**Statistical Considerations for
Evaluating Survival of Migrating
Salmonids in the Columbia River
System: Summary Report from the
Ad Hoc Statistical Committee to
the Water Budget Center**

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March 1985

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STATISTICAL CONSIDERATIONS FOR EVALUATING
SURVIVAL OF MIGRATING SALMONIDS IN THE
COLUMBIA RIVER SYSTEM: SUMMARY REPORT
FROM THE AD HOC STATISTICAL COMMITTEE TO
THE WATER BUDGET CENTER

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SUMMARY

Feasible experimental approaches and designs are developed for the estimation of annual smolt survival rates in some sections of the Columbia River Basin. Key assumptions that need to be evaluated are degree of mixing of marked groups and constancy to recovery effort. Two approaches to establishing control groups are identified and the criteria for evaluation identified. One approach to estimating survival rates includes the requirement for an accurate estimate of the collection efficiency at the recovery site.

Estimation of the survival rate in the Snake River system does not appear to be feasible because of the current transportation activities. Accurate estimates of the number of marked fish transported at Lower Granite and Little Goose Dams does not currently appear feasible. In addition, these removals reduce the number available for recovery at McNary Dam and further reduce our ability to estimate survival rates. Estimation of survival rates in this section of the system requires better estimates of transportation and higher recovery rates at McNary Dam.

The direct quantitative estimation of the effectiveness of the Water Budget flows does not appear to be currently feasible because of our inability to experimentally control the important factors. Evaluation of the Water Budget flows must therefore be based on an accumulation of related information and considerable scientific judgement and interpretation. A modeling effort is suggested to aid in the understanding of the smolt survival rates and hypotheses concerning the relevant factors.

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STATISTICAL CONSIDERATIONS FOR EVALUATING SURVIVAL
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RATIONALE LEADING TO FORMATION OF THE AD HOC COMMITTEE

The ad hoc Statistical Committee was convened by the Water Budget Center to address the statistical design and analysis needed to support the smolt monitoring and water budget evaluation aspects of the Water Budget Measures Program. This program was developed by the state and federal fishery agencies and tribes to address section 304 of the Columbia Basin fish and wildlife program. It was recognized that both of these aspects of the Water Budget Measures Program required a statistically sound measure of smolt survival. To that end, the committee was formed to develop a statistical approach to evaluate survival of downstream migrating smolts.

OBJECTIVES

The objective of the Ad hoc committee was to devise statistically valid approaches to estimating downstream smolt survival within river sections of the Columbia River Basin. For each valid and feasible approach an estimate of the numbers of marked smolts to be released and the associated confidence limits on the resulting survival estimates are desired. To accomplish this, predictions of the relationships among expected survival rate, numbers of marked smolts, percent of the run examined, and expected recoveries for each approach and section of the River were required. In addition, the committee addressed the likelihood of the ability to statistically evaluate the Water Budget based upon the resulting survival estimates that accrue over the next several years.

APPROACHES CONSIDERED

The committee began its deliberations based on the assumption that marked hatchery fish would be available and would provide the data upon which an evaluation would be based. The basic design consisted of hatchery releases of marked fish followed by recovery at a downstream dam. Within this basic design two alternatives were examined, with an additional modification of one alternative to include transportation of marked fish from two dams.

One design is based on release of one group of marked fish and recovery at the downstream dam, and relies upon an estimate of the collection efficiency at that dam. This approach is referred to as the direct method. When fish are transported from above the recovery site, a modification is required to account for the transported marks.

Another design is based on the release of a target group at an upstream point and a control group released immediately upstream of the recovery dam. This approach is independent of the absolute recovery efficiency, but does require that the relative recovery efficiency on the two groups is equal. This approach is referred to as the indirect method.

The committee considered that both methods could potentially be applied to the Mid-Columbia section. However, both were deemed not applicable for the Lower Columbia, as the anticipated recovery effort at Bonneville Dam, at least in the short term, would result in insufficient recoveries to provide reasonable estimates. In the Snake River, the situation is complicated by collection and transport from two intermediate dams, Lower Granite and Little Goose.

The committee developed equations for estimating the survival rates and associated variances. Preliminary estimates of the variance components then permitted calculation of confidence limits for likely parameter values and numbers of marked smolts. In addition to determining the precision that could be expected, the committee identified the assumptions and requirements, for each of the designs.

DIRECT ESTIMATION TECHNIQUE WITHOUT TRANSPORTATION

This approach consists of releasing marked fish at the upper end of the reach of interest, recovering the marked fish in a bypass system of a dam at the lower end of the reach and calculating survival through the reach based on estimated collection efficiencies (see Figure 1). The recoveries are given by:

$$R = S_0 S_1 E N_0$$

where: R = number of recoveries,
 S_0 = initial survival of hatchery releases,
 S_1 = survival of fish through the reach,
 E = percent of run examined,
 N_0 = number of marks released.

Note that:

$$E = fe$$

FIGURE 1. Schematic Diagram for Direct Estimation Technique Without Transportation in Mid-Columbia River

where: e = collection efficiency of the bypass system,

f = fraction of bypass fish examined; component typically varied to achieve a target value for E .

However, the observations (daily recoveries, collection efficiencies, and fraction examined) are generated at the recovery dam over a sequence of several days. To account for this in the estimation equations an index i is introduced and the daily recoveries represented as:

$$R_i = S_0 S_1 E_i P_i N_0$$

where; P_i is the fraction of the surviving fish that reach the dam on day i .

Rearranging this and summing over the recovery period

$$\sum_{i=1}^n \frac{R_i/N_0}{E_i} = \sum_{i=1}^n S_0 S_1 P_i = S_0 S_1 \sum_{i=1}^n P_i$$

Since $\sum_{i=1}^n P_i = 1$, our estimate of survival is therefore:

$$\hat{S_0 S_1} = \sum_{i=1}^n \frac{R_i/N_0}{E_i} = \sum_{i=1}^n \frac{P_i}{E_i}$$

where p_i is the probability of recovery on day i and n is the number of days marks are recovered. The variance of p_i/E_i can be shown to be approximately (Hansen et al. 1953):

$$\text{Var} \left(\frac{p_i}{E_i} \right) \approx \left(\frac{p_i}{E_i} \right)^2 \left(\frac{\text{Var } p_i}{p_i^2} + \frac{\text{Var } E_i}{E_i^2} \right) - \text{Cov. term}$$

$$\text{Var}(\hat{S}_0 \hat{S}_1) = \sum_{i=1}^n \text{Var} \frac{p_i}{E_i}$$

We have assumed that the covariance term is likely to be small and have elected to ignore it in the following calculations. To the extent that the covariance is not zero, we likely will overestimate the variance.

Thus, the daily p_i can be represented as a Poisson variate and the variance of p_i written as:

$$\text{Var}(p_i) = \frac{p_i}{N_0}$$

Collection efficiency regressions from Sims et al. (1983) and McKenzie et al. (1984) were used to establish an estimated value for $\text{Var}(e_i)$, the variance of a single point estimate of collection efficiency for both Lower Granite and McNary Dams.

However, the number of marks examined is of major interest, not the number of marks in the bypass collection system. The $\text{Var}(E_i)$ can be written as: $\text{Var}(E_i) = f_i^2 \text{Var}(e_i)$, by treating the fraction examined (f_i) as a constant.

DIRECT ESTIMATION TECHNIQUE WITH TRANSPORTATION

Because of the transportation of marked fish from Lower Granite and Little Goose Dams to below McNary, the following approach was developed as a modification of the direct method. The following equations represent the marked fish at successive points in the Snake River. See Figure 2 for a schematic representation of the system.

Marks surviving to:

$$\text{Lower Granite:} \quad N_1 = S_0 S_1 N_0$$

Little Goose: $N_2 = S_2(S_0 S_1 N_0 - T_1)$

where $T_1 = e_1 S_0 S_1 N_0$ (transportation from Lower Granite)

substituting, $N_2 = S_0 S_1 S_2 N_0 (1 - e_1)$

McNary: $N_3 = S_3 [S_0 S_1 S_2 N_0 (1 - e_1) - T_2]$

where $T_2 = e_2 S_0 S_1 S_2 N_0 (1 - e_1)$ (transportation from Little Goose)

FIGURE 2. Schematic Diagram for Direct Estimation Technique with Transportation in Snake River

substituting
and simplifying, $N_3 = S_0 S_1 S_2 S_3 N_0 (1 - e_1 - e_2 + e_1 e_2)$

or $N_3 = S \cdot N_0 \cdot CT$

where $S = S_0 S_1 S_2 S_3$

$CT = 1 - e_1 - e_2 + e_1 e_2$ (correction for transportation)

Recoveries at:

Lower Granite: $R_1 = S_0 S_1 N_0 E_1$

McNary: $R_3 = S \cdot N_0 \cdot CT \cdot E_3$

Again these equations must be modified to account for the daily sequence of observations. Thus, the estimate of survival is:

$$\hat{S} = \sum_{i=1}^k \frac{R_{3i}/N_0}{CT \cdot E_{3i}}$$

$$= \sum_{i=1}^k \frac{p_{3i}}{CT \cdot E_{3i}}$$

and the approximate variance is (Hansen et al. 1953):

$$\text{Var}(\hat{S}) \approx \sum_{i=1}^k \left[\left(\frac{p_{3i}}{CT \cdot E_{3i}} \right)^2 \left(\frac{\text{Var } p_{3i}}{p_{3i}^2} + \frac{\text{Var } CT}{CT^2} + \frac{\text{Var } E_{3i}}{E_{3i}^2} \right) + \text{Cov. terms} \right]$$

Further, the variance components are:

$$\text{Var}(p_{3i}) = \frac{p_{3i}}{N_0}$$

$$\text{Var}(E_{3i}) = f_i^2 \text{Var}(e_{3i})$$

If we assume that $e_1 = e_2$, i.e. the collection efficiency is approximately the same at Lower Granite and Little Goose, then CT simplifies to $(1 - e)^2$ and the variance of CT is (Hansen et al. 1953):

$$\text{Var}(\text{CT}) = 4(1 - \bar{e})^2 \text{Var } \bar{e}$$

where
$$\bar{e}_i = \sum_{i=1}^d e_i/d$$

$$\text{Var } \bar{e}_i = \sum_{i=1}^d \text{Var } e_i/d^2$$

and d = number of days marked fish are transported from Lower Granite.

An alternative method for calculating e is to weight the daily estimates, e_i , proportional to the number of fish transported (t_i) if that estimate is available. In that case the estimate is:

$$\bar{e} = \sum_{i=1}^d w_i e_i$$

and

$$\text{Var}(\bar{e}) = \sum_{i=1}^d w_i^2 \text{Var}(e_i)$$

where

$$w_i = \frac{t_i}{\sum_{i=1}^d t_i}$$

This approach would appear to be preferable, but requires that additional information be available about the number of fish transported. Exact estimates of t_i would not be required as a relative index would be sufficient to establish weights. Therefore, we can calculate the expected magnitude of the standard deviation for alternative numbers of marks released. Preliminary calculations with current information on the numbers of fish available for marking and estimates of collection efficiencies suggest that it is not presently feasible to estimate survival with acceptable confidence limits in the Snake River System.

INDIRECT ESTIMATION TECHNIQUE

This approach consists of releasing marked fish at the upper and lower end of the reach of interest (see Figure 3), and calculating the relative recapture (survival) rate for the two groups. This approach has the advantage of not being dependent upon an estimate of collection efficiency, as does the direct method. However, it is dependent on equal recovery rate on the two groups, achieved by constant daily recovery effort or by mixing between the groups so that the ratio of daily recovery rates is constant, i.e. similar migration timing at the downstream dam. In this case a survival estimate can be obtained as follows:

$$\hat{S}_1 = \frac{R_t}{p_c N_t} \quad p_c = \frac{R_c + 1}{N_c + 1}$$

$$\text{Var } \hat{S}_1 = \text{Var} \left(\frac{R_t}{p_c N_t} \right) = \frac{1}{N_t^2} \text{Var} \left(\frac{R_t}{p_c} \right)$$

where: N_t, N_c = number of marks released in upstream or target group, and control groups

R_t, R_c = sum of the daily recoveries from N_t and N_c groups

p_c = proportion of control fish recovered

Then

$$\text{Var}\left(\frac{R_t}{p_c}\right) = \left(\frac{R_t}{p_c}\right)^2 \left[\frac{\text{Var}(R_t)}{R_t^2} + \frac{\text{Var}(p_c)}{p_c^2} \right] - \text{Cov term}$$

and

$$\text{Var}(R_t) = p_t(1 - p_t)N_t$$

$$p_t = p_c S_1$$

$$\text{Var}(p_c) = \frac{p_c(1 - p_c)}{N_c}$$

FIGURE 3. Schematic Diagram for Indirect Estimation Technique in Mid-Columbia

Note: We have assumed that both groups of fish experience S_2 in migrating from the control release point to McNary. Further, we have assumed that $S_2 = 1$.

Although R_t/N_t is an unbiased estimator of the binomial proportion p_t , $1/(R_c/N_c)$ is not an unbiased estimator of $1/p_c$. In this case:

$$E\left(\frac{\hat{1}}{p_c}\right) = \frac{1}{E(p_c)}$$

To correct for this small bias, the survival estimates have been calculated using the formula:

$$\hat{S}_i = \frac{(R_{ti}/N_t)}{(R_{ci} + 1)/(N_c + 1)}$$

An alternative procedure in this approach is to estimate survival rate as a ratio of the two recovery proportions (Anderson 1984). Anderson (1984) defines S_N as the natural estimator,

$$\hat{S}_N = \frac{\sum_{i=1}^n R_{ti}/N_t}{\sum_{i=1}^n R_{ci}/N_c}$$

and shows that this is the maximum likelihood estimator.

A weighted mean of the daily survival estimates can be calculated as:

$$S_w = \frac{\sum_{i=1}^n w_i S_i}{\sum_{i=1}^n w_i}$$

and

$$S_i = \frac{R_{ti} / N_t}{(R_{ci} + 1) / (N_c + 1)}$$

where w_i is the number of control fish captured on day i , and n is the number of separate survival estimates (Seber 1973, p. 6; Steel and Torrie 1980, p. 19). The weighted variance (Seber 1973, p. 6; Steel and Torrie 1980, p. 270) is then:

$$\text{Var}(\bar{S}_w) = \frac{\sum_{i=1}^n w_i (\hat{S}_i - \bar{S}_N)^2}{(n - 1) \sum_{i=1}^n w_i}$$

The experimental design examined by Anderson, 1984, was based on simultaneous release of both groups of marked fish at nearly the same location. Thus, both groups of fish arrived at the recovery site at about the same time, although uniform mixing is not essential. Therefore, application of this approach to the current situation is dependent upon the majority of fish in both groups being recovered during the same period.

Because of the presence of transportation and associated requirements for large numbers of marked fish and estimates of collection efficiencies at Lower Granite and Little Goose dams, the indirect estimation technique was not applied to estimate survival in that system.

COMMENTS ON THE INTERPRETATION OF THE SMOLT SURVIVAL ESTIMATES

While the committee was developing the statistical framework for estimating smolt survival, additional discussion focused on the limitations of a smolt survival estimate and how such an estimate should be interpreted. It was felt that, in general, survival estimates over large areas are useful only as annual indices of overall smolt survival. While such indices are very useful as a yardstick against which to judge the overall, longterm success of fish protection measures, and observe year-to-year changes in smolt survival, relating these indices to specific variables cannot be made on a quantitative basis due to the problem of isolating the effect of any one variable from the effects of others. An example of this is seen in the difficulty that would be encountered in relating the use of the water budget to changes in estimated smolt survival.

A key assumption underlying the establishment of the Water Budget concept was that river flow is the major factor controlling rate of travel (travel time) and thereby survival rate. The Council's Fish and Wildlife Plan, Section 400, also envisions that increased survival can be achieved by improvements to or installation of collection and bypass systems. Spilling water through the spillways has been proposed as an interim action for providing increased survival. An additional factor influencing downstream survival rates is the current or proposed transportation schemes. In order to evaluate the benefits from the Water Budget, an ability to separate these effects (and any other unanticipated influences) is required.

To separate effects resulting from different factors in any experimental design one needs to either isolate the factor of interest (as in a control versus treatment approach) or observe the response under several combinations of factors, each at two or more levels. The lack of baseline data, i.e. survival rates prior to the establishment of the Water Budget, reduces our ability to adopt a control compared with treatment approach. Thus, we are forced to consider our ability to estimate (separate) the change in survival rates due to the Water Budget by observing survival rates over the next n

years (say 10 years). The following scenarios are based on potential 10 year sequences of observations on downstream smolt survival and associated system events.

SCENARIO ONE: EFFECT OF FLOW ON SURVIVAL

For this case assume that everything within the system stays constant, except for the April 1 forecast. Over the ten year period one might expect to observe smolt survival rates associated with Mid-Columbia River flows ranging from 120 to 180 Kcfs. The evaluation of the Water Budget would then consist of plotting survival versus flow rate and making a statistical estimation of the associated relationship. Establishment of the relationship, i.e. determining if it is a statistically significant relationship as opposed to having been observed by chance, is dependent upon the sample size (number of years), natural variability in survival among years, the range of flows (120-180 Kcfs), and the accuracy of the yearly survival estimates. The number of years can be thought of as being rather long (10-15 years), however several factors, timeliness of the information, continued use of hatchery fish for test purposes, continued handling of fish for recovery of marked fish, will result in increasing pressure to limit the longterm continuation of the effort. The magnitude of the variability among years is unknown, but one might anticipate under these assumptions that it is fairly small, i.e. for a single flow condition survival might vary by 10-30%. The range in flows during the monitoring period can be predicted from the hydrological modeling efforts. However, the results will apply only to the observed range, i.e. if it is a series of wet years with all flows about 140 Kcfs, extrapolation to 130 Kcfs will increase the uncertainty in the Water Budget evaluation. The accuracy of the yearly estimates is a function of the number of marked fish released and recovered and is addressed in this report.

Combining all these factors it appears that a reasonably quantitative evaluation of the water budget would result at the end of the study period, under this scenario.

SCENARIO TWO: EFFECT OF FLOW AND OTHER RESOURCE MANAGEMENT FACTORS

Assume for this scenario that the Power Council's Plan is implemented over the ten year period and thus several resource management actions are taken. The Plan calls for improvements, primarily collection and bypass systems, to be made to increase downstream smolt survival. Assuming that successful engineering studies, design, construction and "tuning" of these systems will require several years, we could anticipate a general trend of increasing survival as these facilities come on line. As spill is proposed as an interim measure, we could anticipate a decreasing trend in the use of spill as that survival protection scheme is replaced. However, current limited electrical demand, generation capacity, and nitrogen abatement spill could result in considerable "involuntary" spill during "wet years", e.g. 1982 and 1983. Thus additional factors from natural sources may be encountered.

The assumptions on anticipated sample size, natural variability, range of flows and accuracy of survival estimates are the same as for scenario one. Combining all these factors it appears that it is not feasible to separate the benefits from the water budget, from the other potential changes in the system. For example, if the next few years continue to have above normal runoff and limited electric power demands (and therefore relatively high associated spill levels) followed by dryer years accompanied by successful operation of collection and bypass systems, then the resulting data will not be sufficient to separate these joint or confounded effects.

One might approach this situation from the point of view that estimates of individual components, i.e. spill, turbine, collection and bypass survival rates and associated percentage passage via these routes, could be estimated and the changes in these components "somehow" accounted for in the evaluation of the water budget. Releases of marked fish to obtain estimates of each of the required components, with sufficient precision, is unlikely and consensus or extrapolated values would likely have to be relied upon.

Thus, the evaluation of the water budget under this likely scenario would appear to be a rather qualitative assessment, that would probably not be able to associate benefits of changes in flow and spill to changes in survival.

EXAMPLE CALCULATIONS

In order to evaluate the expected relationships among number of marks released, percent of run examined, survival rate estimates and confidence limits, the standard errors associated with a range of values are presented. Survival estimates of 0.4, 0.5 and 0.6 are examined, along with percent examined values of 0.03, 0.06 and 0.09. Marks released are assumed to be 5000, 15,000, and 30,000 for the direct method and 15,000, 37,500, and 75,000 for the indirect method. The variance of e was estimated based on Sims et al. (1983) and McKenzie et al. (1984).

DIRECT ESTIMATION TECHNIQUE WITHOUT TRANSPORTATION

An example of the expected performance of this approach can be based on existing data from the releases of chinook smolts in the 1982 Systems Mortality Study (McKenzie et al. 1984). The daily recoveries, fraction of the bypass fish examined as presented in Table 1 are from the Pateros group released on April 26, 1982. Daily collection efficiency, e_i , and its variance are calculated from a regression line fitted to efficiency release and recovery 1982 study data. The regression line is:

$$e_i = 0.846 - 0.0152 (\% \text{ SPILL}_i)$$

and

$$\text{Var}(e_i) = 0.00256 \left[1 + \frac{1}{20} + \frac{(e_i - 39.684)^2}{553.37} \right]$$

where: % spill is the average percent of total flow through the spillway over a three day period at 2200 hours.

The number of marks released, N_0 , was equal to 50000 and the recoveries were truncated on 5/31/82 for this example. These calculations indicate that an estimated survival rate of 0.40 would have 95% confidence limits of 0.40 ± 0.086 or .0314 to .0486 (31.4 to 48.6%).

TABLE 1. Example calculation of survival rate and variance for the direct estimation technique without transportation, partially based on the 1982 systems mortality data. N = 50,000.

DATE	R*	E	f*	e	%SPILL	p	p/E	VAR(e)*	VAR(E)	VAR(p)	VAR(p/E)
5/05	1	0.039	0.125	0.32	34.83	0.00002	0.001	0.0028	4.37E-05	4.00E-10	2.64E-07
5/06	4	0.036	0.138	0.26	38.64	0.00008	0.002	0.0027	5.12E-05	1.60E-09	1.48E-06
5/07	15	0.045	0.174	0.26	38.51	0.00030	0.007	0.0027	8.20E-05	6.00E-09	4.69E-06
5/08	20	0.058	0.175	0.33	33.73	0.00040	0.007	0.0029	8.78E-05	8.00E-09	3.57E-06
5/09	68	0.052	0.125	0.41	28.44	0.00136	0.026	0.0033	5.11E-05	2.72E-08	2.35E-05
5/10	27	0.041	0.111	0.37	31.16	0.00054	0.013	0.0030	3.73E-05	1.08E-08	1.01E-05
5/11	33	0.038	0.107	0.36	32.08	0.00066	0.017	0.0030	3.39E-05	1.32E-08	1.59E-05
5/12	41	0.040	0.107	0.37	31.14	0.00082	0.021	0.0030	3.49E-05	1.64E-08	1.96E-05
5/13	53	0.047	0.121	0.39	30.01	0.00106	0.023	0.0031	4.55E-05	2.12E-08	2.01E-05
5/14	40	0.046	0.121	0.38	30.72	0.00080	0.018	0.0031	4.47E-05	1.60E-08	1.42E-05
5/15	35	0.031	0.121	0.26	38.45	0.00070	0.022	0.0027	3.93E-05	1.40E-08	3.39E-05
5/16	31	0.039	0.209	0.19	43.39	0.00062	0.016	0.0028	1.21E-04	1.24E-08	2.88E-05
5/17	22	0.019	0.164	0.11	48.13	0.00044	0.024	0.0030	8.13E-05	8.80E-09	1.60E-04
5/18	13	0.023	0.157	0.14	46.07	0.00026	0.012	0.0029	7.06E-05	5.20E-09	2.85E-05
5/19	53	0.021	0.200	0.11	48.57	0.00106	0.050	0.0031	1.22E-04	2.12E-08	7.24E-04
5/20	37	0.020	0.200	0.10	49.12	0.00074	0.038	0.0031	1.24E-04	1.48E-08	5.04E-04
5/21	21	0.020	0.200	0.10	48.87	0.00042	0.021	0.0031	1.23E-04	8.40E-09	1.48E-04
5/22	35	0.037	0.200	0.19	43.34	0.00070	0.019	0.0027	1.10E-04	1.40E-08	3.84E-05
5/23	44	0.050	0.200	0.25	39.14	0.00088	0.018	0.0027	1.08E-04	1.76E-08	2.04E-05
5/24	20	0.046	0.200	0.23	40.54	0.00040	0.009	0.0027	1.08E-04	8.00E-09	7.78E-06
5/25	13	0.045	0.200	0.22	40.90	0.00026	0.006	0.0027	1.08E-04	5.20E-09	4.46E-06
5/26	16	0.034	0.184	0.19	43.35	0.00032	0.009	0.0028	9.30E-05	6.40E-09	1.25E-05
5/27	13	0.034	0.200	0.17	44.54	0.00026	0.008	0.0028	1.12E-04	5.20E-09	1.06E-05
5/28	11	0.022	0.200	0.11	48.19	0.00022	0.010	0.0030	1.21E-04	4.40E-09	3.21E-05
5/29	4	0.016	0.174	0.09	49.61	0.00008	0.005	0.0031	9.51E-05	1.60E-09	1.65E-05
5/30	2	0.021	0.167	0.13	47.15	0.00004	0.002	0.0029	8.18E-05	8.00E-10	2.40E-06
5/31	5	0.029	0.161	0.18	43.67	0.00010	0.003	0.0028	7.18E-05	2.00E-09	3.35E-06
TOTAL	677						SURVIVAL 0.404			VAR($\bar{S}$) =0.0018893	
										S.E. =0.0434666	

* Based on the 4/26/82 Pateros release group and efficiency release groups.

These calculations can be generalized to evaluate the expected variance under alternative applications. The expected number of recoveries can be estimated by $R = ES N_0$, and an average value, R/n , assigned to each day for which recoveries are anticipated. With an average or approximate value of $Var(e)$ used, Monte Carlo simulations indicate less than a 10% increase in survival results from a wide range of flow conditions. From the two regressions a value of 0.003 (McKenzie et al. 1984) to 0.007 (Sims et al. 1983) appears to be appropriate.

The following standard errors for $S_0 S_1 = 0.4$, $n = 8$ days, can be calculated:

Number Released	Var(e)	Percent Run Examined		
		0.03	0.06	0.09
5000	0.003	0.060	0.048	0.043
	0.007	0.070	0.060	0.056
15000	0.003	0.043	0.037	0.035
	0.007	0.056	0.052	0.050
30000	0.003	0.037	0.034	0.033
	0.007	0.052	0.050	0.049

These values can be interpreted as follows: if 15000 marked fish are released, 6% of the run is examined for marks, and the true survival is 0.40, then we would expect a S.E. of .037 and 95% confidence limits of approximately ± 0.074 (32.6 to 47.4% survival). An example assuming a 6% sampling rate is provided in Table 2.

Appendix A contains additional values for $N_0 = 30000$, $S = 0.4, 0.5, 0.6$ and $n = 8, 15, 25$. These calculations cover a short reach, intermediate without dams, and long reach with several dams. The expected number of recoveries is also included in those calculations to aid in evaluating the experimental validity.

DIRECT ESTIMATION WITH TRANSPORTATION

Approximate standard errors can be calculated for the Snake River section, assuming a survival rate of 0.40 and the following set of parameter values:

TABLE 2. Example calculation of survival rate and variance for the direct estimation technique without transportation, partially based on the 1982 systems mortality data. N = 50,000; 6% examined.

DATE	R	E	f	e	%SPILL	p	p/E	VAR(e)	VAR(E)	VAR(p)	VAR(p/E)
5/05	2	0.079	0.250	0.32	34.83	0.00004	0.001	0.0028	1.75E-04	8.00E-10	1.36E-07
5/06	8	0.071	0.276	0.26	38.64	0.00016	0.002	0.0027	2.05E-04	3.20E-09	8.41E-07
5/07	30	0.090	0.349	0.26	38.51	0.00060	0.007	0.0027	3.28E-04	1.20E-08	3.23E-06
5/08	40	0.117	0.351	0.33	33.73	0.00080	0.007	0.0029	3.51E-04	1.60E-08	2.39E-06
5/09	136	0.103	0.250	0.41	28.44	0.00272	0.026	0.0033	2.05E-04	5.44E-08	1.84E-05
5/10	54	0.083	0.222	0.37	31.16	0.00108	0.013	0.0030	1.49E-04	2.16E-08	6.92E-06
5/11	66	0.077	0.214	0.36	32.08	0.00132	0.017	0.0030	1.36E-04	2.64E-08	1.14E-05
5/12	82	0.080	0.215	0.37	31.14	0.00164	0.021	0.0030	1.39E-04	3.28E-08	1.44E-05
5/13	106	0.094	0.241	0.39	30.01	0.00212	0.023	0.0031	1.82E-04	4.24E-08	1.53E-05
5/14	80	0.091	0.242	0.38	30.72	0.00160	0.018	0.0031	1.79E-04	3.20E-08	1.04E-05
5/15	70	0.063	0.241	0.26	38.45	0.00140	0.022	0.0027	1.57E-04	2.80E-08	2.68E-05
5/16	62	0.078	0.419	0.19	43.39	0.00124	0.016	0.0028	4.83E-04	2.48E-08	2.47E-05
5/17	44	0.037	0.328	0.11	48.13	0.00088	0.024	0.0030	3.25E-04	1.76E-08	1.47E-04
5/18	26	0.045	0.313	0.14	46.07	0.00052	0.012	0.0029	2.82E-04	1.04E-08	2.34E-05
5/19	106	0.042	0.400	0.11	48.57	0.00212	0.050	0.0031	4.89E-04	4.24E-08	7.00E-04
5/20	74	0.039	0.400	0.10	49.12	0.00148	0.038	0.0031	4.96E-04	2.96E-08	4.85E-04
5/21	42	0.041	0.400	0.10	48.87	0.00084	0.021	0.0031	4.93E-04	1.68E-08	1.38E-04
5/22	70	0.074	0.400	0.19	43.34	0.00140	0.019	0.0027	4.40E-04	2.80E-08	3.33E-05
5/23	88	0.100	0.400	0.25	39.14	0.00176	0.018	0.0027	4.30E-04	3.52E-08	1.69E-05
5/24	40	0.091	0.400	0.23	40.54	0.00080	0.009	0.0027	4.31E-04	1.60E-08	5.87E-06
5/25	26	0.089	0.400	0.22	40.90	0.00052	0.006	0.0027	4.31E-04	1.04E-08	3.15E-06
5/26	32	0.068	0.368	0.19	43.35	0.00064	0.009	0.0028	3.72E-04	1.28E-08	9.76E-06
5/27	26	0.067	0.400	0.17	44.54	0.00052	0.008	0.0028	4.48E-04	1.04E-08	8.32E-06
5/28	22	0.045	0.400	0.11	48.19	0.00044	0.010	0.0030	4.84E-04	8.80E-09	2.77E-05
5/29	8	0.031	0.348	0.09	49.61	0.00016	0.005	0.0031	3.80E-04	3.20E-09	1.33E-05
5/30	4	0.043	0.333	0.13	47.15	0.00008	0.002	0.0029	3.27E-04	1.60E-09	1.52E-06
5/31	10	0.058	0.323	0.18	43.67	0.00020	0.003	0.0028	2.87E-04	4.00E-09	2.17E-06
1354						SURVIVAL		0.404	VAR($\bar{S}$) = 0.0017505		
									S.E. = 0.0418394		

Lower Granite and Little Goose

0.25 = collection efficiency (% transported)

0.007 = variance of e

15 = days of transportation

Number Released	Var(e)	Percent Run Examined		
		0.03	0.06	0.09
30000	0.003	0.033	0.027	0.024
	0.007	0.039	0.034	0.032
50000	0.003	0.028	0.024	0.022
	0.007	0.035	0.031	0.030
70000	0.003	0.026	0.022	0.021
	0.007	0.033	0.030	0.029

Additional results for alternate survival rates are provided in Table 3.

INDIRECT ESTIMATION

If $p_c = 0.03$, $S_0 S_1 = 0.5$ and $N_c = \frac{1}{2} N_t$, then

$$\begin{aligned}
 \text{Var}(S) &= \frac{1}{N_t^2} \text{Var}\left(\frac{R_t}{p_c}\right) = \left(\frac{1}{N_t^2}\right) \left(\frac{0.015 N_t}{0.03}\right)^2 \left[\frac{(0.015)(0.985) N_t}{0.015 N_t^2} + \frac{(0.03)(0.97)}{(0.5) N_c (0.03)^2} \right] \\
 &= 0.25 \left(\frac{65.7}{N_t} + \frac{64.7}{N_t} \right) \\
 &= \frac{32.6}{N_t}
 \end{aligned}$$

The following standard deviation can then be easily calculated:

Number Released		Percent Run Examined		
N_t	N_c	0.03	0.06	0.09
10000	5000	0.057	0.040	0.032
25000	12500	0.036	0.025	0.020
50000	25000	0.026	0.018	0.014

TABLE 3. Standard errors for survival estimates from Snake River with transportation.

NUMBER RELEASED = 30000
 RECOVERY PERIOD = 25

DAYS= 15
 $e = 0.25$ $\text{VAR}(e) = 0.007$
 $V(e) = 0.007$ $\text{VAR}(CT) = 0.00105$

S	E	e	f	R	Ri	p	CT	p/E/CT	VAR(E)	VAR(p)	VAR(p/E/CT)	S.E.
0.4	0.03	0.25	0.12	203	8	0.0003	0.563	0.016	0.00010	9E-09	0.00153	0.039
	0.06	0.25	0.24	405	16	0.0005	0.563	0.016	0.00040	1.8E-08	0.00113	0.034
	0.09	0.25	0.36	608	24	0.0008	0.563	0.016	0.00091	2.7E-08	0.00100	0.032
0.5	0.03	0.25	0.12	253	10	0.0003	0.563	0.02	0.00010	1.13E-08	0.00214	0.046
	0.06	0.25	0.24	506	20	0.0007	0.563	0.02	0.00040	2.25E-08	0.00165	0.041
	0.09	0.25	0.36	759	30	0.001	0.563	0.02	0.00091	3.38E-08	0.00148	0.039
0.6	0.03	0.25	0.12	304	12	0.0004	0.563	0.024	0.00010	1.35E-08	0.00285	0.053
	0.06	0.25	0.24	608	24	0.0008	0.563	0.024	0.00040	2.7E-08	0.00225	0.047
	0.09	0.25	0.36	911	36	0.0012	0.563	0.024	0.00091	4.05E-08	0.00206	0.045

DISCUSSION

A direct quantitative evaluation of the effectiveness of the Water Budget does not appear to be feasible due to our inability to experimentally vary the flows and control other factors. Thus, an evaluation of the water budget must be based on an accumulation of related information and considerable scientific judgment and interpretation of the data. It is suggested that a model be developed to serve as a representation of our understanding of how the system functions and to aid in evaluation alternative hypotheses and explanations of the observed data.

It appears that it is feasible to estimate survival rates in some sections of the River Basin on a yearly basis. A caveat for that statement is that discussions on the biological aspects are needed to ascertain if the underlying biological assumptions can be met. For the indirect estimation approach, the key statistical assumption is equal recovery effort on the two groups. This requirement can be met by either: 1) achieving mixing between the two groups at the recovery site, or 2) maintaining a constant recovery effort throughout the period over which marked fish arrive at the recovery site. An approach to mixing is to release the control group in a series of releases that mimic the pattern of the target group passing that point. An approach to constant recovery effort is suggested by the collection efficiency relationships in Sims et al. (1983) and McKenzie et al. (1984), which indicate that a constant proportion of turbine flow to total flow would increase the likelihood of desired results.

The establishment of the control group requires some compromises among the factors being controlled. Two aspects of this problem discussed were the need to control for similar migration and recovery time and to control for similar fish condition at time of release. Holding fish in the hatchery in order to release the control group to attain mixing probably results in different fish condition at time of release. Alternately, releasing both groups at the same time results in similar fish condition, but results in different migration and recovery patterns. A recommended strategy for

dealing with this to have multiple releases for the control groups, releasing both types of controls.

For the direct estimation approach, the key component is accurate determination of the collection efficiency at the recovery dam, viz., McNary Dam. The parameters for the relationship of flow (total, % turbine, % spill) to collection efficiency and associated variances are required for the estimation of survival.

The estimation of survival in the Snake River System is complicated by the transportation activities from Lower Granite and Little Goose Dams. Estimation of survival rates in the Snake River System are dependent upon reasonably accurate estimates of parameters associated with smolt transportation. The minimum amount of information needed appears to be estimates of the percentage of the run transported, which could be based on estimates of collection efficiency. Alternatively, estimates of the number of marked smolts transported could be used, thereby permitting survival rates to be estimated. However, fairly large numbers of marked fish, small variances for the estimates of transportation parameters, and rather high recovery percentages at McNary would be required to estimate survival rates with reasonable confidence limits.

The transportation activity results in potentially removing substantial numbers of the marked fish from the river especially in low flow years. Thus, the expected number of recoveries at McNary Dam would be substantially reduced. In addition, estimates of neither the proportion nor the number of marked fish transported are known with reasonable confidence for use in this approach. Available data provides only an approximation of the percent transported at Lower Granite. Therefore, based on current information on the likely numbers of fish available for marking and transportation parameters, it appears that acceptable estimates of survival would be unavailable.

The variance estimates examined by the committee deal primarily with the variance associated with the survival estimate based on a single set of treatment and control groups. Estimation of variances among groups would require multiple sets of marked fish, and it was felt that this objective

could not be met within present fish availability. Annual variation, that is variation in survival rate among years with similar river flows, requires several years of observation in order to obtain an estimate and those estimates may remain approximate due to changes within the river basin.

In undertaking to evaluate the Water Budget, it is important that rationale, design, anticipated analysis and limitations on interpretability of the results be established prior to initiating a data collection effort. Expenditures of resources, fish and economic, on efforts with little potential for contributing to our understanding of the system functioning should be minimized.

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APPENDIX

ADDITIONAL CALCULATIONS FOR THE DIRECT ESTIMATION TECHNIQUE

TABLE A-1. Calculation of Standard Errors Based on a Short Recovery Period and Var(e) from McKenzie et al. 1984.

NUMBER RELEASED = 30000
RECOVERY PERIOD = 8

VAR(e)= 0.003

S	E	e	f	R	Ri	p	p/E	VAR(E)	VAR(p)	VAR(p/E)	S.E.
0.4	0.03	0.25	0.12	360	45	0.0015	0.05	0.00004	5E-08	0.00140	0.037
	0.06	0.25	0.24	720	90	0.003	0.05	0.00017	1E-07	0.00118	0.034
	0.09	0.25	0.36	1080	135	0.0045	0.05	0.00039	1.5E-07	0.00111	0.033
0.5	0.03	0.25	0.12	450	56	0.0019	0.0625	0.00004	6.25E-08	0.00206	0.045
	0.06	0.25	0.24	900	113	0.0038	0.0625	0.00017	1.25E-07	0.00178	0.042
	0.09	0.25	0.36	1350	169	0.0056	0.0625	0.00039	1.88E-07	0.00169	0.041
0.6	0.03	0.25	0.12	540	68	0.0023	0.075	0.00004	7.5E-08	0.00283	0.053
	0.06	0.25	0.24	1080	135	0.0045	0.075	0.00017	1.5E-07	0.00249	0.050
	0.09	0.25	0.36	1620	203	0.0068	0.075	0.00039	2.25E-07	0.00238	0.049

A-1

TABLE A-2. Calculation of Standard Errors Based on a Short Recovery Period and Var(e) from Sims et al. 1983.

NUMBER RELEASED = 30000
RECOVERY PERIOD = 8

VAR(e)= 0.007

S	E	e	f	R	Ri	p	p/E	VAR(E)	VAR(p)	VAR(p/E)	S.E.
0.4	0.03	0.25	0.12	360	45	0.0015	0.05	0.00010	5E-08	0.00268	0.052
	0.06	0.25	0.24	720	90	0.003	0.05	0.00040	1E-07	0.00246	0.050
	0.09	0.25	0.36	1080	135	0.0045	0.05	0.00091	1.5E-07	0.00239	0.049
0.5	0.03	0.25	0.12	450	56	0.0019	0.0625	0.00010	6.25E-08	0.00406	0.064
	0.06	0.25	0.24	900	113	0.0038	0.0625	0.00040	1.25E-07	0.00378	0.061
	0.09	0.25	0.36	1350	169	0.0056	0.0625	0.00091	1.88E-07	0.00369	0.061
0.6	0.03	0.25	0.12	540	68	0.0023	0.075	0.00010	7.5E-08	0.00571	0.076
	0.06	0.25	0.24	1080	135	0.0045	0.075	0.00040	1.5E-07	0.00537	0.073
	0.09	0.25	0.36	1620	203	0.0068	0.075	0.00091	2.25E-07	0.00526	0.073

TABLE A-3. Calculation of Standard Errors Based on an Intermediate Recovery Period and Var(e) from McKenzie et al. 1984.

NUMBER RELEASED = 30000
RECOVERY PERIOD = 15

VAR(e)= 0.003

S	E	e	f	R	Ri	p	p/E	VAR(E)	VAR(p)	VAR(p/E)	S.E.
0.4	0.03	0.25	0.12	360	24	0.0008	0.0267	0.00004	2.67E-08	0.00096	0.031
	0.06	0.25	0.24	720	48	0.0016	0.0267	0.00017	5.33E-08	0.00073	0.027
	0.09	0.25	0.36	1080	72	0.0024	0.0267	0.00039	8E-08	0.00066	0.026
0.5	0.03	0.25	0.12	450	30	0.001	0.0333	0.00004	3.33E-08	0.00136	0.037
	0.06	0.25	0.24	900	60	0.002	0.0333	0.00017	6.67E-08	0.00108	0.033
	0.09	0.25	0.36	1350	90	0.003	0.0333	0.00039	1E-07	0.00099	0.031
0.6	0.03	0.25	0.12	540	36	0.0012	0.04	0.00004	4E-08	0.00182	0.043
	0.06	0.25	0.24	1080	72	0.0024	0.04	0.00017	8E-08	0.00149	0.039
	0.09	0.25	0.36	1620	108	0.0036	0.04	0.00039	1.2E-07	0.00137	0.037

A-2

TABLE A-4. Calculation of Standard Errors Based on an Intermediate Recovery Period and Var(e) from Sims et al. 1983.

NUMBER RELEASED = 30000
RECOVERY PERIOD = 15

VAR(e)= 0.007

S	E	e	f	R	Ri	p	p/E	VAR(E)	VAR(p)	VAR(p/E)	S.E.
0.4	0.03	0.25	0.12	360	24	0.0008	0.0267	0.00010	2.67E-08	0.00164	0.040
	0.06	0.25	0.24	720	48	0.0016	0.0267	0.00040	5.33E-08	0.00142	0.038
	0.09	0.25	0.36	1080	72	0.0024	0.0267	0.00091	8E-08	0.00134	0.037
0.5	0.03	0.25	0.12	450	30	0.001	0.0333	0.00010	3.33E-08	0.00242	0.049
	0.06	0.25	0.24	900	60	0.002	0.0333	0.00040	6.67E-08	0.00214	0.046
	0.09	0.25	0.36	1350	90	0.003	0.0333	0.00091	1E-07	0.00205	0.045
0.6	0.03	0.25	0.12	540	36	0.0012	0.04	0.00010	4E-08	0.00335	0.058
	0.06	0.25	0.24	1080	72	0.0024	0.04	0.00040	8E-08	0.00302	0.055
	0.09	0.25	0.36	1620	108	0.0036	0.04	0.00091	1.2E-07	0.00291	0.054

TABLE A-5. Calculation of Standard Errors Based on a Long Recovery Period and Var(e) from McKenzie et al. 1984.

NUMBER RELEASED = 30000
RECOVERY PERIOD = 25

VAR(e)= 0.003

S	E	e	f	R	Ri	p	p/E	VAR(E)	VAR(p)	VAR(p/E)	S.E.
0.4	0.03	0.25	0.12	360	14	0.0005	0.016	0.00004	1.6E-08	0.00075	0.027
	0.06	0.25	0.24	720	29	0.001	0.016	0.00017	3.2E-08	0.00053	0.023
	0.09	0.25	0.36	1080	43	0.0014	0.016	0.00039	4.8E-08	0.00046	0.021
0.5	0.03	0.25	0.12	450	18	0.0006	0.02	0.00004	2E-08	0.00104	0.032
	0.06	0.25	0.24	900	36	0.0012	0.02	0.00017	4E-08	0.00076	0.028
	0.09	0.25	0.36	1350	54	0.0018	0.02	0.00039	6E-08	0.00067	0.026
0.6	0.03	0.25	0.12	540	22	0.0007	0.024	0.00004	2.4E-08	0.00136	0.037
	0.06	0.25	0.24	1080	43	0.0014	0.024	0.00017	4.8E-08	0.00102	0.032
	0.09	0.25	0.36	1620	65	0.0022	0.024	0.00039	7.2E-08	0.00091	0.030

TABLE A-6. Calculation of Standard Errors Based on a Long Recovery Period and Var(e) from Sims et al. 1983.

NUMBER RELEASED = 30000
RECOVERY PERIOD = 25

VAR(e)= 0.007

S	E	e	f	R	Ri	p	p/E	VAR(E)	VAR(p)	VAR(p/E)	S.E.
0.4	0.03	0.25	0.12	360	14	0.0005	0.016	0.00010	1.6E-08	0.00116	0.034
	0.06	0.25	0.24	720	29	0.001	0.016	0.00040	3.2E-08	0.00094	0.031
	0.09	0.25	0.36	1080	43	0.0014	0.016	0.00091	4.8E-08	0.00086	0.029
0.5	0.03	0.25	0.12	450	18	0.0006	0.02	0.00010	2E-08	0.00168	0.041
	0.06	0.25	0.24	900	36	0.0012	0.02	0.00040	4E-08	0.00140	0.037
	0.09	0.25	0.36	1350	54	0.0018	0.02	0.00091	6E-08	0.00131	0.036
0.6	0.03	0.25	0.12	540	22	0.0007	0.024	0.00010	2.4E-08	0.00228	0.048
	0.06	0.25	0.24	1080	43	0.0014	0.024	0.00040	4.8E-08	0.00195	0.044
	0.09	0.25	0.36	1620	65	0.0022	0.024	0.00091	7.2E-08	0.00184	0.043

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