Quantification of Vegetation Inputs to Revelstoke Reach Summary of 2000 Field Program – Vegetation and Soil Analyses

July 2002

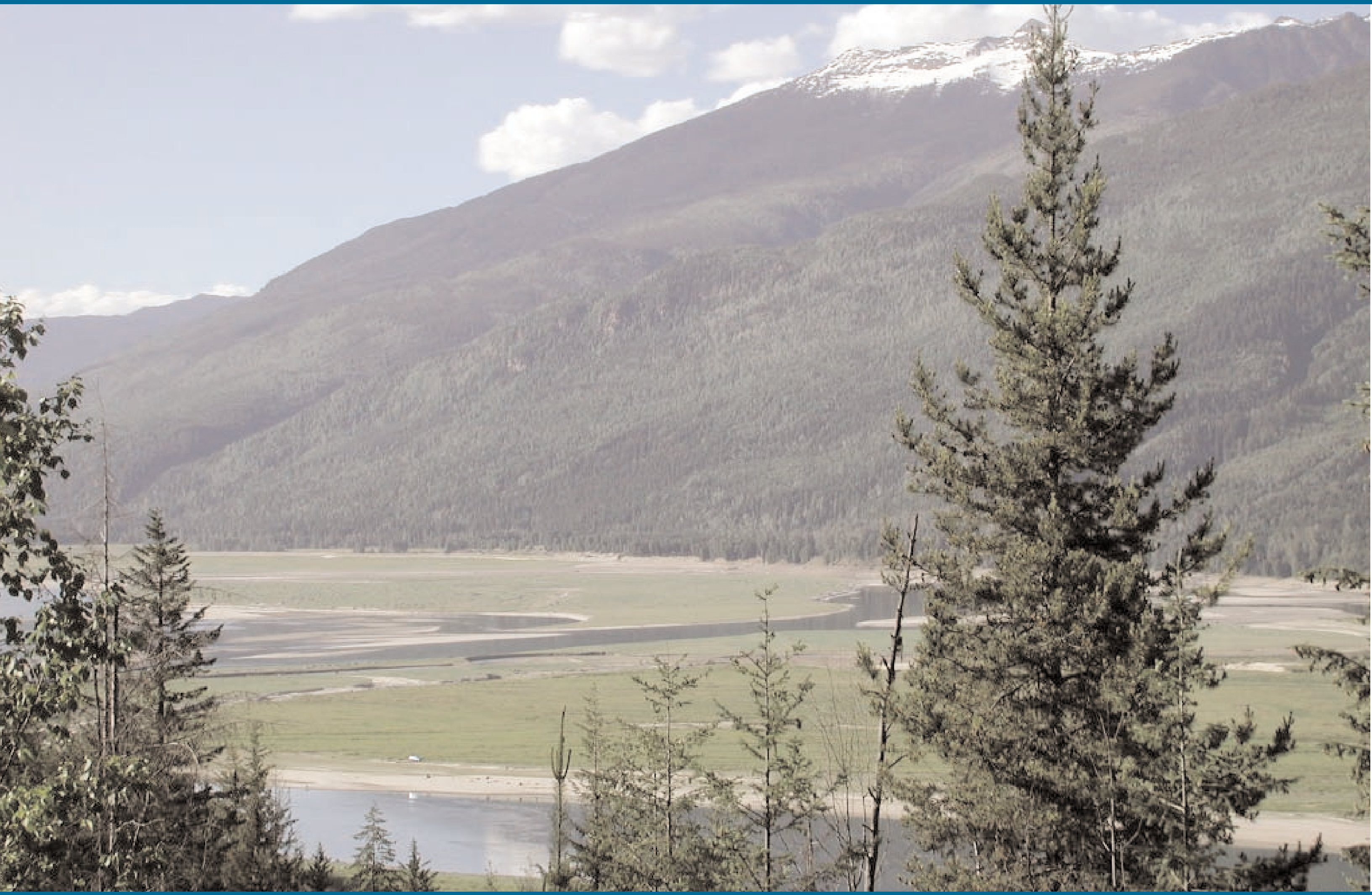

Photo courtesy of Wendy Beauchamp

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Prepared for: BC Hydro Strategic Environmental Initiatives Program
Evaluation of the Ancillary Benefits of Upper Arrow Reservoir Drawdown Zone Revegetation Project

BC hydro

B.C. Hydro

Strategic Environmental Initiatives Program
Evaluation of Ancillary Benefits of Reservoir Shoreline Revegetation Program

Quantification of Vegetation Inputs to Revelstoke Reach

Summary of 2000 Field Program – Vegetation and Soil Analyses

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EXECUTIVE SUMMARY

A key component of the Evaluation of Ancillary Benefits of Reservoir Drawdown Zone Revegetation Study, funded under the BC Hydro Strategic Environmental Initiatives Program, is the quantification of ecosystem contributions from the vegetation community that has established as a result of the Upper Arrow Dust Control Program. Since the late 1980's, significant portions of the Revelstoke Reach of Arrow Reservoir (often referred to as Upper Arrow Reservoir) have been repeatedly seeded with fall rye for wind erosion control and dust abatement. The seeding has continued for dust control on an annual basis, with the program modified each year based on projected water levels, shifts in dust source locations, and the encroachment/establishment of native vegetation on previously seeded areas. Past, informal monitoring of the vegetation establishment within Upper Arrow has indicated that three primary vegetation types exist within the treated (i.e. seeded/planted) portions of the reservoir:

- annually seeded fall rye at lower elevations (<434 m)
- sedge-based community incorporating other native wetland species in middle to upper elevation areas (434 – 436 m)
- reed canarygrass community with an understory of wetland species in the upper elevation areas (436+ m)

Native willows and other riparian shrubs are also beginning to establish in the upper most portions of the reed canarygrass zone.

The sedge-based and reed canarygrass plant communities that have developed above 434 m in elevation constitute a new, permanent wetland that has developed as a result of surface soil substrate stabilization and seed entrapment associated with several years of annual fall rye seeding for dust control. This new wetland, locally referred to as the Revelstoke Wetlands, is tolerant of the variability in the regulated water regime of Upper Arrow Reservoir. While exposed during annual drawdown (late winter through early summer), the vegetation is used for food and shelter by numerous bird species, small and large mammals, and small reptiles. When submerged during reservoir recharge and storage (early summer through early winter), the vegetation is a source of nutrients, carbon, and structural habitat to aquatic organisms. Throughout the year, the Revelstoke Wetlands is also the focus of a wide range of recreational activities by local residents and tourists.

In 1999, a program of field studies was initiated at Upper Arrow Reservoir (Revelstoke Reach) to explore and quantify (within budget limitations) benefits arising from the new wetland that had established within reservoir drawdown zone. Initially the studies, funded under the BC Hydro Strategic Environmental Initiatives Program (SEIP), focused on contributions to the aquatic environment (i.e. fish habitat and periphyton production), but were expanded in the second and third years to include benefits to the terrestrial ecosystem and local recreation. An underlying goal of the SEIP program is to be able to evaluate the potential of expanding the use of reservoir revegetation in drawdown zones for environmental enhancement at other BC Hydro reservoirs.

One of the core field studies within the Upper Arrow SEIP was the quantification of vegetation inputs (biomass, nutrients and carbon) from the new wetlands available to the aquatic and terrestrial phases of the ecosystem within Revelstoke Reach. In 1999, a pilot study was undertaken on the vegetated areas within the drawdown zone associated with the dust control seeding program (AIM and CARR, 2000). This study provided insight into the range in values for various parameters of interest within the vegetated communities, and helped identify sampling issues that would need to be addressed in the second year of the field program.

The following tasks were undertaken in the 2000 field study of vegetation inputs:

- Quantify the distribution of vegetation and evaluate the colonization rates of native species within the revegetated areas in the Revelstoke Reach
- Quantify biomass, nutrients (N, P, & K) and carbon contributions of the plant communities to determine the potential nutrient contribution of vegetation to the surrounding ecosystems
- Develop a system for a long term monitoring program that examines relative abundance, species composition, and biomass within the study area.

The procedures used in the second year of the field program were refined based on the results of the 1999 pilot study, with a shift to a species-based sampling protocol instead of area-based sampling of the plant community. The species specific sampling approach implemented in 2000 yielded biomass and associated nutrient values that provide a clearer understanding of the contribution to production by individual species, which can be extrapolated to the vegetation communities as a whole throughout the revegetated Upper Arrow drawdown zone based on subsequent airphoto mapping undertaken as a separate core SEIP component (Moody, 2002). There was also a decision to focus on the permanent vegetation that had established within the Revelstoke Wetlands, foregoing any study of the temporary fall rye seeded annually as part of the dust control program. The latter was deemed a relatively minor, and highly variable, contributor of aboveground biomass to the drawdown zone from year to year in relation to the contributions of the permanent vegetation in the wetland.

The 2000 vegetation and soil field study revealed that there are major differences not only in the distribution of the wetland species that have recolonized the drawdown area according to reservoir elevation, but also the amount of biomass produced by individual species within and across the elevation range (434 m - 437+ m) of permanent vegetation establishment. As of 2000, el. 434 m appears to be the lower boundary for extensive recolonization by wetland species, although this will be determined in the long run by reservoir operation. Reed canarygrass, lenticulate sedge and horsetail are the predominant wetland species throughout the permanently recolonized zone, with the spatial distribution of the reed canarygrass and lenticulate sedge heavily influenced by reservoir elevation. In general, the percentage ground cover of the reed canarygrass appears to increase with an increase in elevation while the cover contribution of the lenticulate sedge decreases.

The growth performance of the vegetation in terms of biomass and nutrient status also appears to be sensitive to elevation change for all species. On a per unit area basis (g/m^2), the lenticulate sedge is by far the highest biomass producer and highest net exporter of leaf material into the aquatic environment during inundation. Production of the reed canarygrass and Columbia sedge is similar, with the reed canarygrass's contribution to the ecosystem far greater due to its dominant presence throughout the area. Initiation of the development of soil horizons, particularly in the higher elevation areas (436 m and 437+ m), over 10 years is very encouraging from a land reclamation perspective. The increases in soil total carbon, especially in the soil surface layer (0 - 10 cm) but extending down to 30 cm, are significant, and a strong indication that this permanent vegetation community will continue to develop and thrive under the current reservoir operating regime. The quantity of new carbon now sequestered in the vegetation, roots and soil within 10 years (approximately 35 tC/ha) indicates that promoting the development of wetlands in drawdown zones may be a potential area for consideration in the development of carbon off-set credits.

Efforts to expand drawdown zone revegetation within the BCH reservoir network have already begun at Williston Reservoir (dust control) and Stave Reservoir (habitat compensation), with the potential for expansion to other reservoirs for environmental enhancement. As this type of program is unique in managed reservoir systems throughout the world, only the Upper Arrow program is currently available to provide long-term insight as to vegetation production and species development, as well as the influence of water regime management on wetland community establishment. Both the airphoto assessment (conducted under a parallel study – AIM 2002) and field sampling programs undertaken from 1999 through 2001 have provided an excellent test of methods that should be incorporated into a long-term monitoring program. Although the objectives of such a program will determine the specifics with regard to frequency and level of detail, the airphoto assessment appears to be a very cost-effective method for gathering information on vegetation community dynamics (change in composition and rate of spread) within this extensive area. The stratification of the vegetation communities using airphoto assessment is very important if (or when) a detailed assessment of biomass, nutrients, or soil parameters is required. However, it is important for BCH to clearly define the goals and objectives (as well as precision) of any future detailed sampling program.

1.0 INTRODUCTION

A key component of the Evaluation of Ancillary Benefits of Reservoir Drawdown Zone Revegetation Study, funded under the BC Hydro Strategic Environmental Initiatives Program, is the quantification of ecosystem contributions from the vegetation community that has established as a result of the Upper Arrow Dust Control Program. The development of extensive areas of vegetation within the drawdown zone in reservoirs has the potential to affect both local aquatic and terrestrial habitat values by providing organic inputs and structure that can be utilized by a variety of organisms. Quantification of these inputs and linkages is required to properly develop an ecosystem model, which has been put forward in a theoretical stage (Korman, 2002), to help define the linkage between reservoir vegetation and broader ecosystem habitat values.

Since the late 1980’s, significant portions of the Revelstoke Reach of Arrow Reservoir (often referred to as Upper Arrow Reservoir) have been repeatedly seeded with fall rye for wind erosion control and dust abatement. Initially, only 200-350 ha of identified dust source area was seeded with fall rye. However this program was expanded to affect over 1000 ha in 1991. The seeding has continued for dust control annually, with the program modified each year based on projected water levels, shifts in dust source locations, and the encroachment/establishment of native vegetation on previously seeded areas. The shift in treatment areas as a result of native vegetation colonization has allowed the annual seeding program to address other identified dust source areas while leaving wind erosion control to the re-established native vegetation on large portions of the drawdown zone.

Past, informal monitoring of the vegetation establishment within Upper Arrow has indicated that three primary vegetation communities exist within the treated (i.e. seeded/planted) portions of the reservoir (Moody, 1998):

- annually seeded fall rye at lower elevations (<434 m)
- sedge-based community incorporating other native wetland species in middle to upper elevation areas (434 – 436 m)
- reed canarygrass community with an understory of wetland species in the upper elevation areas (436+ m)

Native willows and other riparian shrubs are also beginning to establish in the upper most portions of the reed canarygrass zone. The sedge-based and reed canarygrass plant communities that have developed above 434m in elevation constitute a new, permanent wetland that has developed as a result of surface soil substrate stabilization and seed entrapment associated with several years of annual fall rye seeding for dust control

This new wetland, locally referred to as the Revelstoke Wetlands, is tolerant of the variability in the regulated water regime of the Upper Arrow Reservoir. While exposed during annual drawdown (late winter through early summer), the vegetation is used for food and shelter by numerous bird species, small and large mannals, and small reptiles. When submerged during reservoir recharge and storage (early summer through late fall), the vegetation is a source of nutrients, carbon and structural habitat to aquatic organisms. Over the past decade, there have been anecdotal reports related to the ecological and social benefits from the revegetated drawdown zone, including increased wildlife usage, improved trout fishing, and associated recreational use. However there has been no formal assessment (quantitative or qualitative) of these ecological values and/or usage.

In 1999, a program of field studies was initiated at Upper Arrow Reservoir (Revelstoke Reach) to explore and quantify (within budget limitations) benefits arising from the new wetland that had established within reservoir drawdown zone. Initially the studies, funded under the BC Hydro Strategic Environmental Initiatives Program (SEIP), focused on contributions to the aquatic environment (i.e. fish habitat and periphyton production), but were expanded in the second and third years to include benefits to the terrestrial ecosystem and local recreation. An underlying goal of the SEIP program is to be able to evaluate the potential of expanding the use of reservoir revegetation in drawdown zones for environmental enhancement at other BC Hydro reservoirs.

One of the core field studies within the Upper Arrow Study was the quantification of vegetation inputs (biomass, nutrients and carbon) from the new wetlands available to the aquatic and terrestrial phases of the ecosystem within Revelstoke Reach. A literature review of fish/ vegetation interactions in aquatic systems, with an emphasis on reservoirs, was undertaken in 1999 (AIM et al., 2000). The review found strong evidence linking fish use and submerged vegetation, but little specific information with respect to salmonids. The review also noted that while wetland and shoreline plant species may contribute large quantities of biomass and nutrients to aquatic food webs, the species of plants common to reservoirs in B.C. (with the exception of reed canarygrass) have minimal biomass or nutrient values reported in the literature. This lack of data also makes difficult any inferences of the potential value of the wetlands to terrestrial ecosystem values. In 1999, a pilot study was undertaken on the vegetated areas within the drawdown zone associated with the dust control seeding program to begin to provide some information on the value of these wetland (AIM and CARR, 2000). This study provided insight into the range in values for various parameters of interest within the vegetated communities, and helped identify sampling issues that would need to be addressed in the second year of the field program.

1.1 Objectives

The quantification of vegetation inputs (biomass, nutrients and carbon) from the new wetlands available to the aquatic and terrestrial phases of the ecosystem within Revelstoke Reach will provide important data to assist in the evaluation of the ecological and social benefits of reservoir revegetation at Upper Arrow, and allow for inferences regarding its potential to mitigate environmental impacts at other reservoirs.

To help contribute to the overall assessment of the ecosystem value of the Revelstoke Wetlands, a field study was undertaken in 2000 to quantify the biomass, nutrient and carbon levels associated with the reservoir vegetation that has established over the past decade. Incorporating experience from the 1999 pilot study on vegetation assessment, the objectives of the 2000 vegetation field study were as follows:

- Quantify the distribution of vegetation and evaluate the colonization rates of native species within the revegetated areas in the Revelstoke Reach
- Quantify biomass, nutrients (N, P, & K) and carbon contributions of the plant communities to determine the potential nutrient contribution of vegetation to the surrounding ecosystems
- Develop a system for a long term monitoring program that examines relative abundance, species composition, and biomass within the study area.

This component of the Upper Arrow SEIP program will establish a baseline of key vegetation associated values that will contribute to evaluation of not only the current usage of the wetlands, but also a basis for on-going assessment as the wetland community develops over time.

1.2 Approach

The principal focus of the various field studies within the Upper Arrow SEIP project, including the vegetation study component addressed in this report, is the permanent wetland that has established in Revelstoke Reach as a result of the annual fall rye seeding program used for dust control in the Upper Arrow Reservoir. In 1990, dust source areas were identified (and labeled by letter) between the City of Revelstoke and Shelter Bay within the Revelstoke Reach (Figure 1). The annual seeding program, which was initiated in the late 1980's, focused on what was later identified as areas G and K near the airport. The seeding was primarily carried out on high priority dust source areas between elevation 430m and 438+m. In 1991, the program expanded significantly in response to complaints from the City of Revelstoke to include additional high priority dust source areas from area G through area U. As permanent vegetation established on former priority dust source areas over time, the temporary dust control seeding program shifted to source areas lower in elevation and further south in the reservoir. As of 1999, permanent vegetation (later referred to as the Revelstoke Wetlands) had developed on formerly seeded areas above 434m in elevation, and extended from area G through P, and became the area of interest for quantification of the benefits of reservoir revegetation.

In May/June 1999, an extensive pilot study was conducted throughout four of the largest areas of native recolonization within the area of interest, former dust control areas G, K, M, and P (Figure 1). The objective was to quantify preliminary information on the vegetation community that had established, and provide a basis for future field programs. The data from the pilot study were presented to BC Hydro in a report - Summary Of 1999 Vegetation and Soil Analyses (AIM and CARR, 2000).

A key outcome of the pilot study was modification of the sampling design to be more species specific in the vegetation and soil sampling instead of using an aerial cover approach. In the 1999 pilot study, vegetation and associated soil sampling used randomly selected 0.5 m^2 plots which contained highly variable plant community combinations of the three target species (reed canarygrass, fall rye and lenticulate sedge). A decision was made to attempt to reduce the variability in the biomass and nutrient estimates through a combination of species specific sampling and quantification of the proportion of each species in the plant community. This new sampling procedure allows for better analysis of reservoir elevation impacts on the target species, as well as contributing to the airphoto-based mapping of vegetation in the Revelstoke Reach undertaken in a separate contract (Moody, 2002).

Also as a result of the pilot program, the decision was made to concentrate future biomass and nutrient analyses on the species in the permanent vegetation cover and to forego further sampling of the temporary fall rye cover crop. The overall biomass and nutrient contribution of the fall rye to the productivity of the wetlands within Revelstoke Reach was small relative to the permanent vegetation. At best, the fall rye could be considered an ephemeral contributor to the ecosystem values of in Revelstoke Reach that will have little consistency from year to year depending upon the available growing season and reservoir recharge schedule.

The initial work plan for the 2000 sampling program proposed expansion of the areas sampled in 1999 (areas G, K, M, and P) to include all areas seeded within the Revelstoke Reach above el. 434 m. Due to delays in project approval for 2000, the reservoir elevation at the time of sampling in late June was rapidly approaching 434 m and access was (or became) cut off for all but two areas. As the water elevation was rising quickly, the decision was made to initially concentrate the vegetation and soil sampling on area P (one of the key areas from past studies that provided the full elevation range 434 m - 437+ m which was still accessible), with an expansion to the other areas as time and access allowed. Of the remaining target areas, only the vegetation sampling portion of the field survey on area G was completed before high water levels precluded continued safe access. The summer sampling program was terminated by the end of June.

The field sampling program was continued in early fall 2000. A drawdown of the reservoir to approximately el. 435 m in late September 2000 allowed for a post-inundation sampling of the higher (and accessible) elevations of areas P and G. The fall sampling provided an important opportunity to quantify the potential organic and nutrients inputs from the standing vegetation into the aquatic environment during to 3 months of inundation. More extensive biomass and soil sampling on area G was also completed as part of this second sampling program.

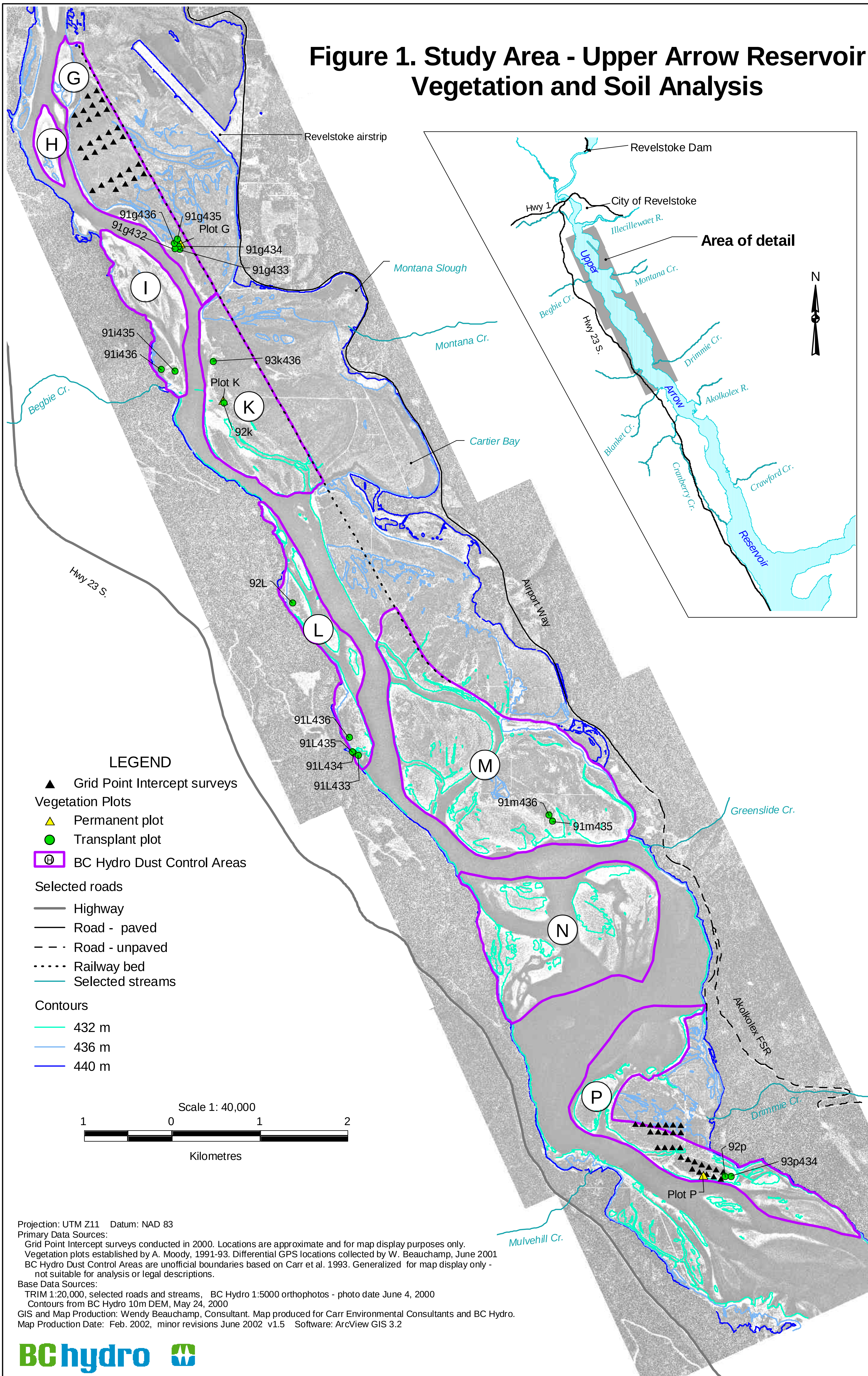


Figure 1. Study Area - Upper Arrow Reservoir Vegetation and Soil Analysis

Projection: UTM Z11   Datum: NAD 83
Primary Data Sources:
Grid Point Intercept surveys conducted in 2000. Locations are approximate and for map display purposes only.
Vegetation plots established by A. Moody, 1991-93. Differential GPS locations collected by W. Beauchamp, June 2001
BC Hydro Dust Control Areas are unofficial boundaries based on Carr et al. 1993. Generalized for map display only - not suitable for analysis or legal descriptions.
Base Data Sources:
TRIM 1:20,000, selected roads and streams,   BC Hydro 1:5000 orthophotos - photo date June 4, 2000
Contours from BC Hydro 10m DEM, May 24, 2000
GIS and Map Production: Wendy Beauchamp, Consultant. Map produced for Carr Environmental Consultants and BC Hydro.
Map Production Date: Feb. 2002, minor revisions June 2002 v1.5   Software: ArcView GIS 3.2

2.0 METHODOLOGY

2.1 Field vegetation survey

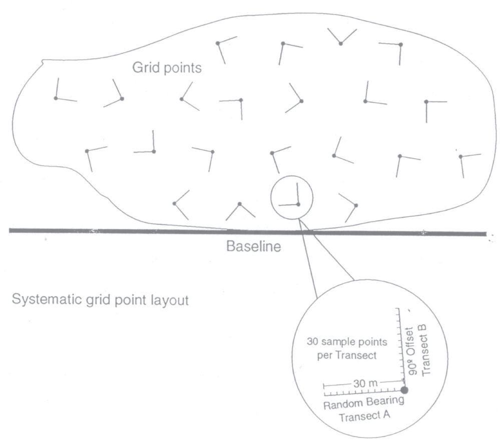
The composition and performance of the vegetation cover throughout the area of interest varies greatly due to elevation gradient, and there is a high degree of variability in species frequency and growth pattern that is not easily addressed using conventional vegetation mapping techniques. *Carex lenticularis* (lenticulate sedge), one of the two main sedges in the area, grows as dispersed, caespitose clumps up to 50 cm in diameter, while the *Carex aperta* (Columbia sedge) grows in larger, rhizomatous patches several square meters in area. The third major species, reed canarygrass (*Phalaris arundinacea*), appears as both pure stands and mixed with a variable proportion of the sedges and horsetail. To accommodate this variability in vegetation cover, a version of the Grid Point Intercept (GPI) soil disturbance inventory procedure developed for forestry applications was adapted to meet the requirements for a repeatable, statistically valid field sampling procedure that can address sporadic ground cover conditions. The main modification in the procedure was the recording of plant species encountered at the “point” instead of soil disturbance category.

The vegetation cover version of the GPI inventory used in this study for the spring sampling of area P and G followed the basic methodology outlined in the Forest Practices Code Soil Conservation Surveys Guidebook (BC MoF, 1997). A systematic grid of sampling points or locations is established throughout the area to be sampled at a sufficient density to provide a statistically valid sampling of the area. The number of grid points is determined by the size of the area, with a minimum of 25 well-distributed grid points. At each point (referred to as a grid point), a 30 m transect is established on a random bearing, and the vegetation type at one-meter intervals is recorded. A 90^{O} off-set is made and a second transect established (Figure 2). The ‘value’ for each point is comprised of percentage frequency of occurrence based on two 30-point sub-samples. Statistics are subsequently derived for the number of grid points for the area. The percentage value associated with the frequency of occurrence for each vegetation category (species or combination) is subsequently assumed to define percentage area cover (% cover) by that category.

The data recorded for each of the points on the sampling transect consisted of the plant species (or species combination) at a point directly below the transect line (i.e. tapes used for this procedure). Many times this was a single vegetation type (reed canarygrass, lenticulate sedge, bare ground, etc.), however there were instances where there was a vegetation mix at the point. For the mixed vegetation points (e.g. reed canarygrass intermixed with horsetail, Columbia sedge with reed canarygrass, etc.), all vegetation encountered was recorded with an associated dominance ranking. Statistical analysis concentrated on the dominant (or co-dominant) vegetation type at each point, but allowed for inferences about other understory or minor species contributions.

Figure 2

Figure 2: Diagram of Grid Point Intercept survey system



2.2 Species specific biomass, root and soil sampling

The basic sampling design for biomass, root and soil was different on areas P and G due to topographical differences, while the sampling procedure at each sampling location was similar. On area P, sampling locations were stratified into elevation bands (i.e. 434-435 m, 435-436 m, 436-437 m, and 437+m). The elevation bands were located based on 1986 orthophotos. Within each elevation band, three randomly located samples of each of the three dominant species were selected for biomass and soil analyses. The three samples were referenced to permanently established elevation reference points. These permanent reference locations were staked in the field and, in 2002, GPS referenced within the development of a GIS map for the project area. Future sampling should also be undertaken near the permanent reference point.

Reed canarygrass and lenticulate sedge were sampled in each of the four elevation bands on area P. Horsetail was sampled in the two lower bands, while Columbia sedge was the third species in the upper two bands. In the fall sampling, only the upper two elevation bands were available for post-inundation sampling, with species specific sampling conducted within 10 m of the permanent points established in June for those bands.

As there was little elevation variability on the portion of G accessible for biomass and soil sampling in October (predominantly a gradual elevation change between 436 and 437+ m), ten sampling locations were selected at random and referenced to the nearest grid point from the previous spring GPI sampling. At each of the sampling points, biomass and soil samples were collected for the two main species, i.e., reed canarygrass and lenticulate sedge. There was no significant presence of Columbia sedge in area G.

The plant species specific sampling procedure for biomass was consistent between the pre- and post-inundation sampling periods. Within each sampling band for area P, three species specific sampling locations were located for the target species. In the case of reed canarygrass, horsetail and Columbia sedge, the selection of the sampling plot was completely random within pure stands of each species. Above ground biomass sampling was conducted within a 0.5 m^2 circular plot which was clipped to ground level. The biomass was stored in plastic bags and kept refrigerated until the samples could be processed, air-dried and re-bagged in paper for shipment to the lab. The soil/root sample was taken to a depth of 30 cm at (or near) the center of the circle using a 10 cm diameter steel core. These cores were placed in plastic bags, kept cool, and shipped to the lab for immediate drying and processing

For the lenticulate sedge, a caespitose species, the three sampling locations were selected randomly from plants (clumps) with a consistent diameter of approximately 25 cm. The above ground biomass from the 25 cm diameter sedge clump was clipped to ground level, and processed as above. The soil/root core was taken from the center of the clump to a depth of 30 cm using the 10 cm diameter steel core, bagged and shipped to the lab.

In the September/October post-inundation sampling of area P and the fall sampling at the on area G, the same basic process was followed with the following exceptions. Only the two upper elevation bands (436 and 437+) were resampled on area P at this time due to the reservoir elevation, and the depth of the soil/root core was only 20 cm. This change in soil depth was a cost savings measure based on observations from the June samples where the small quantity of root in the 20-30 cm section was very difficult (i.e. time consuming and expensive) to separate from the soil. Overall, this is not expected to affect the data because the quantity of root below 20 cm in the cores was minimal, and contributed little to the relative overall root biomass and nutrient estimate. (Note: Five samples within areas P and G were taken to a depth of 50 cm for analysis as a preliminary step to check of the percentage contribution to the carbon and nutrient pools of the deeper soils. Preliminary analyses indicate that over 90% of the roots were contained in the 0-20 cm layer and the soil carbon level did not appear to change by depth below the 10-20 cm layer. Based on this information, the decision made to concentrate only on the surface soil layers).

2.3 Lab procedures for above ground biomass analysis

Above ground biomass samples were initially rinsed to remove accumulated sediment and soil particles, air-dried and shipped to Pacific Soil Analysis Inc. in Richmond for analysis. The samples were dried overnight at 70^0 C and weighed to determine the initial dry weight per 0.5 m^2 (or per plant in the case of *C. lenticularis*). The samples were ground using a Wiley Mill prior to chemical analysis. Total nitrogen (%N), phosphorus (%P) and potassium (%K) were determined on a peroxide-sulfuric acid digest of a sub-sample of the ground material. Total N and P were measured colorimetrically, and the K measured on an Atomic Absorption Spectrophotometer. A second sub-sample was also obtained, oven-dried at 105^0 C to determine oven-dry weight and dry ashed (% loss on ignition) to derive the biomass correction to ash free dry weight (AFDW – the standard reporting unit for biomass corrected to account for inorganic components of plant matter).

The post-inundation above ground samples taken in October were subdivided into standing live and dead components, which were weighed and analyzed as separate fractions. This allowed for estimation of potential nutrient and carbon losses into the aquatic environment due to three months of inundation. Statistical analysis of the data includes conventional analysis-of-variance (ANOVA), with elevation as the key treatment effect, and standard descriptive statistics. In addition to the nutrient analyses on each component, total soil carbon (%C) was also determined using a Leco Carbon Analyzer.

2.4 Lab procedures for soil/root cores

Once in the lab, the soil cores were divided into 10 cm increments for the depth of the sample, initially air-dried and subsequently oven-dried at 35^0 C. The oven dry samples were weighed to determine bulk density (g/cc) and separated into mineral and root (below ground biomass) components through sieving. The root component was weighed for each 10 cm depth increment, then recombined by core into a single sample for chemical analysis using the same procedures as the above ground biomass. Soil carbon (%C), using a LECO Carbon Analyzer, was determined on the June samples from area P by depth increment, and later on the October samples from area G and post-inundation sampling of area P. Statistical analysis of the data includes analysis-of-variance (ANOVA) and standard descriptive statistics.

3.0 RESULTS AND DISCUSSION

3.1 Field vegetation survey

The list of plant species encountered within the field vegetation survey is presented in Table 1, although this is not an exhaustive list of species that may be found in the reservoir. Species presence and abundance, especially that of annuals, may change from year to year.

Table 1: List of indigenous plants encountered within the Upper Arrow drawdown zone

Scientific Name	Common Name
Agrostis alba	redtop
Alopecurus aequalis	water (short awned-)foxtail
Alopecurus pratensis	meadow foxtail
Calamagrostis canadensis	bluejoint
Capsella bursa-pastoris	shepherd's purse
Carex aperta	Columbia sedge
Carex aquatilis	water sedge
Carex bebbii	Bebb's sedge
Carex lenticularis	lenticulate sedge
Carex rostrata	beaked sedge
Equisetum fluviatile	water horsetail
Equisetum hyemale	scouring rush
Juncus balticus	arctic rush
Phalaris arundinacea	reed canarygrass
Phleum pratense	timothy
Poa annua	annual bluegrass
Polygonum amphibium	water smartweed
Polygonum aviculare	common Knotweed
Polygonum coccinueum	smartweed
Polygonum lapathifolium	green smartweed
Polygonum persicaria	lady's thumb
Trifolium pratense	red clover
Scirpus microcarpus	small-fruited bulrush
Senecio vulgaris	common groundsel
Stellaria media	chickweed

The presence and abundance of many of the annual weedy species may change from year to year due to the influence of reservoir water regime and the density of the permanent vegetation cover. In most years, the reservoir level rises, flooding the annual weedy species prior to seed maturation and thus minimizing seed bank development. As well, the increase in the perennial vegetation cover of reed canary grass and sedges is also a major deterrent to the germination and establishment of weedy species (including “noxious weeds”) within the reservoir. No increase in abundance or distribution of the annual weedy species has been noted over the time period from 1990 – 2000 (AIM, unpublished observations).

The B.C. Weed Control Act (1998), administered by the B.C. Ministry of Agriculture and Food, has identified 21 specific “noxious weeds” throughout the province and an additional 19 within the boundaries of regional districts. Five regional “noxious weeds” are identified for the Columbia-Shuswap. These include:

- blueweed (*Echium vulgare*)
- burdock (*Arctium* spp.)
- common tansy (*Tanacetum vulgare*)
- orange hawkweed (*Hieracium aurantiacum*)
- sulphur cinquefoil (*Potentilla recta*)

Sporadic, isolated occurrences of scentless chamomile (*Matricaria maritime*), a provincial “noxious weed”, and Sulphur Cinquefoil (*Potentilla recta*), a regional “noxious weed”, have been noted in the drawdown zone during the decade of field studies in the area. None were encountered in the field assessments undertaken in 2000.

A summary of the results of the GPI field survey of vegetation cover are presented in Table 2 for areas P and G, with the detailed data in the Appendix. The sum of the percent cover in both areas is greater than 100% due to the presence of co-dominant or multi-species plant communities within the areas. Although both areas are dominated by reed canarygrass and, to a lesser extent horsetail, there are significant differences in species frequency between the two areas due to the elevation range over which they were sampled. As the lower elevation areas were not available for sampling on area G during this study, we cannot directly compare the results from two areas and only infer reasons for the differences. Area P, which has an elevation range 434 - 437+ m, has a higher percentage of lenticulate sedge coverage and less reed canarygrass than area G. This probably reflects a higher tolerance of lenticulate sedge in the lower elevation areas of area P which are subject to greater inundation depth and periods.. This ability of the lenticulate sedge to thrive with three and four meters of inundation in the reservoir was evident from planting trials conducted by AIM in the early 1990’s (AIM, 1998).

Table 2: Frequency of occurrence (%) for plant species on areas P and G

Area	Reed canarygrass	Lenticulate sedge	Horsetail	Other species**	Bare ground
P (434+ m) (95% C.I.)*	65% (± 8%)	28% (± 7%)	34% (± 10%)	20% (± 11%)	8% (± 4%)
G (436+ m) (95% C.I.)*	86% (± 7%)	10% (± 4%)	39% (± 11%)	13% (± 7%)	2% (± 1%)

* Denotes 95% confidence interval based on 29 GPI for P and 30 GPI for G.
** Other species encountered, such as those listed in Table 1, are noted on data forms.

In area G, which was sampled over a more limited elevation range (436 - 437+ m), the reed canarygrass is far more dominant, reflecting a more aggressive and competitive growth habit at higher elevations. In environments that are optimum for reed canarygrass growth, i.e. short periods of inundation, it tends to form a monoculture, suppressing the growth and colonization of other wetland species. Although there is a minor component of lenticulate sedge and some other wetland species, it appears that the combination of water regime and elevation in the portion of area G sampled is approaching optimal conditions for reed canarygrass dominance. The lenticulate sedge, which was shown to grow well at higher elevations in the earlier plant trials (AIM, 1998), appears to be strongly suppressed by the vigorous growth of the reed canarygrass.

Of particular interest in the survey of area G was the continued persistence of the inundation tolerant, commercially available agronomic species used in the 1992 dust control planting operation (Carr et al., 1993). The species used in this trial (redtop, timothy, and creeping meadow foxtail) have not spread widely outside their original planting area as hoped, probably due to the dominance of the reed canarygrass. However their continued presence after nine years opens possibilities for expansion of future seeding programs in the upper elevations of other reservoirs to promote greater plant diversity through the incorporation of commercially available wetland grasses in the early stages of seeding programs.

The modified GPI survey technique appears to be very suitable for the patchy, sporadic establishment pattern of the sedges and other wetland species found in conjunction with the more continuous reed canarygrass stands. The sampling system was relatively quick to undertake, can easily be repeated on a periodic basis, and provides quantitative data on species density that can be monitored over time. The results from this type of survey can complement other analyses performed using airphotos (AIM, 2002) and digital terrain modeling. It also facilitates extrapolation of the results from the vegetation and soil sampling to the entire study area.

3.2 Standing crop biomass

3.2.1 Species effects

The species specific sampling approach used in 2000 allowed for a clearer understanding of the contribution of individual species to overall vegetation production in the revegetated portion of the Upper Arrow drawdown zone. Analysis of the June 2000 standing biomass data for area P (Table 3) revealed significant differences on an area basis (per m^2) between all species except between Columbia sedge and reed canarygrass. The lenticulate sedge, with its dense, caespetose growth form, was by far the highest biomass producing species with a mean shoot AFDW of 2061.1 g/m^2. This species accounts for approximately 28% coverage of area P, but dominates the total shoot biomass (76.3 t/ha) on a per hectare basis at 73.0%.

Table 3: Summary of June 2000 standing biomass (g/m^2 AFDW) for area P by species, averaged over the 434m – 437+m, and contribution per hectare (t/ha) based on data from Table 2.

Biomass	Reed canarygrass	Lenticulate sedge	Columbia sedge	Horsetail
Species total/m^2	280.4 g/m^2 b*	2061.1 g/m^2 a	471.9 g/m^2 b	66.0 g/m^2 c
Species total/ha (based on coverage) **	18.2 t/ha	55.7t/ha	0.2 t/ha	2.2 t/ha
% contribution (based on total/ha)	23.8%	73.0%	0.3%	2.9%

* within row, values with different letters are statistically different using ANOVA at p=.05
** weighted by percent occurrence per species based on Table 2

Although shoot biomass production for both of the rhizomatous species (i.e. reed canarygrass and Columbia sedge) did not significantly differ between the species on an area basis, there was a general trend for the Columbia sedge to have higher production per m^2 at each sampling site. However with a 65% area coverage (as inferred from frequency data), the reed canarygrass is a significantly more important contributor to overall biomass at 23.8% than the more sparse Columbia sedge at this time. Horsetail, which occupied 34% of the area in either pure stands at the lower elevations of area P or as an understory in the higher elevations is a very minor contributor of biomass to the ecosystem.

3.2.2 Elevation effects

The June biomass data revealed an overall trend of higher biomass with higher elevation for the three main species (Table 4). A high degree of variability with the low sample number (3/ elevation/species) has probably precluded this trend from being statistically significant at the

95% level of confidence, indicating the need for considering increased sampling in future monitoring if justified by the objectives. However this pattern is consistent with the previous year's biomass sampling results (CARR and AIM, 2000). Lenticulate sedge showed, as in the 1999 data, a tendency toward declining biomass after peaking at elevation 436 m. This may reflect increasing competition from reed canarygrass which dominated the vegetation cover in the higher elevation bands.

Table 4: Standing biomass (g/m^2 AFDW) for area P by species and elevation (June data)

Elevation	Reed canarygrass (g/m^2)	Lenticulate sedge (g/m^2)	Columbia sedge (g/m^2)
434 m	240.1	1502.7	n/a
435 m	262.5	1952.7	n/a
436 m	148.4	2621.0	416.0
437+ m	470.4	2167.7	527.7

3.2.3 Effect of inundation

For the post-inundation assessment in October, the standing biomass was separated into standing live and standing dead fractions to help understand the impact of three months of inundation on each species. Leaves that were partially dead (i.e. brown tipped) were considered live, while only leaves that were predominantly brown classified as dead. No attempt was made to subdivide individual leaves into live or dead portions. Only reed canarygrass, lenticulate sedge and Columbia sedge were included in the sampling. At 435m - 437+ m, which was the elevation range exposed by that date, there were insufficient pure stands of horsetail available for sampling.

By October, the average live standing biomass (averaged for the three species) was approximately half of the June standing crop (Table 5). Over the entire elevation range sampled on area P, the lenticulate sedge demonstrated the greatest level of die-back, retaining approximately one-third of its pre-inundation biomass as live material. The reed canarygrass retained slightly more than half of its June biomass as live material. Columbia sedge appeared to be the most tolerant of inundation, retaining over 60% of its biomass as live material.

Table 5: Above ground biomass (g/m^2 AFDW) for area P for each species as a function of condition (live or dead) after inundation (October data)

	Reed canarygrass	**Lenticulate sedge**	**Columbia sedge**
Standing Live (g/m^2 AFDW)	127.0	540.9	235.0
Standing Dead (g/m^2 AFDW)	102.9	1054.2	151.3
Total (g/m^2 AFDW)	**229.9** a*	**1595.2** b	**386.3** a
% Die back	44.8%	66.1%	39.2%

* within row, values with different letters are statistically different using ANOVA at p=.05

However this may be misleading as Columbia sedge only appears in the higher elevation bands which were subject to less total inundation than the other species that are present over the entire elevation range. For all species, total biomass losses at 437+ m between June and October sampling consistently exceeded that from the lower elevations (Table 6).

Table 6: Percent change in standing live biomass due to inundation and elevation

Elevation	**Reed canarygrass**	**Lenticulate sedge**	**Columbia sedge**
435 m	-56%	-72%	n/a
436 m	-61%	-78%	-38%
437+ m	-71%	-75%	-55%

Inundation also had a further impact on the aboveground biomass through a significant loss from the site of shoot material between the pre- and post-inundation assessments (Table 7). Overall, with approximately 50% of the total standing crop sampled in October classified as standing dead material (i.e. die-back) and the higher elevations more susceptible to physical breakage by surface wind and wave action, this pattern of increased loss of biomass with increasing elevation is not unexpected. Total biomass loss may also include the impacts of waterfowl grazing on exposed or slightly submerged vegetation accessible while the reservoir fluctuated during operations over the summer. Considerable waterfowl grazing on the partially inundated vegetation could also have occurred, with geese in particular observed floating above vegetated areas and feeding on exposed or near surface tips of the vegetation.

Table 7: Percent change in above ground biomass due to inundation and elevation

Elevation	Reed canarygrass	Lenticulate sedge	Columbia sedge
435 m	-25%	-22%	n/a
436 m	-28%	-21%	-5%
437+ m	-46%	-35%	-22%

3.3 Biomass nutrient content

3.3.1 Nitrogen (N)

The nitrogen content (%N) from the June sampling on area P showed a statistically significant trend for increased %N with increasing elevation in the shoots of reed canarygrass and lenticulate sedge (Table 8). Elevation differences within shoots of these two species were significant for all intervals except between 436 m and 437+ m, with the greatest difference between 435 m and 436 m.

Although more in depth research would be required to identify the reasons for this key threshold elevation break, it appears that over the years soil fertility (as indicated by soil carbon level) in the higher elevations has improved with the higher biomass production (refer to later section 3.5.1). In the upper two elevation bands, the Columbia sedge shoots had a significantly higher nitrogen content than the other species, probably reflecting inherent differences between the three main species.

A trend of slightly decreased nitrogen concentration of live shoots between the pre- and post-inundation sampling periods was evident for both sedges. There was also a significant decrease in nitrogen content between the standing live and dead shoots of all three species in the October sampling. The decrease in shoot nitrogen content could be associated with some leaching of nitrogen from the shoots while submerged or due to nutrient translocation into the roots as the shoots become stressed by inundation. However, more intensive sampling would be needed to determine the fate of “missing” shoot nitrogen to determine whether what portion has been leached into the aquatic system or translocated into the roots.

Table 8: Summary of N% in shoots and roots according to elevation and species

Species	Elev.	June 2000		October 2000		
		Shoot	*Root*	*Live Shoot*	*Dead Shoot*	*Root*
Reed Canarygrass	434 m	0.78% a**	0.68% a	na*	na	na
	435 m	0.99% b	0.64% a	1.04% a	0.60% a	0.84% a
	436 m	2.01% c	0.64% a	2.13% c	0.77% a	0.84% a
	437+m	1.63% c	0.88% a	1.61% b	0.73% a	1.19% a
Lenticulate sedge	434 m	1.22% a	0.78% a	na*	na	na
	435 m	1.35% b	0.52% a	1.28% ab	0.60% a	1.16% a
	436 m	1.63% c	0.65% a	1.16% a	0.73% a	1.12% a
	437+m	1.73% c	0.88% a	1.40% b	0.82% a	1.45% a
Columbia sedge	436 m	2.41% a	0.68% a	1.86% a	0.69% a	1.54% a
	437+m	2.23% a	0.61% a	1.52% a	0.69% a	1.46% a

* not available, 434 m was submerged at the time of sampling
** within columns, values for each species with different letters are statistically different at 95% level of confidence

3.3.2 Phosphorus (P)

Shoot phosphorus content (%P) for the June sampling was similar for the reed canarygrass and lenticulate sedge (Table 9). At the two higher elevations, the Columbia sedge shoot %P was significantly greater than the other two species. Although there was not a statistically significant decrease in %P in the live shoots between the pre- and post-inundation sampling, there was a consistent trend toward a decrease in %P between the live and dead shoots in October. Combined with what appears to be a higher root %P concentration between the pre- and post-inundation sampling, it appears that the phosphorus in stressed and dying shoots is translocated into the roots. This indicates a tight internal cycling of phosphorus and little direct release into the aquatic environment except through consumption of live material or detachment (breakage) of standing biomass. However, as with the nitrogen data, a more intensive study of nutrient movement within the wetland plants would be required to track the fate of plant associated phosphorus.

Table 9: Summary of P% in shoots and roots according to elevation and species

Species	Elev.	June 2000		October 2000		
		Shoot	*Root*	*Live Shoot*	*Dead Shoot*	*Root*
Reed Canarygrass	434 m	0.11% a**	0.11% a	na*	na	na
	435 m	0.15% a	0.08% a	0.13% a	0.08% a	0.11% a
	436 m	0.15% a	0.06% a	0.31% b	0.19% b	0.12% a
	437+m	0.26% b	0.11% a	0.23% ab	0.11% a	0.10% a
Lenticulate sedge	434 m	0.17% a	0.15% a	na*	na	na
	435 m	0.19% a	0.09% a	0.15% a	0.10% a	0.10% a
	436 m	0.15% a	0.07% a	0.17% a	0.12% a	0.12% a
	437+m	0.24% b	0.11% a	0.23% a	0.15% a	0.18% a
Columbia sedge	436 m	0.28% a	0.12% a	0.23% a	0.15% a	0.15% a
	437+m	0.29% a	0.12% a	0.21% a	0.17% a	0.23% a

* not available, 434 m was submerged at the time of sampling
** within columns, values for each species with different letters are statistically different at 95% level of confidence

3.3.3 Potassium (K)

The potassium concentration (%K) of the June shoots for reed canarygrass followed a similar pattern as the phosphorus concentration, with elevation influencing concentration (Table 10). However, unlike the phosphorus data, there was no elevation effect on the lenticulate sedge potassium concentration. Also as with the phosphorus data, Columbia sedge had the highest concentration for this nutrient of the three species.

Whereas nitrogen and phosphorus appear to be tightly cycled within the plants when subject to inundation, potassium leakage or export into the aquatic environment is more evident. The relatively large reduction in live shoot %K between the pre- and post-inundation sampling, with no corresponding increase in root concentration, indicates that the potassium may be readily leached from the shoots. However with phosphorus being the limiting nutrient in the Arrow Reservoir, the additional potassium is of questionable value to the aquatic habitat.

Table 10: Summary of K% in shoots and roots according to elevation and species

Species	Elev.	June 2000		October 2000		
		Shoot	*Root*	*Live Shoot*	*Dead Shoot*	*Root*
Reed Canarygrass	434 m	1.36% a**	0.83% a	na*	na	na
	435 m	1.77% ab	0.50% a	0.92% a	0.50% a	0.43% a
	436 m	2.18% b	0.57% a	1.61% b	0.80% b	0.68% a
	437+m	2.07% b	0.54% a	1.51% b	0.50% a	0.43% a
Lenticulate sedge	434 m	2.16% a	0.67% a	na*	na	na
	435 m	2.22% a	0.73% a	1.22% a	0.80% a	0.49% a
	436 m	2.20% a	0.59% a	1.07% a	0.70% a	0.68% a
	437+m	2.19% a	0.54% a	1.06% a	0.60% a	0.65% a
Columbia sedge	436 m	2.31% a	0.61% a	1.58% a	0.60% a	0.61% a
	437+m	2.34% a	0.77% a	1.45% a	0.77% a	0.77% a

* not available, 434 m was submerged at the time of sampling
** within columns, values for each species with different letters are statistically different at 95% level of confidence

3.3.4 Potential nutrient contribution to the aquatic system

Sampling of biomass pre- and post-inundation and a segregation of the samples into live and dead components have allowed for an initial calculation of the aboveground biomass loss during the period of inundation (Table 11). The most significant export of biomass appears to be from lenticulate sedge with a net export of over 500 g/m^2, followed by reed canarygrass with an export of approximately 100 g/m^2. Columbia sedge, although a large producer of aboveground biomass, is able to retain more of its shoot in a viable form much later into the fall season than either of the other two species.

Table 11: Aboveground losses between June and October 2000 due to inundation, averaged over all elevations.

Species	Biomass g/m^2	N g/m^2	P g/m^2	K g/m^2
Reed canarygrass	-108.5	-1.9	-0.3	-4.5
Lenticulate sedge	-555.5	-12.4	-1.7	-34.8
Columbia sedge	-67.6	-4.2	-0.5	-6.1

Due to the high biomass loss from lenticulate sedge, the calculated nutrient losses were correspondingly greater than the other species with over 12 g/m^{2}of nitrogen, 35 g/m^{2}of potassium and 2 g/m^{2}of phorphorus exported. Root analyses indicated a trend toward accumulation of both nitrogen and phosphorus in the below ground component at the end of the season. However, at this time we do not have sufficient data to reliably calculate the magnitude of this transfer versus export into the water column.

3.4 Soil bulk density

Soil bulk density is not only an important parameter in the calculation of the soil carbon pool, it is a key indicator of soil development on degraded soils and enhancement of soil porosity. Analysis of the June soil bulk density measurements from all four elevation bands on area P and the October sampling of the upper band on area G indicates a strong influence of species and elevation on the decrease in soil bulk density (Table 12). This decrease parallels previous data on biomass production, which through root growth and incorporation of detritus, is the causative agent in reducing soil density.

Table 12: Soil bulk density (g/cc) by elevation and depth for each species

Depth	**Area - Elevation**					
	P-434 m	**P-435 m**	**P-436 m**	**P-437+ m**	**G-436+ m**	**Control ****
Reed Canarygrass						
0-10 cm	1.06 a*	1.17 a	0.71 a	0.57 a	0.80 a	1.29 a
10-20 cm	1.05 a	0.98 a	1.02 b	1.09 b	1.14 b	1.31 a
20-30 cm	1.27 b	1.24 b	1.17 c	1.14 b	n/a	1.35 a
Lenticulate sedge						
0-10 cm	0.66 a*	0.52 a	0.37 a	0.41 a	0.64 a	1.29 a
10-20 cm	0.95 b	0.93 b	1.01 b	0.80 b	1.001 b	1.31 a
20-30 cm	0.99 b	1.20 c	1.17 c	1.21 c	n/a	1.35 a
Columbia sedge						
0-10 cm	***	***	0.47 a	0.41 a	***	1.29 a
10-20 cm	***	***	0.94 b	0.80 b	***	1.31 a
20-30 cm	***	***	1.12 b	1.20 c	***	1.35 a

* within columns for each species, values with different letters are statistically different by depth at 95% level of confidence
** Control samples are from a surrogate control area at Blanket Creek
*** Species not present for sampling

The bulk density pattern over depth for all three species demonstrates a decrease in soil density in the surface soil layers compared to no change over depth of the surrogate control (to be referred to as the control) from a non-vegetated area near Blanket Creek. (This surrogate control approximates the soil condition before seeding began in the early 1990’s. Due to the operational goals of the initial seeding program, no control or unseeded areas were left in the main dust control areas.) The accumulation of roots and soil organic matter is greatest in the surface 0-10 cm layer where the majority of roots tend to occur, and this is the zone of lowest soil density. However, all three species appear to be developing sufficient root systems into the lower two layers (10-20 cm and 20-30 cm) to effect a change in soil density compared to the control at similar depth.

The data (0-10 cm and 10-20 cm only) from October for the 436+ m elevation on area G for reed canarygrass and lenticulate sedge parallels the trends observed on area P. However there was an unanticipated change in soil texture on area G, from a sand to a silty sand, over 10 years that was not related to vegetation organic matter inputs. The vegetation on area G has significantly increased the surface roughness, affecting sediment trapping in this higher elevation area near the Illecilleweat River, the source of the sediment in the reservoir. This trend toward sediment trapping and development of a finer textured soil (i.e. higher moisture holding capacity) is worth watching in the future, especially for the potential impact on species composition of the vegetation community.

3.5 Carbon Pool

The results from the carbon assessment on the survey areas, P and G, follow the trends found in the biomass (above ground and root) and soil bulk density sampling as one would expect. The carbon pool is an integration of the organic inputs from the vegetation, its distribution, accumulation and incorporation into the soil profile. Species and elevation have been shown to play a role in the performance of the vegetation throughout the study areas, and this continues with organic carbon distribution and accumulation. The biomass components were converted to carbon using the determined value of the shoots and roots being 45% carbon based on the tissue analysis from 1999. (AIM and CARR, 2000).

3.5.1 Soil carbon

The total soil carbon analysis on the soil from area P demonstrated a significant effect of species and elevation (Table 13) as expected, since it is the quantity of organic inputs (shoot and root detritus) and their subsequent incorporation into the soil matrix that changes the soil carbon content over time. The elevation influence on reed canarygrass production is evident in the surface horizon carbon concentration, with soil carbon concentration in the surface horizon (0-10 cm) increasing from approximately 1% at 434 m and 435 m to approximately 2% at 436 m, and over 3% at 437+ m. It appears that the reed canarygrass sloughs a large percentage of its roots annually. Neither of the sedge species exhibited this strong of a pattern, probably a reflection of their growth habit to tightly cycle nutrients internally and develop significant root accumulations in the surface soil layer.

The data also demonstrate the significant effect of soil depth on carbon accumulation, with most of the carbon in the upper 10 cm, the area with the highest root biomass. There is a rapid decrease in carbon concentration in the lower two layers. When compared to the soil carbon level from the surrogate control area, 0.20%C throughout the soil depth of interest, it also appears that the accumulation of soil carbon appears to continue past 30 cm.

Table 13: Total soil carbon (%) by elevation and depth for each species

Depth	**Area - Elevation**					
	P-434 m	**P-435 m**	**P-436 m**	**P-437+ m**	**G-436+ m**	**Control ****
Reed Canarygrass						
0-10 cm	0.93% a*	0.81% a	1.96% a	3.27% a	1.73% a	0.19 % a
10-20 cm	0.94% a	1.22% a	1.15% b	1.34% b	0.87% b	0.18% a
20-30 cm	0.27% b	0.99% a	0.73% c	0.89% c	n/a	0.18% a
Lenticulate sedge						
0-10 cm	2.27% a*	1.91% a	2.17% a	3.22% a	1.87% a	0.19 % a
10-20 cm	1.04% b	1.09% b	1.22% b	1.52% b	0.99% b	0.18% a
20-30 cm	0.87% b	0.49% c	0.43% c	1.13% c	n/a	0.18% a
Columbia sedge						
0-10 cm	***	***	0.47 a	0.41 a	***	0.19 % a
10-20 cm	***	***	0.94 b	0.80 b	***	0.18% a
20-30 cm	***	***	1.12 b	1.20 c	***	0.18% a

* within columns for each species, values with different letters are statistically different by depth at 95% level of confidence
** Control samples are from a surrogate control area at Blanket Creek
*** Species not present for sampling

The potential for soil carbon accumulation deeper in the soil profile was further investigated in a limited number (5) of deeper core samples (50 cm) taken in the reed canarygrass stands. The carbon concentration was consistently between 0.75% and 0.90% from 20 to 50+ cm in depth (Appendix D). Although very preliminary, future total carbon pool analyses and estimates of sequestration should address the deeper soil layers. The 20-30 cm layer contains roughly 10 tC/ha, a significant proportion of the total pool, indicating that the soil below 30 cm in the profile could further contribute significant carbon quantities to the carbon pool determination.

3.5.2 Total carbon pool

The total carbon pool, above ground biomass through the 30 cm soil depth, is presented by species in Tables 14, 15 and 16.

Table 14: Carbon pool (kg/m^2) distribution for reed canarygrass

Depth	Area - Elevation					
	P-434 m	**P-435 m**	**P-436 m**	**P-437+ m**	**G-436+ m**	**Control**
Shoot	0.11	0.12	0.07	0.21	0.16	0.0
Root	0.46	0.46	0.64	0.65	0.67	0.0
Soil 0-10 cm	1.01	0.81	1.39	1.88	1.58	0.24
Soil 10-20 cm	0.97	1.22	1.15	1.46	1.17	0.23
Soil 20-30 cm	0.54	0.99	0.81	1.02	0.59	0.24
TOTAL (95% C.I.)	**3.08** ($\pm$1.00)	**3.60** ($\pm$0.72)	**4.06** ($\pm$0.23)	**5.22** ($\pm$0.47)	**4.81** ($\pm$0.46)	**0.71**

Table 15: Carbon pool (kg/m^2) distribution for lenticulate sedge

Depth	Area - Elevation					
	P-434 m	**P-435 m**	**P-436 m**	**P-437+ m**	**G-436+ m**	**Control**
Shoot	0.68	0.88	1.05	0.98	0.20	0.0
Root	1.37	1.23	1.22	3.71	1.70	0.0
Soil 0-10 cm	1.45	0.96	0.84	1.31	1.19	0.24
Soil 10-20 cm	0.98	1.01	1.25	1.21	1.26	0.23
Soil 20-30 cm	0.86	0.61	0.51	1.36	0.63	0.24
TOTAL (95% C.I.)	**5.34** ($\pm$1.02)	**4.69** ($\pm$0.65)	**4.87** ($\pm$0.23)	**8.57** ($\pm$1.11)	**4.98** ($\pm$1.11)	**0.71**

Table 16: Carbon pool (kg/m^2) distribution for Columbia sedge

Depth	Area - Elevation					
	P-434 m	P-435 m	P-436 m	P-437+ m	G-436+ m	Control
Shoot	**	**	0.17	0.24	**	0.0
Root	**	**	2.85	3.71	**	0.0
Soil 0-10 cm	**	**	1.65	1.30	**	0.24
Soil 10-20 cm	**	**	1.34	0.83	**	0.23
Soil 20-30 cm	**	**	1.37	0.50	**	0.24
TOTAL (95% C.I.)	**	**	**7.38** ($\pm$2.60)	**6.58** ($\pm$0.89)	**	**0.71**

** denotes no significant presence of species for sampling

Although the trends in the total pool parallel the biomass patterns to a degree, there are some differences.. This to be expected as the carbon pool is an integration of organic matter accumulations over the past 9 years on formerly bare areas, and the current biomass measures are more reflective of growth performance over the past two or three years in response to growing season and water regime. (For this comparison, the 20-30 cm layer of area G, which was not sampled as part of the main study in October, has been assumed to contain one-half of the carbon in the 10-20 cm layer. This is based on limited deeper soil analyses conducted parallel to the main study.)

In area P, the reed canarygrass carbon pool demonstrated a significant elevation influence, increasing progressively with increasing elevation (Table 14). The lenticulate sedge carbon pool was also affected by elevation, however it is not until the highest elevation (437+ m) that there is a significant increase in total carbon production (Table 15). At the higher elevations, it also appears that both sedge species produce more carbon on an area basis (per m^2) than the reed canarygrass, and it may be prudent from a purely carbon perspective to promote sedge as opposed to reed canarygrass. However without direct intervention, the reed canarygrass will dominate in the higher areas, as previously found on area G, due to its more aggressive growth habit.

It is also evident that the pattern of carbon distribution differs by species. The reed canarygrass has only 15 -17% of its carbon in biomass, mostly in its roots, and the remainder of its associated carbon pool has been incorporated into the soil. The two sedge species are much tighter carbon systems, with 35% to over 50% of the carbon still in the plant. However, they too demonstrate growth form differences. The Columbia sedge has a far higher percentage than the lenticulte sedge of its biomass carbon in the roots (38% to 56%) compared to the shoot component (2% to 4%). Further study of these differing carbon storage mechanisms is warranted from a vegetation management perspective to potentially direct vegetation cover development to meet differing objectives, such as palatability or nutritional values. For example, lenticulate sedge could be favored for fish or wildlife enhancement objectives with more carbon in its shoots available to predation, where reed canarygrass and Columbia sedge have most of their carbon below ground and less available to utilization.

In Table 17, an estimate of the average total carbon pool (tC/ha) for area P and G has been developed using the species composition data from the field survey and averages for each species within the respective areas. On a per hectare basis, there is no significant difference for the carbon production at either site using the averages, although there are differences in elevation distribution and cover composition. Elevation trends would be expected with refinement of this calculation by elevation, which should be possible when the new orthophotos are completed and the grid-points in the GPI survey are stratified by elevation. The important interpretation from this data is the level of carbon sequestration (accumulated carbon in the both the above and below ground biomass and as soil organic carbon) achieved by the revegetation of what was previously a problem source drawdown zone.

Table 17: Weighted average total carbon pool (tC/ha to 30 cm soil depth) based on field survey of plant cover composition and average carbon totals for each major species.

Dominant Species*	**Area P**		**Area G**	
	% cover	Weighted C contribution	% cover	Weighted C contribution
Reed canarygrass	65%	25.5	86%	36.4
Lenticulate sedge	27.5%	16.1	11%	5.0
Columbia sedge	0.5%	<0.1	0	0
Bare soil	8%	0.5	3%	0.2
Weighted TOTAL		**42.1 tC/ha**		**41.6 tC/ha**
vs. Control (bare soil)**	100%	7.1 tC/ha	100%	7.1 tC/ha

* dominant plant species represents a grouping of plant data recorded during the GPI survey into categories of principal species
** bare soil is the unvegetated sandy material from Blanket Creek

The net sequestration, total carbon pool to a soil depth of 30 cm in 2000 minus control (or bare soil) content assumed at the beginning of the seeding program, is approximately 35 tC/ha in less than 10 years. This is a level that will increase over time as the vegetation cover continues to build root and soil carbon reserves until reaching a steady state maximum for this unique ecosystem. Aside from the dust control, recreation, fish and wildlife habitat enhancement, and other benefits of reservoir revegetation, the potential for carbon sequestration and carbon off-sets should be further investigated.

4.0 SUMMARY AND RECOMMENDATIONS

4.1 2000 field program

The species specific sampling approach implemented in 2000 yielded biomass values that allowed for a clearer understanding of the contribution to production of the revegetated Upper Arrow drawdown zone for the vegetation communities as a whole and individual species performance and contribution. There are major differences not only in the distribution of the wetland species that have recolonized the drawdown area according to reservoir elevation, but also the amount of biomass produced by individual species within and across the elevation range (434 m - 437+ m) of permanent vegetation establishment. The effect of recolonization on soil development and carbon accumulation parallels, for the most part, the biomass patterns of the vegetation.

As of 2000, 434 m appears to be the lower boundary for extensive recolonization by wetland species, although this will be determined in the long run by reservoir operation. Several consecutive higher than average water level years will probably raise this lower limit, while several lower years may allow for extension of the permanent vegetation community to lower elevations. Reed canarygrass and lenticulate sedge are the two predominant wetland species throughout the permanently recolonized zone, with both species heavily influenced by reservoir elevation. The higher the elevation within the zone of recolonization, the more dominant reed canarygrass becomes and the lenticulate sedge goes from a co-dominant species to more of an understory species. The Columbia sedge is found in sporadic patches above 435 m, but has does not appear to compete well with the reed canarygrass at the higher elevations.

The growth performance of the vegetation in terms of biomass and nutrient status also appears to be sensitive to elevation change for all species. On a per unit area basis (g/m2), the lenticulate sedge is by far the highest biomass producer and highest net exporter of vegetation into the aquatic environment during inundation. Production of the reed canarygrass and Columbia sedge is similar, with the reed canarygrass's contribution to the ecosystem far greater due to its dominant presence throughout the area.

Initiation of the development of soil horizons, particularly in the higher elevation areas (436 m and 437+ m), within 10 years is very encouraging from a wetland reclamation perspective. The increases in soil total carbon, especially in the soil surface layer (0 - 10 cm) but extending down to 30 cm, are very significant and strong indicators that this permanent vegetation community should continue to develop and thrive. The quantity of new carbon now sequestered in the vegetation, roots and soil within 10 years indicates that promotion of wetland development in drawdown zones may be a potential type of project for BC Hydro to pursue in the development of carbon off-set credits.

4.2 Recommendations for future vegetation and soil monitoring

The revegetation program for the Upper Arrow drawdown zone has been a success not only in controlling dust generation, but also provided the basis for numerous spin-off benefits to the area generally associated with wetland development. Among these are increased recreational use, improved (and new) wildlife habitat, and vegetation associated nutrient and carbon inputs into the aquatic environment. Efforts to expand this type of program within the BCH reservoir network have already begun at Williston Reservoir and Stave Reservoir, with the potential for expansion to other areas. As this type of program is unique in managed reservoir systems throughout the world, only the Upper Arrow program is currently available to provide long-term insight as to vegetation production and species development, as well as the influence of water regime management on wetland community establishment.

It has been only through both formal and informal monitoring of the Upper Arrow Dust Control Program over the past decade that BCH has been able to begin understanding the potential for vegetation establishment in drawdown zones. The plant community successional patterns have been shown to be sensitive to reservoir elevation and the dynamics of annual inundation, key factors affecting the future use of reservoir revegetation that need long-term study. Continued assessment of the soil/vegetation carbon pool appears to be warranted given the Corporation's interest in acquiring carbon off-set credits. Other parameters associated with the new wetlands, such as biomass and nutrient distribution, provide important information on this new type of ecosystem and should be part of a long-term monitoring program if BCH wishes to contribute to the science of drawdown zone enhancement.

Both the airphoto assessment (AIM, 2001) and field sampling program undertaken in 2000/2001 have provided an excellent test of methods that should be incorporated into a long-term monitoring program. Although the objectives of such a program will determine the specifics with regard to frequency and level of detail, the airphoto assessment appears to be a very cost-effective method for gathering information on vegetation community dynamics (change in composition and rate of spread) within this extensive area. The level of detail obtained from 1:5000 scale airphotos, especially after scanning and enlargement, allows for easy stratification of the area into vegetation associations that can be related to orthographic elevation data. Only limited field verification is required by an experienced mapper, resulting in a relatively inexpensive assessment that will contribute significantly to BCH's understanding of vegetation community dynamics and the influence of water regime. This type of monitoring should be conducted on a periodic basis, at a minimum of every five years, or at an accelerated time frame in response to a major shift in water management that lasts for three years (at this time believed to be the threshold where significant changes in plant establishment and spread are realized).

The stratification of the vegetation communities using airphoto assessment is very important if (or when) a detailed assessment of biomass, nutrients, or soil parameters is required. The stratification will provide delineation of the detailed sampling units where the modified grid-point intercept method used in the 2000 field program can be applied. This type of approach will provide statistically valid determination of individual plant species presence and abundance within a specific plant community, key information to extrapolate subsequent data throughout the entire sampling area. Further detailed sampling of biomass, nutrients, or soil parameters should then focus on the dominant species found in each stratum. The sampling procedures employed in this study are appropriate for detailed biomass (standing and root), plant and soil nutrients, and carbon pool determination. The number of samples to be taken for each species and design of statistical analyses will be determined by the objectives and desired level of precision. It is important for BC Hydro to clearly define the goals and objectives (as well as precision) of any future detailed sampling program because the cost of laboratory analysis can be considerable.

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Appendix A

Grid point intercept data sheets: Area P and G

Plant species abbreviations on data sheets are as follows:

Ca	*Carex aperta* – Columbia sedge
Cl	*Carex lenticularis* – lenticulate sedge
Ef	*Equisetum fluviatile* – water horsetail
Fr	*Secale cereale* – fall rye
Pa	*Phalaris arundinacea* – reed canarygrass
Pp	*Polygonum amphibium* – water smartweed

Appendix B

2000 Shoot Biomass Data

Appendix C

2000 Root Biomass Data

Appendix D

2000 Soil Bulk Density and %C

(June and October)

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