Hydroacoustic Assessment of Downstream Migrating Salmonids at Lower Monumental Dam in Spring 1985

Final Report

Funded by

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EXECUTIVE SUMMARY

The Bonneville Power Administration and the U.S. Army Corps of Engineers are evaluating bypass methods to increase the survival rate of juvenile salmonids and steelhead migrating downstream through Lower Monumental Dam. For these evaluations it is essential to know the migrants' distribution and timing as they approach and pass the dam, including estimates of the relative proportions utilizing spillway and powerhouse passage routes. In this study migrants passing through the dam were monitored using hydroacoustic techniques. The objectives of the study were to estimate:

1) the effectiveness of the spillway for passing migrants;
2) die1 variability in passage rates of migrants through the powerhouse and spillway;
3) the daily and cumulative run timing of migrant passage;
4) the proportions of migrants that passed through each turbine intake and spill bay;
5) the vertical distributions of migrants approaching the powerhouse and spillway.

The study was conducted from April 22 to May 31, 1985. The results for each study objective are summarized below.

Spill Effectiveness. Nightly spill effectiveness estimates (the number of fish passing through the spillway relative to the number through both the spillway and the poorhouse) averaged 67%, ranging from 52% to 83%. These estimates were obtained from May 4 to 31. The spilling level was maintained at SO% of river flow from 1900 h to 0500 h each night. Relative to fish passage throughout the 24-h day, spill effectiveness was estimated to be 57%.

Die1 Passage. Migrant passage rates were much greater at night than during the day. Eighty-four percent of the 24-h passage total was estimated to have passed during the 10 hours of spilling each night.

Horizontal Distribution. Generally, greater rates of migrant passage were observed at turbines located near the center of the powerhouse. The comparisons of passage through turbines were confined to daylight hours when all turbines were operating.

At the spillway generally greater rates of migrant passage were observed at spill bays nearest the powerhouse. The comparisons of passage through spill bays were confined to night hours.

Vertical Distribution. At the powerhouse migrants were distributed deeper at night than during the day. Roth day and night distributions became somewhat shallower during the course of the study.

1.0 INTRODUCTION

1.1 Background

The salmon and steelhead runs on the Columbia and Snake rivers have declined due to several factors, including the construction and operation of hydroelectric dams. Most downstream migrating juvenile salmonids ("migrants" in this report) pass safely through the turbines at any one dam. But fish above Lower Granite Dam on the Snake River pass through eight dams, including Lower Monumental and The Dalles dams, before reaching the Pacific Ocean, and cumulative mortalities can be substantial (Bell et al. 1967; Schweibert 1977).

In the last decade, considerable effort has been expended exploring ways to restore and enhance these fish runs. The Bonneville Power Administration (BPA) and the US. Army Corps of Engineers (COE; operators of the lower Snake and Columbia River dams) are evaluating bypass methods to increase the survival rate of migrants as they pass the dams. One of the goals of bypass system design is to minimize adverse effects on power production. To meet this goal it is essential to know the migrants' distribution and timing as they approach and pass the dams, including estimates of the relative proportions utilizing spillway and powerhouse passage routes. For this reason, the BPA contracted with BioSonics, Inc. to conduct studies of migrant passage at Lower Monumental and The Dalles dams (Contract No. DE-A C79-85 BP23174). This report contains the results of the study at Lower Monumental Dam, in Spring 1985.

1.2 Studv Objectives

The primary objective of this study was to estimate the effectiveness of the spillway in passing migrants, with the spillway operating per the criteria identified in the COE's 1985 Juvenile Fish Passage Plan.

Specific study objectives were to estimate:

1) the effectiveness of the spillway for Passing migrants;

2) die1 variability in passage rates of migrants through the powerhouse and the spillway;

3) the daily and cumulative run timing of migrant passage;

4) the proportions of migrants that passed through each turbine intake and spill bay (i.e., the horizontal distributions across the powerhouse and the spillway);

5) the vertical distributions of migrants approaching the powerhouse and spillway.

1.3 Site Description

Lower Monumental Dam is located on the Snake River at river mile 41, 34 miles northeast of Pasco, Washington (Figure 1). It is oriented perpendicular to the river's flow, with the powerhouse on the north shore and a navigation lock on the south shore with a spillway between them (Figure 2). It is the second dam from the mouth of the Snake River, above Ice Harbor Dam. It impounds Lake Herbert G. West for 29 miles to the base of Little Goose Dam.

The powerhouse is 550 ft long and contains 6 turbines numbered from north to south (Figure 2). Turbine Unit 1 was inoperable during the study. Each turbine has three intake chambers identified as Intakes A, B, and C, from north to south. Each of the 18 rectangular intake openings is 30 ft wide (including piers) by 76 ft high at the trashrack. The reservoir in front of the powerhouse is between 118 and 126 ft deep, and the dam rises 15 ft above the mean waterline, elevation 540 ft.

The spillway contains 8 deep spill gates numbered south to north (Figure 2). These gates can be automatically opened and closed. Each spill bay is capable of spilling more than 40 kcfs. All 8 spill bays have SO ft wide openings and extend to 57 ft below mean forebay level. Spill Gate 8 was inoperable from April 22 to May 1. Spill Gate 4 was closed the night of April 25, and Gate 2 was under repair from May 24 to May 27.

1.4 Species

The common and scientific names of juvenile salmonids passing through Lower Monumental Dam are as follows:

Chinook salmon	*Oncorhynchus tshawytscha*
Sockeye salmon	*O. nerka*
Steelhead trout	*Salmo gairdneri*

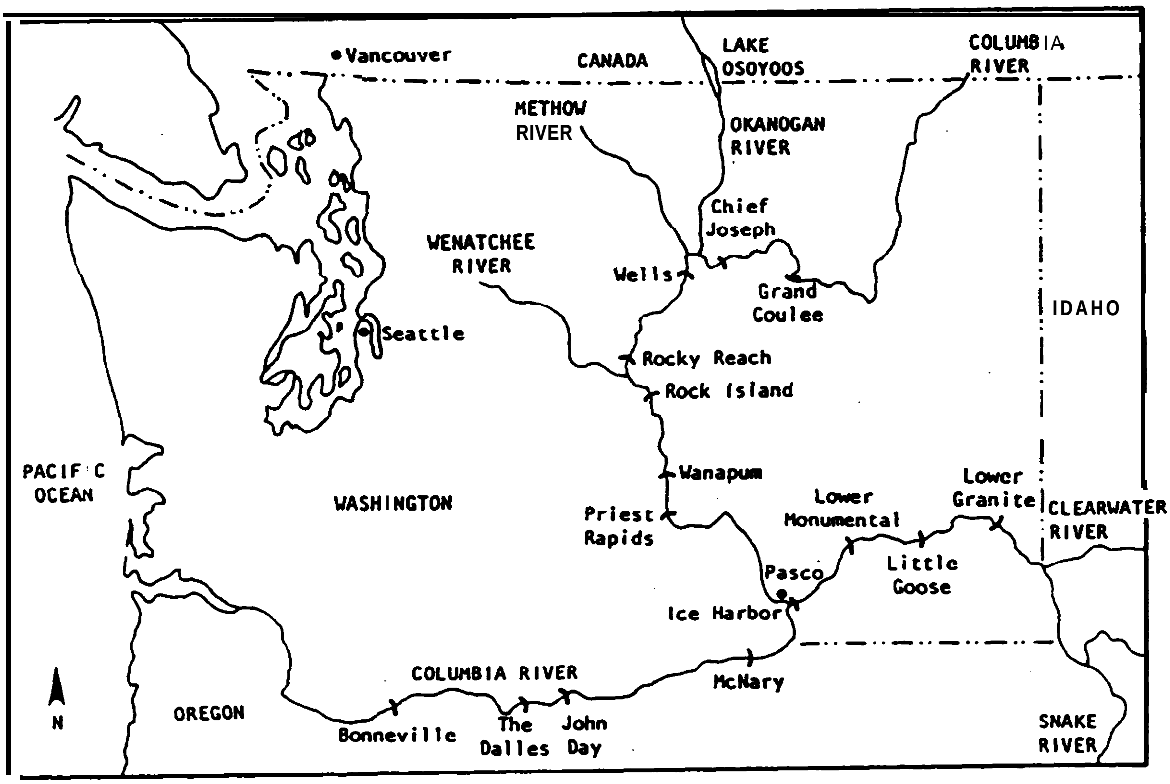

Figure 1. Location of Lower Monumental Dam and other dams affecting anadromous fish passage on the main-stem Columbia and Snake rivers.

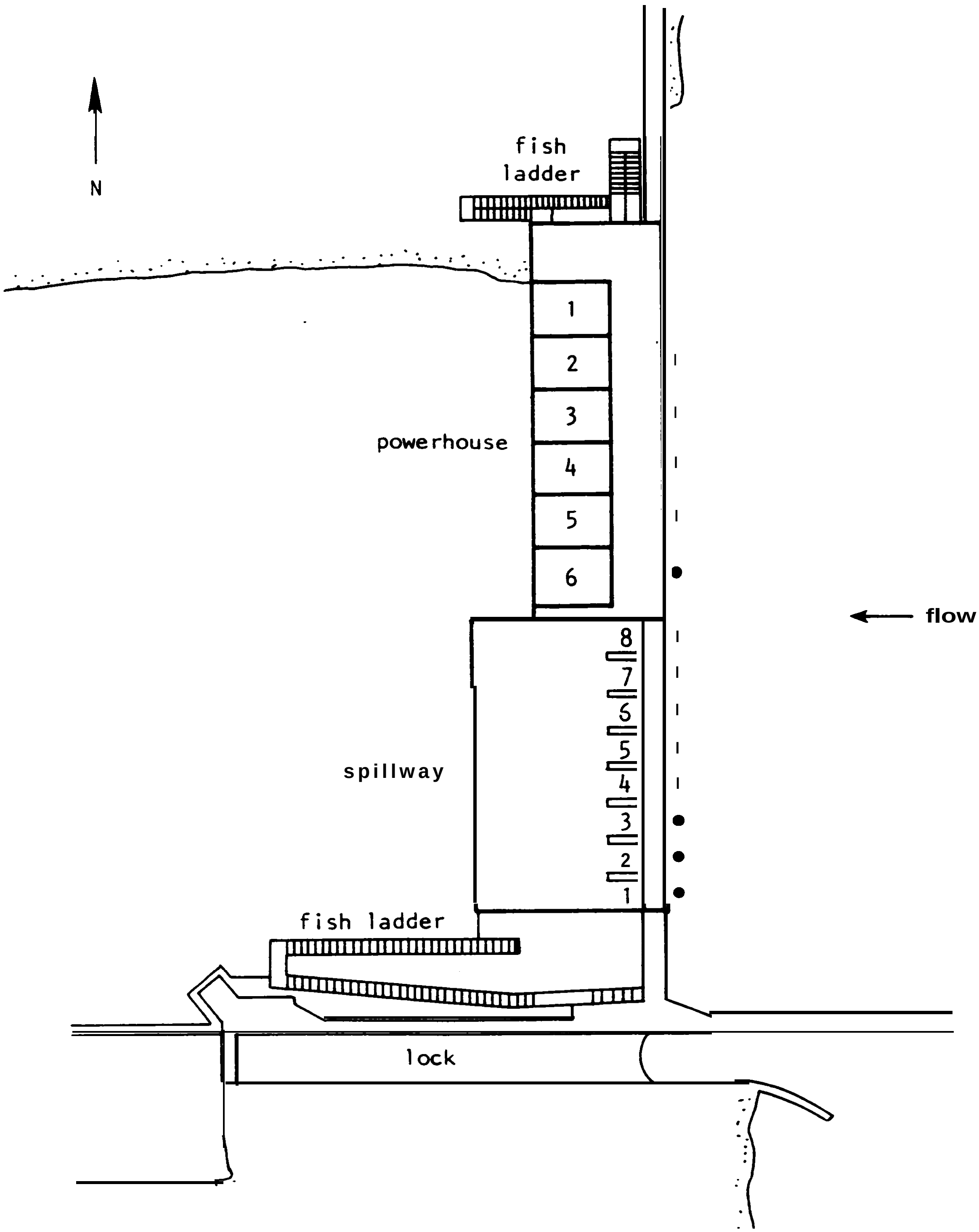

Figure 2. Plan view of powerhouse, spillway, and hydroacoustic sampling locations (indicated by black dots). Lower Monumental Dam, 1985.

2.0 GENERAL METHODS

2.1 Equipment and Operation

In recent years,the development of specialized hydroacoustic equipment has contributed to increasingly accurate measurements of fish abundance, distribution, and movement in proximity to nearby solid structures (Wirtz and Acker 1979, 1980, and 1981). At Columbia and Snake River dams, this equipment has proven useful for monitoring the movements of migrants (Carlson 1982a, 1982b, 1982c; Carlson et al. 1981; Dawson etal.l984b, 1982; Gyldenege et al.1983; Johnson et al.1982, 1984; Karp et al. 1984, 1982; Raemhild et al. 1984a, 1984b, 1983).

For this study, fixed-location hydroacoustic techniques were selected (Dawson et al.1984a), because they allow for an accurate interpretation of migrant movements relative to the dam. Installation of fixed-location hydroacoustic equipment at a new site,such as Lower Monumental Dam, entails experimenting with the deployment configuration until an optimal solution is found. Some of the factors which may affect the feasibility of a proposed configuration include project-specific features, such as-the design of physical structures, water currents, acoustical noise sources, and available transducer. mounting locations. In addition, equipment-dependent factors must be considered, such as the display ranges of the chart recorders and the trigger rates necessary for meeting detection criteria.

A BioSonics echo sounder operating at 420 kHz was the key component of the hydroacoustic system. Thirteen transducers, one in front of each operational turbine intake and spill gate, were sequentially sampled every hour using a programmable multiplexer. ere recorded on echograms. Calibration and operation of the hydroacoustic system are described in Appendix A.

All transducers at the powerhouse were attached to sled mounts lowered down the front of pier noses between Intakes A and B. The transducers were located approximatley 6 ft from the bottom of the reservoir and initially-aimed upstream about 30° and 10° across the B slot (Figure 3). After observing migrant passage. for several days, the upstream aiming angle of these transducers was changed to 20° on April 24. This change moved the detection zone closer to the actual exit, provided slightly increased detectability of fish near the surface, and reduced the possibility of migrants descending undetected close to the face of the powerhouse.

The triggering rate of powerhouse transducers was initially set to 7.5 pings per sec (pps). On May 3 the rate was reduced to 4.0 pps. The relatively slow water velocities in front of the powerhouse and large acoustic volume at long ranges made the higher ping rate unnecessary. The slower ping rate reduced the acoustic noise in the surface 6-8 feet by providing additional time for the reverberation to die out.

Transducers in front of the spillway were surface-mounted and fixed to steel poles clamped to the upstream side of the spillway. The mounts were positioned in the middle of each spill bay. Initially the transducers were aimed 20° upstream (Figure 4). On May 3, after reviewing the initial12 days of data, the transducers were re-aimed straight down. This moved the area of detection closer to the exit,thus providing greater assurance that a detected fish was committed to passing the dam. The change also gave greater distinction between traces moving up from below the spill berm and those diving down from the surface. The clearer trace types provided easier and more consistent interpretation of the data. The final aiming angle, straight down, was the same as that used at The Dalles Dam. The triggering rate of spill transducers was increased from 7.5 to 12 pps to compensate for both faster water velocities closer to the spillgate and smaller ensonified volume.

Because of the changes in aiming angle and triggering rate, the spillway data from the first 12 days of study were omitted from analyses.

Due to slight differences in receiving sensitivity and beam patterns, the transducers employed had effective sampling beamwidths that ranged from 13° to 10°. The differences in sampling beamwidths were compensated for by appropriate weighting factors in the analysis software (Appendix D). Appendix B lists the transducer locations, mount types, mount depths, and effective beamwidths (calculated relative to migrants with a minimum target strength of-56 dB[1]) at each sampling location.

2.2 Data Collection, Storage, and Analysis

Passage of migrants through each operating turbine unit and spill bay was sampled twice each hour. Each turbine and spill bay sample was 6 and 3.75 min long, respectively.

Data were collected 24 h/d from April 22 to May 31, 1985. The spill period each day overlapped the date change at 0000 h, therefore, each spill period is referred to by the day in which it started, i.e., the spill period dated May 31 started at 0500 h May 31 and includes data until 0459-h June 1.

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1. **The average target strength of smolts passing Lower Monumental Dam was assumed to be similar to that estimated using in situ dual-beam techniques at Lower Granite Dam. Use of this value is discussed in Appendix A of this report.**

For purposes of analysis, daylight and night conditions were defined as:

Dates	Daylight Hours	Nighttime Hours
April 22-27 (PST)	0600-1959 h	2000-0559 h
April 28-June 1 (PDT)	0500-1859 h	1900-0459 h

The study was divided into seven sampling periods, referred to as "Blocks". The dates of the Blocks are:

Sampling Period	Inclusive Dates
Block 1	April 22-27
Block 2	April 28-May 3
Block 3	May 4-May 9
Block 4	May 10-14
Block 5	May 15-20
Block 6	May 21-25
Block 7	May 26-31

Data from echograms were entered into computer files on location. Preliminary reduction and analysis were also completed at the project site. Data acquisition and analysis procedures are described in Appendices C and D, respectively.

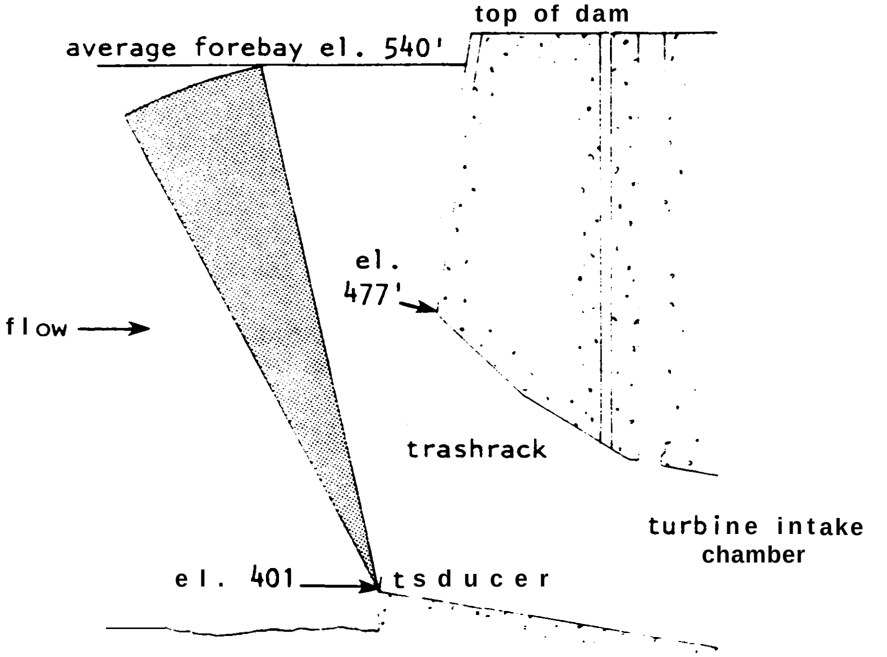

Figure 3. Cross-sectional view of the powerhouse showing transducer location and orientation. Lower Monumental Dam, 1985.

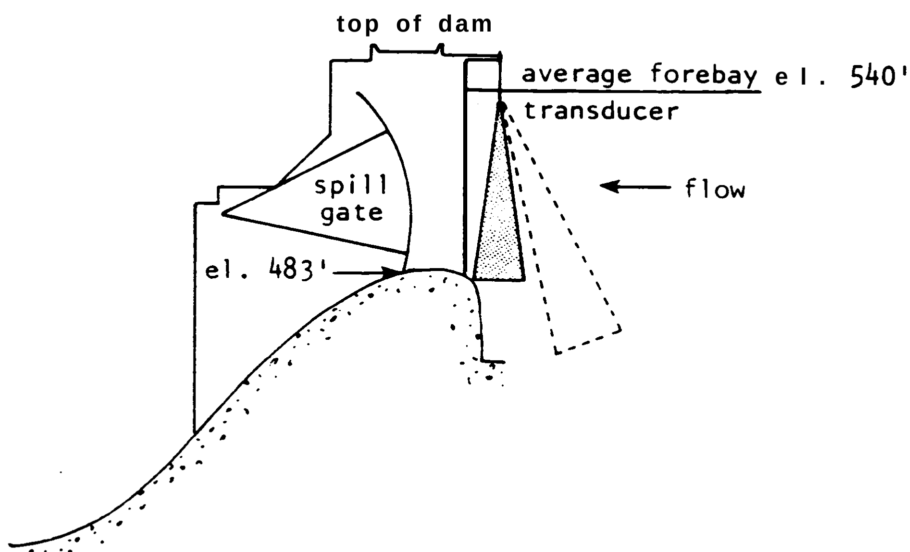

Figure 4. Cross-sectional view of the spillway showing transducer location and orientations before and after May 3. Prior to May 3, the transducer was aimed 20° upstream (dotted line). Lower Monumental Dam, 1985.

3.0 FINDINGS

3.1 Objective 1: Effectiveness of Spill for Passing Downstream Migrants

3.1.1 Introduction

Downstream migrants passing through spill have a significantly greater rate of survival than those passing through turbines. Mark and recapture studies at John Day and The Dalles dams showed that by spilling during periods of high migrant concentration, survival past the dams was enhanced (Raymond and Sims, 1980). Knowledge of the relationship between proportion river spilled and relative proportion of spillway migrant passage is essential for making an informed evaluation of spill as a bypass mechanims.

3.1.2 Methods

Spill effectiveness was defined as the percentage of migrants passed in spill relative to total migrants passing the dam (powerhouse plus spillway). Spill was maintained each night for 10 h, from 1900-0500 h. Data points were established two ways. First, the actual hours of spilling were evaluated to estimate "10-h instantaneous spill effectiveness." Second, spill effectiveness was calculated on a "24-h daily average" basis, with the 24-h period defined as from 0500 to 0459 the following day. Since there was virtually zero spill during daytime, the 24-h averaged estimates do not represent 24 h of spill, but rather the effect of nighttime spill on 24-h of fish passage. Daytime spill did occur on May 6, 9, and 13 for a total of 9 h (Table El). The migrants passed in spill for these 3 days are included in the 24-h spill effectiveness estimates for those days. The two series of data points, 10-h instantaneous and 24-h daily average, were analyzed independently.

Spill effectiveness was evaluated nightly from May 4 to May 31, 1985. Throughout the study the instantaneous spill level was held constant at about 50% of the river flow. This corresponded to a 24-h average spill level of about 20% of river flow. A "crown" spill gate opening pattern was employed, with the end gates (Gates 8 and 1) being opened first and passing more water than the center gates.

3.1.3 Results and Discussion

10-h Spill Effectiveness

10-h spill effectiveness estimates ranged from 52% to 83% during the study (Table 1). Seasonally, the effectiveness estimates were higher during Blocks 3 through 5 than Blocks 6 and 7 (Figure 5). This seasonal change in spill effectiveness was unexpected as the percent of river flow spilled each night was relatively constant at about 50% (Table 1) and dam operations were uniformly maintained throughout the study. Generally, it has been hypothesized that the proportion of smolts passing in spill is related to the percentage of flow spilled and/or dam operating conditions, particularly spillway configuration. Studies conducted by BioSonics have defined the relative proportions of smolts passed for differing percentages of spill at Rock Island, Wanapum, and Priest Rapids dams (Raemhild et al. 1983, 1984; Dawson et al. 1983, 1984). Additionally, BioSonics evaluated the effect of spillway configuration on spill effectiveness at Ice Harbor Dam (Johnson et al. 1983; 1984). However, in none of these studies was a seasonal change in spill effectiveness recognized. Thus, this study provides a unique set of data.

One or several factors could account for the observed seasonal variability in spill effectiveness estimates. For example, the volume of river flow changed during the study with the highest flows observed during Blocks 6 and 7 (Table 2, Figure 6). The different flow conditions during Blocks 6 and 7 may differentially affect the distribution and numbers of migrants approaching the dam. Such differences could then affect spill effectiveness. The results of examinations of migrant horizontal distribution, vertical distribution, and run timing are presented in Sections 3.3, 3.4, and 3.5 of this report.

Another factor potentially contributing to the seasonal aspects of spill effectiveness is species composition of the outmigration. The composition of the outmigration shifts from primarily chinook to primarily steelhead each spring. Unfortunately, the precise timing of such shifts is not known at this dam.

The uniformity of the application of the data collection technique is important to the ability to examine trends in data sets. As stated in the Methods section, the installation of a hydroacoustic system at a new location entails experimenting with the deployment configuration until optimum results are obtained. In this contract the initial portion of the study also served as the period of deployment experiments. Thus, data were not collected with a uniform technique over the study period. Accordingly, spillway data from Blocks 1 and 2 were not included in analyses of seasonal trends.

24-h Spill Effectiveness

Twenty-four hour spill effectiveness estimates ranged from 38% to 73% (Table 1 and Figure 5). The percentage of river spilled each 24 h averaged 20%, with a range of 17% to 24%. Seasonally, changes in 24-h spill effectiveness generally followed the changes observed in the 10-h data set.

Appendix E contains a table of daytime spill effectiveness estimates and figures of percentage migrants spilled vs. percent river spilled.

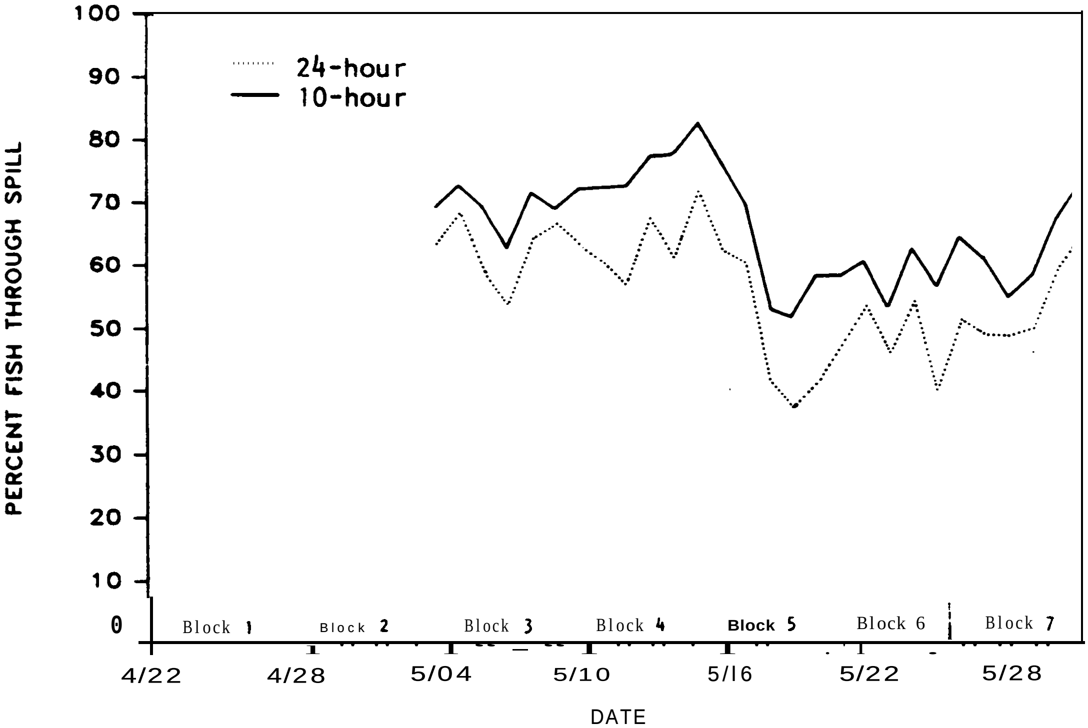

Figure 5. 10-h and 24-h spill effectiveness estimates. Lower Monumental Dam, 1985.

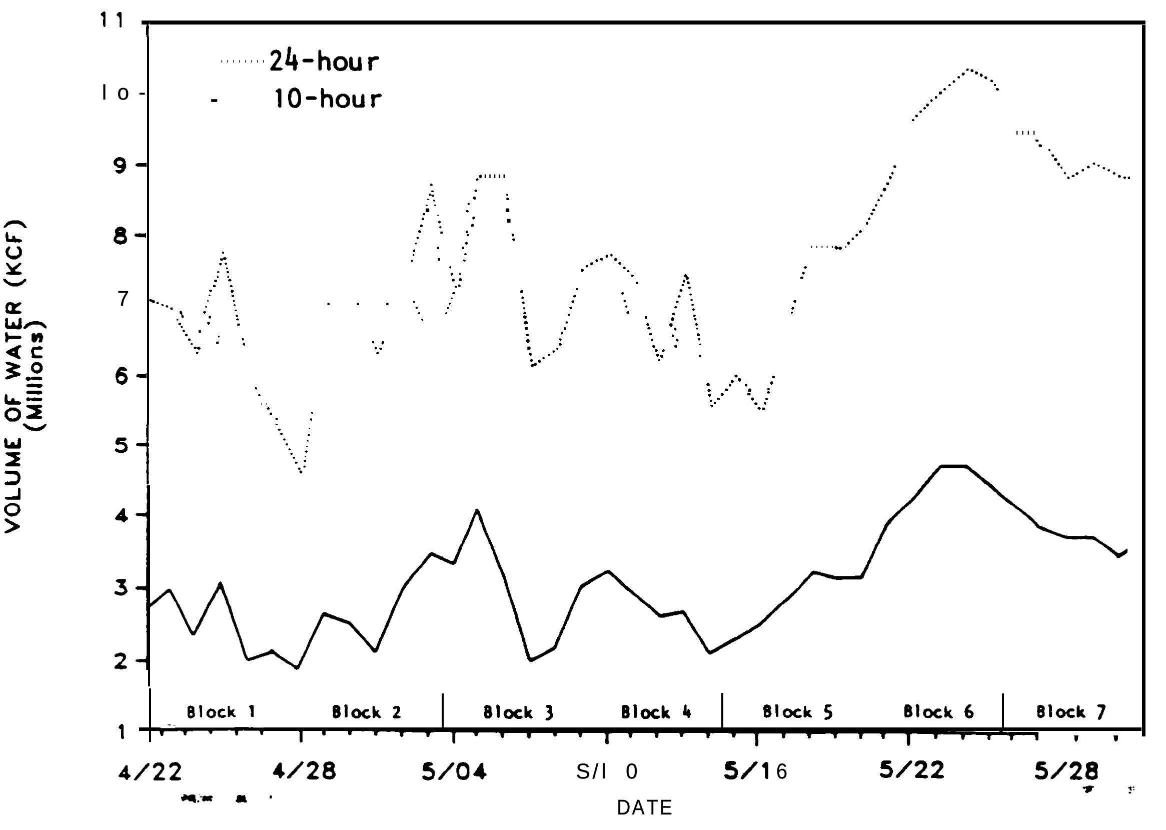

Figure 6. Daily 10-h and 24-h river volumes (KCF) passing through Lower Monumental Dam from April 22 - May 31, 1985.

Table 1. Daily and block (weighted average) 10-h and 24-h spill effectiveness estimates, Lower Monumental Dam, 1985.

Date (Block % is cumulative)	10-h % Fish	10-h % River	24-h % Fish	24-h % River
5/04	69.47	50.18	63.51	24.13
5/05	72.96	49.15	68.84	23.01
5/06	69.39	49.32	59.11	20.09
5/07	62.87	50.63	53.84	16.50
5/08	71.77	49.30	64.31	17.12
5/09	69.14	50.97	66.99	24.54
Block 3	70.15	49.87	64.28	21.14
5/10	72.37	48.49	63.30	21.11
5/11	72.62	49.53	60.72	20.43
5/12	72.75	48.47	57.17	20.00
5/13	77.77	50.02	67.99	20.30
5/14	77.86	49.59	61.54	18.71
Block 4	74.14	49.18	62.44	20.20
5/15	82.97	53.77	72.50	20.54
5/16	76.30	50.19	62.82	22.59
5/17	69.79	48.78	60.84	21.64
5/18	53.21	49.60	42.78	21.14
5/19	51.98	50.38	38.16	20.99
5/20	58.57	50.44	42.04	20.01
Block 5	68.74	50.39	56.05	21.07
5/21	58.83	50.18	47.96	22.35
5/22	61.13	49.75	54.11	22.45
5/23	53.80	48.95	46.93	22.77
5/24	63.26	48.85	55.09	22.24
5/25	56.83	50.03	41.01	22.26
Block 6	58.87	49.52	49.26	22.41
5/26	64.82	50.02	52.16	22.22
5/27	61.59	51.03	49.74	21.55
5/28	55.44	50.33	49.74	21.86
5/29	59.13	so.47	50.88	21.14
5/30	68.27	50.90	60.09	20.45
5/31	74.23	50.86	65.64	21.69
Block 7	63.50	50.59	54.22	21.49

Table 2. Daily 24-h and 10-h river volumes (kcfs) through Lower Monumental Dam, 1985.

Date	24-h Spill Vol.	24-h Powerhouse Vol.	24-h Total Vol.	24-h Average % Spill
4/22	1285200	5842080	7127280	18.03
23	1533960	5316480	6850440	22.39
24	1179000	5121360	6300360	18.71
25	1538640	6125760	7664400	20.08
26	1071000	4960116	6031116	17.76
27	987120	4341600	5328720	18.52
Block 1	7594920	31707396	39302316	19.32
28	885600	3745440	4631040	19.12
29	1281960	5569560	6851520	18.71
30	1311480	5776560	7088040	18.50
5/01	1014480	5305320	6319800	16.05
2	1490040	5801400	7291440	20.44
3	1703520	6870240	8573760	19.87
Block 2	7687080	33068520	40755600	18.86
4	1711080	5380200	7091280	24.13
5	2023200	6768360	8791560	23.01
6	1759680	6997320	8757000	20.09
7	1002600	5073840	6076440	16.50
8	1097280	5313600	6410880	17.12
9	1835640	5644440	7480080	24.54
Block 3	9429480	35177760	44607240	21.14
10	1618200	6048720	7666920	21.11
11	1504800	5862600	7367400	20.43
12	1242000	4969440	6211440	20.00
13	1500480	5891400	7391880	20.30
14	1036800	4503600	5540400	18.71
Block 4	6902280	27275760	34178040	20.20
15	1231200	4764240	5995440	20.54
16	1231200	4218480	5449680	22.59
17	1420200	5143320	6563520	21.64
18	1643400	6131880	7775280	21.14
19	1612800	6070320	7683120	20.99
20	1612800	6446160	8058960	20.01
Block 5	8751600	32774400	41526000	21.07
21	1946160	6759720	8705880	22.35
22	2154600	7444440	9599040	22.45
23	2286720	7757640	10044360	22.77
24	2295360	8026560	10321920	22.24
25	2250720	7862040	10112760	22.26
Block 6	10933560	37850400	48783960	22.41
26	2100240	7352640	9452880	22.22
27	2005200	7299360	9304560	21.55
28	1931400	6903000	8834400	21.86
29	1913040	7136640	9049680	21.14
30	1806840	7027920	8834760	20.45
31	1884240	6804000	8688240	21.69
Block 7	11640960	42523560	54164520	21.49

Table 2. --cont.

Date	10-h			
	Spill vol.	Turbine Vol.	Total 10-h Vol.	Average % Spill
4/22	1285200	1298520	2583720	49.74
23	1533960	1418400	2952360	51.96
24	1179000	1153800	2332800	50.54
25	1538640	1517400	3056040	50.35
26	1071000	953316	20243 16	52.91
27	987120	1091520	2078640	47.49
Block 1	7594920	7432956	15027876	50.54
28	885600	1019520	1905120	46.49
29	1281960	1272240	2554200	50.19
30	1311480	1236240	2547720	51.48
5/01	1014480	1057680	2072160	48.96
2	1490040	1547640	3037680	49.05
3	1703520	1757880	3461400	49.21
Block 2	7687080	7891200	15578280	49.34
4	1711080	1698840	3409920	50.18
5	2023200	2093040	4116240	49.15
6	1562400	1605240	3 167640	49.32
7	1002600	977760	1980360	50.63
8	1097280	1128600	2225880	49.30
9	1589400	1528920	3118320	50.97
Block 3	8985960	9032400	18018360	49.87
10	1618200	1718640	3336840	48.49
11	1504800	1533600	3038400	49.53
12	1242000	1320480	2562480	48.47
13	1349280	1348200	2697480	50.02
14	1036800	1054080	2090880	49.59
Block 4	6751080	6975000	13726080	49.18
15	1231200	1058400	2289600	53.77
16	1231200	1221840	2453040	50.19
17	1420200	1491480	2911680	48.78
18	1643400	1669680	3313080	49.60
19	1612800	1588680	3201480	50.38
20	1612800	1584360	3197160	50.44
Block 5	8751600	8614440	17366040	50.39
21	1946160	1932120	3878280	50.18
22	2154600	2175840	4330440	49.75
23	2286720	2384640	4671360	48.95
24	2295360	2403360	4698720	48.85
25	2250720	2247840	4498560	50.03
Block 6	10933560	11143800	22077360	49.52
26	2100240	2098440	4198680	50.02
27	2005200	1924560	3929760	51.03
28	1931400	1905840	3837240	50.33
29	1913040	1877040	3790080	50.47
30	1806840	1743120	3549960	50.90
31	1884240	1820880	3705120	50.86
Block 7	11640960	11369880	23010840	50.59

3.2 Objective 2: Die1 Passage Rates of Downstream Migrants

3.2.1 Introduction

Evaluations of die1 variability in hourly rates of migrant passage often indicate peaks in migrant passage at certain hours of the day (Dawson etal. 1981; 1982; 1983; 1984; Johnson et al. 1983; 1984; Raemhild et al. 1983; 1984). Such information aids in the efficient implementation and use of migrant bypass measures.

3.2.2 Methods

Die1 variability in rate of migrant passage was analyzed on an hourly basis. Spillway and turbine fish passage data were combined to estimate overall passage. The data were grouped by hour of day within each Block, for Blocks 3 through 7. Then the percentage of passage for each hour of the day was calculated. For more information on methods used to calculate die1 periodicity, see Appendix D.

3.2.3 Results and Discussion

The die1 variability in hourly migrant passage during Block 3 is presented in Figure 7 and Table 3. The distribution shows much higher passage during night hours (1900-0459 h) than during daylight, Day hours averaged less than 1% of total 24-h passage each hour, while at night passage each hour ranged from 4% to 17%. The die1 periodicity of fish passage during Blocks 4 through 7 was similar to that of Block 3. Appendix F contains die1 periodicity figures for these other Blocks.

The comparative passage between the 14-h day and 10-h night periods is very evident in Figure 8 and Table 4. Day passage ranged from 6% to 31%, averaging about 16% of the daily total fish passage. Night passage ranged from 69% to 95%, averaging about 84% of the daily total passage. Considering the day period is 4 h longer, the difference between day and night passage rates are even greater than indicated by this absolute passage comparison.

The greater night passage is probably a result of two factors. First, it is generally recognized that salmonid smolt migrational activities increase during hours of darkness. This has been observed at other mid-Columbia dams (Dawson et al. 1982; Dawson et al.1984; Gyldenege et al. 1983; Johnson et al. 1982; Johnson et al. 1983; Karp et al. 1982; Karp et al. 1984; Raemhild et al. 1983; Raemhild et al. 1984a; Raemhild et al. 1984b).The other important factor at this project site is that the hours of spilling coincide with the hours of darkness.

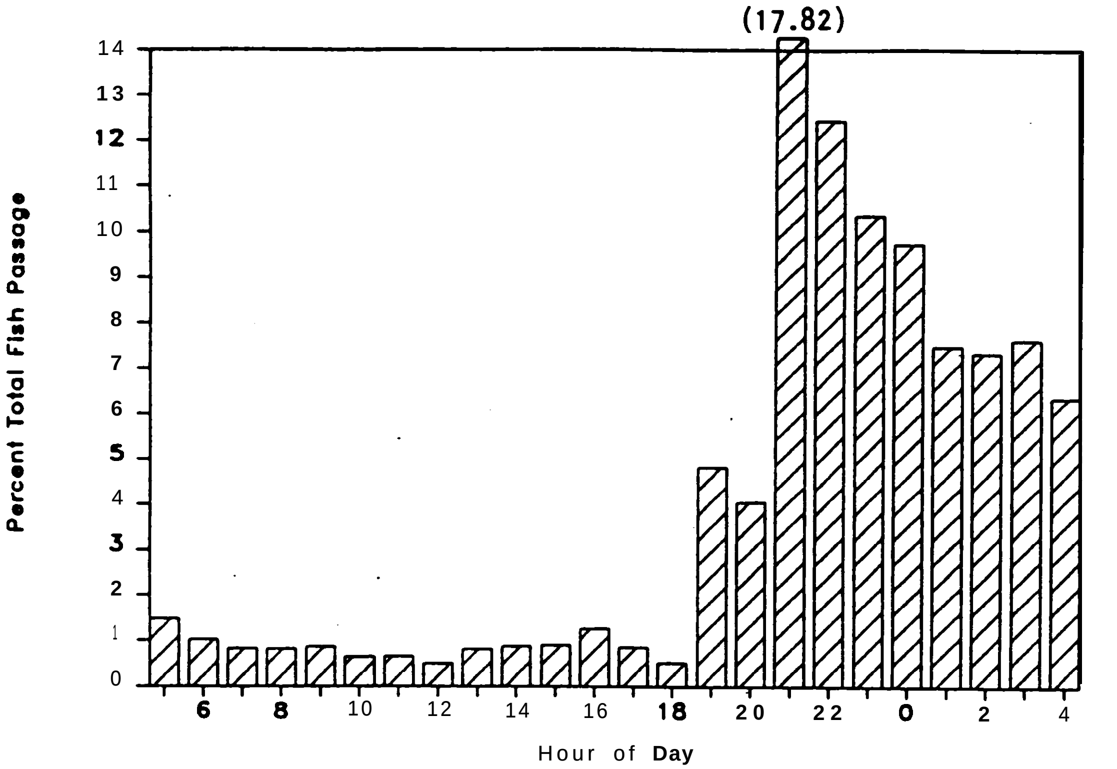

Figure 7. Diel variability in hourly migrant passage during Block 3. Lower Monumental Dam, 1985.

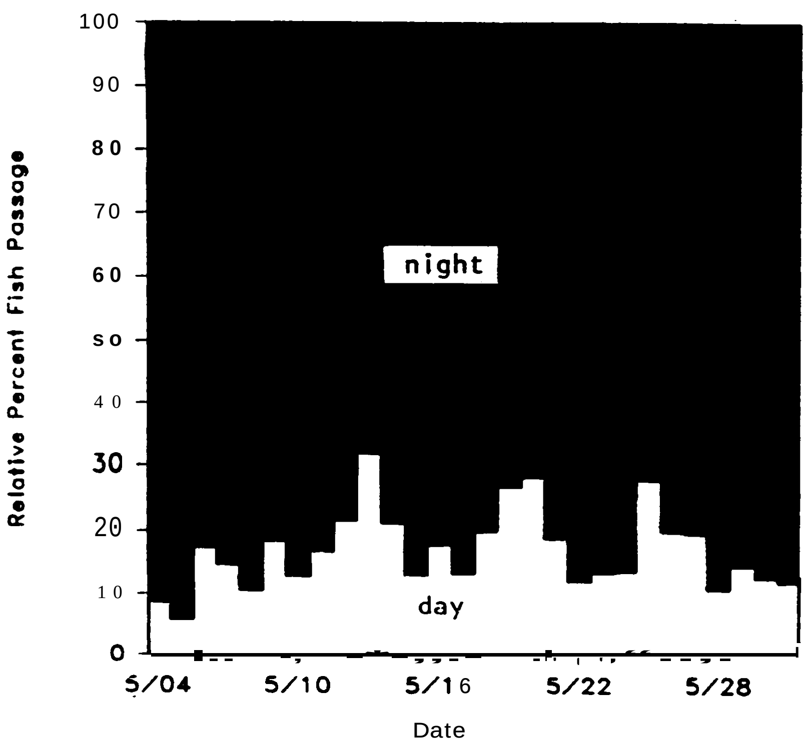

Figure 8. Daily relative passage of migrants for 10-h night and 14-h day periods. Lower Monumental Dam, May 4-31, 1985.

Table 3. Average hourly migrant passage percentage of 24-h total. Lower Monumental Dam, 1985.

Hour	Bl-3	Bl-4	Bl-5	Bl-6	Bl-7
5	1.48	3.19	2.43	2.29	2.05
6	1.02	2.33	1.56	1.51	1.15
7	0.84	1.28	1.60	1.11	1.19
8	0.83	1.11	1.49	1.20	0.88
9	0.86	1.06	1.21	1.29	0.88
10	0.64	1.06	1.31	1.09	0.83
11	0.65	1.97	1.11	1.05	0.95
12	0.50	2.96	1.40	1.25	0.87
13	0.81	0.71	1.19	0.87	1.17
14	0.88	0.76	1.16	0.80	0.90
15	0.90	0.77	1.14	1.38	0.86
16	1.25	0.84	0.84	0.77	0.70
17	0.86	0.84	1.03	0.94	1.16
18	0.53	0.78	0.97	0.77	1.02
19	4.83	4.83	3.56	3.14	5.32
20	4.05	3.25	2.92	1.78	3.07
21	17.82	8.70	11.41	10.38	9.65
22	12.43	10.34	9.86	10.17	13.30
23	10.35	9.09	9.76	9.91	10.40
0	9.70	8.73	9.45	10.17	8.91
1	7.47	8.90	7.99	11.13	9.66
2	7.32	8.26	8.41	10.36	9.57
3	7.61	8.44	8.89	9.41	7.92
4	6.35	9.78	9.29	7.22	7.59

Table 4. Daily and block (weighted average) relative passage rates between the 14-h days and 10-h nights. Lower Monumental Dam, 1985.

Date	% Day	% Night	Cumulative Percent Day	Cumulative Percent Night
5/04	8.58	91.42		
5/05	5.65	94.35		
5/06	17.14	82.86		
5/07	14.37	85.63		
5/08	10.39	89.61		
5/09	18.28	81.72		
Block 3			12.06	87.94
5/10	12.53	87.47		
5/11	16.38	83.62		
5/12	21.42	78.58		
5/13	31.47	68.53		
5/14	20.97	79.03		
Block 4			19.67	80.33
5/15	12.62	87.38		
5/16	17.67	82.33		
5/17	12.82	87.18		
5/18	19.61	80.39		
5/19	26.59	73.41		
5/20	28.23	71.77		
Block 5			18.46	81.54
5/21	18.48	81.52		
5/22	11.48	88.52		
5/23	12.77	87.23		
5/24	12.91	87.09		
5/25	27.84	72.16		
Block 6			16.33'	83.67
5/26	19.52	80.48		
5/27	19.23	80.77		
5/28	10.27	89.73		
5/29	13.95	86.05		
5/30	11.98	88.02		
5/31	11.58	88.42		
Block 7			14.61	85.39

3.3 Objective 3: Run Timing of Downstream Migrants

3.3.1 Introduction

The seasonal timing of migrant passage defines the periods of time when bypass methods may be effectively used. Knowledge of the annual pattern of migrant passage at several points on the Snake and Columbia rivers may enhance the efficiency of bypass methods.

3.3.2 Methods

Daily migrant passage estimates were expressed as percentages of the total number of fish estimated to have passed the project from 4-31 May. An "in-season" index of run timing was also calculated. This index was based on the average number of fish per minute passing the powerhouse transducers between 0000 h to 2359 h April 22 to May 31.

3.3.3 Results and Discussion

Daily estimates of the percentage of migrants passed through the project ranged from 1.49 to 7% (Figure 9, Table 5). Notable peaks occurred May 5, 9, and 22, separated by low-passage days of May 7 and 19. These peaks in rate of outmigration probably reflect seasonal changes in species composition or separation of stocks, influenced strongly by the timing of hatchery releases and river flows. Comparison of trends in daily fish passage and daily river flow (Figure 11) suggests run timing is influenced by river flow. This influence is well-documented in a number of studies and is the basis for many fisheries management considerations, including the Water Budget. In this study the increase in fish passage at the start of Block 3 coincides with the onset of a peak in river flow. Similar coincident river flow and fish passage peaks were observed in later blocks.

The 50th percentile of cumulative passage occurred between May 13 and 14 (Figure 10 and Table 5).

The "in-season" indices of run timing are presented in Table 5 and Figure 11. These were the daily numbers provided to the BPA and the Water Budget Center as the data were processed in the field. The indices were not expanded to total passage estimates. This index was taken from data collected only at turbine units each 24-h period. Although not expressed as a percentage, they are relative to each other and hence can be compared to the final estimate of run timing data. The two sets of data (i.e., the index and the final estimate of run timing) are notably similar. The index numbers show two peaks between May 5 and 9 followed by about 10 days of lower passage until May 21, and then another smaller peak culminating on May 25. The similarity between the two run-timing curves indicates the index was reliable.

Rote that the run timing estimates apply only to the inclusive period, and are therefore not indicative of the timing or size of the entire run of downstream migrants.

The COE requested that the hydroacoustic estimate of run timing be compared with results of daily gatewell dipnetting efforts conducted by NMFS at Lower Monumental Dam. Unfortunately, such a comparison cannot be made because concurrent data were only available for the last few days of this project (Rich Johnsen, personnal communication).

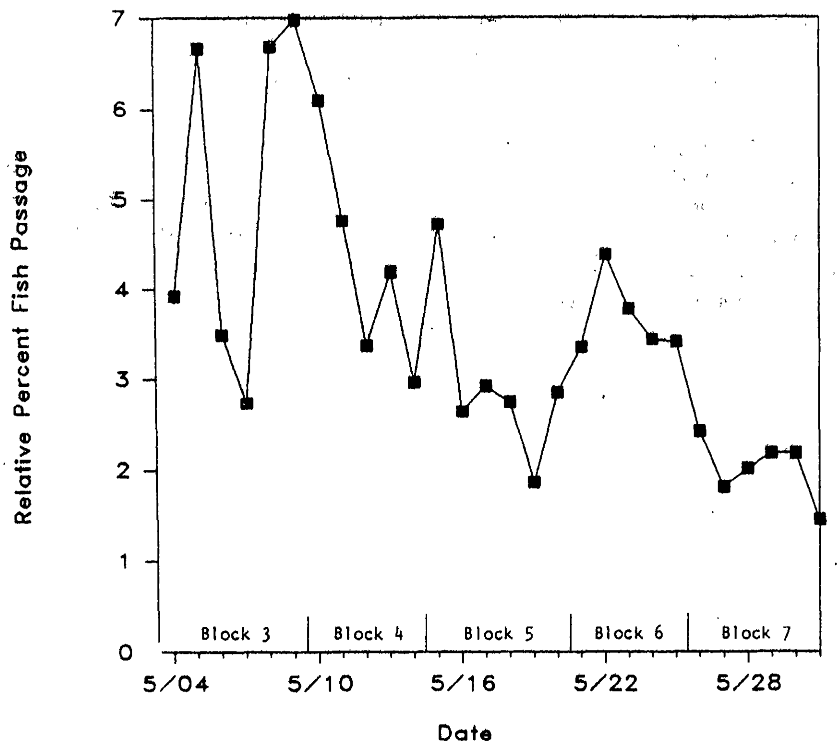

Figure 9. Daily estimates of the percentage of smolt outmigration. Lower Monumental Dam, 1985.

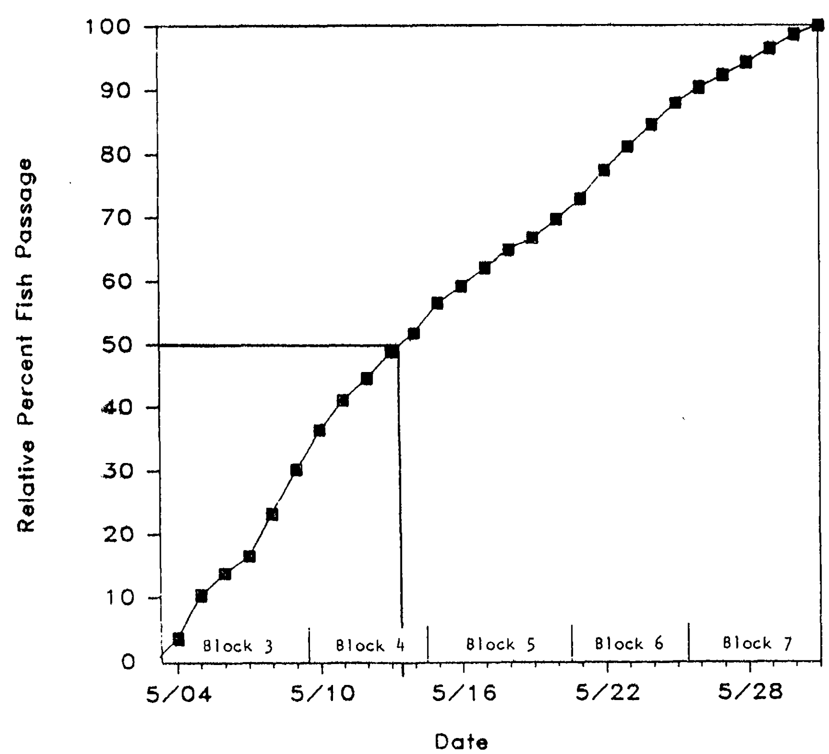

Figure 10. Cumulative estimates of the percentage of smolt outmigration. Lower Monumental Dam, 1985.

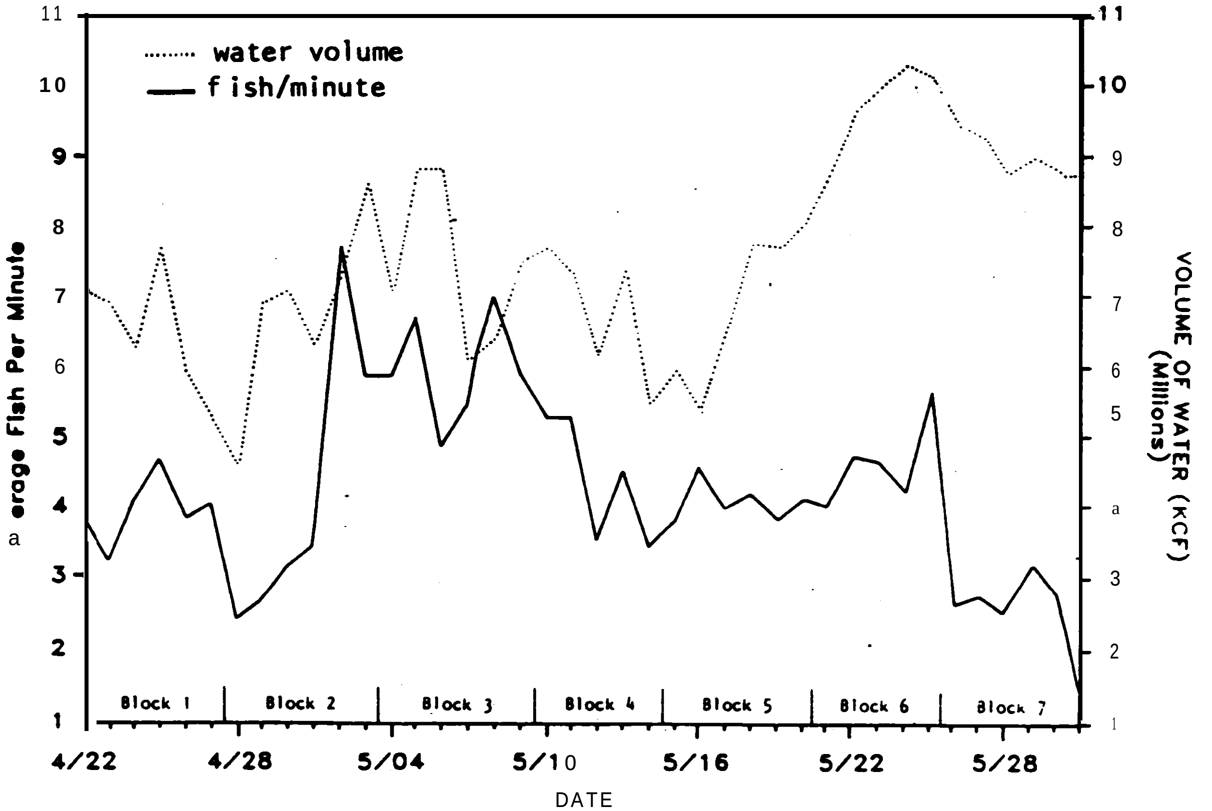

Figure 11. Daily index numbers of migrant passage rates at the powerhouse (data not affected by changes in aiming angles at the spillway) and daily river volumes. Lower Monumental Dam, 1985.

Table 5. Daily, cumulative and index estimates of migrant passage. Lower Monumental Dam, 1985.

Date	Daily % Migrant	Cumulative % Migrant	Migrant/Minute Index
4/22			3.86
4/23			3.32
4/24			4.09
4/25			4.73
4/26			3.87
4/27			4.07
4/28			2.52
4/29			2.71
4/30			3.17
5/01			3.50
5/02			7.69
5/03			5.87
5/04	3.92	3.92	5.91
5/05	6.66	10.58	6.71
5/06	3.49	14.07	4.86
5/07	2.73	16.80	5.50
5/08	6.68	23.48	6.95
5/09	6.98	30.46	5.91
5/10	6.10	36.56	5.33
5/11	4.76	41.32	5.33
5/12	3.37	44.70	3.61
5/13	4.19	48.89	4.63
5/14	2.96	51.85	3.50
5/15	4.72	56.57	3.90
5/16	2.64	59.21	4.58
5/17	2.92	62.13	3.96
5/18	2.74	64.87	4.27
5/19	1.86	66.73	3.95
5/20	2.85	69.58	4.23
5/21	3.35	72.93	4.13
5/22	4.38	77.31	4.77
5/23	3.78	81.09	4.75
5/24	3.44	84.53	4.27
5/25	3.41	87.94	5.66
5/26	2.42	90.36	2.75
5/27	1.81	92.17	2.80
5/28	2.01	94.18	2.58
5/29	2.18	96.36	3.32
5/30	2.18	98.55	2.79
5/31	1.45	100.00	1.42

3.4 Objective 4: Horizontal Distribution of Migrants across the Powerhouse and the Spillway

3.4.1 Introduction

Estimates of the horizontal distribution of migrants across the powerhouse indicate where mechanical bypass efforts could be concentrated to maximize their effectiveness.

The horizontal distribution of migrants across the spillway indicates the relative efficiency of each gate in passing fish. This information could be useful for enhancing the effectiveness of passing migrants through the spillway.

3.4.2 Methods

The powerhouse distributions are from data collected when all operable turbines were running simultaneously between April 22 and May 31. This results in all distributions being from daytime data only because during night hours only 2 or 3 turbines were on-line. Turbine 1 was inoperable during the entire study period.

The horizontal distribution of migrants across the spillway was calculated using data collected when the "crown" pattern of spill gate opening was employed and for hours when all spill gates were open (4-31 May). Spill distributions are from data collected during the night hours because there was virtually no daytime spill.

For more information on methods used for estimating horizontal distributions, see Appendix D.

Rote that spill and turbine distributions are for each section of the dam exclusively and that they are not proportional to each other. The orientation of each figure is noted by "North" and "South" on the figure.

3.4.3 Results and Discussion

Horizontal distribution of migrants across the powerhouse is shown in Figure 12 and Table 6 as a season composite, and in Appendix G by Block. The turbine units showing the highest relative seasonal passage were T3 and T4, each with about 25% of the total powerhouse passage. Turbine 2 was the lowest with 14%. The middle of the powerhouse attracted more smolts than the end units, but the difference was only 10%. There were variations in horizontal distribution throughout the season, with the south turbines (T5 and T6) showing the highest passage in Blocks 2 and 4. Turbine 2, near the north bank, consistently had the lowest passage.

At the spillway, horizontal distribution of migrants was skewed with larger percentages of fish passed at the higher numbered (north) spillgates (Figure 13, Table 7). Spill 8 had almost twice as much passage as spills 1 or 2. This may be an effect of the powerhouse adjacent to Spill 8 providing attractive flow. The horizontal distributions of spill passage during individual blocks are presented in Figures G 8-12.

Again, the horizontal distribution in the spill is for nighttime hours, and in the turbines it is for daylight hours. Each distribution is complete and unique to its respective section of the dam; spill and turbine percentages are not comparable.

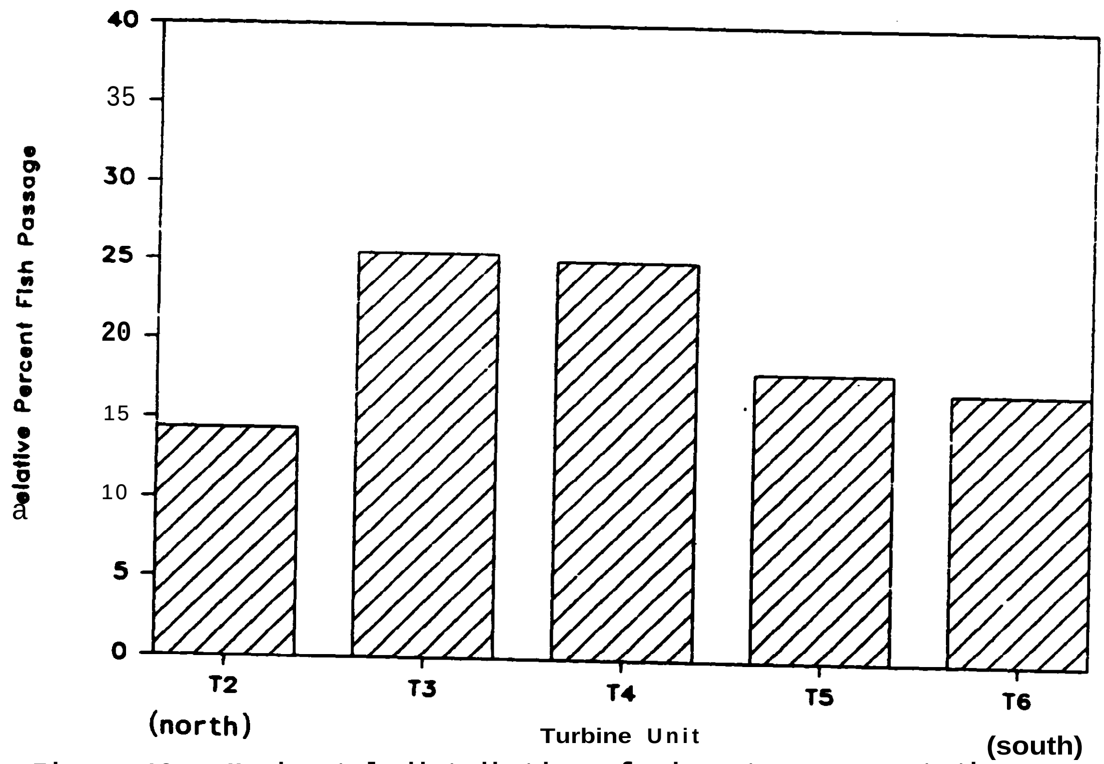

Figure 12. Horizontal distribution of migrant passage at the power-house during daylight. Lower Monumental Dam, April 22 - May 31, 1985.

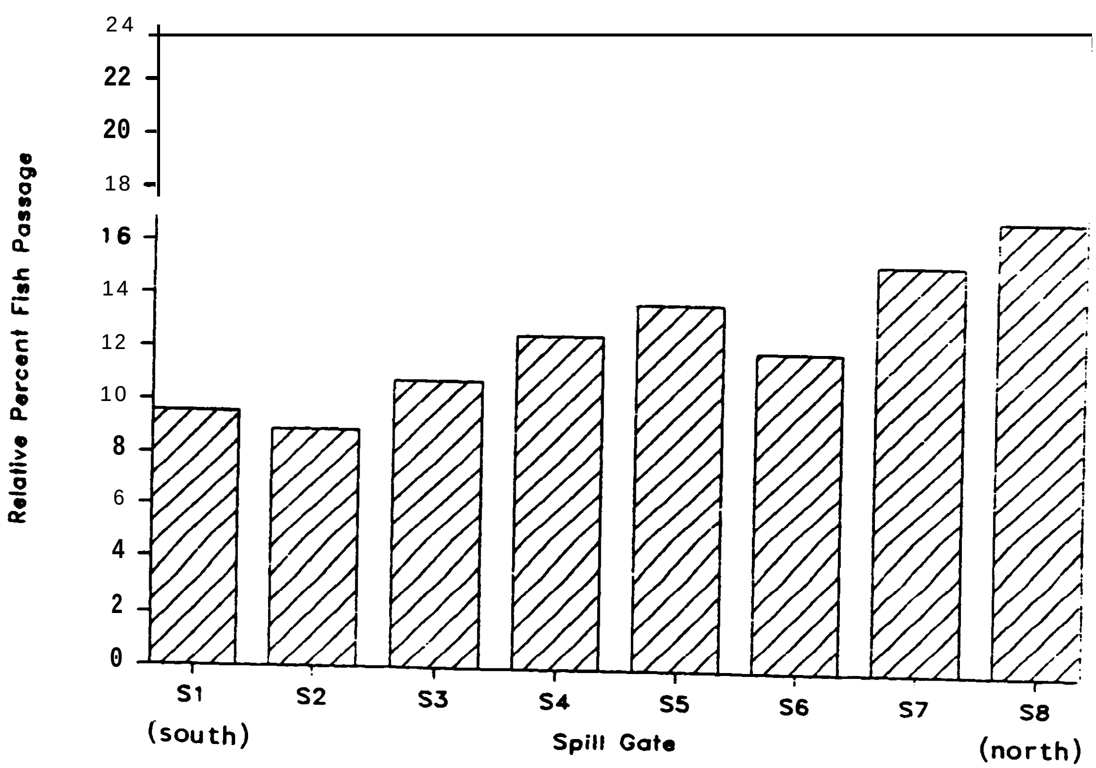

Figure 13. Horizontal distribution of migrant passage at the spill-way at night. Lower Monumental Dam, May 4-31, 1985.

Table 6. Relative percent horizontal distributions of migrants at the powerhouse from hours when all operable units were operating (i.e., daytime). Lower Monumental Dam, 1985.

Unit	Season	Block1	Block2	Block3	Block4	Block5	Block6	Block7
T2	14.35	11.63	14.81	18.79	14.36	14.31	13.04	15.85
T3	25.48	35.13	17.75	28.12	19.43	28.21	24.72	21.90
T4	**25.04**	**27.90**	**19.63**	**17.76**	**21.55**	**25.92**	**25.24**	**29.24**
T5	18.15	18.95	24.81	15.95	23.60	17.11	16.28	15.80
T6	16.98	6.380	22.99	19.38	23.05	14.44	20.72	17.21

Table 7. Relative percent horizontal distributions of migrants at the spillway from periods of "crown" spill pattern when all eight gates were open (nighttime only). Lower Monumental Dam 1985.

Unit	Season	Block3	Block4	Block5	Block6	Block7
S1	9.55	9.41	8.30	11.99	9.38	7.87
S2	8.91	7.57	8.72	9.52	10.67	10.60
S3	10.79	9.27	10.71	12.68	12.31	10.23
S4	12.57	11.45	13.64	11.62	13.19	15.07
S5	13.78	14.54	14.79	13.13	11.69	11.47
S6	12.01	12.42	12.34	10.36	14.55	9.48
S7	15.36	14.69	13.97	16.24	15.01	20.60
S8	17.04	20.63	17.50	14.45	13.21	14.68

3.5 Objective 5: Vertical Distributions of Migrants Passing through Turbines and Spill Gates

3.5.1 Introduction

Vertical distributions provide information about migrants' behavior as they approach the dam. The effectiveness of any migrant bypass mechanism, including spill, will depend on where in the water column migrants are concentrated relative to that mechanism. Many variables affect the vertical distribution of migrants including species, seasonal and die1 period, and flow patterns in the forebay.

3.5.2 Methods

For each migrant detected, its range (distance) from the transducer was measured and recorded. Distributions along the transducer's axis of orientation (e.g., angled 20° upstream at the powerhouse) were developed for operating turbine units and spill gates. Only data with no acoustical or electrical interference were included in these distributions. Cumulative percentage distribution functions were developed using migrant abundance estimates weighted by the effective beamwidth at range for each migrant detected. Appendix D, Section D.5, describes the method in greater detail. Distributions were calculated for each unit for each block of the season by day and night hours (spills are for night only because that was the time of spillway operation).

The distributions are given in range from the transducer; that is distance along the acoustic axis from the transducer (see Figures 3 and 4). The spill transducers were aimed downwards, so the spill vertical distributions show maximum depth equal to maximum range. The turbine transducers were on the bottom so the orientation of the surface is the inverse of the range (i.e., maximum range equals the surface, or minimum depth). Surface and bottom are noted on each figure.

3.5.3 Results and Discussion

Turbine Vertical Distribution

Migrants in front of the turbines had a deeper distribution during night hours than during daylight (Table 8, Figure 14). This trend was most pronounced in the upper third of the range. The trend was consistent throughout the season (Tables Hl-H4). Shallower distributions during daylight hours are typical at Columbia River Basin hydroelectric dams (Dawson et al. 1982; Dawson et al. 1984; Gyldenege et al. 1983; Johnson et al. 1982; Johnson et al. 1983; Karp et al. 1982; Karp et al. 1984; Raemhild et al. 1983; Raemhild et al. 1984a; Raemhild et al. 1984b).

The relative vertical distribution of powerhouse migrants became shallower during the course of the season. Table 10 lists, for each Block, the range from transducer of the cumulative 50% points, indicative of the depth of the overall population. At night, the distributions were shallower during Blocks 1 and 2 than during the remainder of the season. During the day the distributions became shallower with each successive Block except that Block 4 distribution was approximately the same as Block 2. The changes in relative vertical distributions probably reflect changes in species composition. Chinook smolts are generally thought to travel deeper in the water column than steelhead (Johnson et al. 1984). Such changes in the distribution of migrants in front of turbines need to be considered in the design of mechanical bypass systems. Preliminary data from Bonneville Powerhouse No. 2 indicates a strong correlation between acoustically determined vertical distribution in the forebay and the fish guiding efficiency of traveling screens (Bob Magne, personal communication, 1985).

Spillway Vertical Distribution

At the spillway, where changes in mounting configuration produced two discrete data sets, Blocks 1 and 2 (in the first configuration) yielded a distribution from the surface to 125 feet. Blocks 3-7, aimed directly at the ogee, had a maximum range of about 55 ft, The composite observations of vertical distribution for these latter 5 blocks is presented in Table 9 and Figure 15. The distribution for Blocks 1 and 2 is presented in Appendix H. The distribution for Blocks 1 and 2 shows a sharp inflection point at 47 ft. This corresponds to about the range of the ogee, and suggests two distinct populations, one being oriented toward the surface, the other approaching from much deeper, and moving toward the deepest part of the spill gate (where the opening is). The bulk of the deeper population was distributed between 50 and 70 ft. The remainder of the spill vertical distributions, Blocks 3-7, (Tables HS-H6) show no major changes throughout the season.

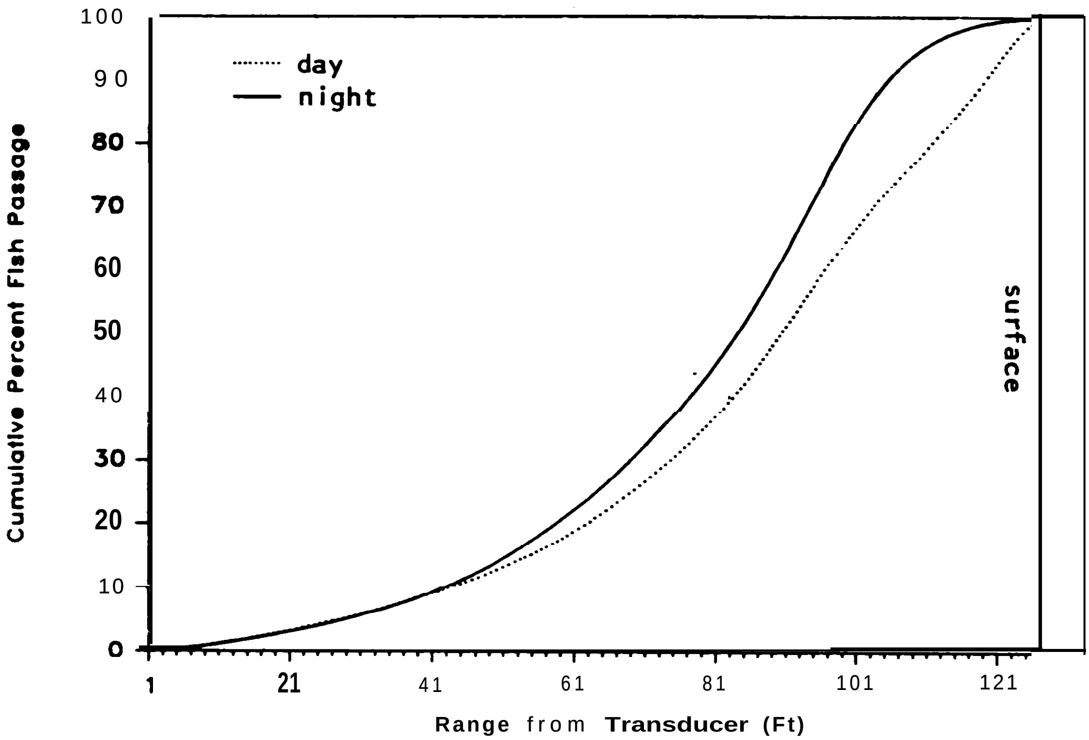

Figure 14. Range distribution of migrants along the transducers' axes, 20° in front of the face of the powerhouse (bottom-mounted, 15° transducers) during 14-h days and 10-h nights. Lower Monumental Dam, April 22 - May 31, 1985.

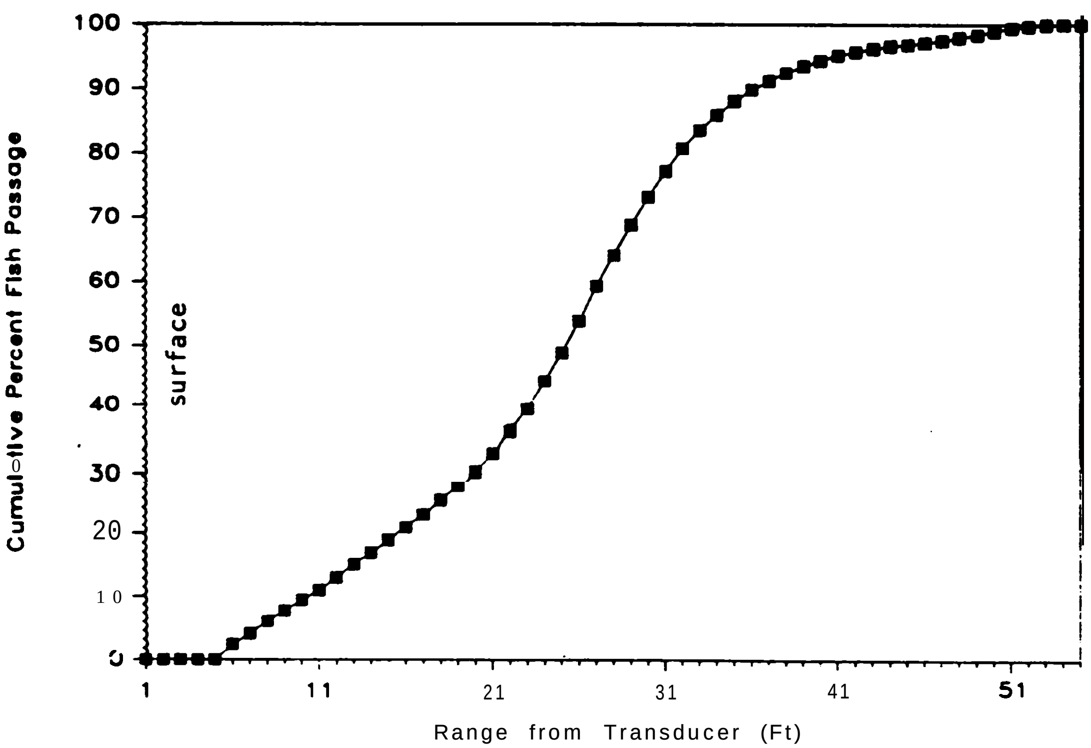

Figure 15. Range distribution of migrants at the spillway (surface-mounted, 15° transducers) during 10-h nights. Lower Monumental Dam, May 4-31, 1985,

Table 8. Seasonal composite of vertical distribution of migrants at the powerhouse, all units combined. Lower Monumental Dam, 1985.

Range (ft)	Day cum. %	Night cum. %	Cont'd: Range (ft)	Day cum. %	Night cum. %
1	0	0	69	24.825	30.094
3	0	0.277	71	26.594	32.370
5	0.130	0.659	73	28.500	34.555
7	0.232	0.920	75	30.165	37.017
9	1.039	1.321	77	32.187	39.550
11	1.287	1.549	79	34.536	42.398
13	1.692	1.749	81	36.819	45.412
15	2.094	1.956	83	39.369	48.512
17	2.328	2.389	85	41.822	51.931
19	2.737	2.787	87	44.776	55.456
21	3.236	3.180	89	47.896	59.281
23	3.636	3.550	91	50.949	63.175
25	4.256	4.110	93	54.128	67.286
27	4.703	4.621	95	57.377	71.567
29	5.112	5.174	97	60.630	75.540
31	5.635	5.658	99	63.428	79.156
33	6.303	6.278	101	66.406	82.906
35	6.933	6.982	103	69.454	86.626
37	7.597	7.688	105	72.159	89.829
39	8.395	8.475	107	74.742	92.480
41	9.055	9.335	109	76.787	94.296
43	9.792	10.311	111	79.115	95.727
45	10.563	11.266	113	81.305	96.914
47	11.354	12.307	115	83.624	97.752
49	12.276	13.702	117	86.391	98.463
51	13.244	14.820	119	89.292	98.987
53	14.194	16.251	121	92.429	99.380
55	15.089	17.578	123	95.546	99.657
57	16.156	19.106	125	97.971	99.867
59	17.432	20.693	127	99.384	99.958
61	18.769	22.304	129	99.900	99.994
63	20.168	24.174	131	100	100
65	21.647	26.080	133	100	100
67	23.323	27.926			

Table 9. Blocks 3-7 composite of vertical distribution of migrants at the spillway, all gates combined. Lower Monumental Dam, 1985.

Range	Night Cum. %	Cont'd: Range	Night Cum. %
1	0	29	68.879
2	0	30	73.193
3	0	31	77.267
4	0	32	80.719
5	0	33	83.590
6	2.482	34	86.036
7	4.133	35	88.132
8	6.077	36	89.889
9	7.768	37	91.242
10	9.401	38	92.513
11	10.983	39	93.557
12	12.964	40	94.463
13	15.061	41	95.232
14	16.888	42	95.773
15	19.016	43	96.318
16	21.023	44	96.687
17	23.076	45	96.894
18	25.258	46	97.214
19	27.652	47	97.543
20	30.476	48	97.955
21	33.292	49	98.434
22	36.246	50	98.966
23	39.569	51	99.412
24	44.163	52	99.739
25	48.951	53	99.969
26	53.871	54	100
27	59.400	55	100
28	64.176		

Table 10. The 50th percentile points by block of the powerhouse vertical distributions (along the acoustic axis). Lower Monumen tal Dam, 1985.

	Range from transducer (ft)	
	Night	Day
Block 1	79	79
Block 2	77	86
Block 3	83	97
Block 4	84	89
Block 5	87	96
Block 6	91	99
Block 7	87	94

4.0 CONCLUSIONS AND RECOMMENDATIONS

Lower Monumental Dam proved to be a location well suited to acoustic monitoring in 1985. Wind and debris generated noise were minimal and the perpendicular-to-flow configuration of the dam facilitated equipment installation, data interpretation, and analyses of results. This year's baseline approach to measuring spatial and temporal aspects of migrant passage provides valuable insights for further studies of bypass capabilities at this site.

During this study, 52% to 83% instantaneous spill effectiveness was observed at instantaneous spill levels of close to 50% of river flow. Spill effectiveness estimates were about 10% higher early in May than late in May. Such seasonal trends should be considered in future studies.

In subsequent studies to further the understanding of spill effectiveness on the lower Snake River, it is recommended that a broader range of spill levels be tested. A test regime to study the effects of different spill levels could be designed like this:

Block 1:	Day 1	30% spill
	Day 2	40% spill
	Day 3	50% spill
	Day 4	60% spill
	Day 5	70% spill
Blocks 2-7:	repeat same 5 spill levels, randomized within each succeeding block.	

This randomized block design would effectively allow evaluation of the influence of spill level on spill effectiveness independent of seasonal factors.

Other sampling designs using hydroacoustics should be used to evaluate non-spill bypass mechanisms. For instance, to evaluate the feasibility of using traveling screens, the vertical distribution of smolts in the turbine intake (at the point of interception) could be evaluated by a transducer mounted at the same point the screen would be deployed.

The technique of in-season migration indexing proved feasible and effective. The final test of it was the comparison to the run timing results calculated from a complete, expanded set of data. The comparison indicates the index was excellent at tracking major trends in the migration, showing changes more than three fold between low and high passage periods. An in-season, close-to-real-time index could be an effective management tool.

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APPENDIX A: Hydroacoustic System Equipment, Operation, and Calibration

Equipment Description

The BioSonics hydroacoustic data collection system consisted of the following components: thirteen 420 kHz transducers, an echo sounder/transceiver, a multiplexer/equalizer, two chart recorders, and an oscilloscope. A block diagram of the basic system is shown in Figure Al. Table Al lists specific manufacturers and model numbers of the electronic equipment used.

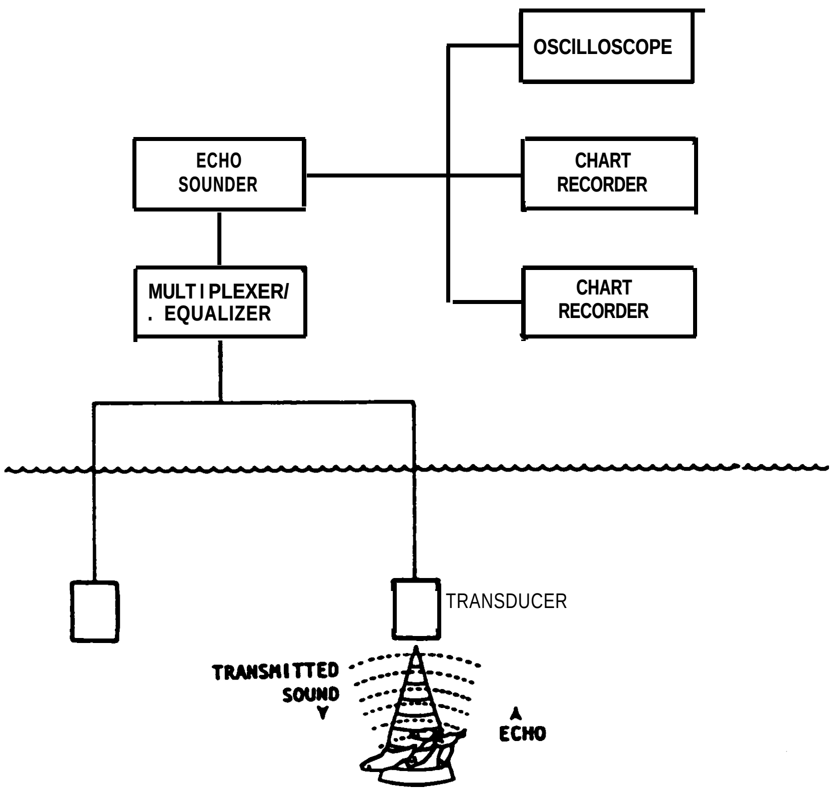


Figure Al. Block diagram of the basic hydroacoustic data acquisition system used at Lower Monumental Dam in 1985.

Table Al. Manufacturers and model numbers of electronic equipment used by BioSonics, Inc. at Lower Monumental Dam during spring 1985.

Item	Manufacturer	Model Number
Echo Sounder	BioSonics, Inc.	101
high Speed Multiplexer/ Equalizer	BioSonics, Inc.	151
Chart Recorders	Raytheon, Inc.	LSR 910M
Transducers (15°)	BioSonics, Inc.,	SP06
Oscilloscope	Hitachi Denshi, Ltd.	V-352
Rotator and Rotator control box	BioSonics, Inc	SP500
Microcomputers	NorthStar	Advantage
	NorthStar	Advantage (hard disk)
Computer Printers	Epson	FX-80
	Epson	MX-80
Digitizing Pad	Summagraphics	Bit Pad II

Note: Specifications for equipment can be obtained by contacting BioSonics, Inc.

Equipment Operation

The hydroacoustic data collection system works as follows: when triggered by the Model 101 Echo Sounder, a high-frequency transducer emits short sound pulses in a relatively narrow beam aimed toward an area of interest. As these sound pulses encounter fish or other targets,echoes are reflected back to the transducer which then reconverts the sound energy to electrical signals. The signals are then amplified by the echo sounder at a time-varied-gain (TVG) which compensates for the loss of signal strength due to absorption and geometric spreading of the acoustic beam with distance from the transducer. Thus, equally sized targets produce the same signal amplitudes at the echo sounder output regardless of their distance from the transducer. A target's range from the transducer is determined by the timing of its echo relative to the transmitted pulse.

The echo sounder relays the returning TVG-amplified signals to the chart recorder and the oscilloscope. The return signals are visually displayed on the oscilloscope for measurements of echo strengths and durations. Individual fish traces are displayed on the chart recorder's echograms which provide a permanent record of all targetsdetected throughout the study. The threshold circuit on the chart recorder eliminates signals of strengths less than the echo levels of interest.

The Model 151 Multiplexer/Equalizer (MPX/EQ) permits a single echo sounder to automatically interrogate up to 16 different transducers in an operator-specified sequence. The MPX/EQ channels transmit pulses from the echo sounder to the appropriate transducers and equalizes the return signals to compensate for the differing receiving channel sensitivities resulting from varying cable lengths and transducer sensitivity. In the "fast multiplexed mode" the MPX/EQ permits simultaneous interrogation of two transducers with the return TVG-amplified signals routed to two separate chart recorders.

System Calibration

The acoustic system was calibrated before the study began. Calibration assured that an echo from a target of known acoustic size passing through the axis of the acoustic beam produced a specific output voltage at the echo sounder. Once this voltage was known, an accurate ($\pm$ 0.5°) estimate of the actual sensivity beamwidth (or "effective" beamwidth) for a given target strength could be determined for each transducer based on sensivity plots.

Based on the calibration information, the adjustable print threshold on the chart recorder was set so that it would print signals from "on-axis" targets larger than -56 dB, thus providing about 15° of sample volume for targets larger than -50 dB. This -50 dB target strength corresponded to the smallest juvenile salmonids expected during the study (approx. 5.7 cm) according to the target strength/size relationship established by Love (1971). The calibration information was also used to equalize (on the MPX/EQ) the systems' sensitivities for each receiving channel. A detailed description of the calibration of hydroacoustic systems can be found in Albers (1965) and Urich (1975).

Dual-beam acoustic measurements were taken at Lower Granite Dam during the same time of the spring migration that was monitored at Lower Monumental. The dual-beam data provided in-situ measurements of actual target strengths encountered. The lower end of target strengths measured at Lower Granite was -50dB. This corresponds with dual beam measurements made at the mid-Columbia hydroelectric dams. Thus the assumed beam width for a smolt-sized target was substantiated with measurements of the actual population being measured.

Relative Detectability'

The hydroacoustic results, including spill effectiveness, die1 periodicity, run timing and horizontal distributions, require accurate relative estimates of fish passage at the individual transducers. Accurate relative estimates will be obtained if the effective beamwidth over which fish are detected is constant for the transducer ranges being processed. As mentioned above in the calibration section, the effective beamwidth is a function of calibration parameters; however, site specific parameters such as ping rate, transducer aiming angle, fish velocity and fish trajectory can also affect relative detectability.

APPENDIX B: Locations and Descriptions of Transducers and Mount Configurations used at Lower Monumental Dam, 1985.

Table B1. Transducer configuration: locations and orientations used in the forebay at Lower Monumental Dam, 1985.

Location	Surface or Bottom Mount	Actual Beam Width (deg)	Mount Depth (ft)	Vertical Aiming Angle[1]
		Powerhouse		
T 1[2]	-	-		-
T 2	b	15	114.0	150/160
T 3	b	16	114.0	150/160
T 4	b	15	120.0	150/160
T 5	b	16	125.0	150/160
T 6	b	13	125.0	150/160
		Spillway		
S 1	s	16	4.0	20/0
S 2	s	15	4.0	20/0
S 3	s	15	4.0	20/0
S 4	s	16	4.0	20/0
S 5	s	15	4.0	20/0
S 6	s	16	4.0	20/0
S 7	s	16	4.0	20/0
S 8[3]	s	16	4.0	20/0

[1] Aiming angles expressed in degrees into the forebay with "0" being straight down and "180" being straight up. The two angles refer to the mount configurations before and after May 3 (see section 2.0, General Methods).

[2] Turbine 1 inoperative entire study

[3] Spill 8 inoperative 4/22 - 5/02

APPENDIX C: Data Acquisition

Migrant Detection Criteria

Echogram traces had to satisfy three criteria to be classified as downstream migrants: (1) the strength of target echoes had to exceed a predetermined threshold; (2) the targets had to be detected by consecutive pulses (redundancy); and (3) the targets had to show general movement toward the intake.

Target Threshold

The data collection system was calibrated so that the chart recorder would mark targets with target strengths greater than -56 dB within the specified beamwidth of the transducer. This target strength threshold was chosen so that even the smallest anticipated migrants at the least sensitive edge of the transducer effective beamwidth would return an echo with an amplitude great enough to mark the echogram.

Target Redundancy

At least four successive ensonifications were required for a target to be classified as a fish. Most of the fish observed were sequentially detected more than four times. The reasons for this high redundancy were: 1) the relatively wide beamwidths of the transducers; 2) the high pulse repetition rates; and 3) the behavior of the fish (fish appeared to be moving at about the same velocity as the water). This redundancy criterion enhanced fish detectability in the presence of background interference and was necessary to obtain sufficient change-in-range information to determine direction of fish travel.

Direction of Movement

Since transducers were in fixed locations at aiming angles that were not perpendicular to the direction of fish travel, it was possible to distinguish fish moving toward the intake from those moving away. Only fish moving toward the dam were classified as downstream migrants. As a fish passed through an ensonified volume, a succession of marks on the echogram indicated a fish's change-in-range relative to the transducer. Since the transducer's positioning was known, this change-in-range information expressed the fish's direction of movement relative to the intake. Figure Cl shows typical fish movement through an ensonified volume, and Figure C2 shows a corresponding echogram trace caused by such a fish. Table Cl lists, by location and depth, the trace types classified as migrants in this study.

Table Cl. Trace types classified as migrants by location and depth. Lower Monumental Dam, 1985.

	Depth				
Location	l-13'	14-26'	27-36'	37-46'	47-55'
Spillway	SL BI	SL BI NC	SL BI NC	SL BI NC	SL BI NC LS BD

	Depth				
Location	1-26'	26-60'	61-93'	94-125'	126-140'
Powerhouse	none	LS BD	LS BD	LS BD	LS BD SL BI NC

Trace type code

LS = Long to short (radiply decreasing)
BD= Bent decreasing (gradually decreasing)
BI = Bent increasing (gradually increasing)
SL = Short to long (rapidly increasing)
NC = No change

Further details of fish detection criteria for fixed-location hydroacoustics can be found in Carlson et al. (1981).

Data Entry and Storage

Microcomputers were used for data storage and analysis. Data from individual fish observations recorded on the echograms were transformed to numeric data files on a microcomputer by using a digitizing pad and appropriate software. For each detected fish passing through the acoustic beam, a technician used the digitizing stylus to record the following:

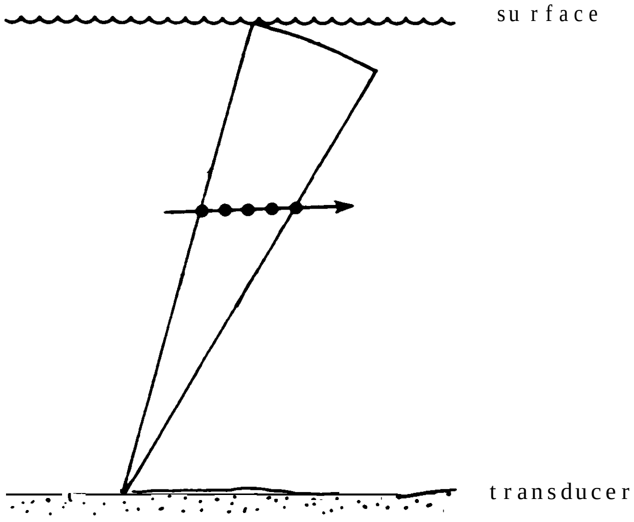
time of entrance
time of exit
range at entrance
range at exit
general direction of fish movement (trace type)

The following information was also recorded for each sampling sequence:

date
start time of transducer interrogation
duration of transducer interrogation
transducer location
transducer depth
transducer beamwidth
transducer orientation
background interference level
background interference range

Powerhouse and Spillway Operation Records

Records of dam operations (i.e., individual turbine unit and spill gate flows by hour) were recorded from the master logsheet in the control room of the dam. They were enterred to a microcomputer and stored on floppy disks. Calculations for daily and night period flow volumes were made from these entries.



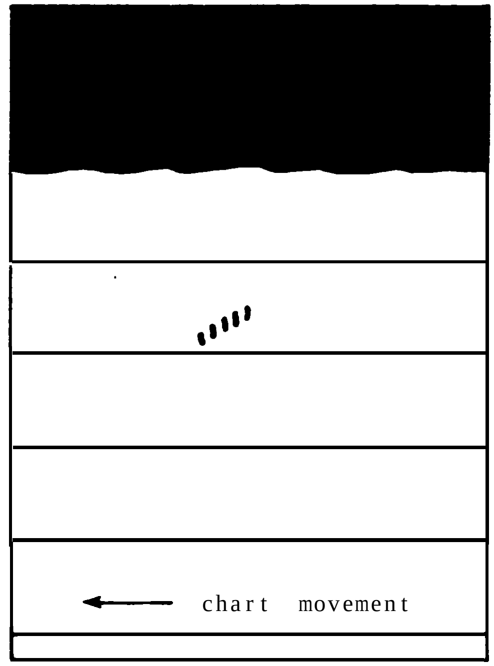


Figure Cl. Typical trajectory of a fish with five detections passing through the region ensonified by a 6° transducer.

Figure C2. Sketch of an echogram with a five-detection fish trace showing typical change-in-range information.

APPENDIX Data Analysis

Computer programs were developed by BioSonics, Inc. to facilitate analysis of spill effectiveness, die1 periodicity, run timing, horizontal distributions, and vertical distributions.

D.1 Extrapolation of Data Affected by High Interference

Periodically, acoustical or electrical interference ("noise") obscured portions of echograms, thus preventing accurate detection of fish and resulting in biased estimates of fish passage rates. In order to compensate for obscured fish traces, an extrapolation based on the distribution of fish from unobscured periods was applied.

Cumulative "standard" distributions along the transducer axis were derived from data not affected by interference. Estimates of weighted fish from these standard distributions were used to extrapolate for those portions of the data obscured by interference.

Location was found to be a more important factor than time in determining the shape of a vertical distribution. Standard cumulative vertical distributions were created (whenever possible) for each location by five-day spill block and by daytime and nighttime period using unobscured data.Data from adjacent sampling locations were combined only when there was an insufficient number of detections from an individual sampling location.

Each sequence which displayed high acoustical interference was then extrapolated. Any visible fish which occurred in the obscured portion were ignored, and fish in the unobscured portion of the echogram were summed. The standard vertical distribution was consulted to determine the percentage of fish which should have occurred in the noisy part of the echogram, had there been no noise. The number of fish estimated to have occurred in the obscured part of the echogram was calculated by:

$$F_o = \left(\frac{F_u}{F_s/100}\right) - F_u \qquad (1)$$

where:

F_o = **obscured weighted fish**

F_u = **unobscured weighted fish**

F_s = **percent of fish in the segment of the standard distribution corresponding to the unobscured portion of the echogram being extrapolated.**

In this way only unbiased data was used to establish standards for estimating obscured (and possibly biased) portions of echograms. Since each noisy sequence (transducer interrogation) was extrapolated individually, all available unobscured data was utilized for extrapolation.

D.2 Method for Estimating Passage Rates

Procedure

The initial hydroacoustic data set consisted of midpoint ranges for each migrant detected. Since the beam did not ensonify the whole area in front of a turbine or spill intake, not all the fish passing into that intake were detected. The total number of migrants passing into an intake at a particular range and instant was estimated by multiplying each detection by the proportion of the intake cross section ensonified at that migrant's range. This dimensionless weight was simply the ratio of the horizontal dimension of the intake to the diameter of the beam at that depth. Based on this weight, each detected downstream migrant represented an estimate of the number of migrants entering the intake at that range and instant of detection.

Theory and Mathematics

The proportion of an intake cross-section that was hydroacoustically sampled was a function of the following variables: range from the transducer (due to spreading of the transmitted acoustic wave with distance); the beam pattern of the transducer; the target properties of the migrants; the acoustic energy transmitted; and the sensitivity of the hydroacoustic system. A discussion of how these variables interrelate to determine effective beamwidth is beyond the scope of this study, but is dealt with in detail by others (Urick 1975).

The effective beamwidth at a given range from a transducer was calculated by:

$$A(r) = 2\, r \tan(a) \qquad (2)$$

where:

$A(r)$ = the effective beamwidth at range r

r = range from the transducer

a = transducer effective beam half angle (see Appendix A)

The proportion of a turbine intake sampled at a specific range from a particular transducer was estimated from:

$$P(r) = \frac{A(r)}{B(r)} \qquad (3)$$

where:

$P(r)$ = proportion of the turbine intake sampled

$B(r)$ = intake width at range r (in this case a constant).

Assuming that the horizontal distribution of fish is constant across the entire turbine intake, the weighting factor W(r) is equal to the inverse of the proportion of the turbine intake sampled:

$$W(r) = \frac{1}{P(r)} \qquad (4)$$

An estimate of the number of fish passing into a turbine intake for each transducer sampling sequence was estimated by:

$$N_t = \sum_{j=1}^{m} D_j W_j \qquad (5)$$

where:

N_t = the estimated number of fish entering the entire turbine intake t during each transducer sampling sequence

D_j = actual number of detected fish within the range j increment

m = maximum range increment (strata) of detected fish

W_j = weighting factor at range j.

The total number of fish entering a turbine intake per day and night during the time when a transducer was being interrogated was estimated from:

$$F_t = \sum_{k=1}^{L} N_{tk} \qquad (6)$$

where

F_t = the total estimate of fish entering the turbine intake t during all the transducer sampling sequences per day and night'

L = total number of sequences sampled per time block

N_{tk} = estimated number of fish entering the entire turbine intake t during time block k.

During data collection and all analysis phases, care was taken to exclude all data collected when a turbine was off-line or a spill gate was closed. Operations data was recorded in increments of 12 minutes.

D.3 Method for Calculating Die1 Periodicity at the Powerhouse

Die1 distributions were examined in two ways: daily, on a night vs. day basis; and by block on an hourly basis. For the 14-h day/10-h night block estimates, the total estimated number of fish entering each intake during the time of interrogation for that time block (F_t in Equation 6) was expanded to account for the total time the intake was operated during the time period. These estimates were then summed over all turbine intakes and spill gates to obtain a total project passage estimate for each period. The estimated percentage passed during each period was then calculated by dividing each period estimate by the sum of the total project passage of both day and night periods and multiplying by 100.

Hourly estimates were calculated in the same way except that each period was 1 hour instead of 10 or 14 hours. The general method is described by:

$$P_b = \sum_{t=1}^{n}\left(F_t \times \frac{T_b}{T_m}\right) + \sum_{s=1}^{n}\left(F_s \times \frac{T_b}{T_m}\right) \qquad (7)$$

where

P_b = total passage for the l-hour or 10-h/14-h time period

t = operating turbine number

n = maximum number of operating turbines or spill gates

F_t = total estimate of fish entering the turbine intake t during all the transducer sampling sequences per time period

T_b = total time turbine or spill gate was operated during the time period

T_m = total time turbine or spill gate was monitored during the time period

s = operating spill gate number

F_s = total estimate of fish entering the spill gate during all the transducer sequences per time period.

The percent passage was then calculated by:

$$\%D = \frac{P_{bi}}{\sum_{i=1}^{n} P_{bi}} \times 100 \qquad (8)$$

where

$\%D$ = percent die1 passage for the given time period

P = total passage for time period

i = time period number

n = number of time periods.

D.4 Method for Estimating the Horizontal Distributions at the Powerhouse and Spillway

Horizontal distributions across the powerhouse were calculated using data from day periods only, when all operable turbines were running approximately 100% of the time. In the spillway, only data from periods of "crown spill patterns" when all gates were open were analyzed.

After first correcting for acoustical interference and weighting factor (described in Sections D.1 and D.2 above), daily daytime and nighttime rates of fish/min were` calculated for each monitored, operational turbine and spill gate. Daily daytime rates were calculated by:

$$R_{jdx} = \frac{N_{jdx}}{M_{jdx}} \qquad (9)$$

where

R_{jdx} = the passage rate (fish/min) at intake j on day x

N_{jdx} = the number of migrants detected at intake j on day x

M_{jdx} = the number of minutes intake j was monitored on day x.

Since all operating turbines and spill gates were monitored, no interpolation for unmonitored locations was neccessary and these passage rates were used directly in plotting horizontal distributions.

D.5 Method for Calculating the Vertical (Range) Distribution Function

The first step in estimating vertical distributions was to determine the depth (or range) of each detected fish based on the echogram traces. Each fish was assigned to a one-foot wide depth stratum along the transducer's acoustic axis (i.e., along the aiming angle of the transducer). Each fish detection was weighted inversely as a function of range, using the following formula:

$$W_j = \frac{K}{L_j} \quad (11)$$

where

W_j = weighted fish j

L_j = range of fish j

K = weighting factor constant.

The percentage of fish detections for each range was calculated by:

$$P_{ij} = \frac{W_{ij}}{\sum_{j}^{n} \sum_{i}^{n} W_{ij}} \quad (12)$$

where

P_{ij} = the percentage each weighted fish represents of the total weighted fish detection

W_{ij} = weighted fish j in stratum i.

The percentage of weighted fish in each range stratum was then summed by:

$$S_i = \sum_{j}^{n} P_{ij} \quad (13)$$

where

S_i = percentage each stratum represents of the total weighted fish detected.

The vertical distribution function is the cumulative percentage of each range stratum, summed with increasing range from the transducer. Surface-mounted transducers were treated the same as those mounted on the bottom. All vertical distribution functions were oriented from transducer to maximum range, regardless of whether the transducer was bottom- or surface-mounted.

APPENDIX E: Spill Effectiveness

Spill effectiveness was defined as the percentage of migrants passed in spill relative to total migrants passing the dam. Daily 10-h and 24-h spill effectiveness estimates with regard to percent river spilled are presented in Figures El and E2, respectively.

Spill occurred outside of the 1900 h to 0500 h standard spilling time period on 3 dates during the study. Spill effectiveness results from these days are presented in Table El.

Table El. Hourly estimates of daytime spill effectiveness; day-time spill occurred for 9 h between May 4 and June 1. Lower Monumental Dam, 1985.

Date	Time	Spill Effectiveness (% Fish)	% Spill
5/O6	1300	63.25	18.37
	1400	0	12.25
5/09	1400	79.66	13.67
	1500	91.18	15.68
	1600	92.05	15.72
	1700	93.01	15.65
	1800	66.86	15.77
5/13	1100	87.38	20.07
	1200	93.08	11.90

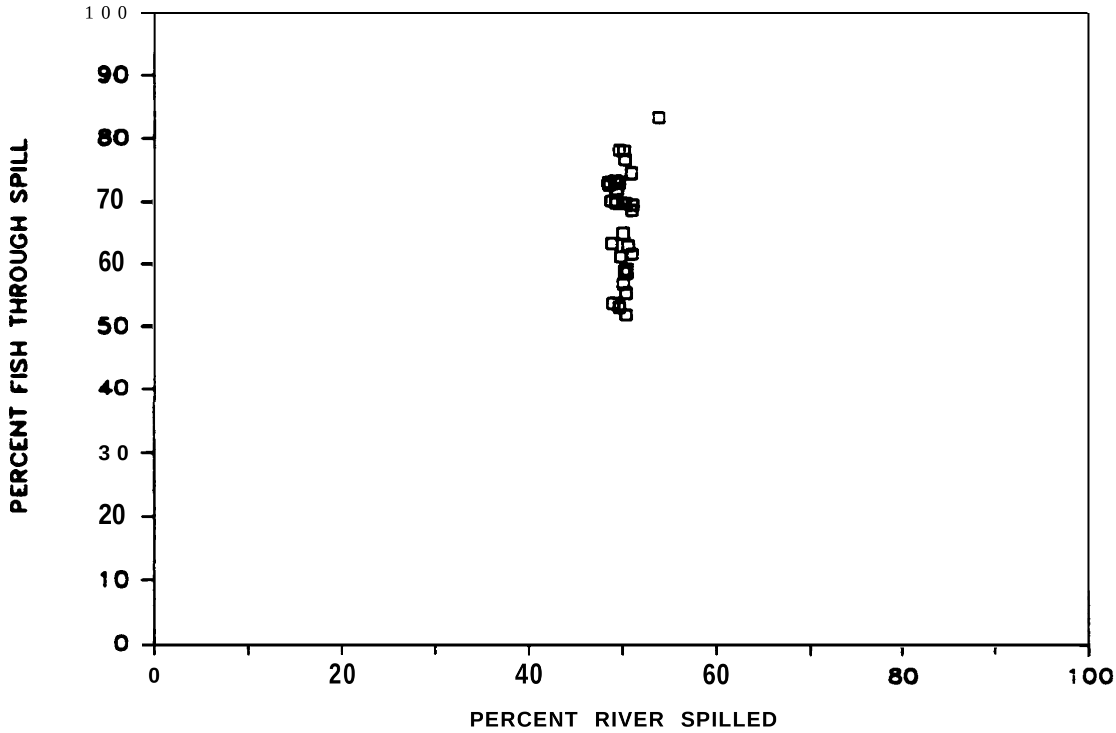


Figure El. Daily 10-h spill effectiveness points. Lower Monumental Dam, May 4-31, 1985.

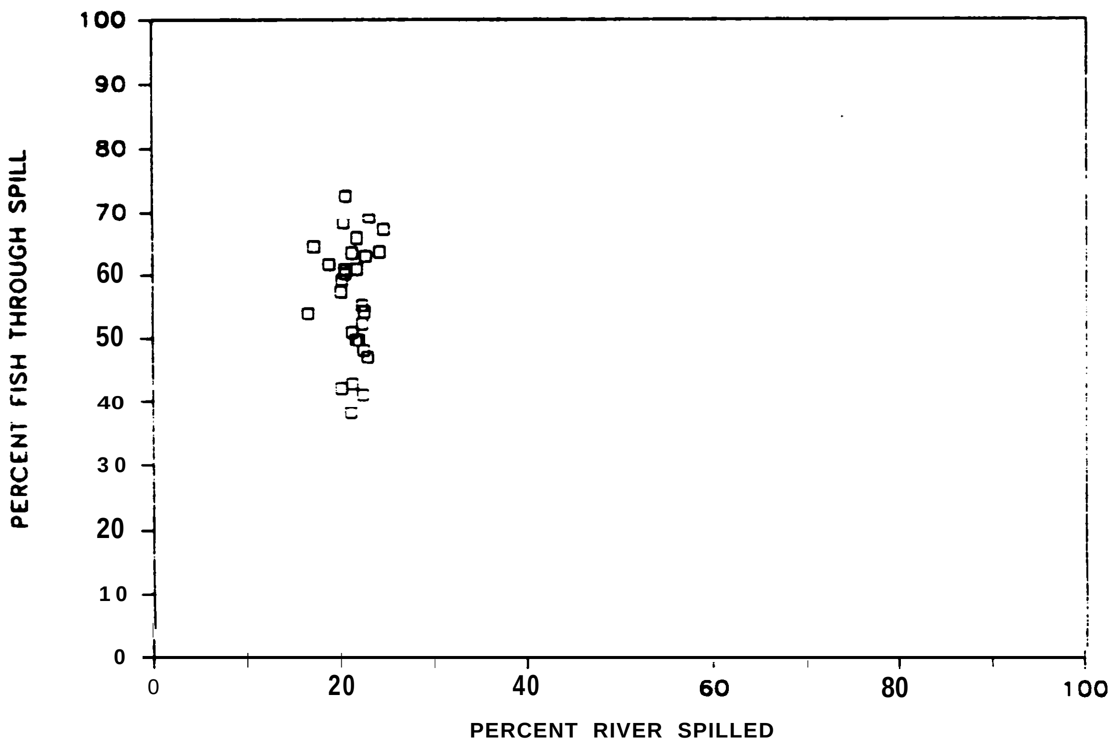


Figure E2. Daily 24-h spill effectiveness points. Lower Monumental Dam, May 4-31, 1985.

APPENDIX F: Hourly Die1 Passage Distribution

The hourly passage distributions for Blocks 3-7 are shown in Figures Fl-F4. These estimates are based on total passage through powerhouse and spillway. These values are also given in text Table 3.

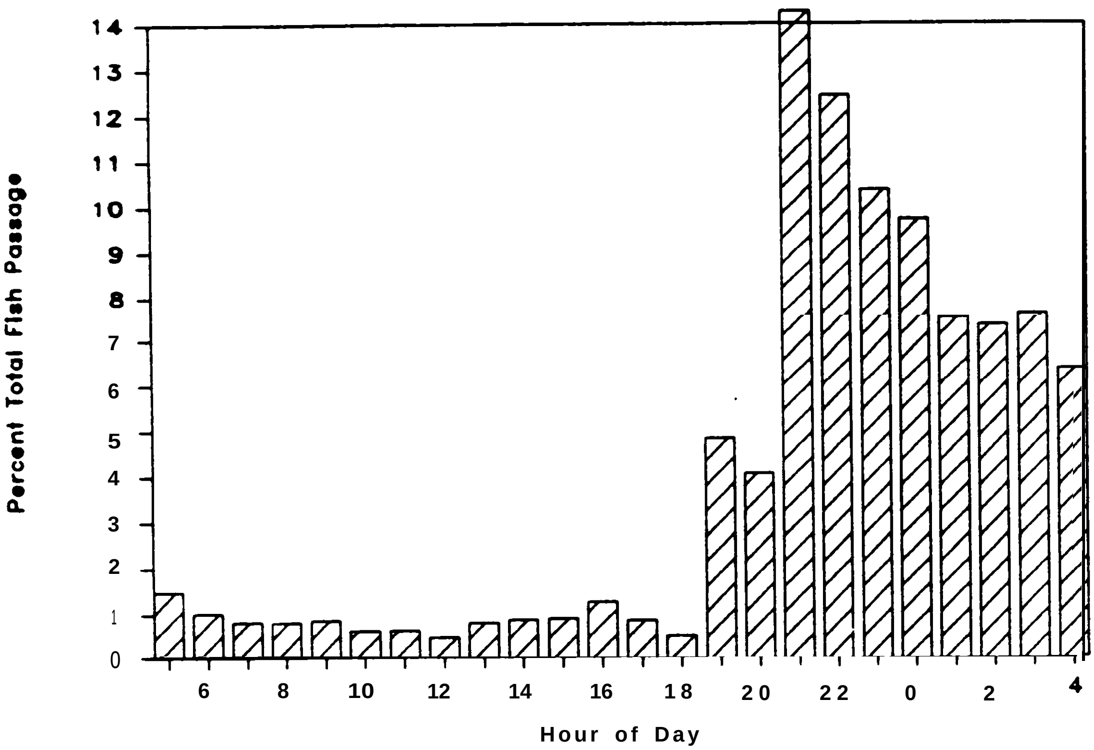


Figure Fl. Hourly distribution of migrant passage for Block 3. Lower Monumental Dam,May 4-9, 1985.

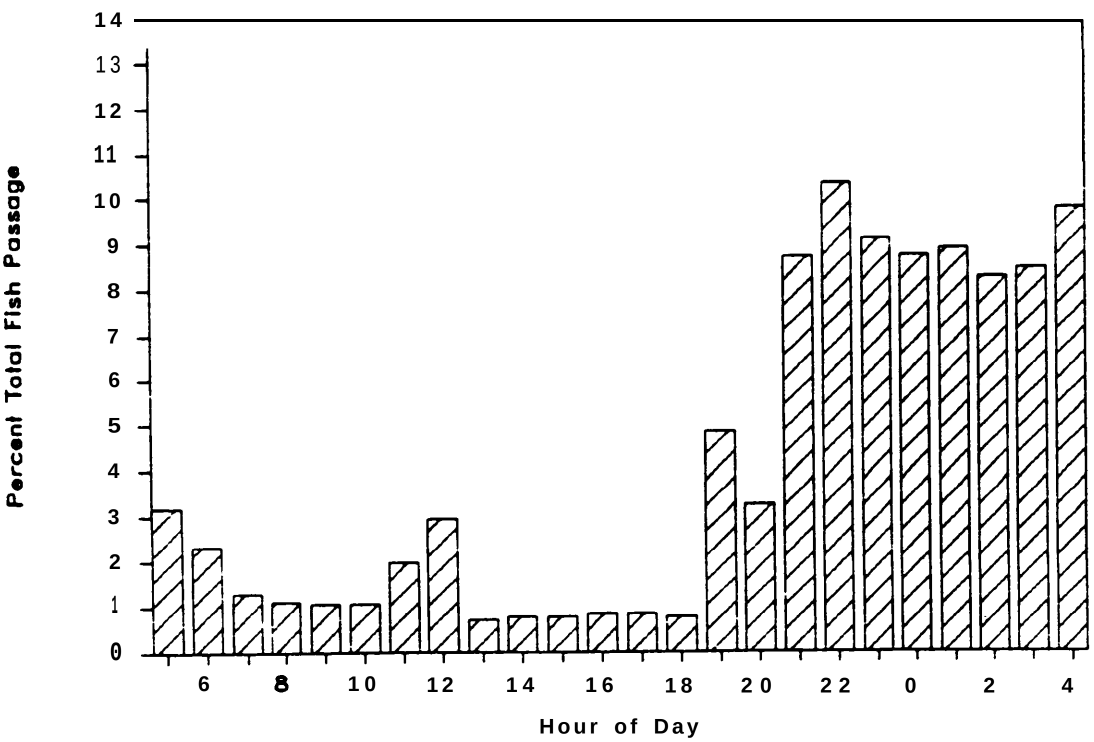


Figure F2. Hourly distribution of migrant passage for Block 4. Lower Monumental Dam, May 10-14, 1985.

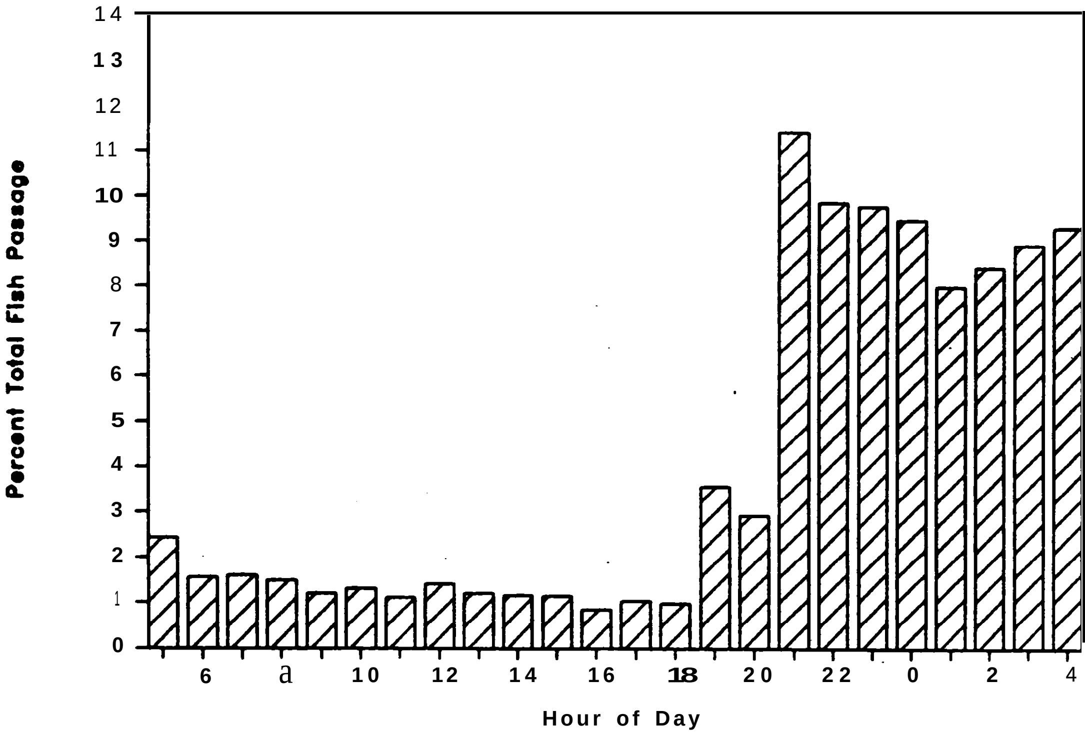


Figure F3. Hourly distribution of migrant passage for Block 5. Lower Monumental Dam, May 15-20, 1985.

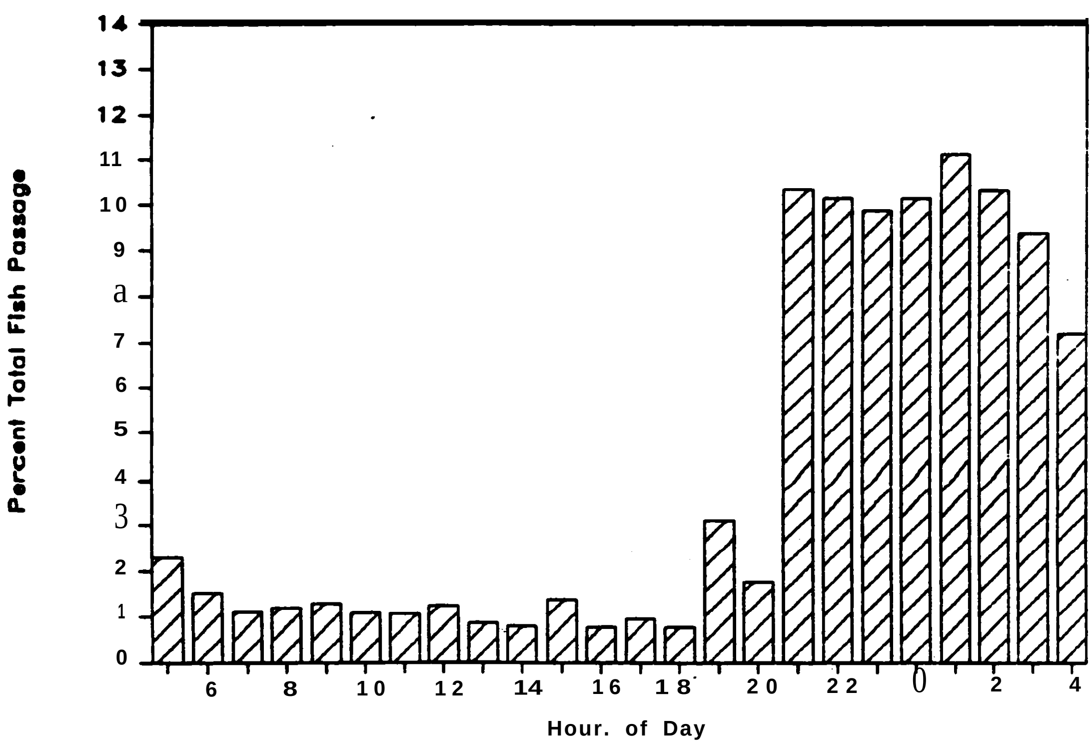


Figure F4. Hourly distribution of migrant passage for Block 6. Lower Monumental Dam, May 21-25, 1985.

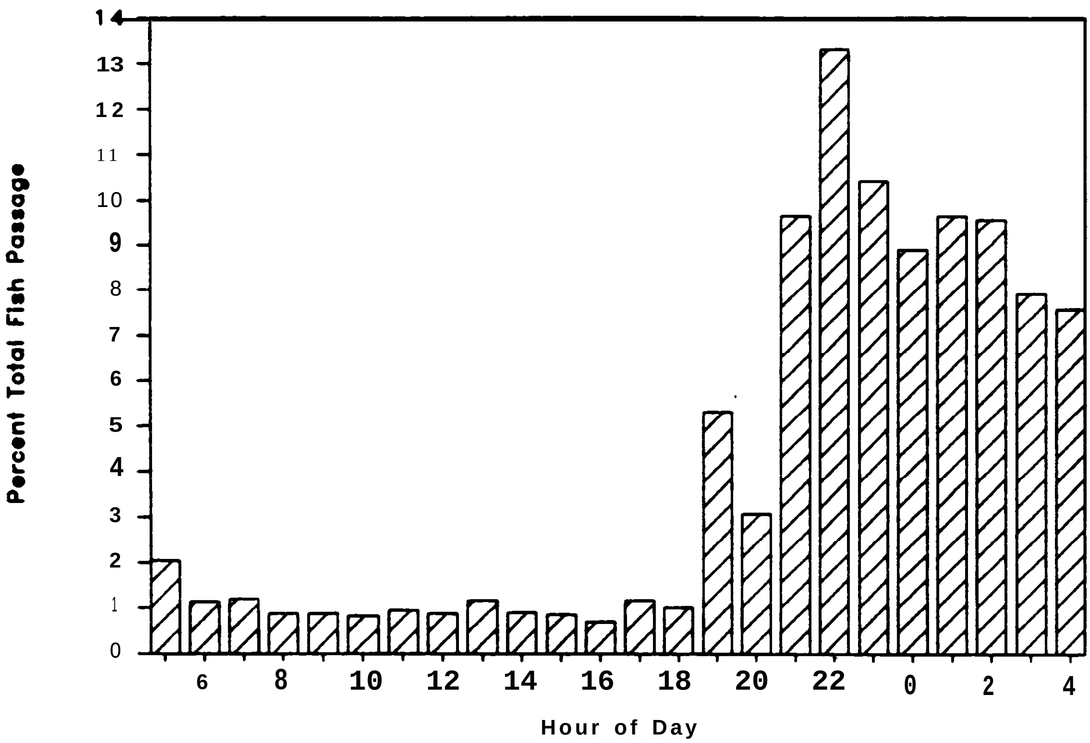


Figure F5. Hourly distribution of migrant passage for Block 7, Lower Monumental Dam, May 26-31, 1985.

APPENDIX G: Horizontal Distribution

Horizontal distributions of migrants across the powerhouse are presented for Blocks 1-7 in Figures Gl-G7, and across the spillway for Blocks 3-7 in Figures G8-G12. Tabled values are given in Tables 6 and 7, respectively.

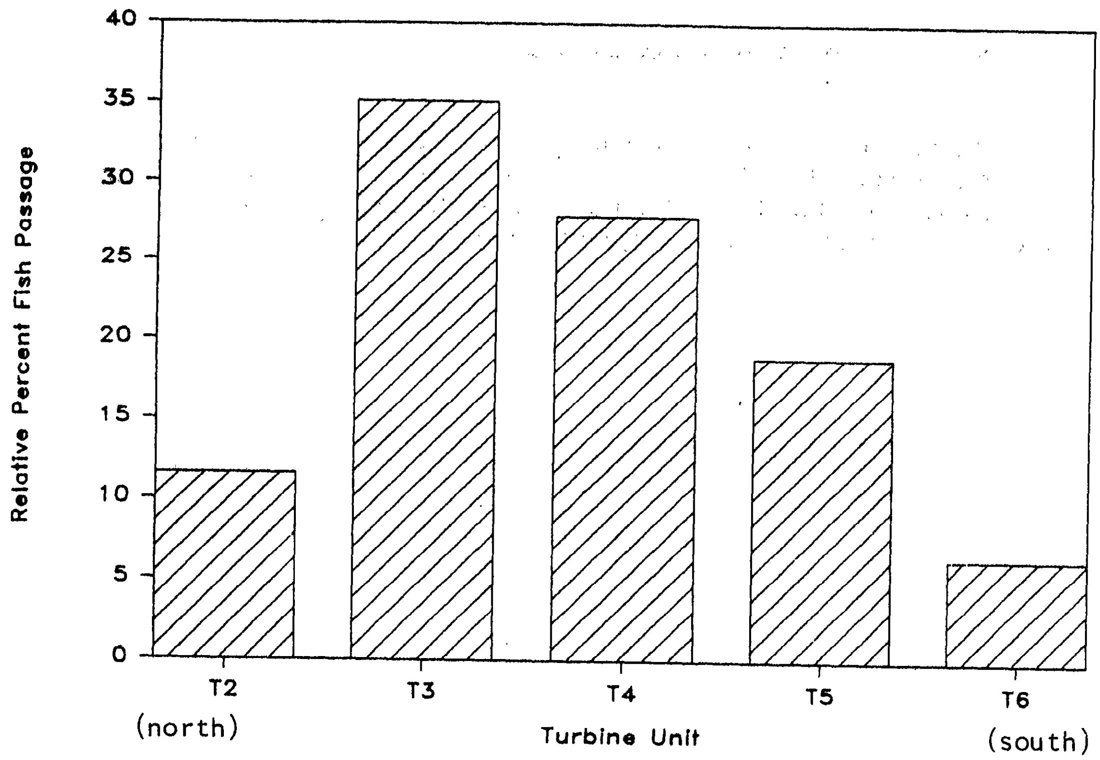


Figure G1. Horizontal distribution of migrant passage across the powerhouse for Block 1 (April 22-27, 1985) at Lower Monumental Dam.

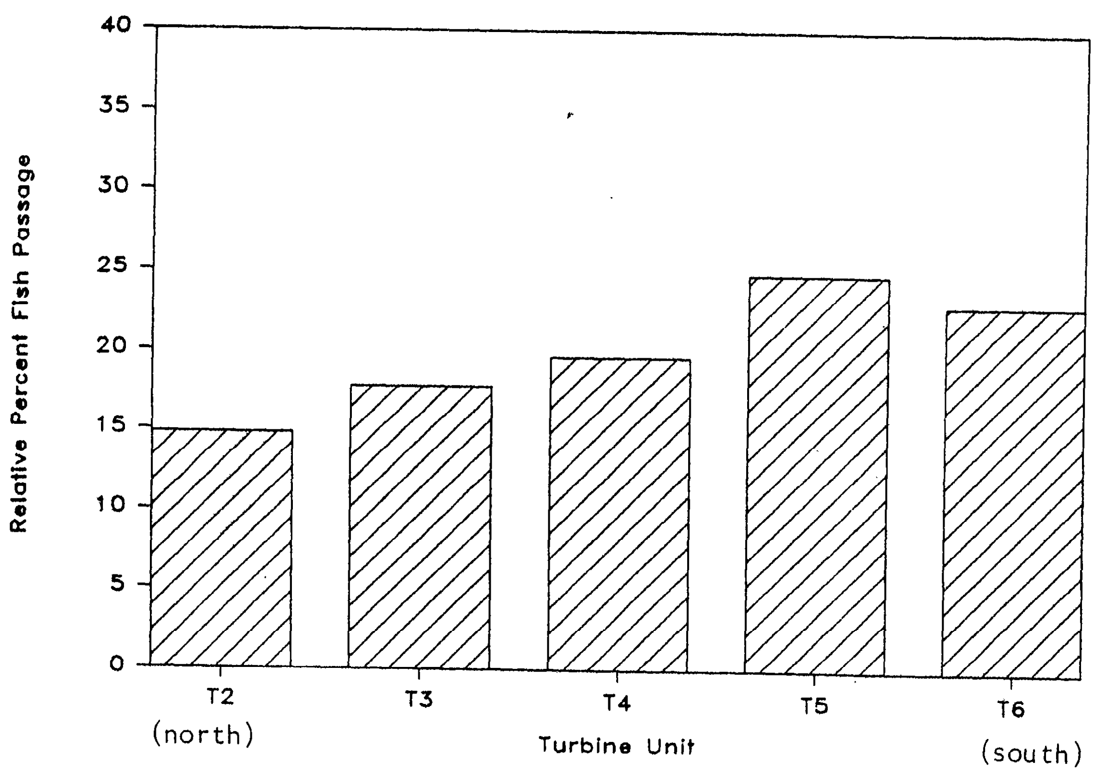


Figure G2. Horizontal distribution of migrant passage across the powerhouse for Block 2 (April 28 - May 3, 1985) at Lower Monumental Dam.

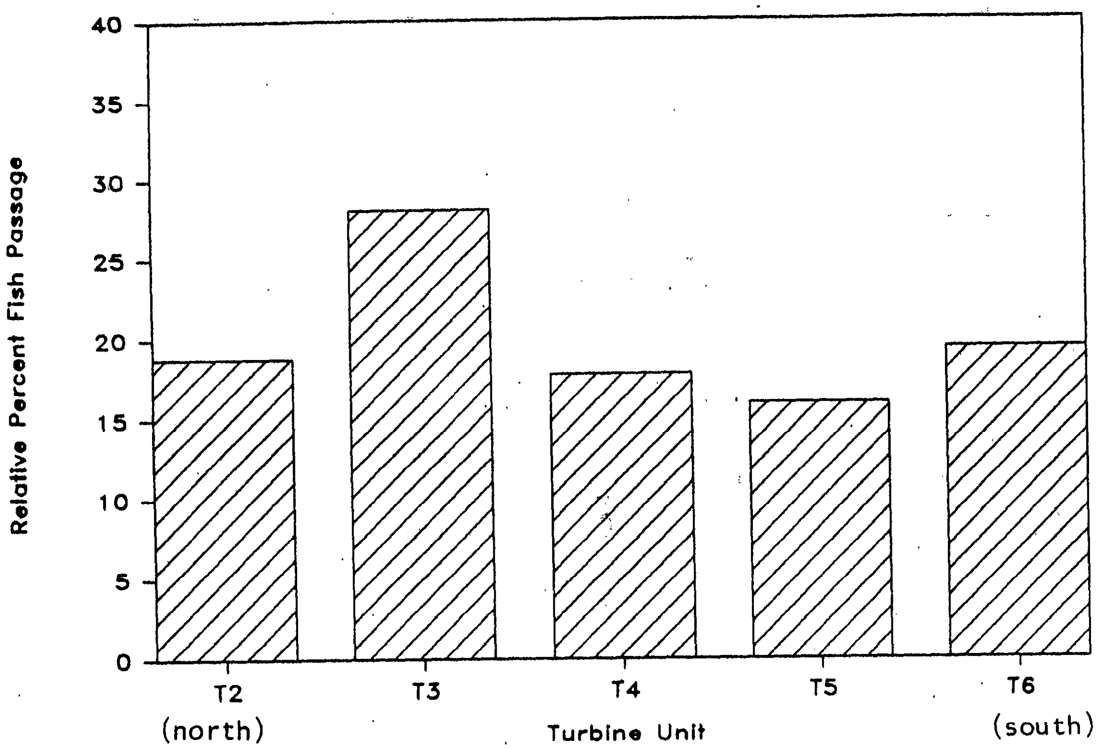


Figure G3. Horizontal distribution of migrant passage across the powerhouse for Block 3 (May 4-9, 1985) at Lower Monumental Dam.

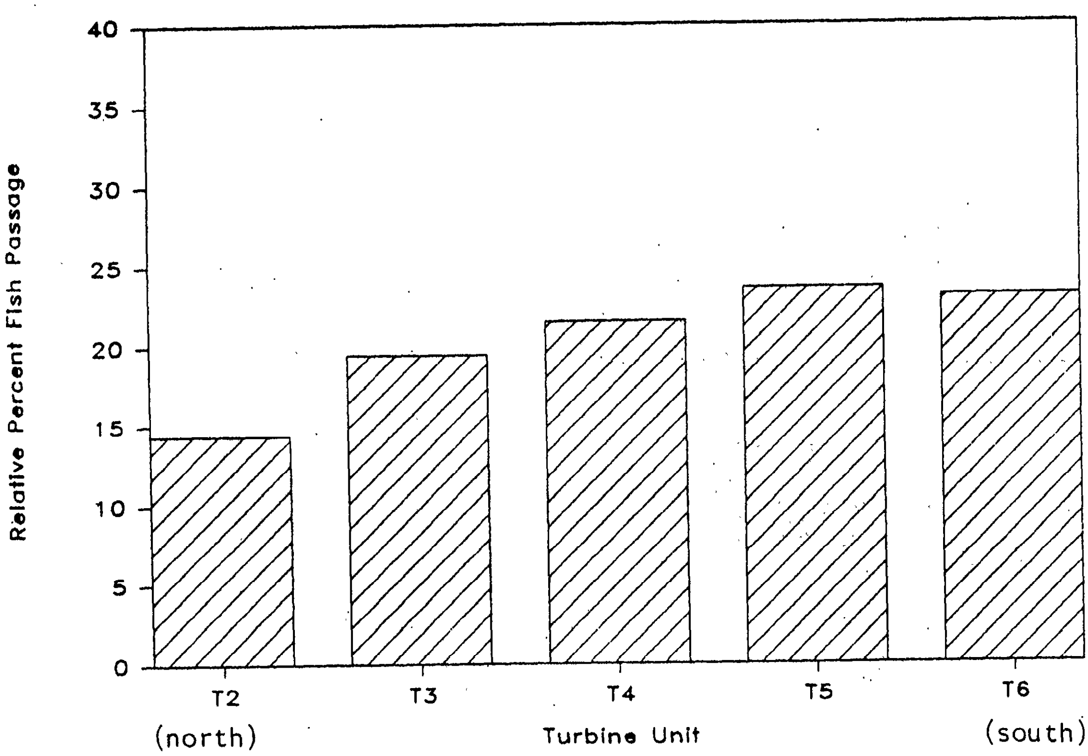


Figure G4. Horizontal distribution of migrant passage across the powerhouse for Block 4 (May 10-14, 1985) at Lower Monumental Dam.

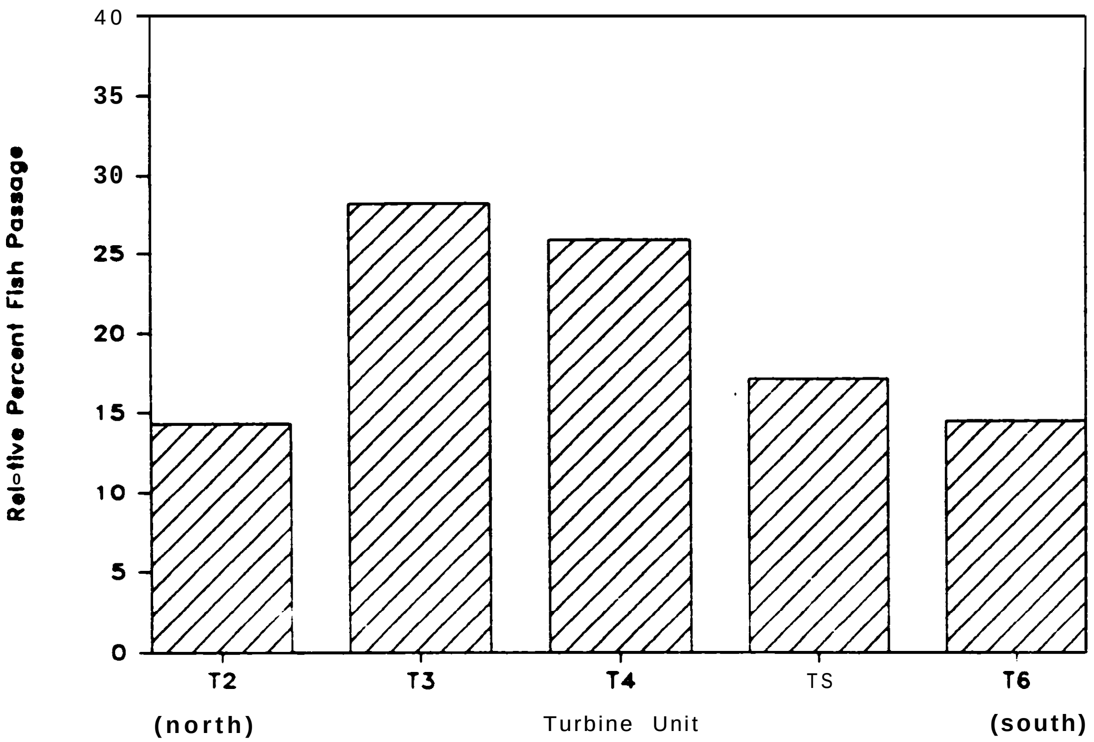


Figure G5. Horizontal distribution of migrant passage across the powerhouse for Block 5 (May 15-20, 1985) at Lower Monumental Dam.

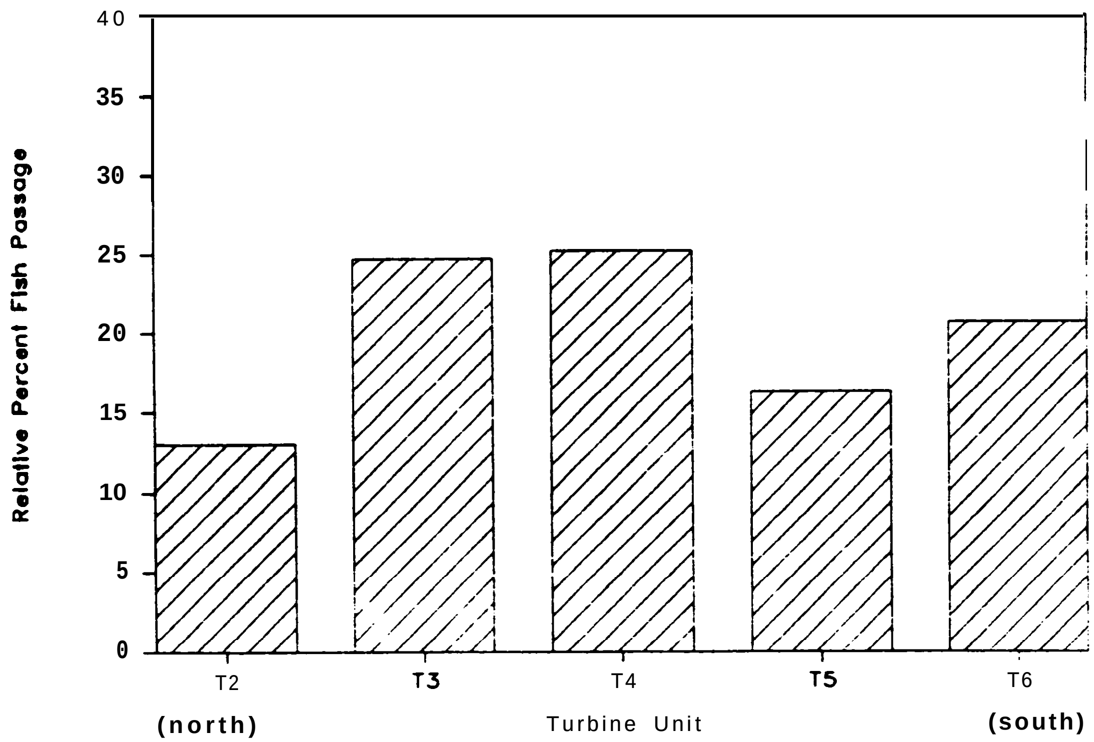


Figure G6. Horizontal distribution of migrant passage across the powerhouse for Block 6 (May 21-25, 1985) at Lower Monumental Dam.

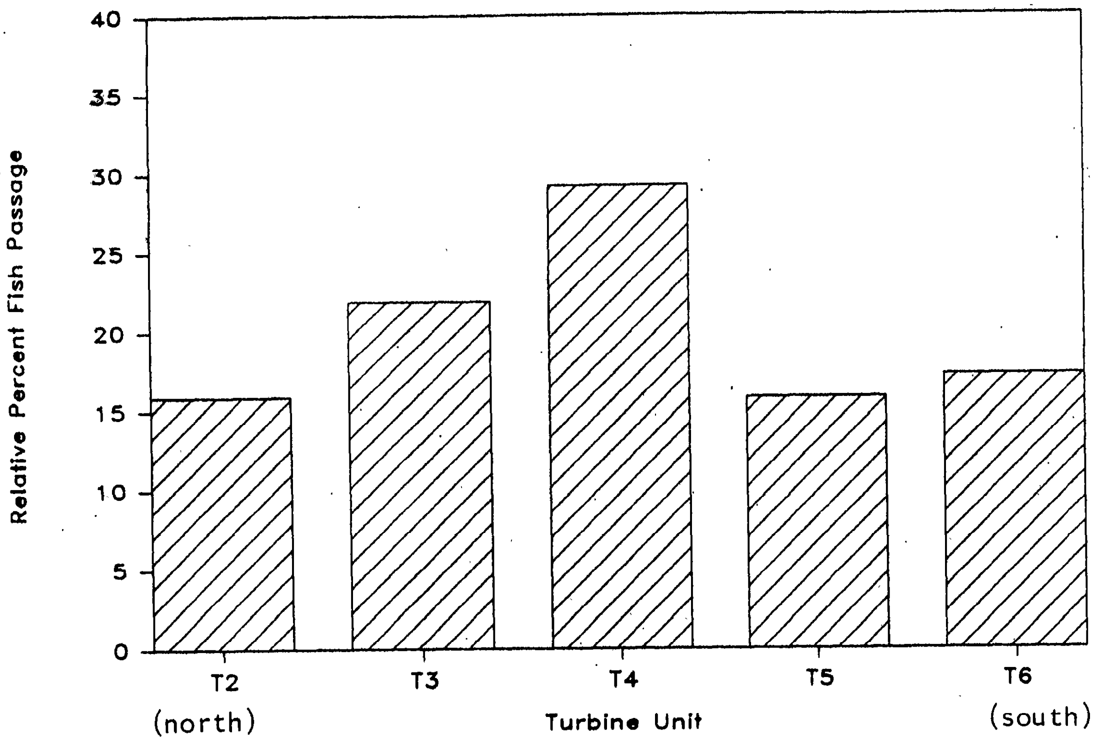


Figure G7. Horizontal distribution of migrant passage across the powerhouse for Block 7 (May 26-30, 1985) at Lower Monumental Dam.

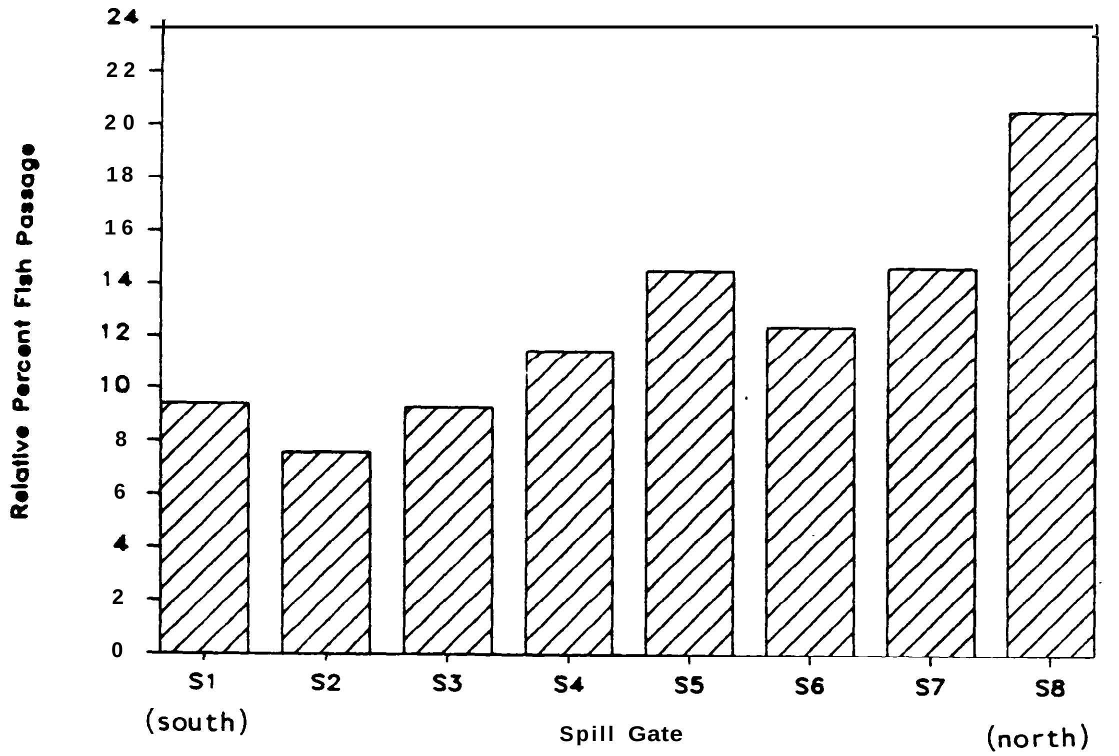


Figure G8. Horizontal distribution of migrant passage across the spillway for Block 3 (May 2-9, 1985) at Lower Monumental Dam.

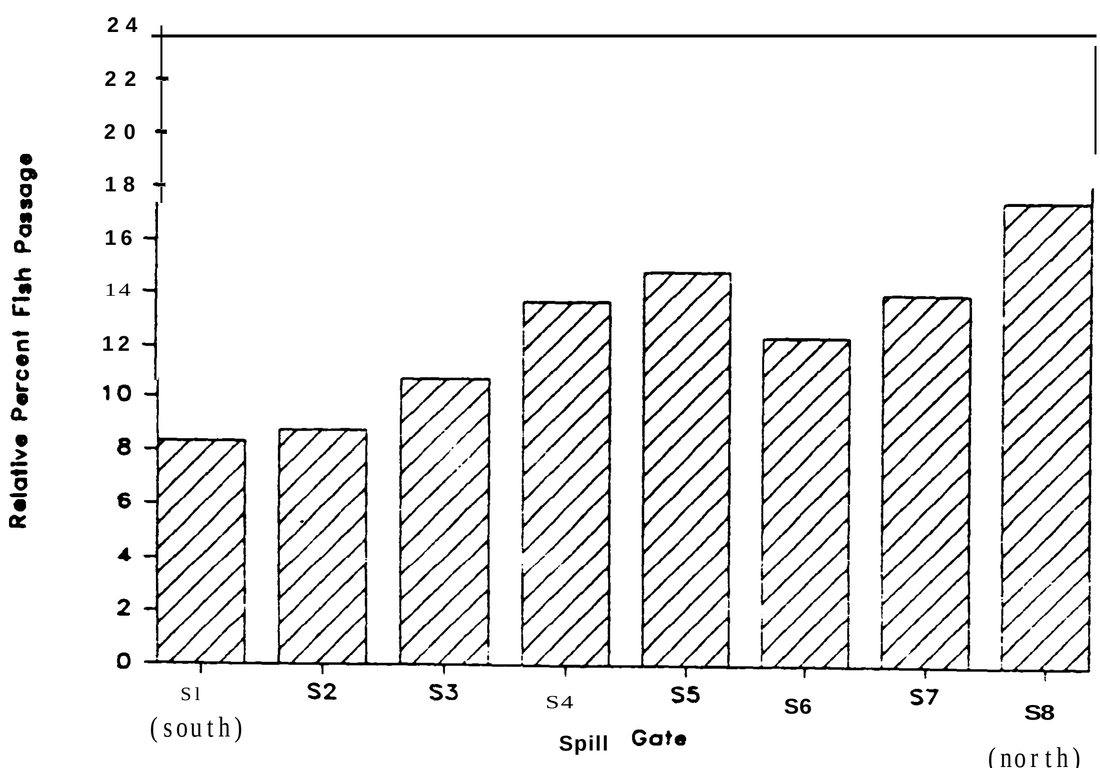


Figure G9. Horizontal distribution of migrant passage across the spillway for Block 4 (May 10-14, 1985) at Lower Monumental Dam.

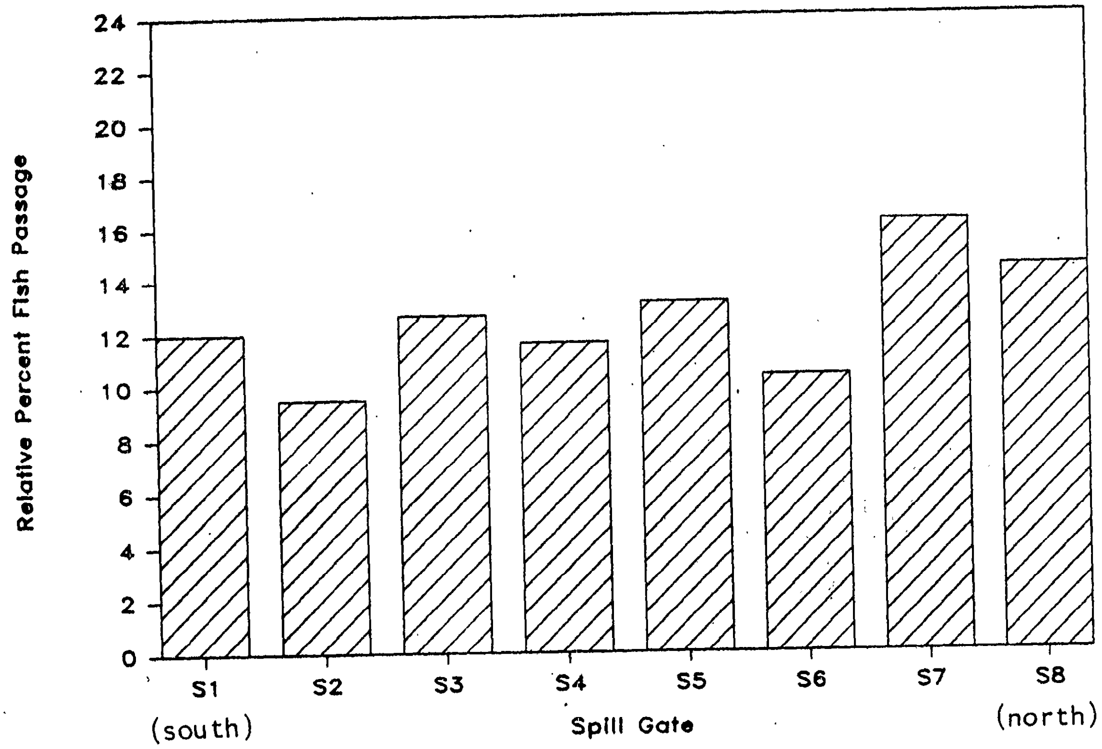


Figure G10. Horizontal distribution of migrant passage across the spillway for Block 5 (May 15-20, 1985) at Lower Monumental Dam.

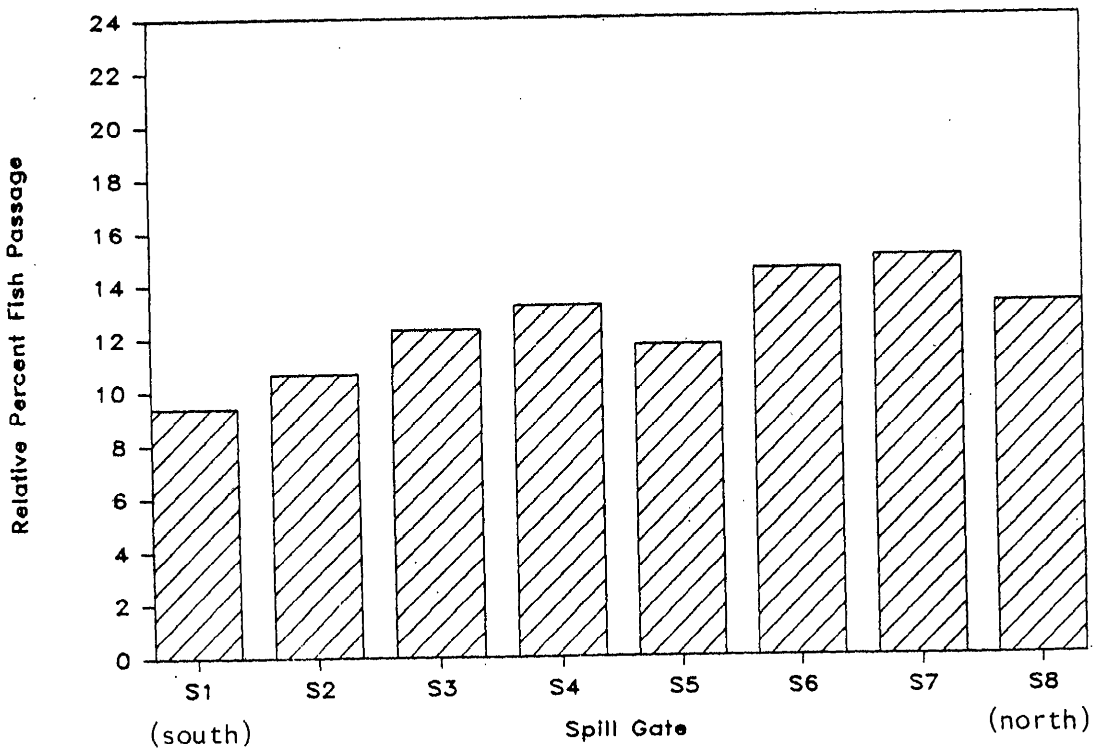


Figure G11. Horizontal distribution of migrant passage across the spillway for Block 6 (May 21-25, 1985) at Lower Monumental Dam.

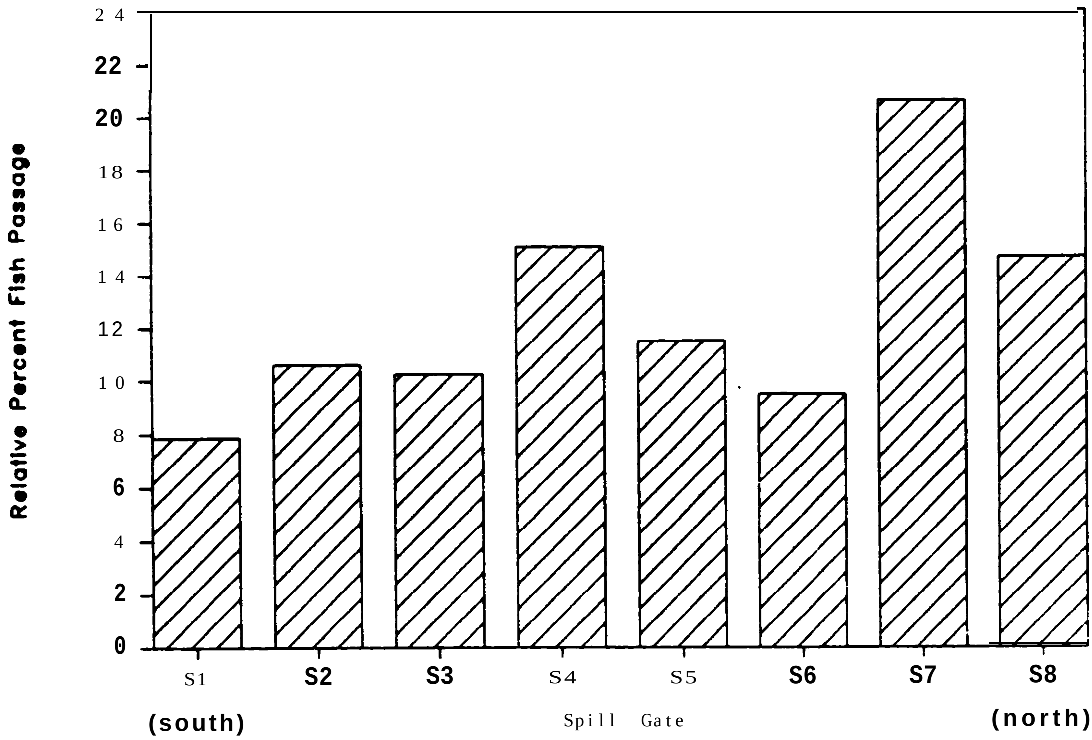


Figure G12. Horizontal distribution of migrant passage across the spillway for Block 7 (May 26-30, 1985) at Lower Monumental Dam.

APPENDIX H: Vertical Distributions

Empirical range distributions were calculated by the method described in Appendix D, Section D.5. Data sets were calculated for each operated unit of the powerhouse and spillway by week and by day and night hours. These results are presented in Tables Hl-H6.

Table Hl. Range distributions at the powerhouse at night for each turbine. Lower Monumental Dam, April 22 to May 31, 1985.

Range (ft)	T-2 Cum. %	T-3 Cum.%	T-4 Cum.%	T-5 Cum.%	T-6 Cum.%
1	0	0	0	0	0
3	0	0	0.639	6.154	0
5	0.183	0.447	1.118	9.231	0
7	0.444	0.589	1.392	9.231	0.748
9	0.965	0.713	2.297	9.231	0.748
11	1.314	0.902	2.489	9.231	0.748
13	1.525	0.985	2.636	9.231	1.496
15	1.708	1.325	2.636	9.231	1.795
17	2.208	1.683	2.974	9.955	2.323
19	2.561	2.116	3.187	9.955	3.280
21	3.097	2.598	3.370	9.955	3.280
23	3.498	2.904	3.453	10.490	4.282
25	4.017	3.589	3.690	10.490	5.382
27	4.635	4.186	3.832	10.946	5.007
29	5.147	4.743	4.306	11.795	6.666
31	5.567	5.492	4.558	12.192	6.955
33	6.212	6.408	4.794	12.565	7.231
35	7.194	7.012	5.014	13.992	7.891
37	0.121	7.558	5.695	13.992	0.501
39	9.186	8.124	6.344	13.992	9.427
41	10.317	8.955	6.915	13.992	10.087
43	11.542	9.607	8.041	15.151	10.827
45	12.651	10.343	8.985	16.525	11.835
47	13.930	11.217	9.602	17.054	13.481
49	16.060	12.323	10.275	18.316	14.315
51	17.471	13.230	11.072	19.040	15.731
53	19.298	14.761	11.877	19.508	16.667
55	21.008	15.889	12.828	20.408	17.983
57	23.030	17.277	13.676	21.056	19.569
59	25.015	18.889	14.559	22.102	20.952
61	27.114	20.463	15.444	22.304	22.510
63	29.484	22.149	16.828	22.900	24.302
65	31.792	24.043	17.928	24.048	26.392
67	33.718	26.088	19.429	24.974	28.144
69	36.070	20.276	20.939	26.774	30.897
71	38.611	30.474	22.948	28.867	32.933
73	41.206	32.528	24.532	30.730	35.163
75	44.409	34.460	26.461	33.552	37.390
77	47.411	36.575	28.916	35.317	39.855
79	50.718	39.509	31.113	37.040	42.085

Table El, cont.

Range (ft)	T-2 Cum. %	T-3 Cum. %	T-4 Cum. %	T-5 Cum. %	T-6 Cum. %
81	54.430	**42.049**	**33.399**	39.791	45.420
83	58.098	44.768	35.558	**42.769**	49.453
85	62.340	47.023	37.985	46.117	52.746
a7	66.388	51.106	41.000	40.958	56.167
89	70.924	54.559	44.117	53.129	59.670
91	75.319	58.157	47.653	55.715	63.635
93	80.182	61.967	51.134	58.512	67.317
95	85.338	66.126	54.581	62.295	70.167
97	89.412	70.446	58.197	65.869	73.201
99	91.891	74.899	62.729	70.118	76.609
101	93.846	79.949	67.614	75.013	80.583
103	95.657	85.151	72.684	78.855	04.217
105	97.006	89.328	77.691	83.332	87.690
107	98.096	91.045	83.218	86.799	91.398
109	98.804	94.234	86.539	89.069	92.630
111	99.268	95.097	09.575	91.632	93.733
113	99.528	97.399	92.269	93.382	94.491
115	99.688	98.223	94.260	94.673	95.705
117	99.900	98.079	95.691	96.152	97.133
119	99.970	99.290	97.099	97.501	97.966
121	100	99.677	98.197	97.910	98.488
123	100	99.912	98.886	98.815	99.073
125	100	99.992	99.533	99.805	99.542
127	100	100	99.851	100	99.026
129	100	100	99.905	100	99.965
131	100	100	100	100	100
133	100	100	100	100	**100**

Table H2. Range distributions at the powerhouse during the day for each turbine. Lower Monumental Dam, April 22 to May 31, 1985.

Range (ft)	T-2 Cum. %	T-3 Cum. %	T-4 Cum.%	T-5 Cum.%	T-6 Cum. %
1	0	0	0	0	0
3	0	0	0	0	0
5	0.811	0	0	0	0
7	0.811	0	0	6.612	0
9	2.781	0.256	0.972	1.071	0.756
11	3.186	0.442	1.208	1.071	1.306
13	3.498	0.942	1.424	1.636	1,771
15	3.498	1.225	2.139	2.143	2.203
17	4.497	1.473	2.139	2.143	2.203
19	4.935	2.150	2.420	2.540	2.203
21	5.717	2.248	2.543	3.701	3.067
23	6.077	2.701	2.892	4.100	3.605
25	6.240	3.463	3.319	4.553	5.086
27	6.546	3.848	3.810	4.825	6.008
29	6.685	4.280	4.356	5.078	6.641
31	7.352	4.886	4.780	5.560	7.038
33	8.227	5.518	5.420	6.353	7.410
35	8.810	5.995	6.024	7.417	7.939
37	9.589	6.554	6.516	8.423	8.602
39	10.426	7.140	6.855	9.087	10.960
41	11.318	7.750	7.560	9.817	11.259
43	12.456	0.379	8.295	10.592	11.691
45	13.914	9.022	8.816	11.170	12.641
47	15.395	9.638	9.375	11.961	13.424
49	16.475	10.694	10.232	12,717	14.173
51	17.520	11.792	11.209	13.376	15.128
53	18.980	12.808	12.048	14.080	15.817
55	20.544	13.600	13.142	14.550	16.257
57	22.118	14.981	13.919	15.002	17.330
59	23.576	16.801	14.933	15.940	18.049
61	25.701	18.293	15.661	17.034	19.449
63	27.984	19.768	16.533	18.564	20.515
65	29.746	21.516	17.622	20.215	21.546
67	31.632	23.394	19.065	21.703	23.183
69	33.700	25.037	20.461	22.828	24.332
71	36.231	26.986	22.080	24.132	25.617
73	38.803	28.654	23.690	26.006	27.074
75	41.197	30.689	25.046	27.041	29.174
77	44.697	32.530	26.641	20.864	30.833
79	48.672	34.912	28.590	30.405	32.911

Table H2, cont.

Range (ft)	T-2 Cum. %	T-3 Cum. %	T-4 Cum. %	T-5 Cum. %	T-6 Cum. %
81	52.195	37.612	29.909	32.275	35.092
83	55,883	40.395	31.889	34.323	37.436
85	59.240	43.206	33.819	36.270	39.581
07	63.590	46.355	36,487	38.401	41.954
89	67.940	49.274	39.268	41.385	44.830
91	71.572	52.943	41.759	43.860	47.571
93	75.250	56.819	44.281	46.479	50.517
95	79.197	60.224	47.188	49.662	53.272
97	82.221	64.069	50.117	52.934	56.029
99	84.112	67.065	53.142	56.214	58.424
101	85.726	71.265	55.620	59.503	60.831
103	88.060	74.342	59.187	63.100	62.834
105	89.807	77.169	62.362	66.139	65.206
107	91.290	79.633	65.281	69.726	67.477
109	93.198	81.728	67.599	71.722	69.090
111	94.887	83.989	70.485	73.882	71.498
113	96.330	86.322	72.998	76.000	73.757
115	97.568	88.612	75.781	78.630	76.188
117	98.438	91.391	79.094	01.813	79.718
119	99.497	93.866	83.227	85.159	82.934
121	99.868	96.637	87.809	88.786	86.950
123	99.968	98.997	92.209	93.281	91.343
125	99.968	99.821	96.289	96.882	95.812
127	100	100	98.852	98.945	98.776
129	100	100	99.781	99.031	99.861
131	100	100	100	100	100
133	100	100	100	100	100

Table H3. Range distributions at the powerhouse at night for each Block, all turbines combined. Lower Monumental Dam, 1985.

Range (ft)	BK-1 Cum. %	BK-2 Cum. %	BK-3 Cum. %	BK-4 Cum. %	BK-5 Cum. %	BK-6 Cum. %	BK-7 Cum. %
1	0	0	0	0	0	0	0
3	0	0	0	0	0	0.979	1.194
5	0	0.412	0	0	0.666	1.468	2.750
7	0	0.412	0.223	0	0.666	2.170	3.774
9	0.285	0.657	0.223	0	1.590	2.908	4.620
11	0.205	0.077	0.223	0.288	2.083	3.307	4.956
13	0.927	1.429	0.223	0.288	2.083	3.307	5.231
15	1.259	1.599	0.438	0.486	2.439	3.446	5.231
17	1.702	2.003	0.762	1.057	2.743	3.815	6.061
19	2.286	2.241	1.237	1.546	3.038	4.160	6.424
21	2.409	2.775	1.711	1.828	3.296	4.352	7.437
23	2.520	3.261	2.242	2.095	3.525	4.834	7.746
25	3.390	3.638	2.663	3.087	4.139	5.246	8.167
27	4.152	4.378	3.171	3.551	4.512	5.694	8.304
29	4.850	'5.152	3.702	4.198	4.607	6.145	8.918
31	5.525	5.790	4.323	4.696	4.931	6.470	9.146
33	6.213	6.941	4.911	5.173	5.554	6.796	9.566
35	7.018	8.006	5.752	5.701	6.222	7.336	9.777
37	7.640	9.259	6.798	6.212	6.577	7.804	10.064
39	8.503	10.359	7.622	7.028	7.240	0.457	10.519
41	9.203	11.792	0.458	7.861	8.008	9.128	11.210
43	10.621	13.157	9.250	0.670	8.976	9.759	12.117
45	12.019	14.483	10.119	9.639	9.500	10.544	12.898
47	13.876	15.861	11.200	10.372	10.390	10.897	13.889
49	15.685	17.754	12.348	11.773	11.302	12.003	15.566
51	17.528	19.455	13.585	12.510	11.913	12.690	16.324
53	19.187	21.241	15.216	14.091	13.278	13.625	17.192
55	20.077	23.038	16.675	15.214	14.428	14.476	18.252
57	22.963	25.055	18.381	16.691	15.426	15.286	19.827
59	24.822	27.162	20.175	18.641	16.299	16.412	21.076
61	27.086	28.585	21.939	20.944	17.699	17.502	22.150
63	29.458	31.175	24.043	22.520	10.736	19.148	23.486
65	31.541	33.351	26.288	24.823	20.062	20.670	24.961
67	33.637	35.216	28.213	27.280	21.618	22.329	26.281
69	35,785	38.016	30.621	29.541	23.887	23.701	28.049
71	38.313	40.723	32.932	31.900	26.519	25.269	29.843
73	41.007	43.696	35.122	34.050	28.504	26.804	31.334
75	44.154	46.866	37.029	36.646	30.663	28.125	33.478

Table H3, cont.

Range (ft)	BK-1 Cum. %	BK-2 Cum. %	BK-3 Cum. %	BK-4 Cum. %	BK-5 Cum. %	BK-6 Cum. %	BK-7 Cum. %
77	46.925	49.604	40.765	30.022	33.340	30.449	35.048
79	50.155	53.160	43.417	41.994	36.141	32.613	37.500
81	53.846	56.177	46.576	44.732	39.037	35.300	40.286
83	57.316	59.603	49.770	47.800	41.643	37.937	43.633
85	61.217	62.818	53.449	51.239	46.014	40.608	46.132
a7	64.617	66.720	56.583	54.712	49.774	44.057	49.918
89	68.917	71.457	60.070	58.170	53.718	47.366	53.473
91	73.474	75.150	63.795	62.372	58.002	50.824	57.009
93	77.697	79.215	67.945	66.807	62.663	54.383	60.796
95	81.557	83.289	71.902	70.860	68.118	50.568	65.540
97	85.154	86.589	75.603	74.446	73.014	62'. 778	70.505
99	88.465	89.469	70.824	78.064	77.058	67.069	74.858
101	91.338	92.082	82.996	81.346	81.367	71.547	79.303
103	94.038	94.027	86.384	85.152	85.905	75.943	04.390
105	96.199	96.827	90.126	08.251	89.075	80.159	88.274
107	98.081	98.060	92.581	91.037	91.585	84.619	91.671
109	98.887	99.012	94.437	92.936	93.509	87.606	93.973
111	99.439	99.561	95.747	94.762	94.816	90.532	95.475
113	99.711	99.853	96.781	96.228	96.166	93.038	96.941.
115	99.755	99.909	97.524	97.571	97.021	94.864	98.070
117	99.755	99.966	98.243	98.617	97.732	96.569	98.743
119	99.819	99.966	98.004	99,189	98.300	97.011	99.339
121	99.840	99.983	99.266	99.495	98.909	98.736	99.609
123	99.859	100	99.587	99.724	99.394	99.315	99.027
125	99.859	100	99.791	99.950	99.791	99.771	100
127	99.920	100	99.925	100	99.959	99.935	100
129	99.980	100	99.985	100	100	100	100
131	100	100	100	100	100	100	100
133	100	100	100	100	100	100	100

Table H4. Range distribution at the powerhouse during the day for each Block, all turbines combined. Lower Monumental Dam, 1985.

Range (ft)	BK-1 Cum. %	BK-2 cum. %	BK-3 Cum. %	BK-4 Cum. %	BK-5 Cum. %	BK-6 Cum. %	BK-7 Cum. %
1	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
5	0	0.972	0	0	0	0	0
7	0	0.972	0	0.589	0	0	0
9	0	1.673	0	1.060	0.492	2.207	2.939
11	0.707	1.673	0	1.781	0.492	2.207	2.939
13	1.570	1.673	0.324	2.052	0.837	2.563	3.636
15	2.141	1.998	0.324	2.524	1.133	2.563	5.241
17	2.591	1.998	0.324	2.745	1.377	2.848	5.730
19	3.377	2.238	0.807	3.140	1.607.	3.088	6.117
21	3.883	3.397	1.021	3.309	1.607	4.020	6.863
23	4.372	4.465	1.452	3.469	1.800	4.206	7.182
25	5.385	5.220	1.834	3.774	1.972	5.037	8.251
27	6.071	5.604	1.996	3.904	2.290	5.573	9.526
29	7.060	5.604	2.292	4.299	2.801	5.573	10.118
31	7.764	6.266	2.712	4.299	3.073	6.607	10.869
33	8.850	7.135	2.844	4.749	3.738	7.475	11.381
35	9.685	8.083	3.088	4.958	4.251	8.145	12.750
37	10.481	8.999	3.860	5.545	4.717	8.387	13.780
39	11.828	9.713	4.693	6.307	5.085	9.142	14.407
41	13.088	10.641	5.014	7.120	5.186	9.803	14.633
43	13.934	12.116	5.735	7.552	5.896	10.340	15.002
45	15.007	12.788	6.254	8.537	6.487	10.639	16.418
47	15.626	14.096	7.185	9.426	6.969	11.157	17.300
49	17.247	15.275	8.008	9.937	7.431	12.311	17.777
51	18.454	16.323	8.890	10.726	8.577	12.942	18.899
53	19.908	17.893	9.469	11.630	9.421	13.360	19.635
55	21.492	18.770	10.139	12.650	10.314	13.860	19.916
57	23.535	19.504	11.062	14.090	10.797	14.544	20.639
59	25.612	21.047	12.493	15.334	11.598	15.247	21.415
61	27.591	22.882	13.356	16.756	12.453	16.457	22.315
63	29.225	24.554	14.359	18.262	13.649	17.885	23.557
65	31.282	26.474	15.438	20.173	14.664	18.664	24.934
67	34.331	28.427	16.508	21.890	16.171	19.633	25.745
69	36.406	29.947	17.774	23.448	17.752	20.829	26.691
71	39.295	31.652	19.281	25.705	19.080	21.467	20.376
73	41.815	33.933	20.866	28.040	20.098	23.026	30.222
75	44.629	35.763	22.285	29.561	21.387	24.244	31.352

Table H4, cont.

Range (ft)	BK-1 Cum.%	BK-2 Cum.%	BK-3 Cum.%	BK-4 Cum.%	BK-5 Cum.%	BK-6 Cum.%	BK-7 Cum.%
77	46.910	37.952	24.490	31.815	23.468	25.655	32.706
79	50.153	40.223	26.629	34.301	25.537	27.414	34.892
81	52.619	43.121	28.581	37.203	27.480	28.973	36.937
83	55.855	46.141	30.845	39.685	29.962	31.125	38.719
85	58.455	48.974	33.369	42.984	32.489	32.519	40.052
87	62.834	51.587	35.990	46.135	35.220	34.459	42.866
89	65.895	55.323	39.187	49.922	38.872	36.785	44.367
91	68.927	58.538	42.268	54.075	41.576	39.247	46.149
93	72.656	61.593	45.205	57.820	45.150	41.565	48.401
95	76.003	64.881	48.086	61.651	48.400	44.419	51.493
97	79.202	68 .554	50.554	65.574	52.078	47.212	54.195
99	82.937	71.548	53.145	68.917	54.443	49.361	55.817
101	86.550	74.366	55.894	72.352	57.597	51.745	57.864
103	89.774	77.380	59.679	75.729	60.725	53.949	59.937
105	92.335	80.353	62.592	78.579	63.559	56.312	62.208
107	94.372	83.536	65.960	81.181	66.071	58.820	63.823
109	95.448	85.618	69.197	83.033	67.894	61.728	65.081
111	96.168	88.321	73.070	85.442	70.010	64.256	67,359
113	96.627	89.942	75.705	88.533	72.534	67.108	69.742
115	96.821	91.869	79.337	90.741	75.572	70.491	72.011
117	97.073	93.739	83.619	93.073	79.304	74.846	75.356
119	97.344	94.857	88.273	95.237	83.382	79.322	80.356
121	97.855	96.674	92.635	97.270	87.505	84.316	86.389
123	98.367	98.243	96.156	99.026	92.712	89.914	91.651
125	98.920	99.124	98.534	99.557	96.650	95.094	97.114
127	99.393	99.764	99.656	100	99.190	98.070	99.601
129	99.771	100	100	100	99.893	99.729	99.931
131	100	100	100	100	100	100	100
133	100	100	100	100	100	100	100

Table H5. Range distributions at the spillway at night for each spill gate. Lower Monumental Dam, May 4 to May 31, 1985.

Range (ft)	S-1 Cum. %	S-2 Cum. %	S-3 Cum. %	S-4 Cum. %	S-5 Cum. %	S-6 Cum. %	S-7 Cum. %	S-8 Cum. %
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	2.462	.612	1.820	2.228	1.052	3.370	3.173	3.914
7	5.334	1.121	2.957	4.394	3.097	3.682	5.337	5.545
8	10.258	3.306	3.607	6.781	4.098	5.822	7.398	6.744
9	11.181	5.218	5.029	7.941	6.289	7.226	9.021	9.190
10	12.548	6.577	6.545	9.385	8.432	8.890	11.425	10.122
11	13.779	6.883	8.592	11.613	10.009	10.762	13.300	11.240
12	15.794	8.273	10.247	13.976	12.718	12.464	15.792	12.511
13	17.640	9.802	12.522	16.297	15.639	14.180	17.595	14.608
14	18.776	11.214	15.671	18.010	17.392	14.756	19.703	16.974
15	21.590	13.180	16.971	20.397	19.896	17.163	21.661	18.772
16	24.052	14.812	19.246	22.501	22.233	18.412	23.969	20.449
17	24.821	16.914	20.667	24.474	24.424	20.869	26.403	22.896
18	26.559	18.174	23.076	26.986	26.486	24.063	28.439	24.869
19	29.020	19.023	25.477	29.977	29.894	26.143	30.603	27.122
20	32.001	21.277	28.949	33.104	32.016	29.099	33.336	30.065
21	33.970	24.488	33.612	36.353	34.382	31.907	36.221	31.952
22	37.018	28.566	37.078	40.066	37.721	34.225	38.557	34.149
23	39.368	32.320	41.421	43.779	40.988	37.204	41.770	37.263
24	43.435	38.703	46.069	49.671	44.874	42.006	45.533	41.517
25	47.231	43.801	52.325	53.384	49.987	47.155	49.259	47.051
26	50.874	49.673	57.875	58.880	54.544	51.723	52.894	53.202
27	56.176	56.378	62.862	64.806	60.139	57.700	57.832	58.525
28	60.279	60.796	67.580	70.101	64.943	61.860	61.999	64.531
29	63.621	65.930	72.617	75.405	69.388	66.741	66.018	69.874
30	67.695	70.676	76.617	79.695	73.317	71.841	70.245	74.164
31	71.388	75.060	79.953	83.160	78.049	77.083	74.284	77.845
32	74.485	78.020	83.329	86.274	81.837	81.190	77.681	81.318
33	77.793	80.123	85.674	88.479	84.850	84.876	80.927	84.070
34	80.479	82.903	87.949	90.561	87.293	87.145	83.593	86.527
35	82.361	85.872	89.287	92.089	89.459	89.348	86.139	88.665
36	84.260	88.144	90.782	93.044	91.011	90.899	88.200	90.902
37	86.312	89.418	91.730	94.076	92.569	92.199	89.682	92.145
38	88.175	90.410	92.468	95.180	93.469	93.515	91.047	93.883
39	89.924	91.376	93.545	96.157	94.207	94.057	91.920	95.391

Table H5, cont.

Range (ft)	S-1 Cum. %	S-2 Cum. %	S-3 Cum. %	S-4 Cum. %	S-5 Cum. %	S-6 Cum. %	S-7 Cum. %	S-8 Cum. %
40	90.997	92.396	94.770	96.871	95.016	94.777	92.918	96.216
41	92.044	93.466	95.395	97.335	95.761	95.619	93.640	97.019
42	93.184	93.988	95.895	97.697	96.146	96.167	94.238	97.463
43	94.005	94.717	96.328	98.139	96.396	96.970	94.890	97.862
44	94.578	95.357	96.645	98.398	96.682	97.274	95.394	98.090
45	94.857	95.774	96.697	98.483	97.199	-97.445	95.525	98.185
46	95.459	95.978	96.849	98.565	97.589	97.777	96.102	98.371
47	96.208	96.310	96.997	98.686	98.046	98.103	96.509	98.554
48	97.151	96.701	97.401	98.923	98.345	98.382	97.123	98.762
49	98.023	97.210	98.145	99.117	98.746	98.772	97.724	99.112
50	98.877	97.835	98.795	99.344	99.176	99.078	98.725	99.368
51	99.616	98.691	99.204	99.530	99.491	99.639	99.273	99.592
52	99.905	99.531	99.695	99.894	99.697	99.713	99.584	99.866
53	100	99.942	99.957	99.965	99.967	99.965	99.973	99.974
54	100	100	100	100	100	100	100	100
55	100	100	100	100	100	100	100	100

Table H6. Range distribution at the spillway at night for each of Blocks 3 through 7,all spill gates combined. Lower Monumental Dam, 1985.

	Cumulative percent fish passage				
Range(ft)	B-3	B-4	B-5	B-6	B-7
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	1.102	3.550	2.032	3.022	3.864
7	2.553	5.512	3.502	3.941	6.745
8	4.340	8.376	4.965	5.118	9.215
9	6.310	9.969	6.589	6.135	11.440
10	8.262	11.269	7.570	8.588	12.740
11	9.756	13.072	9.227	10.108	14.113
12	11.703	14.826	11.180	12.493	16.066
13	13.897	17.240	13.712	13.881	17.676
14	15.537	18.970	15.665	16.240	19.202
15	16.986	21.024	19.061	18.308	21.281
16	18.981	23.155	21.049	19.695	23.993
17	21.344	25.013	23.115	21.618	25.805
18	23.622	26.697	24.981	24.955	27.517
19	25.625	29.494	27.460	27.815	29.360
20	28.557	32.352	30.015	30.949	31.823
21	31.526	35.354	32.059	34.573	33.965
22	35.029	38.076	34.506	37.808	36.374
23	38.723	42.568	37.182	40.827	38.062
24	42.901	48.439	41.283	45.414	42.107
25	47.742	54.506	45.492	49.704	46.017
26	52.444	59.645	50.894	54.815	50.075
27	58.515	64.779	57.036	60.083	54.417
28	63.524	69.767	61.708	63.743	59.958
29	68.646	74.040	66.514	68.299	64.458
30	73.164	77.507	71.682	72.430	68.770
31	76.867	81.221	76.242	76.730	73.355
32	80.186	84.224	79.616	80.239	77.989
33	83.183	86.300	83.357	82.738	81.195
34	85.663	88.208	85.956	85.263	84.200
35	87.961	89.928	88.317	87.225	86.264
36	89.928	91.371	89.971	88.975	88.247
37	91.683	92.315	91.423	90.088	89.539
38	93.118	93.463	92.690	91.350	90.649
39	94.438	94.197	93.967	92.219	91.462

Table H6, cont.

Range (ft)	B-3	B-4	B-5	B-6	B-7
	Cumulative percent fish passage				
40	95.430	95.185	94.518	93.045	92.665
41	96.118	96.088	95.226	93.814	93.488
42	96.822	96.401	95.782	94.255	94.158
43	97.401	96.905	96.181	94.91'2	94.754
44	97.875	97.177	96.479	95.272	95.162
45	98.114	97.376	96.710	95.461	95.295
46	98.325	97.635	97.134	95.829	95.769
47	98.513	98.009	97.412	96.335	96.195
48	98.825	98.398	97.738	96.806	96.944
49	99.038	98.802	98.163	97.617	97.834
50	99.392	99.112	98.556	98.544	98.869
51	99.690	99.474	99.021	99.148	99.579
52	99.846	99.773	99.527	99.554	100
53	99.984	99.980	99.951	99.921	100
54	100	100	100	100	100
55	100	100	100	100	100