Modeling the impacts of John Day drawdown on the survival of salmonid stocks

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1 Introduction

The purpose of this study is to model the effect of a John Day Reservoir drawdown on anadromous salmonid populations, particularly populations listed under the Endangered Species Act. The approach utilizes passage models to characterize smolt survival through the hydrosystem and incorporates the passage model results into life-cycle models to characterize the effects of John Day actions on adult population levels. Because significant uncertainties exist on the effect of mitigation actions on fish survival and on how observed survivals are partitioned throughout the life cycle, a number of hypotheses are included in the analysis. The goal is to characterize the average effects over a range of hypotheses and to demonstrate the range of effects resulting from different hypotheses.

To produce estimates of the impacts of John Day mitigation actions on adult population levels, this analysis has used three methods. First of all, we utilized methods and results produced by PATH (Plan for Analyzing Testable Hypotheses, a group of approximately 25 scientists from state, tribal and federal agencies). The outputs from the PATH analysis are probabilities of meeting survival and recovery standards, and results relevant to this study are reported. Second, we simplified the PATH analysis (by removing the Bayesian decision analysis framework) to produce mean equilibrium spawner levels for particular actions under a range of hypotheses. This method produces intuitive results and can be used to estimate the gain or loss of spawning adults when analyzing one action compared to another. Third, for the more detailed analyses of actions at the John Day project, we further simplified the life-cycle analyses to produce only the difference in spawner levels under two actions. This simplification arises from the assumption that actions taken at the John Day project will not affect survivals in other life stages (e.g., ocean survival or egg to smolt survival) with the result that these survivals will cancel out when comparing two actions.

The specific actions considered at the John Day project were reservoir drawdown to natural river level, reservoir drawdown to the spillway crest, and drawdown to natural river level but using

John Day pool as a storage reservoir for flood control under high flow conditions. The analysis of the direct impacts of these actions on the survival of migrating smolts was conducted using the Columbia River Salmon Passage (CRiSP) model, developed at the University of Washington. In addition results from the FLUSH model (Fish Leaving under Several Hypotheses, developed by state and tribal agencies) were incorporated into life-cycle analyses where available.

For this report, Snake River spring and fall chinook were analyzed. Both these stocks are listed as threatened under the Endangered Species Act and were the focus of the PATH analysis. In addition, Hanford Reach fall chinook and Upper Columbia spring chinook were evaluated.

To summarize, three model systems were applied in the analysis. The PATH Bayesian life-cycle model to estimate the probabilities of survival and recovery, a deterministic model to determine the equilibrium and maximum sustainable spawner populations, and the CRiSP passage model to evaluate the impacts of drawdown on smolt survival and fish travel time.

2 Actions

To model John Day Reservoir drawdown two conditions are evaluated: spillway crest and natural river. The spillway crest draws the reservoir down to the crest of the John Day Dam spillway at 210 ft. Fish would pass through the spillway and plunge 50 ft. down into the tailrace at an elevation of about 160 ft. The full pool elevation is between 257 and 268 ft. giving a spillway crest drawdown level of approximately 50 ft., assuming a typical operating pool elevation of 265 ft. and a forebay elevation 5 ft. above the crest.

Under natural river drawdown, the reservoir elevation is taken to the level of the Dalles reservoir at the John Day tailrace. The natural channel of tailrace is at an elevation of 139 ft. Current minimum tailwater elevation is 155 ft. During a 2-yr flood the tailwater elevation is 166 ft. and under the 20 yr. flood it is 172-ft. Under these conditions, the natural river elevation would vary between 155 and 172-ft. Taking the typical elevation of the natural river as 165-ft., the natural river elevation drop is 100 ft.

John Day reservoir is used for flood control and has a capacity under current operating conditions to store 534,000 AF. The temporary storage of this amount of water requires lowering the elevation in anticipation of a flood event and then raising the level to approximately full pool. The net elevation change is approximately 10 ft. This level of flood control was sufficient to manage the 1997 spring runoff, which was one of the largest on record. In the analysis conducted here the same level of flood control is assumed and the resulting elevation change for a spillway crest and natural river control are estimated.

Table 1 lists the actions analyzed in this report. Some of the actions include a John Day drawdown in addition to a drawdown of the four lower Snake River projects; other actions treat a John Day drawdown without a Snake drawdown.

Table 1. Alternative actions evaluated

Action	**Description**
A0:	Base conditions as the hydrosystem without transportation
A1:	Base conditions as the hydrosystem is currently operated
A2:	Improved transportation with full transport of fish
A3:	Drawdown of the 4 lower Snake River dams
B1:	A3 with John Day drawdown to natural river level
B2:	A3 with John Day drawdown to spillway crest
B3:	A3 with John Day drawdown to natural river with flood control
C1:	Base, no transport, John Day drawdown to natural river level
C2:	Base, no transport, John Day drawdown to spillway crest
C3:	Base, no transport, natural river John Day drawdown with flood control
D1:	Natural river level John Day drawdown and Snake transport
D2:	Spillway crest John Day drawdown with flood control and Snake transport
D3:	Natural river level John Day drawdown with flood control and Snake transport

3 Measures of fish performance

To assess the performance of the drawdown and full transportation actions relative to the current hydrosystem operations, three measures of population performance were used. The first two are probabilities of meeting survival and recovery goals as defined by NMFS Jeopardy Standards. These were the measures used by PATH. The third measure is the equilibrium level of spawners for each recovery action. In addition to these measures, the absolute difference between pairwise comparisons of alternative actions for each measure is reported.

3.1 Survival Standard: 24-year

This measure was developed by PATH and was selected by NMFS as a primary survival standard for the A-Fish Appendix of the Biological Opinion. It is the fraction of simulation runs for which the average spawner abundance over a 24 year time period exceeds a predefined threshold for each index stock. For spring chinook, the survival threshold is 150 or 300 spawners depending on the river. For fall chinook, two survival thresholds have been proposed 300 and 700 spawners (Marmorek et al. 1998, Peters et al. 1999).

3.2 Recovery Standard: 48-year

This measure was developed by PATH and was selected by NMFS as a primary recovery standard. It is the fraction of simulation runs for which the average spawner abundance over the last 8 years of a 48-year simulation is greater than a specified level, which is 60% of the pre-1971 brood-year average spawner counts in each of the index streams (Marmorek et al. 1998). For fall chinook two recovery thresholds have been proposed: 2500 and 5100 spawners (Peters et al. 1999).

3.3 Equilibrium spawners

The equilibrium measure of the population is the level at which the spawning recruits of a brood are exactly sufficient to replace their parental brood. With typical salmon life-cycle models, in the absence of environmental variations and a constant harvest rate, the equilibrium population level is a stable point that a stock will approach over time. Simply put, the equilibrium is a measure of the number of fish a habitat can maintain with a specific set of management actions including hydro operations and fisheries regulations.

3.4 Smolt Passage Measures

The smolt passage measures provide a quantitative description of the direct effects of drawdown actions on smolt passage. These are valuable because they are not complicated by hypotheses on the linkage between effects of passage on ocean survival. Passage measures are defined for migration from the face of lower Granite Dam to the tailrace of Bonneville Dam (used in fall chinook analysis) or from the top of Lower Granite Pool to the tailrace of Bonneville Dam (used in the spring chinook analysis). The measures include fish travel time (FTT) in-river survival (Vn) and the total hydrosystem survival of both transported and in-river passing smolts (Sm). In addition, reported are the fractions of smolts in Bonneville tailrace that arrived through transportation (Pb) and in-river passage (1-Pb).

4 Life-cycle Framework

The models used in PATH, by the National Marine Fisheries Service, and the analysis in this report all are based on a salmon life-cycle model with low number of life history stages. Generally four important stages are identified (Fig. 1). The first stage is a freshwater spawning stage that in this report extends from the adult spawners laying eggs in redds to the beginning of smolt migration. This first freshwater stage characterizes the intrinsic freshwater production of a stock in terms of the number of progeny (per spawner) that survive through the stage. The second stage characterizes the migration of the smolts through the hydrosystem from the Lower Granite project to the tailrace of Bonneville Dam. The third stage characterizes the ocean and estuary survival and ends with the adults at the entrance of the adult bypass channels of Bonneville Dam. The fourth stage begins with the adults entering the upstream bypass channels and ends just prior to the spawning event. These four stages describe a complete salmon life cycle. Further divisions can be made to characterize other sub-stages within each stage, but for the purpose of comparing the impacts of the drawdown of John Day reservoir to other actions on the hydrosystem, these four elements are sufficient.

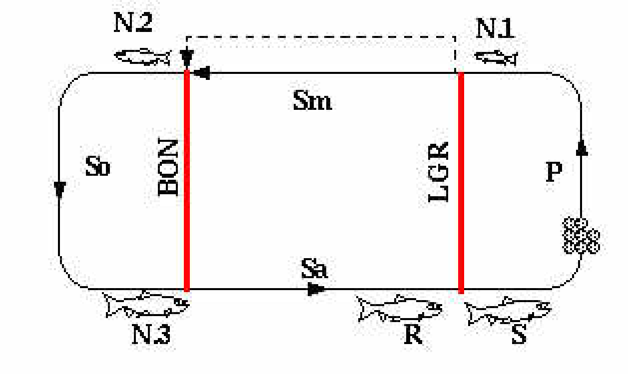

Figure 1. Life cycle of salmon extending from freshwater production stage, P, to hydrosystem survival, Sm, from Lower Granite Dam (LGR) to Bonneville Dam (BON), which includes in river and transport passage, to ocean survival, So, to upriver adult migration survival, Sa. S spawners produce R recruits.

The equation related to Figure 1 can be expressed

eq (1) $$R = S \cdot P \cdot Sm \cdot So \cdot Sa \cdot Ho \cdot Hr$$

where P is the production of smolts per spawner and may contain some form of density dependence, Sm is the survival of smolts through the hydrosystem by both in-river and transportation passage routes, and So is the survival of fish passing through the estuary. Sa is the survival of the returning adults as they migrate through the hydrosystem, with the inclusion of prespawning survival and river harvest. Ocean and river harvest mortality are defined as (1- Ho), and (1- Hr).

4.1 Freshwater production (P)

The freshwater production stage describes now many smolts are produced per spawner. The productivity depends on the number of spawners, with productivity decreasing as the number of spawners increases. In the PATH analysis, the density effects equation included the possibility of depensation in which productivity declines at low numbers of spawners. The spawner recruit data did not reveal any depensation, so functionally PATH used a Ricker density compensation equation. Here we use the functional form of the Ricker equation to express density effects in freshwater production:

eq (2) $P = \exp(a_{fw} - b \cdot S)$

The a_{fw} parameter defines only recruits to the smolt stage so the term is different from the Ricker "a" coefficient, which defines recruits to the spawning stage. The "b" parameter is the same as in the Ricker equation and is a measure of the decline in productivity with increasing spawner numbers.

4.1.1 Density dependence parameter (b)

The density dependent factor b, used in eq(2), is derived from the regression of natural log(recruits/spawner) versus spawners for spring and fall chinook from the Snake River basin. Table 2 presents estimates for this parameter and carrying capacity (a/b) for Snake River spring and fall chinook for the post-1974 period. For spring chinook, the b is taken as the average of the six Snake River index stocks. For the fall chinook, a single stock is represented, and the estimates of recruits take harvest into account. For the Snake River fall chinook, the regression is statistically insignificant ($R^2 = 0.01$). The resulting b is only useful for giving a ball park estimate of the fish numbers in all of the analyses.

Table 2: Ricker coefficients for spring and fall chinook from the Columbia/Snake River system stocks. Spawners were on redds and recruits were estimated to mouth of Columbia River. The Snake River spring chinook estimates are the mean values of 7 index stocks.

Chinook	Region	Ricker a	Ricker b	Reference
spring	Snake River	0.73	0.00174	Schaller et al. 1999
spring	Upper Columbia	1.04	0.00098	Schaller et al. 1999
spring	Lower Columbia	1.48	0.00195	Schaller et al. 1999
spring	Upriver Aggregate	0.41	0.0000016	Schaller et al. 1999
fall	Snake River	1.96	0.00027	Peters et al. 1999
fall	Columbia R. URB	2.65	0.00002	Peters et al. 1999
fall	Deschutes R.	2.84	0.00037	Peters et al. 1999

4.1.2 Stock equilibrium numbers

To extrapolate from the representative index stocks to the basin-wide impact on the species, estimates of the number of individual demes or stocks is required. The endangered stocks in the Snake River Basin are designated as wild and natural stocks. Wild stocks have genetic makeup unlikely to have been altered by hatchery fish. Natural stocks are naturally spawning fish that have genetically mixed with hatchery fish. In the Snake River Basin 23 natural and wild spring chinook and 9 summer chinook stocks were identified by Chapman et al. 1991. Stocks of hatchery origin include 12 spring chinook stocks and 2 summer chinook stocks. One wild-natural population of fall chinook has been identified (Chapman et al. 1991). The total number of natural and wild spring and summer chinook stocks is 32. Members of the Plan for PATH group suggested a more representative number of stocks is 38. This larger estimate was used in this report.

4.2 Passage survival (Sm)

Passage survival in eq(1) must be characterized in drawdown and transportation alternatives. In PATH, a general passage survival equation was developed that accounts for survival from above Lower Granite Dam to the tailrace of Bonneville Dam. The general model includes both direct transportation survival and in-river survival. Here we express smolt survival in a simplified heuristic form, with one transport dam:

eq (3) $$Sm = P1 \cdot Vt + (1 - P1) \cdot Vn$$

where P1 is the percent of the run passing the dam that are transported, Vt is the direct transportation survival, and Vn is the survival of the in-river passing fish. The actual passage models account for transport at a number of dams, adjusting survival of fish down to each transport dam.

4.2.1 In-river survival (Vn)

The in-river smolt passage survival is an important assumption in determining the relative effectiveness of the different actions. In PATH two smolt passage models were used, CRiSP and FLUSH, and subsequent to these model NMFS has developed a simple model for its Anadromous Fish Appendix. Although the models have varying degrees of complexity, CRiSP and FLUSH treat dam passage mortality in similar ways. The differences are in they way they formulate reservoir mortality. The FLUSH spring chinook model has an explicit travel-time /survival relationship in which the rate of mortality increases with time of migration through the reservoirs. This causes the greatest mortality to occur in the lower river, and it makes the survival sensitive to total time in passage and to flow. In the CRiSP fall and spring chinook models and the FLUSH fall chinook model, survival estimates are produced by more mechanistic models where reservoir survival rate is related to factors such as predator abundance. In their general form, the reservoir mortality rate increases with temperature, and for CRiSP it also increases for elevated levels of supersaturation. In these models the mortality rate is not directly dependent on the time of passage, although longer fish travel times will result in lower survivals, all other factors being held constant. The NMFS model assumes no flow/survival relationship, and reservoir and dam mortality are not distinguished. Reservoir survival is essentially constant for each reservoir. The three classes of model can be expressed in general forms as

eq (4) Spring FLUSH $Vn = Vdam^{X} \cdot FTT^{-B}/(\exp(A \cdot FTT) - 1) + 1)$

CRiSP and fall FLUSH $Vn = Vdam^{X} \exp(f(T) \cdot FTT)$

NMFS $Vn = Vproj^{X}$

where Vdam is the survival of dam passage, X is the number of dams the fish pass, FTT is the fish travel time through the hydrosystem, and T is water temperature. In the NMFS model, the average reservoir and dam mortality components are combined in a single term, Vproj. In the spring FLUSH model the reservoir mortality depends on FTT as described by A and B, which are constants obtained by fitting the model to survival data. In CRiSP and fall FLUSH, the reservoir mortality is described by a mortality rate function f(T), which depends on a predator temperature response function, predator consumption rates, and a predator abundance index over the reservoirs. In CRiSP, mortality under high gas levels is also taken into account although this is generally a minor source of mortality.

To estimate the in-river survival of fish under drawdown conditions, a number of auxiliary hypotheses were used. In general, the drawdown survival was estimated independently giving a two part equation: the first part being survival of the drawdown section, the second part being the survival through the impounded sections estimated by the passage models. The survival of in-river fish is modified to

eq (5) $Vn = Vd \cdot Vi$

where Vd is the survival through a drawdown section of the river under a specific drawdown alternative, and Vi is the survival through the impounded sections.

4.2.2 Natural River Drawdown survival (Vd)

A great deal of uncertainty exists over what survivals will be in free-flowing river segments after reservoirs are drawn-down to natural river levels. In PATH, upper and lower bound survivals were used for the drawn-down Snake reservoirs in an effort to characterize the range of uncertainty. These estimates were developed by applying direct or indirect estimates of survival through existing free-flowing reaches to future drawn-down reaches on a per km basis. For fall chinook PIT tag survivals from 1995-1998 were used. These survival estimates encompass both free-flowing and impounded segments, and two methods were used to extract survivals through the free-flowing segment. (Peters et al. 1999). For spring chinook, free-flowing survival estimates were based on survival estimates from the Whitebird trap in the Salmon River to the uppermost dam, either Ice Harbor (1966-1969) or Lower Granite (1993-1996) (Marmorek and Peters 1998). For spring chinook, the John Day estimates were derived by taking survival per km from the Snake River studies and adjusting to the length of the John Day reservoir. For fall chinook, the John Day estimates were derived from the passage models under drawdown conditions. Upper and Lower bound survival estimates are provided in Table 3.

Table 3. Drawdown survivals Vd through free-flowing reaches of the Snake River and John Day reservoir.

Chinook type	river segment	Lower estimate	Upper estimate
spring	Snake R.	0.85	0.96
fall	Snake R.	0.61	0.90
spring	John Day	0.90	0.98
fall	John Day	0.87	0.87

Total system survival Sm generated from CRiSP for the different alternatives are given in Tables 21 and 22.

4.2.3 Spill Crest and Food Control Drawdown survival (Vd)

To estimate survival in John Day pool under a spillway crest drawdown and under natural river with flood control, the CRiSP passage model (Anderson et al. 1996) was used. In this model system reservoir elevation and river flow are used to estimate water velocity. The water velocity in turn is used to predict fish velocity, and this in turn is used to predict fish reservoir survival. Estimating the impacts of spillway crest drawdown and natural river drawdown under flood control then results in estimating the impact on fish velocity which effects survival. These capabilities are integral to the CRiSP model and so estimating these special conditions involved only defining reservoir elevations. Estimating the change in reservoir elevation with flood control involved additional calculations, which are detailed below.

The CRiSP model represents reservoirs through a number of rectangles giving the reservoir side and thalweg slopes as illustrated in Figure 2. The tailwater and forebay ends of the reservoir are set at the actual elevations giving an average thalweg gradient. In addition the angle of sides are set to approximate the slopes of the reservoir banks. As the reservoir is drawn down the upstream portion enters a free-flowing stage where the velocity is constant determined by drag properties of the streambed. In these calculations the free-flowing velocity, Ufree, was set at 5 ft/s.

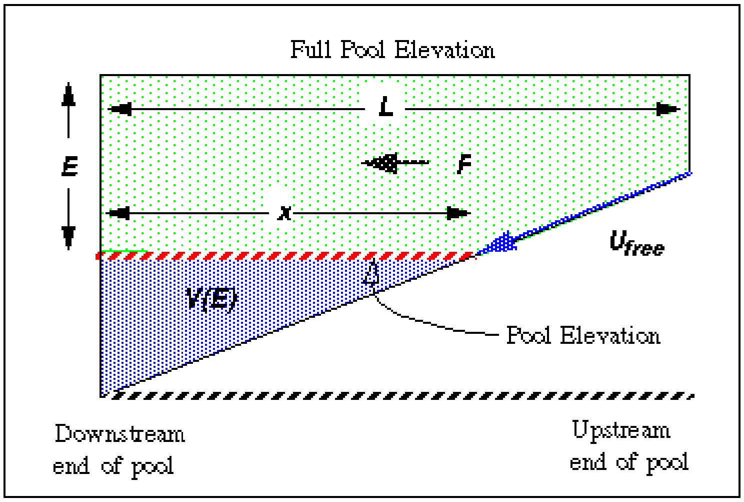

Figure 2. Reservoir with free-flowing and impounded portions. The terms are reservoir elevation E, length L, volume V(E), flow F, and stream velocity Ufree.

Under these model conditions, the reservoir water velocity increases in an approximately linear manner with elevation drawdown. At natural river drawdown levels, though, the river velocity reaches a maximum as velocity is determined by the drag of the channel (Table 4).

Table 4: Water velocities (miles/day) for different flows and pool elevations

Action	Elevation drop (ft)	Normal flow (236 kcfs)	High flow (400 kcfs)
Full pool	0	16	25
Spillway crest	50	53	80
Natural River	100	90	95

To determine the effects of flood control on river elevation and velocity the relationship between elevation and velocity is used. The average river velocity, U, at elevation z is equal to the flow, F, divided by the cross-sectional area, A:

eq (6) $$U(z) = F/A.$$

The velocity under flood control, in which the elevation is raised to absorb the flood control water, can be expressed as

eq (7) $$U(z1) = L \cdot F/(V + L \cdot F/U(z0)).$$

Where z0 and z1 are the base and flood control elevations, L = 76.4 miles is the John Day reservoir length, F = 500 kcfs is the flow at which flood control is typically required and V = 534,000 acre-feet is the flood control volume. If the high flow at a natural river elevation gives a velocity of 100 miles/day or approximately 6 ft/s then the velocity after absorbing the flood control volume becomes about 50 miles/day or 3 ft/sec. Since velocity is approximately linearly related to elevation, the change in reservoir elevation (from natural river conditions) with flood control can be estimated. The elevation under natural river would rise to about the spill crest elevation, and under a spill crest drawdown flood control would raise the elevation another 10 to 15 feet above the spillway crest. These estimates are approximate since they are developed on the assumption of simplified reservoir geometry, and the natural river segment velocity is fixed. The hydraulics is sufficient to estimate the impacts of natural river level flood control on smolt passage.

4.3 Ocean/estuary survival (So)

The survival of fish, between the time they leave the tailrace of Bonneville dam as smolts and return to the fish ladders of Bonneville dam as spawning adults, is an important life stage that exhibits a large range of variability from year to year. A number of assumptions in PATH were developed to characterize the possible factors that determine survival during the ocean residence life stage. Of particular importance, are the effects of hydrosystem passage route on ocean survival. Because fish pass through the hydrosystem in transportation and as run of the river fish, there is the possibility that the ocean survival is different for fish from each passage route. The basic equation for survival in the ocean life history stage (which in this definition includes the segment form Bonneville to the estuary), accounting for the two passage routes, is

eq (8) $So^* = (\lambda t \cdot Pb + \lambda n \cdot (1-Pb)) \cdot \lambda o$

where Pb is the proportion of fish that entered below Bonneville via transportation, (1-Pb) is the proportion of fish entering below Bonneville via in-river passage, λo is the base ocean survival common to both groups, $\lambda t \cdot \lambda o$ is the ocean survival of transported fish and $\lambda n \cdot \lambda o$ is the ocean survival of non-transported fish. The passage route specific survivals λt and λn may change from year to year depending on hydrosystem operations, ocean and climate conditions, and any changes in the fish condition prior to, or during, migration. The common survival λo is constant and typically, in a life-cycle analysis, it is absorbed into the density independent term of the stock recruitment function. That is, λo is contained within exp(a) of the stock recruitment equation mused in this formulation, which is $R = S \exp(a - b \cdot S)$.

Since there are insufficient data to characterize the time-varying ocean survivals of transported and non-transported fish, the equation is rewritten to express the time varying survival of the non-transported fish only. The ocean survival of the transported fish is then characterized relative to the non-transported fish survival. Also the base term λo can be ignored in the deterministic model because in the pairwise comparisons of actions, ratios of productivity are taken and so λo cancels. With these simplifications the ocean survival equation becomes

eq (9) $So = \lambda n \cdot (D \cdot Pb + 1 - Pb)$

where the ratio of the ocean survivals of the transport to the non-transported is

eq (10) $D = \lambda t / \lambda n.$

The estimation of D and λn can be derived in various ways depending on the types of data available. The resulting values of these terms, and how they have changed over time, are extremely significant to the conclusions on the effectiveness of fish transportation as a fish recovery action. Therefore these sources of mortality are discussed further in the sections below.

4.3.1 Extra mortality

Extra mortality is defined as the differences in the mortality estimated from the spawner/recruit data and the mortality that can be accounted for by the smolt passage models and assumptions on adult upstream mortality. Extra mortality for in-river fish is defined as $1- \lambda n$; in other words, if there was no extra mortality in a given year, the ocean survival would be equal to the base ocean survival, λo. For spring chinook, an increasing trend in ocean mortality corresponds with the development of the Snake River dams in the 1970s, the increase in hatchery production, and shift in the ocean climate conditions in 1977. As a result, a number of factors could contribute to the trend in mortality and it is uncertain as to the significance of any individual factor, or others not yet considered. In PATH these possible factors were considered individually and a combination hypothesis was not considered. In particular, the trend in ocean mortality was hypothesized to be the result of either degraded freshwater conditions, increased stress in hydrosystem passage, or changes in the ocean ecosystem. These were designated the BKD, the HYDRO and the CLIMATE hypotheses. Functionally the three hypotheses attribute the cause of ocean mortality to different life stages as described below:

> BKD hypothesis states that the extra mortality is associated with a change in the wild fish condition, possibly from disease such as bacterial kidney disease (BKD) resulting from increased hatchery production beginning in the late 1970s. Under this hypothesis the extra mortality is endemic to the wild Snake River chinook and is here to stay under changes in the hydrosystem operations.
>
> HYDRO hypothesis postulates that the extra mortality is associated with the hydrosystem and specifically the Snake River portion of the hydrosystem. Under this hypothesis it could be associated with the cumulative stress in hydrosystem passage. Consequentially, in this hypothesis removing dams removes the stress and results in higher survival below the hydrosystem.
>
> CLIMATE hypothesis postulates that the extra mortality is associated with a climate/ocean regime shift that occurred in the late 1970s. Under this hypothesis the extra mortality only disappears if the climate shifts back to a fish-favorable ocean regime and the effect is independent of any changes made to the hydrosystem.

Some details of the linkages between life-stage survivals were developed in PATH, but are not important to explore here. What is important though, is that specific mechanisms have not been identified for any of the hypotheses, nor has significant correlation between of variables related to the hypotheses and ocean survival of non-transported fish been demonstrated. As a result of this inability to clarify the mechanisms, the results from PATH should be considered as exploratory of the range of possible consequences.

The range of ocean survivals, expressed as the extra mortality factor as $1-\lambda n$, was derived in PATH from the combination of a life-cycle model with a passage model for the spring and fall chinook. The essential survivals are given in Table 5. Note the examples in the table characterize ocean survival as affected by the extra mortality factor. The possible levels of extra mortality depend on mortality assumptions in the retrospective analysis of stock dynamics. These details are beyond the scope of the deterministic analysis here. Table 5 is intended to illustrate the general ranges over which extra mortality contributes to ocean survival of fish.

Table 5: Characteristic ocean survival factor λn, as determined by extra mortality, under different passage model hypotheses using the Delta model developed in PATH (Hinrichsen and Paulsen 1998) with ranges (min-max). Spring λn estimates from regressions of Vn vs. λn with Vn = 0.2 for 1975-1990 and Vn = 0.4 for 1952-1990 period. Fall chinook estimates from spawner/recruit analysis (Peters et al. 1999).

Chinook	years	CRiSP	FLUSH
spring	1952-1990	0.7 (0.1-1.5)	0.75 (0.1-1.5)
spring	1975-1990	0.4 (0.1-1.8)	0.75 (0.2-1.31)
fall	1964-1991	1	1

4.3.2 Delayed mortality

The transportation efficiency factor D, which is the ratio of ocean survival of transported fish to the ocean survival of non-transported fish, is critical in determining the relative effectiveness of recovery actions. In PATH, this factor has been referred to as the delayed mortality because mortality is thought to occur somewhere below Bonneville Dam as a result of smolts being transported. If D equals one, then the survival from in-river and transport hydrosystem passage routes are equal and fish experience no delayed mortality as a result of being transported. If D is less than one, then the transported fish suffer a delayed mortality relative to the in-river fish.

Exactly where this mortality occurs is unknown though, and the mechanisms resulting in higher mortality of transported fish are unknown. Observed survivals of fish held after transportation range between about 80% and 100% (Reference). Furthermore, radio tracking studies of transported and in-river fish tagged at Bonneville Dam indicate equal survivals in the two groups down to the estuary where the salt water makes the radio tag inoperative.

Estimating D has been problematic for both spring and fall chinook. For spring chinook, D is calculated from estimates of the in-river smolt survival times the ratio of returning adults marked as smolts for transportation and in-river passage groups. As a result, estimates of D have several critical assumptions that increase the uncertainty, especially in the early years of the transportation program, prior to the development of the PIT tag technology. In the early years of the transportation program, a large fraction of the transport studies control fish were transported at a lower dam so the transport to control ratio of the returning adults was actually a comparison of returns of fish from two transport sites. The use of these data is problematic for assessing the difference of transport and in-river fish because further assumptions are required to correct for the transported control fish. Furthermore, recent transport studies indicate that the timing of arrival of fish to the estuary has a significant impact on their ocean survival (Hinrichsen et al. 1996). PATH did not fully address or resolve these issues and so the estimates of D are highly uncertain. Two basic approaches were taken to estimate D in PATH, and it was determined the most important factor was the choice of smolt passage model, FLUSH or CRiSP. Additionally, in the NMFS A-fish Appendix a high value of D was explored, based on the recent PIT tag studies.

Although these details are important in evaluating the historical D, the most important hypotheses concern the D current and future levels. The possible ways that D could have changed from the early years of fish transportation is summarized in the hypotheses listed in Table 6. For spring chinook, the dividing year between the early and the current levels of D is taken as 1980. Prior to 1980 the transportation system was experimental and significant handling problems that stressed the fish were evident at the transport dams (reference). The geometric averages of D for spring chinook transportation for the three hypotheses are given in Table 6.

Table 6: Spring chinook geometric average estimates of D for early experimental period (pre-1980) and current/prospective period (post-1980).

Hypotheses	pre-1980	post-1980
FLUSH	0.476	0.351
CRiSP	0.18	0.65
NMFS	---	0.80

Estimates of D for fall chinook are even more uncertain than for spring chinook because there were no fall chinook transport experiments on which to estimate D independent of the spawner recruit data. In the PATH fall chinook analysis, a single, fixed value of D was estimated as the fitting parameter in the life-cycle analysis based on the spawner/recruit data and the modeled in-river passage. The estimated value of D ranged from 0.03 to 0.52. In addition, a D value for fall chinook transported from McNary Dam was estimated from both a life-cycle analysis and transport-to-control studies at this dam. These values were considerably higher than the estimates for Snake River fall chinook obtained from the life-cycle model. McNary Dam D values ranged between 0.6 and 6, with a geometric mean of 1.7. In PATH, five sets were considered for the change D from the retrospective to the prospective periods (Table 7). In effect, these hypotheses explored the transportation effectiveness in the past and what might be obtained in the future.

Table 7: Five fall chinook hypotheses of D for the existing operations (Retrospective) future period (Prospective).

Scenario	Retrospective	Prospective
D1	0.05	0.24
D2	0.05	1.00
D3	0.05	0.05
D4	0.20	0.20
D5	1.00	1.00

4.4 Adult upstream migration survival (Sa)

The estimates of the number of fish lost during upstream migration are based on comparative dam counts recorded by species and age category, either jack or adults. In this formulation the upstream loss was corrected for in-river harvest, the loss from turnoff to other streams, and natural mortality. The conversion rates for full pool and drawdown conditions as used in PATH (Table 4.5-5 in Peters et al. 1999) are illustrated in Table 8 for A1, A2, A3 and B1. Increased survivals through John Day reservoir drawdown only were set at 5% for natural river as applied in Peters et al. (1999), and 1.5% for spillway crest and 1.3% for natural river with flood control.

Table 8: Conversion rate of adult migration survival (Sa) from Bonneville Dam tailrace to the spawning grounds (Marmorek et al. 1996, Peters et al. 1999).

	A1	A2	A3	B1	B2	B3	C1	C2	C3
Spring	0.67	0.67	0.77	0.81	0.79	0.80	0.70	0.69	0.69
Fall	0.42	0.42	0.83	0.87	0.87	NA	0.44	0.43	NA

5 Bayesian life-cycle analysis

To model the survival and recovery probabilities, a detailed life-cycle model adapted from the PATH analysis has been used. The methods of the PATH analysis are described in Marmorek, Peters and Parnell (eds.) (1998) and Peters Marmorek and Parnell (eds) (1999). The model uses the basic life-cycle dynamics expressed by eq (1) with a Ricker density dependence similar to eq (13). The PATH analysis was set up to explore the consequences of different assumptions on life stages, and in PATH two basic passage models were explored along with different assumptions on how life stages were connected and represented.

A retrospective analysis of spring and fall chinook was conducted in PATH using the historical spawner recruit and passage data to characterize detailed hypotheses on the life stages. In addition, in PATH a prospective analysis was developed to project the time evolution of stocks under differing assumptions about the effects of actions. Using a Bayesian analysis, the different hypotheses could be weighted with output of the probabilities of meeting survival and recovery goals.

Selected results from the PATH analysis are used in this report. Specifically, the retrospective analysis is used to characterize the life stage parameters for the deterministic analysis presented in this report. In addition, the prospective analysis has been applied to produce survival and recovery probabilities and equilibrium spawner levels under different weightings of the hypotheses.

The results of the life-cycle analyses depend on hypotheses used and the weightings applied to each hypothesis. In PATH a large number of hypotheses on life stage parameter values and functional forms of the linkages of ocean survival to the passage survival and the freshwater production life stage were evaluated. In this analysis a reduced set of the most influential hypotheses are included in evaluating survival and recovery probabilities and equilibrium population levels.

5.1 Actions evaluated for spring and fall chinook

The PATH Bayesian Simulation Model (BSM) was only used to evaluate action A1, A2, A3, and B1. In addition, for assessing probabilities of recovery over time, Actions A3 and B1 were evaluated under different delays of implementing the actions (Table 9).

Table 9: Actions evaluated with the PATH Bayesian model

Action	Description
A1:	Uses the existing transportation rules
A2:	Maximizes transportation using current system configuration
A3(3yr):	Drawdown of four Snake River dams (3-year delay)
A3(8yr):	Drawdown of four Snake River dams (8-year delay)
B1(10yr):	Drawdown of four Snake River dams (3-year delay) and drawdown of John Day Dam (10-year delay)
B1(15yr):	Drawdown of four Snake River dams (8-year delay) and drawdown of John Day Dam (15-year delay)

5.2 Hypotheses

The most important hypotheses concerned the survival of smolts through the hydrosystem and the survival of smolts after departing the hydrosystem. Because some smolts migrate through the river while others are collected at dams and transported, survival through both hydrosystem passage routes, and the associated survivals below the hydrosystem, must be considered. Scenarios to evaluate different factors controlling these hypotheses are listed in Table 10 for spring chinook and Table 11 for fall chinook.

5.2.1 Spring chinook hypotheses

The smolt passage models applied in the Bayesian life-cycle model are detailed in Section 4.2. Each passage model is grouped with an assumption on D that characterizes delayed mortality in transportation. CRiSP is paired with midrange D values and FLUSH is paired with low D values. In addition, model runs were conducted with the assumption that D was high. The values for D are described in Section 4.3.2. Three hypotheses on the source of the extra mortality were considered in the Bayesian analysis, the BKD, CLIMATE and HYDRO hypotheses. These are described in Section 4.3.1.

Two life-cycle models were considered in this analysis: the Alpha and Delta models, which differed primarily in the characterization of climatic/ocean change. The Delta model assumed that decadal scale climate/ocean changes in Snake River spring have the same pattern as observed in the mid- and lower Columbia spring chinook. The Alpha model characterized ocean variation through decadal climate indices, the PAPA drift index, and river flow at Astoria.

A lower level hypothesis in the modeling system involves the estimated time required to implement drawdown actions. This affects the success of the drawdown as a recovery action. In the analysis two periods were considered: 3 and 8 year delays for drawing down the four Snake River dams and 10 and 15 year delays for drawing down the four Snake River reservoirs plus the John Day reservoir. Assumptions were also included to characterize the amount of time before the drawdown reservoirs reach equilibrium in terms of the riverine habitat. Two periods were assumed: 2 and 10 years.

Table 10: PATH Hypotheses for spring chinook analysis

Model Group	Hypothesis	Weighting applied to the particular choice in the model group others in group have weight 0 unless otherwise noted.
	EQUAL	Equal weights on all hypotheses associated with particular action
Passage models	FLUSH	Weight of 1 on FLUSH passage/D-values.
	CRISP	Weight of 1 on CRISP passage/D-values.
	NMFS	Weight of 1 on CRISP passage with NMFS D values of 0.8
Extra mortality models	BKD	Weight of 1 on BKD extra mortality hypothesis.
	HYDRO	Weight of 1 on HYDRO extra mortality hypothesis.
	REGIME	Weight of 1 on REGIME shift extra mortality hypothesis.
Life- Cycle models	ALPHA	Weight of 1 on ALPHA life-cycle model.
	DELTA	Weight of 1 on DELTA cycle model.
Equilibrium Times	2 YEAR TRANSITION	Weight of 1 on 2-yr transition to reach equilibrium drawdown survival.
	10 YEAR TRANSITION	Weight of 1 on 10-yr transition to reach equilibrium drawdown survival.
Passage optimism	OPT.PASS	Weight of 1 on optimistic passage survival estimates.
	PESS.PASS	Weight of 1 on pessimistic passage survival estimates.

5.2.2 Hypotheses Evaluated for Fall Chinook

For fall chinook, hypotheses involved different harvest rates during recovery, different assumptions on the transportation effectiveness, D, two passage models, factors controlling the extra mortality, the length of the time required for the drawdown to reach equilibrium conditions, and upper and lower bounds on fall chinook smolt passage survival (Table 11).

A number of harvest-rate actions were considered, including one that increases harvest rates in the ocean by 15% as the stocks recover, and a number of actions that decrease the harvest rate in the ocean and in the river. The CRiSP and FLUSH fall chinook passage models were used in the analysis to define the in-river survival of fish. These models are defined in Section 4.2.1. Five values of D were evaluated. In three cases, the present day level of D was fit as a free parameter in the Bayesian life-cycle model. For projecting future stock levels in the prospective analysis, three different D hypotheses were applied. In the other two hypotheses, the D parameter in the retrospective and prospective analyses were specified. The three extra mortality hypotheses were evaluated as in the spring chinook. It should be noted though that under low values of D, as are derived from the MLE estimation of D, the extra mortality is essentially zero. Only when D is large (~ 1) is an extra mortality factor required to account for the decline in the fall chinook. Two transition periods were evaluated for the time for each drawn-down reservoir to reach a functioning state that stabilizes survival. Finally, the models were run with combinations of juvenile passage survival representing low and high levels of survival.

Table 11: Hypotheses used in the fall chinook analysis

Hypothesis	Weights
EQUAL	All hypotheses weighted equally
Base(-/-)	Base ocean and in-river harvest
+15%/-	(% increase in ocean harvest/% increase in in-river harvest)
-15%/-	(% increase in ocean harvest/% increase in in-river harvest)
-50%/-	(% increase in ocean harvest/% increase in in-river harvest)
-75%/-	(% increase in ocean harvest/% increase in in-river harvest)
-50%/-50%	(% increase in ocean harvest/% increase in in-river harvest)
-75%/-50%	(% increase in ocean harvest/% increase in in-river harvest)
CRISP	CRISP passage model
FLUSH	FLUSH passage model
D1	Retro D value is MLE, prospective D=0.24
D2	Retro D values is MLE, prospective D=1.0
D3	Retro D value is MLE, prospective from posterior distribution
D4	Retro D=.2, prospective D=.2
D5	Retro D=1.0, prospective D=1.0
REGIME	Regime shift extra mortality hypothesis
BKD	BKD extra mortality hypothesis
HYDRO	HYDRO extra mortality hypothesis
2YR.TRANSITION	2-year transition to equilibrium juvenile survival under drawdown
10YR.TRANSITION	10-year transition to equilibrium juvenile survival under drawdown
LOW.EJUV	juvenile survival lower bound in Snake and John Day drawdown
HIGH.EJUV	juvenile survival upper bound in Snake and John Day drawdown

5.2.3 Weighting hypotheses

The Bayesian life-cycle model combined competing, and sometimes mutually exclusive, hypotheses giving probabilities of meeting recovery goals and levels of escapement under equilibrium conditions. To investigate the influence of particular hypotheses on a life stage component of survival, or for a set of hypotheses for several life stages, any of the hypotheses in the life-cycle model can be given different weights. For example, by giving the FLUSH model a weight of one and the CRiSP model a weight of zero the patterns of the stocks over a 48 year future is modeled under the FLUSH passage model hypothesis only. The neutral case gives equal weighting to each competing hypothesis. Decision analysis generally is not designed to give a single answer on the response of a stock to an action, such as drawdown. By combining all the hypotheses with, or without, equal weighting, it is designed to identify which actions are the most robust to the uncertainties in the models.

In the decision analysis approach, differing hypotheses were combined to evaluate actions. The numbers of hypotheses for the spring chinook BSM analysis are given in Table 12.

Table 12: Number of hypotheses under each action

Action	**Total Hypotheses**
A1	36
A2	36
A3	144
B1	144

5.3 BSM Results

5.3.1 Probability of Survival and Recovery

Probabilities of survival and recovery for spring and fall chinook under each of the major alternatives and under different weightings of the important hypotheses are detailed in Table 13 through Table 16. The results are based on the Bayesian life-cycle model. Also provided in Table 17 and 18 are the relative risk expressed as the change in probability in taking Action A3 instead of B1 and loss of probability in taking A1 instead of A3. Table 19 gives the equilibrium stock levels for the six Snake River index stocks under the different actions and under different weightings of the hypotheses.

Table 13: Spring chinook 24-year survival probability mean values.

Hypothesis weighting	A1	A2	A3(3yr)	A3(8yr)	B1(10yr)	B1(15yr)
EQUAL	0.673	0.668	0.725	0.698	0.723	0.702
FLUSH	0.582	0.563	0.689	0.632	0.685	0.640
CRISP	0.730	0.732	0.760	0.741	0.755	0.746
NMFS	0.707	0.709	0.725	0.720	0.728	0.721
BKD	0.607	0.606	0.674	0.642	0.670	0.644
HYD	0.758	0.746	0.794	0.773	0.794	0.780
REGIME	0.654	0.653	0.705	0.677	0.704	0.683
ALPHA	0.647	0.647	0.712	0.682	0.706	0.684
DELTA	0.699	0.690	0.737	0.713	0.740	0.720
2YR.TRANSITION	0.673	0.668	0.739	0.708	0.739	0.711
10YR.TRANSITION	0.673	0.668	0.710	0.687	0.706	0.694
OPT.PASS	0.693	0.693	0.751	0.727	0.749	0.728
PESS.PASS	0.654	0.644	0.698	0.668	0.697	0.677

Table 14: Spring chinook 48-year recovery probability mean values.

Hypothesis weighting	A1	A2	A3(3yr)	A3(8yr)	B1(10yr)	B1(15yr)
EQUAL	0.533	0.514	0.787	0.795	0.822	0.811
FLUSH	0.368	0.328	0.863	0.880	0.911	0.897
CRISP	0.615	0.614	0.789	0.786	0.807	0.815
NMFS	0.616	0.599	0.708	0.719	0.749	0.721
BKD	0.375	0.364	0.668	0.677	0.709	0.699
HYD	0.624	0.594	0.858	0.864	0.895	0.884
REGIME	0.600	0.582	0.834	0.845	0.863	0.850
ALPHA	0.468	0.451	0.728	0.747	0.779	0.760
DELTA	0.598	0.577	0.846	0.843	0.865	0.863
2YR.TRANSITION	0.533	0.514	0.790	0.793	0.822	0.812
10YR.TRANSITION	0.533	0.514	0.784	0.798	0.822	0.811
OPT.PASS	0.568	0.552	0.834	0.844	0.862	0.861
PESS.PASS	0.498	0.475	0.739	0.747	0.783	0.762

Table 15: Fall chinook probability of meeting a 24-year survival standard.

Hypothesis weighting	A2	A3(3yr)	A3(8yr)	B1(10yr)	B1(15yr)
EQUAL	0.940	0.955	0.946	0.952	0.949
Base(-/-)	0.924	0.948	0.935	0.944	0.939
+15%/-	0.918	0.947	0.932	0.942	0.937
-15%/-	0.929	0.950	0.938	0.946	0.942
-50%/-	0.941	0.954	0.946	0.951	0.948
-75%/-	0.946	0.955	0.949	0.952	0.950
-50%/-50%	0.961	0.966	0.963	0.965	0.964
-75%/-50%	0.964	0.967	0.965	0.966	0.965
CRISP	0.915	0.944	0.930	0.940	0.935
FLUSH	0.964	0.966	0.963	0.965	0.964
D1	0.993	0.991	0.993	0.991	0.992
D2	0.999	0.997	0.997	0.998	0.998
D3	0.830	0.918	0.885	0.907	0.895
D4	0.922	0.942	0.929	0.938	0.933
D5	0.956	0.955	0.952	0.953	0.952
REGIME	0.945	0.961	0.952	0.958	0.955
BKD	0.938	0.958	0.949	0.955	0.952
HYDRO	0.938	0.963	0.952	0.959	0.955
2YR.TRANSITION	0.940	0.956	0.948	0.953	0.950
10YR.TRANSITION	0.940	0.954	0.945	0.951	0.949
LOW.EJUV	0.940	0.952	0.943	0.948	0.945
HIGH.EJUV	0.940	0.958	0.950	0.956	0.953

Table 16: Fall chinook probability of meeting the 48-yr recover standard.

Hypothesis weighting	A2	A3(3yr)	A3(8yr)	B1(10yr)	B1(15yr)
EQUAL	0.643	0.955	0.954	0.969	0.969
Base(-/-)	0.578	0.945	0.944	0.961	0.961
+15%/-	0.555	0.94	0.939	0.958	0.958
-15%/-	0.601	0.949	0.948	0.964	0.964
-50%/-	0.672	0.96	0.959	0.973	0.973
-75%/-	0.698	0.964	0.963	0.976	0.976
-50%/-50%	0.723	0.969	0.968	0.979	0.979
-75%/-50%	0.749	0.972	0.971	0.982	0.982
CRiSP	0.557	0.956	0.956	0.967	0.967
FLUSH	0.729	0.954	0.952	0.971	0.971
D1	0.917	1	1	1	1
D2	1	1	1	1	1
D3	0.351	1	1	1	1
D4	0.437	0.999	0.999	0.999	0.999
D5	0.737	0.867	0.864	0.908	0.909
REG	0.735	0.984	0.984	0.991	0.991
BKD	0.665	0.936	0.934	0.954	0.954
HYD	0.665	1	1	1	1
2YR.TRANS	0.643	0.955	0.956	0.97	0.97
10YR.TRANS	0.643	0.955	0.953	0.969	0.969
LOW.EJUV	0.643	0.938	0.937	0.955	0.955
HIGH.EJUV	0.643	0.973	0.972	0.984	0.984

5.3.2 Relative risks

Relative risks are the difference in probabilities of survival and recovery between two action for a given set of weightings of the hypotheses. A positive value indicates the probability of meeting a measure increases by the amount. Relative risk for a Snake River drawdown compared to a Snake River drawdown with a John Day drawdown to natural river level is defined by the difference in the probabilities for A3 and A1, i.e. B1 - A3. The relative risk of Snake River drawdown compared to transportation is defined by the difference in probabilities for A3 and A1, i.e. A3 - A1. Table (17) gives relative risk for spring chinook and Table (18) gives relative risk for fall chinook.

Table 17: Relative risk for spring chinook. B1-A3 is gain in probability of meeting standard due to taking action B1 over action A3. A3-A1 is gain in probability of meeting standard due to taking action A3 over action A1.

	24-Year Survival		**48-Year Recovery**	
Hypothesis weighting	**B1- A3**	**A3- A1**	**B1- A3**	**A3- A1**
EQUAL	0.0010	0.0385	0.0255	0.2580
FLUSH	0.0020	0.0785	0.0325	0.5035
CRISP	0	0.0205	0.0235	0.1725
NMFS	0.0020	0.0155	0.0215	0.0975
BKD	-0.0010	0.0510	0.0315	0.2975
HYD	0.0035	0.0255	0.0285	0.2370
REGIME	0.0025	0.0370	0.0170	0.2395
ALPHA	-0.0020	0.0500	0.0320	0.2695
DELTA	0.0050	0.0260	0.0195	0.2465
2YR.TRANSITION	0.0015	0.0505	0.0255	0.2585
10YR.TRANSITION	0.0015	0.0255	0.0255	0.2580
OPT.PASS	-0.0005	0.0460	0.0225	0.2710
PESS.PASS	0.0040	0.0290	0.0295	0.2450

Table 18: Relative risk for fall chinook. B1-A3 is gain in probability of meeting standard due to taking action B1 over action A3. A3-A2 is gain in probability of meeting standard due to taking action A3 over Action A2.

	24 year survival		48 year recovery	
Hypothesis weighting	**B1-A3**	**A3-A2**	**B1-A3**	**A3-A2**
EQUAL	0	0.0105	0.0145	0.3115
Base(-/-)	0	0.0175	0.0165	0.3665
+15%/-	0	0.0215	0.0185	0.3845
-15%/-	0	0.0150	0.0155	0.3475
-50%/-	-0.0005	0.0090	0.0135	0.2875
-75%/-	-0.001	0.0060	0.0125	0.2655
-50%/-50%	0	0.0035	0.0105	0.2455
-75%/-50%	-0.0005	0.0020	0.0105	0.2225
CRiSP	0.0005	0.0220	0.0110	0.3990
FLUSH	0	0.0005	0.0180	0.2240
D1	-0.0005	-0.0010	0	0.0830
D2	0.001	-0.0020	0	0
D3	-0.0005	0.0715	0	0.6490
D4	0	0.0135	0	0.5620
D5	-0.001	-0.0025	0.0430	0.1285
REG	0	0.0115	0.0070	0.2490
BKD	0	0.0155	0.0190	0.2700
HYD	-0.0005	0.0195	0	0.3350
2YR.TRANS	-0.0005	0.0120	0.0145	0.3125
10YR.TRANS	0.0005	0.0095	0.0150	0.3110
LOW.EJUV	-0.001	0.0075	0.0175	0.2945
HIGH.EJUV	0.0005	0.014	0.0115	0.3295

Equilibrium stock levels

Equilibrium stock levels are the population numbers that stocks at equilibrium. The equilibrium levels are estimated from eq(14) in Section (6.2). For each action, weighting parameters are selected, and the equilibrium levels are determined as the geometric means of all alternative hypotheses. The spring chinook equilibrium levels in Table (19) are given for each ESU index stock for each action and each hypothesis-weighting scheme. Also given are the gains in equilibrium numbers for action B1 relative to action A3 and for action A3 relative to action A1.

The fall chinook equilibrium stock level under different actions and hypotheses are given in Table (20) along with the difference in populations level of action B1 relative to A3 and action A3 relative to A2.

Table 19: Spring chinook equilibrium stock levels for the index Snake River ESU stocks under different actions and hypotheses weightings. B1- A3 and A3- A1 are the relative gains in numbers of spawners between two actions.

Imnaha

Hypotheses	A1	A2	A3	B1	B1- A3	A3- A1
EQUAL	1127	1115	1694	1882	188	567
FLUSH	991	954	2249	2587	338	1258
CRISP	1346	1344	1681	1793	112	335
NMFS	1046	1048	1152	1264	112	106
OPT.PASS	1172	1156	1890	2092	202	718
PESS.PASS	1083	1074	1499	1671	172	416

Minam

Hypotheses	A1	A2	A3	B1	B1- A3	A3- A1
EQUAL	687	681	1003	1108	105	316
FLUSH	612	590	1313	1502	189	701
CRISP	809	808	996	1058	62	187
NMFS	642	644	702	764	62	60
OPT.PASS	712	704	1112	1225	113	400
PESS.PASS	663	658	895	991	96	232

Bear Valley

Hypotheses	A1	A2	A3	B1	B1- A3	A3- A1
EQUAL	1288	1274	1942	2159	217	654
FLUSH	1131	1087	2583	2974	391	1452
CRISP	1540	1538	1927	2056	129	387
NMFS	1193	1196	1318	1446	128	125
OPT.PASS	1339	1321	2168	2402	234	829
PESS.PASS	1237	1227	1717	1916	199	480

March Creek

Hypotheses	A1	A2	A3	B1	B1- A3	A3- A1
EQUAL	681	672	1060	1185	125	379
FLUSH	590	564	1430	1656	226	840
CRISP	826	826	1051	1126	75	225
NMFS	626	628	698	772	74	72
OPT.PASS	711	700	1191	1325	134	480
PESS.PASS	651	645	929	1044	115	278

Sulphur CR

Hypotheses	A1	A2	A3	B1	B1- A3	A3- A1
EQUAL	486	481	678	741	63	192
FLUSH	440	426	866	980	114	426
CRISP	560	559	673	711	38	113
NMFS	458	458	494	532	38	36
OPT.PASS	501	495	744	813	69	243
PESS.PASS	470	468	612	670	58	142

Poverty Flat

Hypotheses	A1	A2	A3	B1	B1- A3	A3- A1
EQUAL	1001	989	1541	1719	178	540
FLUSH	871	835	2070	2391	321	1199
CRISP	1208	1207	1528	1635	107	320
NMFS	922	925	1025	1132	107	103
OPT.PASS	1043	1028	1727	1920	193	684
PESS.PASS	958	950	1355	1519	164	397

Johnson Cr.

Hypotheses	A1	A2	A3	B1	B1- A3	A3- A1
EQUAL	367	363	560	623	63	193
FLUSH	320	308	748	862	114	428
CRISP	441	440	555	593	38	114
NMFS	339	340	376	414	38	37
OPT.PASS	382	377	626	694	68	244
PESS.PASS	352	349	493	552	59	141

Table 20: Fall chinook equilibrium stock level for the index Snake River ESU stocks under different actions and hypotheses weightings. B1- A3 and A3-A2 are the relative gains in spawners for between two actions.

Weighting	A2	A3 3yr	A3 8yr	B1 (10yr)	B1 (15yr)	B1-A3	A3-A2
EQUAL	5396	15751	15326	17875	17677	2238	10143
Base(-/-)	5021	15338	14913	17440	17241	2215	10105
+15%/-	4876	15149	14724	17244	17049	2210	10061
-15%/-	5160	15495	15067	17601	17404	2222	10121
-50%/-	5628	16190	15750	18338	18137	2268	10342
-75%/-	5764	16210	15781	18365	18165	2270	10232
-50%/-50%	5848	16287	15862	18437	18240	2264	10227
-75%/-50%	5976	16303	15889	18460	18263	2266	10120
CRISP	4733	14938	14520	16319	16145	1503	9996
FLUSH	6058	16563	16132	19430	19209	2972	10290
D1	5377	22012	21425	24641	24330	2767	16342
D2	15577	23201	23077	25984	25822	2764	7562
D3	2448	21638	20897	24194	23814	2737	18820
D4	2718	16093	15522	18221	17982	2294	13090
D5	5668	8875	8655	10463	10394	1664	3097
REGIME	6856	18543	18124	20916	20691	2470	11478
BKD	6108	17192	16773	19390	19173	2299	10875
HYDRO	6108	19356	18848	21796	21540	2566	12994
2YR.TRAN	5396	15879	15472	18184	17963	2398	10280
10YR.TRAN	5396	15622	15179	17565	17391	2078	10005
LOW.EJUV	5396	14647	14293	16719	16521	2150	9074
HIGH.EJUV	5396	16854	16358	19030	18833	2326	11210

6 Deterministic Life-cycle analysis

As an alternative to the BSM model analysis, a deterministic life-cycle model was developed to compare the difference in performance measures between two actions. The measures are the difference in equilibrium stock levels, the difference between maximum sustainable yield (MSY) and the difference in MSY plus escapement. This analysis provides a relative comparison of the merits of one action relative to another. It assumes no environmental or intrinsic variability and as such the estimates of productivity and mortality represent long term time averages. In this approach the environmental variations common to the pair of actions do not have to be considered.

The deterministic model is based on the life-cycle model given by eq (1). First, number of recruits to the spawning grounds (R) per spawner (S) is defined from eq (1) as

eq (11) $R/S = P \cdot Sm \cdot So \cdot Sa \cdot H$

where H is the combined ocean and in-river harvest rate. At equilibrium, the number of spawners equals the number of recruits so R = S, and

eq (12) $1/P^* = Sm \cdot So \cdot Sa \cdot H$

where P* is the freshwater productivity at equilibrium conditions. Applying a Ricker type density dependence to the freshwater production term P* yields

eq (13) $P^* = \exp(a_{fr} - b \cdot S^*)$

where S* is the equilibrium spawner level and a_{fr} is the productivity component of the freshwater life stage. Then the equilibrium stock level in terms of spawners is

eq (14) $S^* = (a_{fr} + \log(Sm) + \log(So) + \log(Sa) + \log(H))/b$

The ratio of equilibrium freshwater productivity of two actions can be expressed eq (15) $$G_{x,y} = P^*_y / P^*_x = (Sm_x \cdot So_x \cdot Sa_x \cdot H_x)/(Sm_y \cdot So_y \cdot Sa_y \cdot H_y)$$

where the subscripts refer to alternatives x and y. Applying Ricker type density dependence to the freshwater production term from eq (13) the difference in population numbers between two alternatives is

eq (16) $$S^*_x - (b_y/b_x)S^*_y = (1/b_x) \ln(G_{x,y}) + (a_x - a_y)/b_x$$

Since in the hydrosystem passage corridor actions x and y are not expected to directly alter the spawning habitat productivity rate parameters, $a_x = a_y$ and $b_x = b_y$, so at population equilibrium the difference in population numbers for actions x and y is

eq (17) $$E_{x,y} = S^*_x - S^*_y = (1/b) \ln(G_{x,y})$$

The b factor is the Ricker density-dependent term, which describes how quickly the stock productivity decreases as S increases. It can be estimated from stock recruitment data and is insensitive to assumption to the hypotheses discussed above.

The impact of actions on the maximum sustainable yield (MSY) from a stock, $M_{x,}$ under actions x can be estimated from the intrinsic Ricker a and b parameters and the G factor given by eq (15). No explicit function can be defined for MSY for a Ricker stock recruitment function, but M, and the difference in MSY between actions,

eq (18) $$\Delta M = M_x - M_y,$$

can be obtained numerically. Following Ricker (1978) the MSY spawning level at is obtained from the explicit equation

eq (19) $$(1-b_x \cdot S_{msy,\,x})\exp(a_y - b \cdot S_{msy,\,x}) = 1$$

The MSY for an action x is then obtained with $S_{msy,\,x}$ in

eq (20) $$M_x = S_{msy,\,x}\,(\exp(a_x - b_x \cdot S_{msy,\,x}) - 1)$$

where a_x is the density-independent productivity term under action x. The total spawning population under the MSY conditions is

eq (21) $$R = M + S_{msy}$$

The difference in R between two actions is

eq (22) $$\Delta R = R_x - R_y$$

These MSY measures can be related to G by the equation

eq (23) $$a_x = a_0 - \log G_{0,x}$$

where a_0 is the base, or current conditions, Ricker at term referenced to the spawning grounds and where the Ricker term b_x may or may not change between the two actions. The same equation can be used to identify M_y with the substitution of parameters for action y. For the estimation of MSY and recruitment at MSY the results are referenced to the spawning population. Therefore, since the Ricker density independent parameter, a, given in Table 2 is referenced to the Bonneville dam, it is related to the spawning ground term as

eq (24) $$a_0 = a + \log(Sa_{A1})$$

where Sa_{A1} is the current upriver survival of adults.

Because the MSY estimates depend on the Ricker a parameter as references to the base level according to eq(23) assumptions on the distribution of factors in the base level will affect the pairwise comparison between actions. Therefore, pairwise comparisons between actions not involving transportation, such as A3 and B1, will depend on the assumption made on transportation. This complication does not affect the comparisons of equilibrium levels though.

The ratio of return adults to the number of smolt outmigration (SAR) is an important measure of the performance of the stocks. The ratio of the SAR of one action to another is in turn a relative measure of the performance of two actions. This ratio of ratios can be expressed through G_{xy}. Several measures can be defined depending on the collection point for the adults. The smolt population is defined as the point at which the smolts enter the hydrosystem. Adults can be defined in terms of the return to collection in the fisheries or return to the spawning ground or hatchery. For return to the fisheries we define

eq (25) $$SAR_x/SAR_y = (Sm_x \cdot So_x)/(Sm_y \cdot So_y)$$

For return to the spawning grounds or hatcheries the ratio is defined

eq (26) $$SAR_x/SAR_y = G_{x,y}$$

The difference in equilibrium population and maximum sustainable yields can be expressed in terms of the ratio of life stage survivals, G. The estimates of the life stage terms involve hypotheses on how the stages are coupled and the life stage parameter values under the various actions. In this analysis a wider range of actions are evaluated (see Table 1). Expressing differences in equilibrium population measures in this simple analytical form illustrates the significance of the hypotheses that come into play to produce a specific result.

6.1 Deterministic Life Stage Parameters

The life stage parameters used in the deterministic analysis are given in the Tables below. Four stocks from subbasins are considered. Parameters for a representative Snake River spring chinook are given in Table 21 and Snake River fall chinook parameters are given in Table 22. Parameters for the Upper Columbia are given in Table 23 for Upper Columbia spring chinook and the Hanford Reach fall chinook in Table 24. Most parameters were obtained from the PATH analysis and are described in Section 4. Details for the Upper Columbia chinook, which were not covered in PATH analysis, are discussed below.

The survivals of spring chinook smolts (*Sm*) were taken from PATH analysis as the means of passage models. Specifically the means were taken of CRiSP with TURB 4 hypothesis and FLUSH TURB 5 hypothesis (The results were compiled by NMFS in a spread sheet designated, all98.xls). By taking the means of the model results a middle point estimate of direct hydrosystem survival was obtained. In general, the CRiSP inriver passage survival estimates were higher than the FLUSH estimates by about a factor of two. The mean CRiSP inriver survival was about 0.44, while the FLUSH estimate was about 0.2 giving a mean of 0.32. Although these estimates are significantly different, the direct survival estimates of transported plus inriver passing fish are similar for the two models because most of the fish are transported and the two models have approximately the same transport percentages and used the same direct transport survival of 0.98.

To estimate the effect of John Day drawdown under natural river, spillway crest and natural river with flood control the CRiSP 1.6 passage model was used (See Table 44). These CRiSP derived estimates for the C and D actions were then adjusted to approximate the mean of *Sm* by adjusting the CRiSP A1 base in river survival, designated the A1 inriver survival in Table 44) according to the mean *Sm* of the A1 inriver survival estimate.

To estimate the smolt migration survival, *Sm*, for the Hanford Reach upriver bright fall chinook, first the survival per kilometer of inriver passing fish was estimated from recent PIT tag studies of fall chinook from McNary Dam to John Day Dam. The survival from MCN tailrace to BON tailrace was then expressed over the travel distance plus accounting for passage at three dams. The equation for in-river passage survival is then

eq (27) $$V_{\mathrm{mcn}} = (\text{dam passage survival})^3\, R^{145.6}$$

where R = 0.99309 is the reach survival per km and was estimated from the MCN to JDA reach as the geometric mean of 0.53 over 76.4 km length (Smith and Achord, 1999). Using a dam passage survival of 0.9 and a Hanford Reach (from Ringold Hatchery) to BON migration distance of 146 km the in-river survival is $V_{\mathrm{mcn}} = 0.37$. The PIT tag determined geometric mean of survival from Hanford Reach to MCN dam tailrace was 0.72. Assuming that the collection transportation survival is 1, the direct smolt passage survival can be approximated as

eq (28) $$Sm = V_{\mathrm{mcn}}\,(1 - \mathrm{FGE}) + \mathrm{FGE}$$

where FGE is the fish guidance efficiency at MCN Dam. We use a representative historical (Action A1) FGE (24%) for the base period from 1974 to 1995, which is the period over which the parameters a and b are estimated in Schaller et al. (1999). For prospective analysis (Action A2) we used the recent estimates of FGE = 68% (Peters et al. 1999).

The D factor for transport from McNary Dam is set at 1, which is the estimate obtained from two methods: 1) T/C ratios and in-river survival and 2) from a life-cycle analysis (Peters et al. 1999). To estimate the impacts of John Day drawdown we assume the drawdown survival in JDA is 0.95 and note that smolts cross 3 dams. Upstream conversion rates are taken from estimates for the stock provided in Table 3.1.2-3 in Marmorek, Peters and Parnell (1998).

For upper Columbia spring chinook life-cycle parameter estimates, we used the Snake River spring chinook estimates with changes reflecting the fact that these fish are not affected by the Snake River drawdown.

Table 21: Snake River spring chinook survival information for the calculations.

	A0	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	comments
Sa	0.67	0.67	0.67	0.77	0.81	0.79	0.80	0.70	0.68	0.69	0.70	0.68	0.69	
$\mathbf{Sa}_{low}$	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	lower estimate
Sm	0.34	0.81	0.84	0.61	0.64	0.60	0.63	0.363	0.342	0.358	0.84	0.84	0.84	
$\lambda \mathbf{n}_c$	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	bkd /climate
$\lambda \mathbf{n}_h$	0.40	0.40	0.40	0.70	0.70	0.70	0.70	0.40	0.400	0.40	0.40	0.40	0.40	hydro
Pb	0.00	0.93	0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.96	0.96	

Table 22: Snake River fall chinook survival information for the calculations.

	A0	A1	A2	A3	B1	B2	C1	C2	D1	D2	comments
Sa	0.42	0.42	0.42	0.83	0.87	0.87	0.44	0.43	0.43	0.43	
$\mathbf{Sm}_{high}$	0.28	0.78	0.78	0.51	0.58	0.56	0.31	0.30	0.78	0.78	high est.
$\mathbf{Sm}_{low}$	0.28	0.78	0.78	0.35	0.40	0.39	0.31	0.30	0.78	0.78	low est.
$\mathbf{Sm}_{mean}$	0.28	0.78	0.78	0.44	0.50	0.49	0.31	0.30	0.78	0.78	mean est.
$\lambda \mathbf{n}$	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Pb	0.00	0.97	0.97	0.00	0.00	0.00	0.00	0.00	0.97	0.97	

Table 23: Upper Columbia spring chinook survival information for calculations.

	A0	A1	A2	A3	B1	B2	B3	C1/D1	C2/D2	C3/D3
Sa	0.67	0.67	0.67	0.67	0.70	0.68	0.69	0.70	0.68	0.69
Sm	0.34	0.34	0.34	0.34	0.36	0.34	0.36	0.39	0.37	0.38
$\lambda \mathbf{n}$	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 24: Hanford Reach fall chinook survival information for calculations.

	A0	A1	A2	A3	B1	B2	C1	C2	D1/D2
Sa	0.75	0.75	0.75	0.75	0.79	0.79	0.79	0.79	0.79
Sm	0.31	0.31	0.54	0.19	0.21	0.20	0.21	0.20	0.54
$\lambda \mathbf{n}$	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pb	0.00	0.55	0.89	0.00	0.00	0.00	0.00	0.00	0.89

6.2 Equations for comparison of actions

6.2.1 Equilibrium Population and MSY Differences in Drawdown Actions

The pairwise difference between actions x and y equilibrium populations, $E_{x,y}$, described by eq (17) and the maximum sustained yield $\Delta M_{x,y}$ using eq (19), eq (20) and eq (23), both use $G_{x,y}$ from eq (15). For John Day drawdown actions relative to Snake River drawdown the growth ratio equation reduces to

eq (29) $$G_{x,A3} = (Sa_x/Sa_{A3})(Sm_x/Sm_{A3})$$

where the actions are x = B1, B2, B3, C1, C2, C3 as detailed in Table 1, and the adult and smolt migration survival values are given in Table 21 and 22. In these calculations the ocean survival factors are assumed equal under all alternatives. That is, the effects of hydrosystem passage under Snake River drawdown, (A3), the Snake and John Day (B1, B2, B3) and a John Day drawdown only (C1, C2, C3) are set equal, so the ratio of post-Bonneville survivals, $\lambda n_x/\lambda n_y$, is always 1.

6.2.2 Equilibrium and MSY Differences of Transport vs. Drawdown Actions

For comparing transportation and drawdown actions the population growth index for spring chinook takes the form

eq (30) $$G_{A1,y} = [Sa_{A1}/Sa_y][(D_{A1}Pb_{A1}+1-Pb_{A1})][\lambda n_{A1}/\lambda n_y][Sm_{A1}/Sm_y]$$

The difference in equilibrium populations between A1 and alternative y is estimated by using $G_{A1,y}$ in eq (17) and the difference in MSY is estimated with eq (19), eq (20) and eq (23).

The for comparing transportation to drawdown actions population growth index for Snake River fall chinook is calculated by the equation

eq (31) $$G_{A1,y} = [Sa_{A1}/Sa_y][(D_{A1}\cdot Pb_{A1}+1-Pb_{A1})][Sm_{A1}/Sm_y].$$

Here the ocean survival term under actions A1 and y are assumed equal. This result comes from the PATH fall chinook retrospective analysis, which indicated that under low levels of D that extra mortality was negligible. That is, under an assumption of low D, the decline in the fall chinook is principally the result of their transportation. The result does not hold if D is high though. Then an extra mortality term is required to account for the decline in the fall chinook. In this case eq (31) is still appropriate under CLIMATE and BKD hypotheses. The description of the extra mortality for fall chinook, thus, has not been resolved. This issue is not critical when evaluating the impact of the addition of a John Day drawdown, since ocean survival under this action is not expected to be significantly different from ocean survival under a drawdown of both the Snake River system and John Day.

6.2.3 Equivalence points

An important consideration is the mix of life-stage survivals that make drawdown and transportation actions equivalent in terms of the equilibrium population levels. Note that the different drawdown actions are always different in that additional drawdown produces higher survival under the assumptions of this analysis. The equivalence point at which A2 and A3 given equal population levels can be expressed by setting $G_{A2,A3} = 1$. The resulting equivalence point between transportation and drawdown for Snake River spring chinook is

eq (32) $$Sa_{A3} \cdot Sm_{A3} = D_{A2} \cdot \lambda n_{A2} / \lambda n_y / 2$$

where the factor 1/2 is approximately the product of smolt and adult upstream survivals in the existing system. The Snake River fall chinook equivalence point between transportation and drawdown actions is

eq (33) $$Sa_{A3} \cdot Sm_{A3} \sim D_{A2}/3$$

where the factor 1/3 is the approximate product of the smolt and adult river migration survival under the existing passage conditions.

6.3 Results

6.3.1 Pairwise comparison of drawdown alternatives

The typical equilibrium population of an index stock under action A1 is 419 for spring chinook and 7259 for fall chinook. The resulting difference in spawners at population equilibrium and MSY for a pairwise comparison of drawdown alternatives is given in Tables 25 and 26 for Snake River spring chinook and in Tables 27 and 28 for Snake River fall chinook. For example, comparing action A3 to action B1 in Table 25, at equilibrium, action B1 results in 58 more spawners than action A3. These estimates are based on b given in Table (2). The number of spring chinook stocks in the Snake River Basin is on the order of 38 making a total equilibrium population of about 16000. Thus we expect a 58x38 = 2204 fish increase in the Snake River Basin index spawning population by including the John Day drawdown with a Snake River drawdown action (B1). For fall chinook, the equilibrium population size in the Snake River basin is about 7000 making the maximum benefit of a John Day action in addition to a Snake River drawdown of about 650 spawners. For the fall chinook analysis, the effect of uncertainties in the smolt survival with Snake River drawdown are illustrated by providing equilibrium levels and MSY for high and low smolt survivals (Tables 27 and 28).

The ΔM estimates in Table 26 depends on the assumption on D. To a good approximation the relationship is linear with ΔM decreasing as D increases. For a comparison of A3 to B1 the influence in D can be expressed by the equation

eq (34) $\Delta M_{A3,B1} = 157 - 147\ D$

Table 25: Spring chinook equilibrium population differences $E_{row,col}$. Equilibrium number of spring chinook under A1 is 420 fish per stock.

	B1	B2	B3	C1	C2	C3
A3	56	5	40	-354	-404	-370
B1	0	-52	-17	-410	-461	-427
B2		0	35	-359	-410	-375
B3			0	-394	-445	-410
C1				0	-51	-17
C2					0	34

Table 26: Spring chinook MSY difference population differences $\Delta M_{row,col}$). MSY for spring chinook under A1 is 93 fish per stock.

	B1	B2	B3	C1	C2	C3
A3	108	10	76	-448	-488	-461
B1	0	-98	-32	-556	-596	-569
B2		0	66	-458	-498	-471
B3			0	-524	-564	-537
C1				0	-40	-13
C2					0	27

Table 26a: Snake River spring chinook $G_{row,col}$.

	B1	B2	B3	C1	C2	C3
A3	1.1	1.00	1.07	0.54	0.49	0.52
B1	1.0	0.91	0.97	0.49	0.44	0.47
B2		1.00	1.06	0.53	0.49	0.52
B3			1.00	0.50	0.46	0.49
C1				1.00	0.91	0.97
C2					1.00	1.06

Table 27: Snake river fall chinook equilibrium population differences $E_{row,col}$ under high (0.9) and low (0.6) estimates of free-flowing river smolt survival Vl. Equilibrium number of fall chinook under A1 is 7259 fish.

	Vl_{A3}	B1	B2	C1	C2
A3	0.9	650	520	-4195	-4401
B1	0.9		-130	-4846	-5052
B2	0.9			-4716	-4922
C1	0.9				-207
A3	0.6	668	575	-2801	-3007
B1	0.6		-94	-3469	-3676
B2	0.6			-3376	-3582
C1	0.6				-207

Table 28: Snake River fall chinook differences in MSY population $\Delta M_{row,col}$ under high (0.9) and low (0.6) estimates of free-flowing river smolt survival Vl. MSY for fall chinook under A1 is 6548 fish.

	Vl_{A3}	B1	B2	C1	C2
A3	0.9	12828	10082	-45136	-46290
B1	0.9		-2746	-57964	-59118
B2	0.9			-55218	-56372
C1	0.9				-1154
A3	0.6	9061	7690	-24199	-25353
B1	0.6		-1371	-33260	-34414
B2	0.6			-31889	-33043
C1	0.6				-1154

Table 28a: Snake River fall chinook $G_{row,col}$ with Sm set as the average of high and low estimates from Table 22.

	B1	B2	C1	C2
A3	1.19	1.16	0.37	0.35
B1	1.00	0.98	0.31	0.29
B2		1.00	0.31	0.30
C1			1.00	0.94

6.3.2 Pairwise comparison of transport vs. drawdown alternatives

Differences in equilibrium and MSY populations for Snake River and Upper Columbia stocks, for drawdown actions relative to the current operations conditions, A1, are illustrated in Tables 29 through 37. Positive values indicate the alternative action population is above the level from A1 population. Upper and lower estimates of the population level are illustrated for different assumptions on ocean survival and adult migration conversion rates. Also illustrated are the impacts of the three levels of D for spring chinook (see Table 6 for description) and fall chinook (see Table 7 for description).

For a Snake River spring chinook index stock, G is defined by eq (30). The life-cycle parameter values are given in Table 21, and the results are given in Tables 29, 30, 31, 31a and 33. The greatest increase above A1 occurs for B1 (828 spawners for E) under a low transportation efficiency in A1 (D = 0.35), and in changing from A1 to B1, the ocean survival increases by the factor 1.75 and adult upstream conversion (survival) increases by 1.15 (Table 29). If upstream conversion and ocean survival do not increase between A1 and B1 and transportation is effective, as expressed by D = 0.8, then changing from A1 to B1 causes a decreases in the equilibrium level by 18 spawners under equilibrium E. In Table 32 the effect of C actions are not computed for an increase in ocean survival because a drawdown of John Day reservoir without drawing down the Snake River reservoirs is not expected to increase ocean survival.

For a Snake River fall chinook index stock G is defined by eq (31). The life-cycle parameter values are given in Table 22. Pairwise comparisons of actions are given in Tables 31a, 33a, 34 and 34a, 35, 36 and 37. Comparing the effect of transportation, A1, with putting fish back in the river with no transportation, action A0, is illustrated in Table 33a. A0 is a preferred option except when transportation effectiveness is high (D = 1). Also, improving transportation, represented by D_{A2}, also improves fish stocks. Here, only the D hypotheses are a major determinant of the difference between A2 and A0. The balance between D and the passage survivals is illustrated in eq (33), showing the equivalence point where drawdown and transportation are equal. Table 33a, 34 and 34a show the effects of D hypotheses and the high and low passage survivals on pairwise comparisons of fall chinook.

The Hanford reach fall chinook G is estimated with eq (29) using the life-cycle survival data in Table 24. The resulting differences in equilibrium and MSY levels from comparing different alternatives are illustrated in Tables 39, 40 and 41.

The Upper Columbia spring chinook G is estimated with eq (29) using the life-cycle survival data in Table 23. The resulting differences in equilibrium and MSY levels from comparing different alternatives are illustrated in Tables 42 and 43.

Table 29: Snake River index spring chinook stock pairwise difference in equilibrium population. Equilibrium level under A1 is 420 spawners per index stock.

D	$\lambda n_y / \lambda n_{A1}$	Sa_{A3} / Sa_{A1}	$E_{A1,A2}$	$E_{A1,A3}$	$E_{A1,B1}$	$E_{A1,B2}$	$E_{A1,B3}$	$E_{A1,D1}$	$E_{A1,D2}$	$E_{A1,D3}$
0.35	1.75	1.15	-9	771	828	776	812	17	0	8
0.65	1.75	1.15	11	464	521	470	505	37	20	28
0.80	1.75	1.15	16	356	413	362	397	41	25	33
0.35	1	1	-9	370	397	360	388	-9	-9	-9
0.65	1	1	11	63	90	53	81	11	11	11
0.80	1	1	16	-45	-18	-55	-27	16	16	16

Table 30: Snake River index spring chinook stock G for pairwise comparisons under different D, extra mortality and upstream conversion rates.

D	$\lambda n_y / \lambda n_{A1}$	Sa_{A3} / Sa_{A1}	$G_{A1,A2}$	$G_{A1,A3}$	$G_{A1,B1}$	$G_{A1,B2}$	$G_{A1,B3}$	$G_{A1,D1}$	$G_{A1,D2}$	$G_{A1,D3}$
0.35	1.75	1.15	0.98	3.82	4.22	3.86	4.10	1.03	1.00	1.01
0.65	1.75	1.15	1.02	2.24	2.47	2.26	2.40	1.06	1.03	1.05
0.80	1.75	1.15	1.02	1.86	2.05	1.87	1.99	1.07	1.04	1.06
0.35	1	1	0.98	1.90	1.99	1.87	1.96	0.98	0.98	0.98
0.65	1	1	1.02	1.11	1.17	1.09	1.15	1.02	1.02	1.02
0.80	1	1	1.02	0.92	0.97	0.91	0.95	1.02	1.02	1.02

Table 31: Snake River index spring chinook stock differences in maximum sustainable yield pairwise comparisons of actions.

D	$\lambda n_y / \lambda n_{A1}$	Sa_{A3} / Sa_{A1}	$\Delta M_{A1,A2}$	$\Delta M_{A1,A3}$	$\Delta M_{A1,B1}$	$\Delta M_{A1,B2}$	$\Delta M_{A1,B3}$	$\Delta M_{A1,D1}$	$\Delta M_{A1,D2}$	$\Delta M_{A1,D3}$
0.35	1.75	1.15	-1	648	756	658	724	4	1	2
0.65	1.75	1.15	3	241	297	245	280	8	5	6
0.80	1.75	1.15	4	152	196	156	183	9	6	7
0.35	1	1	-1	162	183	155	176	-1	-1	-1
0.65	1	1	3	15	22	12	20	3	3	3
0.80	1	1	4	-7	-3	-8	-4	4	4	4

Table 31a: Snake River index fall chinook stock differences ΔR pairwise comparisons of actions.

D	$\lambda n_y / \lambda n_{A1}$	Sa_{A3} / Sa_{A1}	$\Delta R_{A1,A2}$	$\Delta R_{A1,A3}$	$\Delta R_{A1,B1}$	$\Delta R_{A1,B2}$	$\Delta R_{A1,B3}$	$\Delta R_{A1,D1}$	$\Delta R_{A1,D2}$	$\Delta R_{A1,D3}$
0.35	1.75	1.15	-5	927	1049	938	1013	11	0	6
0.65	1.75	1.15	8	426	502	433	479	25	14	19
0.80	1.75	1.15	11	300	364	305	345	28	17	22
0.35	1	1	-5	314	345	304	335	-5	-5	-5
0.65	1	1	8	43	63	36	56	8	8	8
0.80	1	1	11	-28	-11	-33	-16	11	11	11

Table 32: Snake River index stock spring chinook levels for E, ΔM, G, and ΔR under different levels of D for comparison of A1 to the C alternatives. Note that with John Day Drawdown no benefit on ocean survival is assumed to occur.

D	$E_{A1,C1}$	$E_{A1,C2}$	$E_{A1,C3}$	$\Delta M_{A1,C1}$	$\Delta M_{A1,C2}$	$\Delta M_{A1,C3}$	$G_{A1,C1}$	$G_{A1,C2}$	$G_{A1,C3}$	$\Delta R_{A1,C1}$	$\Delta R_{A1,C2}$	$\Delta R_{A1,C3}$
0.35	96	46	80	24	10	19	1.18	1.08	1.15	67	31	55
0.65	-210	-261	-227	-16	-14	-16	0.69	0.63	0.67	-118	-142	-125
0.80	-318	-369	-335	-10	-4	-8	0.57	0.52	0.55	-167	-188	-174

Table 33: Snake River spring chinook difference in equilibrium E, maximum sustainable yield ΔM, and total population under MSY ΔR under different D hypotheses

D	$E_{A1,A0}$	$E_{A1,A2}$	$\Delta M_{A1,A0}$	$\Delta M_{A1,A2}$	$\Delta R_{A1,A0}$	$\Delta R_{A1,A2}$
0.35	35	-9	8	-1	23	-5
0.65	-272	11	-14	3	-147	8
0.80	-380	16	-2	4	-192	11

Table 33a: Snake River fall chinook difference in equilibrium E, maximum sustainable yield ΔM, and total population under MSY ΔR under different D hypotheses

D_{A1}	D_{A2}	$E_{A1,A0}$	$E_{A1,A2}$	$\Delta M_{A1,A0}$	$\Delta M_{A1,A2}$	$\Delta R_{A1,A0}$	$\Delta R_{A1,A2}$
0.05	0.24	5631	4475	13700	8827	15054	9995
0.05	1.00	5631	9424	13700	46673	15054	48404
0.05	0.05	5631	0	13700	0	15054	0
0.20	0.20	1747	0	2103	0	2650	0
1.00	1.00	-3794	0	-1499	0	-3099	0

Table 34: Snake River fall chinook difference in equilibrium populations for passage survivals and D assumptions. Note equilibrium population under A1 is 7259 spawners.

Passage	D_{A1}	$E_{A1,A3}$	$E_{A1,B1}$	$E_{A1,B2}$	$E_{A1,D1}$	$E_{A1,D2}$
	0.05	10373	11024	10894	172	87
Sa_{A3} high	0.20	6490	7141	7011	172	87
Sm_{A3} high	1.00	949	1599	1469	172	87
Sa_{A3} low	0.05	6456	6951	6857	0	0
Sm_{A3} low	0.20	2573	3067	2973	0	0
	1.00	-2969	-2474	-2568	0	0

Table 34a: Snake River fall chinook difference in ΔR for passage survivals and D assumptions.

Passage	D_{A1}	$\Delta R_{A1,A3}$	$\Delta R_{A1,B1}$	$\Delta R_{A1,B2}$	$\Delta R_{A1,D1}$	$\Delta R_{A1,D2}$
	0.05	63548	76406	73654	214	107
Sa_{A3} high	0.20	19963	24498	23528	214	107
Sm_{A3} high	1.00	1300	2381	2151	214	107
Sa_{A3} low	0.05	19749	24365	23665	214	107
Sm_{A3} low	0.20	4364	6033	5781	214	107
	1.00	-2625	-2177	-2244	214	107

Table 35: Snake River fall chinook difference in maximum sustained yield for different passage survivals and D assumptions.

Passage	D_{A1}	$\Delta M_{A1,A3}$	$\Delta M_{A1,B1}$	$\Delta M_{A1,B2}$	$\Delta M_{A1,D1}$	$\Delta M_{A1,D2}$
	0.05	61764	74592	71846	155	77
Sa_{A3} high	0.20	18494	22955	21999	155	77
Sm_{A3} high	1.00	987	1876	1683	155	77
	0.05	18284	22824	22135	155	77
Sa_{A3} low	0.20	3600	5113	4881	155	77
Sm_{A3} low	1.00	-1419	-1271	-1297	155	77

Table 36: Snake River fall chinook G for passage survivals and D assumptions.

Passage	D_{A1}	$G_{A1,A3}$	$G_{A1,B1}$	$G_{A1,B2}$	$G_{A1,D1}$	$G_{A1,D2}$
	0.05	16.46	19.62	18.94	1.04	1.02
Sa_{A3} high	0.20	5.76	6.87	6.63	1.04	1.02
Sm_{A3} high	1.00	1.29	1.54	1.48	1.04	1.02
	0.05	5.71	6.53	6.36	1.00	1.00
Sa_{A3} low	0.20	2.00	2.28	2.23	1.00	1.00
Sm_{A3} low	1.00	0.44	0.51	0.50	1.00	1.00

Table 37: Snake River fall chinook levels for E, ΔM and G under different levels of D and passage survivals for comparison of A1 to the C alternatives.

Passage	D_{A1}	$E_{A1,C1}$	$E_{A1,C2}$	$\Delta M_{A1,C1}$	$\Delta M_{A1,C2}$	$G_{A1,C1}$	$G_{A1,C2}$	$\Delta R_{A1,C1}$	$\Delta R_{A1,C2}$
	0.05	6179	5972	16628	15474	5.30	5.01	18058	16877
Sa_{A3} high	0.20	2295	2089	3055	2678	1.85	1.75	3749	3318
Sm_{A3} high	1.00	-3246	-3452	-1458	-1479	0.41	0.39	-2793	-2912
	0.05	6179	5972	16628	15474	5.30	5.01	18058	15877
Sa_{A3} low	0.20	2295	2089	3055	2678	1.85	1.75	2749	3318
Sm_{A3} low	1.00	-3246	-3452	-1458	-1479	0.41	0.39	-2793	-2912

Table 38. Hanford Reach fall chinook difference in equilibrium populations, $E_{row,col}$, between actions. Equilibrium population under A1 is 132500 spawners.

	A2	A3	B1	B2	C1	C2	D1/D2
A1	27749	-24478	-16876	-19315	-16876	-19315	30347
A2		-52228	-44626	-47065	-44626	-47065	2597
A3			7602	5162	7602	5162	54825
B1				-2440	0	-2440	47223
B2					2439	0	49662
C1						-2440	47224
C2							49663

Table 39 Hanford Reach fall chinook difference in MSY for actions, $\Delta M_{row,col}$. Note MSY under A1 is 214640 spawners.

	A2	A3	B1	B2	C1	C2	D1/D2
A1	142694	-72715	-54066	-60391	-54066	-60391	160677
A2		-215409	-196760	-203085	-196760	-203085	17983
A3			18649	12324	18649	12324	233392
B1				-6325	0	-6325	214743
B2					6325	0	221068
C1						-6325	214743
C2						-6325	221068

Table 40 Hanford Reach fall chinook $G_{row,col}$.

	A2	A3	B1	B2	C1	C2	D1/D2
A1	1.74	0.61	0.71	0.67	0.71	0.67	1.83
A2		0.35	0.40	0.39	0.40	0.39	1.05
A3			1.16	1.10	1.16	1.10	2.99
B1				0.95	1.00	0.95	2.57
B2					1.04	1.00	2.70
C1						0.95	2.63
C2						0.95	2.70

Table 41. Upper Columbia spring chinook difference in equilibrium populations, $E_{row,col}$, between actions. Note equilibrium population under A1 is 1061 spawners.

	A2	A3	B1	B2	B3	C1/D1	C2/D2	C3/D3
A1	0	0	184	101	143	184	101	143
A2		0	184	101	143	184	101	143
A3			184	101	143	184	101	143
B1				-84	-42	0	-84	-42
B2					42	83	0	42
B3						41	-43	0
C1/D1							-84	-42
C2/D2								42

Table 42 Upper Columbia spring chinook difference in maximum sustained yield, $\Delta M_{row,col}$ for actions. Note MSY under A1 is 369 spawners.

	A2	A3	B1	B2	B3	C1/D1	C2/D2	C3/D3
A1	0	0	91	47	68	91	47	68
A2		0	91	47	68	91	47	68
A3			91	47	68	91	47	68
B1				-44	-23	0	-44	-23
B2					21	44	0	21
B3						23	-21	0
C1/D1							-44	-23
C2/D2								21

Table 43. Upper Columbia spring chinook $G_{row,col}$.

	A2	A3	B1	B2	B3	C1/D1	C2/D2	C3/D3
A1	1	1	1.19	1.10	1.15	1.19	1.10	1.15
A2		1	1.19	1.10	1.15	1.19	1.10	1.15
A3			1.19	1.10	1.15	1.19	1.10	1.15
B1				0.92	0.96	1.00	0.92	0.96
B2					1.04	1.08	1.00	1.04
B3						1.04	0.95	1.00
C1/D1							0.92	0.96
C2/D2								1.04

7 Downstream passage model

The CRiSP model (Anderson et al. 1999) was used for the detailed analysis of actions at the John Day project. The model tracks release groups of juvenile salmonids as they migrate through the hydrosystem. Mortality is attributed to direct dam mortality (as fish pass through the turbines, bypass, or spillways of dams), predation (in the forebays, tailraces and main reservoirs), and gas bubble disease resulting from nitrogen supersaturation. Fish migration rate is modeled in terms of river velocity date in the season, and length of time in migration (Zabel and Anderson 1997, Zabel et al. 1998). In addition, fish are collected at several dams and transported to below Bonneville Dam.

For the life-cycle modeling, a combination of CRiSP v1.5 and v1.6 was utilized. CRiSP v1.5 was used in the PATH spring chinook analysis, and the results from these runs were used in the life-cycle analysis, with the following exception. For the more detailed analysis of explicit actions at the John Day project (results presented below) we utilized CRiSP v1.6. The previous v1.5 results were then scaled to reflect the proportional survival increases under the various actions. CRiSP v1.6 was used for all fall chinook analyses since this was the version used in PATH.

The primary difference between v1.5 and v1.6 is the data used for survival calibration. CRiSP v1.6 relies on NMFS survival estimates from PIT tag data (details in Anderson et al. 1999). CRiSP v1.5 was calibrated to predator consumption and abundance indices (Anderson et al. 1996). Comparisons between the two versions show that they produce similar results. All dam passage parameters (FGE, spill effectiveness, dam passage mortality) for both versions were taken from PATH reports (e.g., Marmorek et al. 1998) and were common to both CRiSP and FLUSH models.

7.1 Configuration for John Day drawdown

For spring chinook, survival through John Day was modeled with both reservoir improvement and John Day Dam passage improvements. Reservoir survival was modeled to reflect a decrease in reservoir passage time resulting from the increased water velocity through the reservoir. In natural river drawdown, John Day Dam passage survival was set at 100%. With spillway crest drawdown, passage survival was set at 98%.

For fall chinook, upper and lower bounds were modeled for John Day drawdown. Both bounds assumed that with natural drawdown the survival in dam passage and the forebay would be removed. An upper bound of reservoir survival was modeled to increase in proportion with the increase in water velocity, which reflects a decrease in reservoir residence. For a lower bound the fish travel time was not decreased with drawdown. For spillway crest drawdown these same scenarios were applied for reservoir survival but dam passage survival was set to 98% reflecting a small mortality in spillway passage.

7.2 Passage Model Results

For CRiSP model runs presented in this analysis, fish were released at the forebay of Lower Granite Dam. The release distributions were based on passage index data for wild spring and fall chinook. Survivals and travel times were computed from release point to Bonneville tailrace. The survivals reported were a weighted average based on release size. The travel times were the median travel times for all fish in a given year.

The model runs utilized historical flows and temperatures with current dam operations and survivals. Water years modeled, including flow and temperature conditions, were 1975-1998 for spring chinook and 1975-1992 for fall chinook.

7.2.1 Mortality associated with the John Day project

The improvement in survival as a result of an action at the John Day project can be calculated as

eq (35) $$\Delta S = S_Y / S_X - 1.0$$

where S_X is the total in-river survival with John Day project at full pool and S_Y is the total in-river survival under an action X at John Day projects. This can be expressed as a percentage by multiplying the result by 100.

7.2.2 Changes in travel time under John Day operations

The change in travel time associated with different John Day operations can be expressed

eq (36) $$\Delta tt = tt_X - tt_X$$

where tt_X is the travel time through John Day reservoir with full pool operation and tt_Y is the travel time through John Day pool under various actions.

7.2.3 Spring Chinook Results

The results of the spring chinook passage modeling analysis are presented in Tables 44 to 47. The flood control scenario was performed for 1997 only, which was a high flow year.

Table 44: In-river survival for Snake River spring chinook under various management actions. Survivals are from the forebay of Lower Granite Dam to the tailrace of Bonneville Dam. High survival uses drawdown survival through Snake River of 0.95, low survival used drawdown survival of 0.85.

	min	**mean**	**max**	**S.D.**
A1 (inriver only)	0.327	0.437	0.551	0.062
A3 (high survival)	0.533	0.619	0.719	0.042
A3 (low survival)	0.477	0.554	0.635	0.038
B1 (high survival)	0.640	0.705	0.777	0.042
B1 (low survival)	0.570	0.631	0.695	0.038
C1 (JD draw down)	0.391	0.498	0.603	0.062
C2 (JD spill crest)	0.360	0.471	0.580	0.064

Table 45: Travel times in days for Snake River spring chinook under various management actions. Travel times are from the forebay of Lower Granite Dam to the tailrace of Bonneville Dam.

	min	mean	max	S.D.
A1 (inriver only)	15.3	18.0	20.8	1.1
A3	10.6	12.7	15.1	0.9
B1 (JD draw down)	9	10.6	12.7	0.8
C1 (JD draw down)	13.7	15.9	18.4	1.0
C2 (JD spill crest)	14.3	17.0	19.8	1.1

Table 46: Proportional changes in survival between various management actions as change in survival.

	min	mean	max
C2/no transport	0.053	0.079	0.105
C1/no transport	0.094	0.145	0.196
C1/C2	0.040	0.061	0.086
C1/C3 (97 only)		0.01	
B1/A3	0.09	0.14	0.19

Table 47: Changes in travel time of Snake River spring chinook between various management scenarios as change in travel time for in river fish.

	min	mean	max
A1 - A3	4.7	5.3	5.7
A1 - B1	6.3	7.4	8.1
A3 - B1	1.6	2.1	2.4
A1 (inriver only) - C2	1.0	1.1	1.0
A1 (inriver only) - C1	1.6	2.1	2.4
C2 - C1	0.6	1.0	1.4
C3 - C1 (97 only)		0.5	

Mean survival under John Day drawdown was estimated to improve by 14.5 percent as compared to a full river/no transport option. The drawdown to spillway crest option improved survival by

7.9 percent. In the flood control model run, survival decreased by 1.3 percent as compared to the full river drawdown with no flood control.

The full river drawdown decreased travel times by 2.1 days as compared to the full pool option, and the spill crest option decreased travel time by 1 day. The flood control option increased median travel time by half a day as compared to full drawdown with no flood control.

7.2.4 Fall Chinook results

The results of passage modeling for fall chinook are presented in Tables 48 to 51. For the A3 and B1 scenarios, we modeled both a lower bound (0.61) and upper bound (0.89) survival through the free-flowing Snake River based on the latest PATH fall chinook report (Marmorek et al. 1999).

We did not run a "C3" scenario (flood control) for fall chinook because the water was released prior to the onset of fall chinook migration. If flood-control water was stored in John Day pool until the migration, fall chinook could receive a potential benefit. The tables below show fall chinook survivals from LGR forebay to BON tailrace with modifications to John Day pool only.

Table 48: Inriver survival for Snake River fall chinook under various management actions. Survivals are from the forebay of Lower Granite Dam to the tailrace of Bonneville Dam.

	min	**mean**	**max**	**S.D.**
A2	0.263	0.292	0.319	0.019
A3 (lower bound)	0.341	0.352	0.363	0.006
A3 (upper bound)	0.498	0.513	0.530	0.009
B1 (lower bound)	0.385	0.397	0.409	0.007
B1 (upper bound)	0.562	0.579	0.596	0.011
C1 (JD draw down)	0.283	0.312	0.342	0.021
C2 (JD spill crest)	0.273	0.301	0.329	0.020
No transport	0.254	0.279	0.305	0.018

Table 49: Travel times in days for Snake River fall chinook under various management actions. Travel times are from the forebay of Lower Granite Dam to the tailrace of Bonneville Dam.

	min	mean	max	S.D.
A2	21.7	24.2	26.6	1.6
A3	13.8	17.1	21.1	2.0
B1	10.4	13.2	17.7	2.0
A1 (in-river only)	21.5	24.0	26.6	1.6
C2 (JD spill crest)	20.3	22.9	25.8	1.7
C1 (JD draw down)	19.0	21.5	24.6	1.7

Table 50: Proportional changes in Snake River fall chinook survival between various management actions.

	min	mean	max
C2/no transport	0.071	0.078	0.085
C1/no transport	0.110	0.120	0.126
C1/C2	0.036	0.039	0.043
B1/A3	0.115	0.127	0.137

Table 51: Changes in Snake River fall chinook inriver passage travel time between as a result of various management actions.

	min	mean	max
A2-A3	5.4	7.2	8.5
A2-B1	8.8	11.0	12.1
A3-B1	3.4	3.9	4.2
A1 (inriver only) - C2	0.8	1.0	1.2
A1 (inriver only) - C1	2.0	2.4	2.7
C2-C1	1.2	1.4	1.5

The improvement in survival conferred by drawing down John Day pool to a natural river level as compared to full pool operations is estimated to be 12-13 per cent. This is based on comparing survival under A3 (drawdown of all four Snake River projects) to B1 (drawdown of Snake projects and John Day) and by comparing C1 (John Day drawdown only) to the full river/no transport option. Note that this improvement in survival results from both reduced reservoir and dam mortality. Approximately 2/3 of this improvement could be realized by only drawing the river down to the spill crest level.

Travel times were reduced by 2-4 days with John Day drawdown.

8 Discussion

The impact of John Day drawdown action on the Snake River and Upper Columbia spring and fall chinook was evaluated using several response measures and three modeling approaches. The analysis was conducted with the PATH Bayesian life-cycle analysis, which provided probabilities of meeting survival and recovery goals. In addition, the analysis was applied to determine the equilibrium spawner levels. This analysis was conducted for Snake River listed spring and fall chinook. A second approach used a deterministic life-cycle analysis under equilibrium conditions. This approach provided the equilibrium number of spawners, the MSY and the total adult population under MSY of Snake River spring and fall chinook, Hanford Reach fall chinook, and Upper Columbia spring chinook. A third analysis evaluated the impact of the drawdown actions on the smolt passage survival and travel time using the CRiSP smolt passage model.

Actions evaluated include transportation, Snake drawdown only, John Day drawdown only, with and without transportation from the Snake River, and a drawdown including the Snake River and John Day reservoir. Three variations of John Day drawdown were evaluated: natural river drawdown, spillway crest drawdown, and natural river drawdown with flood control measures in the spring that allowed for partial refilling of the reservoir during times of high flow.

Six of stock performance measures were evaluated: probability of survival over 24 years, probability of recovery over 48 years, equilibrium population level, maximum sustainable yields, smolt passage survival, and smolt passage travel time. A number of hypotheses were explored on in-river survival of smolts and the linkages between freshwater survival, smolt passage stages, and ocean survival. In addition, several hypotheses were explored on the expected levels of survival under drawdown and on the survival of adults migrating up river.

The Bayesian analysis and the deterministic analysis both provide pairwise estimates of the difference in equilibrium population levels between two alternatives. The Bayesian results for Snake River spring chinook are given in Table 19 and the deterministic results are given in Table 25. The Bayesian analysis gave larger values. For example, the difference in equilibrium population levels between alternatives B1 and A3 for the Bayesian analysis were between 68 and 217 spawners under equal weighting of hypotheses, while the deterministic value was 58. Although these estimates are different the ratio of the equilibrium levels defined (B1-A3)/A1 is nearly identical for the two methods. From the Bayesian analysis (Table 19) the geometric mean of this ratio, across the 7 index stocks, is 0.163. For the deterministic model the ratio is 0.138. Noting from eq (17) that the equilibrium level in the deterministic model is scaled by the Ricker parameter b, it follows that the value of a pairwise comparison depends on b, but in the ratio measure, (B1-A3)/A1, the Ricker b terms cancel. This is also true of the Bayesian model.

We note that the equilibrium ratio (B1-A3)/A1 is very close in the two methods while the measure B1-A3 is different. Therefore, the main difference in pairwise comparisons from the two methods involves the choice of the Ricker b used in each method. For the Bayesian analysis the mean value of the Ricker b is 0.00122 while the mean value for the deterministic method was 0.00174. The difference in the estimates of b accounts for over 80% of the difference in the results of the two methods. The remaining difference in the methods is a result of slightly different passage assumptions. Mathematically the two approaches are functionally equivalent, so using the same input in the two methods should give very similar results.

The question of which set of Ricker b estimates are better can not be resolved. In this work the estimates used in the Bayesian analysis and the estimates used in the deterministic method were both extracted from work by the same researchers developed at different times. The Bayesian analysis used b values prepared by Schaller, Petrosky and Langness for the PATH analysis (Marmorek and Peters 1998) and the deterministic estimate used b values published by Schaller et al (1999).

8.1 Bayesian Analysis

The analysis showed a range of probabilities of survival and recovery depending on the action and hypotheses. Irrespective of the details, general trends emerge that are illustrated by taking the upper and lower estimates of the absolute values and differences in survival and recovery probabilities of transportation relative to drawdown actions

The ranges in survival probabilities with different hypotheses were small and indicated that in the BSM analysis the hypotheses projecting 24 year survival probabilities for spring or fall chinook did not give significantly different results. The second feature is that all three actions, transportation (A2), Snake River drawdown (A3) and Snake River plus John Day drawdown (B1) gave essentially the same chance of survival, which was estimated to be high. The third result was that assumptions were not important in distinguishing actions A3 vs. B1 for recovery. The model predicted a high chance of recovery for both actions. The fourth result was that hypotheses were important in determining the effectiveness of transportation actions. The range of recovery probabilities was large and under some hypotheses drawdown actions were significantly better than transport actions. The assumptions making drawdown better than transportation were explored with the deterministic model.

Table 52: Range of Snake River spring and fall chinook survival and recovery probability means under actions A1, A2, A3 and B1.

Standard	Action	Range	A3 - A1	B1 - A3
24-year survival spring chinook	A1, A2	0.56-0.76	0.01 to 0.08	
	A3	0.63-0.79		-0.002 to 0.005
	B1	0.64-0.79		
48-year recovery spring chinook	A1, A2	0.33-0.60	0.10 to 0.50	
	A3	0.67-0.88		0.02 to 0.03
	B1	0.70-0.91		

Standard	Action	Range	A3 – A2	B1 - A3
24-year survival fall chinook	A1, A2	0.83-0.99	-0.002 to 0.07	
	A3	0.88-1.00		-0.001 to 0
	B1	0.89-1.00		
48-year recovery fall chinook	A1, A2	0.35-0.92	0 to 0.65	
	A3	0.86-0.92		0 to 0.043
	B1	0.91-1.00		

The equilibrium level, which is also a measure of how well an action can lead to recovery, was estimated individually for each of the index stocks for both spring chinook and fall chinook. The total equilibrium values of the index stocks for spring chinook, as the sum of individual stocks from Table 19, are given in the Table 53 below. The analysis used seven index stocks. The Snake River Basin has about 38 index stocks, so the modeled stocks may represent about one quarter of the total spring chinook population in the Snake River Basin. For spring chinook the equilibrium level under drawdown actions were about 50% higher than under the transportation actions. John Day drawdown, with Snake River drawdown, added an additional 10% to the equilibrium population level beyond just the Snake River drawdown. For the fall chinook (See Table 20), the drawdown actions increase the equilibrium level of stocks by a factor of three, and adding John Day drawdown to the Snake River drawdown increased the stocks by 10%.

Table 53: Total equilibrium spring chinook population (index stocks) for each action and hypotheses plus the difference in index stocks comparing actions B1 to A3 and A3 to A1.

Hypotheses	**A1**	**A2**	**A3**	**B1**	**B1-A3**	**A3-A1**
EQUAL	4956	4903	7418	8232	814	2462
FLUSH	4365	4200	9829	11296	1467	5464
CRISP	5904	5896	7360	7846	486	1456
NMFS	4600	4611	5067	5552	485	467
OPT.PASS	5149	5081	8267	9146	879	3118
PESS.PASS	4763	4726	6571	7319	748	1808

8.2 Deterministic life-cycle analysis

Using the deterministic model, pairwise comparisons were made between the drawdown alternatives (i.e. A3, B and C) and between the transportation and drawdown alternatives (i.e. A vs. B, C, and D). A John Day drawdown, along with a Snake River drawdown, always improved the fish population measures (A3 vs. B1). Drawing down John Day only, and ending transportation (A3 vs. C1), was significantly worse for Snake River spring and fall chinook than if the Snake River system were drawn down only (A3 vs. C2) (Table 54).

Table 54. Pair-wise comparison of differences in Snake River drawdown equilibrium level, MSY and R with various combinations of John Day drawdown.

	Snake spring			Snake fall		
	E	ΔM	ΔR	E	ΔM	ΔR
A3 vs. B1	2128	4104	4636	668	9061	9104
A3 vs. C1	-13452	-17024	-21166	-2801	-24199	-24471
A3 vs. C2	-15352	-18544	-23370	-3007	-25353	-25652
A3 vs. C3	-14060	-17518	-21888			

A comparison of the base action (A1) to a natural river drawdown of John Day produced mixed results for stocks depending on the assumptions made and the stocks being considered (Table 55). High transportation efficiency assumptions produced negative numbers in the A1 vs. C1 comparisons. That is, compared to the current operating conditions, equilibrium numbers and MSY decreased with a John Day drawdown that also terminated the transportation program. Using an assumption of low transportation effectiveness, C1 produced positive numbers for Snake River spring and fall chinook relative to A1. For Hanford Reach fall chinook, John Day drawdown was detrimental. Studies on the effectiveness of transporting Hanford Reach fish from McNary dam suggest a high transport effectiveness for this system. Thus, transportation was always better than passing the fish through the lower Columbia River hydrosystem. Upper Columbia spring chinook, which are currently not transported from McNary dam, experienced a small increased in equilibrium numbers and MSY with John Day drawdown.

Table 55: Difference in equilibrium population levels and MSY comparing base action A1 to drawdown of John Day reservoir, C1.

	$\mathbf{E_{A1,C1}}$	$\mathbf{\Delta M_{A1,C1}}$	$\mathbf{\Delta R_{A1,C1}}$
Snake River spring chinook	-11791 to 2336	-2976 to 1280	2546 to -6346
Snake River fall chinook	-3428 to 6179	-1487 to 16791	18058 to -2793
Hanford Reach fall chinook	-16876	-54066	-57322
Upper Columbia spring chinook	184	91	165

8.3 Smolt passage analysis

Smolt passage information derived from the CRiSP passage model show small changes in travel time for spring chinook and relatively large changes for fall chinook. For spring chinook, the comparison was made only between full-pool travel time and the drawdown options. The difference was two days between full pool and natural drawdown of John Day reservoir. Flood control delayed fish an additional half-day. The spillway crest option gave results between full pool and the natural river drawdown. There was little difference in the survivals between the different C alternatives. Fall chinook exhibited a larger response to John Day drawdown with the benefit of a decreased travel time up to one week. In a comparison between full pool and drawdown of the Snake River dams plus the John Day Dam, the average in-river survival changed from 0.29 to 0.51. The travel time of the fall chinook changed from 24 days to 13 days between the two configurations.

8.4 Summary

To develop an understanding of the relative benefits of John Day drawdown under the Bayesian model analysis, we compared results of a Snake River drawdown (A3) to the Snake River plus John Day drawdown to natural river level (B1). The results in Table 56 used passage assumptions that optimized the smolt and adult passage survival (OPT.PASS and HIGH.EJUV in Tables 13 through 20). The difference in the measures of A3 and B1 illustrates the individual contribution of a natural river drawdown of John Day reservoir. The drawdown contributed nothing to Snake River spring and fall chinook recovery and survival probabilities. Under current conditions (A1), the Bayesian analysis suggested equilibrium populations of about 5000 adults for both spring and fall chinook. The John Day drawdown increased the equilibrium population by approximately 20% for spring chinook and 50% for fall chinook.

Table 56: Difference in Snake River salmon survival and recovery probabilities and the difference in equilibrium populations between A3 and B1. Results are from the Bayesian model with weightings of hypotheses favoring optimum passage conditions.

	Δ 24-yr Surv. Prob.	**Δ 48-yr Recov. Prob.**	**$E_{A3,B1}$**
spring chinook	-0.0005	0.022	879
fall chinook	0.0005	0.011	2326

To characterize the effect of a John Day drawdown on the Upper Columbia and the Snake River stocks, the deterministic model was used in pairwise comparison of actions. For actions without transportation, the effect of John Day can be characterized by comparing action A3 to B1, B2 and B3. That is, to characterize the effects of the John Day drawdown on the equilibrium conditions, the difference in including a John Day drawdown to the Snake River drawdown is compared to a

Snake River drawdown alone. The maximum improvement of adding the John Day drawdown was between 1 and 17%, depending on species (Table 57).

Table 57. Effects of John Day drawdowns are illustrated with pair-wise comparisons to Snake River drawdown equilibrium levels. Equilibrium population under current condition, A1, is Equ. Pop. The total Snake River spring chinook population is estimated assuming 38 stocks.

Stock	Equ. Pop.	$E_{A3,B1}$	$E_{A3,B2}$	$E_{A3,B3}$
Snake River spring chinook	15942	2128	190	1520
Snake River fall chinook	7259	647	572	
Hanford Reach fall chinook	132499	7602	5162	
Upper Columbia spring chinook	1061	184	101	143

The impact of the actions on the pairwise difference of MYS plus escapement is illustrated in Table 57a. The spring and fall chinook estimates were generated with high and low D values, which give the least and most benefit to action B1, B2 and B3.

Table 57a. Effect of John Day drawdowns are illustrated with pair-wise comparisons to Snake River drawdown equilibrium levels. Recruitment plus harvest at MSY population under current conditions, A1, is R_{A1}. Difference in R is ΔR. The total Snake River spring chinook population is estimated assuming 38 stocks.

Stock	R_{A1}	D	$\Delta R_{A3,B1}$	$\Delta R_{A3,B2}$	$\Delta R_{A3,B3}$
Snake River spring chinook	4006	0.35	4636	418	3268
		0.80	2432	190	1710
Snake River fall chinook	3288	0.05	11043	9667	
		1.00	942	825	
Hanford Reach fall chinook	190404	1.00	20358	13502	
Upper Columbia spring chinook	422	NA	165	88	126

The effect of John Day drawdown without transportation, compared to the current transportation of fish in A1, presents mixture benefits and detriments depending on the value of transportation effectiveness as characterized by the D factor (Table 58). The maximum and minimum effects are illustrated by comparing A1 to C1, C2 and C3. For Snake River stocks, when D is low, John

Day drawdowns by themselves are beneficial, but if D is high, drawdown is detrimental to fish. For the Hanford Reach stock, a John Day drawdown that removes the transportation of these fish is always detrimental, while the drawdown has a small benefit for Upper Columbia Spring chinook, since none of these fish are currently transported at McNary Dam. In Table 58 other factors are selected that give the maximum benefit for the low D calculation and maximum detriment for the high D calculation.

Table 58. Effect of John Day drawdowns relative to transportation actions are illustrated with pair-wise comparisons of John Day drawdowns to current conditions. Measures give differences in equilibrium levels relative to A1. Transportation effectiveness is D. Equilibrium population under current condition, A1, is Equ. Pop.

Stock	Equ. pop.	D	$E_{A1,C1}$	$E_{A1,C2}$	$E_{A1,C3}$
Snake River spring chinook	15942	0.35	3648	1748	3040
		0.80	-12084	-14022	-12730
Snake River fall chinook	7259	0.05	18058	16877	
		1.00	-2793	-2912	
Hanford Reach fall chinook	132500	1.00	-16876	-19315	
Upper Columbia spring chinook	1061	NA	184	101	143

Table 58a. Effect of John Day drawdowns relative to transportation actions are illustrated with pair-wise comparisons of John Day drawdowns to current conditions. Measures give difference in populations at MSY relative to A1. Transportation effectiveness is D. Recruitment plus harvest at the MSY population under current condition, A1, is R_{A1}. Difference in R is ΔR. The Snake River is assumed to have 38 spring chinook stocks.

Stock	R_{A1}	D	$\Delta R_{A1,C1}$	$\Delta R_{A1,C2}$	$\Delta R_{A1,C3}$
Snake River spring chinook	4006	0.35	2546	1178	2090
		0.80	-6346	-7144	-6612
Snake River fall chinook	3288	0.05	18058	16877	
		1.00	-2793	-2912	
Hanford Reach fall chinook	190404	1.00	-57322	-64178	
Upper Columbia spring chinook	422	NA	165	88	126

The final comparison shows the effects of John Day drawdown relative to current conditions, assuming that a fish transportation system can be implemented along with a drawdown. In this case the pairwise comparisons is between A1 vs. D1, D2 and D3 (Table 59 and 59a). The result is that the effect of drawdown depends on the transportation effectiveness on Snake River spring chinook. If transportation is effective (D = 0.80) then John Day drawdowns are beneficial. If the transportation is ineffective (D= 0.35) then drawdown with transportation is detrimental. For Snake River fall chinook, drawdown is insignificant relative to current condition, but it does improve Hanford Reach fall chinook. The impact on Upper Columbia spring chinook is small.

Table 59. Effect of John Day drawdowns with transportation relative to the current operating conditions are illustrated with pairwise comparisons of equilibrium levels relative to A1. Parameters, selected to produce estimates, are given as Param. Equilibrium population under A1 is Equ. pop.

Stock	**Equ. pop.**	**Param.**	$E_{A1,D1}$	$E_{A1,D2}$	$E_{A1,D3}$
Snake River spring chinook	15942	D = 0.35	-342	-342	-342
		D = 0.80	608	608	608
Snake River fall chinook	7259	Sa,Sm high	172	87	
		Sa,Sm low	172	87	
Hanford Reach fall chinook	132500		30347	30347	
Upper Columbia spring chinook	1061		184	101	143

Table 59a. Effect of John Day drawdowns with transportation relative to the current operating conditions are illustrated with pairwise comparisons of population levels at MSY relative to A1. Parameters, selected to produce estimates, are given as Param. Recruitment plus harvest at MSY population under current conditions, A1, is R_{A1}. Difference in R is ΔR. Snake River spring chinook consists of 38 stocks.

Stock	R_{A1}	**Param.**	$\Delta R_{A1,D1}$	$\Delta R_{A1,D2}$	$\Delta R_{A1,D3}$
Snake River spring chinook	4006	D = 0.35	-190	--190	--190
		D = 0.80	418	418	418
Snake River fall chinook	3288	Sa,Sm high	214	107	
		Sa,Sm low	214	107	
Hanford Reach fall chinook	190404		164908	164908	
Upper Columbia spring chinook	422		165	88	126

This analysis indicates that a John Day drawdown can have a positive or negative impact on the stocks above the reservoir. The relative effects are clear when comparing the contribution of a John Day reservoir drawdown to the drawdown of the Snake River dams. Under this comparison the effectiveness of transportation is not a large issue, since neither action has transportation. Then under the assumptions of the model, the contributions of John Day are incremental and small. As illustrated in Table 57, spring chinook equilibrium increases by up to 2000 fish, while the fall chinook increase by about 600 fish. The increase in the harvest plus escapement at MSY (Table 57a) is up to four thousand spring chinook adults and eleven thousand fall chinook adults. In comparison, the current equilibrium levels for the Snake River spring and fall chinook are about sixteen thousand and seven thousand respectively. Historically, the runs were considerably larger. In the 1950s, annual spring chinook returns to the Snake River were over one hundred thousand adults and in the 1960s they were about sixty thousand. The Snake River fall chinook spawning population, including escapement to the mouth of the Columbia and harvest, averaged about seventeen thousand adults over the period 1966-1991 (Peters et al 1999). This level could be obtained by fall chinook transportation, if the current transportation is ineffective (Table 58). Furthermore, under this assumption, the contribution of improved passage with a John Day drawdown is insignificant (Table 59). If fall chinook transportation is effective, then stopping transportation decreases the population (Table 58).

8.5 Final Remarks

This analysis suggests that benefits of a John Day drawdown are uncertain. In general, the effect of a John Day drawdown on Snake River fish depends on the assumptions about the extra mortality and delayed mortality in transportation. If transportation is effective, then drawdown is ineffective. If transportation is ineffective, then drawdown is effective. Hanford Reach fall chinook are not improved with John Day drawdown, unless transportation is continued with the drawdown. The Upper Columbia stocks generally are not affected by drawdown since the fish are currently not transported and the change in survival with and without drawdown is small. In all cases, a natural river drawdown is better than a spillway crest drawdown and flood control has an insignificant impact on smolts passing through John Day reservoir.

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10 Comments by PATH and Responses

10.1 Comments provided by Paul Wilson of CBWFW are included below.

Below are comments on the Sept. 13, 1999 draft of the paper. Many of these comments were made to two of the authors on a conference call on Sept. 14. (Note: the numbering does not refer to this draft of the document)

Pg. 17, Table 3. Lower bound (pessimistic) estimates of survival rate through the free-flowing John Day reach were used in PATH modeling, for both spring and fall chinook. The pessimistic estimate for spring chinook was a fixed value of 0.90 [EJUV1 – Marmorek et al. (1998), Table 2.2.1-1]. Note also that the optimistic survival rate value was 0.98, not .95, as indicated in Table 3. For fall chinook, modeled estimates of free-flowing survival rate, not fixed values, were used for both the optimistic and pessimistic values. The alternative assumptions differed in whether there would be a decrease in fish travel time through the reach due to drawdown (Peters et al. 1999, Section 5.2.2).

Pg. 20, Section 4.3. The term λo is not one that was used or defined within PATH. It appears the definition intended here is "the base ocean survival common to transported and non-transported groups." It's not clear what the criteria are for including a PATH-modeled factor influencing post-Bonneville survival in λo as opposed to λn or λt. If λo is "contained within the exp(a) of the equation (sic) stock recruitment equation $R = S \exp(a - bS)$" then the year effect (δy) of the Delta model in PATH is not contained in λo, and must somehow be applied to both λn and λt to be analogous to what was done in PATH

Pg. 22, Section 4.3.1. The three hypotheses about the trend in ocean mortality are not presented in an equitable manner. The claim is made that, only for the hydro hypothesis, "a direct link between fish survival and hydrosystem passage has not been identified", even though it's the only hypothesis of the three for which a credible, direct evidential link *has* been identified (see Schaller et al. 1999).

Pg. 23, Table 5. Description of λn as "characteristic ocean survival factor" is misleading, since it is really only the complement of the extra mortality experienced by Snake R. spring chinook. Ocean survival in the Delta model is composed of several modeled factors, including the year effect. By presenting λn as the ocean survival factor, it leads the reader to believe with FLUSH there is no apparent decline in ocean survival in the period from 1975 on. Inclusion of the year effect with FLUSH model estimates results in reduced ocean survival of spring chinook in the period 1975-90 compared to 1952-90.

Pg. 26, Table 8. Something seems to be amiss here: the conversion rates for B1 and B3 for spring chinook are lower than the A3 value. This makes no sense, unless a detriment to adult passage from dam removal is being assumed.

Pg. 41, Section 6. The text above eq. 17 indicates that hydrosystem passage corridor actions are never expected to alter the spawning habitat. However, in PATH an assumed increase in spawning habitat under Snake River drawdown was simulated for fall chinook, when escapements were very high (Peters et al. 1999).

Pg. 42, Eq 18. Not necessary to estimate S_{msy} numerically. Hilborn (1985) presents direct formulas approximating the spawning level at MSY and MSY for the Ricker curve, and the conditions under which they are useable.

Pg. 46, Eq. 25. This formulation of the benefit of John Day drawdown plus Snake R. drawdown vs. Snake R. drawdown alone illustrates one of the limitations of this analysis. This equation assumes that there are benefits of B1 over and above A3 only in the juvenile and adult hydrosystem passage stages. In PATH, under the hydro extra mortality hypothesis, there would be a benefit to post-Bonneville survival of actions that improve in-river conditions for smolts, such as John Day drawdown. We didn't explicitly consider or model the additional benefits of Snake River plus John Day drawdown compared to Snake River drawdown alone. Effectively, this analysis give a 100% weight to the hypothesis that there is no additional benefit to later life stages of a John Day drawdown, above that of a Snake R. drawdown alone, and 0% to any other hypothesis. However, PIT tag studies indicate that post-hydrosystem survival of spring chinook smolts is influenced by hydrosystem passage experience (Sandford and Smith 1999, Schaller et al. 1999).

Pg. 48, Section 6.3.1. The number of spring chinook stocks in the Snake R. basin is indicated to be 24. This may be close to the truth, but the ESU consists of both spring and summer chinook stocks, which number 35-40 total. Thus, the increase in the "Snake River Basin index spawning population" is underestimated by an amount proportional to the underestimate in number of stocks in the ESU.

Pg. 52, first paragraph. The claim that "a drawdown of John Day reservoir without drawing down the Snake River reservoirs is not expected to increase ocean survival" is not a conclusion reached, or even discussed, in PATH. We did not do any analysis of scenarios where only John Day is drawn down. PIT tag data indicate that the higher the number of times a smolt passes a dam through bypass, the lower the SAR (Sandford and Smith 1999, Schaller et al. 1999), suggesting that ocean survival decreases with number of dams passed.

Pg. 52, last paragraph. Upper Columbia spring chinook "G" is estimated with eq 25, which includes no effect of transportation. Since, under A2, upper Columbia origin smolts would be transported at McNary dam, eq. 26 or 27 is more appropriate. Tables 41 and 42 treat A1, A2, and A3 as identical in their effect on upper Columbia fish. Because of the MCN transport under A2, they are not. Also, A3 flow timing and magnitude in the lower Columbia would be different from A1 and A2.

Pg. 60, Section 7.2.3. In tables 44 – 47, why weren't B1 vs. A3 comparisons done? C1, C2 and C3 are not necessarily good surrogates for gauging the effect of B1 or B2 vs. A3. Snake River drawdown would increase the water velocity in the Snake, accelerating the arrival time of smolts to McNary dam in either CRiSP or FLUSH. This would, for example, affect flows and temperatures, increasing flows and lowering temperatures experienced by smolts in the lower part of the hydrosystem, and hence affect survival in John Day and the lower reservoirs. Differences of C1, C2, or C3 from. A1 are therefore likely underestimates of the additional benefits to smolt survival provided by John Day drawdown with Snake River drawdown.

Pg. 71, Section 8.5, last paragraph. Earlier comments detail why this analysis does not represent "the expected range of positive and negative impacts of a John Day drawdown." The text about the Ricker equation here makes no sense in the context of this analysis. If Ricker equation is inappropriate, the biggest effect here would be to underestimate the number of spawners resulting from B1, relative to A3 or any other scenario. This is because of the descending right hand limb inherent in the Ricker curve. If productivity doesn't decline at higher abundances, but stays about the same, many more recruits per spawner would be produced at the higher abundances expected under A3 and B1 scenarios.

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10.2 Response to review.

The responses to the review of P. Wilson and other PATH comments communicated by D. Marmorek are listed below:

1. The differences in the Bayesian and deterministic methods was evaluated and resolved. The main result is the two approaches are mathematically equivalent and the differences in pairwise comparisons depend on inputs selected for each method.

2. Concerns were considered related to the interpretation and characterization of ocean mortality using information from the PATH analysis. The Bayesian analysis in this study was conducted with the programs used in PATH and so the approach to characterizing ocean factors is identical to the PATH treatment. For the deterministic method, the approaches are different. The deterministic approach looked at pairwise comparisons at equilibrium, allowing great simplification of the analysis. In this approach all factors that are common between two alternatives, whether they are time variable or not, cancel. Because of this simplification basic differences in ocean survival need only reflect the differences resulting from the compared alternatives. Factors such as the ocean delta factor are subsumed into the Ricker a parameter.

3. It was assumed in this analysis, as was done in PATH, that the John Day reservoir drawdown did not alter ocean survival of stocks. The evidence for a linkage between ocean survival and passage experience remains uncertain and contradictory. Studies suggesting ocean survival increases with passage through fewer bypass systems (Stanford and Smith 1999) are equivocal and more adult returns are needed to establish if a pattern exists. In PATH (Hinrichsen and Paulsen 1998) demonstrated there was no correlation between the post Bonneville survival and the juvenile inriver passage survival. In the analysis here, the effects of juvenile passage experience on ocean survival were encompassed through the Hydro hypotheses for Snake River drawdown, but the possible effects of John Day drawdown were not considered.

4. For spring chinook from the Snake River, the number of stocks in the September draft of this paper was 24. This was changed to 32 spring and summer wild and natural stocks from the Snake River basin. This increased all estimates of stock numbers for equilibrium and the MSY levels by 1/3.

5. No attempt was made to evaluate the expansion of Ricker b factors by a drawdown action. The expansion of the Snake River fall habitat was not considered because the possible competition of Hanford Reach fall chinook for any new habitat could not be resolved, in addition to this being beyond the scope of this study.

6. The MSY calculations were estimated exactly rather than through the Hilborn (1985) approximation. For this study the Hilborn method was invalid.

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