Columbia River Project Water Use Plan

Kinbasket and Arrow Reservoirs Revegetation Management Plan

Arrow Lakes and Kinbasket Reservoirs Plant Response to Inundation

Implementation Year 2 – Final Report

Reference: CLBMON-35

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LGL Limited environmental research associates

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CLBMON-35 ARROW LAKES AND KINBASKET RESERVOIRS PLANT RESPONSE TO INUNDATION




Final Report 2019

Prepared for

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Cover photos:

From left to right: black cottonwood (*Populus trichocarpa*) live stakes at Lower Inonoaklin Road, Arrow Lakes Reservoir; Kellogg's Sedge *(Carex kelloggii*) at Burton Creek, Arrow Lakes Reservoir; vegetation growing in the drawdown zone of Arrow Lakes Reservoir, and live staking at the Bush Arm Causeway, Kinbasket Reservoir.

Executive Summary

CLBMON-35 (this report) catalogues in detail the revegetation treatments that have been applied to Kinbasket and Arrow Lakes drawdown zones since 2008 and documents the biotic and abiotic variables that contributed to the successes or failures of each type of revegetation treatment. The goal of cataloguing and analyzing these data was to provide a permanent, integrated record of the revegetation techniques applied at each site, and to help determine the treatments and associated factors that were effective. BC Hydro has undertaken studies on the vegetation in the drawdown zones of Kinbasket and Arrow Lakes Reservoirs since 2007. These studies, which were undertaken in lieu of operational changes to reservoir management, were variously designed to assess the impacts of reservoir operations on existing vegetation (CLBMON-10 and -33) and to determine the effectiveness of revegetation efforts (CLBWORKS-1 and -2; CLBMON-9 and -12). Key assumptions tested were: that existing vegetation conditions could be maintained over the long term; that the current operating regime could maintain the existing riparian and wetland vegetation communities and associated ecosystems at the landscape scale; and that the drawdown zone of each reservoir could be revegetated under the current operating regime. Studies also addressed the intra-community responses of existing vegetation in the two drawdown zones to the continued implementation of the operating regime at the local (site) level.

To assess species-specific responses to reservoir operations in Kinbasket and Arrow Lakes Reservoirs, four species—Kellogg's sedge (*Carex kelloggii* [formerly *C. lenticularis.* var *licocarpa*]), Columbia sedge (*C. aperta*), wool-grass (*Scirpus atrocinctus*), and black cottonwood (*Populus trichocarpa*)—were selected for analyses. These species were selected because they were used extensively in the revegetation program and occur across the elevation range considered in each reservoir (Kinbasket: 742 to 754 m ASL; Arrow Lakes Reservoir: 434 to 440 m ASL). In Year 1, the association between the inundation regime and its effect on growing degree days and plant communities in the drawdown zone was examined in Arrow Lakes and Kinbasket Reservoirs using regression trees, generalized linear mixed models (GLMMs), and Wald tests (Hawkes et al. 2018). It was observed that inundation variables were associated with all modelled species; however, the nature of the association (positive or negative) varied between species, environmental conditions, and reservoir. Further, one and two-year lags in response were observed, suggesting that inundation events can have delayed impacts on vegetation (Hawkes et al. 2018).

In this Year 2 update report, we convey the results of supplementary field inventories of revegetation treatments that were conducted in Arrow Lakes Reservoir in 2017 and in Kinbasket Reservoir in 2018. These extensive inventories, which were initially reported in Miller et al. (2018, 2019, 2020), helped to fill several outstanding data gaps with respect to both species- and site-specific revegetation performance and to the topo-edaphic (microsite) conditions prevailing at the various CLBWORKS-1 and 2 treatment sites. Key information obtained during those inventories are summarized in the two updated Prescription Catalogues appended to the report. In the report's main body, we assess these inventory results in terms of the further insights they provide on the four focal revegetation species' response to inundation.

In Kinbasket Reservoir, tall shrub and tree sized black cottonwood occupy the bottom left portion of the hydrologic grid (representing less frequent and shorter duration inundation episodes); wool-grass occupies the upper portion of the grid (representing more frequent inundation episodes); Columbia sedge occupies the middle left portion; and Kellogg's sedge (with the broadest amplitude) occupies a more intermediate

position on the hydrologic spectrum. In Arrow Lakes, species amplitudes segregate in a similar fashion but with more overlap among species.

Black cottonwood, being the least inundation tolerant of the four revegetation species assessed, is predicted to respond the most rapidly (and in a negative direction) to increases in the frequency, depth, and duration of inundation. The three sedge and sedge-like species, being more closely adapted to the variable flood cycles of the drawdown zone environment, are less sensitive to annual variations in inundation. Furthermore, these species appear to perform best under a regime of periodic inundation (which may help to reduce summer drought stress as well as create suitable conditions for germination and establishment).

Existing vegetation can be regarded, generally, as an emergent property of the multidecadal hydro-operating regime, with minor fluctuations in cover and distribution being modulated by year-to-year variations in that regime. Therefore, the most effective way to maintain existing vegetation is to retain the inundation patterns (including patterns of variability) previously established by the long-term hydroregime. Nonetheless, it may be possible to “tweak” the hydroregime to maximize individual vegetation components. For example, shortening the average duration of inundation at low elevations (~433-436 m ASL and ~744-750 m ASL in Arrow and Kinbasket, respectively) to <171 days per year (Arrow) or to <142 days per year (Kinbasket), and extending both spring (May-June) and late summer (August-September) exposure times, should benefit graminoids such as Kellogg’s and Columbia sedge. Reducing the frequency of full pool events to ≤1 every 10 years would benefit high-elevation woody riparian species such as black cottonwood (Table 5-1, below).

If, however, the desired outcome is the establishment of new plant communities at different spatial scales, our operational decision trees suggest that effecting such changes will require, at minimum, a long-term directional change in the duration and frequency of inundation for the elevation band(s) of interest. Moreover, any directional change in the hydro-operating regime is likely to impact on different vegetation communities in different ways. The direction of the regime change (decrease or increase), and whether the change occurs in concert with a decrease in the variability (CV) of annual reservoir maxima, coupled with the timing, duration, and frequency of reaching that maxima, will be important factors determining which species groups or structural attributes are facilitated, and which ultimately are replaced during transition to a new stable state. For example, successive years of below-average reservoir levels would eventually lead to a more shrub-dominated system supporting lower overall covers of herbaceous groups such as sedges (Table 5-1, below). Thus, the nature of the desired plant community at a given elevation band will need to be explicitly considered when making long-term operational decisions aimed at influencing vegetation patterns.

Table 5-1. **Summary table of predicted species responses (increase ↑, decrease ↓, or neutral <-->) to different hypothetical long-term operational scenarios in Arrow Lakes and Kinbasket Reservoir.** Depending on the individual context, a predicted change could be related to a species' cover, its presence, or both. CV = coefficient of variation (SD/mean). DOI = duration of inundation. FOI = frequency of inundation. FFP = frequency of full pool/surcharge events. Median elevations (m ASL) occupied by each species under current conditions are shown in () after species names. Full elevation ranges are displayed in greater detail (as box plots) in Figure 5-1.

Arrow Lakes Reservoir	Black cottonwood (~438.5)	Kellogg's sedge (~436.0)	Columbia sedge (~436.3)	Wool-grass (~435.7)

• 30-yr (1977-2006) baseline pattern of variability in annual operating regime is maintained, specifically:
  • CV (ann. reservoir maxima): ~0.60
  • DOI >436 m ASL: 0-226 days annually (avg. 125 days)
  • DOI >433 m ASL: 0-267 days annually (avg. 171 days)
  • FFP: ~1 out of 3 years
	<-->	<-->	<-->	<-->

• CV (ann. reservoir maxima): <<0.60, resulting in more predictable inundation frequencies for each elevation band • FOI above 436 m ASL: all years • avg. DOI above 436 m ASL: >125 days	↓ all elevations	↓ all elevations	↓ all elevations	↓ all elevations
• CV (ann. reservoir maxima): <<0.60 • FOI above 436 m ASL: <2 out of 10 years • avg. DOI above 436 m ASL: <125 days • avg. DOI above 436 m ASL (during growing season): <21 days • FFP: ≤1 out of 10 years	↑ (cover and height) above 436 m ASL	↓ above 436 m ASL	↓ above 436 m ASL	↓ above 436 m ASL
• CV (ann. reservoir maxima): <<0.60 • FOI above 433 m ASL: <4 out of 10 years • avg. DOI above 433 m ASL: <171 days • avg. DOI above 433 m ASL (during growing season): <50 days • extended Aug.-Sept. exposure	↑ below 436 m ASL	↓ below 436 m ASL	↓ below 436 m ASL	↓ below 436 m ASL
• CV (ann. reservoir maxima): <<0.60 • FOI above 433 m ASL: ≥6 out of 10 years • avg. DOI above 433 m ASL: <171 days • avg. DOI above 433 m ASL (during growing season): <50 days • extended May-June and Aug.-Sept. exposure above 433 m ASL	<--> below 436 m ASL	↑ below 436 m ASL	↑ below 436 m ASL	↑ below 436 m ASL
• CV (ann. reservoir maxima): ≥0.60 • FOI above 436 m ASL: ≥6 out of 10 years • avg. DOI above 436 m ASL: >125 days • FFP: ≥2 out of 3 years	↓ above 436 m ASL	<--> above 436 m ASL	↓ above 436 m ASL	↑ above 436 m ASL

Arrow Lakes Reservoir	Black cottonwood (~438.5)	Kellogg's sedge (~436.0)	Columbia sedge (~436.3)	Wool-grass (~435.7)
• CV (ann. reservoir maxima): ≥0.60 • FOI above 436 m ASL: <6 out of 10 years • avg. DOI above 436 m ASL: <125 days • avg. DOI above 436 m ASL (during growing season): <21 days • FFP: <1 out of 3 years • extended Aug. -Sept. exposure	↑ (cover) above 436 m ASL; <--> (height) above 436 m ASL	<--> above 436 m ASL	↑ above 436 m ASL	↓<--> above 436 m ASL
• CV (ann. reservoir maxima): ≥0.60 • FOI and avg. DOI above 436 m ASL: same as 30-year baseline • FFP: ≤1 out of 10 years	↑ above 436 m ASL	<--> above 436 m ASL	<--> above 436 m ASL	<--> above 436 m ASL
• CV (ann. reservoir maxima): ≥0.60 • FOI above 433 m ASL: <8 out of 10 years • avg. DOI above 433 m ASL: <171 days • avg. DOI above 433 m ASL (during growing season): <50 days • extended May-June and Aug.-Sept. exposure above 433 m ASL	<--> below 436 m ASL	↑ below 436 m ASL	↑ below 436 m ASL	↑ below 436 m ASL
Kinbasket Reservoir	**Black cottonwood** (~753.2)	**Kellogg's sedge** (~750.1)	**Columbia sedge** (~750.1)	**Wool-grass** (~750.1)

• 30-yr (1977-2006) baseline pattern of variability in annual operating regime is maintained, specifically:
  ◦ CV (ann. reservoir maxima): ~0.59
  ◦ DOI >750 m ASL: 0-180 days annually (avg. 62 days)
  ◦ DOI >744 m ASL: 0-235 days annually (avg. 142 days)
  ◦ FFP: ~1 out of 6 years
	<-->	<-->	<-->	<-->

• CV (ann. reservoir maxima): <<0.59, resulting in more predictable inundation frequencies for each elevation band • FOI above 750 m ASL: all years • avg. DOI above 750 m ASL: >62 days	↓ all elevations	↓ all elevations	↓ all elevations	↓ all elevations
• CV (ann. reservoir maxima): <<0.59 • FOI above 750 m ASL: <2 out of 10 years • avg. DOI above 750 m ASL: <62 days • avg. DOI above 750 m ASL (during growing season): <21 days • FFP: ≤1 out of 10 years	↑ (cover and height) above 750 m ASL	↓ above 750 m ASL	↓ above 750 m ASL	↓ above 750 m ASL
• CV (ann. reservoir maxima): <<0.59 • FOI above 744 m ASL: <4 out of 10 years • avg. DOI above 744 m ASL: <142 days • avg. DOI above 744 m ASL (during growing season): <50 days • extended Aug.-Sept. exposure	↑ below 750 m ASL	↓ below 750m ASL	↓ below 750m ASL	↓ below 750m ASL

Arrow Lakes Reservoir	Black cottonwood (~438.5)	Kellogg's sedge (~436.0)	Columbia sedge (~436.3)	Wool-grass (~435.7)
• CV (ann. reservoir maxima): <<0.59 • FOI above 744 m ASL: ≥6 out of 10 years • avg. DOI above 744 m ASL: <142 days • avg. DOI above 744 m ASL (during growing season): <50 days • extended Aug.-Sept. exposure above 744 m ASL	<--> below 750 m ASL	↑ below 750 m ASL	↑ below 750 m ASL	↑ below 750 m ASL
• CV (ann. reservoir maxima): ≥0.59 • FOI above 750 m ASL: ≥6 out of 10 years • avg. DOI above 750 m ASL: >62 days • FFP: ≥2 out of 6 years	↓ above 750 m ASL	<--> above 750 m ASL	↓ above 750 m ASL	↑ above 750 m ASL
• CV (ann. reservoir maxima): ≥0.59 • FOI above 750 m ASL: <6 out of 10 years • avg. DOI above 750 m ASL: <62 days • avg. DOI above 750 m ASL (during growing season): <21 days • FFP: <1 out of 6 years • extended Aug.-Sept. exposure above 750 m ASL	↑ (cover) above 750 m ASL; <--> (height) above 750m ASL	<--> above 750m ASL	↑ above 750m ASL	<--> above 750m ASL
• CV (ann. reservoir maxima): ≥0.59 • FOI and avg. DOI above 750 m ASL: same as 30-year baseline • FFP: ≤1 out of 10 years	↑ above 752 m ASL (high elevation)	<--> above 750 m ASL	<--> above 750 m ASL	<--> above 750 m ASL
• CV (ann. reservoir maxima): ≥0.59 • FOI above 744 m ASL: <8 out of 10 years • avg. DOI above 744 m ASL: <142 days • avg. DOI above 744 m ASL (during growing season): <50 days • extended June and Aug.-Sept. exposure above 744 m ASL	<--> below 750 m ASL	↑ below 750m ASL	↑ below 750m ASL	↑ below 750m ASL

KEYWORDS: Kinbasket Reservoir; Arrow Lakes Reservoir; inundation, revegetation; plant community; existing vegetation; drawdown zone; hydro-operating regime; reservoir elevation.

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Table of Contents

List of Tables

List of Figures

List of Appendices

1 Preface

This CLBMON-35 Year 2 implementation report serves as a supplement and update to the Year 1 implementation report of Hawkes et al. (2018), *Arrow Lakes and Kinbasket Reservoirs plant response to inundation*. The report summarizes results and conclusions from the Year 1 report, expanding on those conclusions by incorporating updated data from the CLBMON-12, -9, -57 monitoring programs, and the two physical works programs (CLBWORKS-1 and -2). This includes recent findings from follow-up field surveys of CLBWORKS-1 and-2 revegetation sites conducted in 2017 (Arrow Lakes Reservoir) and 2018 (Kinbasket Reservoir) under the CLBMON-12 and -9 monitoring programs, and which were not available for inclusion in the initial, Year 1 report. These extensive inventories, which were initially summarized in Miller et al. (2018, 2019, 2020), helped to fill several outstanding data gaps with respect to both species- and site-specific revegetation performance and to the topo-edaphic (microsite) conditions prevailing at the various CLBWORKS-1 and 2 treatment sites. Key information obtained during those inventories are presented in the two updated Prescription Catalogues appended to this report.

For context and continuity, the Introduction and Methods from the Year 1 report (Hawkes et al. 2018) are re-presented below (in slightly abbreviated form), along with a brief reprise of the key Year 1 findings.

2 Introduction

Shorelines of reservoirs managed for power production can undergo seasonal and diurnal water level changes that far surpass those associated with natural flood regimes. Usually measured in tens of vertical metres, reservoir drawdown zones (area between low- and high-water lines) tend to be highly dynamic, ruderal environments whose vegetation bears little similarity to that which existed prior to river impoundment (Abrahams 2006, Lu et al. 2010). Submergence of the original shoreline requires that new shoreline vegetation develop at higher elevations, often on poorer soils that lack a riparian seed bank. The cycle of winter drawdown, followed by rising water levels through the spring, summer, and fall months, runs counter to the natural flood regime (spring/summer freshet) and results in an abbreviated growing window. Prolonged inundation during the growing season produces a repeating cycle of succession consisting of establishment, growth, and disturbance that can serve to retain vegetation in an early (often depauperate or weedy) seral state. Steep and unstable banks, long fetches and associated wave action, loss of organic matter, low soil nutrients, accumulations of woody debris and associated mechanical scouring, erosion and sediment deposition provide additional challenges to vegetation establishment in the drawdown zone (Johnson 2002, Abrahams 2006, Miller et al. 2017). Despite these challenges, vegetation does grow in the drawdown zones of reservoirs, with some species adapting and persisting in the drawdown zone over time (Hawkes and Gibeau 2017; Miller et al. 2017).

In Arrow Lakes Reservoir, an impoundment of the Columbia River in British Columbia, water level elevations are managed by BC Hydro under a regime that permits a normal annual minimum of 418.64 metres above sea level (m ASL), and a normal maximum of 440.1 m ASL—a difference of 21.46 m. The approximately 216 km long Kinbasket Reservoir is located in southeastern B.C. and is surrounded by the Rocky and Monashee Mountain ranges. The Mica Dam, located 135 km north of Revelstoke, B.C., spans the Columbia River and impounds Kinbasket Reservoir. The Mica powerhouse, completed in 1973, has a generating capacity of 1,805 MW, and Kinbasket Reservoir has a licensed storage volume of 12 million-acre feet (MAF; BC Hydro 2008; Hawkes and Miller 2016). The normal operating range of the reservoir is between 707.41 m and 754.38 m elevation but can be operated to 754.68 m ASL with approval from the Comptroller of Water Rights.

Between the annual allowance in each reservoir, water levels change daily throughout the growing season. Primary drawdown occurs during the winter, with reservoir elevations reaching their minimum in April. With the arrival of warmer spring temperatures comes snow melt and the freshet along with a reduced need to produce power. This results in the refilling of the reservoir until the maximum elevation for the year is achieved in later summer or early fall, at which time power production increases, and drawdown recommences. While the overall pattern is predictable, the timing, depth, and duration of inundation experienced by each elevation band varies markedly from year to year. The resulting stress on vegetation establishing within those elevation bands is exacerbated by processes of wave action, sediment deposition, and erosion (Miller et al. 2017). Because of these difficult growing conditions, much of the foreshore is barren or only lightly vegetated. Where conditions do support plant growth, hydrological gradients or topographic relief can produce strong patterns of plant community zonation, resulting in a mosaic of vegetation types that includes wetland complexes, pioneering annual forb, perennial sedge and graminoid associations, shrub and treed communities, and driftwood zones (Miller et al. 2017).

BC Hydro has undertaken studies related to vegetation in the drawdown zones of Kinbasket and Arrow Lakes Reservoirs since 2007. These projects were designed to study the effects of reservoir operations on existing vegetation (CLBMON-10, -33) and to determine the methods of revegetation that were the most successful in each reservoir (CLBWORKS-1, and -2, and CLBMON-9 and -12). These studies were undertaken in lieu of any operation changes to reservoir management, and to test the key assumptions that existing vegetation conditions could be maintained over the long term and that the current operating regime maintains the existing riparian and wetland vegetation communities and associated ecosystems at the landscape scale. Similarly, assumptions about revegetation effectiveness were also tested to determine whether the drawdown zone of each reservoir could be revegetated under the current operating regime and to address the intra-community responses of existing vegetation in the drawdown zone of Kinbasket Reservoir to the continued implementation of the operating regime at the local (site) level.

In Kinbasket Reservoir, ~2234 ha of existing vegetation have been mapped and monitored since 2007 (CLBMON-10; Hawkes et al. 2015), while a total of 72.45 ha were planted with sedges, grasses, and live stakes between 2008 and 2013. The efficacy of the revegetation trials was assessed from 2008 to 2013, although most of the treatments failed during the initial establishment phase (Hawkes et al. 2013). Subsequent (2013) revegetation trials with sedge plugs at Km88 Big Bend are, however, continuing to do well (Miller and Hawkes 2019a, b), while live staking and sedge transplants established in 2015 at the Bush Arm Causeway had high rates of survivorship one year following planting (Hawkes 2016). In Arrow Lakes, ~2067 ha of existing vegetation have been monitored since 2008, and several areas of the ~106 ha that were treated (revegetated) have had moderate success [as discussed in Hawkes et al. (2014) and Miller et al. (2016, 2018)]. While a substantial volume of work has been completed in both reservoirs, there is a need to synthesize the data collected to date and distill the results of the revegetation program into a user-friendly and informative catalogue. The concept for the cataloguing of existing data was presented at the Revegetation Technical Review (RTR) in 2014[1], and was subsequently supported by the participants of the RTR.

The objective of the cataloguing exercise (CLBMON-35) was to document site conditions, revegetation methods, and revegetation success to elucidate variables (biotic and abiotic) that contributed to the successes or failures of each type of vegetation treatment at a given site within Arrow Lakes and Kinbasket Reservoirs. These variables included species choice, site preparation, planting method, stocking density, woody debris, erosion and sediment deposition, wave and wind action, soil characteristics, ecological suitability, soil compaction, human activity, and physicochemical parameters such as soil anoxia.

[1] The concept for the cataloguing of existing data was developed by Virgil Hawkes, Dr. Michael Miller, and Douglas Adama of LGL Limited and presented at the Revegetation Technical Review by Virgil Hawkes.

Investigations also aimed to address existing uncertainties regarding the relative contribution and importance of timing, frequency, depth, and duration of inundation on survival of plants of different sizes and ages, and the effect of multi-year stresses on trends in plant viability.

2.1 Key Operating Decision

The key operating decision for the original CLBMON-35 monitoring program is the maintenance of the soft constraints operating regime for Arrow Lakes Reservoir. The decision of the Water Use Plan Consultative Committee (WUP CC) to implement a revegetation program in lieu of operational changes in Arrow Lakes Reservoir assumed that such a program could be successful under the soft constraints regime. A key objective of soft constraints is maintaining (or enhancing) existing vegetation communities and associated ecosystems in the drawdown zone by maintaining lower water levels during the growing season.

In accepting the soft constraints operating regime for Arrow Lakes Reservoir, the WUP CC recognized the uncertainty associated with the response of existing vegetation communities to flexible operations on a yearly basis, and consequently recommended a monitoring program comprised of a series of interlinked studies at different spatial scales to investigate the effects of the operating regime on riparian and wetland vegetation communities. The CLBMON-35 study was originally established to determine experimentally the relative contributions and importance of timing, frequency, depth and duration of inundation on the survival of plants of different sizes and ages, and the effect of multi-year stresses on trends in plant viability. The revised Terms of Reference, summarized in the following section, asks that these questions be addressed on a post-hoc basis, using past monitoring data collected under CLBMON-9, -10, -12, and -33.

2.2 Management Questions

Under the CLBMON-35 Terms of Reference (Revision 1), data from CLBWORKS-1 and -2, and results from the four vegetation monitoring programs (CLBMON-9, -10, -12, and -33; CLBWORKS-1 and -2), are to be assimilated into two catalogue-style databases (one for each of Arrow Lakes and Kinbasket Reservoirs). Analyses already completed for the monitoring programs will not be replicated in this study but may be used to augment additional analyses. Management questions will be answered separately for each reservoir, on the assumption that the data are sufficient and available to answer the questions. The four management questions addressed are:

1. What trends are apparent in the responses of plant species used for revegetation to the operating regimes to date with respect to timing, frequency, duration and depth of inundation?
2. Do plant species respond differently from one another to variables of the operating regime, including timing, frequency, duration and depth of inundation?
3. How do the responses of plant species to the operating regime interact with other biotic and abiotic factors (e.g. substrate, climate, reservoir filters, and presence of other plant species)?
4. What recommendations may be made to more effectively maintain existing vegetation, help persisting species, and establish new plant communities at different spatial scales (i.e. community versus species scale) in the future?

3 Study Area

The study area, including the geographic context, physiography, and climate, was described in Hawkes et al. (2018).

4 Methods

4.1 Database Creation

Database creation was detailed in Hawkes et al. (2018) and, for brevity, is not repeated here.

4.2 Data Gap Analysis

All data associated with each reservoir was assessed to determine if the necessary data are present to answer the four management questions identified above. Several key databases were considered in the overall gap analysis: (1) the original prescription data from CLBWORKS-1 and -2 for location, species planted, density of planting, and specific planting methods used; (2) the field ground data that were collected by LGL Limited and Delphinium Holdings Inc. over the years for a random subsample of existing and planted sites (i.e., the CLBMON-9, -10, -12, and -33 data); (3) the orthomosaic data (which contain some useful information about the spatial extent of vegetation in the areas treated under CLBWORKS-1 and -2); and (4) reservoir operations and climate data. The gap analysis focused on identifying data gaps in these datasets that might prevent answering the MQs as currently stated, and emphasis was placed on the relationships between data in (1) and (2) above.

4.3 Response and Explanatory Variables

Numerous variables (biotic and abiotic) have been identified as potentially contributing to the success or failure of vegetation treatments within Arrow Lakes and Kinbasket Reservoirs. We grouped the important variables of interest as follows:

(A) Response variables:

- **Survivorship** of planted stock, including seedlings/plugs and live stakes, over time (1-yr, 2-yr, 3-yr, 5-yr, 6-yr, and 7-yr following planting). Based on work completed to date, survivorship must be inferred indirectly by comparing surviving numbers against reported stocking rates, because non-surviving individuals generally do not persist in the drawdown zone long enough to be enumerated.
- **Cover** of vegetation 1-yr, 2-yr, 3-yr, 5-yr, 6-yr, and 7-yr following planting. Because planted stock can be indistinguishable from native vegetation where it has been interplanted with the latter, cover of planted stock has typically been measured indirectly, by comparing the joint covers of planted and existing vegetation with those of existing vegetation in adjacent, non-treated (control) areas.
- **Vigour** of revegetation. “Vigour” of transplanted material has been reported using categorical variables such as “poor,” “moderate,” “good,” and “excellent.”
- **Presence/absence** of surviving planted stock at given sites 1-year, 2-year, 3-year, 5-year, 6-year, and 7-year following planting. This yields binomial data that can be analyzed using Chi-square or logistic regression to relate establishment success to other variables (e.g., location).
- **Community response** to planting. In the CLBMON-9 and -12 programs, this has usually been inferred through hypothesis testing around observed increases/decreases in plant cover and diversity, as well as species turnover rate or constancy, relative to non-treated controls.

(B) Explanatory variables*:*

Explanatory variables are further divided into the following categories:

Operational

- Species planted

- Propagation/collection method (e.g., nursery-potted or wild; age of nursery stock)
- Transplant methods, including but not limited to timing (year, month), planting depth, manual versus machine-assisted, size of cuttings used, and planting density.
- Fertilizer: applied or not, type, timing, frequency of application

Reservoir effects

- *Frequency, timing, depth, and duration of inundation*. To date these variables have been examined on their own because of the observational nature of the CLBMON monitoring programs. Because the frequency, timing, duration and depth of reservoir operations are highly correlated, it is not statistically possible to assign a value of variation to each of them in isolation from the others. To infer the effects of the frequency, timing, duration, and depth or reservoir operations on vegetation growing in the drawdown zone we have used integrative measures such as elevation and growing degree days (which weights exposure time to the ambient growing conditions [temperature] during the period of exposure).
- Exposure to wave action: This can be predicted based on topographic features (e.g., protected coves versus exposed headlands) in combination with fetch (wind travel).
- Erosion and deposition: This information has been recorded for some field plots over time; it can also be assessed remotely from aerial imagery.
- Woody debris movement and deposition: We have previously used fetch to predict woody debris movements in Kinbasket. Debris deposition events in the drawdown zone can be tracked spatially over time using available time series of orthophotos to determine potential correlations with establishment failures.

Abiotic

- Location in reservoir (reach, sub-reach)
- Elevation band: obtained from available data or, if not available, from the digital elevation model (DEM)
- Topography: meso-slope position and microtopography (convex, straight, concave)
- Slope and aspect: indicators of slope stability and heat load
- Substrate texture: e.g., cobble, gravel, sand, silt, or clay
- Soil nutrient regime
- Soil moisture regime: e.g., saturated, mesic, xeric
- Drainage: is soil well-drained or poorly drained, etc.
- Water inputs: Are there external water sources (e.g., creek, seepage, ponds) aside from the reservoir?

Biotic

- **Human activity:** Many seedlings on sandy soils were destroyed by off-road vehicles, and in some places (e.g., Edgewood), live stakes were deliberately removed by the public. While there are data on some types of disturbance (e.g., presence of ATV tracks on monitored plots), some effects are difficult to observe or quantify. Nevertheless, anthropogenic effects need to be accounted for to the extent possible when cataloguing factors that limit revegetation success.

- **Pests:** e.g., herbivory. Girdling of live stakes by voles has been identified as a potential source of mortality at certain revegetation sites such as Duncan Flats in Arrow Lakes Reservoir.
- **Associated species** will be used to assess questions like: What is the existing vegetation community type at each revegetation site? How sparse or dense was the existing vegetation at the time of planting? Is there evidence of in-growth by competitor species? The existing CLBMON-9 and -12 databases contain community typing for monitored treatment sites; for non-sampled areas, it is sometimes possible to obtain this information remotely through a study of aerial imagery and the existing vegetation mapping associated with CLBMON-10 and -33.

4.4 Management Questions 1 to 4: Species-specific Modelling

4.4.1 Year 1 Methods and Summary Results

Management questions 1, 2, and 3 were addressed using statistical methods. The response to Management Question 4 was derived from the results associated with answering questions 1, 2, and 3, but did not entail statistical analyses. Four species were modelled separately in the two reservoirs: Kellogg's sedge (*Carex kelloggii*, syn. *C. lenticularis*), Columbia sedge (*C. aperta*), wool-grass (*Scirpus atrocinctus*), and black cottonwood (*Populus trichocarpa*). These four species were selected because they were used extensively in the revegetation program and occur across the elevation range considered in each reservoir (see Appendix A for a discussion regarding the selection of these focal species for the modelling). Data from CLBMON-9 and -10 (Kinbasket Reservoir) and CLBMON-12 and -33 (Arrow Lakes Reservoir) were used. Data included 0's (i.e., no cover) only for plots and transects that were sampled more than once, and where species either appeared or disappeared over time. Therefore, plots and transects where a species was never observed were not analyzed with respect to that species. This enhanced the model's ability to assess the biotic and abiotic variables that influenced cover of the species, and not simply presence/absence.

For Arrow Lakes Reservoir, site-specific physical environmental variables such as type of plot (control or treated), landscape unit, surface and micro-topography, soil moisture, water source, slope, and heat load (aspect) were included in the model. All site-specific variables were consistent between years, and the most recent data were used to populate all years (usually from 2016, but not always). In Kinbasket Reservoir, site-specific variables included transect type, landscape unit, vegetation community, slope, and heat load. In Kinbasket Reservoir, data from all quadrats were averaged per transect. In both reservoirs, quantitative data were screened for outliers. Heat load was computed from aspect by using the following formula: $(1-\cos(\theta-45))/2$, where θ is the aspect in degrees east of north (McCune and Keon 2002). Aspects of 999 and slopes of 0 (i.e. flat plots) were given a median heat load of 0.5.

Elevation-specific variables were also included for all plots and transects. Elevation-specific variables were growing degree days (GDDs) and inundation variables that related to reservoir operations over time. GDDs were computed for each month of the growing season as detailed in Hawkes et al. (2018).

Inundation variables included timing of inundation (number of days under water since April 1), duration of inundation (total number of days for which a given elevation band was under water for a growing season), average depth of water, median depth of water, and maximum depth of water above each elevation band. Median depth was computed in case extreme values of depth were skewing values of mean depth. The coefficient of variation (standard deviation/mean) of the depth of water was also computed to provide an indication of the variation in depth over each elevation band over the growing season. Growing seasons were defined as the period April 1 to September 30th in Kinbasket Reservoir and April 1 to October 31st in Arrow Lakes Reservoir. Elevation ranges considered in the analyses were 741 to 754 m ASL and from 434 to 440m ASL for Kinbasket and Arrow Lakes Reservoir, respectively. Because GDDs and inundation variables are derived from elevation, elevation could not be included in models that contained these variables, therefore, elevation was omitted. Finally, as GDDs are influenced by inundation regimes, we considered them as inundation variables.

Two models were built for each species in each reservoir: a regression tree and generalized linear mixed effects models (GLMM). Each model was computed with both 1- and 2-year lags associated with the inundation variables to allow for the possibility that vegetation is affected by conditions occurring in years prior to the year of sampling (sampling typically occurred in late spring/early summer, prior to inundation, and thus would not reflect the current year's inundation). Two time lags were evaluated as this enabled us to detect if reservoir operations from one year prior, two years prior, or both, are impacting vegetation. Significance of GLMMs was tested via a Wald test that approximates the likelihood ratio test and tests each coefficient against the full model (Hawkes et al. 2018).

Taken in combination, regression trees, GLMMs, and Wald tests suggested that all modelled species in Arrow Lakes and Kinbasket Reservoirs were associated with inundation variables; however, the nature of these relationships varied greatly between reservoir and species (Table 4-1). In both reservoirs, sedge cover was positively and negatively influenced by inundation variables from one and two years previously, but the nature of the relationships varied between species and reservoir. Conversely, wool-grass in Arrow Lakes Reservoir was only associated with inundations variables from the previous year, while in Kinbasket Reservoir it was associated with inundation variables from one and two years previous. Finally, black cottonwood was associated with inundation variables from one and two years previous, but these associations were predominantly negative in Arrow Lakes Reservoir, and positive in Kinbasket Reservoir (Table 4-1).

4.4.2 CLBMON-57 Summary Results

As part of CLBMON-57 implementation in 2018 (Hawkes et al. 2019),simulations were undertaken to model the predicted impacts of increasing Kinbasket Reservoir levels by 60 cm in 3 out 10 years (the anticipated hydroregime change associated with Mica 5), focusing specifically on the uppermost elevation bands (741 m ASL to 754 m ASL). This analysis benefited from the availability of an additional year (2018) of collected field data, which were applied in conjunction with the existing CLBMON-10 dataset (2007-2016) for the same upper elevation bands.

Three different operational scenarios were modeled using simulations (Hawkes et al. 2019). The three scenarios differed with respect to the timing and duration of the 60 cm increase in reservoir level. Each scenario was applied to the following vegetation parameters: total herb cover; total shrub cover; cover and frequency of sedges (*Carex* spp.); and cover and frequency of willows (*Salix* spp.). Simulation results were then compared to baseline models for each parameter. These models did not detect any substantive effects on herb or shrub cover, or on sedge or willow frequencies, from increasing reservoir elevations by 60 cm in 30% of years. Acknowledging that the available data set is limited in terms of size and scope, the study indicated that potential vegetation impacts associated with a semi-periodic increase in reservoir levels by 60 cm were likely to be swamped by the environmental noise of much larger inter-annual fluctuations in inundation depth and duration (Hawkes et al. 2019).

Table 4-1. Relationships between naturally occurring vegetation species and the effect of inundation variables on the percent cover of those species in Arrow Lakes and Kinbasket Reservoir. Variables without a +/- were identified as of interest in the regression trees, but not in the GLMM or Wald test. From Hawkes et al. (2018).

Arrow Lakes Reservoir

Kellogg's sedge

- August growing degree days (two-year lag)
- April growing degree days (two-year lag); **"+"**
- July growing degree days (two-year lag); **"- "**
- Duration of inundation (one-year lag); **"- "**
- Maximum depth of inundation (one-year lag); **"- "**
- Inundation depth coefficient of variation (one and two-year lags); **"+"**
- Inundation timing (two-year lag); "**+"**
- Inundation depth (one and two-year lags); **"+"**

Columbia sedge

- July growing degree days (one-year lag)
- August growing degree days (two-year lag); **"- "**
- October growing degree days (one-year lag); **"- "**
- Duration of inundation (one-year lag)
- Maximum depth of inundation (one-year lag)
- Inundation depth coefficient of variation (one and two-year lags)
- Maximum depth of inundation (two-year lag); **"- "**
- Inundation depth (two-year lag); **"+"**

Wool-grass

- May growing degree days (one-year lag); **"+"**
- Inundation depth (one-year lag); **"- "**
- Duration of inundation (one-year lag); **"- "**
- Maximum depth of inundation (one-year lag); **"+"**

Black cottonwood

- October growing degree days (one-year lag); **"- "**
- April growing degree days (two-year lag); **"- "**
- May growing degree days (two-year lag); **"- "**
- Duration of inundation (two-year lag); **"- "**
- Inundation timing (one-year lag); **"- "**

Kinbasket Reservoir

Kellogg's sedge

- July growing degree days (two-year lag)
- August growing degree days (one-year lag) **"- "**
- May growing degree days (two-year lag); **"- "**
- April growing degree days (one-year lag); **"+"**
- June growing degree days (two-year lag); **"+"**
- Inundation depth coefficient of variation (two-year lag)
- Maximum depth of inundation (one-year lag); **"- "**
- Average depth of inundation (one-year lag); **"+"**

Columbia sedge

- April growing degree days (one-year lag)
- July growing degree days (two-year lag); **"+"**
- August growing degree days (two-year lag); **"+"**
- Inundation depth coefficient of variation (one and two-year lags); **"- "**
- Inundation timing (one and two-year lags); **"- "**
- Maximum depth of inundation (one-year lag); **"- "**
- Duration of inundation (two-year lag); **"+ "**

Wool-grass

- May growing degree days (two-year lag)
- April growing degree days (one-year lag); **"+"**
- June growing degree days (two-year lag); "- "
- Inundation depth (two-year lag)
- Duration of inundation (one-year lag); **"- "**

Black cottonwood

- August growing degree days (two-year lag)
- May growing degree days (two-year lag); **"+"**
- September growing degree days (two-year lag); **"+"**
- April growing degree days (two-year lag); **"- "**
- June growing degree days (two-year lag); **"- "**
- Inundation timing (two-year lag); **"+"**

4.4.3 Year 2 Approach

Year 1 analyses (above) focused primarily on the annual variation in reservoir operations (i.e., on the timing, duration, and depth of inundation at different elevations during the growing season) to determine how these variables relate to year-to-year changes in the per cent covers of Kellogg's sedge, Columbia sedge, wool-grass, and black cottonwood within the two drawdown zones. The somewhat muted, sometimes ambiguous, species-specific responses to annual reservoir operations served to emphasize that the composition of drawdown zone vegetation is the cumulative outcome of the hydroperiod experienced over the last five decades, dating from the impoundment of the Columbia River by the Mica and Hugh Keenleyside Dams in 1973 and 1968, respectively. This multidecadal regime has resulted in communities whose species composition is maintained in a persistent, primarily herbaceous, disclimax state by frequent but highly variable inundation. While the vegetation systems of the drawdown zone may be dynamic (prone to minor fluctuations from year to year), in order for detectable, directional changes in species composition/abundance to manifest at the local scale there probably needs to occur a successive sequence (spanning several years) of above- or below-average inundation durations.

In Year 2, we expanded the time scale under consideration to include the 30-year period prior to the commencement of the WUP monitoring programs. We assumed that the distribution and abundance of vegetation in the two drawdown zones over the monitoring period have fundamentally been set by long-term (decadal) hydroregimes in combination with prevailing topo-edaphic conditions; that is, they are not governed primarily by variation in reservoir operations over shorter time scales of 1-2 years.

Using known elevational distributions of species and community types in combination with: (1) daily reservoir elevation records from 1997 to 2006 (the pre-monitoring period of current studies); (2) available topo-edaphic information; (3) transplant establishment rates and suspected biotic and abiotic impediments to transplant establishment (summarized in the appended Prescription Catalogues); and (4) results of prior models relating plant cover and frequency to the number of available growing degree days, we estimated the hydrologic and edaphic amplitudes of the four focal species within each drawdown zone. We then used these accumulated results to develop a set of operational decision trees to assist reservoir managers interested in maximizing focal plant cover (or in facilitating specific structural forms) and to guide site selection for future revegetation trials. In terms of maximizing/facilitating cover, key decision tree metrics considered for each reservoir were:

- the predictability of inundation frequency, estimated by the CV (coefficient of variation) of annual reservoir maxima, relative to the 30-year (1996-2006) baseline;
- average duration and frequency of inundation within the current zones of establishment of the selected key species, relative to the 30-year baseline;
- average duration and frequency of inundation within the current zone of sedge establishment, relative to the 30-year baseline; and
- the frequency of full pool or surcharge events, relative to the 30-year baseline.

In terms of site selection for revegetation trials, key metrics considered were:

- the elevation of the proposed treatment site, relative to the current zones of establishment of the selected key species;
- substrate texture and drainage;
- presence of, and proximity to, to perennial moisture sources;
- slope;
- presence/absence of existing vegetation cover;
- and dominant vegetation community type.

Each decision tree (one operational tree and one site-selection tree for each reservoir [total of four trees]) used a flowchart-like structure in which each internal node represented a test (“yes”/”no”) of one of the environmental attributes or combination of attributes listed above to arrive at a set of alternative hypothetical outcomes. The most likely outcomes of each path were arrived at through a combination of monitoring data, observed trends, model outputs, and the authors’ professional opinion. The two operational decision trees were then summarized into a table describing the main operational requirements needed to increase the cover/survival of each of the four focal species in Kinbasket and Arrow Lakes Reservoirs.

Previously unavailable data from the 2017 and 2018 re-surveys of CLBWORKS-1 and -2 revegetation sites (Miller et al. 2018b, 2019a, b) were used to inform the Year 2 analysis. Newly available data included:

- Updated, species-specific establishment rates for a comprehensive sample of CLBWORKS-1 revegetation polygons in Kinbasket Reservoir.
- Topo-edaphic data on substrate textures, drainage, moisture sources, and microtopography for all surveyed Kinbasket revegetation sites, along with soil nutrient analyses for a subsample of sites.
- Topo-edaphic data on substrate textures, drainage, moisture sources, and microtopography for all surveyed Arrow Lakes revegetation sites.

5 Year 2 Results

5.1 Data Gaps

Hawkes et al. (2018) reported that few topo-edaphic (microsite) variables (soil, substrate, drainage, nutrients, microtopography) were consistently available for Kinbasket Reservoir and that reliable metrics of wave action, erosion, deposition, and wood debris movement could not be calculated for either reservoir. As a result of recent (2018) fieldwork undertaken in Kinbasket Reservoir through CLBMON-9, we were able to fill several of these topo-edaphic data gaps as they pertained to the CLBWORKS-1 physical works sites (Miller and Hawkes 2019a, b). However, other data gaps pertaining to reservoir effects (wave action, wood debris movement, etc.) remain to be filled and thus cannot be used to model species-specific response of plants to inundation.

The 2018 re-survey of CLBWORKS-1 physical works sites also helped to fill many data gaps around site-specific revegetation performance in Kinbasket Reservoir (see Prescription Catalogues). However, data gaps around reported planting procedures used from site to site, along with the overall lack of experimental replication (Hawkes et al. 2018), continued to pose major data challenges for the cataloguing exercise. Due to the low numbers of surviving individuals, and lack of experimental replication (both in time and space), it is not always possible to directly link revegetation performance to specific annual hydro-operating regimes. Instead, much of the learning in this program was extrapolated from the observed responses of existing vegetation and communities to operations.

5.2 Management Questions

5.2.1 Responses to Inundation

A microsite's elevation in the drawdown zone determines the frequency, depth, and duration of inundation that it experiences over time. These inundation cycles, in turn, help determine the complement of species that come to inhabit a given elevation band. In Arrow Lakes, all four focal species appear able to establish across most monitored elevation bands (434-440 m ASL); however, they differ with respect to where they are most typically found. With occasional exceptions (e.g., at the confluence with Illecillewaet River), black cottonwood occurrences tend to be limited to elevations >437 m ASL (median = ~438.5 m AS; Figure 5-1). The three graminoid species each has a median elevation of around 436 m ASL. Columbia sedge has a slightly higher zone of concentration than Kellogg's sedge, while wool-grass has a slightly lower (and narrower) zone of concentration (Figure 5-1). In Kinbasket, black cottonwood is generally restricted to elevations >752 m ASL (median = ~753 m ASL). Kellogg's sedge and wool-grass occupy all elevation zones down to at least 742 m ASL (median = ~750 m ASL). Columbia sedge, a less common species overall, has a similar median elevation but a more conscribed range, primarily occupying elevations between 749 and 751 m ASL (Figure 5-1).

Figure 5-2 and Figure 5-3 show the distribution of surviving transplant numbers plotted against the planting elevation in samples taken in 2017 (Arrow Lakes) and 2018 (Kinbasket), 6-10 years post-treatment. It is important to note that the count data correspond to the original planting elevations, and that these were determined selectively (non-randomly) during the original implementations of CLBWORKS-1 and 2. Consequently, not all possible elevation bands within the general treatment zone were effectively "sampled" by a given revegetation species. However, the scatter plots indicate some informative patterns with respect to elevation and transplant establishment.

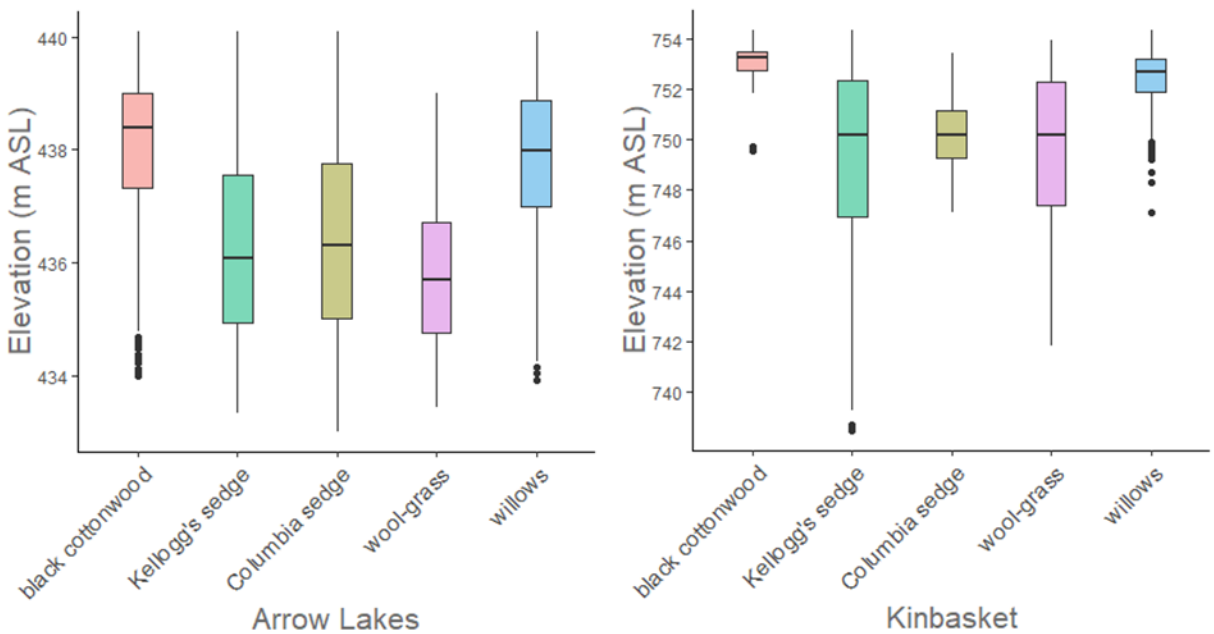

Figure 5-1. **Elevations of sample plots containing black cottonwood, Kellogg's sedge, Columbia sedge, and wool-grass. Elevations of willows (*Salix* spp.) are shown for comparison.**

In Arrow Lakes Reservoir, planted plugs of Kellogg's sedge have established and survived (up to nine years post-planting) over a relatively wide elevational range between 434 and 438 m ASL, with peak survivorship occurring between 434 and ~ 436.5 m ASL (Figure 5-2). The ecologically similar species, Columbia sedge, also showed establishment success over a relatively broad gradient of elevations (434.5 to 437.5 m ASL) but in this case peak survivorship occurred within a slightly higher band: ~ 435.5 to 437.5 m ASL. This result is consistent with previous field observations that natural populations of Columbia sedge tend to be found at slightly higher elevations in the drawdown zone than those of Kellogg's sedge, suggesting a reduced tolerance for early and/or prolonged inundation (Miller et al. 2017). It is also notable that, in the case of both species, there was limited revegetation survivorship at elevations > 438 m ASL (although samples sizes, especially for Columbia sedge, were small for this elevation). This result also concurs with previous observations that these species, which are well-adapted to inundation, are more likely experience summer moisture deficits in the upper drawdown zone (Miller et al. 2016).

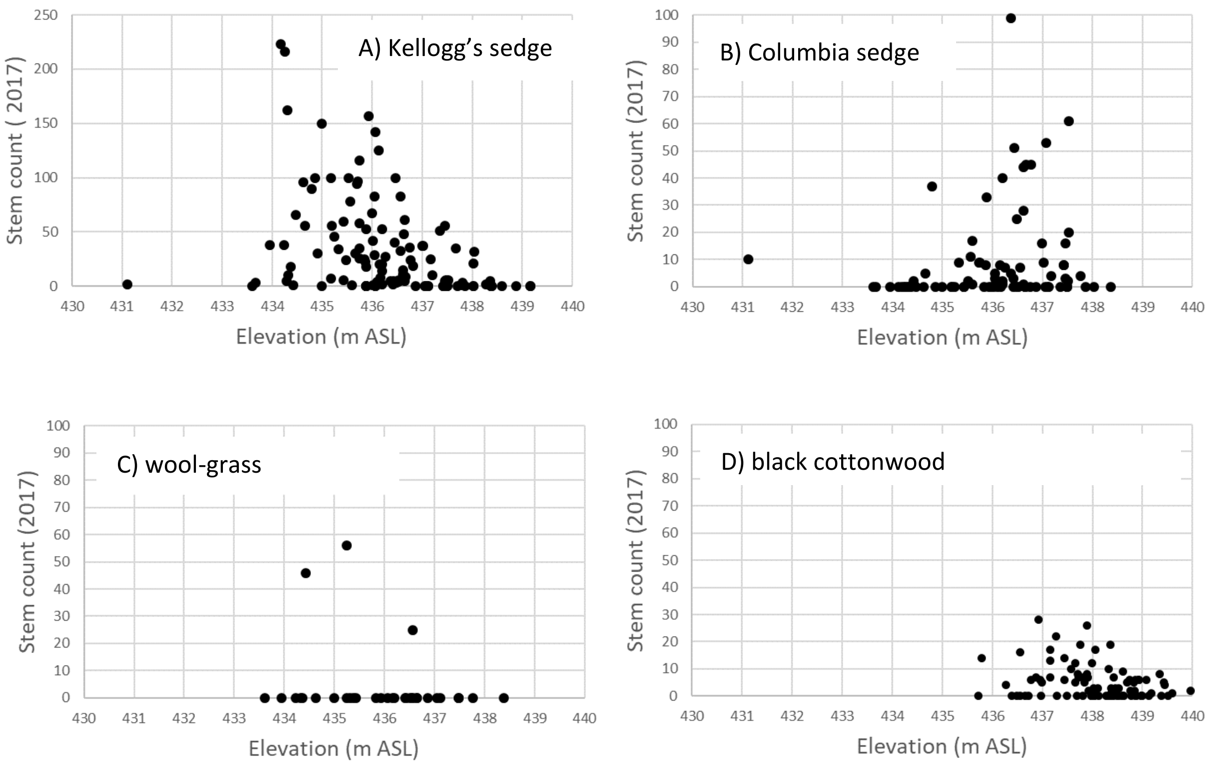

Figure 5-2. Surviving stem counts for four revegetation species at various elevations within the drawdown zone of Arrow Lakes Reservoir. Stem counts were recorded in 50-m^2 plot samples during the 2017 re-survey of CLBWORSK-2 physical works treatment polygons, 6-9 years post-treatment.

Planting prescriptions involving wool-grass were associated with limited establishment success in Arrow Lakes Reservoir (Figure 5-2). The few sample plots containing surviving plants in 2017 occurred between ~ 434.5 and 436.5 m ASL, implying a relatively narrow elevational tolerance. The low survival rates at even these elevations is an indication that biotic or abiotic factors other than inundation, (e.g., a lack of suitable wetland conditions at treated areas), were combining to limit establishment. In the case of black cottonwood, both the planting trials, and instances of survival, were concentrated in the upper elevation bands (437 to 440 m ASL). Stems tended to establish at highest densities between 437 and 438 m ASL (Figure 5-2), consistent with this species' presumed more limited tolerance for prolonged inundation (Hawkes et al. 2010).

Within the range of elevations over which planting prescriptions were sampled in Arrow Lakes Reservoir, how important was elevation (and, by extension, inundation regime) as a predictor of survivorship probability compared to other variables such as geographic location (site), community type, slope, and substrate type? Multivariate models developed for CLBMON-12 showed that, in all instances, the local site conditions were as important, or more important, than elevation in determining the likelihood of establishment (Miller et al. 2018b). In the case of Kellogg's sedge, treatments benefited primarily from location in certain vegetation community types (e.g., PA, PC-Sedge) and/or in certain locations (e.g., Burton, Lower Inonoaklin, Arrow Park) on shallowly sloped, mesic (moist) ground with fine- to loam-textured soils. In contrast, xeric sites with poorly anchored substrates achieved relatively low establishment rates. For Columbia sedge and black cottonwood, predicted survivorship was also higher for certain sites (e.g., 12 Mile) than for others (e.g., Arrow Park). Prescriptions located within the BE, BG, PC-Reed canarygrass, and

PE-Foxtail community types resulted in poor survivorship for Columbia sedge and, at some sites, in moderate survivorship for Kellogg's sedge and black cottonwood (Miller et al. 2018b).

In Kinbasket Reservoir, planted plugs of Kellogg's sedge have established and survived (up to 10 years post-planting) over a relatively wide range of elevations between 743 and 753 m ASL, with peak survivorship occurring between 746 and 750 m ASL (Figure 5-3). Isolated instances of establishment occurred as low as 742 m ASL and as high 753 m ASL. The bell-shaped distribution of establishment elevations, both here and in Arrow Lakes Reservoir, attests to this species' overall tolerance to inundation. However, it also indicates that the species performs best (from a revegetation perspective) under what might be termed an "intermediate" inundation regime. That is, some inundation during the growing season is probably beneficial, and perhaps necessary, for establishment. However, inundation is detrimental beyond a certain duration and depth, or when it occurs too early or late in the season. This conclusion is supported by previous multivariate models involving natural (existing) cover of Kellogg's sedge (Hawkes et al. 2018): natural cover was negatively associated with increased growing degree days (a correlate of exposure time) in July (Kinbasket) and August (Arrow Lakes), but it was also negatively associated with greater maximum inundation depths (Hawkes et al. 2018).

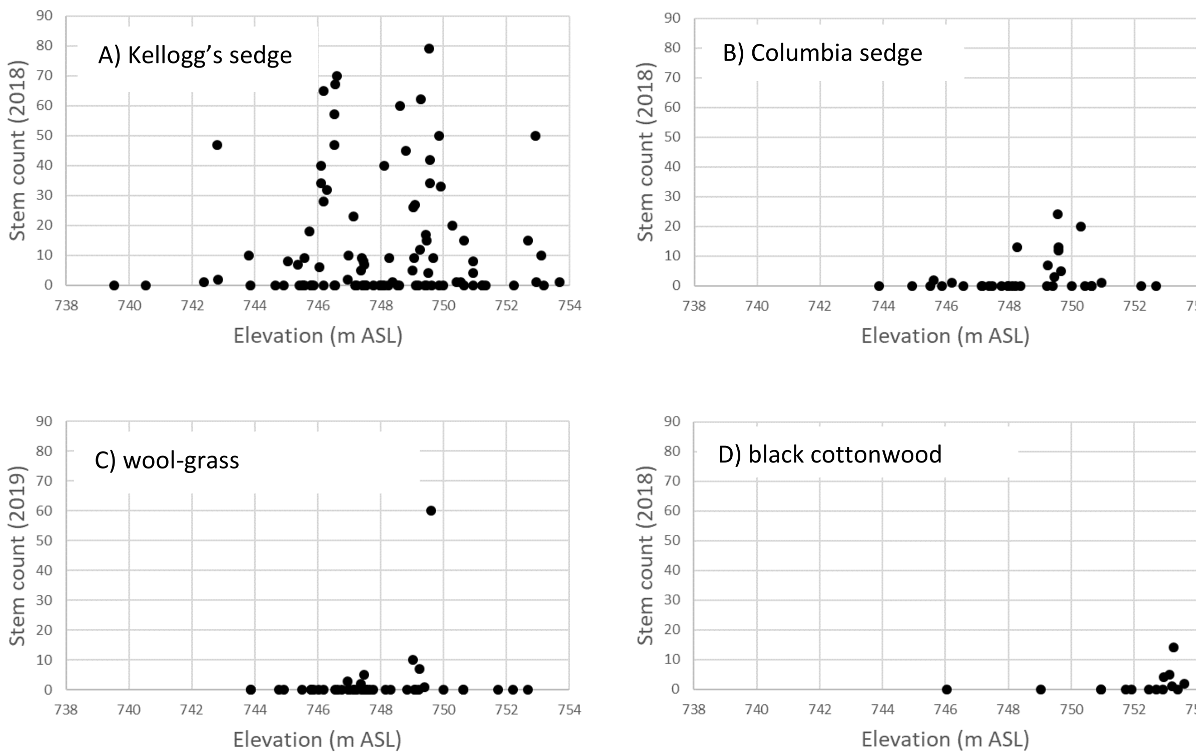

Figure 5-3. Surviving stem counts for four revegetation species at various elevations within the drawdown zone of Kinbasket Reservoir. Stem counts were recorded in 50-m^2 plot samples during the 2018 re-survey of CLBWORSK-1 physical works treatment polygons, 7-10 years post-treatment.

Revegetation prescriptions involving Columbia sedge met with limited success in Kinbasket Reservoir (Figure 5-3). A few instances of establishment occurred between 748 and 750 m ASL but were largely restricted two locations in Bush Arm: km77 and Km88 Big Bend. Plantings *of* wool-grass were even less successful, with just a small number of establishments recorded in 2018 between 749 and 750 m ASL (Figure 5-3). Similarly, only a few instances of establishing black cottonwood were recorded within the 2018 sample plots. These all occurred in the uppermost elevation band (753 m ASL or above), and in most cases the provenance of the specimens (whether planted or naturally occurring) could not be definitively ascertained (see Prescription Catalogue).

As for the Arrow Lakes prescriptions, above, multivariate models were used to examine the relative influence of elevation versus other microsite variables on surviving plug densities, and cover values, of planted Kellogg's sedge in Kinbasket Reservoir (Miller and Hawkes 2019b). For these analyses, soil nutrient information, obtained through lab analysis of soil collections made during the 2018 comprehensive resurvey of CLBWORKS-1 sites, were included in the models. Soil information included the following parameters: Calcium (mg/Lsoil dry); total, inorganic, and organic Carbon (% dry); Potassium (mg/Lsoil dry); Magnesium (mg/Lsoil dry); Sodium (mg/Lsoil dry); total Nitrogen (mg/Lsoil dry); organic matter (% dry); and soil particle size. Other variables modeled included elevation, geographic location, slope, heat load, and microtopography. Topo-edaphic site conditions were predicted to have a greater impact on the probability of plug survival than elevation. Specifically, a high percentage of the variation in establishment rates could be explained by location in the reservoir, nutrient factors including sodium (Na) and potassium (K), and soil texture. Na explained the largest proportion of the variation, but Potassium (K) was also a predictor of variability, particularly at Km77, Km79, and Ptarmigan Creek in low Na environments having some organic matter content (Miller and Hawkes 2019b).

In an analogous model that substituted the percent cover of Kellogg's sedge (including naturally occurring Kellogg's sedge) for standing stem counts, the existence of a stream-fed, subsurface moisture source was the most important predictor of high cover values. In this case, Na was the most important limiting factor on dry to mesic soils where precipitation was the primary water source (Miller and Hawkes 2019b).

Similar multivariate models could not be applied individually to Columbia sedge, Wool-grass, or black cottonwood, due to the paucity of successful revegetation examples. However, Columbia sedge is naturally uncommon in the drawdown zone of Kinbasket Reservoir (in contrast to Arrow Lakes, where it is relatively ubiquitous), implying that other factors aside the physiological challenges of prolonged inundation may have prevented its widespread establishment there. These may be climate-related: Kinbasket is > 300 m higher in elevation and has a deeper and more persistence snowpack than Arrow Lakes, resulting in a different suite of growing conditions. Alternatively, Columbia sedge'*s* relative sparsity in Kinbasket may be a function of a (as yet unidentified) nutrient deficiency within the substrate.

Natural occurrences of *S. atrocinctus* are more common, but this hydrophytic species is strongly associated with wetland-type habitats with a perennial water source, which, because of their typically well-established plant covers, were not the primary targets of revegetation efforts under CLBWORKS-1. Most of the sites where *S. atrocinctus* treatments were applied between 2008 and 2011, namely, sparsely vegetated alluvial fans, mud flats, sandy barrens, and gravelly banks, would likely have presented poor habitat matches for this species. Consequently, knowledge of habitat requirements and community associations can be key in site selection.

Low tolerance to inundation can likely account for much of the widespread establishment failures of black cottonwood in Kinbasket, even though plantings have established successfully at elevations > 2 m below full pool in some regions of Arrow Lakes Reservoir (e.g., at 12 Mile and Edgewood; see Prescription Catalogue). The differential response could be related to differences in the timing and duration of extreme high-water events experienced by the two reservoirs since revegetation trials were implemented in 2008. In Kinbasket, reservoir levels reached or exceeded the topmost elevation band (753-754.38 m ASL) in 2010 (30 Sept.-24 Oct.), 2011 (4 Aug.-25 Oct.), 2012 (19 Jul.-14 Sept.), 2013 (16 Aug.-10 Nov.), and 2014 (8 Aug.-

16 Nov.). In Arrow Lakes, reservoir levels reached or exceeded the topmost elevation band (439-440.1 m ASL) in 2008 (30 Jun.-22 Aug.), 2010 (29 Jun-14 Jul), 2011 (6 Jul.-21 Aug.), 2012 (26 Jun.-17 Aug.), 2013 (24 Jun.-12 Jul.), and 2014 (2-8 Jul.).

In both reservoirs, these high-water events coincided closely with the implementation of the CLBWORKS planting programs, as well as with the post-planting establishment windows for black cottonwood, when the root and shoot development of live stakes (and seedlings) were in the nascent stages. However, the annual inundation events tended to be of much longer duration in Kinbasket (average: 70.6 days) compared to those in Arrow Lakes (average: 29.2 days; Figure 5-4). They also occurred substantially later in the season in Kinbasket (August-November) than in Arrow Lakes (June-August). Both factors may have contributed to the particularly poor establishment rates obtained for black cottonwood in Kinbasket (as well as for Columbia sedge, above). Physiological intolerance to prolonged, deep inundation and/or soil anoxia appears to have caused a high proportion of woody stems to fail (drown) within the first year or two of planting. At the same time, rapidly receding water tables at many treated sites following winter drawdown likely produced strong early summer moisture deficits, adding to the physiological stress. For any initial black cottonwood survivors, the late onset of summer inundation, atypical for this species under natural freshet conditions, may have further reduced annual photosynthetic potential, impeding late-season energy storage within the roots and shoots and reducing the physiological resilience needed to withstand the next drought/flood cycle. Lastly, the prolonged high-water events between 2010 and 2014 facilitated transport of large floating woody debris into upper elevation bands, resulting in widespread plant abrasion, breakage, and/or burial.

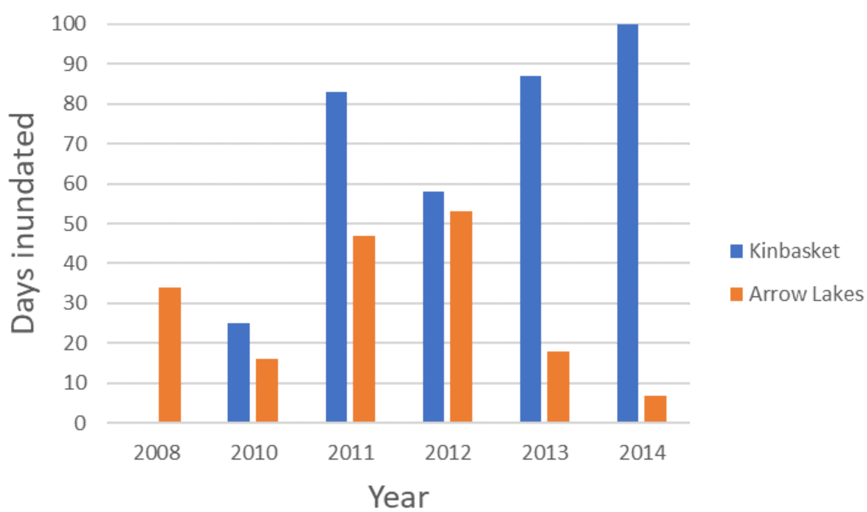

Figure 5-4. Duration, in days, of high-water (full pool) inundation events in Arrow Lakes and Kinbasket Reservoirs since 2008. For Arrow Lakes, the total duration > 439 m ASL was computed; for Kinbasket, the total duration > 753 m ASL. These elevations correspond to the top ~1-m elevation band of each drawdown zone.

These inferences appear borne out by field data collected on natural occurrences of black cottonwood over the same period in Kinbasket Reservoir. Between 2007 and 2018, the average recorded cover of black cottonwood declined by ~ 18 % within monitoring transects (unpubl. data, CLBMON-10). Declines since 2007 in the overall cover and diversity of woody-stemmed plants in the upper drawdown zone were also reported (Hawkes and Gibeau 2015).

Multivariate models computed for CLBMON-57 (Hawkes et al. 2019) indicated that, above 750 m ASL, woody plant cover was negatively associated with increased inundation duration over the study period ($p < 0.01$), positively associated with slope ($p = 0.04$; possibly because steeper slopes tend to experience quicker drainage), and weakly but positively associated with increased July growing degree days ($p = 0.09$). In contrast, herb cover at the same elevations was predicted to decrease with increasing growing degree days in July and August ($p < 0.01$) as well with slope ($p = 0.001$), suggesting that some mid-summer inundation (and water retention) is beneficial, and perhaps necessary, for sustaining existing herbaceous ground cover at higher elevations.

5.2.2 Hydrologic and Edaphic Amplitude

We used combined field observations and modeling outputs from CLBMON-10, -33, -9, -12, and -57 to predict generalized hydrologic and edaphic amplitudes for the four focal species (Figure 5-5). Inundation ranges (frequency and duration) for different elevation bands over the growing season (15 Apr. to 15 Oct.) were estimated using the 30-year period (1997-2006) prior to the commencement of monitoring as the baseline. In Kinbasket, tall shrub and tree sized black cottonwood occupy the bottom left portion of the hydrologic grid (representing less frequent and shorter duration inundation episodes); wool-grass occupies the upper portion of the grid (representing more frequent inundation episodes); Columbia sedge occupies the middle left portion; and Kellogg's sedge (with the broadest amplitude) occupies a more intermediate position on the hydrologic spectrum (Figure 5-5).

In Arrow Lakes, species amplitudes segregate in a similar fashion but with more overlap among species (Figure 5-5). This could reflect the greater degree of floristic intermixing across elevation bands in Arrow Lakes Reservoir, where a generally milder environment (in terms of both climate and water energy) may help to moderate somewhat the negative impact of inundation on plant establishment and growth. Reduced specificity with respect to elevation should, in practice, increase the range of habitats amenable to revegetation efforts. This prediction appears to be borne out by the overall higher success rates of planting prescriptions observed for this reservoir.

Across the two reservoirs, wool-grass and black cottonwood also tend to occupy different parts of the edaphic grid from each other as well as from the two sedge species (Figure 5-5). The *Scirpus* is typically associated with poorly to imperfectly drained, fine-textured (clay to coarse loam) substrates, whereas the *Populus* prefers more well drained (but still fresh), coarser (fine loam to gravel) substrates. Kellogg's sedge, with the broadest edaphic amplitude, occurs on substrates ranging from poorly drained clay to rapidly drained sand (although fresh to mesic conditions are preferred), while Columbia sedge tends to be less tolerant of wet/saturated conditions than Kellogg's sedge (Figure 5-5).

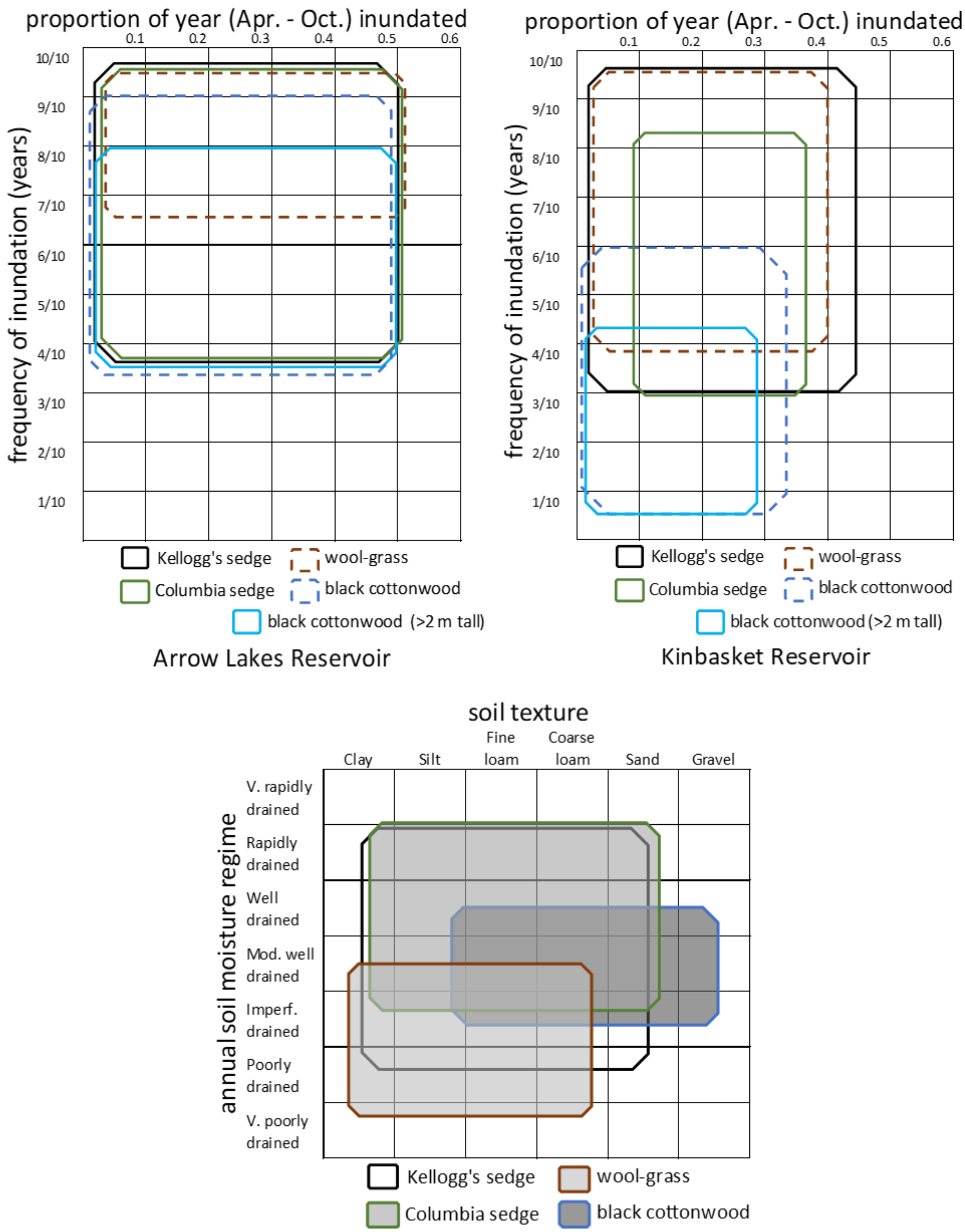

Figure 5-5. **Top: generalized hydrologic amplitudes for Kellogg's sedge, Columbia sedge, wool-grass, and black cottonwood (all size classes, and stems >2m tall) in Kinbasket and Arrow Lakes Reservoirs.** Bottom: generalized edaphic amplitudes for the same four species (applicable to both reservoirs).

5.2.3 Operational Decision Trees for Maximizing Focal Plant Cover

The predicted hydrologic and edaphic amplitudes for the four focal species (previous section), together with site- and elevation-specific information on revegetation results following implementation of CLBWORKS-1 and -2 (detailed in the appended Prescription Catalogues), were used to propose an operational decision tree for each reservoir (Arrow Lakes and Kinbasket). The trees (Figure 5-6, Figure 5-7) show the likely outcomes of various (hypothetical) operational scenarios on the long-term performance of the four focal plant species and can as serve as operational guidance for reservoir managers interested in establishing or maximizing cover of different vegetation groups. For example, in Arrow Lakes Reservoir, a trend toward less variable annual max reservoir elevation, combined with a directional increase in the average frequency and duration of inundation >436 m ASL is predicted to lead, over time, to declines above this elevation in the cover of all focal species except possibly for wool-grass (Figure 5-6). In Kinbasket Reservoir, an increase in the predictability of annual reservoir maxima combined with: a directional decrease in the average frequency and duration of inundation >750 m ASL; and a decrease in the frequency of full pool events, is predicted to lead to increased cover of black cottonwood and to decreased cover for both Kellogg's and Columbia sedge (Figure 5-7). The various potential outcomes are further summarized in Table 5-1.

As noted, the diagrams present hypothetical scenarios and require further testing under real-world scenarios. Predictions are further complicated by the interaction of inundation with related variables such as bank erosion and the deposition of large woody debris, the near-term impacts of which can easily override those of inundation alone at the local scale (Miller et al. 2019b). Moreover, these factors can operate synergistically to exacerbate vegetation loss and make recovery to a previous state more difficult. For example, reduction of vegetation cover induced by the deposition of wood debris during prolonged inundation can result in the erosion of existing soil, further impacting vegetation establishment and leading to additional bank erosion.

Between 2007 and 2014, Kinbasket Reservoir reached full pool, or near full pool, on six separate occasions. As noted previously, this operating regime appeared to be associated with simultaneous declines in the overall cover and diversity of woody-stemmed plants in the upper drawdown zone. By contrast, since 2014, the reservoir has been maintained at elevations <753 m ASL for five straight years (2015 to 2019), with the duration of inundation >750 m ASL averaging 54 days. This recent regime could offer an early test of the prediction (above) that reduced full pool events, combined with a consistent, directional decrease in the average frequency and duration of inundation at high elevations, should facilitate establishment and growth of cottonwood while reducing sedge cover at affected elevations. However, since reservoir elevations are currently forecast to exceed full pool in 2020, any high-elevation vegetation shifts resulting from the recent series of low reservoir maxima are liable to be short-lived.

5.2.4 Site-selection Decision Trees for Revegetation

Similarly, predicted ecological amplitudes together with site- and elevation-specific data on past revegetation outcomes were used to construct decision trees to assist in future evaluations of the revegetation potential of different target sites in each reservoir (Figure 5-8 and Figure 5-9). For example, in Arrow Lakes Reservoir, a site with well-anchored substrates consisting of mesic to moist fines, loams, or organics; flat to minimal slopes; and low to moderate existing vegetation cover comprising a PC-Sedge, PE-Sedge, PE-Foxtail, PA, BG, or pond, is identified as a potential candidate for planting prescriptions involving Kellogg's and/or Columbia sedge (Figure 5-8). In Kinbasket Reservoir, a high elevation site adjacent to a low gradient stream entry, or one occurring on imperfectly to well drained (but not rapidly drained) coarse-textured soils within an existing CT (Cottonwood-*Trifolium*) community type (with some natural cottonwood establishment already occurring), could be a potential candidate for further black cottonwood trials (Figure 5-9). However, additional site modifications through physical works (such as mounding or bank contouring) may be required to increase likelihood of establishment. In general, sites occurring at elevations <746 m ASL would not be recommended for revegetation trials involving any of the four focal species, nor would be sites entirely lacking in existing vegetation cover (which could be indicative of the presence of other, potentially intractable, biotic or abiotic impediments to plant establishment, such as chronic erosion or critical nutrient deficiency).

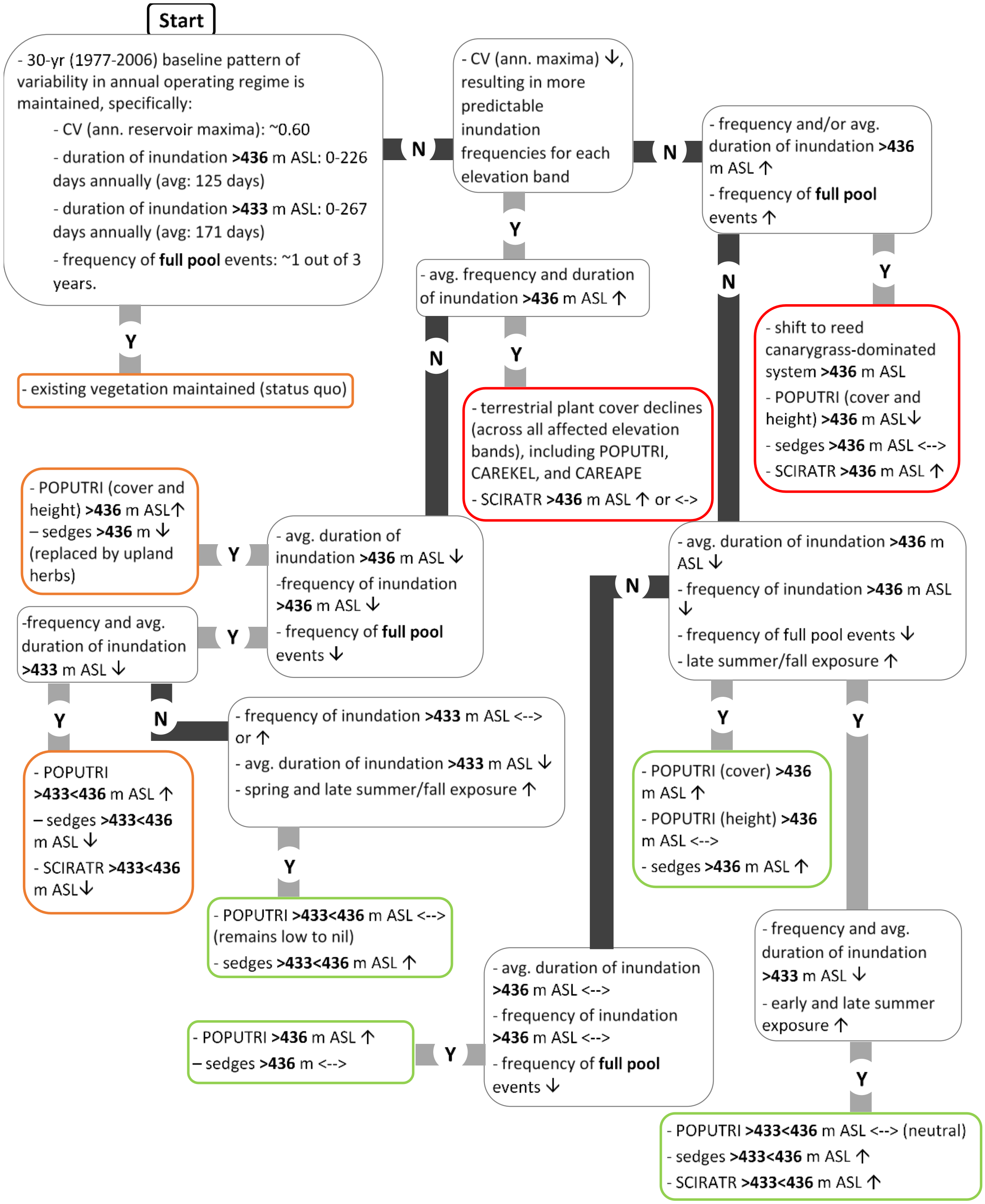

Figure 5-6. **Flow chart of potential vegetation outcomes resulting from different hypothetical operational scenarios in Arrow Lakes Reservoir.** CV = coefficient of variation (SD/mean). Orange boxes: neutral outcome; green boxes: positive outcome; red boxes: negative outcome. CAREKEL: Kellogg's sedge; CAREAPE: Columbia sedge; SCIRATR: wool-grass; POPUTRI: black cottonwood.

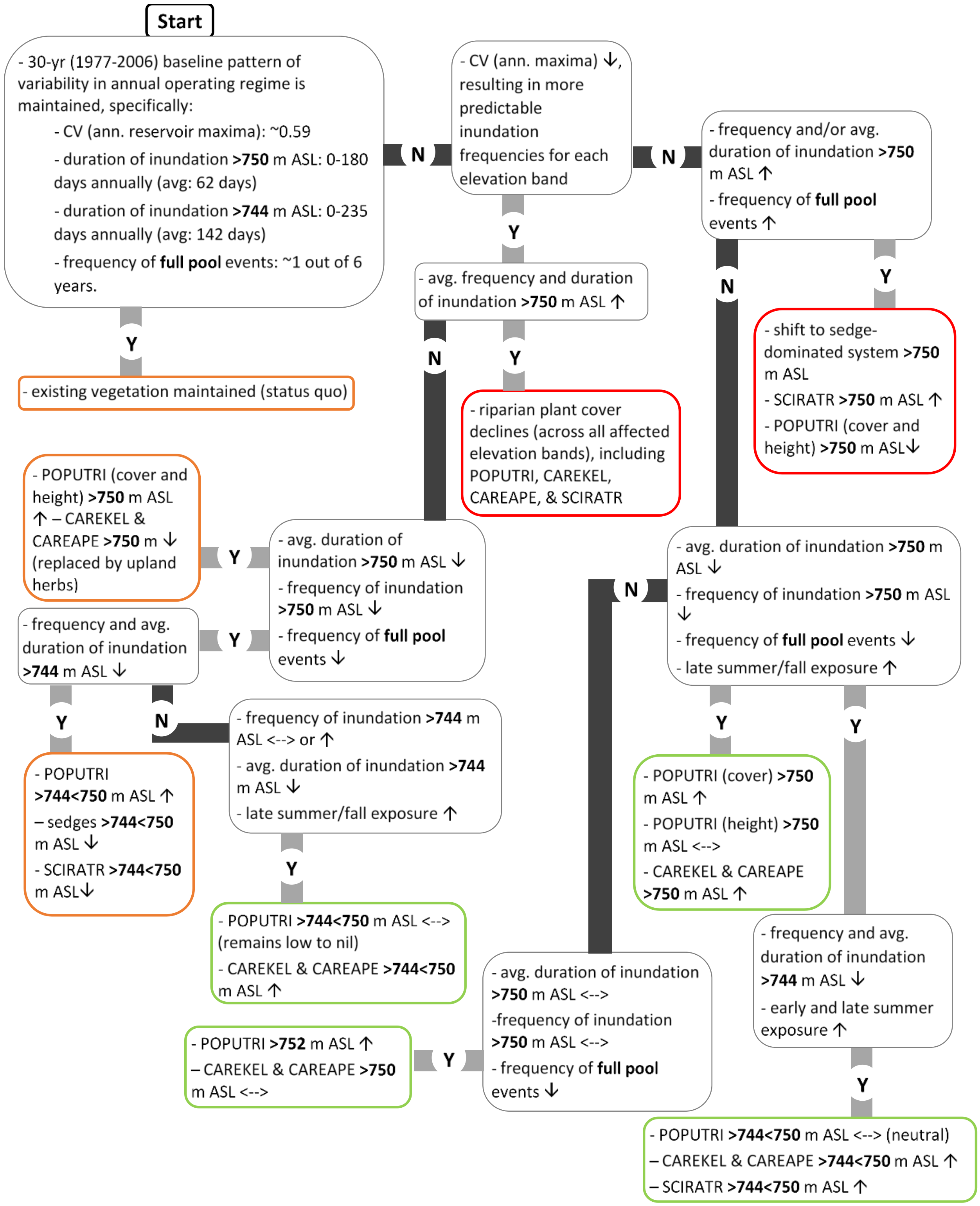

Figure 5-7. Flow chart of potential vegetation outcomes resulting from different hypothetical operational scenarios in Kinbasket Reservoir. CV = coefficient of variation (SD/mean). Orange boxes: neutral outcome; green boxes: positive outcome; red boxes: negative outcome. CAREKEL: Kellogg's sedge; CAREAPE: Columbia sedge; SCIRATR: wool-grass; POPUTRI: black cottonwood.

Table 5-1. Summary table of predicted species responses (increase ↑, decrease ↓, or neutral <-->) to different hypothetical long-term operational scenarios in Arrow Lakes and Kinbasket Reservoir. Depending on the individual context, a predicted change could be related to a species' cover, its presence, or both. CV = coefficient of variation (SD/mean). DOI = duration of inundation. FOI = frequency of inundation. FFP = frequency of full pool/surcharge events. Median elevations (m ASL) occupied by each species under current conditions are shown in () after species names. Full elevation ranges are displayed in greater detail (as box plots) in Figure 5-1.

Arrow Lakes Reservoir	Black cottonwood (~438.5)	Kellogg's sedge (~436.0)	Columbia sedge (~436.3)	Wool-grass (~435.7)

• 30-yr (1977-2006) baseline pattern of variability in annual operating regime is maintained, specifically:
  • CV (ann. reservoir maxima): ~0.60
  • DOI >436 m ASL: 0-226 days annually (avg. 125 days)
  • DOI >433 m ASL: 0-267 days annually (avg. 171 days)
  • FFP: ~1 out of 3 years
	<-->	<-->	<-->	<-->

• CV (ann. reservoir maxima): <<0.60, resulting in more predictable inundation frequencies for each elevation band • FOI above 436 m ASL: all years • avg. DOI above 436 m ASL: >125 days	↓ all elevations	↓ all elevations	↓ all elevations	↓ all elevations
• CV (ann. reservoir maxima): <<0.60 • FOI above 436 m ASL: <2 out of 10 years • avg. DOI above 436 m ASL: <125 days • avg. DOI above 436 m ASL (during growing season): <21 days • FFP: ≤1 out of 10 years	↑ (cover and height) above 436 m ASL	↓ above 436 m ASL	↓ above 436 m ASL	↓ above 436 m ASL
• CV (ann. reservoir maxima): <<0.60 • FOI above 433 m ASL: <4 out of 10 years • avg. DOI above 433 m ASL: <171 days • avg. DOI above 433 m ASL (during growing season): <50 days • extended Aug.-Sept. exposure	↑ below 436 m ASL	↓ below 436 m ASL	↓ below 436 m ASL	↓ below 436 m ASL
• CV (ann. reservoir maxima): <<0.60 • FOI above 433 m ASL: ≥6 out of 10 years • avg. DOI above 433 m ASL: <171 days • avg. DOI above 433 m ASL (during growing season): <50 days • extended May-June and Aug.-Sept. exposure above 433 m ASL	<--> below 436 m ASL	↑ below 436 m ASL	↑ below 436 m ASL	↑ below 436 m ASL
• CV (ann. reservoir maxima): ≥0.60 • FOI above 436 m ASL: ≥6 out of 10 years • avg. DOI above 436 m ASL: >125 days • FFP: ≥2 out of 3 years	↓ above 436 m ASL	<--> above 436 m ASL	↓ above 436 m ASL	↑ above 436 m ASL

Arrow Lakes Reservoir	Black cottonwood (~438.5)	Kellogg's sedge (~436.0)	Columbia sedge (~436.3)	Wool-grass (~435.7)
• CV (ann. reservoir maxima): ≥0.60 • FOI above 436 m ASL: <6 out of 10 years • avg. DOI above 436 m ASL: <125 days • avg. DOI above 436 m ASL (during growing season): <21 days • FFP: <1 out of 3 years • extended Aug. -Sept. exposure	↑ (cover) above 436 m ASL; <--> (height) above 436 m ASL	<--> above 436 m ASL	↑ above 436 m ASL	↓<--> above 436 m ASL
• CV (ann. reservoir maxima): ≥0.60 • FOI and avg. DOI above 436 m ASL: same as 30-year baseline • FFP: ≤1 out of 10 years	↑ above 436 m ASL	<--> above 436 m ASL	<--> above 436 m ASL	<--> above 436 m ASL
• CV (ann. reservoir maxima): ≥0.60 • FOI above 433 m ASL: <8 out of 10 years • avg. DOI above 433 m ASL: <171 days • avg. DOI above 433 m ASL (during growing season): <50 days • extended May-June and Aug.-Sept. exposure above 433 m ASL	<--> below 436 m ASL	↑ below 436 m ASL	↑ below 436 m ASL	↑ below 436 m ASL
Kinbasket Reservoir	**Black cottonwood (~753.2)**	**Kellogg's sedge (~750.1)**	**Columbia sedge (~750.1)**	**Wool-grass (~750.1)**

• 30-yr (1977-2006) baseline pattern of variability in annual operating regime is maintained, specifically:
  ◦ CV (ann. reservoir maxima): ~0.59
  ◦ DOI >750 m ASL: 0-180 days annually (avg. 62 days)
  ◦ DOI >744 m ASL: 0-235 days annually (avg. 142 days)
  ◦ FFP: ~1 out of 6 years
	<-->	<-->	<-->	<-->

• CV (ann. reservoir maxima): <<0.59, resulting in more predictable inundation frequencies for each elevation band • FOI above 750 m ASL: all years • avg. DOI above 750 m ASL: >62 days	↓ all elevations	↓ all elevations	↓ all elevations	↓ all elevations
• CV (ann. reservoir maxima): <<0.59 • FOI above 750 m ASL: <2 out of 10 years • avg. DOI above 750 m ASL: <62 days • avg. DOI above 750 m ASL (during growing season): <21 days • FFP: ≤1 out of 10 years	↑ (cover and height) above 750 m ASL	↓ above 750 m ASL	↓ above 750 m ASL	↓ above 750 m ASL
• CV (ann. reservoir maxima): <<0.59 • FOI above 744 m ASL: <4 out of 10 years • avg. DOI above 744 m ASL: <142 days • avg. DOI above 744 m ASL (during growing season): <50 days • extended Aug.-Sept. exposure	↑ below 750 m ASL	↓ below 750m ASL	↓ below 750m ASL	↓ below 750m ASL

Arrow Lakes Reservoir	Black cottonwood (~438.5)	Kellogg's sedge (~436.0)	Columbia sedge (~436.3)	Wool-grass (~435.7)
• CV (ann. reservoir maxima): <<0.59 • FOI above 744 m ASL: ≥6 out of 10 years • avg. DOI above 744 m ASL: <142 days • avg. DOI above 744 m ASL (during growing season): <50 days • extended Aug.-Sept. exposure above 744 m ASL	<--> below 750 m ASL	↑ below 750 m ASL	↑ below 750 m ASL	↑ below 750 m ASL
• CV (ann. reservoir maxima): ≥0.59 • FOI above 750 m ASL: ≥6 out of 10 years • avg. DOI above 750 m ASL: >62 days • FFP: ≥2 out of 6 years	↓ above 750 m ASL	<--> above 750 m ASL	↓ above 750 m ASL	↑ above 750 m ASL
• CV (ann. reservoir maxima): ≥0.59 • FOI above 750 m ASL: <6 out of 10 years • avg. DOI above 750 m ASL: <62 days • avg. DOI above 750 m ASL (during growing season): <21 days • FFP: <1 out of 6 years • extended Aug.-Sept. exposure above 750 m ASL	↑ (cover) above 750 m ASL; <--> (height) above 750m ASL	<--> above 750m ASL	↑ above 750m ASL	<--> above 750m ASL
• CV (ann. reservoir maxima): ≥0.59 • FOI and avg. DOI above 750 m ASL: same as 30-year baseline • FFP: ≤1 out of 10 years	↑ above 752 m ASL (high elevation)	<--> above 750 m ASL	<--> above 750 m ASL	<--> above 750 m ASL
• CV (ann. reservoir maxima): ≥0.59 • FOI above 744 m ASL: <8 out of 10 years • avg. DOI above 744 m ASL: <142 days • avg. DOI above 744 m ASL (during growing season): <50 days • extended June and Aug.-Sept. exposure above 744 m ASL	<--> below 750 m ASL	↑ below 750m ASL	↑ below 750m ASL	↑ below 750m ASL

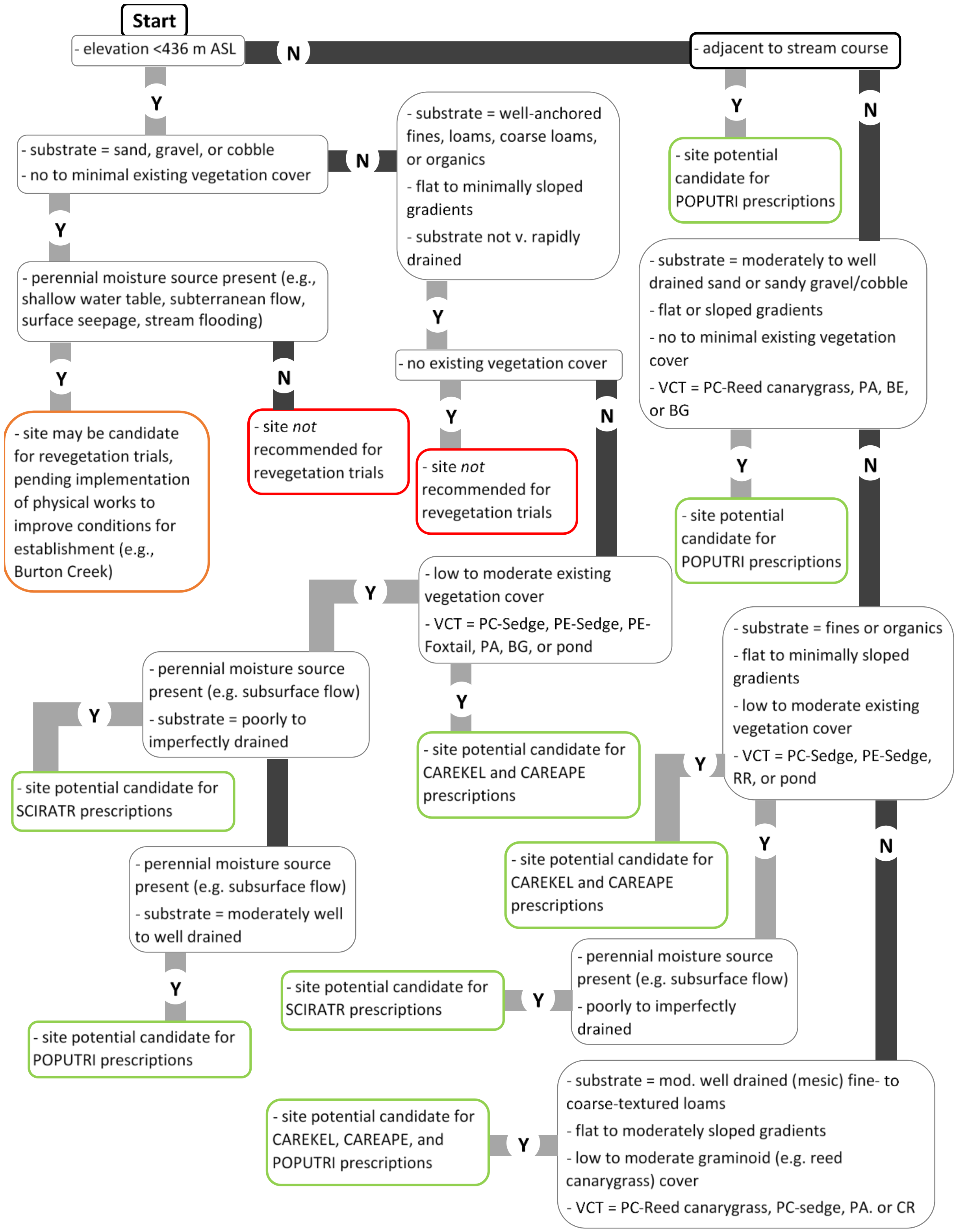

Figure 5-8. **Flow chart of the revegetation potential of target sites based on hypothetical topo-edaphic site conditions in Arrow Lakes Reservoir.** VCT: vegetation community type. Orange boxes: neutral or potential revegetation conditions (may require additional physical works); green boxes: potential candidate for revegetation; red boxes: poor candidate for revegetation. CAREKEL: Kellogg's sedge; CAREAPE: Columbia sedge; SCIRATR: wool-grass; POPUTRI: black cottonwood.

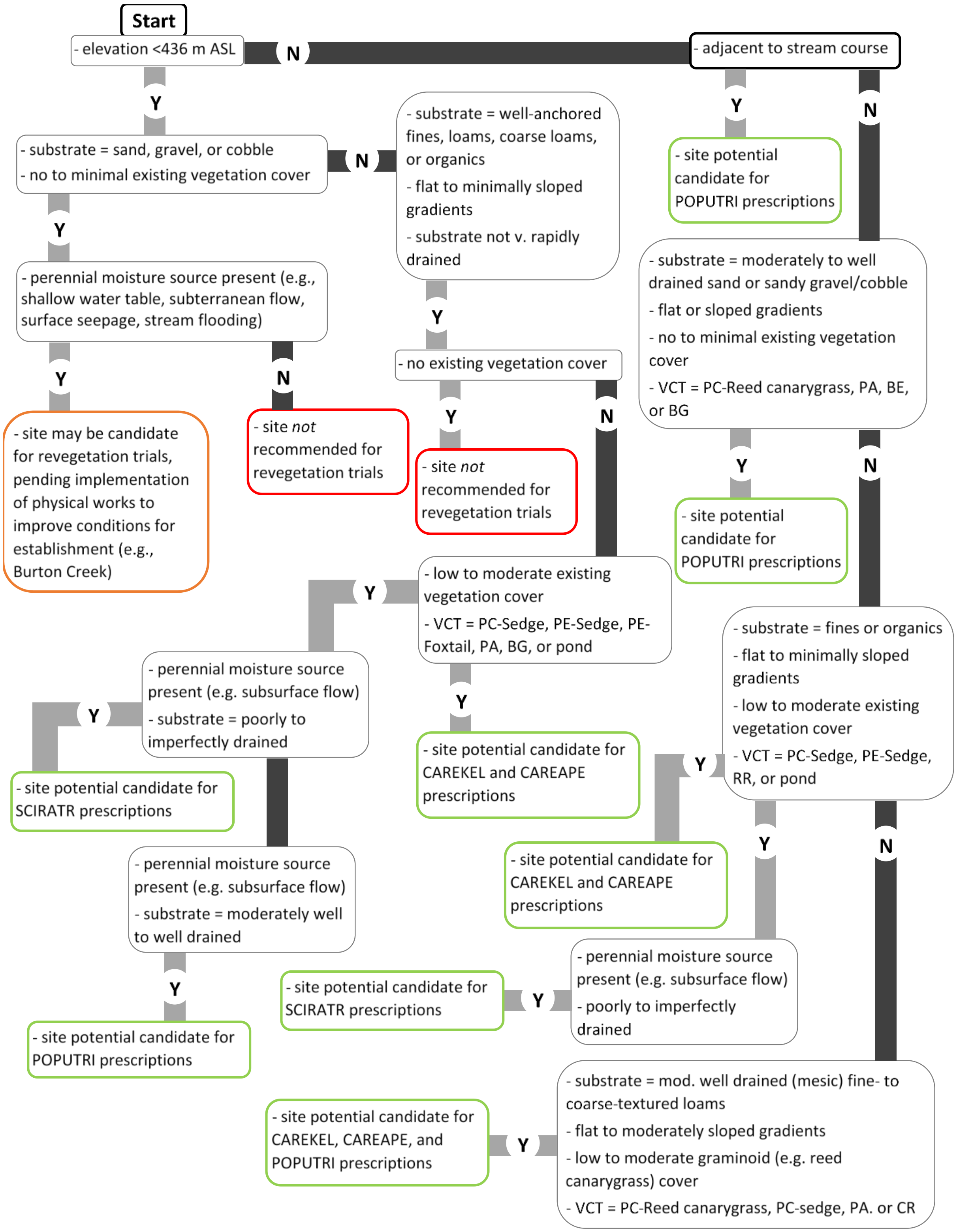

Figure 5-9. **Flow chart of the revegetation potential of target sites based on hypothetical topo-edaphic site conditions in Kinbasket Reservoir.** VCT: vegetation community type. Orange boxes: neutral or potential revegetation conditions (may require additional physical works); green boxes: potential candidate for revegetation; red boxes: poor candidate for revegetation. CAREKEL: Kellogg's sedge; CAREAPE: Columbia sedge; SCIRATR: wool-grass; POPUTRI: black cottonwood.

6 Discussion and Summary

Management Question 1: What trends are apparent in the responses of plant species used for revegetation to the operating regimes to date with respect to timing, frequency, duration and depth of inundation?

Inundation variables were associated with all modelled species; however, the nature of the association (positive or negative) varied with species, variable, environmental conditions, and reservoir. Further, one and two-year lags were observed, suggesting that inundation events have delayed impacts on vegetation. The somewhat muted, sometimes ambiguous, species-specific responses to annual reservoir operations served to emphasize that the composition of drawdown zone vegetation is the cumulative outcome of the hydroperiod experienced over the last five decades, dating from the impoundment of the Columbia River by the Mica and Hugh Keenleyside Dams in 1973 and 1968, respectively. This multidecadal regime has resulted in communities whose species composition is maintained in a persistent seral state by a frequent but variable disturbance regime. While the vegetation systems of the drawdown zone may be dynamic (prone to minor fluctuations from year to year), in order for detectable, directional changes in species composition/abundance to manifest at the local scale there probably needs to occur a successive sequence (spanning several years) of above- or below-average inundation durations.

Management Question 2: Do plant species respond differently from one another to variables of the operating regime, including timing, frequency, duration and depth of inundation?

Yes. In Kinbasket Reservoir, tall shrub and tree sized black cottonwood occupy the bottom left portion of the hydrologic grid (representing less frequent and shorter duration inundation episodes); wool-grass occupies the upper portion of the grid (representing more frequent inundation episodes); Columbia sedge occupies the middle left portion; and Kellogg's sedge (with the broadest amplitude) occupies a more intermediate position on the hydrologic spectrum. In Arrow Lakes, species amplitudes segregate in a similar fashion but with more overlap among species (Figure 5-5).

Black cottonwood, being the least inundation tolerant of the four revegetation species assessed, is predicted to respond the most rapidly (and in a negative direction) to increases in the frequency, depth, and duration of inundation. The two sedge species, being more closely adapted to the variable flood cycles of the drawdown zone environment, are less sensitive to annual variations in inundation. Furthermore, these species appear to perform best under a regime of periodic inundation (which may help to reduce summer drought stress as well as create suitable conditions for germination and establishment). Thus, cover of these species is predicted to decline over time in response to a directional, multi-year decrease in the average frequency and duration of inundation.

Management Question 3: How do the responses of plant species to the operating regime interact with other biotic and abiotic factors (e.g. substrate, climate, reservoir filters, and presence of other plant species)?

Vegetation zonation in the drawdown zones, as well as the individual distributions of the four focal species, are closely tied to substrate and other reservoir filters (e.g., nutrient availability, slope gradients, erosion, sediment deposition, large woody debris depositions, and off-road vehicle traffic). Surprisingly, these edaphic factors were more important at explaining the variation in establishment rates than elevation (which can be regarded as a general proxy for inundation depth and duration; Miller et al. 2018b, Miller and Hawkes 2019b). This finding could be highly useful for informing future decisions around site selection in subsequent transplant trials or where other physical site improvements are being considered. For example, black cottonwood is most likely to establish on deep, moderately well drained (but fresh), relatively coarse (fine loam to gravel) substrates. The performance of the inundation-tolerant, hydrophytic species wool-grass is primarily predicated on the presence/absence of suitably wetted, poorly to imperfectly drained substrates (such as occur in a wetland environment). Most sites treated with *S. atrocinctus* under CLBWORKS-1 and -2 lacked true wetland conditions, which may explain the low overall establishment rates achieved for this species. Kellogg's sedge, with the broadest edaphic amplitude, can establish on substrates ranging from poorly drained clay to rapidly drained sand (although fresh to mesic loams are preferred), while Columbia sedge tends to be less tolerant of wet/saturated conditions than *C. kelloggii.* Regardless of the operational regime, the lack, or near lack, of existing vegetation cover at a given site is a strong indication of the presence of some other, possibly intractable, biotic or abiotic impediment to plant establishment. Common impediments include unstable substrates, sediment deposition, nutrient deficiency, and moisture deficiency). Since such sites have already been demonstrated to be inherently inimical to plant establishment, they are usually unsuited to revegetation attempts in the absence of supplementary physical works aimed at ameliorating site conditions.

Management Question 4: What recommendations may be made to more effectively maintain existing vegetation, help persisting species, and establish new plant communities at different spatial scales (i.e. community versus species scale) in the future?

Existing vegetation can be regarded, generally, as an emergent property of the multidecadal hydroregime, with minor fluctuations in cover and distribution being modulated by year-to-year variations in that regime. Therefore, the most effective way to maintain existing vegetation is to retain the inundation patterns (including patterns of variability) previously established by the long-term hydroregime. Nonetheless, it may be possible to "tweak" the regime to maximize individual vegetation components. For example, shortening the duration of inundation in some years and increasing both spring and late summer exposure should benefit mid-elevation herbs such as Kellogg's sedge, while reducing the frequency and duration of full pool events should benefit woody riparian species such as black cottonwood (Figure 5-6 and Figure ***5-7***).

If, however, the desired outcome is the establishment of new plant communities at different spatial scales (part 2 of MQ 4), our operational decision trees suggest that effecting such changes will require, at minimum, a long-term directional change in the duration and frequency of inundation for the elevation band(s) of interest (Figure 5-6 and Figure ***5-7***). Moreover, any directional change in regime is likely to impact on different communities in different ways. The direction of the regime change (decrease or increase), and whether the change occurs in concert with a decrease in the variability (CV) of annual reservoir maxima, will be important factors determining which species groups or structural attributes are facilitated, and which ultimately are replaced during transition to a new stable state. For example, successive years of below-average reservoir levels could eventually lead to a more shrub-dominated system supporting lower overall covers of herbaceous groups such as sedges (Figure 5-6 and Figure ***5-7***). Thus, the nature of the desired plant community at a given elevation band will need to be explicitly considered when making long-term operational decisions aimed at influencing vegetation patterns (Abrahams 2006; Miller et al. 2016).

As illustrated by the site-selection decisions trees for revegetation (Figure 5-8 and Figure ***5-9***), the impacts of inundation interact with local soil conditions, habitat type, and topography over small spatial scales. Because microhabitats vary over a small spatial scale, and reservoir operations occur at a broad spatial scale, it is probably not possible to manage reservoir operations in a way that sustains plant life in all microhabitats. With respect to revegetation efforts, success or failure of prescriptions is closely tied to the elevation of planting (reflecting operational filters) but microhabitat conditions can also have critical impacts on success. Site-specific examples of both situations are provided in the appended Prescription Catalogues.

Future planting efforts should focus on further enhancing those areas that have already experienced some prescription survivorship (see Prescription Catalogues), as these area appear to offer the greatest promise of subsequent success. Lower Inonoaklin and Drimmie Creek in Arrow Lakes Reservoir, and Yellow Jacket Creek and Km88 Big Bend in Kinbasket Reservoir, are examples of sites that have demonstrated some enhancement potential (see Prescription Catalogues). Other areas that, by virtue of their existing vegetation cover, have already demonstrated a natural ability to support the targeted vegetation type (e.g., cottonwood stands, sedges), also present logical choices for vegetation enhancement trials. Familiarity with the different community types occurring in two reservoir drawdown zones, and prior knowledge of which sites support which community types, will be vital when choosing which vegetated sites to target for enhancements (Figure 5-8 and Figure 5-9).

Finally, due to the presence of certain (often unidentified) abiotic or biotic factors, many areas of the drawdown zone appear fundamentally hostile to riparian plant establishment—at least under the current, multidecadal hydroregime. In other words, if native plants could have established on these barren areas, they probably would have by now. Prioritizing barrens for revegetation enhancements over less depauperate sites is inherently tempting because the immediate payoffs appear to be high. However, prior experience from CLBWORKS-1 and -2 has taught that the likelihood of achieving successful establishments (to say nothing of functional community development) on such sites is very low. In such areas, and in lieu of wholesale changes to the management of the reservoirs, active restoration (i.e.., supplemental physical works beyond straight revegetation) will likely be required to create conditions suitable for long-term plant establishment (Figure 5-8 and Figure 5-9).

7 Recommendations

In lieu of wholesale changes to the management of Arrow Lakes and Kinbasket Reservoirs, the following recommendations are made regarding existing vegetation and revegetation efforts in the drawdown zones of Kinbasket and Arrow Lakes Reservoir. These recommendations have been adapted and updated from the CLBMON-35 Year 1 report (Hawkes et al. 2018).

Existing Vegetation

1. Define the desired plant communities relative to elevation for the drawdown zone of Kinbasket and Arrow Lakes Reservoirs. Lower elevations in both Arrow Lakes and Kinbasket Reservoir are likely to be inundated earlier and longer than those closer to the normal operating maxima. As such, vegetation targets for lower elevations should differ from those at higher elevations. Previous work has shown that species richness increases with elevation in both Kinbasket and Arrow Lakes Reservoir. These finding support defining vegetation targets by elevation. In each reservoir, pioneering communities dominate the drawdown zone at lower elevations with species richness and cover increasing with elevation. The upper two to three metres of the drawdown zone in each reservoir could be targeted for vegetation communities defined by high species richness, high cover, and a greater percentage of woody stemmed species. The species targeted for each reservoir, and within reaches of each reservoir, should be dictated by the local flora at those sites. In this report, we have provided a set of decision trees to help identify some vegetation shifts that could result from different hypothetical operating regimes. We have also provided a set of decision trees to assist in quickly identifying which of four commonly planted species (including three graminoid and one tree species) it would be appropriate to attempt to establish at a given location.

2. Continue to assess the effectiveness of wood debris removal and mounding as a way to increase the cover of existing vegetation in the drawdown zone, particularly in Kinbasket Reservoir (as per Hawkes 2016, 2017). Because wood tends to settle higher in the drawdown zone, removal of wood will benefit the upper two to three metres of the drawdown zone, helping achieve targets identified above.
3. Over the past five years (2015 to early 2020), Kinbasket Reservoir levels have not exceeded 753.85 m ASL. In chronological order, the annual maximum elevations were: 750.95 m (2015); 753.85 m (2016); 752.13 (2017); 747.25 (2018); and 748.20 m (2019). This continuous sequence of relative low water years for upper elevations (but not for lower elevations) presents BC Hydro with an uncommon opportunity to undertake a preliminary evaluation of the predicted responses of vegetation (Figure 5-7, Table 5-1) to:
   i. a multi-year release from the pressure of full pool events;
   ii. a decrease of 8 days in the average duration of inundation > 750 m ASL, combined with a simultaneous reduction of variability (↓CV) in the annual reservoir maxima; and
   iii. an increase of 22 days in the average duration of inundation > 744 m ASL.

   The last year a comprehensive sample of vegetation transects was made in Kinbasket Reservoir (for CLBMON-10) was 2016. A subsequent partial sample, covering just the upper (750-754 m) elevation bands, was made in 2018 as part of CLBMON-57 implementation. Available monitoring data thus do not provide a complete picture of vegetation responses to the atypical 2015-2020 hydroregime. The most recent set of aerial images of the reservoir obtained by BC Hydro (May 2019) could be used in conjunction with additional field ground-truthing in 2020 (prior to the forecasted return to high water conditions in the summer of 2020) to assist in addressing this important question.

Revegetation

1. Local site conditions should be considered when developing a revegetation plan for a given reservoir. This should include an assessment of the current distribution of vegetation (by elevation) and an assessment of the local flora, which can guide the selection of plant species to use in a revegetation program. The revegetation plan should be developed after visiting the site to determine the best prescription to implement at the site.
2. In some cases, augmenting existing communities with nursery-grown or locally harvested stock may be the most cost-effective approach to increasing vegetation cover (as opposed to trying to translocate plants into barren areas where certain abiotic or factors may be precluding vegetation establishment).
3. Revegetation efforts may require multiple entries/planting sessions before vegetation establishes on the site. The likelihood of this requirement should be assessed as part of the revegetation prescription, as it can provide guidance on whether to plant the site.
4. The four species modelled (Kellogg's sedge, Columbia sedge, wool-grass, and black cottonwood) are among the most widely used species in both CLBWORKS-1 and -2 (the Prescription Catalogues list all the species applied at each treatment site). Many more plant species could be investigated for revegetation potential aside from the ones already trialed. The existing flora of the Kinbasket and Arrow Lakes drawdown zones provides more than 200 well-adapted species to draw from. Among these, emphasis should be on (preferably native) species that (1) provide clear discernable benefits in terms of ground cover, dust control, slope stabilization, and/or wildlife habitat structure, and (2) have demonstrated "staying power," either via a persistent root system (perennials) or a persistent seed bank (annuals). Also of interest are species that are either adapted to a wide variety

of conditions (i.e., are relatively ubiquitous) or are habitat specialist that are known to do particularly well in a specific habitat type, such as dry and sandy soil, debris mounds, mudflats, or recovering wetlands. One such species, swamp horsetail (*Equisetum fluviatile*), is tolerant of extreme variations in water depth and high rates of sedimentation and can colonize exposed mineral soils. It has been used to revegetate the extreme environment of the drawdown zones of reservoirs but has not been explored as a potential option for the revegetation programs in CLBWORKS-1 or -2. The following is a partial list of plant species that would appear, based on field observations, to meet one or more of these criteria:

Mountain alder (*Alnus incana*), Pacific willow (*Salix lucida*), short-fruited willow (*S. brachycarpa*), bluejoint reedgrass (*Calamgrostis canadensis*), tufted hairgrass (*Deschampsia cespitosa*), annual hairgrass (*D. danthoniodes*), moss grass (*Coleanthus subtilis*), fowl bluegrass (*Poa palustris*), little meadow-foxtail (*Alopecuris aequalis*), beaked sedge (*Carex utriculata*), slender sedge (*C. lasiocarpa*), common horsetail (*Equisetum arvensis*), swamp horsetail (*E. fluviatile*), marsh yellow cress (*Rorippa palustris*), dagger-leaf rush (*Juncus ensifolius*), thread rush (*Juncus filiformis*), buckbean (*Menyanthes triofoliata*), marsh cinquefoil (*Comarum palustre*), spike-rush (*Eleocharis* spp.), Norwegian cinquefoil (*Potentilla norvegica*), Scouler's popcornflower (*Plagiobothrys scouleri*), and fireweed (*Epilobium angustifolium*).

5. In addition to considering which species to include in a more in-depth analysis, other aspects of the revegetation programs should be considered. For example, the propagation of plants requires further investigation in terms of seed collection and sourcing, the size of plugs or live stakes to use, or whether rooted live stakes are used (rather than cuttings). The size and/or age of sedge plugs used in a revegetation program may influence success. In 2013, ~68,000 sedge plugs were planted at KM88 (Kellogg's and Columbia sedge) in the drawdown zone of Kinbasket Reservoir. The size of the sedge plugs was similar to that of plugs used previously (i.e., between 2008 and 2011 for CLBWORKS-1), but they were one year older and had (presumably) larger and better-established roots. This treatment continues to thrive while others that were treated with younger plugs between 2008 and 2011 have died. The planting of live stakes may also require further experimentation with the depth of planting, which is an important consideration along with the timing of planting. A recent small-scale trial in Kinbasket Reservoir (Hawkes 2016) revealed that live stakes planted in the fall had much higher survival rates than those planted in the spring. Further assessments of the conditions that foster the natural establishment of plants in the drawdown zone would also be informative.
6. At Bush Causeway, elevated mounds and windrows constructed in 2015 out of local wood debris and mineral soil (Hawkes 2016) are currently showing evidence of successful plant colonization (both natural and via planted live stakes), with over 70 species recorded in 2018 (Miller and Hawkes 2019b). Adjacent wood-choked ponds that were cleaned of wood debris during mound construction are also showing indications of vegetative recovery, with various sedge species as well aquatic macrophyte genera being observed to have established in or adjacent the ponds. However, the constructed habitats are situated at high elevation in the drawdown zone and have yet to undergo an inundation cycle due to the series of relatively low water years in Kinbasket since 2015. This trial is now affording BC Hydro with an unusual opportunity to evaluate the effectiveness of revegetation when prescriptions are applied in the absence of inundation pressure. At the same time, the structural integrity and vegetation responses of the mounds, windrows, and ponds to seasonal flooding remain untested and unknown. Therefore, ongoing monitoring of this trial is recommended.
7. The non-replicated design of the original planting program, combined with annually variable reservoir operations, has limited the ability to test assumptions around factors affecting

revegetation success. We thus recommend that future revegetation treatments be experimentally replicated in space and time. This will assist in identifying the most successful combinations of methods and site conditions, while allowing future physical works prescriptions to evolve within an adaptive management framework.

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9 Appendices

Appendix A. Justification for selection of focal species.

Based on our experience with the revegetation programs in Kinbasket and Arrow Lakes Reservoirs, and on our expertise in vegetation ecology and studies of effects on vegetation communities in the drawdown zones of large hydroelectric reservoirs, the following plant species are considered to be appropriate candidates for more in-depth analyses: Kellogg's sedge (*Carex kelloggii*), Columbia sedge (*C. aperta*), wool-grass (*Scirpus atrocinctus*), and black cottonwood (*Populus trichocarpa*). Other species planted in the drawdown zone of Kinbasket Reservoir (e.g., water sedge [*C. aquatilis*] and small-fruited bulrush [*Scirpus microcarpus*]) have been used in revegetation trials, but for reasons pointed out in Fenneman and Hawkes (2012), they are not considered to be ideal candidates (relative to Kellogg's sedge, Columbia sedge, wool-grass, and black cottonwood). Willow (*Salix*) species have also been planted (via live staking), but results to date suggest that they may not be ideal candidates for revegetation. However, if they are planted under the right combination of conditions (e.g., elevation, exposure, and moisture), they will likely flourish; therefore, site selection will be important for *Salix* spp.

Fenneman and Hawkes (2012) summarized the physiological and ecological characteristics of the most widely planted species in Kinbasket Reservoir and Arrow Lakes Reservoirs.

***Carex kelloggii* (Kellogg's sedge) (syn. *C. lenticularis* ssp. *licocarpa*)** occurs in areas where water levels fluctuate, such as lakeshores, riverside pools, and the margins of reservoirs (Wilson et al. 2008). This species has medium anaerobic capacity and low drought tolerance and is adapted to medium- and coarse-textured soils (USDA-NRCS 2011). It is a common, naturally occurring species in the drawdown zone of Kinbasket Reservoir, and its capacity to tolerate fluctuating water levels made it a logical choice for revegetation. Kellogg's sedge is known to establish on disturbed sites (Wilson et al. 2008), which lends further credence to its use for revegetation. Furthermore, once established, this species has the potential to form a dominant cover if the tussocks are densely packed enough to exclude competition and the substrate remains appropriately saturated (Wilson et al. 2008). Field observations of revegetated areas have indicated that the success of individual plantings in the reservoir is highly variable: some are highly successful in establishing from seedling plugs, while others fail completely. This is likely related to the hydrology and substrate at each site because these factors are integral to the success of revegetation.

Kellogg's sedge is said to have a low seed spread rate, low seedling vigour, and slow vegetative spread (USDA-NRCS 2011). A contrasting account claims this species has the ability to produce a large number of seeds that readily sprout on exposed soils along receding water lines (Wilson et al. 2008). This latter reference agrees with field observations around Kinbasket Lake, where seedlings of this species are common on areas of bare substrate that are exposed as the reservoir's water level drops. The fate of these seedlings is not known, but presumably prolonged periods of inundation or sediment deposition results in extremely low survivorship.

Kellogg's sedge has been less intensively studied than Water sedge, but it likely shares many adaptations and physiological responses. It should be noted, however, that Kellogg's sedge is considered to be a facultative wetland species and it has short, ascending rhizomes that form individual large tussocks, whereas water sedge is considered to be an obligate wetland plant and it has long, rapidly spreading rhizomes originating from a genet leading to a series of ramets. Regardless of their differences in growth form, it is expected that Kellogg's sedge undergoes similar responses to that of Water sedge when it experiences prolonged anoxic or hypoxic conditions; i.e., translocation of resources from aboveground biomass to the roots, formation of aerenchyma, and a decrease in leaf gas exchange. Direct observations and indirect evidence pertaining to other *Carex* species with similar hydrologic requirements seem to add weight to this suggestion (e.g., Visser et al. 2000, Steed et al. 2002, Wilson 2006).

Carex aperta **(Columbia sedge)** like Kellogg's sedge, occurs on wet lakeshores, floodplains, reservoir margins, riverbanks, and wet sedge meadows (Douglas et al. 2001, Wilson et al. 2008). It is similarly drought-intolerant, but in contrast to Kellogg's sedge, it has minimal anaerobic capacity and is adapted to medium- and fine-textured soils but not coarser substrates (USDA-NRCS 2011). A long-lived species, Columbia sedge spreads primarily through deep rhizomes and over time can form large, monospecific stands. Wilson et al. (2008) note that it was once a dominant community along the lower Columbia River bottomlands, where it was harvested for hay, but populations have been greatly reduced by hydrologic changes associated with Columbia River dams. In Kinbasket and Arrow Lakes Reservoirs, Columbia sedge co-occurs frequently with Kellogg's sedge at mid to high elevations in the drawdown zone, although at generally lower densities. It does not presently form large monocultures in these reservoirs; it usually occurs as scattered tussocks mixed in with other vegetation. However, it is possible that stands were more extensive in the region prior to dam construction. Columbia sedge is one of the few plants that can persist in wetlands dominated by Reed Canarygrass (*Phalaris arundinacea*). For this reason, in combination with its tolerance for fluctuating water levels, low nutrient requirements, and ease of transplantation, the species shows considerable potential for restoration of reservoir riparian areas (Wilson et al. 2008, Adama 2015). Broadcast seeding of Columbia sedge in the lower Columbia basin (U.S.) has met with limited success, while survival of vegetative plantings has been variable (Newhouse et al. 1995). Results achieved at Blue River Reservoir (Oregon) inspired researchers to label this plant "an unqualified success" (Newhouse et al. 1995), although establishment elsewhere has been less exemplary (Comes and McCreary 1986). In Kinbasket and Arrow Reservoirs, previous revegetation treatments using Columbia sedge (Keefer et al. 2010) have shown similarly variable success rates as those involving Kellogg's sedge.

Scirpus atrocinctus **(wool-grass)** occurs naturally in marshes, moist meadows, ditches, and disturbed areas (Whittemore and Schuyler 2002), and it is known to have a high anaerobic tolerance (USDA-NRCS 2011). The *Biogeoclimatic Ecosystem Classification* database indicates that in B.C., this species tolerates a soil moisture regime ranging from mesic to hydric, with the average being subhydric (Klinkenberg 2011). Subhydric soils maintain a water table at or near the surface for most of the year, experience poor drainage, and occur on very shallow slope gradients (BC MOE 1998). Like small-fruited bulrush, wool-grass is adapted to fine-, medium- and coarse-textured soils, and it does not tolerate drought (USDA-NRCS 2011). Compared to small-fruited bulrush, wool-grass inhabits areas that are, on average, wetter during the early portion of the growing season and have lower water level fluctuations throughout the growing season (Cooke and Azous 1997). It occurs frequently throughout much of the drawdown zone of Kinbasket Reservoir, particularly in areas of saturated soils (e.g., seepage areas, pond margins).

Information on the effects of flooding on wool-grass is limited because the species was recently split from *S. cyperinus*, but studies have used congeners, and the results should be applicable to the target species. However, studies on *S. cyperinus* have shown that in response to inundation, net photosynthesis decreases over the first several days of inundation, but within a week the plants begin to recover (Spencer 1994). After two weeks, individuals nearly recover to pre-inundation net photosynthesis rates. Thus, this species (and by proxy, *S. atrocinctus*) appears to be very well adapted to the widely fluctuating inundation regimes that occur in the drawdown zone. However, because this species does best on moist microsites, site selection should factor into the decision-making process regarding revegetation.

Populus trichocarpa **(black cottonwood)** typically occurs along streams and in other very moist conditions, is well adapted to seasonal water fluctuations, and has a high tolerance for flooding (Polzin 1998). Cottonwoods are adapted to fine-, medium-, and coarse-textured soils (USDA-NRCS 2011) that maintain a saturated water table (Polzin 1998). Despite this inherent capacity to withstand flooding and periodic inundation, this species has only a moderate tolerance to anaerobic conditions and a low tolerance to both water stress and exposure to drought (USDA-NRCS 2011). Black cottonwood is a common component of upland forested communities adjacent to the drawdown zone of Kinbasket Reservoir, and commonly occurs into the upper elevation bands (although these individuals rarely reach maturity). Low drought tolerance is the primary concern in using this species to revegetate areas of the drawdown zone of Kinbasket Reservoir (Rood et al. 2003).

A study on the physiological response of black cottonwood to flood conditions identified several changes that occurred over the flooding period: (1) altered nutrient uptake and transport, (2) production of adventitious roots originating from the stem, (3) production of aerenchyma, (4) dieback of roots, (5) production of lenticels, and (6) decreased water xylem potential and root hydraulic conductance (Harrington 1987). Due to the numerous adaptations exhibited by black cottonwood, the species has excellent potential for revegetating sites with saturated or periodically inundated water tables.

Although black cottonwood is subject to drought mortality (Rood et al. 2003), and is only moderately tolerant of anaerobic conditions created by inundation, it appears to be a suitable choice for revegetating upper portions of the drawdown zone with woody vegetation. Its low drought tolerance, however, will limit its applicability to sites with a high-water table and/or fine sediments because coarse sediments and a low water table would result in rapid draining and subsequent drought conditions, even adjacent to a large water body such as Kinbasket Reservoir.