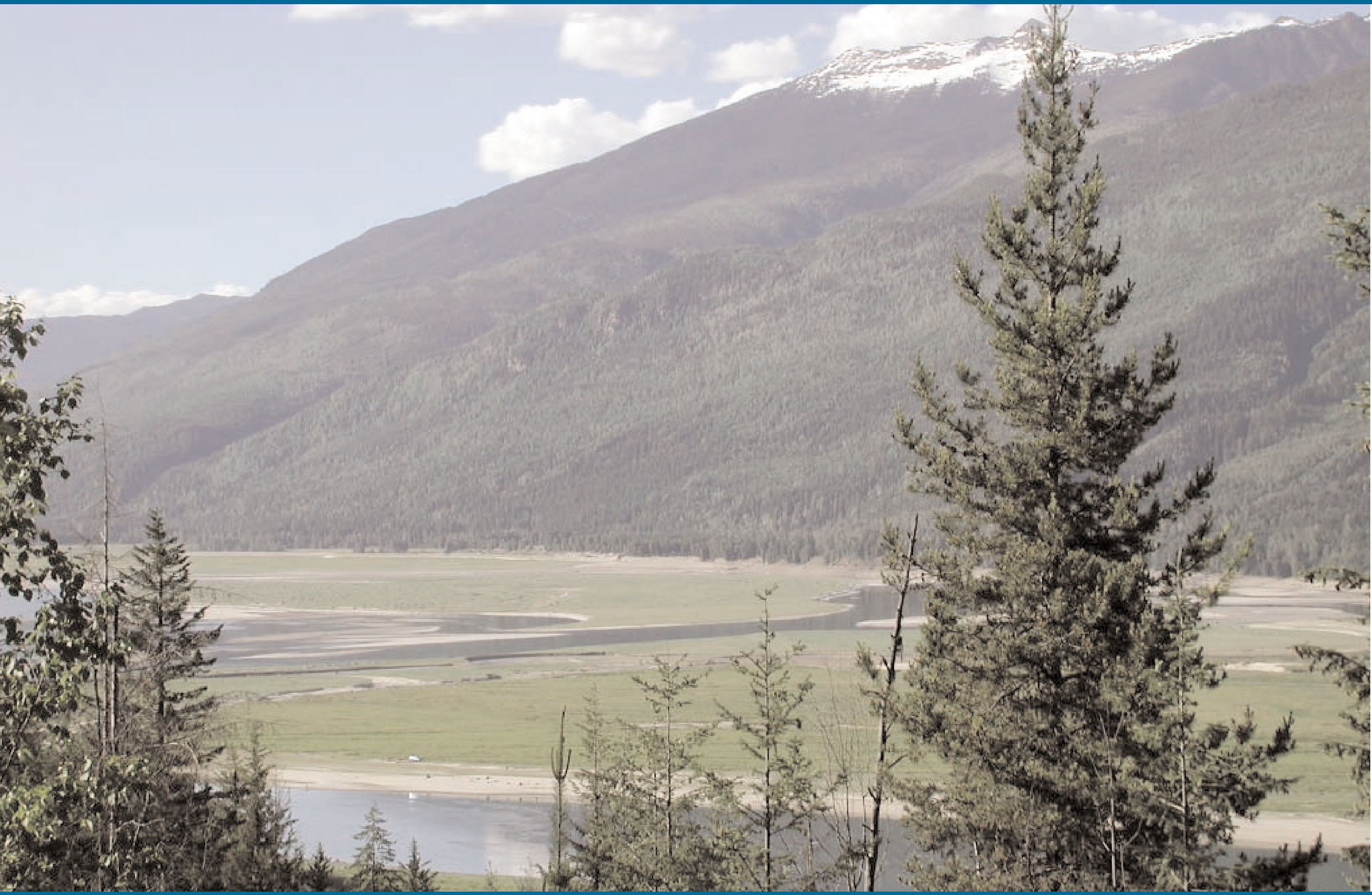
Simulating the Response of Aquatic and Riparian Productivity to Reservoir Operations: Description of the Vegetation and Littoral Components of BC Hydro's Integrated Response Model (IRM)

December 2002



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

BC hydro

Simulating the Response of Aquatic and Riparian Productivity to Reservoir Operations: Description of the Vegetation and Littoral Components of BC Hydro's Integrated Response Model (IRM)

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EXECUTIVE SUMMARY

A simulation model, predicting the response of riparian vegetation and benthos produced in the littoral zone to water surface elevation schedules and fall rye planting in storage reservoirs was developed. The intent of the modeling effort was to provide a predictive tool for water management, but more importantly, to highlight key gaps in data and understanding to strengthen future monitoring and research efforts. Model development was a collaborative effort that integrated data and hypotheses from vegetation ecologists and limnologists who were actively working in the Revelstoke Reach of the Arrow Reservoir, British Columbia.

The vegetation component of the simulation model makes predictions about changes in biomass of various plant groups on a weekly timestep over the growing season. A multi-year sequence of average weekly reservoir water surface elevations is provided as input to the model. In conjunction with a digital elevation model, this time series is used to compute statistics on wet and dry stresses that are accumulated at each 1-meter elevation band in the reservoir. These stress statistics in turn are used to determine seedling establishment rates, and the survival and growth rates of mature plants. The groups of plants that are simulated are: fall rye, horsetail, reed canary grass, sedge, willow, and cottonwood. These plant groups were defined based on differences in growth rates, their responses to wet and dry stress, and their importance to wildlife habitat. A summary of the data used to parameterize the model and model dynamics is provided.

Two major weaknesses in our understanding of the response of vegetation to reservoir operations and fall rye planting were identified in the modeling process. There is almost a complete absence of multi-year data collected in a consistent manner from an informative monitoring design. The lack of this type of information makes it difficult to separate the effects of wet and dry stress on growth, survival, and seedling establishment. The other major uncertainty identified in the model development process was the lack of quantitative understanding of the effects of fall rye planting on native vegetation establishment.

The littoral-benthic component of the simulation model predicts the production of benthos on an annual timestep for 1-meter elevation bands in the reservoir. The two key processes that are simulated are the effects of inundation and flooding of vegetation. The contribution of fall rye, and to a lesser extent reed canary grass and sedge, to the total littoral biomass in the Revelstoke Reach of Arrow Reservoir is potentially very large. Fall rye generates about 12 mg dry wt/g plant after 10 wks of inundation, a value that is almost an order of magnitude higher than the estimates for sedge and reed canary grass). Fall rye is 5-fold more productive that native vegetation. Taken together, these data imply that flooded fall rye generates about 50 times more benthic invertebrates per m^2 relative to that from sedge or reed canary grass in situations when these vegetation groups are at maximum biomass levels. There is large uncertainty about whether this contribution to benthic production is translated into any benefits for fish populations.

Recommendations for the design of future monitoring programs and model improvements are provided. A user’s guide describing the installation and operating procedures for the simulation model is provided.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

Reductions in water surface elevation during the winter and early spring is a common dynamic in the operation of many storage reservoirs used for hydroelectric generation. The magnitude of this annual cycle, or reservoir drawdown regime, can be extensive in British Columbia because of steep valley morphology and reduced inflows during winter months. As a result of water level changes, much of the shoreline in the drawdown zone is denuded of vegetation. These denuded areas are unattractive, have little wildlife value, and can generate dust storms that degrade air quality. As a result of the latter issue, a dust control program, consisting of seeding fall rye, was initiated in the Revelstoke Reach of the Arrow Reservoir in the late 1980's. The program successfully reduced dust levels by stabilizing fine sediments that were exposed during the drawdown period (Carr et al. 1993). Over time, additional benefits of the program became apparent. Native vegetation began colonizing areas that had been planted with fall rye (AIM 2002a). Planting rye improved the carbon content of the soil and provided a roughness that, coupled with the drill seeding process and fertilization to improve seedling growth, enhanced the establishment of native seedlings (W. Carr, Carr Environmental, Cloverdale, BC, pers. comm.). Newly vegetated areas have apparently been heavily used by geese, songbirds, and other wildlife (B. Gadbois, BC Hydro, Revelstoke BC, pers. comm., J. Jarvis and J. Woods, Parks Canada, unpublished data). Flooding riparian vegetation during the reservoir cycle has the potential to increase aquatic productivity by providing a nutrient source and colonization substrate for bacteria, periphyton, and benthic invertebrates. Increases in aquatic productivity associated with the inundation of fall rye and other plants in the Revelstoke Reach is well documented (Perrin and Stockner 2002). In addition, fish have been observed to follow rising water in the drawdown zone each year, and an active rainbow trout fly fishery developed after annual seeding started where no fishery was present before (Perrin and Stockner 2002). It has been hypothesized that the fishery is a result of the additional food production associated with the flooded riparian vegetation. As a result of all these observations, the perception of fall rye planting has evolved from a means of controlling dust to an enhancement technique that can be used to improve riparian and aquatic productivity of reservoirs.

Vegetation communities that establish in the drawdown zone of reservoirs are determined by a combination of factors including topography, aspect, substrate, and the inundation frequency and duration. The planting of crops such as fall rye also assists in the establishment of vegetation cover. The potential enhancement of aquatic productivity will depend on the biomass and composition of the vegetation that is flooded, as well as the depth and duration of inundation. Given the multitude of potential interactions between reservoir operations and riparian and aquatic responses, it became apparent that a computer model, which predicts the growth, survival, and colonization of vegetation and aquatic productivity responses to alternate planting and water management strategies, would be a useful planning tool. It was also recognized that the conceptual model and data required to build the computer model would improve future monitoring and research activities. The development of this model began in 1999 through funding from the BC Hydro Strategic Environmental Initiatives Program as part of the Ancillary Benefits of Reservoir Revegetation Project.

Model development integrated data and hypotheses from vegetation ecologists and limnologists who were actively working on the Arrow Reservoir. This report describes the computer model that was developed through this effort. The main component of the model consists of a vegetation module that predicts the response of different vegetation groups to reservoir water surface elevation schedules. The model simulates the dynamics of plant growth, survival and seedling establishment. An aquatic productivity module simulates the response of benthic invertebrates utilizing the littoral zone of the reservoir to water elevations and inundation of riparian vegetation. The model has been applied to the Revelstoke Reach of the Arrow Reservoir and Carpenter Reservoir, and has been used to evaluate alternate reservoir operating strategies in the Columbia and Bridge River systems as part of the Water Use Planning (WUP) process.

This report consists of four sections. The structure and assumptions of the vegetation model, data used to parameterize it, and model dynamics are summarized in Section 2. Section 3 describes the aquatic production model, and its parameters and dynamics. Section 4 provides recommendations for the design of future monitoring programs and model improvements. Section 5 is a user's guide that describes how to install and operate the modeling software.

2.0 VEGETATION MODEL STRUCTURE

The vegetation model simulates changes in biomass of various plant groups on a weekly timestep over the growing season. A multi-year sequence of average weekly reservoir water surface elevations is provided as input to the model. In conjunction with a Digital Elevation Model (DEM, Fig. 1), this time series is used to compute statistics on wet and dry stresses that are accumulated at each 1-meter elevation band in the reservoir. These stress statistics in turn are used to determine seedling establishment rates, and the survival and growth rates of mature plants. The groups of plants that are simulated are: fall rye, horsetail, reed canary grass, sedge, willow, and cottonwood. These plant groups were defined based on differences in growth rates, their responses to wet and dry stress, and their importance to wildlife habitat.

2.1 PLANT GROWTH

A logistic model is used to simulate the change in above-ground plant biomass over time,

$$B_{iv,ib,t+1} = B_{iv,ib,t} + g_{iv,ib,t} * B_{iv,ib,t} * (1 - \frac{B_{iv,ib,t}}{K_{iv}}) + Seed_{iv,ib,t}, \tag{1}$$

where B_t is the biomass (grams in dry weight/m^2) on timestep t for vegetation group iv at elevation band ib, $g_{iv,ib,t}$ is the weekly growth rate, K_{iv} is the carrying capacity which is the maximum biomass that can be achieved under ideal growing conditions, and $Seed_{iv,ib,t}$ is the biomass contribution from seedlings which have survived the seedling establishment window (see Section 2.2) through natural reproduction or from planting.

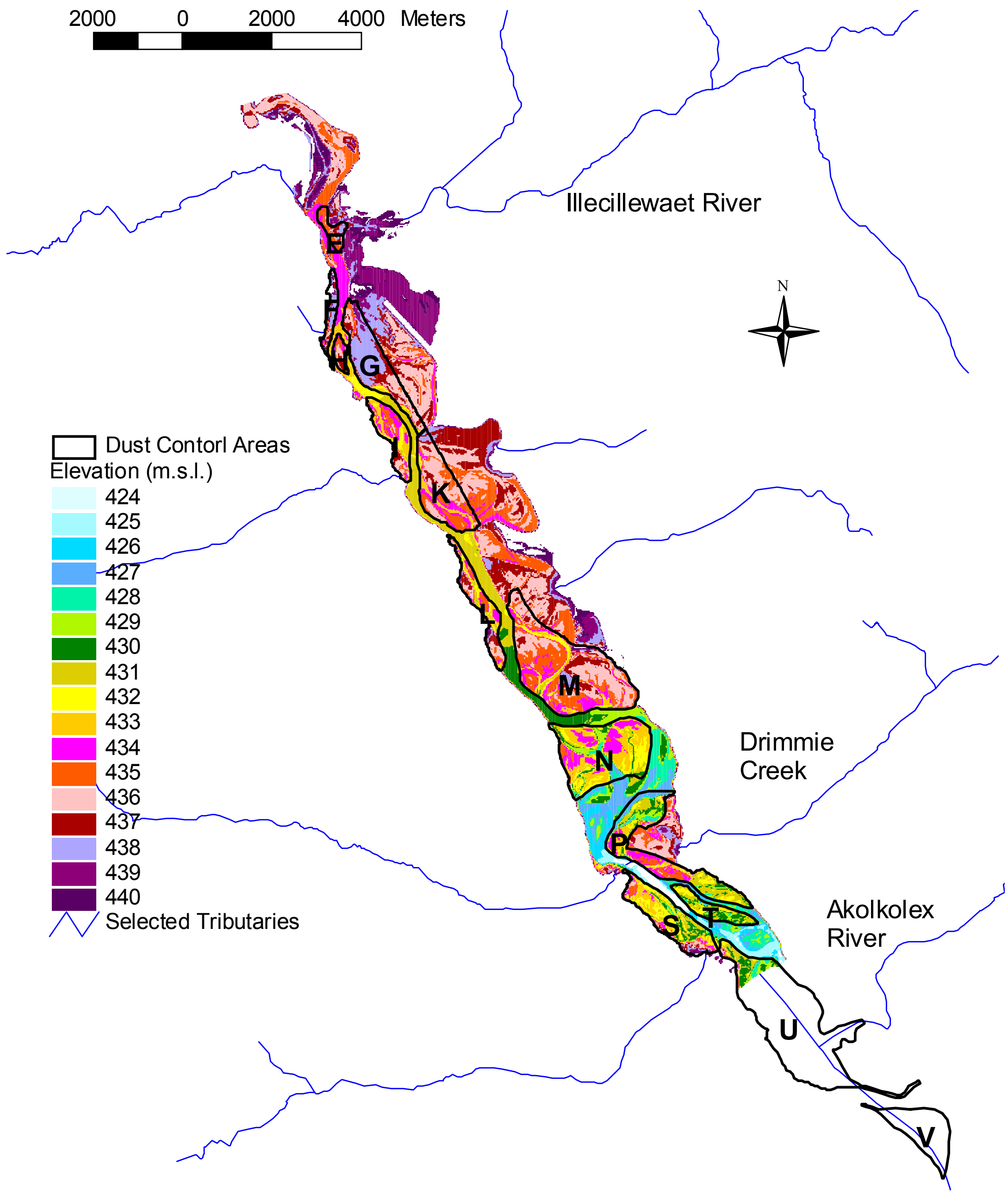


Figure 1 Elevation contours for the Revelstoke Reach of Arrow Reservoir based on the Digital Elevation Model (DEM) derived from the May 2000 air photographs. The elevation data show the total extent of the area that can be modeled. Also shown are the locations of the dust control polygons. The extent of the DEM used in the Arrow Reservoir vegetation model extends beyond the colored area shown here to below the confluence of Akokolex River (to just below dust control area 'V').

Biomass values for each vegetation group at each elevation band must be initialized for the first week of the growing season in the first year of the simulation (*t*=1). This is accomplished by specifying the % cover for each plant group for each elevation band ($IniCover_{iv,ib}$) and converting this value to its biomass equivalent using the equation,

$$B_{iv,ib,1} = IniCover_{iv,ib} * \frac{1}{CB_{iv}}, \tag{2}$$

where CB_{iv} is the cover-to-biomass ratio for each vegetation group. The model can be initialized using data from current surveys for forecasting purposes, or using cover estimates from older surveys when running the model in hindcasting mode to recreate historical trends in vegetation development.

The growth and survival of each plant group is determined by their responses to flooding and desiccation as indexed by stress statistics calculated by the model. Stress statistics for each 1-meter elevation band in the reservoir are computed using a 'degree-day' approach. The wet stress for each band at any point during the growing season ($WetStress_{ib,t}$, in units of meter-weeks), is simply the sum of the depth of water over each band up to any week in the growing season,

$$WetStress_{ib,t} = \sum_{t=1}^{GrowWks} WS_t - Elev_{ib}, \quad \text{if } \mathrm{WS_t} > \mathrm{Elev_{ib}} \tag{3}$$

where, depth is computed as the difference between the water surface elevation on week t (WS_t) and the elevation of the band ($\mathrm{Elev_{ib}}$). Note that wet stress will increase with both the duration and depth of inundation and is 0 until the elevation band is flooded.

A dry stress statistic is used to quantify the stress that a vegetation group will accumulate by being in conditions that are too dry. A large component of this stress is determined by the plants position relative to the water table. This can be indexed by the difference between the elevation of each band and the reservoir water surface. Vegetation groups in elevation bands near the water table should undergo less dry stress than plants that are in elevation bands well above the water table. Dry stress ($DryStress_{ib,t}$, in units of meter-weeks) for each elevation band is simply the sum of the differences between the elevation of each band and the reservoir water surface,

$$DryStress_{ib,t} = \sum_{t=1}^{GrowWks} Elev_{ib} - WS_t \,, \qquad \text{if } \mathrm{Elev}_{ib} > \mathrm{WS}_t \tag{4}$$

Note that dry stress will increase with the duration of exposure and the height difference between the elevation band and the reservoir water surface.

The growth rate of each vegetation group at each elevation band on each week ($g_{iv,ib,t}$ from eqn. 1) is determined based on a maximum growth rate under ideal conditions ($gBase_{iv}$) and multipliers that depend on the amount of wet ($gMultWet_{iv,ib,t}$) and dry stress ($gMultDry_{iv,ib,t}$) that is accumulated,

$$g_{iv,ib,t} = gBase_{iv} * gMultWet_{iv,ib,t} * gMultDry_{iv,ib,t} \tag{5}$$

where, $gMultWet_{iv,ib,t}$ and $gMultDry_{iv,ib,t}$ must range from 0-1. These growth rate adjustments are predicted from a declining Type III functional response of the form,

$$gMultX_{iv,ib,t} = 1 - \frac{XPStressi_{iv,ib,t}{}^{XSl_{iv}}}{XHf_{iv}{}^{XSl_{iv}} + XPStress_{iv,ib,t}{}^{XSl_{iv}}} \tag{6}$$

where, all references to ‘X’ should be replaced with the words ‘Wet’ or ‘Dry’, $XPStress_{iv,ib,t}$ is the proportion of accrued wet or dry stress relative to the maximum tolerable values (i.e., $WetPStress_{iv,ib,t} = WetStress_{ib,t}/MaxWetStress_{iv}$), XHf_{iv} (i.e., $WetHf_{iv}$ or $DryHf_{iv}$) is a parameter that determines the stress level where growth is reduced to ½ of its maximum value (i.e., 0.5*$gBase_{iv}$), and XSl_{iv} (e.g., $WetSl_{iv}$ or $DrySl_{iv}$) is the slope coefficient determining the steepness of the relationship.

2.2 PLANT SURVIVAL AND SEEDLING ESTABLISHMENT

Survival of mature plants is determined by specifying maximum-tolerable wet and dry stress levels for each vegetation group ($MaxWetStress_{iv}$, and $MaxDryStress_{iv}$, respectively) and comparing these values with the accumulated stress levels at each elevation band over time. Biomass ($B_{iv,ib,t}$ in eqn. 1) is set to zero whenever the stress levels equal or exceed the maximum tolerance values, that is,

$$\begin{aligned} WetStress_{ib,t} &\geq MaxWetStress_{iv} \\ DryStress_{ib,t} &\geq MaxDryStress_{iv} \end{aligned} \tag{7}$$

Note that equivalent wet stresses can be achieved by flooding an elevation band to 10 meters depth for one week or flooding the band for 10 weeks to a depth of one meter. The model therefore assumes that survival is equivalent under these two scenarios. The identical issue applies to computation of survival from dry stress. The model also assumes that the survival response to wet and dry stress is similar across all ages of plants beyond the seedling stage. It may be that younger or smaller plants have a lesser ability to withstand wet and dry stress relative to older and larger plants, but there was not sufficient data to model this dynamic. Note that the model does not account for stress accumulated in previous years when computing survival from Eqn. 7. It may be that plants that approached the maximum stress level in year t-1 have a lower stress threshold in following years, i.e., that stress is accumulated across years. Again, the data that is available is not sufficient to model processes at this level of detail.

Seedling establishment in the model has little effect on biomass trajectories, except in situations where a vegetation group is absent from an elevation band, either due to mortality from flooding or desiccation, or because the elevation band was never initialized with a cover value for the first week of the simulation. Seedling establishment is controlled by six parameters. A seedling establishment window defines the period of the growing season when seeds are available and can potentially grow into seedlings (*SeedWkMin*$_{iv}$, *SeedWkMax*$_{iv}$). During this time period, wet and dry stress statistics are computed and seedling establishment for a weekly-cohort fails whenever these statistics exceed maximum tolerances (*SeedFloodMax*$_{iv}$ *SeedMaxDrySress*$_{iv}$). If these tolerances are not exceeded for the minimum number of weeks required for seedling establishment (*SeedWks*$_{iv}$), a seedling establishment event is simulated,

$$SeedWks_{iv} \leq \sum_{t=SeedWkMin_{iv}}^{SeedWkMax_{iv}} wk = wk + 1 \left| \begin{array}{l} WS_t - Elev_{ib} < 0 \\ DryStress_{ib,t} < SeedMaxDryStress_{iv} \end{array} \right. \qquad (8)$$

The contribution of biomass from newly established seedlings (*Seed*$_{iv,ib,t}$ in eqn. 1) to the total above-ground biomass on any timestep depends on a parameter that specifies the additional cover associated with a seedling establishment event (*SeedIniCover*$_{iv}$),

$$Seed_{iv,ib,t} = SeedIniCover_{iv} * \frac{1}{CB_{iv}}. \qquad (9)$$

2.4 PARAMETERIZATION OF VEGETATION MODEL

A large number of parameters are required to model the growth, survival, and seedling establishment of six different vegetation groups (Table 1). The reliability of the parameter values used in the model varies considerably. In some cases, the values could be directly estimated from data collected in the Revelstoke Reach of the Arrow Reservoir. For many parameters, professional judgment (L. Stevens, Flagstaff AZ., W. Carr, Cloverdale B.C.) was used to provide initial guesses that were further refined by tuning the estimates so that model predictions of biomass or relative abundance-by-elevation fit the observed patterns in the Revelstoke Reach of Arrow Reservoir based on a recent mapping exercise (Moody 2002a). What follows is a brief summary of how the various parameters values of the vegetation model were derived.

2.4.1 Maximum Wet and Dry Stress Parameters

Initial estimates of maximum tolerable wet ($MaxWetStress_{iv}$) and dry stress ($MaxDryStress_{iv}$) values were obtained from data on the spatial distribution of vegetation groups derived from an air photograph mapping analysis. 1: 5000 scale color air photographs taken on May 24, 2000 were used to classify polygons within dust control areas F-T according to dominant vegetation type and relative biomass classes (Moody 2002a). Note that these polygons are not homogenous stands comprised of a single vegetation type but represent a complex made-up of multiple species, but classified according to the most dominant type. The polygons were then overlaid on 1-meter elevation contours (W. Beauchamp, B.C. Hydro, unpublished data), to compute the area of each dominant vegetation group-biomass class for each 1-meter elevation band (Fig. 2). Reed canary grass is the dominant vegetation group in the drawdown zone of the Revelstoke Reach covering about 350 Ha of the sampled area. Sedge is the next most abundant group covering 92 Ha. Horsetail and willow vegetation groups were relatively rare, covering only 30 Ha and 4 Ha of the sampled areas, respectively.

Table 1 Summary of parameters used in vegetation model.

PARAMETER DESCRIPTION	Units	Parameter Name in Equations	Fall Rye	Horsetail	Reed Canary Grass	Sedge	Willow	Cotton-wood
Maximum Growth Rate	$gC/m^2/wk$	gBase	0.53	0.015	0.03	0.015	0.03	0.03
Carrying Capacity (maximum potential biomass)	gC/m^2	K	3000	200	650	650	1000	1000
Crown Cover-to-Biomass Ratio	no units	CB		0.23	0.13	0.14	0.1	0.1
Root-to-Shoot Biomass Ratio	no units	RS	0.65		2.5	3.2		
Maximum tolerable wet stress	meter-weeks	MaxWetStress	0	85	85	125	20	30
Maximum tolerable dry stress	meter-weeks	MaxDryStress	1000	300	150	150	175	1000
Wet stress at which growth rate is reduced by 50%	meter-weeks	WetHf	0.5	0	0.2	0.05	0.05	0.05
Slope of wet stress - growth relationship	no units	WetSl	5	10	10	10	10	5
Dry stress at which growth rate is reduced by 50%	meter-weeks	DryHf	0.5	0.4	0.01	0.6	0.05	0.5
Slope of dry stress - growth relationship	no units	DrySl	5	10	10	10	10	10
Maximum number of flooded weeks that seedlings can tolerate	weeks	SeedMaxWetStress	0	0	5	5	1	5
Maximum tolerable dry stress for seedlings	meter-weeks	SeedMaxDryStress	600	0	600	600	1000	10
Number of consecutive wks. required for seedling establishment	weeks	SeedWks	5	5	5	5	10	10
First week of seedling establishment period	julian week	SeedWkMin	28	28	28	28	19	28
Last week of seedling establishment period	julian week	SeedWkMax	42	42	42	42	42	41
Crown cover following seedling establishment	%	SeedIniCover	5	5	5	5	5	5
Constant of invertebrate biomass - plant biomass relationship	mg dry wt / g of plant	BenVegConst	0	0	1.27	0	0	0
Slope of invertebrate biomass - plant biomass relationship	mg dry wt / g of plant	BenVegSlope	1.181	0	0	0.15	0	0

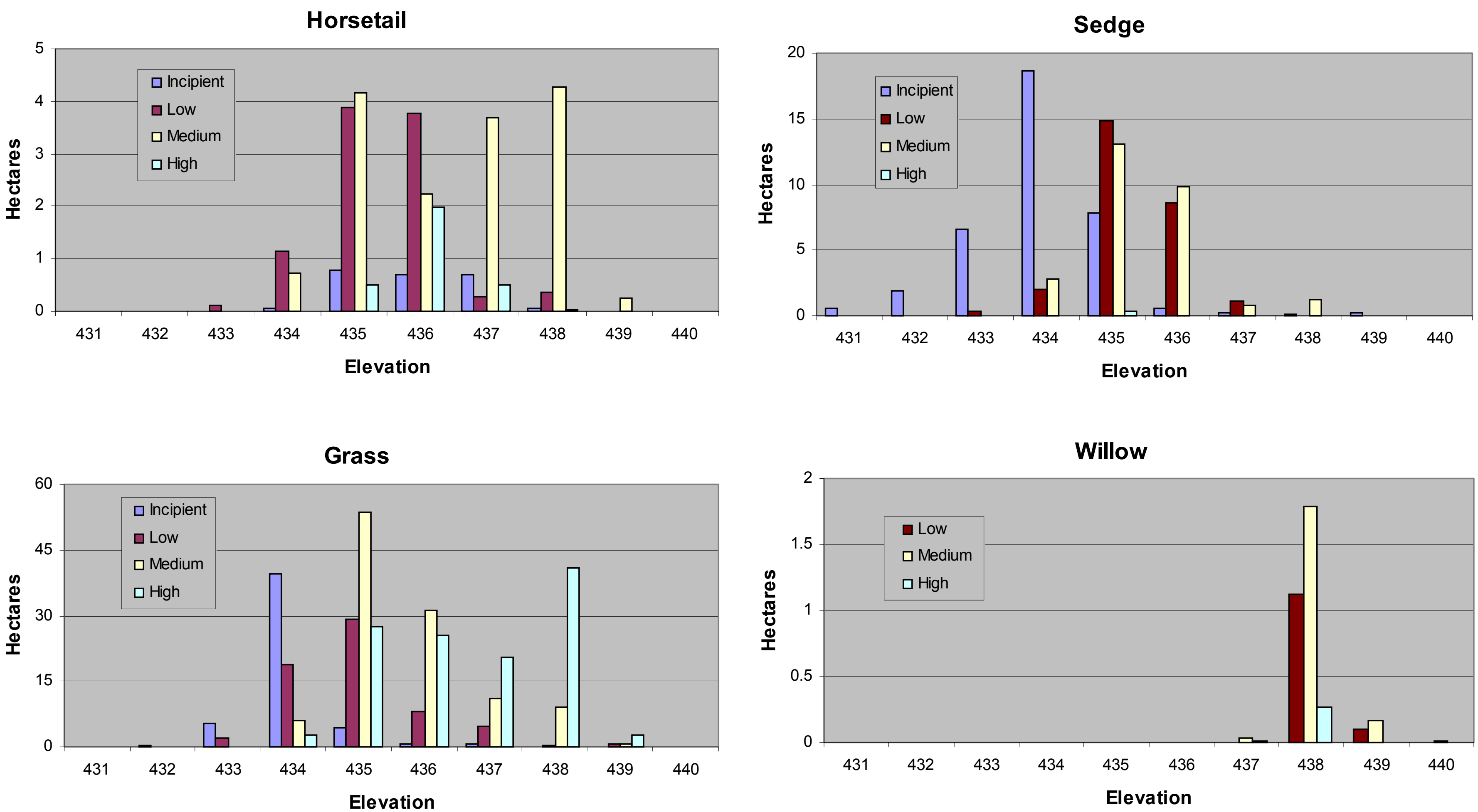


Figure 2 Total area of vegetation groups by different biomass classes and 1 meter elevation bands (data modified from Moody 2002a).

Data on the distribution of vegetation groups by elevation can be used to parameterize model relationships predicting growth and survival to wet and dry stress. The mapping data provides the raw information to do this but it must be corrected because, the areas of 1-meter elevation bands that can potentially be mapped, are not equivalent. The surface of dust control areas F-T, where vegetation mapping data was produced, is dominated by elevations 431-434 m.s.l. (Fig. 3). Thus, the presence of vegetation at elevations above this range will be under-represented in the mapping results because these elevations represent a smaller proportion relative to what exists in the Revelstoke Reach covered by the DEM (i.e, the modeled area). To adjust for this bias, a correction factor was developed which standardized the vegetation area to 432-m.s.l.-equivalnts (the elevation band with the greatest total area). Correction factors were computed for each 1-meter elevation band as the ratio of the total area across dust control areas F-T for elevation 432 m.s.l. to the total area for that band (i.e., $CF_{ib} = \mathrm{Area}_{432}/\mathrm{Area}_{ib}$). The total vegetated area for any vegetation group at an elevation band is the product of the mapped area and the correction factor. Note that these correction factors can be substantial (15 or greater) for elevations above 437 m.s.l. Average wet and dry stress statistics for each 1-meter elevation band (eqn.'s 3 and 4) were then computed using the 1990-1999 Arrow Reservoir elevation data. The statistics were overlaid on the area-corrected vegetation group-biomass results to determine the maximum tolerable wet and dry stress limits (Fig. 4, Table 1). The following general conclusions about vegetation distribution as a function of elevation and stress levels can be made:

- Horsetail cannot survive at elevations below 434 m.s.l. corresponding to a maximum wet stress level of about 80 meter-weeks.
- Reed canary grass has a wide tolerance for both wet and dry conditions. It extends down to an elevation of 434 m (wet stress <=75 meter-weeks) and attains very high abundance levels up to 439 m (maximum dry stress <= 180 meter-weeks).
- Sedge is the most flood-tolerant vegetation group with coverage down to (431 m.s.l.). Sedge appears to be quite sensitive to dry stress, and was rarely observed at elevations greater than 438 m (dry stress < 140 meter-weeks).

- Willow is sensitive to flooding and was not found at elevations below 438 m.s.l., which corresponds to a maximum wet stress level of <=15 meter-weeks.

Initial estimates of maximum wet and dry stress were used in model simulations driven by historical reservoir elevations from 1990 – 2000. Predictions of the distribution of vegetation groups by elevation were compared to the standardized observations (Fig. 4). Adjustments to the maximum wet and dry stress parameters were made to improve the fit between observed and predicted elevation distributions.

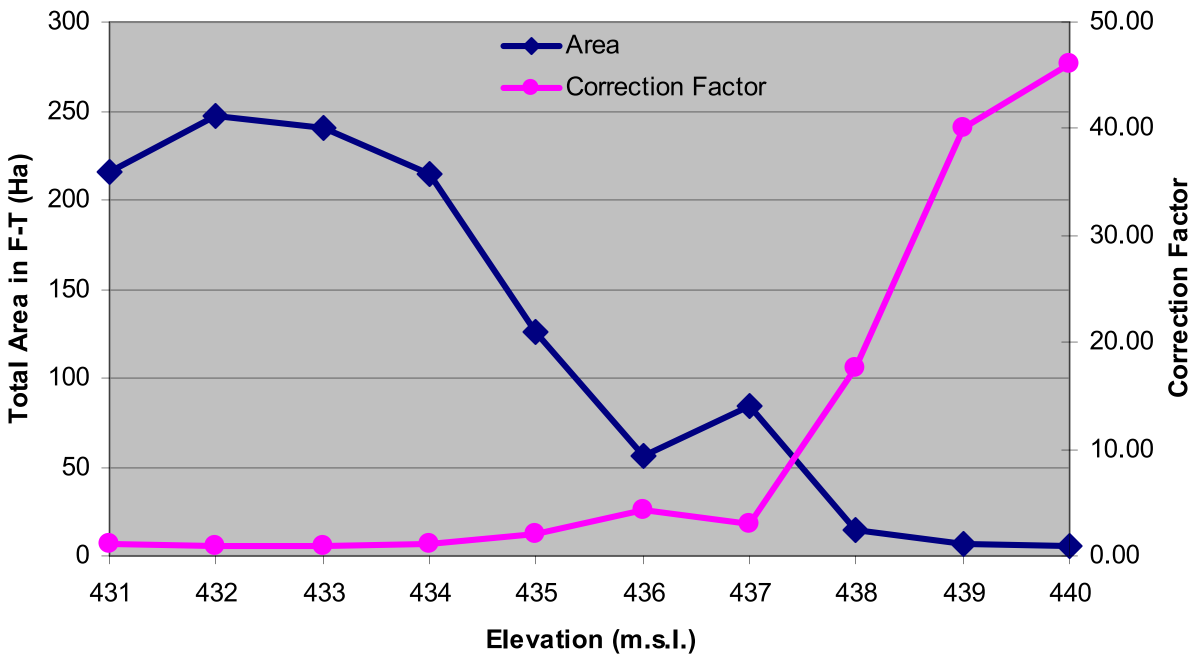


Figure 3 Total area for 1-meter elevation bands in dust control areas F-T in the Arrow Reservoir, and the correction factors used to standardize vegetation mapping results from Moody (2002a). The correction factor is computed as the ratio the area at 432 m.s.l. (the elevation that has the most area across dust control areas F-T) to the area from each elevation band. Multiplying the area of mapped vegetation polygons at any elevation slice by its corresponding factor corrects for differences in the availability of total area across elevation bands.

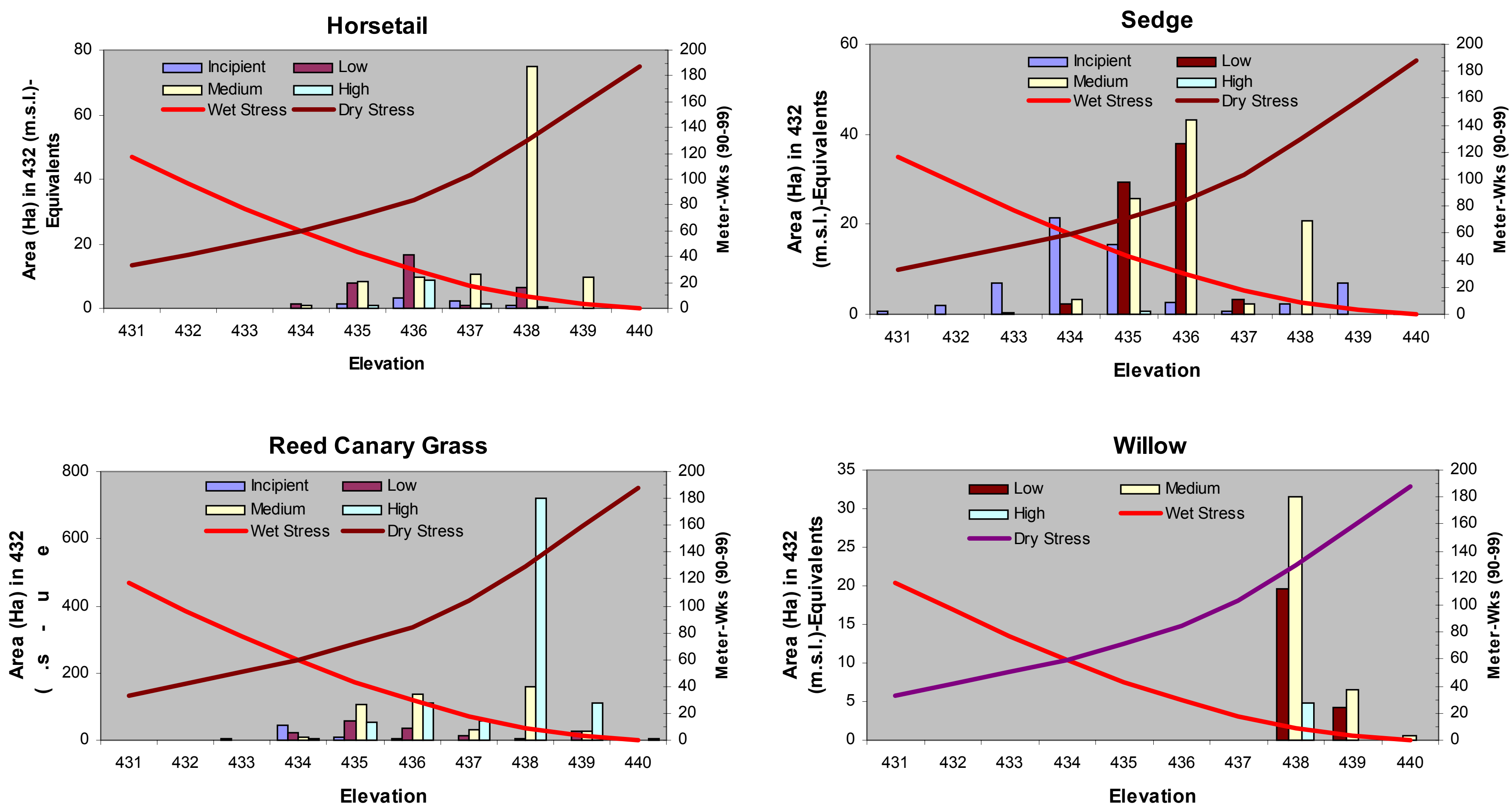


Figure 4 Area (in 432 m.s.l.-equivalent Hectares) of vegetation groups by different density classes and 1-meter elevation bands. The 432-equivlant area for any elevation-density class combination is computed as the total area for this class (Fig. 2) times a correction factor (Fig. 3). See caption for Fig. 3 and text for details.

2.4.2 Growth Parameters

Carrying Capacity

Carrying capacity refers to the maximum potential biomass that vegetation groups can attain under ideal natural growing conditions in the absence of flooding. Note that the actual biomass achieved for any vegetation group on any week of the simulation ($B_{iv,ib,t+1}$) depends not only on carrying capacity, but also on the antecedent conditions ($B_{iv,ib,t}$), the mature plant growth rate ($g_{iv,ib,t}$) and potential seedling recruitment ($Seed_{iv,ib,t}$). Estimates of carrying capacity (*K* in Table 1 and eqn. 1) were based on a combination of professional judgment and field data. Field data from the Arrow Reservoir vegetation studies were used to estimate carrying capacity estimates (maximum potential biomass value) for fall rye (Carr et al. 1993), horsetail, reed canary grass, and sedge (Moody 2002b) based on maximum observed biomass values (Fig. 5). Maximum biomass estimates for willow and cottonwood were not measured and are based on professional judgment.

Maximum Growth Rate

There is a paucity of data to estimate maximum growth rates (*gBase* in Table 1 and eqn. 1) for most of the vegetation types that were modeled except for fall rye and sedge. The model operates on a weekly timestep and growth rates must be estimated at this same resolution. Estimating growth rates for fall rye was relatively easy as the plant is an annual and studies evaluating the effectiveness of fall rye planting (Carr et al. 1993) quantified the biomass change of fall rye over the course of the growing season in 1991 and 1992. The maximum growth rate for fall rye was fit using a non-linear iterative search procedure to find a *gBase* value that minimized the sums of squared differences between observed and model predictions of biomass over the growing season (Fig. 6). During the fitting procedure the *K* parameter of the logistic model (eqn. 1) was held constant at the maximum biomass value of 3000 gC/m^2 observed by Carr et al. (1993). As fall rye dies when inundated to any degree, there was no need to account for the effects of flooding when trying to estimate maximum growth rate. The fall rye growth rate estimate was 0.53 gC/m^2/wk, which is about 35-fold greater than the sedge growth rate estimated below (Table 1).

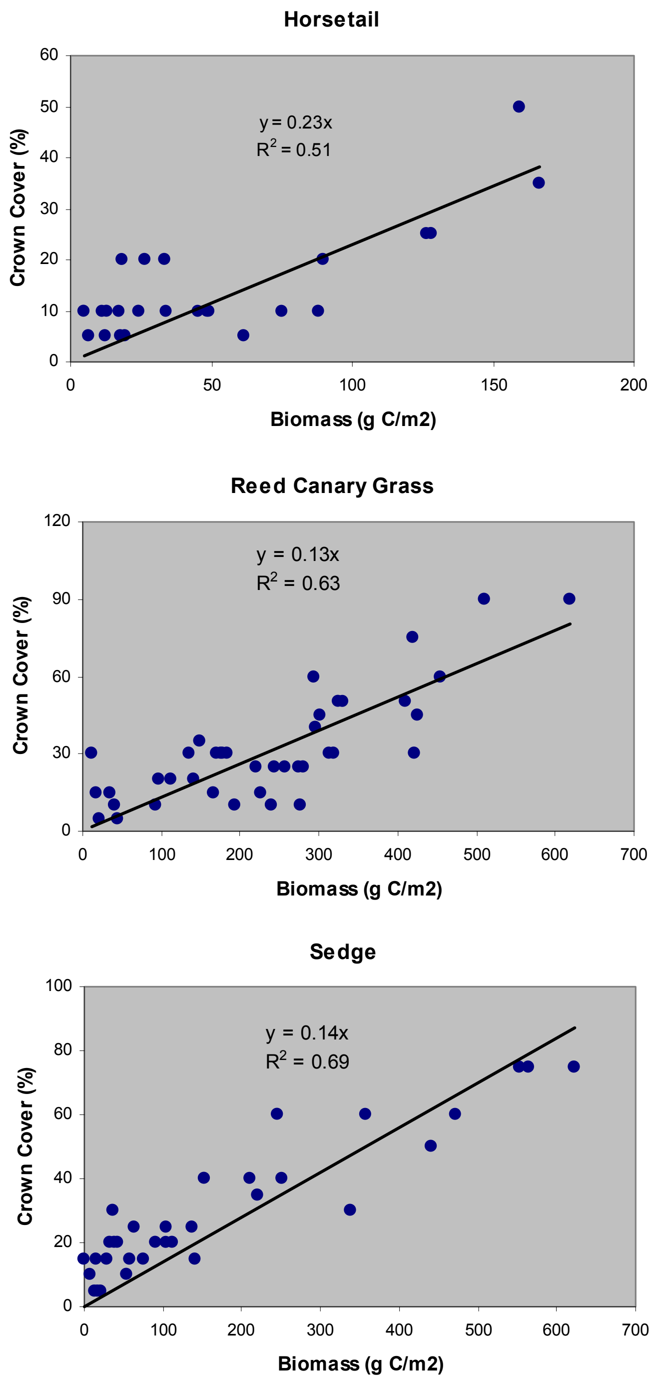


Figure 5 Relationships between crown cover and biomass for horsetail, reed canary grass and sedge based on data collected in 1999 and 2000 in the Arrow Reservoir (data provided by Anne Moody).

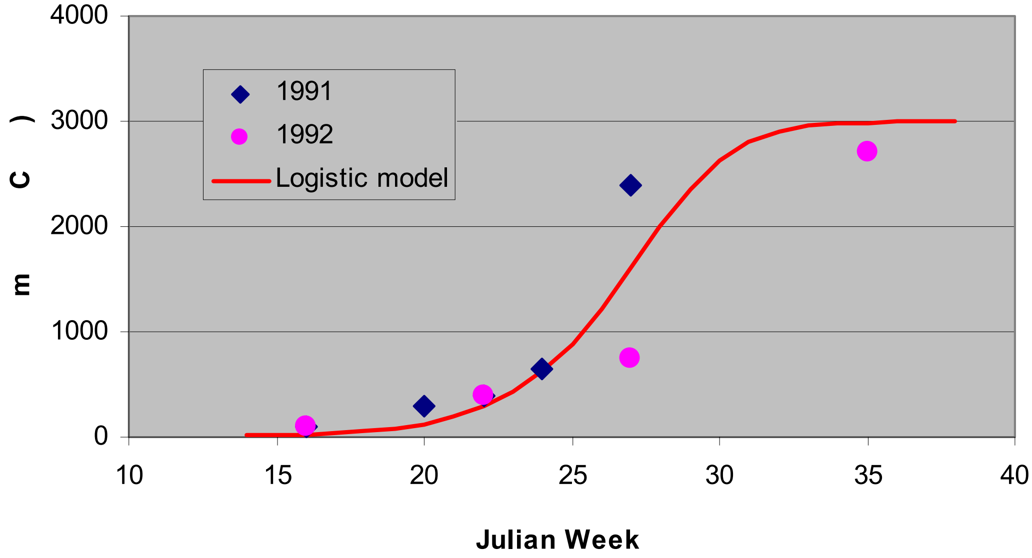


Figure 6 Logistic growth model fit to fall rye biomass data collected in the Arrow Reservoir in 1991 and 1992 (data from Carr et al. 1993).

Estimation of growth rate for sedges is more complex relative to fall rye due to the nature of the long-term plot data, the perennial life history of the plant, and the effects of flooding on growth. Data that can be used to compute sedge growth was only collected on one date within each growing season, so weekly estimates of growth rate must be computed by fitting to a series of annual estimates. In addition, sedges can survive when inundated and the elevations of the long-term plot data used in this analysis (435-437 m.s.l.) were inundated in most years. Thus any estimate of the maximum growth rate based on these data includes the effects of flooding. As the long-term plot data did not span a large range of elevations with very different inundation frequencies (because vegetation has extended in elevation from approximately 436 m.s.l in 1990 to 434 m.s.l. in 2000), it is not possible to directly estimate both the maximum growth rate (*gBase* in eqn. 5) and the parameters that determine the reduction in growth due to inundation (eqn. 6).

Data on sedge basal diameter (B.D.) and number of sedges per unit area is available from 1993 to 2001 at long term monitoring sites in dust control areas P, G, and K (Moody 2002b). These data were converted to biomass estimates by developing a linear relationship between plant weight and basal diameter for plots at elevations above 436 m.s.l. (Dry Weight = 6.26 * BD – 37.54, r^2 = 0.88, n= 15 plants) where effects of inundation on plant diameter-weight relationships were relatively consistent. The converted long-term plot data shows an initial sedge biomass in 1992 of approximately 20 gC/m^2 for areas P and G, increasing to values of about 200 gC/m^2 by 2000-2001 (Fig. 7). Data from dust control area K were excluded from the analysis because plant biomass was considerably reduced due to foraging by Canada Geese (A. Moody, pers. comm.). The growth rate parameter of a logistic model (*gBase* of eqn. 1) was then fit to data from areas P and G while holding the carrying capacity value constant (*K* in eqn. 1) at the maximum observed biomass level of approximately 650 gC/m^2) (Fig. 5, Table 1). The growth rate was estimated by fitting the dynamic model predictions from the long-term plot elevation (435-436 m.s.l.) to the trajectory of observed biomass levels at these plots (Fig. 7). Under ideal conditions (no reductions in growth rate due to wet or dry stress), this estimate of the maximum growth rate predicts that a barren plot can achieve maximum biomass levels in about 10-12 yrs.

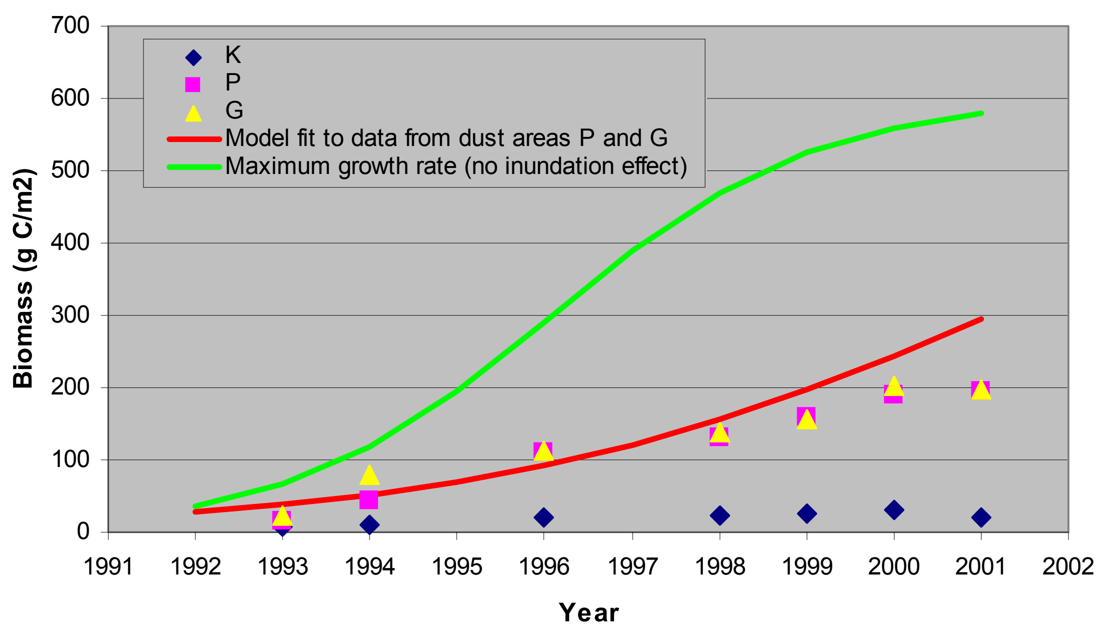


Figure 7 Biomass of sedges from long-term monitoring plots in dust control areas K, P, and G (A. Moody, unpublished data) in the Arrow Reservoir. A logistic growth model (red line) was fit to data from areas P and G. The increase in biomass assuming no inundation effects (green line) is shown for reference.

Data to estimate growth rates for other vegetation groups were not available in the Arrow system. There is no long-term or within-season plot data for horsetail, reed canary grass, willows, or cottonwood. Growth rates for these vegetation groups were derived by setting their values relative to the growth of sedge using the following assumptions: 1) horsetail grows at the same rate as sedge (0.015 $gC/m^2/wk$); 2) reed canary grass, willow and cottonwood grow two times faster than sedge (0.03 $gC/m^2/wk$). These assumed relative differences in growth rates are highly uncertain.

Wet and Dry Stress Growth Adjustments

Parameters controlling the computation of growth reduction multipliers resulting from wet and dry stress (*WetHf, WetSl, DryHf, DrySl* from eqn. 6) could not be computed directly from field data. To do this, one would need a multi-year dataset that measured above-ground biomass at a range of elevations with different wet and dry stress levels. Sedge was the only vegetation group monitored in Arrow Reservoir over successive years and unfortunately, only within a narrow elevation band (435-437 m.s.l.) relative to the current distribution of this group (Fig. 4). Growth reduction parameters were therefore tuned by running the model with the historical reservoir elevation schedule from 1990-2000 and comparing the predicted biomasses at each elevation in 2000 with rough estimates of the observed values in the same year measured from the mapping analysis (Fig. 4, Moody 2002a).

Cover-to-Biomass Conversion Rates

The ratio of % crown cover to biomass (CB_{iv}) was estimated from field data collected in Arrow Reservoir in 1999 and 2000. Ratios for horsetail (0.23, r^2= 0.51), reed canary grass (0.13, r^2=0.63), and sedge (0.69, r^2 =0.69) were estimated (Fig. 5). Data for other vegetation groups were not available so the following estimates were assumed: fall rye=0.03; willow and cottonwood=0.1 These estimates are highly uncertain.

2.4.3 Seedling Establishment Parameters

There was no field data available to fit parameters of the seedling establishment component of the vegetation model, and there was little useful information available from the literature. The following assumptions were made (Table 1):

1. Cover following seedling establishment was set to 5% for all vegetation groups except for fall rye, which was set to 0. This ensured that fall rye did not naturally reproduce and would only grow if planted.
2. The seedling establishment period spanned from mid-July to mid-October for all vegetation groups except for Willow, where the period was greater and ran from mid-May to mid-October.
3. 5 consecutive weeks were required to establish seedlings for reed canary grass and sedge, while 10 wks were required for willow and cottonwood.
4. Seedlings from all vegetation groups could withstand up to 5 weeks of inundation except for Willow, which could only withstand 1 week of inundation.
5. Seedlings from all vegetation groups were not sensitive to dry stress with the exception of horsetail and cottonwood.

While many of these assumptions are not supported by data, they have little effect on the model in most cases. Model predictions are driven by initial cover estimates at each elevation and growth/survival parameters for mature plants. The only time seedling establishment parameters come into play is when a vegetation group is eliminated from an elevation band due to wet- or dry stress-related mortality. In these situations, the seedling establishment component determines whether the vegetation group can re-establish in a particular year. This establishment process is suspected to be dominated by effects from the fall rye planting program.

2.5 DYNAMICS OF VEGETATION MODEL

An example of the effects of reservoir elevation on stress statistics and plant growth rates at 3 elevation bands (430, 435, and 440 m.s.l.), using the Arrow Reservoir water surface elevations for 2000, is provided in Figure 8. As water surface elevation increases from the start of the growing season (Julian week 14, or April 15), wet stress (eqn. 3) begins to accumulate when the water surface exceeds the elevation of the band (Fig. 8a). Wet stress attains higher values at lower elevations that are submerged to greater depth for longer periods. Dry stress (eqn. 4) accumulates quickly at higher elevations at the beginning of the growing season when the difference between these elevations and the water surface is greatest (Fig. 8b). The functional relationships (eqn. 6) predicting the responses of the maximum growth rate to stress levels are shown in Figure 8c. Based on the parameter values and stress statistics (Fig. 8a and b) used in this example, growth rates (Fig. 8d) attain near maximum values at the intermediate elevation (435 m.s.l.), are severely impaired at the lowest elevation (430 m.s.l.) when the wet stress level exceeds about 80 meter-weeks, and moderately impaired at the highest elevation (440 m.s.l.) due to the dry stress (ca. 140 meter-weeks) accumulated during the initial two months of the growing season.

Time series of model projections of vegetation biomass at 432, 436, and 440 m.s.l. using the historical Arrow Reservoir water surface elevations from 1990-2000 are presented in Figure 9. Model predictions match observed elevation gradients in biomass (Fig. 4) relatively well. The distribution of horsetail-dominated communities is limited at the upper elevation by dry stress and cannot grow at the lowest plotted elevation due to wet stress. Relative to reed canarygrass- and sedge-dominated communities, biomass of horsetail-dominated communities is relatively low due to the lower carrying capacity estimate used in the model (Table 1). In contrast, reed canarygrass-dominated communities attain much higher biomass levels due to their higher carrying capacity and growth rate estimates. Sedge-dominated communities achieve higher biomass levels at lower elevations relative to reed canarygrass ones, and although sedge-dominated communities have the same carrying capacity as reed canarygrass ones, biomass levels of the former vegetation group are lower due their lower maximum growth rate. In contrast to the other vegetation groups shown, sedge-dominated communities can colonize lower elevation bands because of their higher tolerance to wet stress (Fig. 10).

On a reach-wide basis, predictions of the distribution of vegetation across elevations match the observed data relatively well (Fig. 9 vs. Fig. 4), however, on a site-specific basis there can be significant discrepancies. For example, in dust control area 'N' (Fig. 1), the model predicts a low-biomass sedge-dominated community (Fig. 10) while the mapping data shows that the area is mostly unvegetated except for small areas at higher elevations (Moody 2002a). Note that model predictions of vegetation biomass at an elevation band are not site-specific because the model does not include site-specific factors (e.g., aspect, substrate, fall rye planting history). Site-specific factors were not included in the model because the existing data and understanding was not sufficient to quantify relationships between planting history, substrate, aspect, etc. with key processes like plant survival and seedling establishment. In other cases, discrepancies at a site-specific level reflect the quality of the DEM. For example, the model predicts vegetation presence in the river channel (e.g., river channel in area K, see Fig's 1 and 10) because the elevations in these areas as specified by the DEM are incorrect. The current DEM used in the model was developed from an air photograph, so elevations for the topography in the river channel is incorrectly measured as the water surface elevations, not the elevations of the land.

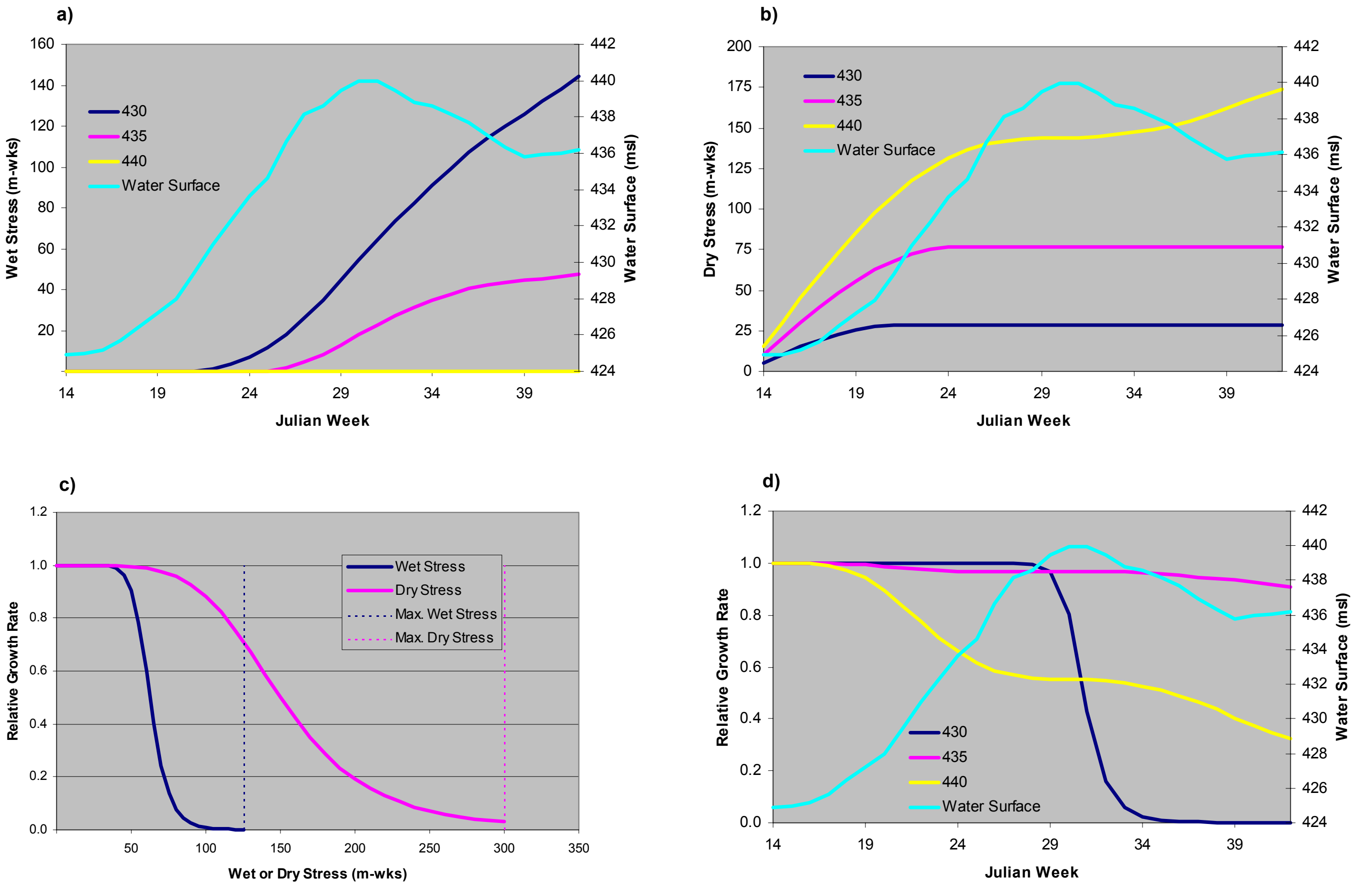


Figure 8 The simulated effects of wet and dry stress on the growth rate of plants in the vegetation model. In this example, water surface elevation in Arrow Reservoir from 2000 drives model predictions at 3 elevation bands (430, 435, and 440 m.s.l.). Wet (a) and dry (b) stress statistics accumulate as a function of the depth and duration of inundation and exposure over the course of the growing season. Functional relationships (eqn. 6) determine the relative change in the maximum growth rate that will occur as wet and dry stress levels increase (c). The actual reduction in the maximum growth rate (d) results from the combined effect of wet and dry stress levels (a, b) and the functional relationship determining the growth response to these stresses

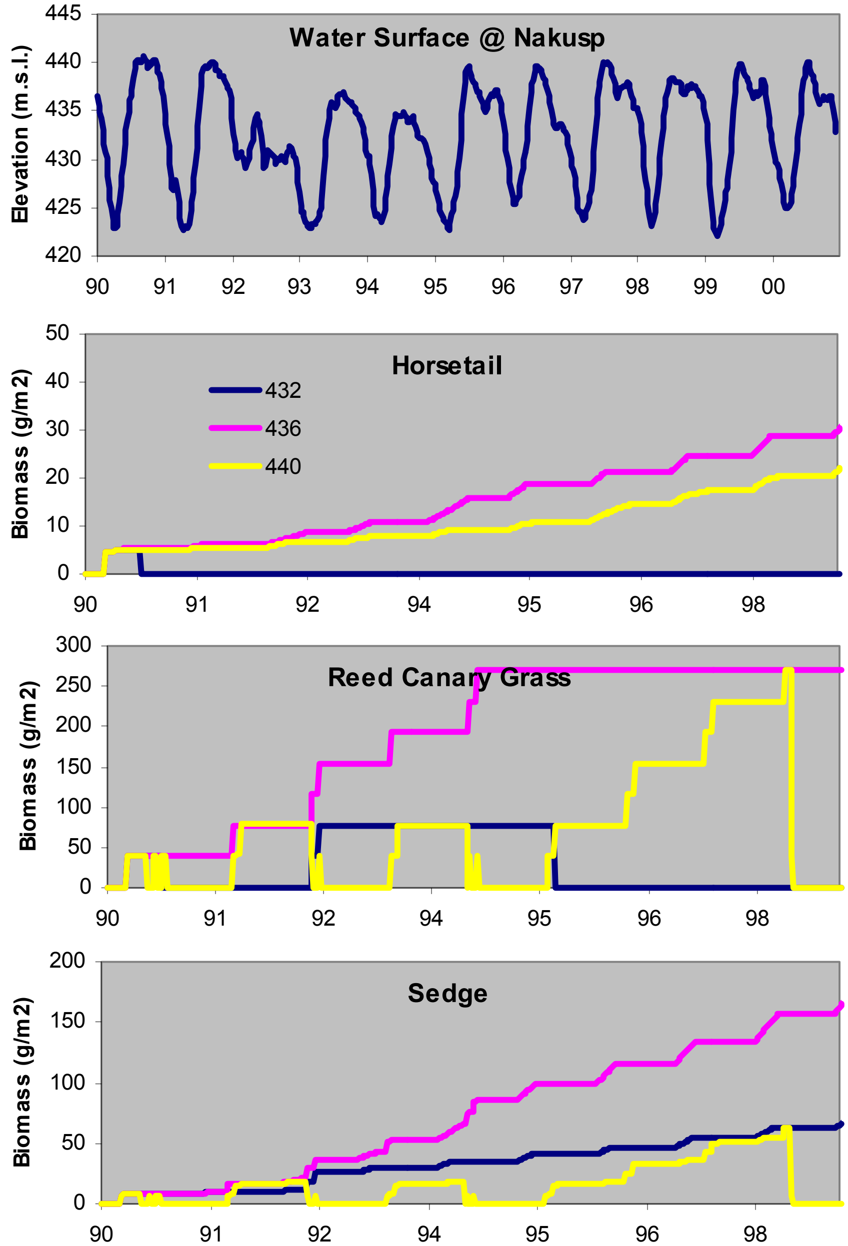


Figure 9 Arrow Reservoir water surface elevations at Nakusp (1990-2000) and the predicted biomass trajectories for horsetail, reed canary grass, and sedge at 3 elevations.

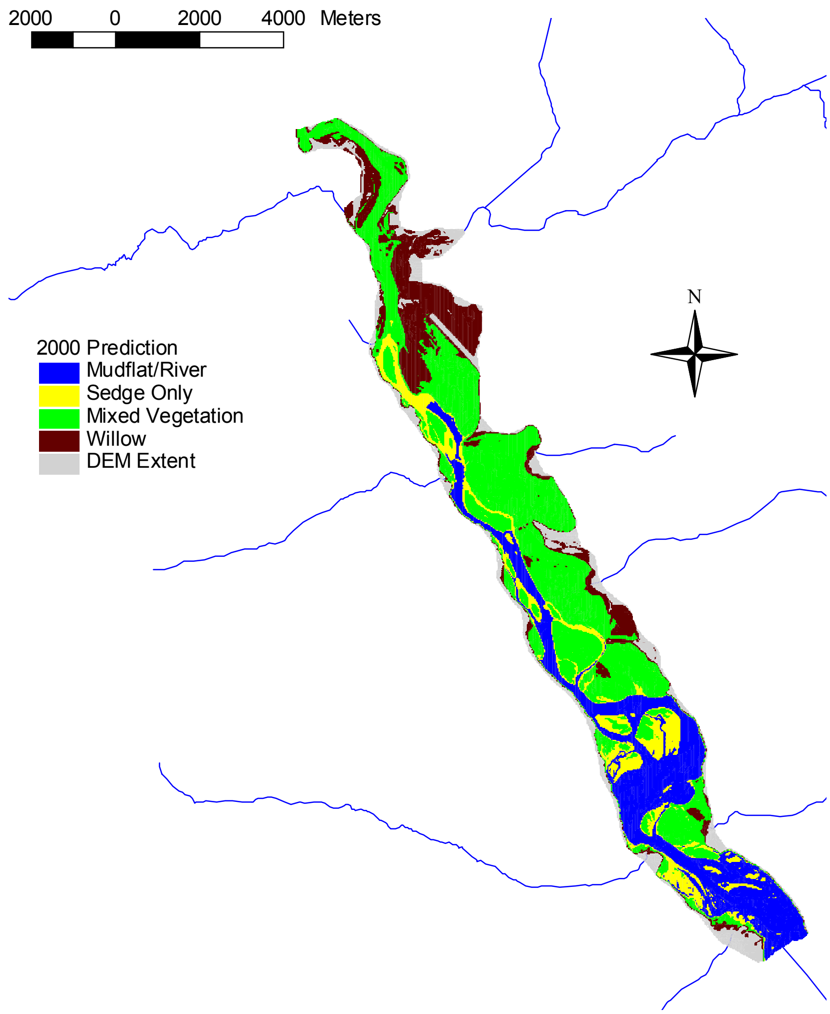


Figure 10 Map of the Revelstoke Reach of Arrow Reservoir showing the predicted distribution of willow (437-440), mixed vegetation (mostly reed canary grass with some sedge and small amounts of horsetail at elevations 433-437), sedge only (431-433), and barren substrate (< 431). The map shows results from 2000 from an 11 yr. simulation beginning in 1990 using the historical reservoir elevation schedule.

The vegetation model has been used to compare alternate reservoir operating strategies in both the Bridge and Columbia River WUP processes. An example of such a comparison is given in Figure 11 where elevation schedules for Arrow Reservoir were provided by BC Hydro operations modelers based on below average inflows to simulate a range of alternatives in a typical dry year. It is clear that '1-Dry' scenario provides the best conditions for both sedge and willow. The lower elevations during the latter half of the growing season allows sedge to extend down to 431 m.s.l. and willow to 436 m.s.l. Scenarios '0-Dry' and '2-Dry' maintain full pool elevations for about ½ of the growing season. As a result, willow distribution is limited to 439-440 m.s.l. The patterns of sedge distribution under '0-Dry' and '1-Dry' scenarios are similar and are mostly controlled by wet stress. The greatest biomass levels are achieved at the highest elevations that are also the driest.

2.6 KEY UNCERTAINTIES IN MODELLING RIPARIAN VEGETATION

Development of a computer simulation requires the articulation of key hypotheses that drive the predicted responses of modeled variables (e.g., vegetation biomass) to management actions. To fit the parameters of the models that embody these hypotheses, existing data must be compiled and analyzed. Difficulties in parameterizing these models highlight deficiencies in the data, and can therefore identify improvements for future research and monitoring programs. The primary focus of the Upper Arrow revegetation program has been dust control since it was implemented in the 1980's. However, as ancillary ecological benefits became apparent, a small monitoring program developed. , The combination of limited funding for monitoring, and limited knowledge about potential vegetation responses to planting and reservoir operations early in the program, has resulted in a dataset which provides only a limited quantitative understanding of the response of native plants to alternate planting regimes and reservoir operation scenarios.

Two major weaknesses in our understanding of the response of vegetation to reservoir operations and fall rye planting were identified in the development of the vegetation model for the Revelstoke Reach of Arrow Reservoir. Separation of the effects of wet and dry stress on growth, survival, and seedling establishment was problematic due to an almost complete absence of informative data on changes in vegetation over time. Although data from vegetation sampling began in 1991, changes in methodology and relatively uninformative sampling designs limited the utility of this information for making representative and quantitative statements about changes in vegetation. Fall rye is the only vegetation group where we have good information to estimate growth rates because only within-season data is required. For other vegetation groups, a multi-year dataset is required, which only exists for sedge (Moody, 2002b). Unfortunately, there was little variation in elevation among the long-term sedge monitoring sites. Consequently all these sites experienced similar wet and dry stresses over the duration of monitoring, making it impossible to tease-out the effects of these stresses on growth and survival. There is no long-term monitoring data available for other important vegetation groups like reed canary grass, willow, and cottonwood. This is a significant data gap as reed canary grass is the dominant vegetation group in the Revelstoke Reach at the lower elevations influenced by hydro operations (Fig. 4), and the latter two groups provide valuable wildlife habitat as documented in a recent study (J. Jarvis and J. Woods, Parks Canada, Revelstoke, B.C., unpublished data).

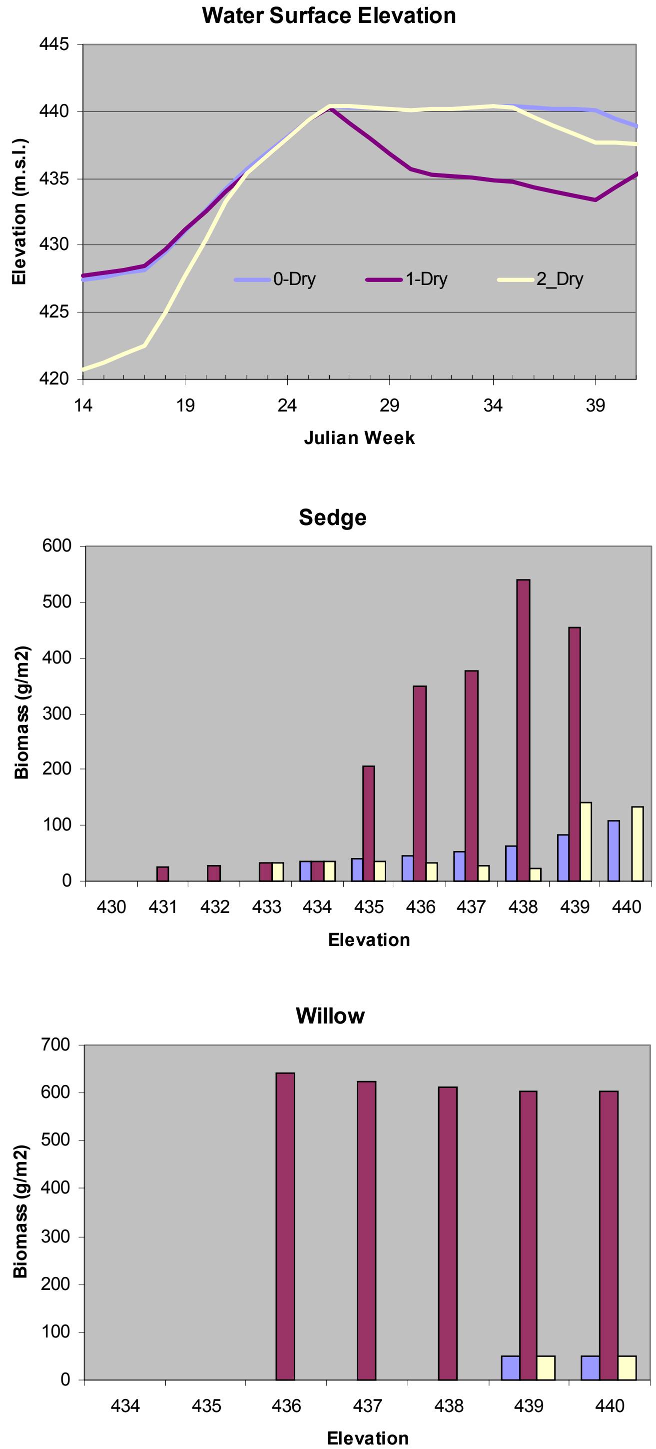


Figure 11 Model predictions of sedge and willow biomass in the Revelstoke Reach of Arrow Reservoir (bottom graphs) based on alternate water surface elevation schedules (top graph) being considered in the Columbia River Water Use Planning process. Reservoir elevations were provided by BC Hydro operations modellers' based on input hydrology from a typical dry year where inflows are lower than normal.

A recent mapping exercise (Moody, 2002a) attempted to quantify the changes in vegetation distribution over time. Such data would have been very helpful to estimate survival, growth, and seedling establishment parameters for all vegetation groups. However, technical problems and the restricted scope of the study limited its utility for modeling. The classification of vegetation varied considerably among the 4 years when air photographs were available due to differences in the scale and color of the photographs. Thus, the historical air photograph analysis could not quantify changes in the distribution of vegetation groups over time except in the grossest sense (e.g., area of vegetated vs. barren terrain). Only the 2000 air photographs, which had sufficient detail to classify polygons by vegetation group and relative density, provided useable data for the model. However, with only one year of data, the effects of wet and dry stress on growth, survival, and seedling establishment are heavily confounded. That is, we can fit the predicted distribution of vegetation groups and biomass classes across elevations to the 2000 data through many different combinations of survival, growth, and seedling establishment parameters. Confounding among parameters increases uncertainty in model predictions. The spatial extent of the mapping exercise was also limited to the northern dust control areas (F-T), so inferences about changes in vegetation at higher elevations (>436 m.s.l., see Fig. 3), in the southern portion of the Revelstoke Reach (Fig. 1), and for the most important vegetation for wildlife (willow and cottonwood) are either very limited or impossible to make from the available data.

The other major uncertainty identified in the model development process was the lack of quantitative understanding of the effects of fall rye planting on native vegetation establishment. A number of hypotheses for why natural vegetation has established in areas previously planted with fall rye were identified by participants during the model building process:

- Fall rye planting and fertilization increases the carbon and nutrient content of the substrate leading to higher seedling establishment rates;

- Fall rye protects fragile seedlings from high winds and hot temperatures that could jeopardize their survival;
- The presence of fall rye 'stubble' helps retain seedlings that would otherwise be washed or blown away; and
- The mechanical action of the drill seeding process pushes native seeds into the substrate and potentially enhances their survival.

Unfortunately, there is little data to quantify these hypotheses. The elevations and areas where fall rye has been planted have not been recorded in sufficient detail. Even if this information were available, there is no systematic long term monitoring of natural vegetation in areas that were exposed to different treatments (different planting intensities, durations, fertilization rates, etc.). Consequently, the hypotheses outlined above cannot be tested from the available data or developed into quantitative models that can be incorporated into the simulation framework.

One of the key reasons for predicting vegetation responses to reservoir operations and fall rye planting is to make inferences about potential benefits to wildlife habitat. Recent studies by Jarvis and Woods (Parks Canada, Revelstoke, B.C., unpublished data) document how songbird species diversity and abundance varies by vegetation group in the Revelstoke Reach of Arrow Reservoir. These data were collected from a statistically sound design and are representative and informative. An obvious next step in the analysis of this information is to link the point count data with the vegetation biomass mapping data from Moody (2002a) to develop statistical models predicting diversity and abundance as a function of vegetation group, vegetation biomass, and other factors. Once these statistical models are developed they could easily be integrated into the simulation framework to make predictions about changes in songbird habitat under different operational strategies. Preferences of ducks and geese to vegetation and flooding conditions are generally known but not well quantified, but will need to be if they are to be included in a wildlife habitat simulation model.

3.0 LITTORAL PRODUCTION OF BENTHIC INVERTEBRATES

3.1 LITTORAL MODEL STRUCTURE

Benthic invertebrate production and community structure in reservoirs can be severely affected by fluctuations in water surface elevations. Larger forms (Ephemoeroptera, Gammarus) are typically replaced by smaller forms (Oligochaeta, Chironomidae) and total biomass is reduced. Hellsten et al. (1996) developed a model predicting the dry weight of macrozoobenthos in the 0-3 m depth zone (B, in mg dry wt/m^2) based on data from twelve Finnish lakes and reservoirs,

$$B = 10^{4.25 - 1.33\log(\frac{W_y}{D_s}100)} \tag{10}$$

where, W_y is the annual water level fluctuation (m) and D_s is the secchi depth (m). Perrin et al. (2002) measured a mean total benthic biomass in the Revelstoke Reach of the Arrow Reservoir in barren soils of about 50 mg dry wt/m^2 and a macrobenthic (> 1mm) biomass of 7 mg dry wt/m^2. Based on the average secchi depth during the sampling period (3 m) and the 15 m yearly water level fluctuation in 2000, Hellsten et al.'s (1996) model predicts a macrobenthic biomass of 5 mg dry wt/m^2, quite close to the value measured by Perrin et al. (2002). Hellsten et al.'s model predicts a macrobenthic biomass in a more natural environment with fluctuations of 1 meter per year of 170 mg dry wt/m^2. The modeling results, coupled with Perrin et al.'s data, indicate the benthic production in the littoral zone of Arrow Reservoir is severely impaired, and that the effects of water level fluctuations must be accounted for in any model that tries to predict the response of benthos to different operations.

Flooding of terrestrial vegetation is known to stimulate benthic invertebrate productivity by providing additional substrate for colonization and by releasing nutrients required for autotrophic and heterotrophic production. Perhaps the best-known documentation of this dynamic is the "Flood Pulse Concept" of Junk et al. (1989). The drawdown zone of a reservoir is identical to the "aquatic / terrestrial transition zone" or "moving littoral zone" described by Junk et al. Recent studies in Arrow Reservoir (Perrin et al. 2002) have quantified the additional contribution of submersed terrestrial plants to benthic invertebrate biomass. The extent of the enhancement in the Arrow Reservoir was shown to be a function of the vegetation type and the period of inundation.

A simple benthic littoral production model was developed to simulate these processes on an annual timestep for 1-meter elevation bands in the reservoir. Mean benthic invertebrate biomass in barren substrates at all elevations that are wetted is assumed to remain at a constant value ($BenBio_{barren}$). This assumption is supported by data from Perrin et al. (2002), who showed that biomass measured at 10 and 80 days after inundation in barren substrates was fairly similar. The vegetation model tracks the biomass of vegetation groups and duration of inundation at 1-meter elevation bands over the course of the growing season (Section 2). The maximum biomass of each vegetation group ($MaxTotBio_{iv,ib}$) and maximum inundation period for each elevation band ($FloodWks_{ib}$) over the growing season is used as input to the benthic biomass – plant weight relationships developed by Perrin et al. (2002) to predict the additional biomass produced from flooded vegetation ($BenBio_{veg,iv,ib}$),

$$BenBio_{veg,ib} = \sum_{iv=1}^{6} MaxTotBio_{iv,ib} * (BenVegConst_{iv} + BenVegSlope_{iv} * FloodWks_{ib}) \qquad (11)$$

where, $BenVegConst_{iv}$ and $BenVegSlope_{iv}$ are the slopes and constants of vegetation group-specific linear regressions. The maximum total plant biomass for each vegetation group-elevation band combination is computed as the sum of above and below-ground biomass, where the above-ground biomass is computed from eqn. 1, and below-ground biomass is computed by multiplying above-ground biomass by the root-to-shoot ratio (RS_{iv}), which is specific to each vegetation group. The total biomass of benthic invertebrates at each elevation band is the sum of the barren-ground estimate plus the sum of the additional contribution provided by all vegetation groups.

The total production of benthic invertebrates in the reservoir over the growing season (*PBen*) is computed as the product of the sum of benthic biomass across all elevations and the turnover rate, also termed the production-to-biomass ratio (*PtoB*),

$$PBen = \sum_{ib=MinElev}^{MaxElev} (BenBio_{barren} + BenBio_{veg,ib}) * PtoB * \frac{FloodWks_{ib}}{GrowWks}, \qquad (12)$$

where $FloodWks_{ib}$ is the number of weeks each 1-meter elevation band is inundated over the growing season, and *GrowWks* is the total number of weeks in the growing season. The latter ratio is an adjustment that accounts for the effect of the period of inundation on the opportunity for benthos to turnover.

3.2 PARAMETERIZATION OF LITTORAL MODEL

A barren-ground benthic invertebrate biomass ($BenBio_{barren}$ from eqn. 12) of 50 mg dry wt/m^2 was used in the model based on the average value measured by Perrin et al. (2002) in the Revelstoke Reach of Arrow Reservoir in 1999. A production-to-Biomass ratio (*PtoB* from eqn. 12) of 10 was used, based on the average value of estimates provided from the literature documenting studies of chironomid production in temperate oligotrophic lakes (Waters 1969, Benke 1984), one of the common taxa found in the Revelstoke Reach benthic samples.

Root to shoot (RS_{iv}) ratios were used to convert above-ground biomass of each vegetation group estimated by the model (eqn. 1) to total plant biomass values required by the plant-benthic invertebrate relationships (eqn. 11). Ratios for sedge (RS_{iv} = 3.2, see Table 1), reed canarygrass (2.5), and fall rye (0.65) were computed from field data collected in Arrow Reservoir in 1999 and 2000 (AIM and CARR 2002). Root to shoot ratios for other vegetation groups (horsetail, willow, and cottonwood) do not influence the benthic invertebrate biomass computations as it was assumed that these vegetation groups do not make any contribution to the biomass of invertebrates when flooded. This is a reasonable assumption as the vegetation biomass from these groups is either very limited (horsetail), or distributed over high elevations (willow and cottonwood) that are rarely inundated.

The linear relationships used in the model for predicting the contribution of benthic invertebrate biomass from flooded vegetation as a function of the inundation period and total plant biomass (eqn. 11, Perrin et al. 2002) are shown in Figure 12. Estimates are only available for fall rye, sedge, and reed canary grass. Invertebrate biomass tended to increase for fall rye and sedge with the period of inundation, so in these cases, a regression model fit to the data without a constant ($BenVegConst_{iv}$=0, i.e., no inundation = no invertebrate contribution) was used to estimate the slope ($BenVegSlope_{iv}$). For reed canary grass, there was no evidence that inundation period affects the plant-specific biomass of invertebrates. In this case the slope of the regression was set to zero and the average plant-specific biomass of 1.3 mg dry wt/g plant was used as the constant. It was assumed that additional benthic invertebrate production from flooded horsetail, willow, and cottonwood is minimal for reasons described above, hence constant and slope parameters for these vegetation groups were set to zero.

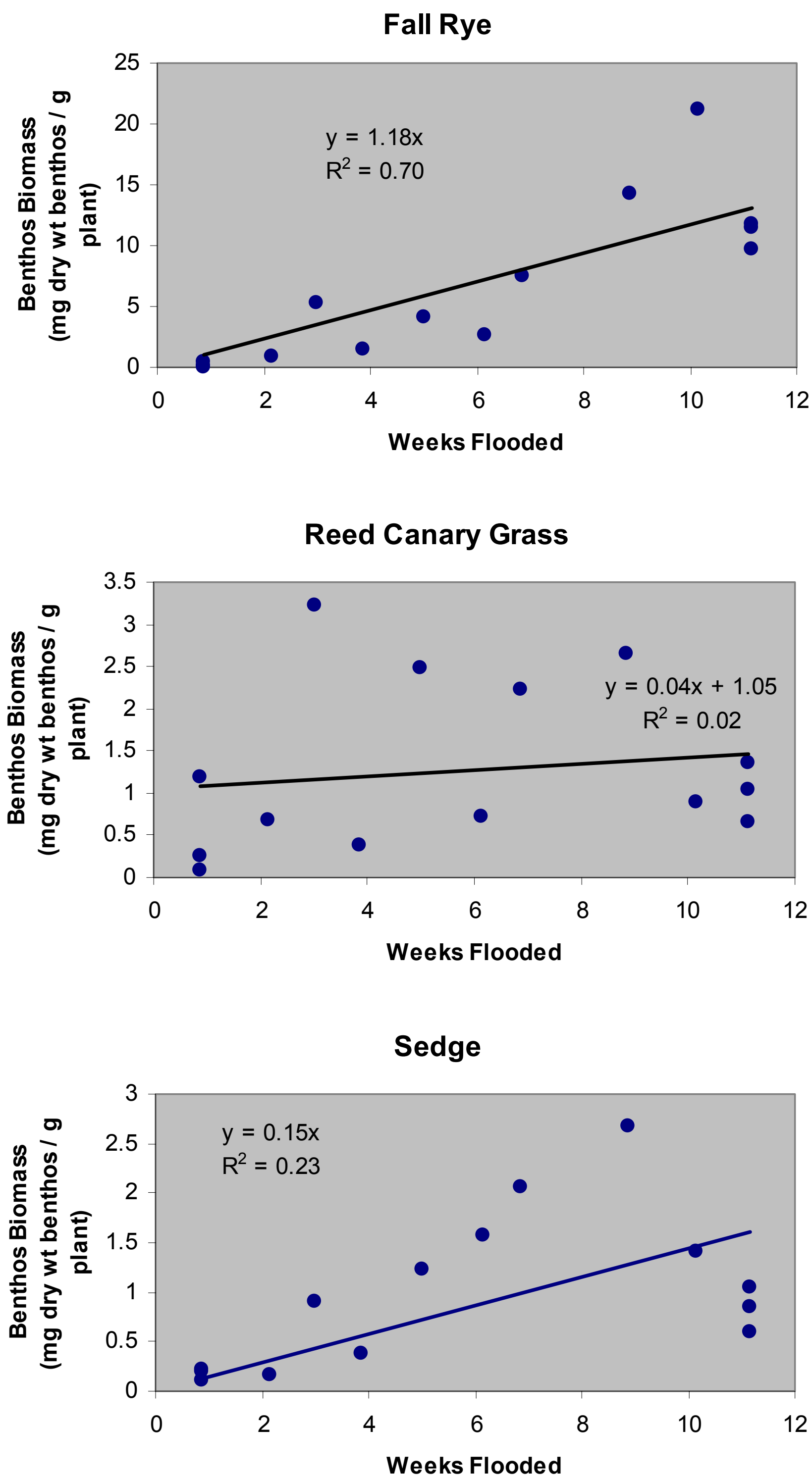


Figure 12 Relationships between plant-specific benthic invertebrate biomass (mg dry wt invertebrates / g plant, dry weight) and inundation period for fall rye, reed canary grass, and sedge (data from Perrin et al. 2002).

3.3 DYNAMICS OF LITTORAL MODEL

The contribution of fall rye, and to a lesser extent reed canary grass and sedge, to the total littoral biomass in the Revelstoke Reach of Arrow Reservoir is potentially very large (Table 2). Fall rye generates about 12 mg dry wt/g plant after 10 wks of inundation, a value that is almost an order of magnitude higher than the estimates for sedge and reed canary grass. Fall rye can achieve maximum biomass levels that are about 5-fold higher than those for sedge and reed canary grass (Table 1). Taken together, these data imply that flooded fall rye generates about 50 times more benthic invertebrates per m^2 relative to that from sedge or reed canary grass in situations when these vegetation groups are at maximum biomass levels. However, inundated fall rye rarely occurs at its carrying capacity as growth stops following inundation, so the typical production from fall rye will be less then the theoretical value presented above. Based on the 1999 submergence study (Fig. 5 from Perrin and Stockner 2002), benthos biomass from fall rye (at the intermediate elevation of 431.2 m.s.l.) was typically 2-fold higher compared to the biomass values associated with sedge or reed canary grass.

When plant specific benthic invertebrate estimates from Perrin and Stockner (2002) are applied to the portion of the Revelstoke Reach contained by the DEM that is likely to support vegetation of any kind (431-440 m.s.l., Fig.'s 1 and 2) it is clear that flooded vegetation can provide an enormous benefit to benthic invertebrate biomass (column 3 of Table 2). Under current conditions in areas where we have sufficient data (mapped polygons of vegetation in dust control areas F-T by Moody 2002a), sedge and reed canary grass biomass levels are generally well below maximum values. The additional contribution to benthic biomass from sedges in the dust control areas is about equivalent to the biomass produced by barren substrate in unvegetated areas (1090 Ha). Reed canary grass development is more extensive, and produces about a 4-fold higher contribution to benthic biomass relative to either sedge or barren substrate. In contrast, if the entire 500 Hectares of the vegetated area was composed of fall rye that grew to 50% of its maximum biomass levels (plants about 50 cm high), the contribution would be about 35-fold higher relative to that provided by the combined contribution from sedge and reed canary grass.

Table 2 Estimates of benthic biomass contributions from barren substrate and flooded vegetation in the Revelstoke Reach of Arrow Reservoir. Plant specific-benthic biomass estimates are from Perrin et al. (2002). Maximum biomass estimates are from A. Moody (AIM Ecological Consultants, unpublished data). The 4th column computes the benthic biomass over the entire area of the DEM at elevations between 431 and 440 m.s.l. (ca. 3500 Ha) assuming that the entire surface area is covered at maximum biomass levels for each vegetation group (or covered with barren substrate). The last column computes benthic biomass for vegetated polygons in the dust control areas mapped by Moody (2002a, 500 vegetated Ha out of a 1590 Ha total in dust control areas F-T) and represents the approximate inputs under current conditions.

Substrate Type	Plant Specific Benthos Biomass (mg dry wt / g Plant) after 10 weeks of inundation	Maximum Plant Biomass (g/m^2)	Benthic Biomass (tons) @ Maximum Plant Biomass over DEM from 431-440 m.s.l. (3500 Ha)	Benthic Biomass (tons) @ Current Conditions in Dust Control Areas F-T (500 Ha mapped out of 1590 Ha total)
Barren	50[1]		2	0.5[2]
Fall Rye	11.8	3000	1,246	88.6[3]
Reed canary grass	1.3	650	30	2.0[4]
Sedge	1.5	650	33	0.4[4]

[1]Barren substrate value has units of mg dry wt/m^2
[2]Based on barren area estimate for dust areas F-T of 1090 Ha (=1590 total – 500 vegetated)
[3]Assumes that entire vegetated area of dust control areas F-T (500 Ha) is covered with fall rye growing to 50% of it's maximum biomass level.
[4]Biomass of reed canary grass and sedge used in these computations based on translating the areas of Moody's (2002a) density classes into the following biomass equivalents (Incipient = 111 g C/m^2, Low = 278 g C/m^2, Medium=444 g C/m^2, High = 650 g C/m^2).

Variation in benthic littoral production predicted by the model based on the 1990-2000 Arrow Reservoir water surface elevations (Fig. 13) demonstrates the effects of both water surface elevation and riparian vegetation biomass. In this example, an index of naturally growing vegetation biomass that potentially contributes to littoral production is computed as the sum of reed canary grass and sedge biomass at 435 m.s.l. The simulations do not include the contribution from fall rye. Biomass increases over the course of the simulation as the vegetation expands from the low cover estimates used to initialize the simulations. The total benthic production (yellow line), which includes contributions from both barren sediment and flooded vegetation, is driven mostly by the increase in vegetation. In years when the reservoir does not fill to near-full pool levels (e.g., 1992 to 1994), very little riparian vegetation is flooded, hence littoral benthic production is produced. The benthos biomass contributed by barren substrate (magenta line) is not dependent on vegetation biomass and only responds to direct effects from changes in water surface elevations across years. In years when the reservoir fills, the wetted surface area over which production can occur, and the proportion of the growing season available for benthic production (eqn. 12), are both higher, leading to higher production values.

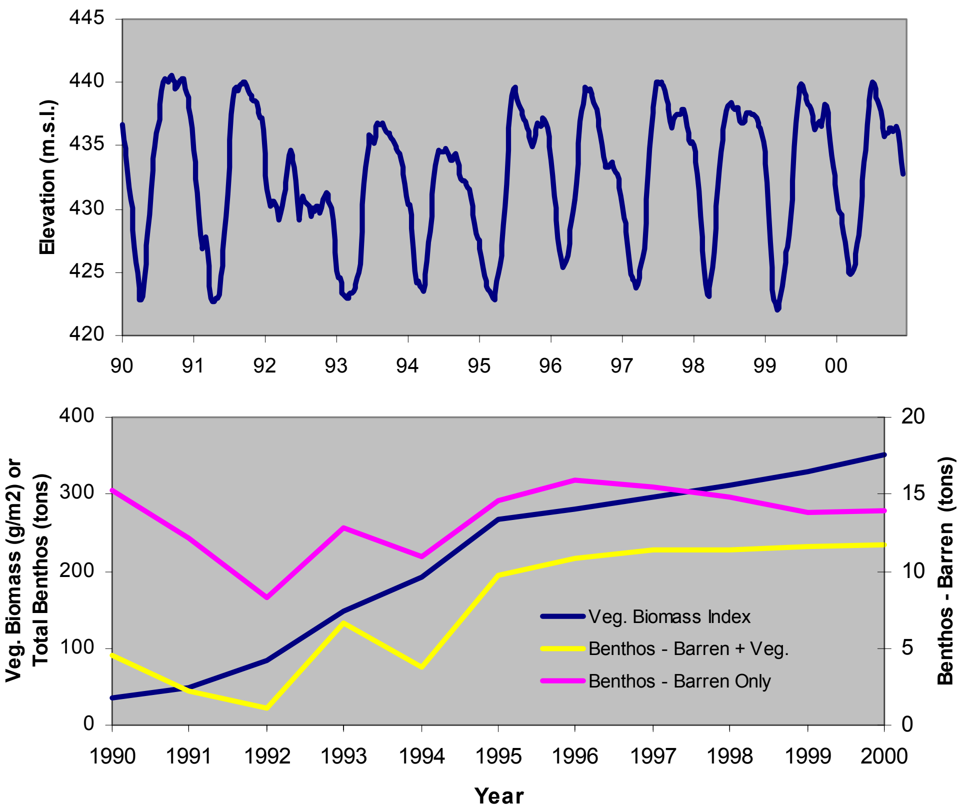


Figure 13 Time series of historical Arrow Reservoir water surface elevations at Nakusp and responses of riparian vegetation and benthic invertebrate production predicted by model. The sum of reed canary grass and sedge biomass at elevation 435 m.s.l. is plotted (blue line) as index of vegetation biomass that contributes to total benthic production over the growing season (yellow line). The benthic production that would be produced in the absence of any enhancement from flooded vegetation is also shown (magenta line on secondary axis).

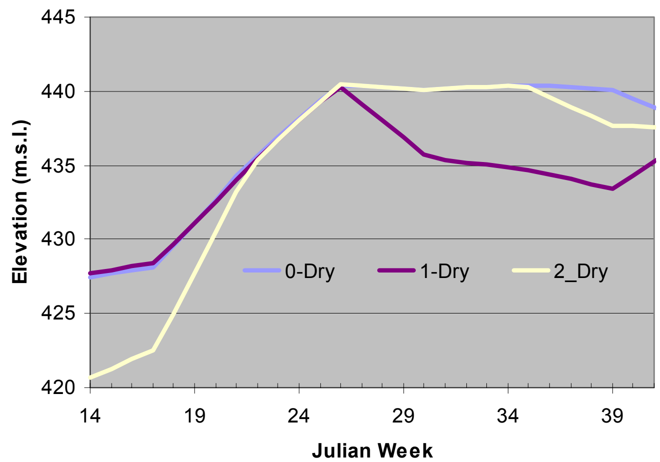
An examination of the effects of some operating strategies for Arrow Reservoir being considered as part of the Columbia River WUP process on benthic production in the littoral zone is shown in Figure 14. In the absence of any vegetation effect on benthic production (blue bars), scenarios ‘0-Dry’ and ‘2-Dry’ produce the greatest benefits because the reservoir fills and is maintained at full pool for a much longer period of time relative to the ‘1-Dry’ scenario. This increases both the total area of substrate that is flooded and the duration of flooding. When the effect of flooded vegetation on benthos production is considered (red bars), the '1-Dry' scenario outperforms the others because it provides the greatest benefits for riparian vegetation due to the lower water surface elevations (Fig. 11), yet still floods these elevations for sufficient time to generate a significant contribution to the benthos. Operating regimes that attain full pool levels for long enough to stimulate benthic production, but short enough to allow extensive riparian development, are probably optimal for enhancing reservoir productivity in the littoral zone.

3.4 KEY UNCERTAINTIES IN MODELLING AQUATIC PRODUCTIVITY

Model predictions about the response of benthic invertebrates in the littoral zone to flooded vegetation are relatively certain due to the informative data collected by Perrin et al. (2002). Ideally, it would have been useful to quantify the biomass of terrestrial insects made available as fish food when plants are flooded. Other components of related studies that focused on bacterial-algal-microflagellate community structure, or the nutrient content of the flooded plants, did not provide any useful information for the model.

The ultimate objective of the aquatic productivity component of the model is to evaluate the impacts of operations and fall rye planting on fish communities. The littoral-benthic module makes predictions about the amount of food potentially available to fish, but this is only part of the story. There is large uncertainty about whether this additional food is translated into any benefits to fish populations such as increased growth or survival. Documenting the relative abundance of fish in vegetated and unvegetated areas as done by Perrin et al. (2002) may indicate fish preference, but it says little about whether the fish found at vegetated sites are gaining any energetic or survival benefits. Stable isotope analysis (SIA) could be used to determine the extent to which production of benthos in vegetated littoral zones contributes to the biomass of different fish species. Only a properly designed Adaptive Management experiment, where fish populations are monitored for many years before and after the initiation of a substantial fall rye planting program, will provide useful information for assessing population level effects. It is too late to conduct such an experiment in the

Revelstoke Reach of Arrow Reservoir, but this approach should be considered for other systems prior to implementing large-scale fall rye planting programs.



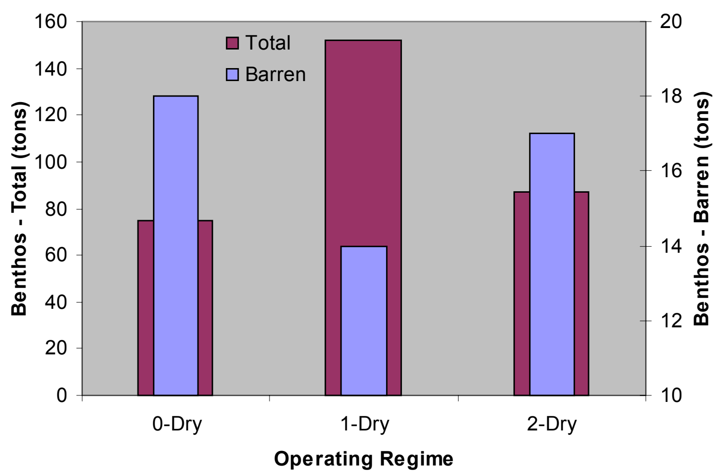


Figure 14 Model predictions of benthic production from the littoral zone (tons carbon over growing season) in the Revelstoke Reach of Arrow Reservoir (bottom graph) based on alternate water surface elevation schedules (top graph) being considered in the Columbia River Water Use Planning process. Reservoir elevations were provided from BC Hydro operations modellers based on input hydrology from a typical dry year where inflows are lower than normal. The lower graph shows the average total littoral benthic production (red bar, left-hand axis) and the production without including the enhancement from flooded vegetation (blue bars, right-hand axis).

4.0 RECOMMENDATIONS FOR THE DESIGN OF FUTURE MONITORING PROGRAMS AND MODEL IMPROVEMENTS

A key objective for any modeling exercise should be to expose data gaps and uncertainties in the processes that are being modeled. For many ecological models where data is limited and uncertainties are high, the benefits of meeting this objective often outweigh the utility of being able to make quantitative predictions about various policy alternatives such as water level management and planting. The development of the vegetation model for the Revelstoke Reach of the Upper Arrow Reservoir was very helpful in differentiating what we know about this system from quantitative and qualitative perspectives. While monitoring on this system has been conducted since the early 1990's and many numbers have been collected, our quantitative understanding on how vegetation has changed over time, and the response of this vegetation to inundation and fall rye planting, is quite weak. Section 4.1 provides a set of recommendations for improving future monitoring efforts based on the problems identified in the development of the vegetation model.

Development of a computer model is a continual process. As our understanding improves and more data becomes available over time, model structure and parameters can be refined to make better predictions. The review process of this document has identified improvements to model parameters that should be implemented in the next application of the model. Section 4.2 summarizes these improvements.

4.1 MONITORING RECOMMENDATIONS

A vegetation monitoring program should track changes in vegetation and seedling establishment over time, and help establish key relationships between survival, growth and various management practices such as planting and water elevation schedules. Quantifying of changes in vegetation is most important component of the monitoring program and should be accomplished by repeat sampling of plots and interpretation of aerial photographs. The selection of sampling plots should be based on a random-stratified design with the strata being defined by key variables that control the establishment, growth, and survival of vegetation (elevation, fall planting intensity, substrate, aspect). It is very important that these plots cover the potential range of elevations that could be colonized by terrestrial plants (and submerged marcophytes if appropriate). It is also important that sampling plots be established in areas that receive a range of fall rye planting intensities. Sampling should be conducted on a monthly basis from the start of the growing season, and all elevations that are not inundated should be sampled on each monthly period. Parameters to be measured at each sample plot should include cover, biomass (of roots and shoots), mortality of mature plants, and some index of seedling establishment. Measures of cover should be consistent across vegetation groups. Using different methods to estimate cover for different vegetation groups introduces unnecessary complications and error into any subsequent analysis. Plot boundaries should be spatially referenced to a reasonable degree of horizontal accuracy (+/- 2-5 meters) to assist in the interpretation of aerial photographs.

The interpretation of aerial photographs will provide a system-wide estimate of vegetation change over time. A DEM for the monitoring area should be developed and color photographs taken at a pre-determined intervals (e.g. every 3 yrs). The photographs for the DEM should be flown when the water surface elevation is at its lowest, usually in the early spring. For vegetation monitoring, the photographs should be taken early enough in the year to document before vegetation at lower elevations is flooded, but not too early so that vegetation has not had sufficient time to green-up. Ideally, field sampling of plots should be conducted close to the time air photographs are taken to assist in the interpretation. Analysis of the photographs should be based on modern image-processing techniques. The photographs should be rectified so they can be overlaid on the DEM. Algorithms should be developed to predict vegetation community structure and cover based on the color and intensity of each pixel. Such an approach would avoid problems encountered by AIM (2002a) where polygons classified as 'incipient vegetation' contained large areas of barrens substrate, resulting in substantial overestimates in the amount of vegetation cover. Plot data should be spatially linked to the photographs to develop the interpretation algorithms.

The development of the aerial photograph interpretation methods is a substantial task and should not be underestimated. The level of resolution at which these algorithms can predict community structure and cover is uncertain. It may be that manual interpretation is the only way to estimate community structure with any reasonable degree of resolution (e.g., AIM 2002a). In this case, a stratified random subsample of the total area covered by the aerial photographs will likely be required. The stratification should follow the same delineation developed for monitoring the plots. A combination of manual and automated interpretation should be explored. For example, community structure for plots could be estimated manually, with cover estimated by a computer algorithm.

The monitoring program should contain an experimental component that allows estimation of certain model parameters that could not be achieved by the monitoring activities described above. Quantifying the effects of inundation on survival and growth of seedlings and mature plants could be accomplished by experimental planting at a range of elevations. These areas would be sampled over the growing season to determine the proportion of seedlings and mature plants that died under different inundation conditions (duration and depth) and how their growth was affected. Similar experiments could be conducted to estimate the effects of dry stress. The feasibility of performing these experiments in the field should be compared to the feasibility and utility of performing them under more controlled conditions that could be attained in a greenhouse.

The bounds of the monitoring program should be carefully defined. The lateral and elevational extent of the monitoring area should include not only areas that are currently vegetated, but also include barren areas that have the potential to recover under conceivable planting and water management schedules. The types of vegetation to be monitored should be based on not only their dominance in the current community, but also on their importance to wildlife. There was virtually no monitoring of cottonwoods or woody shrubs (e.g., willow) in the Revelstoke Reach monitoring program, yet these vegetation groups are influenced by dam operations and very important to wildlife. A similar argument can be made for wetland species. The design of a vegetation monitoring should consider the needs of other programs.

For example, if mammals and birds are monitored, ensure that the types of variables collected by the vegetation program are useful in the interpretation of the mammal and bird data. This argument is also relevant for linkages with aquatic productivity or fish population monitoring programs.

4.2 MODELLING IMPROVEMENTS

Refinements to vegetation model parameters effecting seedling establishment (Table 1) were suggested by W. Carr and A. Moody. A summary of these changes is presented in Table 3. A structural change to the seedling establishment component of the vegetation model was also suggested. The maximum number of flooded weeks that seedlings can tolerate will change according to the age of the seedlings (A. Moody, pers. comm.). The original values used in this modeling exercise (5 wks for most groups) are potentially too high for very young seedlings and too low for older seedlings. In general, seedlings less than one month old cannot tolerate any inundation and those greater than 3 months can tolerate inundations of up to 8 weeks. This dynamic could be simulated in the model by developing a functional relationship between the age of the seedling and the maximum wet stress that it can tolerate. While this improvement could be easily made, it should be noted that we have no data to tune or test the seedling establishment component of the vegetation model. Predictions of seedling establishment are highly uncertain, and increasing model complexity will not reduce this uncertainty.

Table 3 Refinements to vegetation model parameters that should be implemented for future applications of the vegetation model.

Parameter Description	Parameter Name	Vegetation Group	Original Value	Refined Value
First week of seedling establishment period	SeedWkMin	Fall Rye	28	16
Last week of seedling establishment period	SeedWkMax	Fall Rye	42	36
Number of consecutive weeks required for seedling establishment	SeedWks	All groups	5-10	8
Crown cover following seedling establishment	SeedIniCover	All groups	5	1
Maximum tolerable dry stress for seedlings	SeedMaxDryStress	All groups	600-1000	Higher values

A significant improvement to the littoral production model was suggested by C. Perrin (Limnotek Research and Development Ltd., Vancouver, B.C.). Benthos biomass at any one-meter elevation slice is the sum of barren substrate biomass and biomass on the roots and leaves of vegetation (eqn. 11). Benthic biomass in barren substrate is assumed to be independent of the inundation period. Perrin pointed out that this assumption in valid in barren substrate at lower elevations that are not surrounded by plants. At higher elevations, very little barren substrate was observed, and benthic biomass increased with inundation time, presumably in response to increased benthic biomass on plants adjacent to the barren substrate. To simulate this dynamic the following changes to the littoral model should be made. First, the amount of barren substrate for each one-meter elevation slice ($Area_{barren}$) should be computed as,

$$Area_{barren} = TotalArea * (1 - \sum_{i=1}^{MaxVegTypes} prop\_co) \quad (13)$$

where, *TotalArea* is the total area of the elevation slice and *prop_co* is the proportion of cover for each vegetation group at that model timestep. In cases where the total cover across all vegetation groups exceeds 1, no barren area will be present. The benthic biomass for this remaining area ($BenBio_{barren}$) would then be predicted based on the number of days since inundation (t) by the equation,

$$BenBio_{barren} = 4.33 * 10^{0.016*t} \tag{14}$$

The total benthic biomass for barren areas for any elevation slice is simply the product of the barren area (eqn. 13) and the unit area-biomass of this area (eqn. 14).

5.0 MODEL USER'S GUIDE

The vegetation and littoral-benthic models are incorporated into the Integrated Response Modelling (IRM) framework. IRM is a Visual Basic application that will run on PC-compatible computers under any of the Mircosoft Windows-based operating systems. This section describes how to install and use IRM.

IRM can incorporate multiple models that can be run in multiple areas within a watershed. The Bridge River configuration for IRM is extensive, incorporating over 13 different models that can be applied to as many as six modeling areas. The Arrow configuration is much simpler, consisting of only two models (Riparian Vegetation and Littoral-Benthic) in a single area, the Revelstoke Reach of the Arrow Reservoir. Note that this guide does not describe how to manipulate the input data files to incorporate additional models or areas into the IRM framework. This task requires an advanced knowledge of the modeling environment and is best left to the model developers.

5.1 SETUP

To install IRM on your computer, insert the IRM CD into your CD-Drive and click on the file 'setup.exe' to initiate the installation program. This program will copy IRM and supporting files onto your hard disk, and register the required '*.dll' and '*.ocx' files. You will be prompted to specify the directory where you want IRM to be installed. Two subdirectories will automatically be created below this directory (/Arrow and /Bridge). These subdirectories contain all the required data and parameter files to run IRM in the Bridge River and Columbia River watersheds.

5.2 RUNNING THE MODEL AND UNDERSTANDING THE OUTPUT

To start the model click on the file 'irm.exe' located in the directory where you installed the model. The main form of the IRM interface consists of three elements (Fig. 15). A menu system allows you to access a variety of dialogue boxes to control model output, parameter values, and hydrologic and planting scenarios. Below the main menu, output graphics are displayed as time series graphs and maps. At the bottom of the main form are a series of controls that let you define how the model will be run.

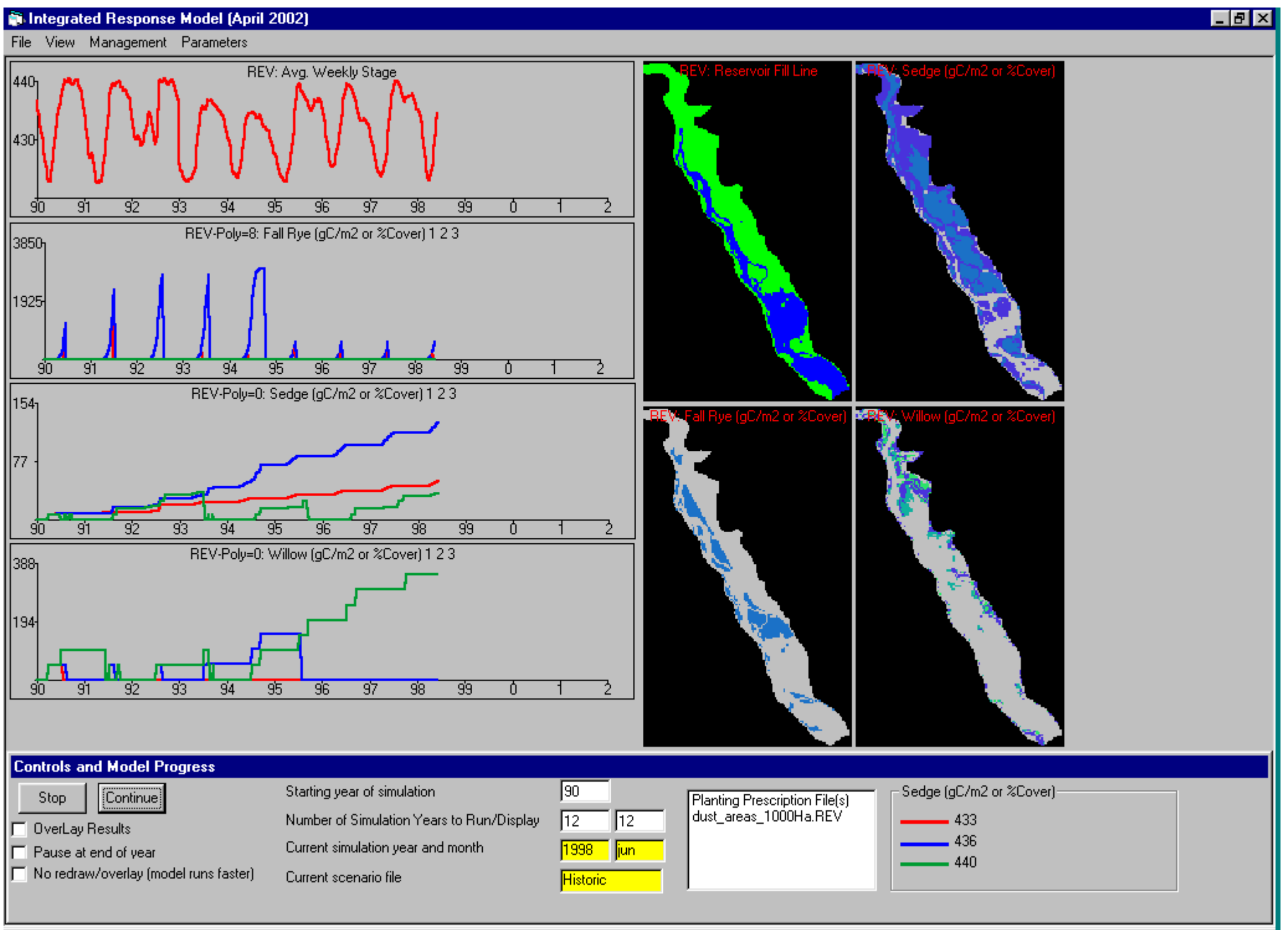


Figure 15 The main form of the Integrated Response Modelling (IRM) framework.

Click on the ‘Start’ button to begin a simulation. To temporarily suspend model execution click on the ‘Pause’ button. While the model is paused you can change parameter values or management actions or graphics. To resume execution, click on the ‘Continue’ button. To stop a simulation completely in order to restart from the start year, click on the ’Stop’ button. The ‘Pause at end of year’ option forces the model to automatically pause after each simulation year is complete. You can define the starting year of the simulation, the duration of the simulation, and the number of years that will be displayed on the time series graphs. The ‘Overlay results’ option allows you to compare the previous simulation’s results with values from a new run. To use this option, complete the first simulation, click on the ‘Overlay results’ check box, modify any parameters or management actions, and click on the ‘Start’ button to begin the second simulation. The results from the original simulation will be displayed as lines, while the more recent simulation results will be displayed as filled circular symbols. Clicking on a time series graphic will update the legend for the graph (defining what the lines represent) that is displayed in the lower-right corner of the main IRM form.

5.3 CONTROLLING OUTPUT GRAPHICS

To adjust the graphics that are displayed on the main IRM form, access the ‘Set Graphics’ dialogue box from the ‘View-Select Graphics’ menu item (Fig. 16). The hierarchical list on the left side of the dialogue box displays the models, the areas where each model can be applied, and the indicators that are specific to each model. You can ‘drill-down’ through this list to select indicators to plot. Clicking on an indicator will bring up a pop-up menu where you determine whether the indicator is displayed as a time series graph or map. When one of these items is selected, the indicator will appear in the list box on the right side of the dialogue box. For indicators that are specific to polygons and elevation slices (e.g., the vegetation biomass indicators), you must specify the polygon and elevation slices that will be plotted via the dropdown list boxes located below the list. These selections can automatically be applied to other indicators in the list by clicking on the ‘Sync Elevations…’ button. For time series graphs, the y-axis minimum and maximum can be specified. The order of an indicator on the output graphic component of the main IRM form can be adjusted by selecting an indicator and moving it up or down the list by clicking on buttons of the same name located below the list.

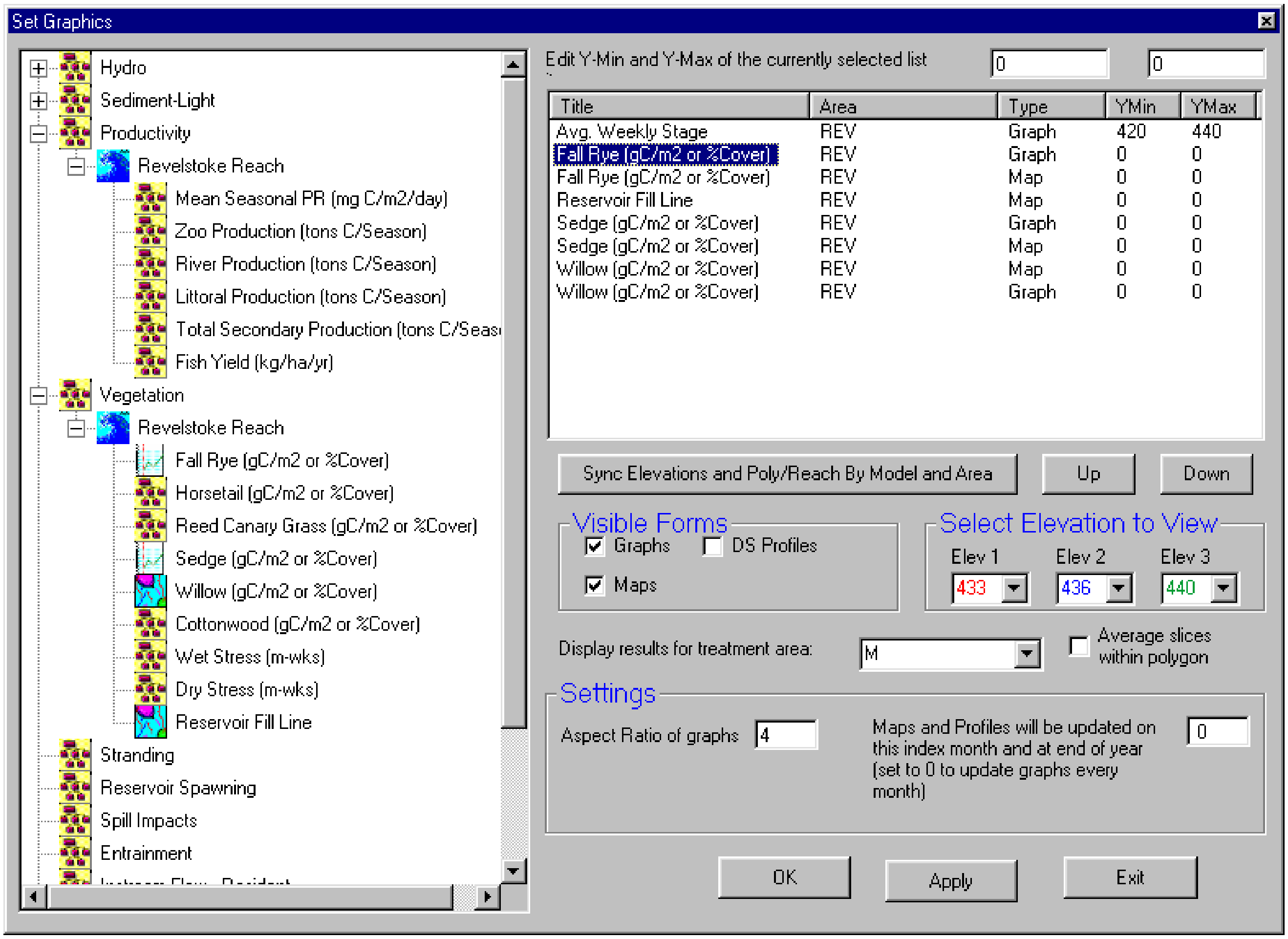


Figure 16 The 'Setup Graphics' dialogue box in IRM allows you to select indicators to plot as time series graphs and maps.

Once output configuration has been specified, click on the 'OK' button to dismiss the 'Set Graphics' dialogue box and implement the graphic changes. To implement the graphic changes without closing the dialogue box, click on the 'Apply' button. To exit the dialogue box and loose the changes you have made, click on the 'Exit' button. To save the graphic configuration to a project file ('*.prj), select the 'File-Save Project Settings File' menu item from the menu of IRM's main form. To restore a previously saved graphic configuration, select the 'File-Load Project Settings File' menu item.

The legends controlling the colors and breakpoints of the map displays can be adjusted by accessing the 'Legend Editor' dialogue box (Fig. 17) accessed by clicking on the 'View – Map Legends' main menu item or by selecting the 'Legend' item from the pop-up menu that appears when right-clicking on any of the maps. For each model indicator, which you specify by selecting the appropriate item form the 'Available Legends' dropdown list box, you can specify whether you want a continuous or categorical color range. With a continuous range, 50 colors will be used to represent the range of values between a minimum and maximum that you specify. For a categorical display, you specify the number of categories to use, and set the upper and lower limits for the range. When you press on the return key after clicking on the "Number of Categories" text box, the break points for each range and color selection will be automatically populated. If you wish to change the colors for a particular range, click on the new color in the color palette and then click on the color box beside the category in the 'Palette' frame. You can manually edit the breakpoints as well. When you exit the dialogue box via the "OK" or "Apply/Save" buttons, any changes you make to the map legend are automatically saved to the file that stores this information ('default.leg') and will be available for subsequent modelling sessions. Note you can create and load alternate legend files from the 'File' menu item within the 'Legend Editor' dialogue box.

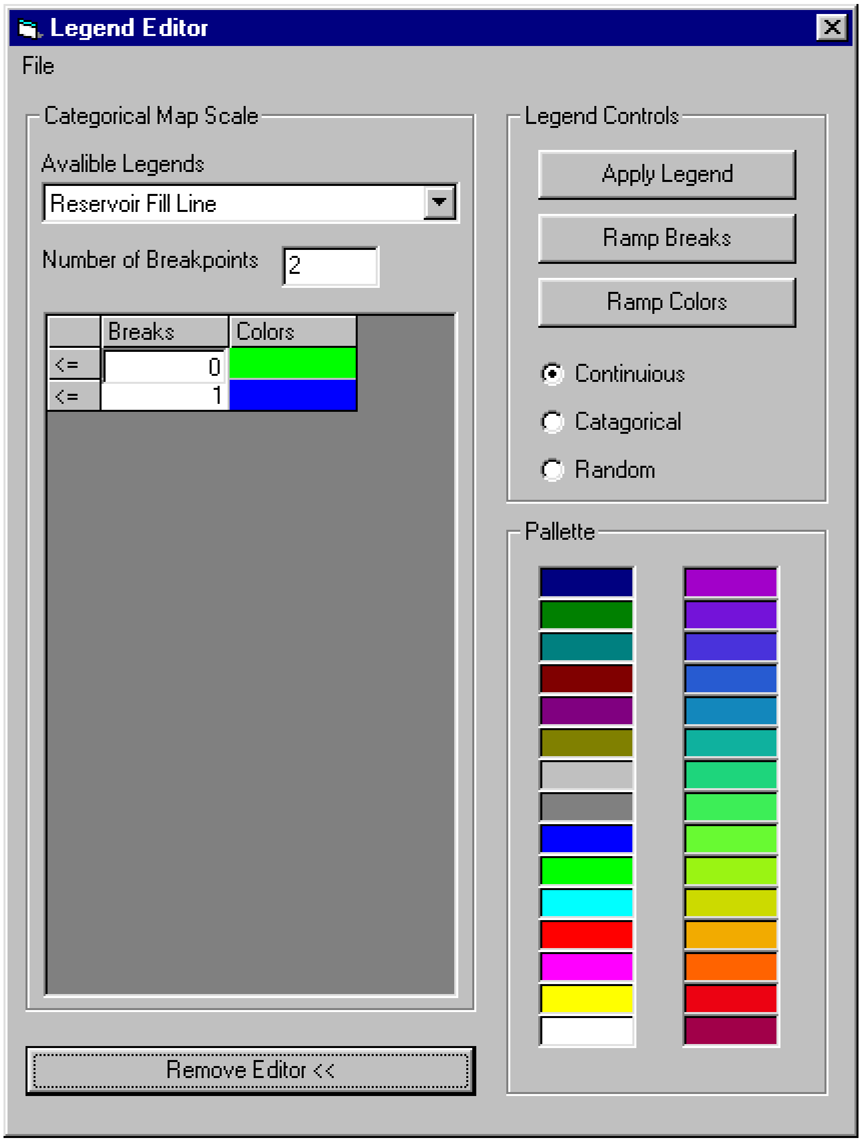


Figure 17 The 'Legend Editor' dialogue box in IRM allows you to manipulate the legends used to display maps.

5.4 Loading and Creating Reservoir Operating Strategies

The main forcing data driving model predictions is a multi-year set of weekly reservoir elevations and discharges for each modeled area. These data are stored in the file 'scenarios.xls' for each project watershed. By default, the model loads the historical scenario (the actual historical values), however you can load any other scenarios that exist in 'scenarios.xls' via the 'Hydrologic Scenarios' dialogue box (Fig. 18) accessed by clicking on the 'Management- Load Hydrologic Scenario from Spreadsheet' menu item.

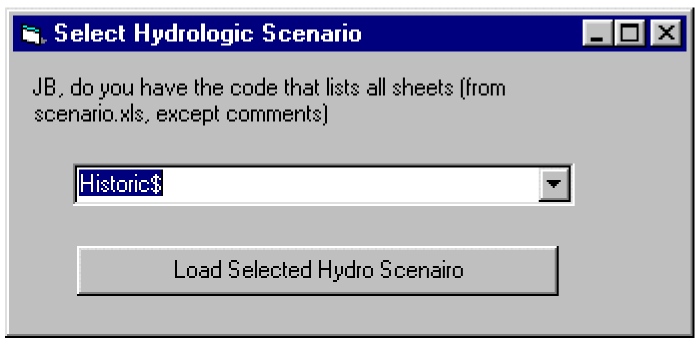


Figure 18 The 'Hydrologic Scenarios' dialogue box in IRM allows you to select alternate hydrologic scenarios to drive model predictions.

To develop your own hydrologic scenarios, create a new sheet in 'scenarios.xls' by creating a copy of the 'historic' sheet. Then open the 'Scenario Builder' dialogue box (Fig. 19) by selecting the 'Management – Build New Hydrologic Scenario' menu item. Select the sheet name you just created from the 'Scenario' dropdown list box. Select the area and variable of interest in the dropdown list boxes below this. If you also select a year and click on the 'Display Profile' button, the 52 values for that year will be displayed in the graphic.

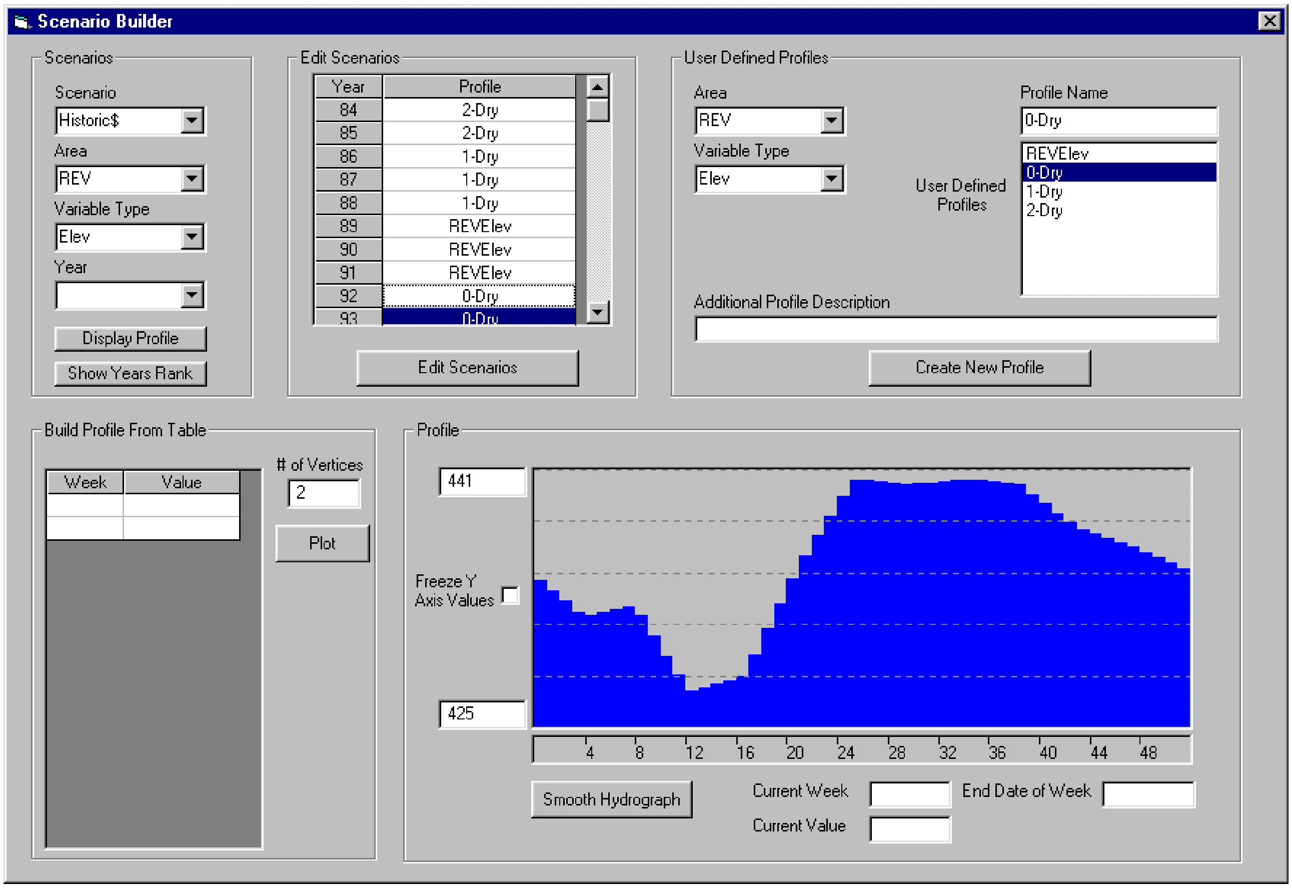


Figure 19 The ‘Scenario Builder’ dialogue box in IRM allows you to review, edit, and create alternate hydrologic scenarios.

You can edit this weekly time series by holding down the left mouse button while dragging the pointer over the graphic to sketch in a new profile. You can smooth the profile, or create a new one by defining a set of vertices (week and value for ‘n’ vertices) in the grid within the ‘Build Profile from Table’ grid. If you want to save this weekly profile to scenarios.xls, select the modeling area and variable type in the dropdown list boxes in the ‘User Defined Profiles’ frame, type in the name of the new profile in the ‘Profile Name’ text box, and click on the ‘Create New Profile’ button’. To use this profile in a simulation, you must assign it to specific years for the currently loaded scenario-area-variable type specified in the ‘Scenarios’ frame. To do this, click on the profile name is the ‘User Defined Profiles’ list, and then click on a cell for a specific year in the grid within the ‘Edit Scenarios’ frame. If you want to assign the profile to multiple years, hold the mouse down while you drag it over the appropriate cells in the grid. Click on the ‘Edit Scenarios’ button when you are done to save the edits to ‘scenarios.xls’.

5.5 VEGETATION MODEL PARAMETERS AND PLANTING SCENARIOS

Parameters controlling the vegetation model can be viewed and edited by accessing the ‘Vegetation Parameters’ dialogue box (Fig. 20) by clicking on the ‘Parameters-Vegetation Model Parameters’ menu item from IRM’s main form. Alternate parameter values can be saved and restored from different files by selecting the ‘Load…’ and ‘Save Vegetation Parameter File’ menu items.

Planting scenarios, defining the years, quantity, and areas in which fall rye and other vegetation types can be planted are set by accessing the ‘Planting’ dialogue box (Fig. 21) from the ‘Management – Define Planting Regime’ menu item. Select the desired modeling area from the dropdown list box at the top of the dialogue box (e.g., the ‘Revelstoke Reach’ for the /Arrow configuration of IRM) and click on the ‘Map Horizontal’ or ‘Map Vertical’ option to optimize the display of the map in the dialogue box (e.g. Vertical for Revelstoke Reach because it runs North-South).

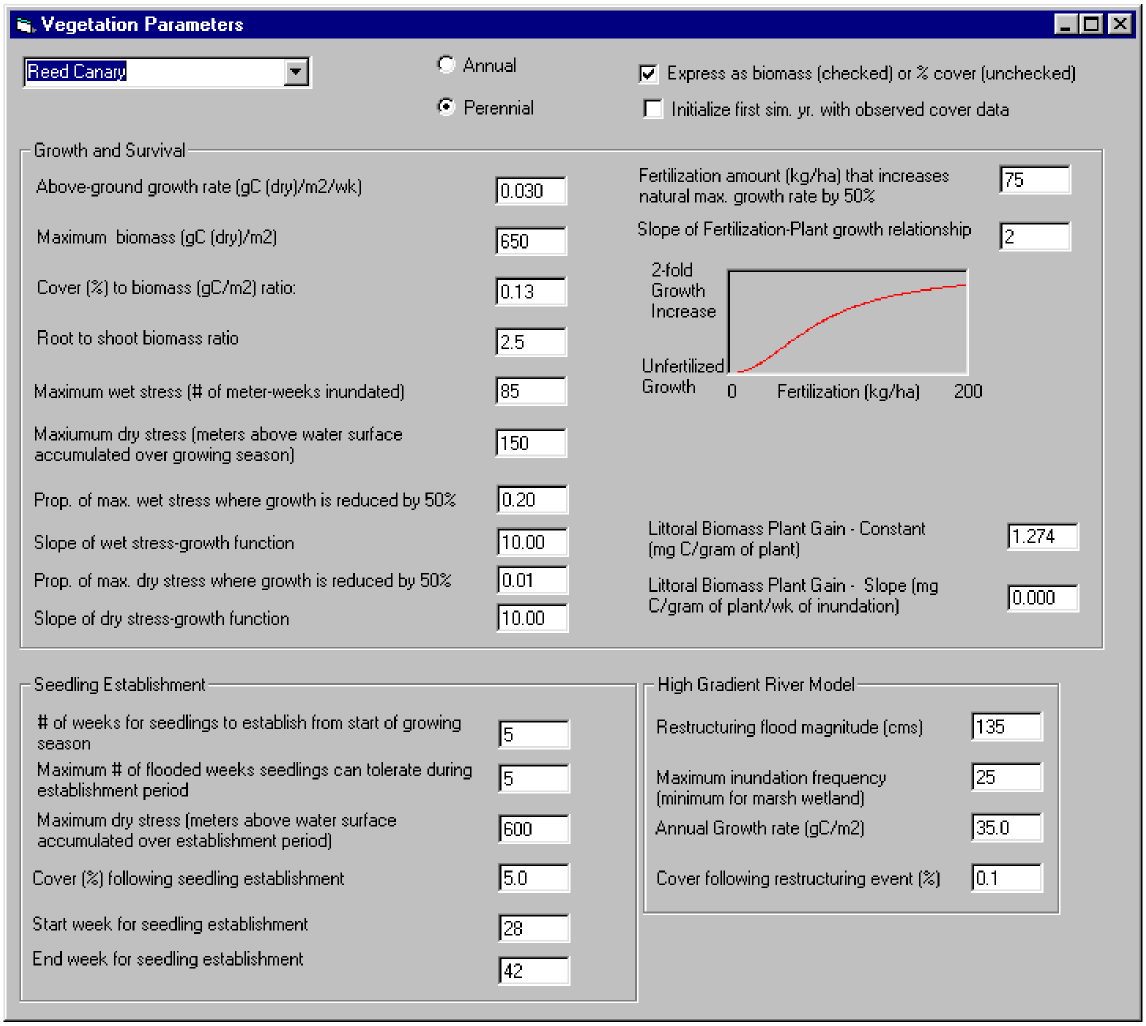


Figure 20 The 'Vegetation Parameters' dialogue box in IRM lets you review and edit parameters that control the vegetation component of the model.

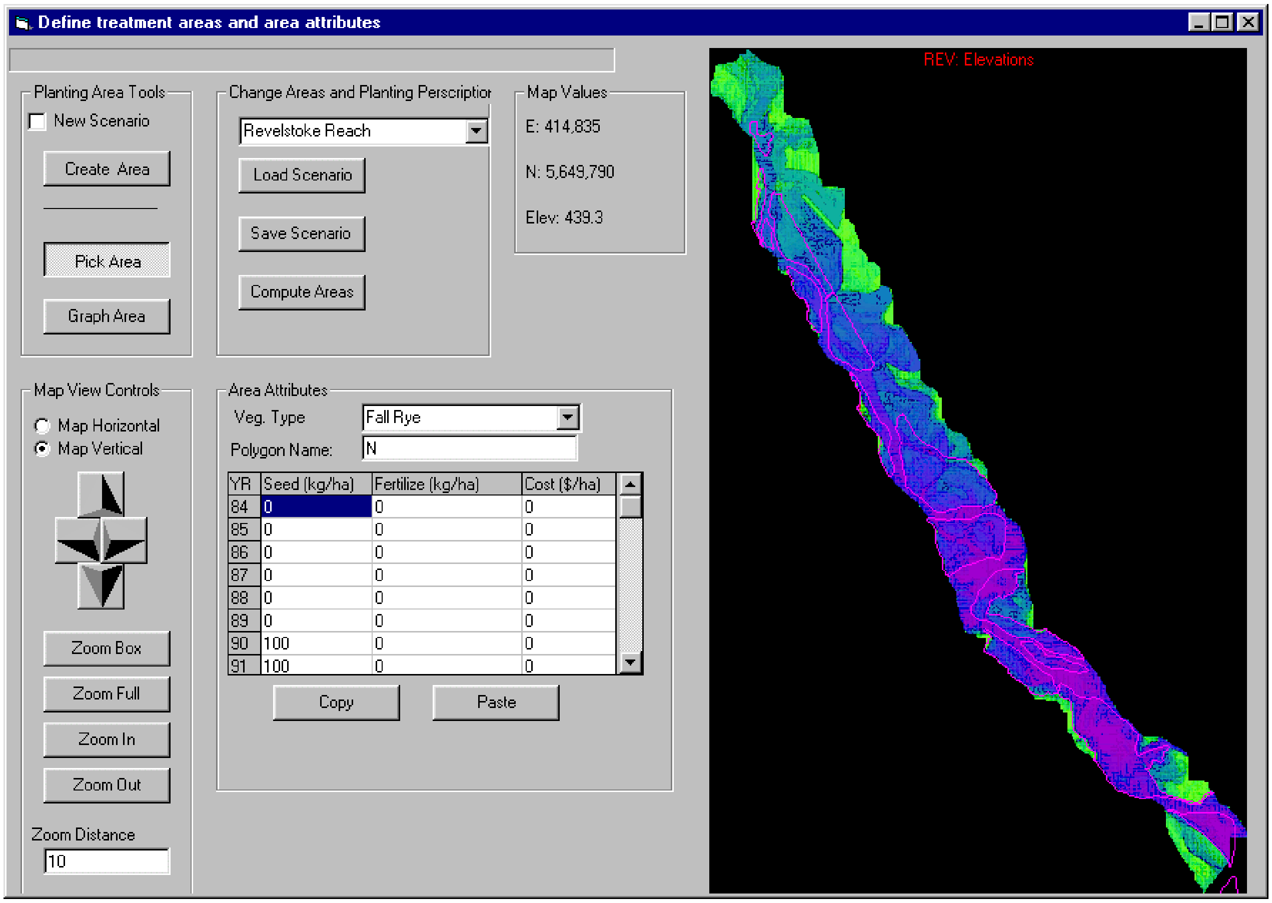


Figure 21 The ‘Define Planting Regime’ dialogue box lets you view existing planting polygons and their associated planting histories, create new planting polygons and histories, and review other characteristics of the digital elevation model.

The map that is displayed in the ‘Planting’ dialogue box is the digital elevation model used for many of the model calculations. As you move your mouse over the map, the Easting, Northing, and elevation of each pixel (representing a 25 * 25 m grid) is updated in the ‘Map Values’ frame. Use the controls in the ‘Map View Controls’ frame to zoom in/out or pan over the map. Planting scenario files contain the coordinates of any planting polygons (e.g., dust control areas in the Revelstoke Reach) as well as the planting history for these areas. If you click on a polygon, the planting history will be displayed in the grid adjacent to the map. If you click on the ‘Graph Area’ button and then click on a polygon, the hypsometry for the polygon (the amount of area at each elevation band) will be displayed in a graph adjacent to the map. To create a new polygon in an existing scenario file, click on the ‘Create Area’ button and then digitize the polygon onto the map by pointing and clicking on the vertices. Double-click on the last vertex to close the polygon. Once this is complete, name the polygon and defined the seeding rate for specific years for any or all of the vegetation groups. Save the planting scenario file to keep these changes. To create a new planting scenario file from scratch, select the ‘New Scenario’ option.

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