**
Terrestrial	3,844.3	4,199.1	13,035.7	860.0	1,646.8	241.7	204.6	47.1	0.7	**24,080.1**
Total	**51,269.9**	**11,451.4**	**42,647.3**	**7,301.4**	**6,683.2**	**430.5**	**1,769.6**	**48.7**	**1.1**	**121,602.9**

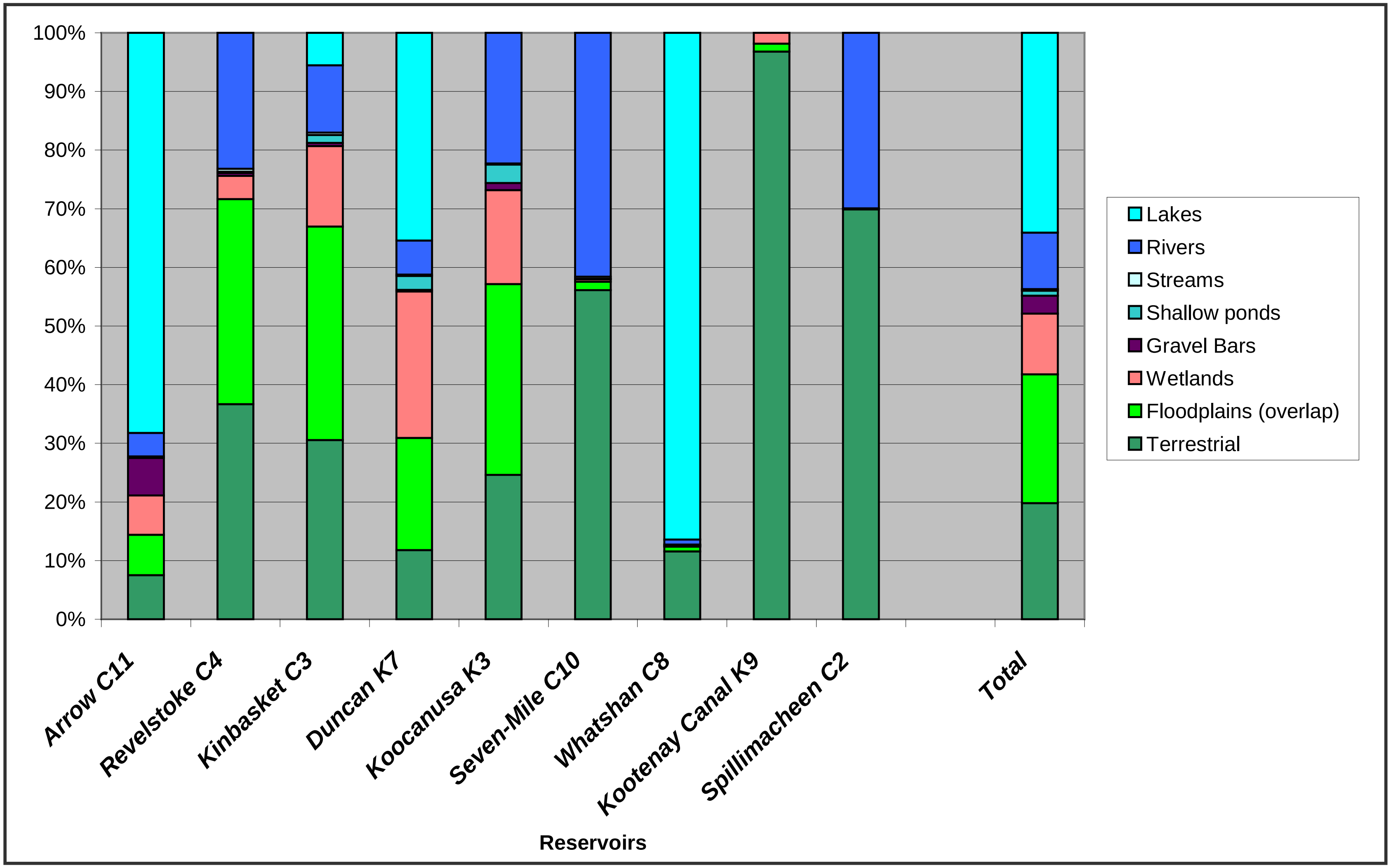

Figure 2.1. Percentages of various aquatic and terrestrial ecosystems by reservoir. Data from ecosystem mapping (Ketcheson et al. 2005 and aquatic/ wetland report (Moody et al. 2007) and findings of this report (long-term average NPP scenario).

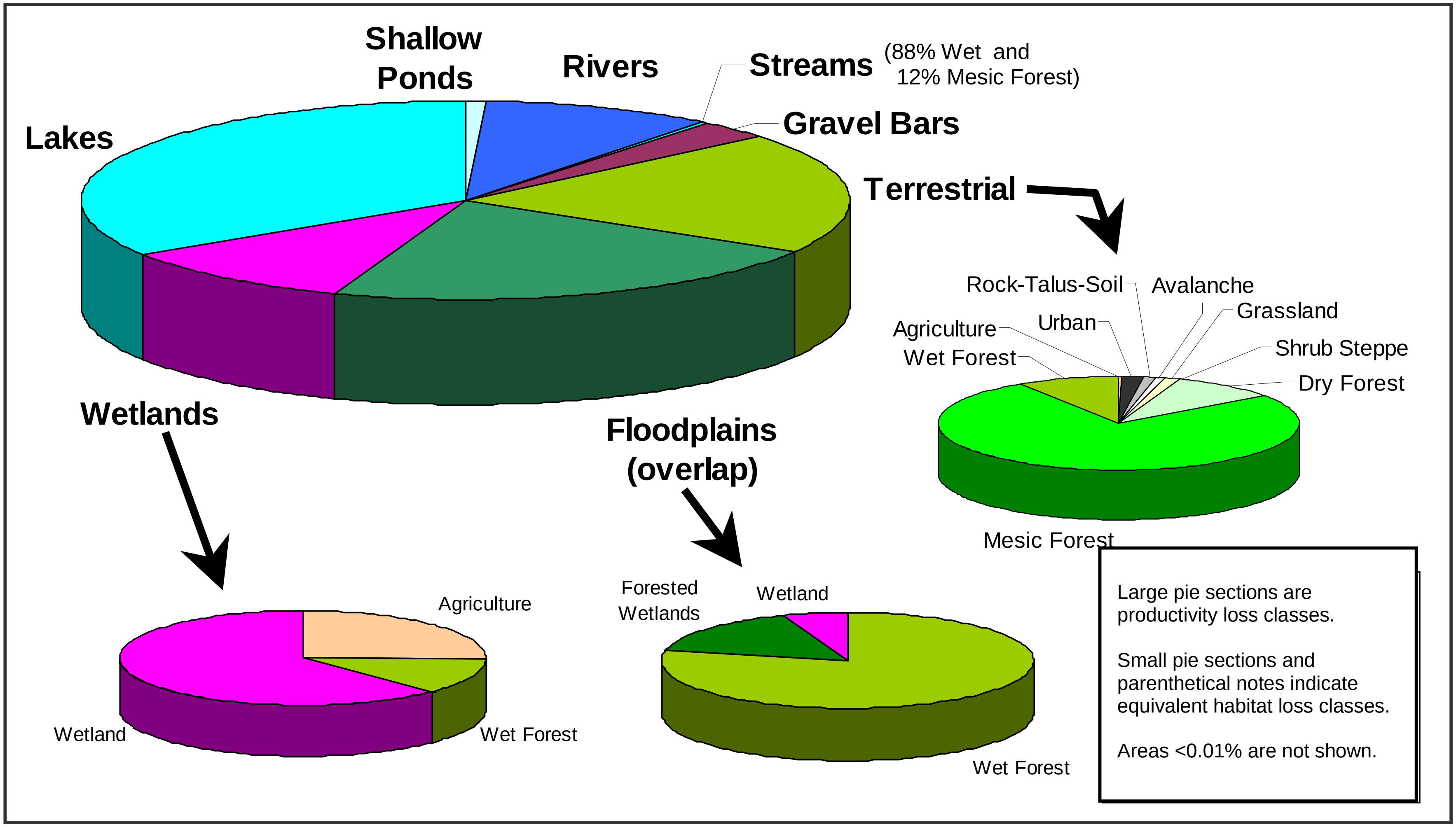

Figure 2.2. Distribution of terrestrial ecosystem groups described in the habitat loss report (MacKillop 2008) in relation to the productivity classes described in the aquatic/wetland report (Moody et al. 2007) and this report (long-term average NPP scenario). Total area is 121,603 ha (see Table 2.1 and Appendix 2 for a more detailed breakdown.

Correlation between the aquatic/wetland report, this report and the habitat loss report (MacKillop 2008) adds a further layer of complexity. Figure 2.2 provides a summary of the ecosystems groups by productivity class for the long-term average scenario. A more detailed correlation between the aquatic/ wetland report areas, the Canadian Wetland classification, the terrestrial classes used in this report and the ecosystem groups of the habitat loss report can be found in Appendix 2.

2.3.2 Terrestrial NPP

The results of the long-term average scenario NPP calculations are presented in Table 2.2 and Figure 2.3. Figure 2.4 provides a summary comparison for all three scenarios. Results for the mapped and maximum scenarios can be found in Appendix 3.

The total losses for all reservoirs combined are just over 300,000 tons of C/yr of NPP. Over half the total is located in the Mica Reservoir, with the High Revelstoke and the Keenlyside dams accounting the most of the additional losses. As indicated in the tables and figures, the terrestrial NPP losses due to inundation are generally proportional to area flooded. However, there is a clear trend of increased losses where the more productive wet and very wet forests are concentrated (mainly under the Mica and Revelstoke Reservoirs).

As indicated in Figure 2.4, the Maximum NPP scenario shows a substantial increase in NPP values over both the Long-term average RONV and Mapped scenarios. The similarity in values for the Mapped and Long-term average scenarios for most of the reservoirs is a reflection of limited human disturbance in the areas flooded, and the fact that natural disturbance was still generally the dominant force in those areas up until the time of the airphotos used for mapping (mainly early 1960s). Koocanusa reservoir has generally lower values for the Mapped scenario, likely as a result of forest harvesting and clearing of riparian areas for agriculture in that area at the time of flooding.

Further details on these results can be found in the Excel spreadsheets that accompany this report (see Appendix 4).

2.4 Discussion

2.4.1 The Aquatic-Wetland-Floodplain-Terrestrial Interface

As described in Section 2.2.1, estimates of wetland and floodplain productivity were compartmentalized to ensure no double-counting occurred. However, there are additional factors that contribute to uncertainty in the aquatic, wetland, floodplain and terrestrial classes utilized for calculation of NPP values. These are highlighted below:

- classification of aquatic, wetland and terrestrial ecosystems: neither the Canadian Wetland Classification, nor the functional wetland classification utilized by Moody et al. 2007 are well-suited to airphoto mapping without ground-verification; neither system has documented productivity measurements for each classification unit; their homogeneity with respect to productivity is unknown, and likely poor;
- the TEM mapping format severely limited the mapper’s ability to properly document ecosystems with complex structure, especially those represented by open stands with interspersed shrub communities, herb communities and open water – such as commonly occurred in floodplains in this study;
- the BEC classification used for the ecosystem mapping was primarily developed for terrestrial ecosystems, and at the time of mapping, did not have well-developed ecosystem units for many wetland and floodplain ecosystems;

Table 2.2. Terrestrial NPP (tC/yr) by ecosystem group and reservoir. Ecosystem mapping data from Ketcheson et al. 2005 and productivity data from MacKillop and Utzig 2005. These values are based on the long-term average scenario.

	Arrow C11	Revelstoke C4	Kinbasket C3	Duncan K7	Koocanusa K3	Seven-Mile C10	Whatshan C8	Kootenay Canal K9	Spillimacheen C2	Total
Urban	286.4	50.4	278.0	2.7	26.0	15.7	0.9	13.6	0.0	673.7
Agriculture	217.8	0.0	0.0	16.3	0.0	0.0	0.0	0.0	0.0	234.0
Rock-Talus-Soil	5.9	50.1	19.4	1.4	3.2	3.1	0.2	0.0	0.0	83.4
Avalanche	0.0	4.2	272.2	3.7	0.0	0.0	0.0	0.0	0.0	280.1
Grassland	1.7	0.0	0.0	0.0	705.9	0.0	0.0	0.0	0.0	707.6
Shrub Steppe	0.0	0.0	0.0		17.4	0.0	0.0	0.0	0.0	17.4
Dry Forest	4,235.1	1,893.7	3,932.0	2,522.5	204.5	361.1	383.7	79.4	0.0	13,612.0
Mesic Forest	12,389.7	26,006.5	77,045.3	1,961.5	5,559.1	772.3	634.5	162.1	3.8	124,534.7
Wet Forest	16,185.2	20,926.6	89,640.5	5,804.4	8,063.4	69.2	367.1	3.5	0.0	141,059.9
Very Wet Forest	12,464.3	2,866.8	4,060.5	2,507.8	3,155.3	0.0	0.0	0.0	0.0	2,5054.7
Total	45,786.0	51,798.2	175,248.0	12,820.3	17,734.7	1,221.4	1,386.5	258.7	3.8	306,257.6

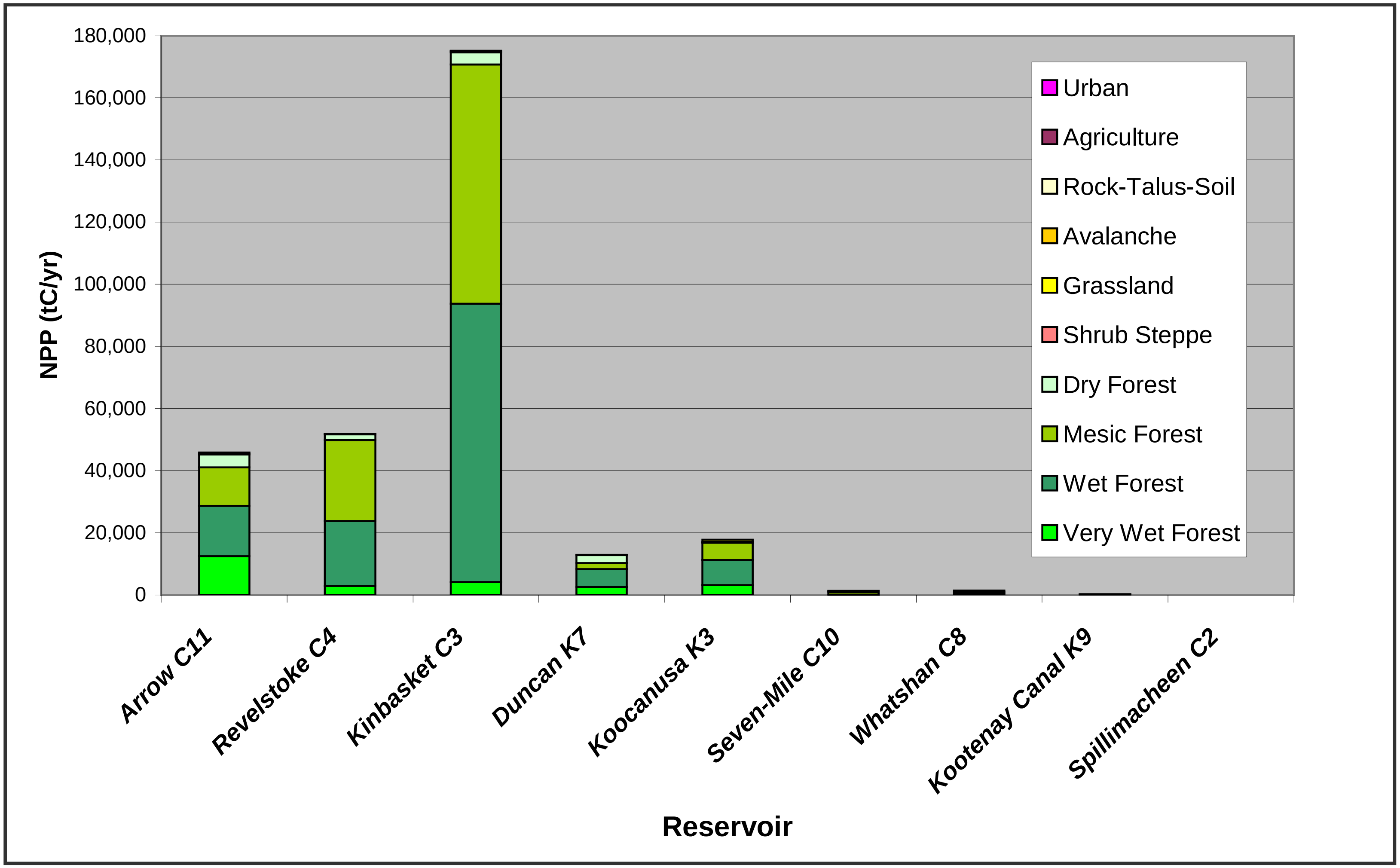

Figure 2.3. Terrestrial NPP (tC/yr) by ecosystem group and reservoir. Ecosystem mapping data from Ketcheson et al. 2005 and productivity data from MacKillop and Utzig 2005. The values are based on the long-term average scenario.

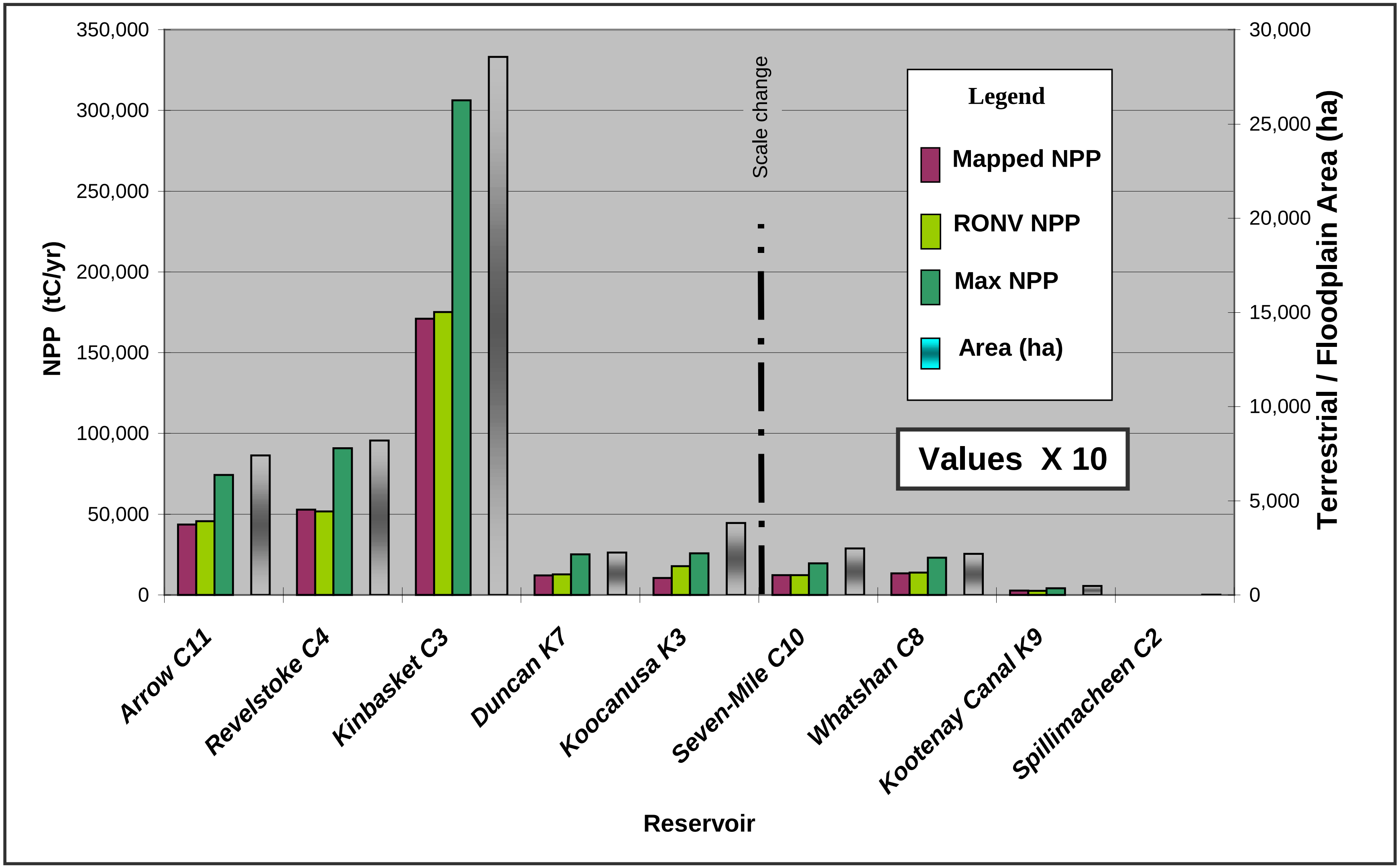

Figure 2.4. Terrestrial NPP by reservoir and scenario. The NPP and area values include terrestrial contributions to NPP from floodplain and terrestrial productivity classes. Note that NPP is on the left axis and area on the right axis, and that the values to the right of the dashed/dotted line are increased by a factor of ten to make them more visible.

- map unit and boundary identification for wetland, floodplain and terrestrial ecosystems – poor quality airphoto coverage, lack of field verification;
- difficulty discriminating between structural stages that were the result of natural ecosystem processes such as high water tables and flooding, and those that were the result partial harvesting or other human-caused disturbance; and,
- uncertainty in estimating all productivity values, but especially the gross generalization of assigning a single productivity value to all wetlands and inputs from floodplain ecosystems.

While these factors likely contribute to uncertainty in productivity values attached to individual map polygons, it is assumed that they are likely balanced out over the expanse of a whole reservoir or groups of reservoirs. However, this remains an untested hypothesis.

2.4.2 Additional Wetland Considerations

The aquatic/wetland report (Moody et al. 2007) does not account for Gravel Bars (GB and GB-Df) in their calculations of Wetland NPP. This likely should be accounted for as an addition to their category of “non-forested floodplain”. Note that the aquatic/wetland report includes GB/ Df (but neglects GB/ non-Df) in their initial calculations of wetland area in Table 19, but does not include any gravel bars in Tables 21 and 22 where they calculate NPP. The area of gravel bars is shown in Table 2.1. Based on an estimated NPP of 0.14 tC/ha/yr, Table 2.3 provides the estimated NPP by reservoir.

The aquatic/wetland report (Moody et al. 2007, p 89) discusses the presence of Ponds and Shallow Water (PD,OW,Ws), but also fails to include them in their calculations of aquatic or wetland NPP. An option would be to account for these as an additional category on its own, similar to small streams. The areas for Shallow Water are provided in Table 2.1. Based on information provided by the aquatic/wetland report (Moody et al. 2007, p 89), and an assumption that few of these were ephemeral, one could assign an average productivity value similar to that of Bush Lakes, and note that the number has a low level of reliability. Table 10 of the aquatic/wetland report indicates that Bush Lakes has an estimated total annual productivity (pelagic+littoral+macrophyte) of 83 tC/yr over 300.1 ha of lake. Applying a similar productivity rate to the Shallow Water would indicate a productivity of 0.277 tC/ha/yr (note this is GPP and not NPP). Table 2.3 provides results by reservoir.

Table 2.3. Estimated productivity for gravel bars and shallow ponds. The gravel bars are tC/yr NPP and the shallow ponds are tC/yr GPP. Calculations are explained in the text.

	Arrow C11	Revelstoke C4	Kinbas-ket C3	Duncan K7	Koocanusa K3	Seven-Mile C10	Whatshan C8	Kootenay Canal K9	Spillima-cheen C2	Total
Gravel Bar	449.6	7.8	32.5	3.0	11.1	0.1	0.0	0.0	0.0	504.1
Shallow ponds	28.5	7.4	153.8	47.7	58.3	0.0	1.4	0.0	0.0	297.1

3.0 MITIGATION OPTIONS

Loss of productivity in ecosystems affected by hydroelectric power generation is a concern from a full-cost accounting perspective, as it reduces the 'green' value of such development. Loss of terrestrial processes in itself is a concern as outlined in Section 1. In addition, there are associated habitat and biodiversity losses associated with that productivity. From a global climate change perspective, loss of ecosystems that resulted in release of carbon into the atmosphere or loss of the ability to sequester and store carbon both add to the causes of climate change. This project is however, focusing on productivity mitigation – although with the understanding that productivity mitigation potentially has concomitant benefits regarding carbon sequestration and habitat losses as well.

A series of potential mitigation activities have been developed, and many provide mitigation benefits for habitat losses and carbon sequestration as well as productivity losses. The potential activities and various factors associated with each activity are presented in Table 3.1.

Mitigation options can potentially occur in two locations: within the reservoir footprint, or outside the footprint. Fixed location, land-based terrestrial productivity mitigation projects within the reservoir footprint are generally going to require infilling of the reservoir, dyking and/ or reducing the maximum flood level. These types of within-footprint mitigation options will likely involve tradeoffs with reservoir management for downstream flood control, and possibly electrical generation timing. There may be some limited options for ecosystem restoration/ reclamation in seasonally flooded areas, and these have been described in the aquatic/ wetland report (see Moody et al 2007, p. 137). Planting of tree species with a high tolerance for flooding (e.g., cottonwood) may be feasible in some areas, but this would likely entail limiting seasons and duration of maximum flood levels, especially in high water years (making this option likely to have trade-offs with downstream flood control).

Another option for within-footprint option would be the use of floating island structures on the surface of the reservoir. This technology has been utilized successfully for centuries in various parts of the world in both marine and freshwater locations (e.g., Van Duzer 2004, Nakamura et al. 1997, Sasser et al. 2007). Examples of commercial sources for installation of floating wetland structures can be found at http://www.water-lines.co.uk/index.php?section=252&page=1878 and http://www.floatingislandinternational.com/ . Use of floating structures has the advantage of minimizing the displacement of reservoir storage volume, increasing the amount of area available and increasing the potential locations available, as well as having a large net increase in terrestrial productivity. Flexibility in design and location of the floating ecosystems also allows for maximization of habitat values by allowing for greater control over species composition connectivity/ isolation factors. Larger fully terrestrial forested ecosystems would require increased flotation and structural components than floating wetlands, and likely increased costs. However, there are also possibilities of utilizing decommissioned barges, wharves, and other re-usable flotation materials.

Terrestrial productivity mitigation options outside the reservoir footprint will only have a significant net benefit when they are applied to lands that have inherently low productivity, or lands that have had their inherent productivity severely reduced by past disturbance. Enhancement of productivity on naturally low productivity lands will require significant inputs such as soil amendments, fertilization and/or irrigation. In some cases, fertilization and/or irrigation may be required indefinitely, entailing long-term costs. This would generally require conversion of grassland or shrub lands into forests, which may have undesirable costs from a habitat perspective. The availability of lands with very low inherent productivity is limited within a reasonable distance from the reservoir.

Table 3.1. Terrestrial productivity mitigation options, and various considerations regarding each option.

General Compensation Actions	Compensation Activities and location	Specific activities	Potential productivity considerations	Success and uncertainty considerations	Overall potential benefits
1. Historic Ecosystem Restoration – outside reservoir footprint	Restore historic ecosystem, with goal of creating a successional pathway through to climax forest type. On cleared land – clearings, early successional forest or agricultural land.	Replant with species appropriate for the former ecosystem. Future management to speed up regrowth, potentially including fertilization, spacing and manual pruning.	Gains will vary by ecosystem potential (see table of potential productivity – Utzig and MacKillop 2005).	Long timeframe. Unknown ability to restore full ecosystem complement. Consider which elements can be restored with most chance of success.	High potential for complementary gains for habitat, wildlife and productivity. Consider full-cost accounting in relation to fertilizer use and other treatments
2. Alternative 'ecosystem' creation - outside reservoir footprint	Replant with species that maximize rate and potential maximum carbon storage. On cleared land – clearings, early successional forest or agricultural land.	Plant grass, shrubs, deciduous trees, wetland species to maximize short-term productivity gains. May or may not include fertilization and other treatments.	Gains will vary by specific elements planted and the level of productivity existing prior to replanting. May, or may not, be higher than historic ecosystem condition	Shorter timeframe for endpoint. Relatively known success for specific plants (e.g. willow) in certain settings.	Likely limited overlap of gains for other values.
3. Habitat element restoration	Specific element restoration	Mowing/ Shrub slashing/ Forest thinning / Wildlife tree creation / CWD restoration	Few obvious productivity gains	Variable uncertainty, depending on the element under consideration.	Potentially high habitat benefits, where specific habitat deficits are known to occur.
4. Ecosystem creation – terrestrial reclamation within reservoir footprint	Creating ecosystems that are similar to historic ecosystems within the drawdown zone.	Potentially requires dyking and/or adjustments to water level management to create land suitable for terrestrial growth. Plant with riparian associated species. May require provision of alternative water inflows in some situations.	Relatively large potential gains, because current zero or minimal terrestrial productivity on these sites.	Uncertainty in success. Little or no known use of this reclamation procedure in similar ecosystems. Potential difficulties in understanding long-term hydrologic regimes. Could attempt small-scale research trial to gain know-ledge, before attempting large-scale project.	High potential complementary gains for habitat, wildlife and productivity.

General Compensation Actions	Compensation Activities and location	Specific activities	Potential productivity considerations	Success and uncertainty considerations	Overall potential benefits
5. Ecosystem creation – terrestrial ecosystems on floating islands within reservoir footprint	Creating terrestrial ecosystems similar to historic ecosystems on floating islands on the reservoir	Construction of artificial floating islands upon which terrestrial ecosystems would be established	Large potential gains, because the only offsetting long-term losses would be reductions in the reservoir aquatic productivity under the islands	Generally untested option for dry ecosystem types, but proven technology for some wetland ecosystems; moderate to high uncertainty and high costs	Some potential for complimentary habitat gains – terrestrial, wetland and aquatic; opportunities to select locations and habitat types based on need.
6. Habitat Stewardship	Managing an existing ecosystem to maintain and/or enhance its values	Incentives for landowners to manage to maintain productivity and other associated values.	Variable impacts on productivity, depending on the alternate use. For example, stewardship of an existing OG site that otherwise would be harvested may result in significant gains, depending on the ecosystem, its productivity, the type of harvesting and end use for the harvested wood.	Relatively high probability of success, depending on mechanism. Difficulties in enforcement, unless linked to covenants (below). Owner-dependent.	High potential complementary gains for habitat and wildlife.
7. Habitat Acquisition	Land purchase Stewardship covenants	May require additional management activities, depending on current condition.	As above – gains are variable, depending on alternative use (i.e. marginal gain).	High / variable probability of success. Depends on current condition.	High potential complementary gains for habitat, wildlife and productivity.
8. Invasive species control inside and / or outside reservoir footprint	Mechanical or biocontrol of invasive species, particularly those likely to reduce success rate of restoration activity (could be associated with all other options).	Surveys, and site-specific mechanical and biocontrol treatments; potentially limited pesticide use in extreme situations.	May be trade-offs with overall productivity on some sites (invasive spp. can be highly productive).	Success is difficult, but possible at least for some species. May assist in increasing success for other options.	Complementary gains for habitat and wildlife. Less obvious for productivity. Consider particularly under reclamation. High likelihood of invasives.

There are also limited opportunities for productivity mitigation through reclamation of disturbed sites. Most forest conversion due to past development has occurred in valley bottoms, and these areas in limited supply in the region (partly due to reservoir flooding). Many of the potential reclamation sites are presently utilized for human activities, such as agricultural, industry, recreation and human habitation. Areas with potential for reclamation are also generally located on privately held land, which increases the costs of acquiring the sites. The acquisition costs can potentially be offset to some extent by utilizing stewardship agreements and/or covenants to ensure long-term productivity gains without outright purchase of the lands.

Another consideration is that net primary production changes through time with the state of succession, especially in forested ecosystems. In general, production is very low early in succession, it increases to a maximum around 'maturity' – anything between 60 – 200 years depending on the site, and then may level off and decline as the stand growth rate declines[8]. It should always be remembered that any forest productivity mitigation projects are of necessity long-term projects with most benefits coming long into the future. This reality should be factored into project objectives, project planning and the monitoring program.

The following descriptions provide more detail around selected mitigation options:

1. **Historic Ecosystem Restoration** – outside reservoir footprint.
    - Create 'goal' for the ecosystem by defining climax ecosystem condition.
    - Consider potential 'short-cuts' to achieve this goal (rather than going through typical succession)
    - Consider pruning or spacing to increase growth rate.
    - Consider fertiliser addition to increase growth rate.
    - Most likely sites will be in places where productivity potential is high, or where habitat loss has been greatest. However, this approach could be appropriate on any sites with reasonable productivity potential. Factor in both short-term and long-term gains.
    - Consider both riparian sites (focus on cottonwood since this has been heavily impacted), and upland sites. For example, degraded riparian ecosystems are being restored on Haida Gwaii, with the intention of meeting global carbon credits and restoring habitat (see http://www.haidaclimate.com/
    - Could be implemented through management of existing lands in very poor condition, or speed-up of attributes on better condition sites.

    Costs: Highly variable, depending on current condition.

    Benefits / unit cost: High variable. Potentially high overlap with other values.

2. **Alternative 'ecosystem' creation** – outside reservoir footprint.
    - Set a desired future condition, based on maximising productivity (and / or habitat gains – see conclusions).
    - Plant fast-growth species, to maximise growth rate. Fast growing species such as hybrid popular may be appropriate. Many projects world-wide are attempting this, in relation to carbon storage in particular. For example: http://www.treesforchange.info/ which is being implemented around Prince George.
    - Consider long-term potential for biomass storage (relating to carbon sequestration).

[8] Note that this is not the same as carbon storage, which may continue to grow or level off and stay high much further into the future.

- Fertilise / prune as necessary to maximise shorter term productivity gains.
- Consider potential success of the project (e.g.. some fast-growth projects fail due to lack of compatability of seedlings with site type).
- Could occur on any site, however alternative 'futures' for the site should be considered. For example, sites with potentially high habitat value sites should be returned to their natural conditions (e.g. riparian areas/ high productivity former wetland/ riparian sites). May only be appropriate on upland sites.
- Consider trade-offs with habitat values.

Costs: likely high energy input required to establish non-native ecosystem. Consider efforts planting / fuel costs / transport costs for trees / fertiliser etc.

Benefits / unit cost: productivity benefits likely relatively high, due to focused effort here. However, broader benefits are likely to be low. Overall, low benefits / unit cost.

3. Reclamation within reservoir footprint.

- Creation of new habitat areas. Likely all sites adjacent to reservoirs have high potential habitat values.
- Identify potential sites for dyking – low gradient areas, small bays etc.
- May require initial planting that focuses on productivity and stability (e.g. salix spp.), but move to native riparian vegetation due to high habitat values on these sites.
- Consider combining with other habitat element work (e.g. perch / snag creation in adjacent forest zones).
- Likely high incidence of browse on these sites. Consider short-term seedling protection.
- Implementation monitoring is likely to be important on these sites, since this type of mitigation is relatively difficult, and adaptive management should be integral to the process (e.g., see failures associated with unusual water levels – MacKillop and Dushenko undated)

Costs: likely very high due to need to create suitable substrate for planting, and maintain adequate moisture / nutrient regime on site. Plus planting and protection from browse. Potential for high invasive species impacts on new ground. Potential costs of lost reservoir storage.

Benefits / unit costs: could be very low. However, combined benefits for different values may be very high, if the project is well managed and successful.

4. Habitat stewardship.

- Stewardship can be used (in combination with convenants, or not) to promote an understanding of productivity issues, and as an educational incentive to landowners to manage for carbon sequestration / productivity.

Costs: likely very low.

Benefits / unit cost: potentially very high. However, difficult to enforce.

5. Habitat acquisition

- Acquire habitat and undertake activity 1, or 2. See above.

Costs: relatively high – land prices are high. However, success rates are also likely to be high, since control is with landowner.

Benefits / unit cost: variable.

6. Invasive species control.

- May be necessary within any of the other options.
- Could be contradictions between establishing native community, and invasive species productivity (which tends to be high rate and high establishment, though low carbon storage).
- Factor in potential invasive species management costs into any planned projects.

As outlined in the introduction the impacts of inundation on other terrestrial and aquatic/ wetland values have been developed (MacKillop 2008 and Moody et al. 2007). Mitigation decisions should therefore take into account synergies between losses at multiple levels. For any particular project, (suggested from a productivity / habitat / wildlife perspective) the factors below can be used to identify those with the broadest gains and lowest costs:

- The potential rate of productivity gains for the site
- Maximum productivity potential
- Maximum overlapping benefits (e.g. optimise mitigation for productivity / habitat / wildlife /etc.)
- Marginal gain assessment (i.e. what productivity would have existed without intervention?).
- Costs versus assumed benefits versus measured benefits

Some potential projects that likely have highest ratings in a number of categories include:

- **I**dentification of lost ecosystems with highest productivity (and area) losses – focus mitigation work in these areas.
- **I**dentify suitable drawdown zone areas (low gradient, or where dykes could be built) that may be suitable for soil creation and planting. Plant fast growing spp first for stability (potentially willow species), and move towards natural riparian habitats dominate by native cottonwood.
- **I**dentify other potential land where ecosystems could be restored (agricultural land / logged private land), particularly in the most productive zones. Plant to restore habitats with high long-term potential for productivity
- **I**dentify covenant opportunities, close to, and away from the reservoirs, within the same broad zones. Covenants should include objectives for maintaining natural forest cover through time to provide gains from productivity, carbon sequestration and habitat provision.
- Explore the opportunities for testing the establishment of floating island ecosystem sites. Although novel, this has the potential for productivity increases, as well as gains with respect to specific habitat losses (e.g., nesting sites with low predation rates).

4.0 TERRESTRIAL PRODUCTIVITY MITIGATION MONITORING FRAMEWORK

In order to determine an appropriate monitoring framework, the exact goals of each mitigation effort need to be determined. For example, is the goal to replace productivity per se, to offset carbon losses through time, or to replace lost habitat? Within each goal, both implementation and effectiveness monitoring will likely be relevant. The measures of implementation and effectiveness monitoring will likely be unique for each option and each goal.

Implementation monitoring would look at the short-term success of making a project happen. For example, a project along the Kootenay River near Creston to establish fast-growing deciduous plantations and increase wood supply was very similar to some of the mitigation projects recommended here. In the Creston case, survival surveys and short-term establishment monitoring determined that the project failed due to the use of ecologically unsuited seedlings (Forest 2020: S. Walsh pers. comm.). Similarly, other projects have suffered from ungulate browse effects and flooding damage when trying to re-establish riparian ecosystems adjacent to reservoirs (e.g., MacKillop and Dushenko undated). Implementation monitoring requires that a specific strategy is outlined and then checked to determine the extent to which it has been successfully implemented.

Effectiveness monitoring would be the broader scale monitoring required to test the extent to which productivity gains and other goals have been delivered, at periods into the future. In order to undertake this, benchmarks should be set, and may consider:

- the original ecosystem condition. Does the restored ecosystem meet productivity levels of the original ecosystem? A theoretical baseline has been produced for ecosystems affected (see MacKillop and Utzig 2005), and this can be used to assess the extent of future success.
- the productivity potential of the site without mitigation efforts. This ‘marginal gain’ is an important component to determine whether the efforts taken provide sufficient gains to be worthwhile. This can be a relatively easy test (e.g., drawdown zones have little or no existing productivity), or can be complex and costly to complete (e.g., agricultural or young coniferous forest being managed to promote deciduous riparian values would require productivity measurements prior to treatment).
- a future desired condition (e.g., setting goals to create specific habitat conditions, with only moderate productivity increases as a secondary goal, where the primary effectiveness focus would be the presence of the specified habitat conditions).

In order to assess effectiveness of mitigation options, a measure of productivity must be chosen that can be measured directly, or modeled, for each ecosystem. An evaluation of the trade-offs between accuracy of measurement, and costs of measurement should be made. A summary of different options, and their potential usefulness is made below.

Measuring Primary Productivity

Measuring NPP typically involves estimating dry-weight biomass changes over time. Detailed methodologies for calculating above-ground NPP are provided in Clark et al. 2001. Biomass is then converted to an energy measure such as kilocalories using a conversion factor. Figure 3.1 illustrates the different elements that require measurements to fully understand NPP changes through time. (from Clark et al. 2001).

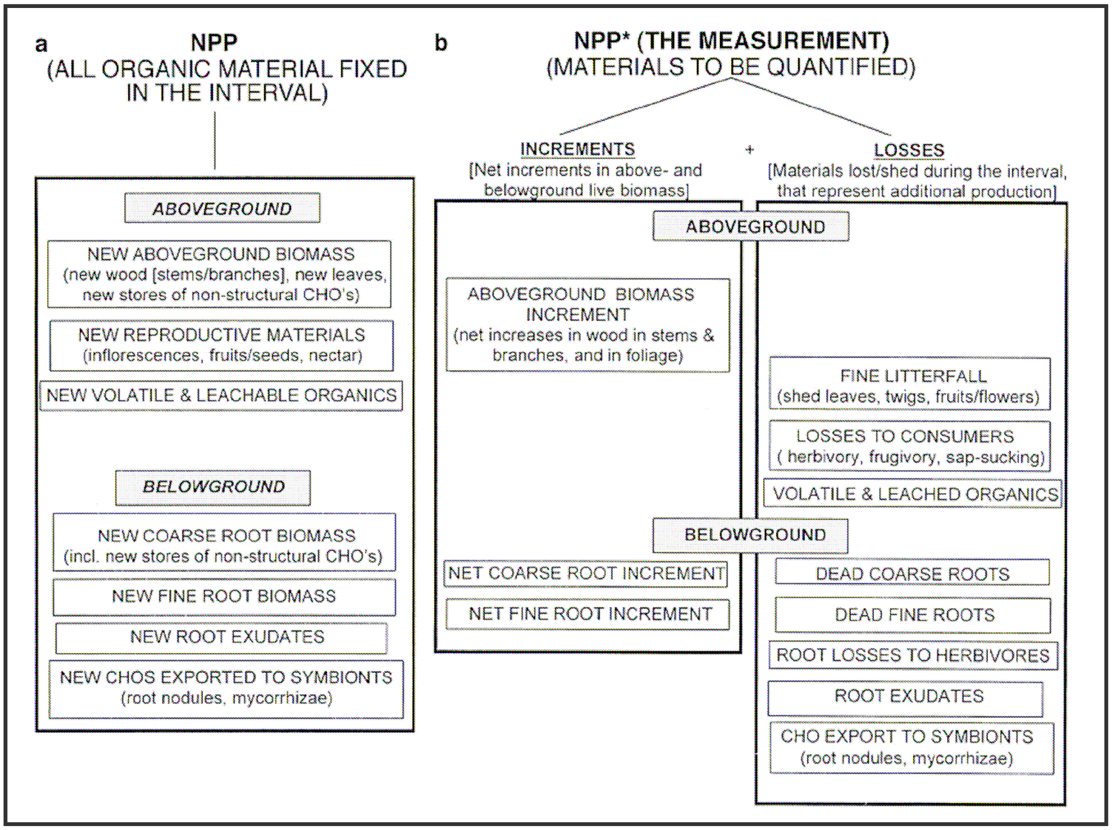

Figure 3.1. Measurement components for determining NPP (from Clark et al. 2001). The left column lists the primary components of NPP. The middle column indicates the biomass production elements requiring measurements, while the right column indicates biomass loss elements that must also be measured to subtract from the production values to determine "net" primary production.

Field methods used to measure NPP in forests typically fail to adequately account for below-ground values (Clark et al. 2001), as below-ground biomass is very costly to sample. Unfortunately, below-ground biomass is a significant portion of overall productivity in both forest and grassland ecosystems. To calculate below-ground biomass, estimates are required for biomass increments of coarse and fine roots, mortality of coarse and fine roots, losses of roots to consumers, rhizodeposition (sloughed cells etc) and carbohydrate inputs to mycorrhizal fungi and root nodule symbionts.

Overall, Clark et al. (2001) conclude that "the substantial efforts that are required for NPP field studies, the unresolved methods challenges and a frequent lack of conceptual clarity are continuing obstacles ..". For this reason, we suggest that it is unlikely to be a priority to attempt to directly measure NPP. We recommend the use of alternative less costly surrogate measures of NPP for effectiveness monitoring.

Surrogate Measures of NPP

Since NPP largely reflects biomass gains versus biomass losses, the simplest surrogate is to attempt to obtain an estimate of broad biomass gains on a site. This can then be compared to an estimate of biomass prior to mitigation in order to get an estimate of the relative gain on different sites.

For forested ecosystems, above-ground biomass can be estimated using standard growth and yield plots (detailed methods can be found at: http://www.for.gov.bc.ca/hts/vri/ip/standards/index.html . These data can then be used in conjunction with the models used to project terrestrial productivity for this project (see

Utzig and MacKillop 2005). For grassland and shrub/ herb communities effectiveness monitoring could utilize standard range utilization methodologies.

5.0 CONCLUSIONS

There have been significant terrestrial productivity losses associated with the construction of the BC Hydro dams on the Columbia/ Kootenay River system. This study has estimated the total at approximately 300,000 tC/yr of NPP. This represents approximately 3 times the NPP calculated as lost from the hydroriparian environments of the reservoirs (lakes, rivers, wetland/floodplains – Moody et al. 2007).

In order to mitigate productivity losses caused by the dams, the most pragmatic approach may be to focus on highest potential productivity systems identified by MacKillop and Utzig (2005), and focus restoration/ creation and acquisition attention in these zones (e.g., wetter forest types). However, given the limited availability and high costs of acquiring suitable restoration/ reclamation sites outside the reservoir footprint, it is still unlikely that a significant portion of the terrestrial productivity losses can be mitigated, at least within the local area surrounding the reservoirs. Floating islands of terrestrial habitat on the reservoirs probably offer the best overall opportunity for potential productivity gains, but this option is essentially untested, and costs may be significant.

Given the coincident loss in terrestrial habitat values (see MacKillop 2008), especially habitat associated with species-at-risk, choice of ecosystems types for terrestrial restoration/ reclamation should take into account habitat quality as well as productivity, to increase the benefit/ cost ratio of any projects under consideration.

Implementation monitoring can then be undertaken to assess how well specific goals are met. However, as discussed above, effectiveness monitoring of NPP (and/ or carbon sequestration) is extremely difficult to undertake accurately, and is definitely very costly. A more efficient approach, if effectiveness monitoring is considered necessary, may be to use growth and yield plots combined with a modeling approach to assess potential long-term benefits.

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APPENDIX 1: RANGE OF NATURAL VARIATION SCENARIO

Table A1.1 Ecosystem groups and structural stage distributions employed for calculating long-term average NPP based on a RONV scenario. Ecosystem groups where stand-replacing disturbances were not modelled are indicated by a "c" under estimated return interval (i.e. constant NPP).

BEC Unit	Ecosystem Group	Estimated Return Interval (ys)	Ecosystem Code	Percentages of Structural Stages				
				Old	Mature	Pole/ Sapling-Young	Shrub/ Herb	Sparse/ Bryoid-Herb
ICHdw1	Average	160						
ICHdw1	Dry Forest	120	2a	19	32	26	16	7
ICHdw1	Mesic Forest	160	2b	28	32	22	12	5
ICHdw1	Wet Forest	220	2c	40	29	18	9	4
ICHdw1	Rock-Talus-Soil	c	2h					
ICHdw1	Agriculture	160	2f	28	32	22	12	5
ICHdw1	Urban	160	2g	28	32	22	12	5
ICHdw1	Gravel Bar	c	2i					
ICHdw1	Wetland	c	2j					
ICHmm	Average	180						
ICHmm	Dry Forest	140	3a	24	32	24	14	6
ICHmm	Mesic Forest	180	3b	33	31	20	11	5
ICHmm	Wet Forest	220	3c	40	29	18	9	4
ICHmm	Very Wet Forest	260	3d	46	27	16	8	3
ICHmm	Avalanche	c	3e					
ICHmm	Rock-Talus-Soil	c	3h					
ICHmm	Urban	180	3g	33	31	20	11	5
ICHmm	Gravel Bar	c	3i					
ICHmm	Wetland	c	3j					
ICHmw1	Average	220						
ICHmw1	Dry Forest	180	4a	33	31	20	11	5
ICHmw1	Mesic Forest	220	4b	40	29	18	9	4
ICHmw1	Wet Forest	260	4c	46	27	16	8	3
ICHmw1	Avalanche	c	4e					
ICHmw1	Agriculture	220	4f	40	29	18	9	4

BEC Unit	Ecosystem Group	Estimated Return Interval (ys)	Ecosystem Code	Percentages of Structural Stages				
				Old	Mature	Pole/ Sapling-Young	Shrub/ Herb	Sparse/ Bryoid-Herb
ICHmw1	Urban	220	4g	40	29	18	9	4
ICHmw1	Rock-Talus-Soil	c	4h					
ICHmw1	Gravel Bar	c	4i					
ICHmw1	Wetland	c	4j					
ICHmw2	Average	240						
ICHmw2	Dry Forest	200	5a	37	30	19	10	4
ICHmw2	Mesic Forest	240	5b	43	28	17	8	4
ICHmw2	Wet Forest	280	5c	49	26	15	7	3
ICHmw2	Very Wet Forest	320	5d	53	24	13	6	3
ICHmw2	Avalanche	c	5e					
ICHmw2	Rock-Talus-Soil	c	5h					
ICHmw2	Agriculture	240	5f	43	28	17	8	4
ICHmw2	Urban	240	5g	43	28	17	8	4
ICHmw2	Wetland	c	5j					
ICHmw2	Gravel Bar	c	5i					
ICHmw3	Average	200						
ICHmw3	Dry Forest	160	6a	28	32	22	12	5
ICHmw3	Mesic Forest	200	6b	37	30	19	10	4
ICHmw3	Wet Forest	240	6c	43	28	17	8	4
ICHmw3	Very Wet Forest	280	6d	49	26	15	7	3
ICHmw3	Rock-Talus-Soil	c	6h					
ICHmw3	Agriculture	200	6f	37	30	19	10	4
ICHmw3	Urban	200	6g	37	30	19	10	4
ICHmw3	Gravel Bar	c	6i					
ICHmw3	Wetland	c	6j					
ICHvk1	Average	460						
ICHvk1	Dry Forest	420	8a	62	20	10	5	2
ICHvk1	Mesic Forest	460	8b	65	19	10	5	2
ICHvk1	Wet Forest	500	8c	67	18	9	4	2
ICHvk1	Very Wet Forest	540	8d	69	17	8	4	2
ICHvk1	Avalanche	c	8e					

BEC Unit	Ecosystem Group	Estimated Return Interval (ys)	Ecosystem Code	Percentages of Structural Stages				
				Old	Mature	Pole/ Sapling-Young	Shrub/ Herb	Sparse/ Bryoid-Herb
ICHvk1	Rock-Talus-Soil	c	8h					
ICHvk1	Urban	460	8g	65	19	10	5	2
ICHvk1	Gravel Bar	c	8i	0				
ICHvk1	Wetland	c	8j	0				
ICHwk1	Average	400		61	21	11	5	2
ICHwk1	Dry Forest	360	7a	57	23	12	6	2
ICHwk1	Mesic Forest	400	7b	61	21	11	5	2
ICHwk1	Wet Forest	440	7c	63	20	10	5	2
ICHwk1	Very Wet Forest	480	7d	66	19	9	4	2
ICHwk1	Avalanche	c	7e					
ICHwk1	Rock-Talus-Soil	c	7h					
ICHwk1	Urban	400	7g	61	21	11	5	2
ICHwk1	Wetland	c	7j					
ICHwk1	Gravel Bar	c	7i					
ICHxw	Average	140						
ICHxw	Dry Forest	100	1a	13	31	29	18	9
ICHxw	Mesic Forest	140	1b	24	32	24	14	6
ICHxw	Wet Forest	180	1c	33	31	20	11	5
ICHxw	Rock-Talus-Soil	c	1h					
ICHxw	Agriculture	140	1f	24	32	24	14	6
ICHxw	Urban	140	1g	24	32	24	14	6
IDFdm2	Average	120						
IDFdm2	Shrub Steppe	140	9o	24	32	24	14	6
IDFdm2	Dry Forest	180	9a	33	31	20	11	5
IDFdm2	Mesic Forest	120	9b	19	32	26	16	7
IDFdm2	Wet Forest	180	9c	33	31	20	11	5
IDFdm2	Very Wet Forest	240	9d	43	28	17	8	4
IDFdm2	Rock-Talus-Soil	c	9h					
IDFdm2	Agriculture	120	9f	19	32	26	16	7
IDFdm2	Urban	120	9g	19	32	26	16	7
IDFdm2	Gravel Bar	c	9i					

BEC Unit	Ecosystem Group	Estimated Return Interval (ys)	Ecosystem Code	Percentages of Structural Stages				
				Old	Mature	Pole/ Sapling-Young	Shrub/ Herb	Sparse/ Bryoid-Herb
IDFdm2	Wetland	c	9j					
IDFun	Average	120						
IDFun	Grassland	180	10n	33	31	20	11	5
IDFun	Dry Forest	180	10a	33	31	20	11	5
IDFun	Mesic Forest	120	10b	19	32	26	16	7
IDFun	Wet Forest	180	10c	33	31	20	11	5
IDFun	Rock-Talus-Soil	c	10h					
IDFun	Agriculture	120	10f	19	32	26	16	7
IDFun	Urban	120	10g	19	32	26	16	7
IDFun	Gravel Bar	c	10i					
PPdh2	Average	?						
PPdh2	Grassland	240	11n	43	28	17	8	4
PPdh2	Mesic Forest	180	11b	33	31	20	11	5
PPdh2	Wet Forest	240	11c	43	28	17	8	4
PPdh2	Rock-Talus-Soil	c	11h					
PPdh2	Agriculture	180	11f	33	31	20	11	5
PPdh2	Urban	180	11g	33	31	20	11	5
PPdh2	Gravel Bar	c	11i					
SBSdh1	Average	140		24	32	24	14	6
SBSdh1	Mesic Forest	140	12b	24	32	24	14	6
SBSdh1	Wet Forest	180	12c	33	31	20	11	5
SBSdh1	Very Wet Forest	220	12d	40	29	18	9	4
SBSdh1	Urban	140	12g	24	32	24	14	6
SBSdh1	Wetland	c	12j					
SBSdh1	Gravel Bar	c	12i					
All	Shallow Water	c	k					
All	River		l					
All	Lake		m					

APPENDIX 2: ECOSYSTEM CLASS DISTRIBUTION FOR THE MAXIMUM AND MAPPED NPP SCENARIOS

Table A2.1. Area (ha) of various aquatic and terrestrial ecosystems by reservoir. Data from ecosystem mapping (Ketcheson et al. 2005 and AIM report (Moody et al. 2007) and findings of this report (NPP max scenario).

	Arrow C11	Revelstoke C4	Kinbasket C3	Duncan K7	Koocanusa K3	Seven-Mile C10	Whatshan C8	Kootenay Canal K9	Spillimacheen C2	Total
Lakes	34,992.3	0.0	2,343.0	2,583.9	0.0	0.0	1,528.9	0.0	0.0	**41,448.1**
Rivers	2,021.9	2,654.4	4,896.6	424.5	1,490.1	179.0	14.6	0.0	0.3	**11,681.5**
Streams	50.6	53.4	192.1	17.7	10.3	1.5	0.5	0.0	0.0	**326.1**
Shallow ponds	102.9	26.9	555.1	172.3	210.6	0.0	4.9	0.0	0.0	**1,072.7**
Gravel Bars	3,262.8	56.9	235.6	22.0	80.4	0.4	0.0	0.0	0.0	**3,658.1**
Wetlands	3,383.2	328.1	5,183.6	1,219.0	964.0	1.8	0.0	0.9	0.0	**11,080.6**
Floodplains (overlap)	3,611.7	4,132.5	16,208.1	2,001.7	2,281.0	6.0	16.6	0.7	0.0	**28,258.3**
Terrestrial	3,844.4	4,199.2	13,033.1	860.3	1,646.8	241.8	204.0	47.1	0.7	**24,077.5**
Total	**51,269.9**	**11,451.4**	**42,647.3**	**7,301.4**	**6,683.2**	**430.5**	**1,769.6**	**48.7**	**1.1**	**121,602.9**

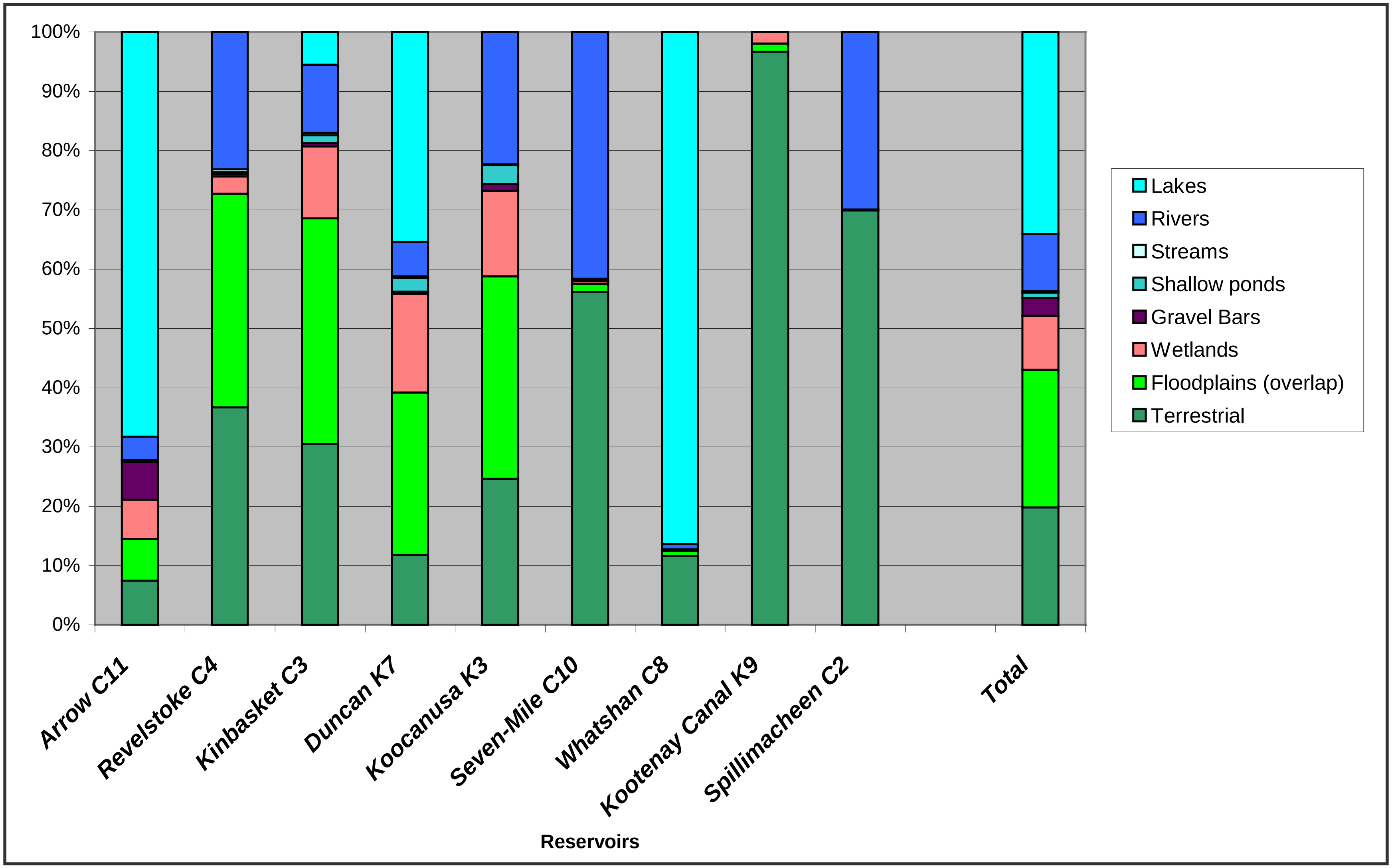

Figure A2.1. Percentages of various aquatic and terrestrial ecosystems by reservoir. Data from ecosystem mapping (Ketcheson et al. 2005 and aquatic/ wetland report (Moody et al. 2007) and findings of this report (NPP max scenario).

Table A2.2. Detailed cross-tabulation of wetland and riparian/floodplain classification for the Maximum scenario. Areas are in ha.

Classification System: Moody et al. Forested Non-forested	Utzig & Holt Wetland/ floodplain	Canadian Wetland Classif.	MacKillop Ecoystem Groups	Reservoir: Arrow C11	Revel-stoke C4	Kinbasket C3	Duncan K7	Kooca-nusa K3	Seven-Mile C10	Whatshan C8	Kootenay Canal K9	Spillima-cheen C2	Total
Aquatic/ wetland Non-Forested Wetlnds	Wetland	CAN wtlnd	Wet Forest	123.5			0.6						124.2
Aquatic/ wetland Non-Forested Wetlnds	Wetland	CAN wtlnd	Wetland	456.3	328.1	5151.4	401.8				0.9		6338.5
Aquatic/ wetland Non-Forested Wetlnds	Wetland	NOT CAN wtlnd	Agriculture	2152.8	0.0	29.7	48.3	964.0	1.8				3196.6
Aquatic/ wetland Non-Forested Wetlnds	Wetland	NOT CAN wtlnd	Avalanche				0.4						0.4
Aquatic/ wetland Non-Forested Wetlnds	Wetland	NOT CAN wtlnd	Wet Forest	386.1			279.9						666.0
Aquatic/ wetland Non-Forested Wetlnds	Riparian/ Floodplain	NOT CAN wtlnd	Wet Forest		171.7	3165.4		492.3		6.3			3835.7
Aquatic/ wetland Non-Forested Wetlnds	Riparian/ Floodplain	NOT CAN wtlnd	Very Wet Forest	514.5	53.1	62.5	29.3						659.4
Aquatic/ wetland Non-Forested Wetlnds	Riparian/ Floodplain	NOT CAN wtlnd	Wetland	15.9									15.9
Aquatic/ wetland Non-Forested Wetlnds	Riparian/ Floodplain	CAN wtlnd	Wet Forest					366.2					366.2
Aquatic/ wetland Non-Forested Wetlnds	Riparian/ Floodplain	CAN wtlnd	Very Wet Forest			474.1		428.4					902.5
Aquatic/ wetland Non-Forested Wetlnds	Riparian/ Floodplain	CAN wtlnd	Wetland	6.5	127.8	681.6	605.1	103.5		1.5			1526.0
Aquatic/ wetland Forested Wetlands	Wetland	NOT CAN	Wet Forest	274.5			488.3						762.8
Aquatic/ wetland Forested Wetlands	Riparian/ Floodplain	CAN wtlnd	Wet Forest	321.2	489.9	2529.9	335.1	595.1					4271.2
Aquatic/ wetland Forested Wetlands	Riparian/ Floodplain	CAN wtlnd	Very Wet Forest	389.3	286.9	358.9	21.4	280.8					1337.3
Aquatic/ wetland Forested Wetlands	Riparian/ Floodplain	CAN wtlnd	Wetland	15.9				4.5					20.4
Aquatic/ wetland Forested Wetlands	Riparian/ Floodplain	NOT CAN wtlnd	Wet Forest	1307.4	2785.9	8938.3	575.0		6.0	8.3	0.7		13621.7
Aquatic/ wetland Forested Wetlands	Riparian/ Floodplain	NOT CAN wtlnd	Very Wet Forest	1031.1	217.2		435.8						1684.1
Aquatic/ wetland Forested Wetlands	Riparian/ Floodplain	NOT CAN wtlnd	Wetland					10.2					10.2
			Total	6995.0	4460.6	21391.7	3221.0	3245.0	7.8	16.1	1.6	0.0	39339.0

APPENDIX 3: TERRESTRIAL NPP FOR THE MAXIMUM AND MAPPED SCENARIOS

Table A3.1. Terrestrial NPP (tC/yr) by ecosystem group and reservoir. Ecosystem mapping data from Ketcheson et al. 2005 and productivity data from MacKillop and Utzig 2005. These values are based on the Maximum scenario.

	Arrow C11	Revelstoke C4	Kinbasket C3	Duncan K7	Koocanusa K3	Seven-Mile C10	Whatshan C8	Kootenay Canal K9	Spillimacheen C2	Total
Urban	286.4	50.4	278.0	2.7	26.0	15.7	0.9	13.6		673.7
Agriculture	217.8			16.3		0.0				234.0
Rock-Talus-Soil	5.9	71.4	29.4	1.4	3.2	3.1	0.2			114.7
Avalanche		4.2	272.2	3.7						280.1
Grassland	1.7				705.9					707.6
Shrub Steppe					17.4					17.4
Dry Forest	7,328.3	3,706.7	6,840.9	4,178.0	343.1	575.3	648.1	140.0		23,760.4
Mesic Forest	21,695.5	52,913.9	144,886.9	3,062.7	9,644.8	1,243.8	994.0	259.0	6.6	234,707.2
Wet Forest	27,028.5	28,499.7	143,321.3	8,269.0	10,773.8	120.0	652.3	6.3		218,670.9
Very Wet Forest	17,547.4	5,154.9	7,970.4	4,646.0	3,990.6					39,309.4
Wetland	340.5	472.1	2,805.5	5,075.6	354.7		12.6			9,061.0
Total	74,452.0	90,873.4	306,404.7	25,255.5	25,859.4	1,957.8	2,308.2	418.8	6.6	527,536.5

Table A3.2. Terrestrial NPP (tC/yr) by ecosystem group and reservoir. Ecosystem mapping data from Ketcheson et al. 2005 and productivity data from MacKillop and Utzig 2005. These values are based on the Mapped scenario.

Mapped	Arrow C11	Revelstoke C4	Kinbasket C3	Duncan K7	Koocanusa K3	Seven-Mile C10	Whatshan C8	Kootenay Canal K9	Spillimacheen C2	Total
Urban	286.4	50.4	278.0	2.7	26.0	15.7	0.9	13.6		673.7
Agriculture	217.8			16.3						234.0
Rock-Talus-Soil	5.9	54.2	3.9	1.4	3.2	3.1	0.2			71.8
Avalanche		4.2	272.2	3.7						280.1
Grassland	1.7				705.9					707.6
Shrub Steppe					17.4					17.4
Dry Forest	4,851.8	2,010.7	4,019.3	2,517.3	113.6	341.2	392.0	83.2		14,328.9
Mesic Forest	13,103.6	27,738.7	80,390.9	1,977.1	3,901.5	789.2	605.9	164.8	4.2	128,676.0
Wet Forest	14,297.4	20,053.6	83,747.1	4,950.3	4,225.1	75.5	351.6	3.7		127,704.3
Very Wet Forest	10,765.6	2,871.3	2,482.7	2,509.5	1,491.3					20,120.3
Wetland	83.7			97.1	15.2					196.0
Total	43,613.9	52,783.0	171,194.0	12,075.4	10,499.1	1,224.7	1,350.7	265.3	4.2	293,010.2

APPENDIX 4: ADDITIONAL SPREADSHEET DATA

Annotated list of Excel spreadsheets with data and calculations utilized in the preparation of the report.

File Name	Description
Terr-prod_Wetland-correltn_2-12-08.xls	Wetland polygon mapping units are classified according to criteria defined in Moody et al. 2007
Terr-prod_Total-area-calc-graphs_2-12-08.xls	Combines information on wetlands and aquatic features from Moody et al. 2007, terrestrial ecosystem groups from MacKillop 2008 and results on floodplain/overlap areas from this report to classify the total footprints into terrestrial and aquatic components; summary graphs and tables are prepared
Terr-prod_RONV_2-12-08.xls	Includes worksheets with a summary of RONV stand-replacing return intervals from the literature for relevant ecosystems, estimates of return intervals for each footprint ecosystem group and calculations of seral stage distributions for each ecosystem group based on application of the exponential equation
Terr-prod_NPP-poly-lookup_2-12-08.xls	Look-up table assigns appropriate NPP values to each polygon mapping unit
Terr-prod_RONV-lookup_NPP-poly-calc_2-12-08.xls	Look-up tables assign appropriate seral stage distributions to each polygon mapping unit; calculations determine NPP for each polygon mapping unit for each scenario; calculations determine the area of wetlands, floodplain overlap and terrestrial landbase for each scenario
Terr-prod_Area-Prod-pivot_2-12-08.xls	Results of NPP and area calculations are summarized through a series of pivot tables
Terr-prod_Prod-graph_2-12-08.xls	Graphs of terrestrial NPP are prepared for each scenario