Analysis of the Affects of Yakima River Basin Water Storage Feasibility Study Alternatives on Black Cottonwood Seedling Recruitment

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Introduction

Background

Reduced cottonwood reproduction has been identified as a key biological issue for the Yakima River (Jaimeson and Braatne, 2001; Biology Technical Work Group, 2004; Braatne, Jamieson, Rood and Gill, 2007; Reclamation, 2002; Yakima Subbasin Fish and Wildlife Board, 2004). Black cottonwoods (Populus balsamifera ssp. trichocarpa), the local species, are the dominant plant in lowland riparian forests of the Yakima River basin and are essential to the integrity of these ecosystems. Black cottonwoods interact with the water, sediment, and other biota of the river system (Fierke and Kauffman, 2005). While hydrologic and sedimentary processes drive the creation and destruction of cottonwood habitat, the trees, in turn, modify physical river processes through increased channel and floodplain roughness, increased bank stability, and inputs of large woody debris (Montgomery et al. 2003). Black cottonwoods also influence aquatic ecosystems through exchanges of nutrients, species, and energy. Because black cottonwoods are integral components of the river system, it follows that changes in cottonwood recruitment can affect salmonid species both directly and indirectly in both the short and long terms (Naiman and Latterell, 2005).

Black cottonwoods range from northern California to the timberline in Alaska and grow mostly in riparian zones (DeBell, 1990). Their reproduction, growth, and mortality are closely linked to river processes (Auble and Scott, 1998). Grazing by native ungulates and cattle, fire, insect predation, and disease have also been linked to black cottonwood ecology.

Seedling reproduction in black cottonwoods is the usual means of new stand establishment, and occurs in periodic pulses on western U.S. snow-fed rivers. Clonal (asexual) regeneration is important for stand expansion and survival, but does not colonize new substrates as rapidly nor does create genetic diversity as seedling recruitment does. Mortality appears to be driven by floods which undercut trees during channel avulsions and migration (Lytle and Merritt 2004). Rapid declines in water table levels have also been shown to cause early mortality in cottonwoods (Rood et al. 1995).

Objective

The objective of this report is to extend the analysis of study alternatives in the body of the EIS by assessing hydrograph components in five water year classes during the period of record as opposed to grouping all years together.

Study area and data used

This report uses hydrological data from four gaging stations that represent four river reaches. The Cle Elum reach extends from the confluence of the Cle Elum and Yakima rivers to the point where the Yakima River enters a canyon downstream. The Naches reach of the Naches River extends from the town of Naches to the confluence of the Naches and Yakima Rivers. The Gap to Gap reach, represented by the Terrace Heights gage, runs from the confluence of the Naches and Yakima Rivers to Union Gap. Finally the Wapato reach with the Parker gage extends from Union Gap downstream to the confluence of Toppenish Creek.

Hydrological data from water years (October 1st to September 30th) 1981 to 2005 was used. Data was obtained from the Riverware hydrological model and from online archives of the U.S. BOR hydromet system for the Cle Elum, Naches, and Parker gages. Flow records for the Gap to Gap reach were obtained from the USGS online database from the Union Gap gage (gage # 12503000). All flow data were daily means. Flow is expressed in cubic feet per second (cfs), and stage is expressed in feet and tenths of feet.

The exception to data used was in the water year class calculation. For this I used USGS modeled unregulated flow for the water years 1951 to 1998 to supplement Riverware data.

This report only considers the Black Rock and Wymer Dam plus pump exchange alternatives. The Wymer Dam and Reservoir alternative would have negligible affects on cottonwood seedling recruitment, as shown in the Storage Study EIS. Also, observed flow is substituted for the No Action alternative since they are very similar but observed flow represents actual observed data.

Study approach

I have combined several methods in order to analyze the study alternatives. I use the recruitment box model (RBM), a conceptual model that links cottonwood recruitment to stream hydrology, to identify flow components that drive cottonwood seedling reproduction. I then compare values for each flow component between modeled unregulated flow and observed flow for each reach and for five water year classes. This procedure, called a hydrograph components analysis (HCA) (RMC Water and Environment and McBain and Trush, Inc.. 2007), reveals the extent to which each component for cottonwood seedling recruitment has been altered by current river operations compared to more natural hydrological conditions

Using the HCA methodology I then calculate flow component values for the Black Rock and Wymer Plus alternatives and compare these to values from unregulated flow and the empirical data. This provides specific understanding of how each alternative affects recruitment. Finally, I suggest a managed flow regime for cottonwood seedling recruitment for the Wapato reach. Full descriptions of the recruitment box model and the hydrograph components analysis are provided in their respective sections.

A weakness of this approach is that it relies on modeled unregulated flow data. The modeled data represents a reasonable estimate of river flow if dams and diversions were to suddenly disappear but watershed, floodplain, channel, and groundwater conditions remained the same. For example, the difference between Riverware modeled data of current operations and actual observed data from river gages is less than 10%. However, the modeled flow should by no means be understood as estimating the natural flow regime, the flow patterns that riparian and aquatic organisms evolved with. Watersheds, floodplains, and channels in the Yakima basin have been fundamentally altered in the last 2 centuries with unknown effects on the magnitudes, timing, seasonality, and duration of river flow patterns (Eitemiller et al. 2000, Snyder et al. 2000). However, because no other reference condition exists for the Yakima River, models of unregulated flow provide a useful means of comparing current conditions with some approximation of a more natural flow

The Recruitment Box Model

Description

Cottonwood seedling recruitment is the germination of seedlings and their survival to the second summer after germination (3 years old). Seedling recruitment is an episodic process on western U.S. rivers. This means that while a few seedlings may recruit each year, large numbers of seedlings germinate and survive only in years when certain hydrological conditions are met. The most widely accepted model for cottonwood seedling recruitment is the recruitment box model (RBM) (Mahoney and Rood 1998), which is based on many observations linking the flow regime of western U.S. rivers to cottonwood seedling biology. It identifies parts of the annual hydrograph that are important for seedling recruitment and specifies ranges of values for them. The RBM thus defines flow conditions in space and time that are necessary for the germination and establishment of large numbers of seedlings. It has been expanded and refined since its introduction (Stillwater Sciences and Stella 2006, Braatne et al. 2007) and has been used to develop river management regimes favorable to cottonwood recruitment (Rood et al. 2003). The RBM also incorporates two observations: it is river stage rather than discharge that directly drives recruitment patterns even though discharge values are used for convenience, and it is the pattern of river flow, not the presence or absence of dams per se, that induces or impedes seedling recruitment. See figures 1-4 for reference in this narrative.

The first element of the RBM is a large flood that scours existing vegetation, deposits new sediment, and creates bare patches along rivers. Bare patches are required since cottonwood seedlings are intolerant of competition with other plants for moisture and shade (Braatne et al. 1996, Cooper et al. 1999). Second, the snow melt flood must peak during or before cottonwood seed release in the spring; presumably seed release timing has evolved in response to this annual hydrological event. The snow melt flood moistens bare substrates which enables seed germination (Fenner et al. 1984). The spring flood must also be high enough to moisten bare patches high above summer baseflow so that seedlings are not eroded by floods in the 2 to 3 years following germination. Thirdly, the recession rate (rate of stage decline) of the snow melt flood must be slow enough that developing seedling roots can keep in contact with the capillary fringe. This is the area of moist soil above the water table and can extend 8 to 16 inches above the water table in coarse substrates (Mahoney and Rood 1998). The capillary fringe moves in response to the water table, which in turn is linked to river stage. Fourthly, the summer and fall base flow must remain high enough to sustain the capillary fringe at the root level of seedlings; generally seedling roots do not grow more than 3 feet in a season (Braatne et al. 1996). Finally, the water years following germination must have low to moderate peak flows so that new seedlings are not scoured or buried by the river. Here establishment is defined as surviving until the third fall after germination, at which point seedling mortality from flood and drought decreases (Lytle and Merritt 2004).

Selection of Hydrograph Components

Five distinct flow components thus comprise the RBM. To summarize: a disturbance flood is large enough to erode and deposit sediments and creates bare nursery sites; a recruitment flood coincides with cottonwood seed release and has a high enough stage to allow seeding germination above the height of subsequent flows; the gradual recession limb of the recruitment flood keeps seedling roots in contact with soil moisture; summer baseflow must be high enough to maintain soil moisture for seedling roots; and flood peaks in the 2 years post-germination must be low or moderate.

The RBM also specifies ranges of values for each flow component expressed in terms of flood return interval and stage above base flow. These values are empirically derived from observations on western U.S. rivers, mostly in the northern Rocky Mountains. See table 1 for values for each flow component suggested by the RBM. Unfortunately I was not able to derive flow component values for the Yakima River using these empirical relationships. Flow component values are expressed in either flow return interval or elevation above baseflow, but return interval information was not readily available for the Yakima River. More problematically, stage to flow relationships are not available for anywhere on the Yakima but at gaging stations. Gaging stations are normally located along a well-defined channel for ease of measurement. Stage flow relationship there will not usually reflect the stage flow curves for sites likely to support cottonwood forests because these are usually reaches with gently sloping bars and many side channel connections. Thus stage flow curves need to be calculated on a site basis, not for entire river reaches.

This report will consider only the first four flow components for simplicity of analysis. Peak flows in the post-germination years are important but I will focus on flow events that are necessary for large scale germination of seedlings and survival through the first summer as the crucial first step in recruitment.

Hydrograph Component	Biological Function	Suggested Value from RBM
Disturbance flood magnitude	Scours and deposits sediment, creates suitable bare nursery sites	3 to >10 year return interval
Recruitment flood magnitude and timing	Moistens bare substrates at suitable elevations above baseflow, timing before or during cottonwood seed release	Peak stage must be 24 to 60 inches above summer base flow
Recruitment flood recession rate	Must be gradual enough for seedling roots to keep in contact with capillary fringe	About 1 inch per day for a 3 day running average
Summer base flow	Must be high enough to maintain soil moisture within reach of seedling roots	No more than 3 feet below seedling establishment elevation
Peak flows in the following 2 years	Must be low enough not to erode or bury new seedlings. Duration of peak flows must be short.	No value specified

Table 1. Biological functions and estimated values for cottonwood recruitment flow components from the recruitment box model. Information is adapted from Mahoney and Rood, 1998.

Figure 1. Band of successful recruitment for cottonwood seedlings controlled by peak flow elevation and summer base flow elevation. (Stillwater Sciences and Stella 2006).

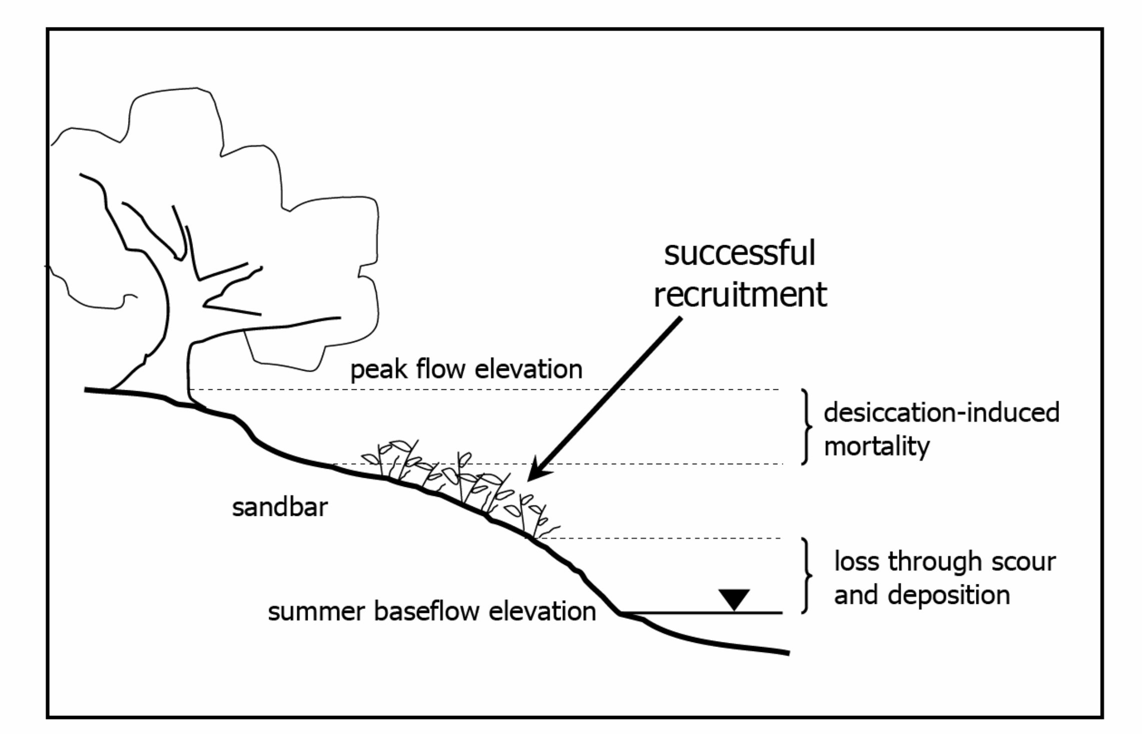


Figure 2. A more detailed depiction of the same band of successful recruitment showing typical elevations above summer baseflow on a meandering river (Mahoney and Rood 1998).

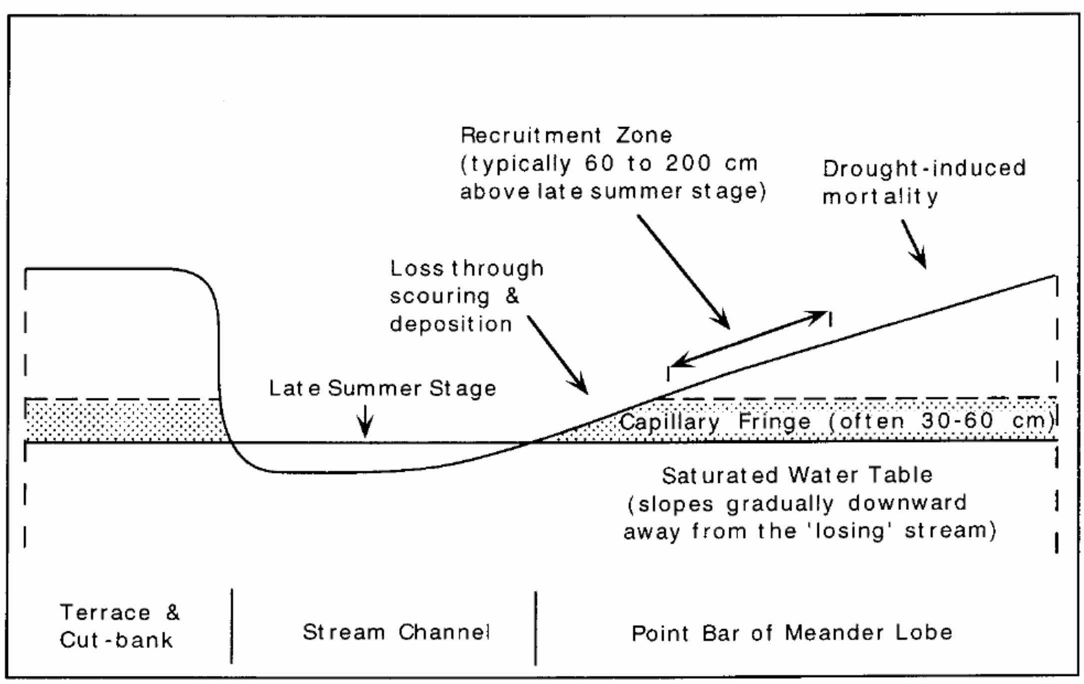


Figure 3. The elements of the recruitment box model: seed release timing, proper stage of recruitment flood, and gradual recession rate. These elements produce the successful seedling band shown in figures 1 and 2 (Stillwater Sciences and Stella 2006).

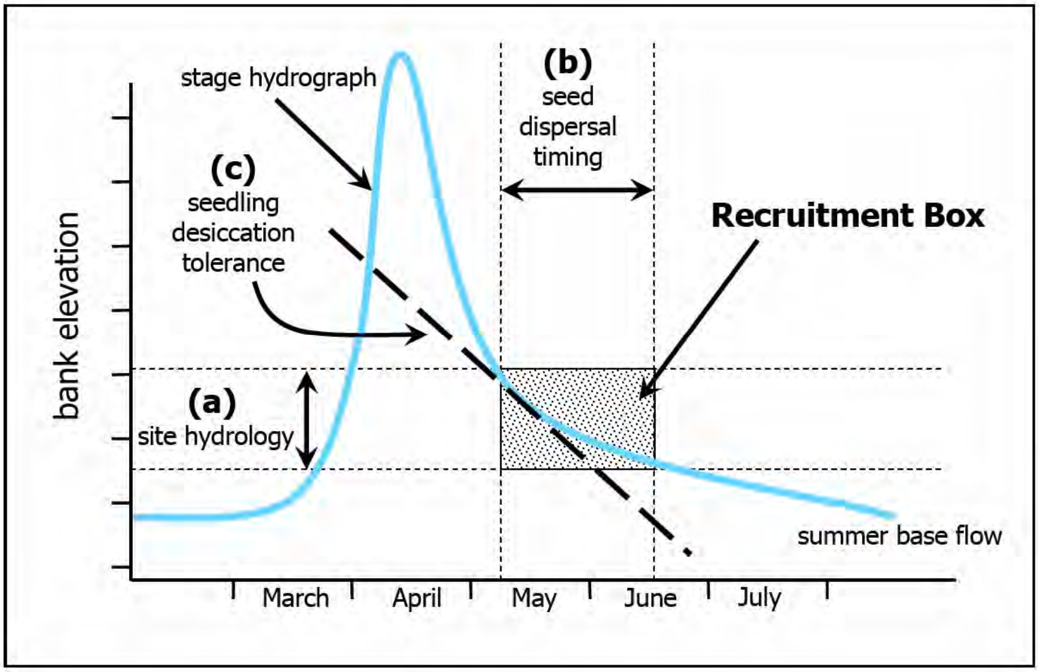
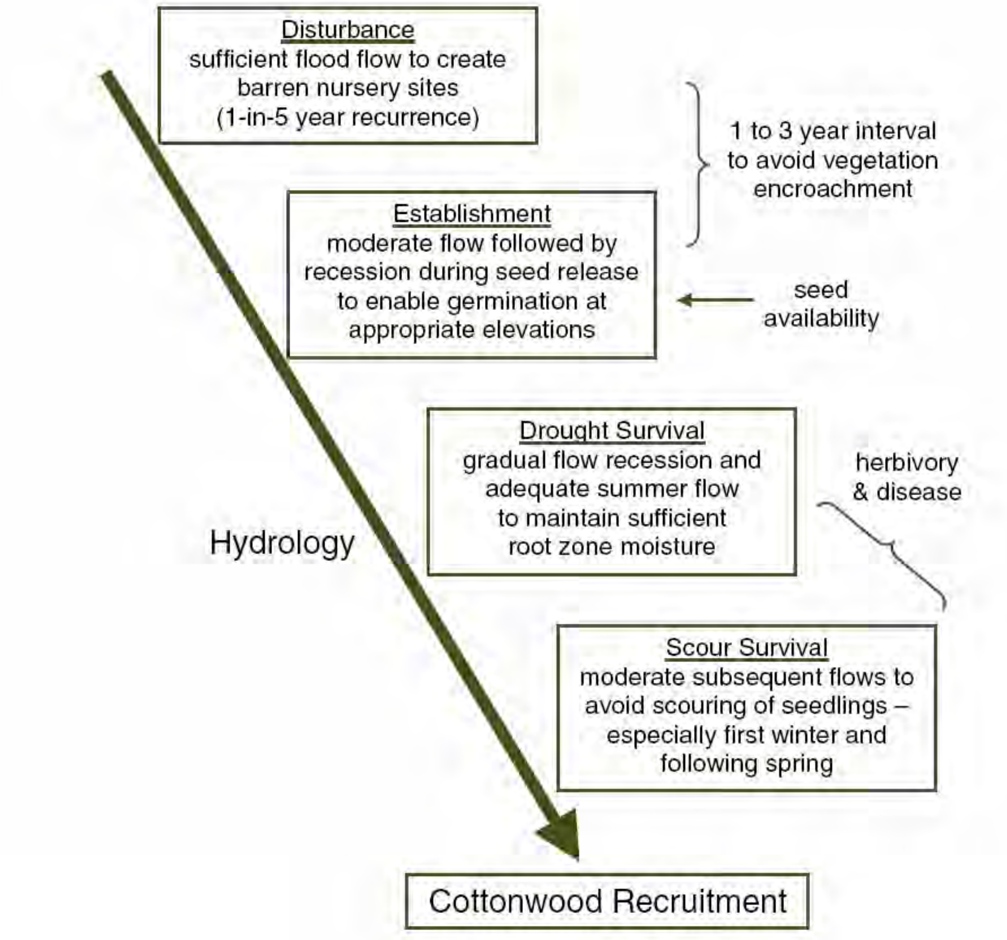


Figure 4. The recruitment box model shown as a multi-year pattern (Braatne et al. 2007).



Hydrograph Component	Timing	Water Year Type	Biological Function for Cottonwood Recruitment
Disturbance flood magnitude	November through April	Dry	No scour of seedlings allows for survival of seedlings from previous years.
		Normal	Minor scour and deposition create small nursery sites.
		Wet	Creates large bare nursery sites for seedlings by major scouring or deposition; causes channel avulsion. Woody debris recruited from floodplains provides sheltered nursery sites on bars.
Recruitment flood magnitude	May 1st to June 15th	Dry	No scour of seedlings allows for survival of seedlings from previous years. No recruitment of seedlings of the year.
		Normal	Some bare sites wetted, moderate to small numbers of seedlings germinate.
		Wet	Scour and deposition; broad wetted band on bare sites allows for potentially large numbers of cottonwood seedlings to germinate.
Recruitment flood recession rate	Mid-June to August	Dry	Recession ends early in the summer, no same year seedling survival. Seedlings from previous years survive.
		Normal	Gradual recession ends mid-summer, some seedlings of the year survive.
		Wet	Gradual recession far into summer allows growing seedling roots to maintain contact with receding capillary fringe; large numbers survive the first summer.
		Normal	Needs to be synchronized with seed release in order for seeds to land on moist nursery sites.
		Wet	Needs to be synchronized with seed release in order for seeds to land on moist nursery sites.
Summer base flow	August-October	Dry	Low baseflow prevents survival of seedlings of the year, causes drought stress and mortality for established seedlings and juveniles.
		Normal	Moderate baseflow allows some survival of seedlings of year, prevents stress to existing seedlings and juveniles.
		Wet	High base flow promotes high survival of seedlings of year, growing season may be prolonged.

Table 2. Generalized flow components for cottonwood recruitment for western U.S. rivers. Adapted from RMC Water and Environment and Mcbain & Trush Inc. 2007.

Hydrograph Components Analysis

Description

The hydrograph components analysis is a method of assessing stream ecosystem function in relation to steam hydrology. It isolates specific flow (hydrograph) components that are biologically relevant to the species of interest, and compares component values between impaired or current conditions and some reference condition. This procedure reveals specific parts of a hydrologic regime that have been altered and could cause reduced biological function for the species of interest. It relies on the concept of the natural flow regime, which states that stream organisms have evolved for the particular flow patterns and variability in their home stream or region. The HCA also considers each hydrograph component over a range of water year classes, which shows inter-annual variation as well as intra-annual patterns. Here the HCA is applied to riparian cottonwoods, although it could equally well be used to assess changes for other stream organisms. In this report the hydrograph components for cottonwood recruitment have been identified using the RBM, and the next step is to assess how they have been altered by river regulation. (Information summarized from RMC Water and Environment and McBain and Trush, Inc.. 2007) Please see table 2 for a description of generalized hydrograph components for western U.S. snow-melt fed rivers and their function in cottonwood recruitment.

Methods

Dividing the period of record into water year classes provides insight into patterns of inter-annual as well as the intra-annual change shown by the comparison of flow components.
I calculated water year classes on the basis of annual yield. I combined model unregulated data from the USGS for water years 1951 to 1998 and Riverware model unregulated data for years 1981 to 2005 in order to extend the period of record and include a full range of water years types. For both data sets I summed daily means for each year and converted the result to acre-feet. I then correlated the annual yield from the two data sets using a linear equation for the period of overlap (1981 to 1998); the relationship was strong (r=0.98). This equation was then used to project USGS modeled values to water year 2005. Using this adjusted data set I ranked annual yields and calculated exceedance probabilities for each year. Years from the period of the study (1981 to 2005) were grouped into these water classes. Flow data from the Parker gage was used to represent most of the Yakima River watershed. Water year classes were assigned names and exceedance probabilities: very wet = 90%, wet = 65%, normal = 35%, dry = 10%, and very dry < 10 %.

After assigning water year classes, I calculated the appropriate statistic for each hydrograph component for each year in the record. For example, for disturbance flows I calculated the maximum daily flow from November to April for each year (table 2) and then took the median of these values for each water year class. For recession rate, I subtracted each daily mean flow value from the preceding day’s value. I then calculated a 3 day running average from the differences for the recession rate. The three day average dampens small fluctuations in flow that are not reflected instantaneously in soil moisture. The results are shown in tables 3a to 3d and figures 5a to 5d, and are followed by a narrative for each reach.

Cle Elum Reach

3 a.

hydrograph component	very wet: unregulated model	very wet: observed	wet: unregulated model	wet: observed	normal: unregulated model	normal: observed	dry: unregulated model	dry: observed	very dry: unregulated model	very dry: observed
disturbance peak flow	25655	6810	11128	3628	11445	4011	7629	2074	7362	1402
recruitment peak flow	9493	6258	9336	4494	7989	4730	8497	2900	6349	1901
summer base flow	647	1445	514	1495	554	2725	516	2541	384	1837
average 3 day running recession	70	-35	29	-56	39	-22	25	-29	30	-16

Naches Reach

3 b.

hydrograph component	very wet: unregulated model	very wet: observed	wet: unregulated model	wet: observed	normal: unregulated model	normal: observed	dry: unregulated model	dry: observed	very dry: unregulated model	very dry: observed
disturbance peak flow	14478	12280	8269	5862	6792	5182	4915	3029	4148	2596
recruitment peak flow	9515	7317	7521	5767	6361	4704	5301	5767	4268	2685
summer base flow	701	1129	538	1320	553	548	438	677	335	399
average 3 day running recession	64	54	47	38	51	45	21	5	26	21

Table 3 a & b. Median modeled unregulated versus observed flows for hydrograph components for water years 1981 through 2005. Disturbance flood is from November 1st to April 30th, recruitment flood is from May 1st to June 15th, summer base flow is from August 1st (August 15th very wet and wet years) to September 30th. Top row indicates water year classes.

Gap to Gap Reach

3 c.

	very wet		wet		normal		dry		very dry	
hydrograph component	unregulated model	observed	unregulated model	observed	unregulated model	observed	unregulated model	observed	unregulated model	observed
disturbance peak flow	43309	31350	24692	13800	20278	14000	14440	6990	12540	4520
recruitment peak flow	24419	15550	20261	11800	15916	8690	17667	6230	11886	4000
summer base flow	2244	3140	1773	2915	1541	3130	1339	2850	1227	2460
average 3 day running recession	149	36	98	10	102	11	56	-7	51	-2

Wapato Reach

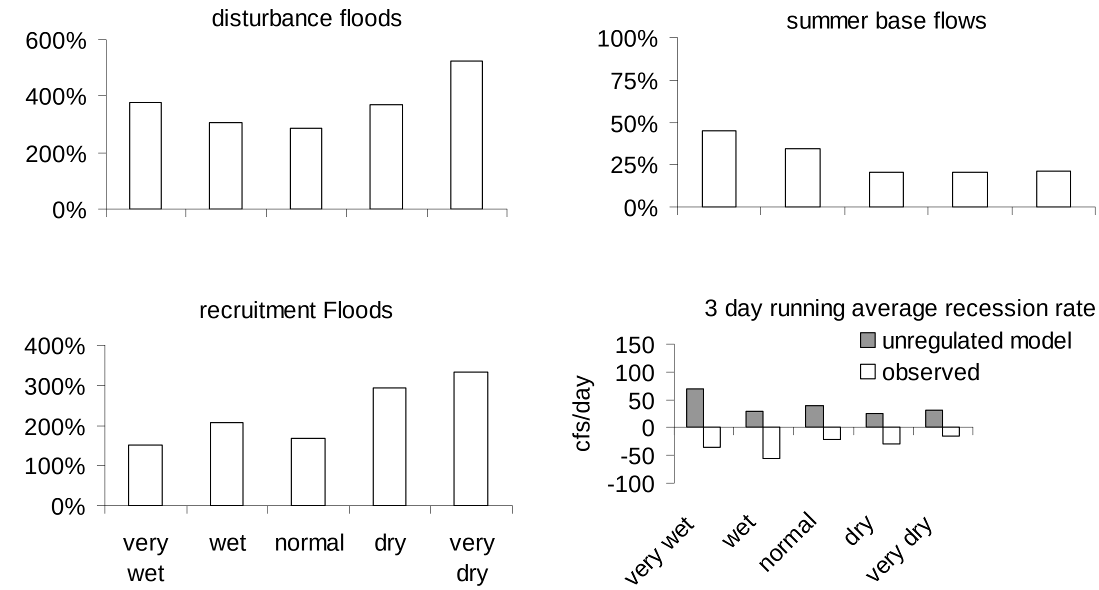
3 d.

	very wet		wet		normal		dry		very dry	
hydrograph component	unregulated model	observed	unregulated model	observed	unregulated model	observed	unregulated model	observed	unregulated model	observed
disturbance peak flow	40784	36312	23138	14600	19382	16154	14439	5217	12049	2654
recruitment peak flow	24703	13414	20011	9081	15530	6376	16892	3937	11772	1703
summer base flow	2277	646	1767	498	1577	392	1345	400	1240	390
average 3 day running recession	158	40	103	13	106	13	57	2	53	0

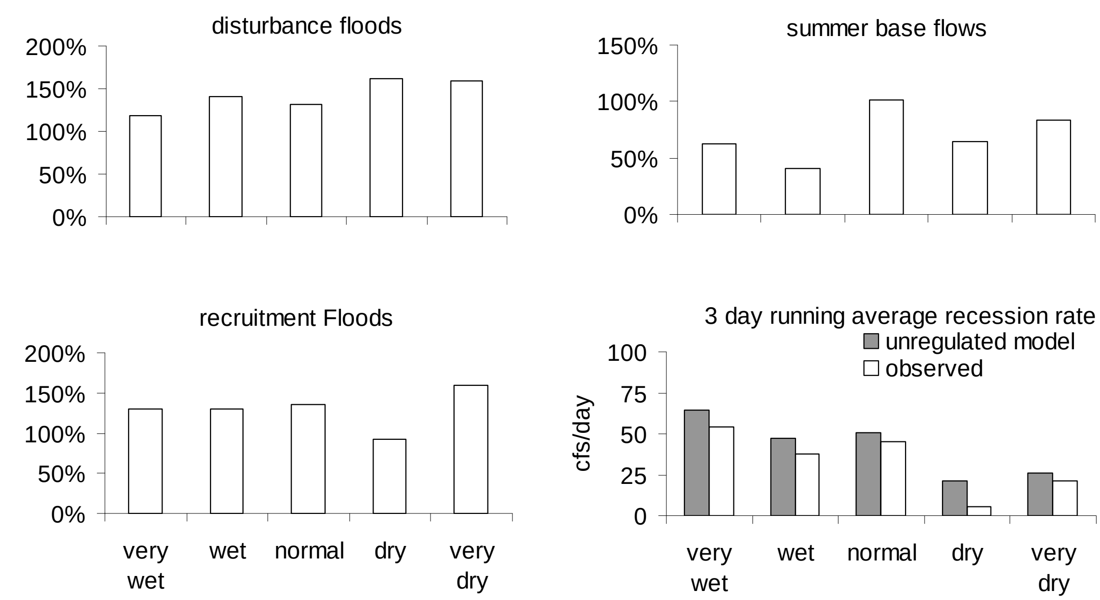
Table 3 c & d. Median modeled unregulated versus observed flows for hydrograph components for water years 1981 through 2005. Disturbance flood is from November 1st to April 30th, recruitment flood is from May 1st to June 15th, summer base flow is from August 1st (August 15th very wet and wet years) to September 30th. Top row indicates water year classes.

Cle Elum Reach-5 a.

Figures 5 a & b. Modeled unregulated flows as relative percentage of observed flows for hydrograph components (modeled flow divided by observed flow x 100). Recession rate is shown as decline in cfs/day.

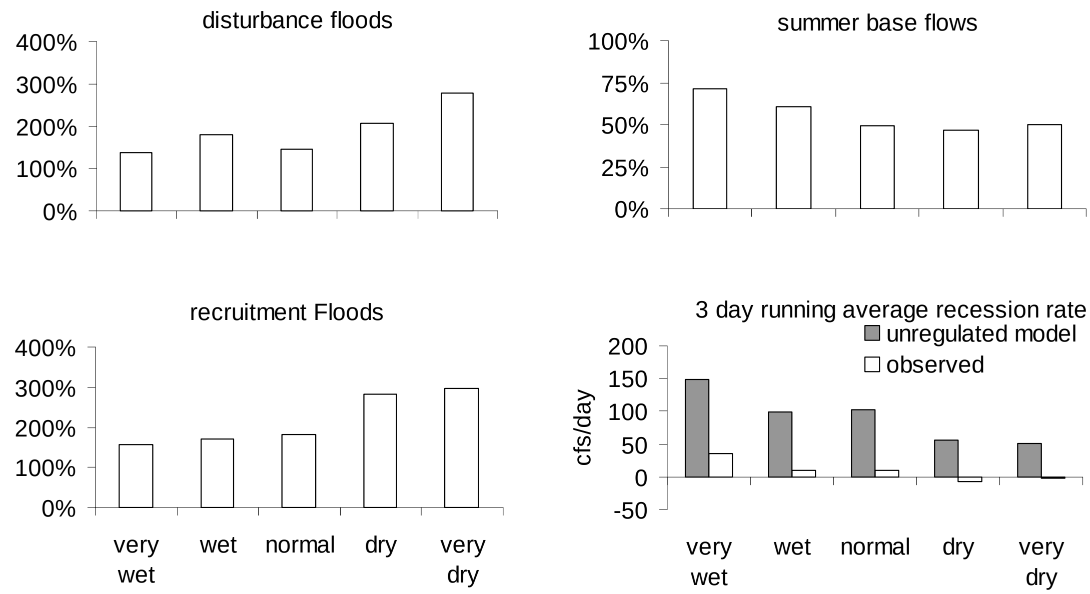


Naches Reach-5 b.

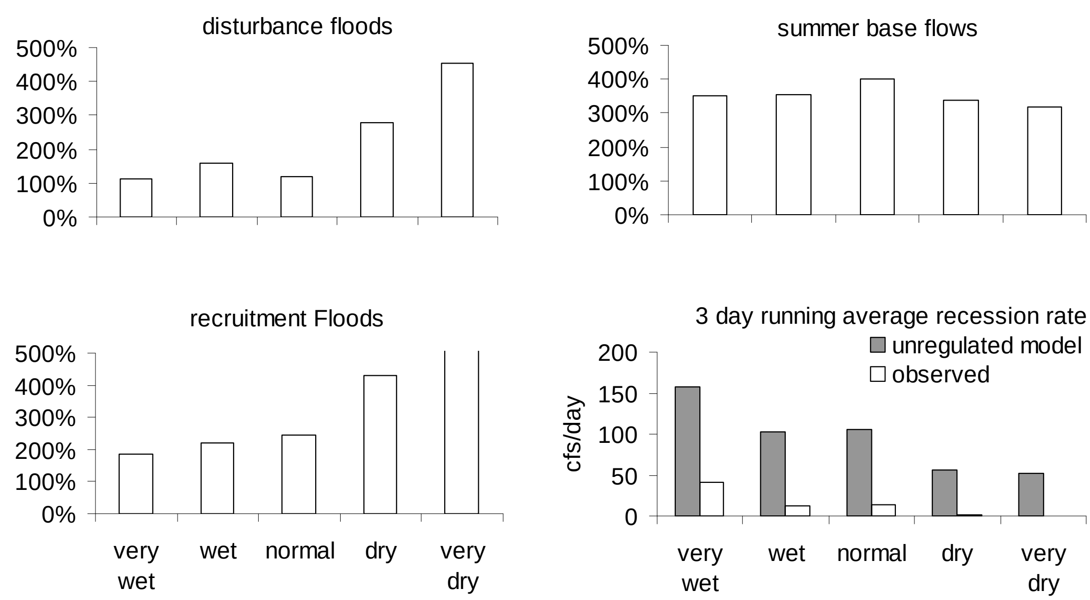


Gap to Gap Reach-5 c.

Figures 5 c & d. Modeled unregulated flows as relative percentage of observed flows for hydrograph components (modeled flow divided by observed flow x 100). Recession rate is shown as decline in cfs/day.



Wapato Reach-5 d.



Narratives

Cle Elum

All flow components differ dramatically between modeled unregulated and observed flow. Modeled unregulated flow disturbance floods range from around 300% to 500% higher than observed flow, and recruitment floods are from about 150% to 300% higher. Summer base flows for the unregulated model are less than half of observed flows in all water year classes. Observed recession rates are negative, meaning that on average the flow increases during the recession period. Unregulated flows decline slightly during recession.

This reach shows severely impaired flow components for cottonwood recruitment. Reduced disturbance and recruitment flows would reduce the rate of creation of bare nursery sites and reduce the height above base flow at which seedlings germinate. Furthermore, the elevated summer base flows of the observed data would in many years erode seedlings that have germinated at low elevations. Rising flows in the recession period would also flood and erode new seedlings or inundate potential nursery sites before they can be colonized by seeds.

Naches

Differences between observed and modeled unregulated flow show fewer differences in the Naches reach than for other reaches. Disturbance and recruitment floods are moderately higher in the unregulated model, while summer base flows are moderately lower overall; in wet years they are less than half of observed flows. Recession rates show a minimal difference.

Recruitment flow components are slightly impaired on the Naches reach. Sufficient disturbance and recruitment flows exist to create nursery sites and establish seedlings at appropriate elevations above summer baseflow. Summer base flows are probably not elevated enough to erode most seedlings, and recession rates are conducive to root growth for seedlings.

Gap to Gap

Disturbance and recruitment flows are impaired, especially in dry and very dry water years, in unregulated model compared to observed flow. Modeled summer base flows are lower than observed flows by close to half in most year classes. Modeled recession rates are much higher than observed recession rates, which show almost no decline in very wet to normal years and a slight rise in dry and very dry years.

This reach is moderately impaired for cottonwood recruitment. At least in wet and very wet years nursery sites would be created and seedlings would germinate high enough to avoid erosion. However, elevated summer base flows would reduce the extent of the seedling band (figure 1), perhaps eroding a substantial proportion of new seedlings. In addition, an almost flat recession rate would not expose nursery sites and would limit root growth rates, also narrowing the band of potential establishment.

<u>Wapato</u>

All flow components differ drastically between modeled unregulated and observed flows, with the exception of disturbance flows in very wet years, which is almost equal in the two data sets. Otherwise disturbance and recruitment flows and summer based flows are much higher in the model. Recession rates are also much higher for unregulated flows.

The Wapato reach is highly impaired for cottonwood recruitment. Bare nursery sites would be created in very wet, wet, and normal years. However, seedlings would only germinate at low relative elevations because of low recruitment flows, and extremely low base flows would have the same effect. Overall, seedlings would be at high risk of erosion in the following years. Apparently gentle recession rates are more a function of low recruitment flows than functional hydrology.

Conclusions

Overall, not surprisingly, all reaches show impaired flow under current river management compared to modeled unregulated flow. In the upstream Cle Elum and Gap to Gap reaches summer flows are currently higher than modeled flow, but in the Wapato reach summer base flows are much lower. Recruitment flows in the Gap to Gap and Wapato reaches are much lower than modeled unregulated flow, but disturbance flows in very wet, wet, and normal years are close to modeled flow values. This suggests that bare nursery sites are being created on downstream reaches but that seedlings may be establishing at low relative elevations and so are eroded in the seasons and years after germination. Recession rates are difficult to interpret given the large differences in recruitment flows that represent the starting point for the spring recession. Only on the Naches reach is observed flow somewhat close to modeled unregulated flow, which suggests that some cottonwood recruitment is occurring there.

Alternatives Analysis

The analysis of alternatives uses flow component values from the HCA for the unregulated model and observed flow. The HCA procedure was also used to calculate component values for the Black Rock and Wymer plus pumpback study alternatives. These values are presented in tables 6 a. to 6 d. and narratives by reach, followed by an overall discussion. The objective is to compare the study alternatives with unregulated and observed flow to assess their potential impact on cottonwood seedling recruitment. In this context, improved flows mean that the flow component value for the study alternatives is closer to the unregulated model value than the observed value is. A general observation is that the Black

Rock and Wymer alternatives are very similar for all reaches and so will be discussed together.

Narratives

Cle Elum Reach

With few exceptions, neither the Black Rock nor Wymer Plus alternatives seem likely to improve cottonwood recruitment in the Cle Elum reach. For disturbance flows in very wet years there is a marginal improvement over observed flow, as there is for recruitment flows in very dry years. Even though both Black Rock and Wymer show slightly reduced summer flows compared to observed flows, the difference is likely not great enough to enhance cottonwood recruitment, particular as disturbance and recruitment flows remain impaired. Similarly, the small improvement in recession rate over observed flow is not likely to show biological effects.

Naches Reach

The Black Rock and Wymer Plus alternatives may further impair cottonwood recruitment on the Naches reach. Disturbance and recruitment flows for most water year classes are smaller for the study alternatives than for observed flow, moving the flow component farther away from the unregulated model. Similarly, summer base flow values for the alternatives are higher than observed flows for dryer year classes and are only slightly smaller for very wet and wet years. This would contribute to flooding and erosion of seedling growing at relatively low elevations.

Gap to Gap Reach

The study alternatives are not likely to change cottonwood seedling recruitment rates in the Gap to Gap reach. Disturbance and recruitment flows are not very different from observed data so the rate site creation and elevation of seed germination would not change. Summer base flows do show a slight improvement (reduction), which may allow some seedlings that would be flooded under observed conditions to survive. Because summer base flow improvements are slight, however, the impact on seedling recruitment is likely to be small.

Wapato Reach

On the one hand, the Black Rock and Wymer Plus alternatives show a slight reduction in disturbance and recruitment flows the observed flow data. This means that the creation of recruitment sites would continue at the same rate or slightly slower rate and that germination elevations would be similar to current conditions. On the other hand, summer flows under the study alternatives are substantially improved. This would perhaps increase seedling survival over observed conditions. Overall the study alternatives probably would not substantially change recruitment conditions at Parker.

Conclusions

Overall, across all reaches, hydrograph components, and year types, the study alternatives show little change over observed conditions when compared to the substantially impaired flow conditions shown in the hydrograph components analysis. This means that cottonwood seedling recruitment is unlikely to improve on the Yakima River under the study alternatives in the context of this analysis. However, the available data constrain the assessment in several ways. First, while Riverware generated flow data for the unregulated, Black Rock, and Wymer plus pumpback scenarios are helpful, it by definition does not reflect real conditions on the river. The analysis is only as good as the data it uses, and the predictions of the model for the study alternatives are not testable. Therefore large errors could have been unknowingly introduced. Secondly, the Riverware model uses current operating criteria when it generated flow data for the study alternatives. Running the model under different operating criteria could result in different results in relation to cottonwood seedling recruitment.

Finally, it is puzzling that the analysis of the affect of alternatives on cottonwood recruitment in the EIS (conducted by the author of this report) produced different results than the technical report. Namely, the EIS analysis showed that some improvements in recruitment would occur on the Gap to Gap and Wapato reaches while here no improvements are found. This could be because of two reasons. First, the EIS analysis used Riverware generated data as a stand-in for observed data. This model data differs in average daily flow by about 9% from the observed data used for the technical report, which could account for the difference in results. Second, the EIS analysis did not consider water year classes, rather it used medians for each flow component for all years combined. Separating out water year classes may have revealed some finer distinctions that were averaged out in the EIS. Whatever the case, neither the Black Rock nor the Wymer plus pumpback alternatives change flow patterns substantially under the modeled operations criteria compared to the highly impaired conditions shown in the hydrograph components analysis, with the exception of summer flows in the Wapato reach.

Cle Elum Reach

flow component	year class	unregulated model	Black Rock	Wymer Plus	observed
disturbance flow	very wet	25655	8052	8222	6810
	wet	11128	3531	3512	3628
	normal	11445	3918	3934	4011
	dry	7629	1929	2169	2074
	very dry	7362	1996	1901	1402
recruitment flow	very wet	9493	5496	5117	6258
	wet	9336	2990	3734	4494
	normal	7989	2952	3422	4730
	dry	8497	2665	3257	2900
	very dry	6349	2940	2441	1901
summer base flow	very wet	647	1308	1548	1445
	wet	514	1016	1309	1495
	normal	554	1574	2569	2725
	dry	516	1605	2142	2541
	very dry	384	1189	1343	1837
3 day running average recession rate	very wet	70	36	-9	-35
	wet	29	-16	0	-56
	normal	39	-10	5	-22
	dry	25	5	4	-29
	very dry	30	2	7	-16

Table 4 a. Hydrograph components for unregulated and observed flow and Black Rock and Wymer Plus study alternatives. Values for the flow components and water year classes are calculated as described for the hydrograph components analysis. Unregulated flows should be interpreted as the target flow, and observed flow is the baseline.

Naches Reach

flow component	year class	unregulated model	Black Rock	Wymer Plus	observed
disturbance flow	very wet	14478	9428	9428	12280
	wet	8269	5697	5697	5862
	normal	6792	5572	5572	5182
	dry	4915	3816	3816	3029
	very dry	4148	2408	2514	2596
recruitment flow	very wet	9515	7152	6743	7317
	wet	7521	6682	6682	5767
	normal	6361	4988	5088	4704
	dry	5301	3237	3572	5767
	very dry	4268	2498	1974	2685
summer base flow	very wet	701	1099	1085	1129
	wet	538	1212	1284	1320
	normal	553	1197	663	548
	dry	438	778	852	677
	very dry	335	682	875	399
3 day running average recession rate	very wet	64	58	7	54
	wet	47	43	26	38
	normal	51	42	13	45
	dry	21	7	4	5
	very dry	26	18	1	21

Table 4 b. Hydrograph components for unregulated and observed flow and Black Rock and Wymer Plus study alternatives. Values for the flow components and water year classes are calculated as described for the hydrograph components analysis. Unregulated flows should be interpreted as the target flow, and observed flow is the baseline.

Gap to Gap Reach

flow components	year class	unregulated model	Black Rock	Wymer Plus	observed
disturbance flow	very wet	43309	24495	24093	31350
	wet	24692	13606	12973	13800
	normal	20278	12871	11618	14000
	dry	14440	6859	6503	6990
	very dry	12540	4203	3775	4520
recruitment flow	very wet	24419	14284	14045	15550
	wet	20261	9125	7807	11800
	normal	15916	7637	8794	8690
	dry	17667	5355	4457	6230
	very dry	11886	4509	2884	4000
summer base flow	very wet	2244	2639	3046	3140
	wet	1773	2641	3045	2915
	normal	1541	2880	3253	3130
	dry	1339	2538	3034	2850
	very dry	1227	1998	2559	2460
3 day running average recession rate	very wet	149	108	-2	36
	wet	98	60	17	10
	normal	102	62	-1	11
	dry	56	19	-1	-7
	very dry	51	19	-1	-2

Table 4 c. Hydrograph components for unregulated and observed flow and Black Rock and Wymer Plus study alternatives. Values for the flow components and water year classes are calculated as described for the hydrograph components analysis. Unregulated flows should be interpreted as the target flow, and observed flow is the baseline.

Parker Reach

flow component	year class	unregulated model	Black Rock	Wymer Plus	observed
disturbance flow	very wet	40784	25005	25057	36312
	wet	23138	13754	12756	14600
	normal	19382	12408	11976	16154
	dry	14439	6235	6000	5217
	very dry	12049	3241	3065	2654
recruitment flow	very wet	24703	12233	13153	13414
	wet	20011	6915	6394	9081
	normal	15530	6083	8114	6376
	dry	16892	3866	3526	3937
	very dry	11772	3014	1837	1703
summer base flow	very wet	2277	1304	1503	646
	wet	1767	1304	1500	498
	normal	1577	1304	1503	392
	dry	1345	957	1503	400
	very dry	1240	535	1493	390
3 day running average recession rate	very wet	158	110	4	40
	wet	103	65	32	13
	normal	106	65	0	13
	dry	57	19	0	2
	very dry	53	19	0	0

Table 4 d. Hydrograph components for unregulated and observed flow and Black Rock and Wymer Plus study alternatives. Values for the flow components and water year classes are calculated as described for the hydrograph components analysis. Unregulated flows should be interpreted as the target flow, and observed flow is the baseline.

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