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EVALUATION OF EXISTING FISHERIES MEASURES AT THE WYNOOCHEE LAKE PROJECT

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INTRODUCTION

The Wynoochee Dam was built at river mile (RM) 50 of the Wynoochee River in Grays Harbor County and closed in October, 1972. Coho, steelhead, and sea-run cutthroat had utilized the area upstream of the resulting reservoir. The dam was designed to maintain natural anadromous fish production in the river above the reservoir. To this end, adult fish are trapped at a barrier dam two miles below the main Wynoochee Dam and released at the head of the reservoir. Outlet pipes with openings at several levels along the upstream face and leading down to the tailrace were incorporated into the dam to allow juvenile fish to freely migrate downstream.

Coho and steelhead smolt mortality due to the dam soon became evident (Dunn 1978, Lavoy and Fenton 1979), although the exact effect on adult run sizes has not been as clearly demonstrated. To determine adult losses, Gerke (Sandison 1979) estimated the mean annual coho runs before and after the effects of closure of the Wynoochee Dam, based on returns to the barrier dam. The Washington Department of Fisheries (WDF) requested additional mitigation for these losses. The Washington Department of Game (WDG) also requested additional mitigation for the entire estimated run of steelhead and cutthroat produced above the reservoir (Corps of Engineers 1979). The Corps then commissioned Mathews (1980) to assess these studies and present other information pertinent to these runs. Finally, the Corps requested the U.S. Fish and Wildlife Service (FWS) evaluate the existing fishery measures, and specifically:

1. consider the requests for additional mitigation,

2. address the trends and status of fish runs into other Washington coastal rivers and the relationship with Wynoochee runs,and

3. recommend additional mitigation measures, if needed.

This report will estimate the loss of coho and steelhead runs naturally produced above the lake by calculating the mean wild run sizes produced by the river upstream from the lake, before and after completion of the dam. This is the method used by Gerke (Sandison 1979) to calculate losses of naturally-produced coho above Wynoochee Lake. We define "upper Wynoochee" as the barrier dam trap and the area upstream, and "lower Wynoochee" as the river below that point.

We assume the dam's only significant impact is the reduced survival to adulthood of smolts produced upstream of the dam. The dam was completed and the reservoir began filling in October, 1972. We assumed that smolt migration from the river above the lake site was first affected in the spring of 1973. By this assumption, adult coho and steelhead returns would first be affected in the fall and winter of 1974-75. There is not enough data available to evaluate the possible effects of basin clearing which began in 1969 and was completed in 1972. Wild runs produced by the Wynoochee above the lake are estimated by expanding the total return to the barrier dam by the catch-to-escapement ratio (C/E) and by subtracting projected returns of hatchery releases.

The years are then divided into two groups: those that represent smolt outmigration before completion of the dam, and those that represent outmigration after completion of the dam. The mean adult return is calculated for each group. Losses due to the dam are then determined by calculating the percent loss to the upper Wynoochee wild run. From this we subtract the percent loss in the rest of the Grays Harbor coho run, or the lower Wynoochee steelhead run, as appropriate. Mitigation should be requested for the remaining percent loss.

Evaluation of steelhead planted under the existing mitigation agreement is assessed in a separate report (Hiss et al. 1983).

Throughout these analyses it was necessary to assume that all returns of hatchery fish to the barrier dam represent releases made in the immediate vicinity of the dam and not in the lower river, and that no smolts released near the barrier dam spawned in the lower river. It was also necessary to treat upper and lower river wild fish as separate populations.

WILD COHO RUN STATUS

The original mitigation agreement did not address coho because WDF believed that virtually all the run spawned above the lake (Deschamps et al. 1966) and fish passage facilities designed into the dam would allow downstream migration with relatively little mortality. However, studies by Dunn (1978) showed that the dam did cause coho smolt mortality. Passage through the pipes apparently was not as significant a cause of smolt mortality as the unavoidable turbulence in the tailrace.

The dam also appeared to delay outmigration by about one month. Perhaps as a result of this delay, adult coho returns from marked releases above the dam were slightly higher than controls released downstream of the tailrace. These results were discussed by Mathews (1980) but the extent to which the extra rearing time might compensate for tailrace mortality was not determined.

Three methods of determining loss to the upper Wynoochee coho run have been proposed. Dunn (1978) based his estimates on original escapement estimates (Deschamps et al. 1966), smolt production per mile of habitat, and coded wire tag (CWT) returns from one small group of native fish. We did not use this method because of the availability of other pertinent information.

Gerke (Sandison 1979) examined pre-dam and post-dam trap counts, hatchery smolt releases, annual survival rates, and annual C/E ratios. We used this method, with some refinements, because it took into account all available information for a number of years. This method also accounts for losses due to inundation of any spawning grounds in the lake site. That is, run sizes were estimated from total barrier dam counts in all years, including those before dam closure. The third method of assessing losses was used by Mathews (1980) and is similar to Gerke's except it assumes constant survival and exploitation over all years. In view of hatchery problems in some years and definite changes in ocean exploitation, we did not think this method was representative.

In the present analysis, wild runs were calculated from annual total returns to the barrier dam, estimated returns of both first-and second-generation hatchery fish, and the catch-to-escapement (C/E) ratios. First-generation hatchery fish are those released as smolts the previous year. Second-generation hatchery fish are offspring of hatchery-origin fish that spawned above the dam three years before the return year. The apparent wild run is the combination of wild stock and second-generation hatchery stock; that is, the progeny of the hatchery-stock adults that spawned in the wild. Both first- and second-generation hatchery fish were discounted from the total run to calculate the wild run.

Returns of the first-generation hatchery fish to the barrier dam were usually calculated from releases of smolts in the immediate vicinity of the barrier dam, and their percent survival. Returns of second-generation hatchery fish to the dam were calculated from broodyear escapement, survival, and hatchery/wild composition when such data was available.

Catch-to-escapement ratios and smolt survival rates were calculated from the latest available WDF data for Grays Harbor (see Appendix I-A for calculations of smolt survival and Appendix I-B for C/E). Catches were expanded to account for ocean interception. Jacks were not considered in these calculations because they had essentially no contribution to the fisheries.

The return years 1971 to 1973 constitute the base period. The upper Wynoochee wild run for the 1971 return was calculated by the formula:

$$R = E(C/E + 1) - PS$$

where:

R = run size of wild fish produced in the upper Wynoochee
E = escapement to upper Wynoochee (barrier dam count)
C/E = estimated catch-to-escapement ratio
P = number of smolts planted at or near the barrier dam in the previous year
S = estimated survival of planted smolts.

No adjustment for second-generation hatchery stock was necessary because no hatchery origin coho returned to the upper Wynoochee in 1967. The upper Wynoochee wild run for the 1972 and 73 return years was calculated by the formula

$$R = 0.677\ [E(C/E + 1) - PS].$$

A factor of 0.677 is applied to account for second-generation hatchery stock derived from 1966 and 1967 brood years. This factor is the mean proportion of apparent wild fish in the base year runs (1971-73). Because escapements at the dam in 1969 and 1970 are not known, it was assumed that the hatchery/wild ratio was constant through 1973. The factor of 0.677 was then applied to the 1969 and 1970 returns to compute the wild run size.

Return years 1974 to 1982 constitute the post-dam period. Within this period, returns from 1974 through 1976 were estimated using Dunn's (1978) mark recoveries at the barrier dam to calculate returns of first generation hatchery fish (see Appendix I-C for calculation). This method was necessary because the adult returns represented experimental releases atypical of normal hatchery procedures. Moreover, this mark recovery information was the most direct way of accounting for hatchery versus wild escapement. Unfortunately this data was not available in other years. We are not aware of any bias between this method and that used for other years in estimating the hatchery-produced return to the dam.

The apparent number of wild fish at the barrier dam was adjusted annually by the apparent proportion of wild fish in the brood year escapement. This was assumed to account for second-generation hatchery stock, based on the assumption that the actual hatchery/wild composition of the apparent wild returns was the same as the first-generation hatchery/wild composition of the brood year escapement to the dam. The total wild run was then calculated by applying the C/E ratio. Thus:

$R = (Ew)(Ewb)(C/E + 1)/Eb$

where: Ew = apparent wild escapement to upper Wynoochee; that is, wild stock and second-generation hatchery stock but not first-generation hatchery stock.
Ewb = apparent wild broodyear escapement, and
Eb = total broodyear escapement, including first-generation hatchery stock.

Upper Wynoochee wild run for the 1977-82 return years was calculated by the formula:

$R = [E(C/E + 1) - PS] Ewb/Eb.$

Run sizes for all years are presented in Table 1.

The wild run to the rest of Grays Harbor was calculated for comparison to the upper Wynoochee run size trends before and after the dam. A similar formula was used to calculate the estimated wild component of the coho run to Grays Harbor as a whole. The previously-calculated Wynoochee run was then subtracted from this total. See Appendix I-D for calculations.

The wild run averaged 6,348 before the dam and 3,732 afterward, for a difference of 2,758 fish. Applying a correction (Dunn 1978) for reduced size wild fish, we have 3,732/26.3, or 142 additional fish, for a total post-dam loss of 2,616. This amounts to a 43.4% decline.

The loss of 2,616 fish in the upper Wynoochee is based in Gerke's procedure with updated and revised survival and C/E data and an accounting of second-generation returns of hatchery stock. In contrast, Gerke's original request was 2,225 adults (Sandison 1979). This difference is due to our higher C/E ratios in the post-dam years (Appendix I-B), and to the the accounting for second-generation hatchery stock. This decline was compared to trends in other wild runs bound for the rest of Grays Harbor (Figure 1) (run size data are not available for individual rivers). The Grays Harbor run size (calculated in Appendix I-D) declined 30.7% from 1971-73 to 1974-82. Considering the overall decline in run sizes for Grays Harbor rivers, the net impact of the Wynoochee dam on the upper Wynoochee coho run appears to be a loss of 12.7% of the mean pre-dam natural run; that is, (6,348)(0.127) = 806 adult coho.

These calculations support the theory that temporary residualism caused by the dam does not compensate for mortality in smolt passage. We agree with Mathews' (1980) conclusion that the experiments with hatchery coho showing greater survival to adult return from smolts released above the dam as opposed to those released below the dam were not directly applicable to wild fish.

Further, the decline of 43.4% in the upper Wynoochee run is probably an underestimate of the actual decline from average pre-dam conditions, because the 1972 and 1973 runs may have been depressed by basin clearing which was done in 1971 and 1972. Therefore, the actual loss most likely is greater than the 806 fish calculated here.

Table 1. Annual wild coho run size produced above the Wynoochee Dam.

Return Year	Total escapement to dam [a] (E)	Upper Wynoochee plant [b] (P)	Percent survival [c] (S)	C/E [d]	Wild escapement (Ew)	Wild run size (R)	Mean
71	5,727 [e]	306,800 [f]	2.17	2.78	3,966	14,990	
72	1,019	202,500	1.10	3.75	550	1,768	6,348
73	882 [g]	96,000	0.92	3.83	699	2,286	
74	2,944	-	-	2.74	1,816 [h]	4,720	
75	1,054	-	-	7.79	549 [h]	2,607	
76	3,049	-	-	7.36	1,672 [h]	11,044	
77	444	63,000 [i]	0.16	5.19	428	1,634	3,732
78	708	98,940	2.58	6.45	365	1,416	
79	1,618	0	-	2.61	1,618	3,210	
80	525	0	-	3.67	525	2,362	
81	1,586	127,300	1.115	3.34	1,249	2,792	
82	604	0	-	5.29	604	3,799	
Change							2,616
Size correction factor (3,732/26.3)							-142
Combined loss							2,758
Percent change							-43.4%

Footnotes to Table 1

a. Source: Corps of Engineers records, adjusted as noted.
b. Source: Dick Stone, WDF Montesano, personal communication except as noted. All releases are smolts.
c. Calculated in Appendix I-A and divided by 2 to account for lower survival of off-station releases, as recommended by D. Stone, personal communication.
d. Calculated in Appendix I-B.
e. Actual return/0.995 to correct for the early portion of the run that could have returned before the trap was opened at the barrier dam. Timing was averaged from 1975-82 weekly dam counts. The trap was operated all season in these years.
f. Source: Bob Gerke, WDF, personal communication. Some doubt exists as to whether these fish were released on the Wynoochee or the Satsop, due to conflicting information on hatchery records.
g. Actual return/0.990 to correct for early portion of run not sampled. See note e for details.
h. Source: Dunn 1978. Calculations in Appendix I-C.
i. Planting location not recorded. We assumed it was close to dam.

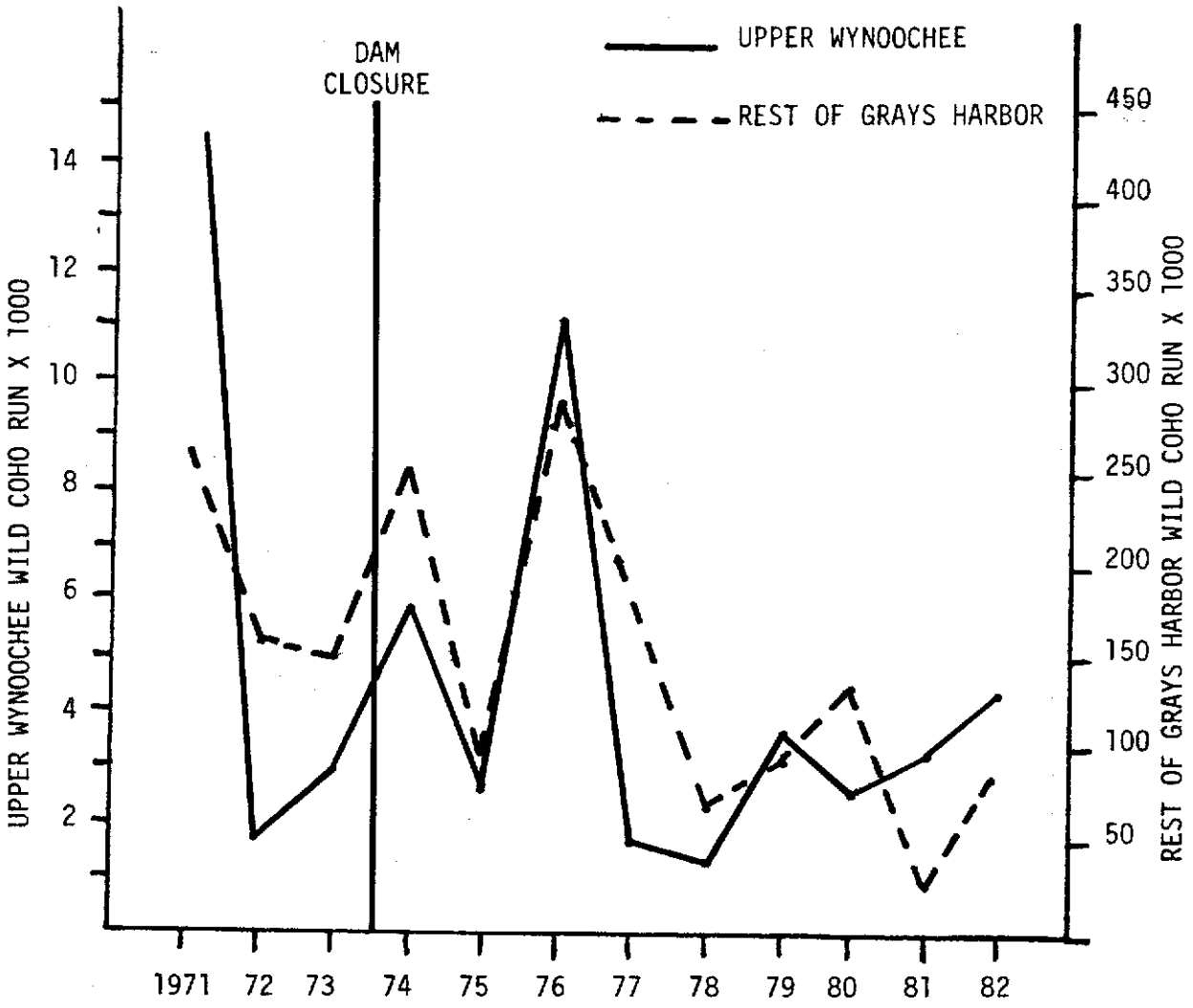

FIGURE 1. Coho run size to upper Wynoochee and to rest of Grays Harbor. Values are from text Table 1 and Appendix I-D.

WILD STEELHEAD AND CUTTHROAT RUN STATUS

LaVoy and Fenton (1979) demonstrated that the dam is a serious detriment to steelhead smolt migration. As with coho, passage through the tubes did not seem to be as much a factor as tailrace turbulence. Also, a large portion of the steelhead smolts in the reservoir failed to migrate downstream in some years. As a result, adult steelhead returns from fish originating or released above the dam were much lower than returns of fish released downstream of the tailrace. Delay in migration time did not enhance survival in the case of steelhead (Mathews 1980).

For the sake of consistency with the coho analysis we calculated annual run sizes of wild steelhead produced above the lake on the same general basis. The hatchery segment was subtracted from the total dam return and a C/E ratio was applied to the remainder (Table 2). The formula used to compute wild steelhead run size was:

$$R = (E-Eh)(1 + C/E)$$

where:

R = run size of wild fish produced upstream of reservoir
E = escapement to upper Wynoochee at the barrier dam
Eh = first-generation hatchery escapement to upper Wynoochee at barrier dam
C/E = catch-to-escapement ratio.

In contrast to coho, the hatchery return was usually estimated at the barrier dam by examination for dorsal fin stubbing. In the 1980-81 return year, when such direct data was not available, the hatchery return was calculated from smolt releases and the average rate of survival to escapement.

Also, in contrast to the coho method, the C/E could not be calculated separately for each year due to lack of escapement data. Instead, it was derived either from mark returns or aerial spawner survey when available, and applied to other years. No adjustment was made for returns of second-generation hatchery stock because of relatively poor survival of the 1973 to 1975 smolt releases, and because the more recent releases have not yet produced second-generation returns.

The wild runs from 1970-71 to 1973-74 return years make up the base period. Because this analysis concerns only steelhead spawning above the lake, the total dam counts for this period had to be adjusted to represent only the fraction of the escapement that occurred above the lake site, as estimated by early WDG surveys (LaVoy and Fenton 1979). (See Appendix II-A for calculation.)

Table 2. Annual wild steelhead run size produced above Wynoochee Lake.

Return year	Escapement to upper Wynoochee [a] (E)	Hatchery escapement to upper Wynoochee (Eh)	Wild escapement to Wynoochee above lake site	C/E [b]	Wild run to upper Wynoochee (R)	Mean
70-71	1,123 [c]	0	321 [d]	0.81	581	
71-72	1,173 [c,e]	0	335 [d]	0.81	606	463
72-73	562	0	161 [d]	0.81	291	
73-74	719	0	206 [d]	0.81	373	
74-75	444 [f]	44 [f]	400	1.38	952	
75-76	432 [f]	137 [f]	295	0.51	445	
76-77	152 [f]	24 [f]	128	1.50	320	
77-78	143	0	143	0.69	242	
78-79	31 [g]	0	31	0.69	52	
79-80	46 [g]	0	46	0.60	74	137
80-81	257 [g]	257 [h]	0	0.60	0	
81-82	281 [g]	201 [h]	80	0.60	128	
82-83	522 [g]	431 [h]	91	0.60	146	
Percent change						-70.4

a. Source: Corps of Engineers records except where noted.

b. See Appendix II-B for calculation.

c. Source: Jim Neilson, WDG, unpublished records.

d. See Appendix II-A for calculation.

e. Count begun on December 1, because previous species identifications for that year were unreliable.

f. Source: LaVoy and Fenton 1979.

g. Returns from 12-1 through 5-28 only, to eliminate summer-run returns. See Appendix II-C for selection of dates.

h. See Appendix II-D for calculation.

The wild runs from 1976-77 to 1982-83 constitute the post-dam period. The 1974-75 and 1975-76 returns were left out of the analysis because they represent a transitional period between pre-dam and post-dam run sizes. In this analysis, it was assumed that average runs were at a high, stable level before the dam, declined in the years just after completion of the dam, that is 1974-75 and 1975-76, and stablized at a lower level afterwards. On this basis, the 1976-77 to 1982-83 period was chosen to represent post-dam run sizes.

Our analysis indicates a wild run size of 463 fish before the dam and 137 afterwards, for a difference of 326 fish; that is, a decline of 70.4%. This decline was compared to the trend in another wild steelhead stock for the same period. This comparison was not made with other Grays Harbor rivers because of a lack of run size data, and environmental influences not present on the Wynoochee. It was concluded that the best comparison was with steelhead returning to the lower Wynoochee River. The annual lower river run sizes were calculated in Appendix II-E and presented in Figure 2. Over a comparable period, the lower Wynoochee run declined 21.3%. Thus the upper river had a net decline of 49.1%, for a loss of 227 fish attributable to the dam.

Trends in sea-run cutthroat abundance could not be calculated because of a lack of data on catch-to-escapement ratio or comparable runs. However, abundance of cutthroat (Table 3) appears very closely related to that of steelhead. Cutthroat counts at the barrier dam had a strong positive correlation with winter steelhead counts ($r = 0.852$, p less than 0.01). The regression equation used was:

$$c = 0.205(s) - 20$$

where:

c = cutthroat count at barrier dam
s = wild winter steelhead escapement at barrier dam.

Assuming that both species had the same vulnerability to the barrier dam trap, catch-to-escapement ratio, trend in abundance in the lower Wynoochee run and past spawning distribution above and within the present lake area, then the number of cutthroat required for mitigation should be

$$c = (0,205)(227) - 20$$
$$= 27.$$

This estimate may be low because there is some question whether cutthroat enter the trap as readily as steelhead. On the other hand, the estimate may be too high if the C/E for cutthroat is smaller than for steelhead. This may be the case since there is no commercial fishery for cutthroat.

We have calculated a combined loss of 227 steelhead and 27 cutthroat, or 254 anadromous trout. In contrast, WDG requested additional mitigation for 565 fish. This was their total estimated run above the lake site (Findlay 1967). Our estimate is less because we have not been able to demonstrate a total loss of this portion of the Wynoochee run. Nor can we predict such a loss after comparison to other run size trends. Nonetheless, our pre-dam total anadromous trout run size estimate is quite close to that of WDG.

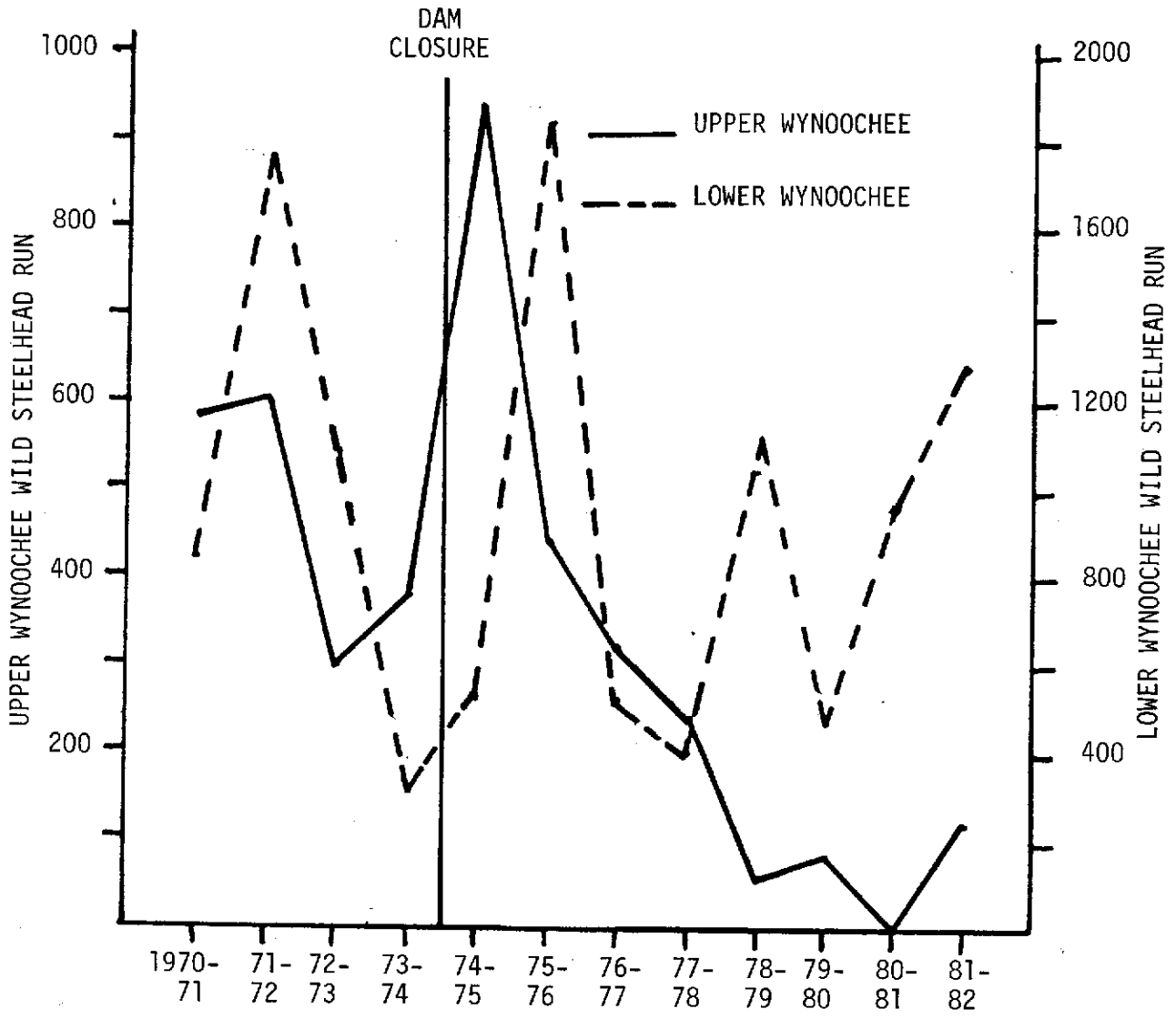

FIGURE 2. Steelhead wild run size produced in upper and lower Wynoochee River. Values are from text Table 2 and Appendix Table II-E-2.

Table 3. Relation of cutthroat and wild winter steelhead escapement to the upper Wynoochee

Return year	Cutthroat escapement [a] (c)	Steelhead escapement [b] (s)
71-72	303	1,173
72-73	11	562
73-74	83	719
74-75	31	400
75-76	11	295
76-77	19	128
77-78	4	143
78-79	0	31
79-80	0	46
80-81	22	0
81-82	33	80

a. Source: Corps of Engineers data
b. Source: Table 2. Total wild escapement used in all years.

From the steelhead-cutthroat relationship, we calculate

$$c = (0.205)(463) - 20$$
$$= 75 \text{ cutthroat}$$

in the run before the dam was closed. This number combined with the steelhead run is 463 + 75 = 538 trout. This is only slightly less than the 565 estimated by WDG.

SUMMARY

This analysis showed a loss of 806 coho from the total run produced above the Wynoochee Dam when trends in coho run size to the rest of Grays Harbor were taken into consideration. The actual loss probably is somewhat greater, but the exact magnitude cannot be determined. WDF had requested mitigation for 2,225 coho although that estimate did not consider comparable trends in Grays Harbor runs or recent data.

We determined a loss of 227 adult steelhead and 27 sea-run cutthroat, for a total of 254 anadromous trout, from the runs produced above the lake. These figures account for trends in steelhead run size to the lower Wynoochee. WDG has requested additional mitigation for 565 anadromous trout, assuming a total loss of upriver spawning due to smolt mortality at the dam. Our calculations showed only a partial loss to the run above the lake, based on current data.

APPENDIX I - SUPPORTING DATA FOR WILD COHO ANALYSIS

Appendix I-A. Grays Harbor hatchery coho smolt survival.

Total hatchery smolt survival was calculated for each year as

$$S = Rhg\ [1 + U/(1-U)]/Pg$$

where:

S = survival to all fisheries and to escapement
U = ocean exploitation
Rhg = estimated hatchery run size to Grays Harbor
Pg = on-station plant of smolts in Grays Harbor corresponding to return as age-3 adults.

The term $Rhg[1 + U/(1-U)]$ represents the total run size. It consists of the Grays Harbor run (Rhg) and the ocean catch ($RhgU/(1-U)$). The ocean catch term is derived from the definition of ocean exploitation

$$U = C/(C + Rhg)$$

where: C = ocean catch.

Solving for C we have

$$(C + Rhg)U = C$$
$$CU + RhgU = C$$
$$RhgU = C-CU$$
$$RhgU = C(1-U)$$
$$RhgU/(1-U) = C.$$

This hatchery survival is calculated in Appendix Table I-A-1.

Table I-A-1. Calculation of hatchery survival for on-station releases.

Return year	On-station Smolt plant x1000 [a] (Pg)	Grays Harbor hatchery run [b] (Rhg)	Ocean exploitation [c] (U)	Percent hatchery survival (S)
71	826	16,500	0.54 [d]	4.34
72	1,060	10,500	0.55 [d]	2.20
73	1,118	9,100	0.56 [d]	1.85
77	693	450	0.80	0.32
78	1,065	10,850	0.80	5.09
81	3,738	38,800	0.55	2.30

a. Source: Dick Stone, WDF Montesano, personal communication
b. Source: Dick Stone, WDF Montesano, unpublished data revised 1983.
c. Source: Rich Lincoln, WDF, unpublished data revised April 1983.
d. Interpolated from U = 0.50 for 1967 and 1968 return years and U = 0.57 for 1974. Source: Rich Lincoln, WDF, unpublished data revised 1983.

Appendix I-B. Catch-to-escapement ratio of Grays Harbor coho

Catch-to-escapement ratio for coho in Grays Harbor was calculated for hatchery and wild fish combined, as:

$C/E = [RgU/(1-U) + Cg]/Eg$

Where:

C/E = catch-to-escapement ratio of the total run produced in Grays Harbor
Rg = run entering Grays Harbor
U = ocean exploitation
Cg = catch in Grays Harbor
Eg = escapement in Grays Harbor

The term RgU/(1-U) was derived in Appendix 1-A. Thus:

Return year	Ocean exploitation [a] (U)	Grays Harbor Run size [b] (Rg)	Grays Harbor Catch [b] (Cg)	Escapement [b] (Eg)	C/E	Mean
71	0.54 [c]	152,700	64,800	87,900	2.78	
72	0.55 [c]	96,600	51,450	45,150	3.75	3.45
73	0.56 [c]	88,600	46,950	41,650	3.83	
74	0.57	154,700	58,550	96,150	2.74	
75	0.65	38,900	26,250	12,650	7.79	
76	0.79	81,500	35,050	46,450	7.36	
77	0.80	33,500	6,450	27,050	5.19	
78	0.80	28,300	9,300	19,000	6.45	4.94
79	0.66	78,200	14,400	63,800	2.61	
80	0.56	77,600	39,800	37,800	3.67	
81	0.55	65,800	32,100	33,700	3.34	
82	0.57	82,000	51,700	30,300	5.29	

a. Source: Rich Lincoln, WDF, personal communication, April 1983.
b. Source: Appendix Table I-A-2.
c. Interpolated from U = 0.50 in 1967 and 68 return years and U = 0.57 in 1974 return year.

Appendix I-C. Calculation of apparent wild run produced above Wynoochee Dam 1974, 1975, and 1976 return years.

Apparent wild returns to the barrier dam were calculated directly from mark recoveries at the dam instead of general Grays Harbor survival and C/E ratios. A high percentage of the dam return was sampled for marks, making this form of hatchery-wild determination the most accurate. The apparent wild escapement above the dam was calculated as

$$Ew = E[1-P(Np + No)/PpN]$$

where: Ew = escapement of fish other than first-generation hatchery stock to the upper Wynoochee; that is, apparent wild escapement
E = total escapement to the upper Wynoochee
P = plants of hatchery fish at or near the barrier dam
Np = number of fish recovered with permanent marks or tags
No = number of adipose-clipped fish recovered without coded-wire tag
Pp = plant of permanently-tagged or marked fish
N = number of fish examined for marks or tags.

This equation takes the return of permanently marked or tagged adult fish to the dam (Np), adds missing tags (No), and expands by the sampling rate (E/N) to get a survival rate (E/N)(Np + No)/Pp. This is then applied to all hatchery releases (P), including those with temporary marks or without marks to calculate the hatchery portion of the upper river escapement. The result is subtracted from the total escapement to get the apparent wild component. Thus:

Return year	Total escapement (E)	Total plant (P)	Permanent mark recovery (Np)	Missing tags (No)	Permanent marks planted (Pp)	Mark sample (N)	Apparent wild Escapement (Ew)
74	2,944	162,930	1,045	0	150,884	2,944	1,816
75	1,054	150,678 a/	417	21	145,686	945	549
76	3,049	252,530	385	78	121,055	2,139	1,672

a. Planted 145,686 fish in experiments plus 4,992 fish at Big Creek for total of 150,678.

Appendix I-D. Grays Harbor wild run size outside the upper Wynoochee River.

Run size outside the upper Wynoochee was calculated for comparison as follows:

$$Ro = Rg(Egwb/Egb) - R$$

where: Ro = wild run size in the Grays Harbor system produced outside the upper Wynooche run
Rg = run of wild fish produced in Grays Harbor
Egwb = broodyear wild escapement of apparent wild stock in the Grays Harbor system
Egb = broodyear escapement of all stocks spawning in the wild in the Grays Harbor system.
R = run size of the upper Wynoochee wild fish, including ocean interception.

Thus, the percent loss is calculated as follows:

Return year	Broodyear apparent wild escapement [a] (Egwb)	Return per spawner [a] (Rg/Egb)	Wild run [a] (Rg)	Upper Wynoochee wild run [b] (R)	Wild run outside upper Wynoochee	Mean
71	74,900	3.66	274,134	14,990	259,144	
72	29,900	5.63	168,337	1,768	166,569	195,756
73	102,400	1.60	163,840	2,286	161,554	
74	73,600	3.60	264,960	4,720	260,240	
75	37,550	2.33	87,492	2,607	84,885	
76	35,250	9.38	330,645	11,044	319,601	
77	75,250	2.09	157,272	1,634	155,638	
78	10,650	6.24	66,456	1,416	65,040	135,619
79	41,950	2.36	99,002	3,210	95,812	
80	26,500	5.01	132,765	2,362	130,403	
81	9,100	2.64	24,024	2,792	21,232	
82	33,400	2.74	91,516	3,799	87,717	
Difference						60,137
Percent change						-30.7%

a. Source: Dick Stone, WDF, personal communication, September, 1983.
b. Source: Text, Table 1.

APPENDIX II - SUPPORTING DATA FOR WILD STEELHEAD AND CUTTHROAT ANALYSIS

Appendix II-A. Calculation of pre-dam escapement to the area above the reservoir, 1970-71 through 1973-74 return years.

Escapement to the upper river above the lake-to-be was calculated as

$$Er = (E)(0.09)/(0.09 + 0.23)$$

where:

Er = Wynoochee escapement in the river above the lake site
E = total upper Wynoochee escapement
0.09 = fraction of total Wynoochee escapement estimated to spawn above the lake site (La Voy and Fenton 1979)
0.23 = fraction of total Wynoochee escapement estimated to spawn within the lake site (La Voy and Fenton 1979).

Values of Er appear in Table 2 of the text.

Appendix II-B. Steelhead catch-to-escapement ratios.

Ratios were calculated either from marked recoveries in creel census or from aerial spawning ground survey and catch records, depending on the year. Ratios up to and including the 1976-77 return year were based on creel census. Ratios were calculated from 1974-75 through 1976-77 data, averaged, and applied to 1970-71 through 1973-74.

Ratios from 1977-78 to the present were based on spawner survey. This change was necessary because in 1977 a one-fish bag limit was placed on the Wynoochee. This changed the C/E to a degree that could not be predicted using the old estimates, so a new method of estimation was required. The ratio was calculated from 1982-83 data and applied to return years 1979-80 through 1982-83. The ratio was then adjusted to account for a difference in fishing regulations and applied to the 1977-78 and 1978-79 return years.

1970-71 through 1973-74

The C/E applied to these years was the mean from the 1974-75 through 1976-77 recovery years. However, the effect of Quinault Tribal fishery interceptions was not used in the calculation because that fishery had not yet been opened. Marked steelhead were collected from the Wynoochee River by creel census, and from the barrier dam. These fish represented releases of Chambers Creek smolts at the barrier dam. Creel census recoveries from each year were expanded to include the assumed interception in the Chehalis River sport fishery as follows: first the entire number of Wynoochee-bound fish intercepted in the Chehalis sport fishery was calculated, assuming that half the Chehalis sport catch was composed of either Wynoochee-bound or Satsop-bound fish.

Thus:

$$Ccw = (Cc)(Cw)/[2(Cw + Cs)]$$

where:

Ccw = sport catch in the Chehalis River of Wynoochee-bound fish
Cc = total sport catch in the Chehalis River
Cw = sport catch in the Wynoochee River
Cs = sport catch in the Satsop.

Next, the number of Wynoochee-bound marked fish intercepted in the Chehalis sport fishery was calculated by direct proportion:

$$Ccwm = (Ccw)(Cwm)/Cw$$

where:

Ccwm = catch in the Chehalis of Wynoochee-bound marked fish
Cwm = catch in the Wynoochee of marked steelhead, expanded from creel census.

These equations can be combined so that

$$Ccwm = (Cc)(Cwm)/[2(Cw + Cs)]$$

Thus:

Return Year	Wynoochee Catch (Cw)	Satsop Catch (Cs)	Chehalis Sport Catch (Cc)	Marked Wynoochee Catch (Cwm)	Marked Chehalis Interception (Ccwm)
74	627	602	1,113	50	23
75	254	283	391	21	8
76	261	345	205	17	3

Finally, the C/E ratio was calculated as

$$C/E = (Cwm + Ccwm)/Em$$

where: Em = escapement of marked fish to the barrier dam.

Thus:

Return Year	Marked Wynoochee Catch (Cwm)	Marked Chehalis Interception (Cwm)	Marked Escapement (Em)	C/E
74	50	23	53	1.38
75	31	8	140	0.21
76	17	3	24	0.83
Mean				0.81

The mean of 0.81 was applied to the 1970-71 through 1973-74 return years.

1974-75 through 1976-77

The ratios for these years were calculated and applied to each year individually, based on marked steelhead recovered from the Wynoochee River sport fishery and the barrier dam. Wynoochee River recoveries for all years were expanded to account for interception in the Chehalis River sport fishery as described earlier. However, this expansion is adequate only for the 1974-75 recovery year, because in the following years the Quinault Indian commercial fishery began in upper Gray Harbor and the Chehalis River. This fishery required further expansion of marked recoveries to account for assumed interceptions. Stock composition of Quinault catch was assumed to be the same as that in the Chehalis River sport fishing area over the whole season. That is,

$$Cqw = (Cq)(Ccw)/Cc$$

where:

Cqw = catch in the Quinault fishery of Wynoochee-bound fish

Cq = total Quinault catch.

We expanded the marked recoveries as if they had the same timing as wild stock. This allowed us to apply the resulting C/E ratio to the native run. Thus the number of Wynoochee-bound marked fish intercepted in the Quinault fishery was calculated by direct proportion:

$Cqwm = (Cqw)(Cwm)/Cw$

where:

Cqwm = catch in the Quinault fishery of Wynoochee-bound marked fish.

The equations relating to Cqwm can be combined to yield

$Cqwm = (Cq)(Cwm)/[2(Cw + Cs)]$.

Thus:

Return Year	Quinault Catch (Cq)	Marked Wynoochee Catch (Cwm)	Wynoochee Catch (Cw)	Satsop Catch (Cs)	Marked Quinault Interception (Cqwm)
75-76	2,144	21	254	283	42
76-77	1,132	17	261	345	16

Finally the C/E ratio was calculated as:

$C/E = (Cwm + Ccwm + Cqwm)/Em$. Thus:

Return Year	Marked Wynoochee Catch (Cwm)	Marked Chehalis Sport Interception (Ccwm)	Marked Quinault Interception (Cqwm)	Marked Upper-river Escapement (Em)	C/E
74	50	23	0	53	1.38
75	21	8	42	140	0.51
76	17	3	16	24	1.50

These ratios were applied to their respective return years.

1977-78 and 1978-79

The ratio for these years was the 1981-82 catch-to-escapement ratio adjusted to account for the more liberal Wynoochee River fishing season than was allowed in 1981-82. The 1981-82 ratio is based on catch records and estimated total Wynoochee escapement. The C/E for that season was calculated as

$C/E = (Cw + Ccw + Cqw)/(Eu + El)$

where:

Eu = total escapement at barrier dam, 1981-82

El = total escapement from river mouth to barrier dam, from aerial survey, 1982.

Ccw was calculated as before; that is,

$Ccw = (Cc)(Cw)/[2(Cw + Cs)]$

$= (806)(45)/[2(45 + 49)]$

$= 193.$

Cqw was also calculated as before; that is,

$Cqw = (Cq)(Ccw)/Cc$

$= (1,718)(193)/806$

$= 411$

Thus the $C/E = (45 + 193 + 411)/(281 + 801)$

$= 649/1,082$

$= 0.60$

This ratio was then adjusted to account for the more liberal fishery regulations in 1977-78 and 1978-79. The fishery was closed on January 31 from the 1979-80 season to the present, but was open until March 31 in 1978 and 1979. Before the limited fishing season of 1979-80 to the present, 41.8% of the Wynoochee sport fish had been caught by the end of January and 93.6% by the end of March. The fishery had been open until the end of March in 1982 Wynoochee River catch would have been $(45)(0.936)/0.418 = 101$ fish, for a difference of $101-45 = 56$ fish. Thus the catch would be that much higher and the escapement that much lower, for a C/E of $(649 + 56)/(1,082-56) = 0.69$. This ratio was applied to the 1977-78 and 1978-79 return years.

1979-80 through 1982-83

The ratio for these years was the 1981-82 ratio, or 0.60, as calculated in the previous section. It was applied to the 1979-80 through 1982-83 return years.

Appendix II-C. Separation of winter and summer steelhead at the barrier dam.

Winter and summer runs were separated on the basis of timing difference between the average of years having only native winter run and years having both winter and summer run returns. Return years 1970-71 through 73-74 and 1977-78 represented pure native winter run. Return years 1978-79 through 1982-83 represented winter and summer runs combined. A three-week moving average of weekly percent of total run, weighting each year by total dam return was calculated (Table II-C-1). I considered the summer run to be predominant in those weeks when the above mentioned moving average was greater for the native-plus-summer years than in the native-only years, and the winter run to be predominant in the remaining weeks. For years when both summer and winter runs were present, I calculated the winter run escapement as the total escapement during the weeks when the winter run predominated. Thus the winter run began about December 1 and ended about May 25, for the purposes of my calculations.

Table II-C-1. Winter and summer steelhead run separation.

Week Ending	Percent Of Return: Native Run 1970-71 Through 73-74 and 1977-78	Percent Of Return: Native Plus Summer Run 1978-79 Through 82-83	Predominant Run
10-2	0	0.4	Summer
10-9	0	1.1	
10-16	0	1.3	"
10-23	0	1.2	"
10-30	0	1.0	"
11-6	0	1.1	"
11-13	0.1	1.0	"
11-20	0.4	0.6	"
11-27	0.6	0.3	Winter
12-4	0.5	0.2	"
12-11	0.7	0.2	"
12-18	1.0	0.4	"
12-25	1.2	0.5	"
1-1	0.9	0.6	"
1-8	0.6	0.6	"
1-15	1.2	1.2	"
1-22	1.8	1.4	"
1-29	2.3	1.6	"
2-5	2.7	1.0	"
2-12	2.9	1.0	"
2-19	3.3	1.6	"
2-26	3.0	2.5	"
3-5	3.8	3.0	"
3-12	4.6	3.9	"
3-19	6.3	4.0	"
3-26	7.4	5.2	"
4-2	7.6	4.2	"
4-9	7.2	4.3	"
4-16	6.3	4.6	"
4-23	6.6	5.9	"
5-1	7.4	4.9	"
5-8	7.5	4.7	"
5-15	5.9	3.5	"
5-22	3.5	3.1	"
5-29	1.5	3.3	Summer
6-5	0.6	3.0	"
6-12	0.2	2.4	"
6-19	0.1	1.8	"
6-26	0	1.5	"
6-30	0	1.4	"
7-3	0	2.2	"
7-10	0	2.5	"
7-18	0	3.1	"
7-24	0	2.2	"
7-31	0	1.6	"
8-7	0	1.2	"
8-14	0	0.8	"

Appendix II-D. Estimated hatchery escapement for 1980-81 through 1982-83 return years.

1980-81

Hatchery escapement for the 1980-81 return year was calculated based on the average survival for the two following years:

$$E80 = P79(E81/P80 + E82/P81)/2$$

where:

E80 = Escapement to the barrier dam of hatchery fish in the 1980-81 return year

P79 = Plant of smolts near the barrier dam in 1979

E81 = Escapement to the barrier dam of hatchery fish in the 1981-82 return year from the 1980 release only

P80 = Plant of smolts near the barrier dam in 1980

E82 = Escapement to the barrier dam of hatchery fish in the 82-83 return year from the 1981 release only

P81 = Plant of smolts near the barrier dam in 1981

Thus:

$$E80 = (20,330)(74/7500 + 461/20,750)/2$$

$$= 326.$$

Since this estimate is far greater than the total observed winter escapement of 257 fish, it is probable that the entire return was of hatchery origin.

1981-82 and 1982-83

The 1981-82 and 1982-83 winter-run hatchery escapements to the barrier dam were calculated as

$$Eh = E(Nm + Ns + Nj)/N$$

where:

Eh = escapement of hatchery fish to the barrier dam

E = total escapement at barrier dam

Nm = number of marked fish in sample

Ns = number of stubbed-dorsal in sample

Nj = number of jacks in sample

N = sample size.

Appendix II-E. Lower Wynoochee wild steelhead run sizes.

Lower Wynoochee wild steelhead run sizes were calculated as a base for comparison to the changes in upper Wynoochee wild run size changes before and after construction of the dam. The formula used was

$$Rl = [(Cw + Ccw + Cqw)/(C/E) - (E + Elh)](1 + C/E)$$

where:

Rl = run size of lower river wild fish

Cw = Wynoochee sport catch

Ccw = catch in Chehalis River sport fishery of Wynoochee-bound fish

Cqw = catch in Quinault fishery of Wynoochee-bound fish

C/E = catch-to-escapement ratio of total run

E = escapement to the upper river

Elh = escapement to the lower river of hatchery fish, as calculated below

Distribution of catch is shown in Table II-E-I. Escapement to the lower river from hatchery plants occurred in the 1978-79 and 1979-80 return years. It was calculated from hatchery plants in the lower river and mean survival from the 1973 and 1975 releases of marked steelhead released at the dam as presented by Mathews (1980). Thus:

$$Elh = P(E73/P73 + E75/P75)/2$$

$$= P(0.0046)$$

where:

Elh = escapement to the lower river of hatchery fish planted in the lower river

P = hatchery release in lower river

E73 = escapement of marked steelhead from the 1973 release to the upper river in 1974-75 and 75-76

P73 = plant of marked steelhead below the barrier dam in 1973

E75 = escapement of marked steelhead from the 1975 release to the upper river in 1975-76 and 1976-77

P75 = plant of marked steelhead below the barrier dam in 1975.

Values of Elh appear in Appendix Table II-E-2.

The lower Wynoochee wild run averaged 1,007 before the dam and 793 afterward for a decline of 21.3%.

Thus:

	Return Year	
	1981-82	1982-83
Total escapement (E)	281	544
Marked adults in sample (Nm)	21	5
Stubbed-dorsal adults in sample (Ns)	30	163
Jacks in sample (Nj)	19	3
Sample size (N)	98	216
Hatchery escapement (Eh)	201	431

Table II-E-1. Wynoochee sport catch and interception.

Return Year	Wynoochee Sport Catch [a] (Cw)	Chehalis Sport Catch of Wynoochee fish [a] (Ccw)	Quinault Commercial Catch of Wynoochee fish [a] (Cqw)	Total Catch
70-71	823	478	0	1,301
71-72	1,056	693	0	1,749
72-83	733	198	0	931
73-74	510	206	0	716
74-75	627	284	0	911
75-76	254	109	507	870
76-77	261	44	244	549
77-78	109	40	96	245
78-79	246	76	167	489
79-80	26	187	103	316
80-81	77	71	372	649

[a] Calculated in Appendix II-B. 1970-71 through 1973-74 punch card returns have been corrected for bias.

Table II-E-2. Lower Wynoochee wild run trend, 1970-71 thru 1981-82

Return Year	Total Catch	C/E a/	Total escapement	Upper river escapement a/ (E)	Lower river escapement	Lower river hatchery escapement (Elh)	Lower river wild escapement	Lower river wild run (Rl)	Mean
70-71	1,301	0.81	1,606	1,123	483	0	483	880	
71-72	1,749	0.81	2,159	1,173	986	0	986	1,785	1,007
72-73	931	0.81	1,149	562	587	0	587	1,062	
73-74	716	0.81	884	719	165	0	165	299	
74-75	911	1.38	660	444	216	0	216	514	
75-76	870	0.51	1,706	432	1,274	0	1,274	1,924	
76-77	549	1.50	366	152	214	0	214	535	
77-78	245	0.69	355	143	212	0	212	358	
78-79	489	0.69	709	31	678	10	668	1,129	793
79-80	316	0.60	527	46	481	184	297	475	
80-81	520	0.60	867	257	610	0	610	976	
81-82	b/	b/	b/	b/	801	0	801	1,282	
Percent change									-21.3

a. Source: Text, Table 2.
b. Not used in calculation because lower river escapement was estimated directly by spawner survey.

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