QUANTIFICATION OF LIBBY RESERVOIR LEVELS NEEDED TO MAINTAIN OR ENHANCE RESERVOIR FISHERIES

INVESTIGATIONS OF FISH ENTRAINMENT THROUGH LIBBY DAM, 1990-1994

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EXECUTIVE SUMMARY

We investigated fish entrainment through Libby Dam from December 1990 to June 1994. This study was one portion of the effort by the Montana Department of Fish, Wildlife and Parks to quantify Libby Dam operations necessary to maintain or enhance Libby Reservoir fisheries.

Fyke nets were fished in the draft-tubes of units 1,2 or 3 in order to quantify rates of entrainment. A total of 13,186 fish were captured during 501 hours of netting from January 1992 through June 1994. Kokanee comprised 97.5% of the catch, with 74.1, 12.7 and 13.2% of the fish being age 0+, 1+ and 2+, respectively. Surges of age 0+ fish were seen during June for all years, and the peak number occurred in the evening of January 13, 1993, when 1,246 were captured, yielding an entrainment rate of 41.99 fish/10^4 m^3 of water. High numbers of age l+ fish were captured in June of 1993 and 1994, reaching highest numbers (330) in the morning of June 4, 1993. Age 2+ fish were captured from June to October in 1992 and again in June of 1993 and 1994. Peak numbers were reached on June 2-3, 1994 when 244 fish were captured between 1930-0718 hrs. The remainder of the catch was composed of the following species, in decreasing order of abundance: largescale sucker, peamouth chub, mountain whitefish, longnose sucker, burbot, rainbow trout, yellow perch, cutthroat trout, redside shiner, bull trout, longnose dace and northern squawfish.

About 81% of kokanee (>124 mm TL) captured in draft-tube nets were deemed to have suffered turbine-induced injuries. About 21% of these fish had lethal or soon-to-be lethal injuries: decapitation, deep lacerations, two eyes missing or crushed, torn gill arch(es), and large body cavity rupture. Another 28% sustained injuries that were major--not immediately fatal, but were prolonged and damaging injuries. Another 32% suffered injuries that were minor and not lethal. The remaining 19% had injuries of an unknown origin; they may have been caused by the turbines, the draft-tube nets, or some combination of the two.

Die1 patterns of entrainment were measured with single-beam hydroacoustic equipment, by using a transducer which was mounted to the trashracks of unit 3 and sounded down the center of the penstock. There was a distinct difference between diurnal and nocturnal entrainment. All hourly intervals between sunrise and sunset had median rates of 0% of the daily rate. Entrainment increased immediately after sunset and reached a peak at 144% of the daily rate in the interval from 2-3 hours before midnight. Rates dropped for the next two hours, but then showed sustained high levels from midnight until sunrise. On the average, 78% of all fish were entrained between sunset and sunrise, while only 22% were entrained between sunrise and sunset.

Entrainment rates derived from sonar and draft-tube netting were used to estimate the total number of fish entrained through Libby Dam for various periods of time. The longest period of continuous sampling was from January.1992 to January 1993, where nightly draft-tube netting sessions occurred on a bl-weekly basis. We calculated both a high and low estimate of total entrainment for this period. The high estimate of 4.47 million fish assumed that rates from biweekly sampling applied to unsampled days preceding and following the netting session. A low estimate of 1.15 million fish assumed that the rate of entrainment during unsampled periods was the mean of all measurements for the year. These numbers were compared to a reservoir fish population estimate of 4.78 million fish, which was calculated by using boat-mounted sonar in August 1991. The low and high entrainment estimates were 23 and 92% of the total fish population, respectively.

Fish densities in the forebay were measured with boat-mounted sonar. Acoustic data were collected along 711 transects between December 1990 and June 1993. Area1 density of sonar targets reached its highest levels during May and June 1991, peaking at 63.4 targets/100 m^2 at midnight on May 20. Other prominent periods of high densities occurred in May and June of 1992 and 1993 as well as during November and December 1992. In spring, nearly all sonar targets were

found in the top 20 meters of the water column. In summer, a die1 vertical migration pattern was seen. At midday, about 48% of the fish were in the top 10 m, but at midnight only 14% were in the top 10 m and 69% were below 20 m. In the fall, die1 vertical migrations were not apparent. There was a slight concentration of fish in the top 20 m (49-72% of total), and another 26-46% of the fish were found between 20-50 m. Winter distributions were similar to those in fall: 51-73% in the top 20 m and an additional 27-47% between 20-50 m.

Entrainment rate was most highly correlated with forebay fish density at 10-20 m below withdrawal depth in the near-dam forebay transects (r=0.789), with discharge (r=0.758), and with area1 density in near-dam forebay area (r=0.676). Multiple regressions were performed on these and other variables, and the model explaining the most variance (R^2=0.776) incorporated discharge, forebay density at O-10 m above withdrawal depth (for both near- and far-dam transects), and area1 density for all transects. We applied these predictor variables to typical dam operations over the past 10 years to make generalizations about seasonal trends in entrainment. Spring (late April-early July) and fall (October-December) are the seasons with the highest potential for entrainment. In spring, this is because forebay fish densities are high and at depths close to the depth of withdrawal (20-30 m). The likelihood of entrainment during spring will be even greater if discharges are kept high to augment flows for Pacific salmon and/or white sturgeon. In fall, potential is high primarily because of the high discharges typical for this time of year. Conditions are somewhat less conducive for entrainment in summer (July-September), but the potential remains because the fish exhibit die1 vertical migration through the depth of withdrawal. Entrainment should be lowest in winter (January-March), due to low fish densities and discharge, as well as very deep withdrawal depths.

The kokanee in Libby Reservoir have exhibited strong density-dependent growth since the mid 198Os with spawner size ranging from 410 mm in 1986 to 257 mm in 1990. From a fish management perspective, large kokanee are desirable to stimulate angler interest, but extremely low densities are undesirable because the fishery can become unstable and susceptible to collapse. We have shown that entrainment is a predictable phenomenon, and should be useful as a management tool to control kokanee numbers. It should be possible to manipulate entrainment by controlling dam operations (withdrawal depth, discharge and load following), particularly during periods of high forebay fish densities. A controlled entrainment program should target age 0+ kokanee, because they typically occur in higher densities than older age classes and are not sought by anglers. Removal of age 0+ fish will also reduce competition for food with older age classes.

SCOPE OF WORK

Entrainment, or passage, of fish through the turbines of **dams** is a well-researched phenomenon. Much of the work has dealt with anadromous fishes, particularly the smolts of Pacific salmon passing through Columbia River dams. The timing and magnitude, as well as the mortality and injuries associated with this entrainment have been described by numerous investigators (Cramer and Oligher 1961a & 1961b, Schreck and Li 1984, Johnson et al. 1985, Johnson et al. 1992) and summarized by others (Either et al. 1987, Bell 1981 & 1990, Winchell et al. 1992). Much effort has also gone toward developing technologies that will reduce entrainment or provide for safe passage through or around turbines (Stone and Webster 1986).

Less well understood is the entrainment of nonanadromous or "resident" fishes. In the Pacific Northwest, the entrainment of kokanee salmon (Oncorhvnchus nerka) is of particular concern. t is an important gamefish in many lakes and reservoirs, and is susceptible to entrainment because it resides in the pelagic zone of lakes, establishes itself in high densities and is found throughout the water column (Northcote et al. 1964). Recent work by Tilson et al. (1994) has suggested that **some** kokanee entrainment may actually be downstream migration induced by physiological changes similar to those experienced by smolting sockeye salmon.

Kokanee have become an important gamefish in Libby Reservoir since their introduction in about 1977. The entrainment of kokanee through Libby Dam was observed as early as 1981 (Huston, Hamlin and May 1984). Since that time, the population has displayed marked fluctuations in its numbers. Because kokanee growth is strongly density-dependent, their size has also fluctuated. The change in size has had a powerful influence on angler interest. When spawner length was 352 mm in 1985, angler pressure was 115,000 angler days. In 1989, spawner size dropped to 278 mm and angler pressure dropped to 44,000 angler days.

The methods typically available to fisheries managers to control kokanee numbers include changes in fishing regulations and changes in stocking rates of kokanee or kokanee predators. Another tool that is potentially available in reservoirs is to control entrainment losses. We initiated this study to determine the feasibility of manipulating Libby Dam operations to control entrainment losses. Specific study objectives were:

1. Quantify the daily, seasonal and yearly rates of entrainment;

2. Identify biotic and abiotic variables (including those related to dam operation) that can be statistically related to entrainment rates;

3. Describe the types of injuries sustained by fish passing through Libby Dam turbines. Estimate mortality rates;

4. Recommend changes in dam operations that will enhance or optimize reservoir and river gamefish populations.

DESCRIPTION OF LIBBY DAM AND STUDY AREA

Libby Dam is located on the Kootenai River about 18 kilometers east of Libby, Montana. This concrete gravity dam measures 131.7 m in height and 13.6 m in width at the top. The dam was authorized by the Flood Control Act of 1950 and is operated by the U.S. Army Corps of Engineers. Construction of the dam began in 1966 and was completed in March 1972. Water was directed through the sluice gates or over the spillways until the installation of the first four generators between August 1975 and March 1976. A fifth generator was installed in the fall of 1984. The dam has the capacity for eight generators, but the remaining three have not been installed. The dam is currently operated so that all water goes through the turbines.

Full pool (749.7 m or 2,459 ft msl) was first attained in August 1974 with the reservoir stretching 145 km in length (Figure 1). Maximum water depth is slightly over 100 m at the face of the dam (Figure 2). The penstocks are arranged into two groups of four and are numbered beginning on the west shore. Units 1 and 8 are 113 m and 227 m from the west and east shores, respectively; the distance between units is 19.2 meters. The top and bottom of the penstock intakes are at 692.7 m msl (2,272 ft) and 677.4 m msl (2,222 ft), respectively. The penstocks are rectangular at the face of the dam (4.6 x 15.2 m) and narrow to a 6.1-m diameter cylinder within 46 meters. Wicket gates control water flow into the vertical-shaft Francis turbine chambers; midline turbine runner elevation is 645.7 m msl (2,118 ft) (Table 1). Water drops from the turbine chamber into a vertically-oriented draft tube, which makes a 90 degree turn to the horizontal. The draft tube then splits, with water flowing into the tailrace through two draft tubes.

A selective withdrawal system was retrofit to the upstream face of the dam between 1971 and 1974. This structure allows for the withdrawal of water anywhere from the depth of penstock intakes to the elevation at full pool. However, current dam operating guidelines restrict withdrawal depth to no shallower than 15.2 m (50 ft) from the water surface. The structure consists of 14 bays, into which 3.1-m (10 ft) high bulkheads are added or removed in order to adjust withdrawal depth. The bays are located in front of and between the penstocks, and bulkheads can be adjusted independently for each penstock. In recent years, it has been customary to keep withdrawal depth the same for all penstocks.

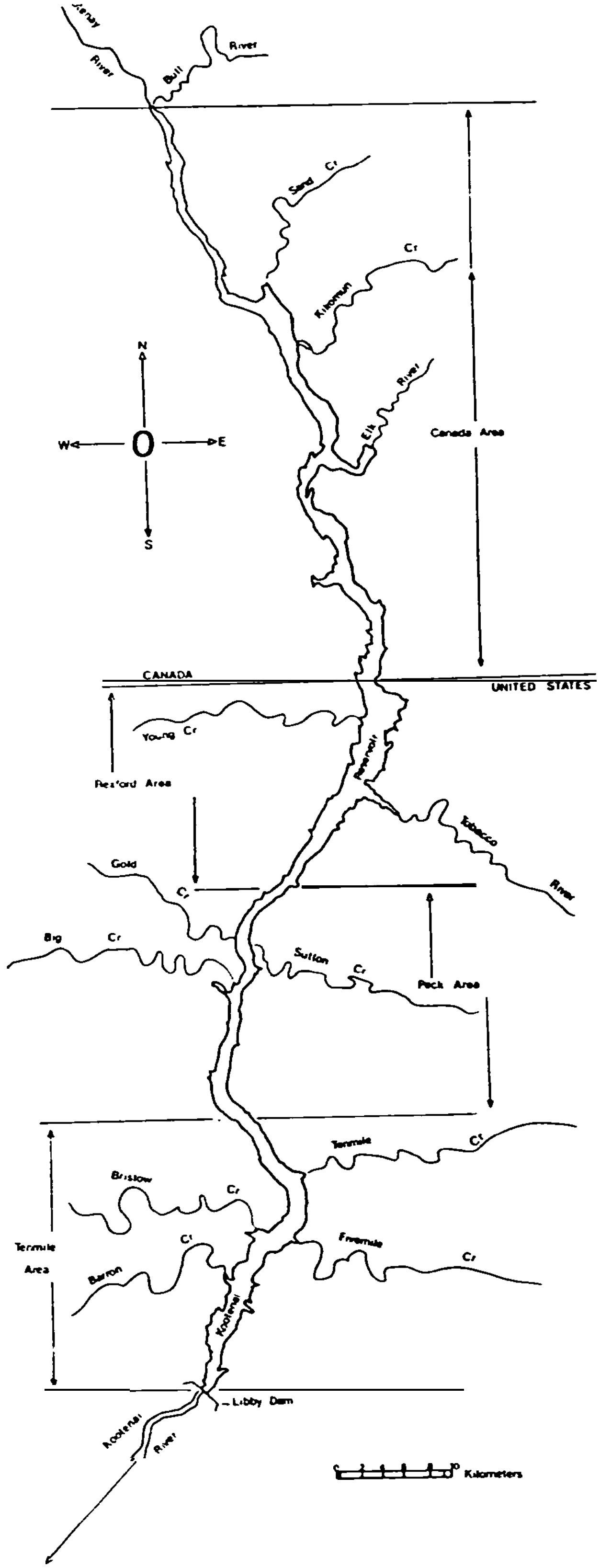

Figure 1. Map of Libby Reservoir, showing hydroacoustic sampling areas.

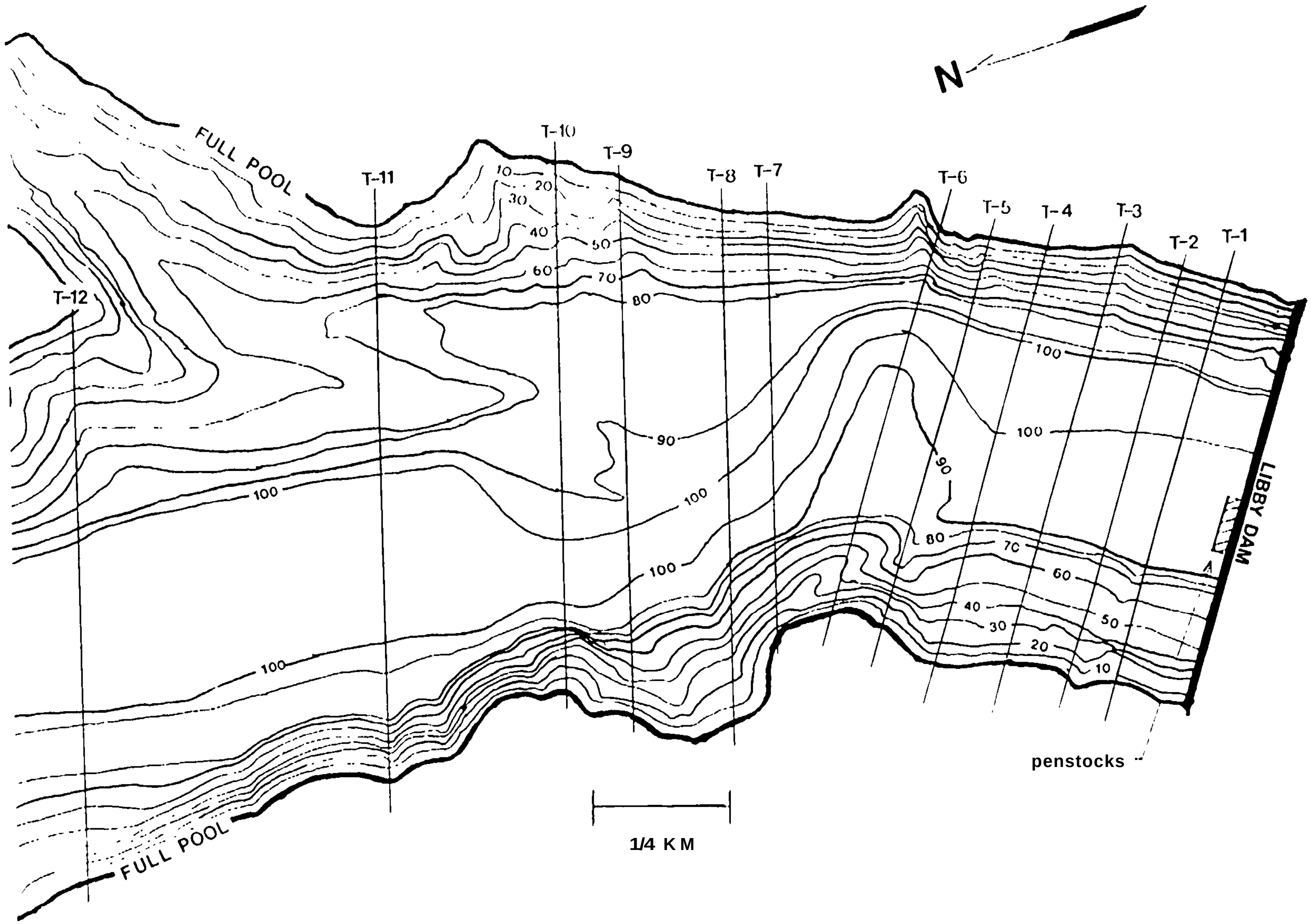

Figure 2. Plan view of the Lake Koocanusa forebay and Libby Dam. Isopleths indicate depths (m) at full pool. Mobile-sonar transects indicated by T-1 through T-12.

Table 1. Selected hydraulic and physical conditions of Libby Dam, penstocks and turbines.

Powerhouse discharge:
- Minimum (per operations manual) : 56.7 ems (2,000 cfs)
- Normal minimum: 113.4 cms (4,000 cfs)
- Maximum: 793.5 cms (28,000 cfs)

Physical dimensions:
- Penstock at upstream face of dam: 4.6 x 15.2 m (15 x 50 ft)
- Penstock diameter immediately above scroll case: 5.3 m (17.5 ft)
- Draft tube at downstream face of dam: 5.8 x 7.2 m (19 x 23.75 ft)
- Trashrack grating (open space between bars) : 0.76 x 0.15 m (2.5 x 0.5 ft)

El.evations (msl) :
- Full pool: 749.7 m (2,459 ft)
- Penstock:
  - at top of intake: 692.5 m (2,272 ft)
  - at bottom of intake: 677.4 m (2,222 ft)
- Turbine runner midline elevation: 645.6 m (2118.0 ft)
- Tailwater elevation:
  - at normal minimum discharge: 645.6 m (2117.8 ft)
  - at maximum discharge: 647.6 m (2124.2 ft)

Turbine characteristics:
- Type: Francis, vertical shaft
- Runner diameter: 4.8 m (15.83 ft)
- Number of blades: 15
- Blade tip clearance: 16.8 cm (6.6 in)
- Space between blades at periphery: 1.0 m (3.3 ft)
- Runner speed: 128.6 rpm
- Maximum peripheral velocity: 32.5 m/s (106.6 ft/s)
- Turbine flow (maximum) : 158.7 cms (5,600 cfs)

Hydraulic head:
- Minimum: 51.5 m (169.0 ft)
- Maximum: 104.0 m (341.2 ft)

Water velocity through dam (113 cms):
- At entrance to penstock: 1.6 m/s (5.3 ft/s)
- In penstock immediately upstream from scroll case: 5.1 m/s (16.6 ft/s)
- Through wicket gates (100% opening): 8.4 m/s (27.5 ft/s)
- At draft-tube gateslot: 1.7 m/s (5.7 ft/s)

METHODS AND MATERIALS

Fish Entrainment

Penstock Sonar

We selected the penstock of unit 3 to monitor entrainment because this unit is kept on-line continuously during normal dam operations. It withdraws water out of the east half of the selective withdrawal structure, and is located about 140 m from the east shore (at the depth of the penstock intake) and 360 m from the west shore.

Equipment. A BioSonics Model **101** Echosounder was used to transmit and receive electrical signals from a BioSonics transducer (6° circular beam, 420 kHz), which was mounted on the trashracks of unit 3. A BioSonics rotator was used to angle the transducer so that it sounded directly down the center of the penstock. The transducer cable was brought across the face of the trashrack (protected by steel conduit) and then up the face of the dam (protected by garden hose). About 229 meters of cable (152 m after October 1991) was used to connect the transducer to the echosounder, which was located inside the dam. Output from the echosounder was filtered through a BioSonics Model 165 Chart Recorder Interface, using a 200 mV threshold. Signals were then recorded on an EPC Model 1600 Graphic Recorder using 24 meter electrosensitive rolls (from December 4, 1990 to May 7, 1991) or a Raytheon LSR-910M Line Scan Recorder using 61 m electrosensitive rolls (beginning on May 23, 1991). Recording sessions typically lasted about 24 hours.

The echosounder and transducer were calibrated by personnel at BioSonics, Inc. At system settings of 0 dB for both the receiver and transmitter and **a** 200 mV signal threshold, the threshold target strength value was -61.8 dB for a target directly on axis. Effective full-beam width was calculated to be 1.7° for a -61 dB target and 7.1" for a -49 dB target.

Initial echosounder settings were: receiver gain, **-6** dB; transmitter level, 0 dB; trigger interval, **0.3** set, pulse width, **0.4** msec, blanking distance, 1.5 m, range, 22.0 m. Range was changed to 26.0 m on February 4, 1991, trigger interval was changed to 0.1 sec on February 21, **1991**, and receiver gain was changed to 0 dB on April 1, 1991.

In October 1991, it was discovered that the protective covering on the transducer cable had been worn away by the continual action of debris and water turbulence. As the cable wore away, the background electrical noise became stronger and the echo return signals became weaker. The cable was repaired, but soon the protective covering began to wear away again and by August 1992 the signal was very weak. Chart recordings made during the times of severe wear were of limited use in calculating hourly and daily entrainment rates, because we could not quantify the loss of voltage in the return signals.

Chart Interpretation. All charts were inspected for echoes that could be interpreted as fish. Charts typically had an dark band at a range of seven meters, representing echo returns from the upstream gateslot in the penstock (Figure 3). Beyond this range, the charts tended to get more heavily marked with distance, presumably due to the amplification of background electrical noise caused by the time-varied gain (TVG) function of the echosounder. The amount of background noise varied considerably, although typically the markings from the noise rendered the charts unreadable beyond a range of about 22-23 m (Figure 3).

Moving targets were assumed to pass through the transducer beam parallel to the line of the acoustic axis. Because the chartpaper moved during the time a target traveled through the beam, successive echoes formed a trace that was at an angle tangential to the direction of paper movement (Figure 3). Traces were interpreted to represent moving targets if at least three echoes were found along the expected angle of the trace.

It was difficult to distinguish aa fish trace from woody-debris trace. Traces on chart recordings from the fall, winter or early spring were almost certainly those of fish, as debris was virtually nonexistent during this time. These traces were typically made up of echoes of similar strength. Debris was usually dense in May, June and July, and traces from this time often had echoes quite variable in strength.

Estimation of fish entrainment rates on a daily basis. The number of chart-recording traces determined to represent fish were used to estimate the total number of fish going through the penstock for the duration of sampling. This effort was made difficult by two fundamental characteristics of hydro'acoustic systems: 1) the transducer beam width is relative to the target strength of the objects it is detecting; and 2) the target strength of a fish is a function of its size and orientation to the transducer. Since we never knew the size or orientation of fish represented in the traces, we were never able to determine the beam width, and were therefore unable to determine the percentage of the penstock being ensonified. We were able to deal with this problem by using a specially developed computer program that calculated the beam width for fish of any length. The program then simulated the progression of each fish through th penstock and estimated the percentage of fish that were detected by the transducer.

The program began by randomly choosing a path for each fish to take as it passed through the penstock. The orientation of the fish was then chosen and simulated in two ways--by estimating a

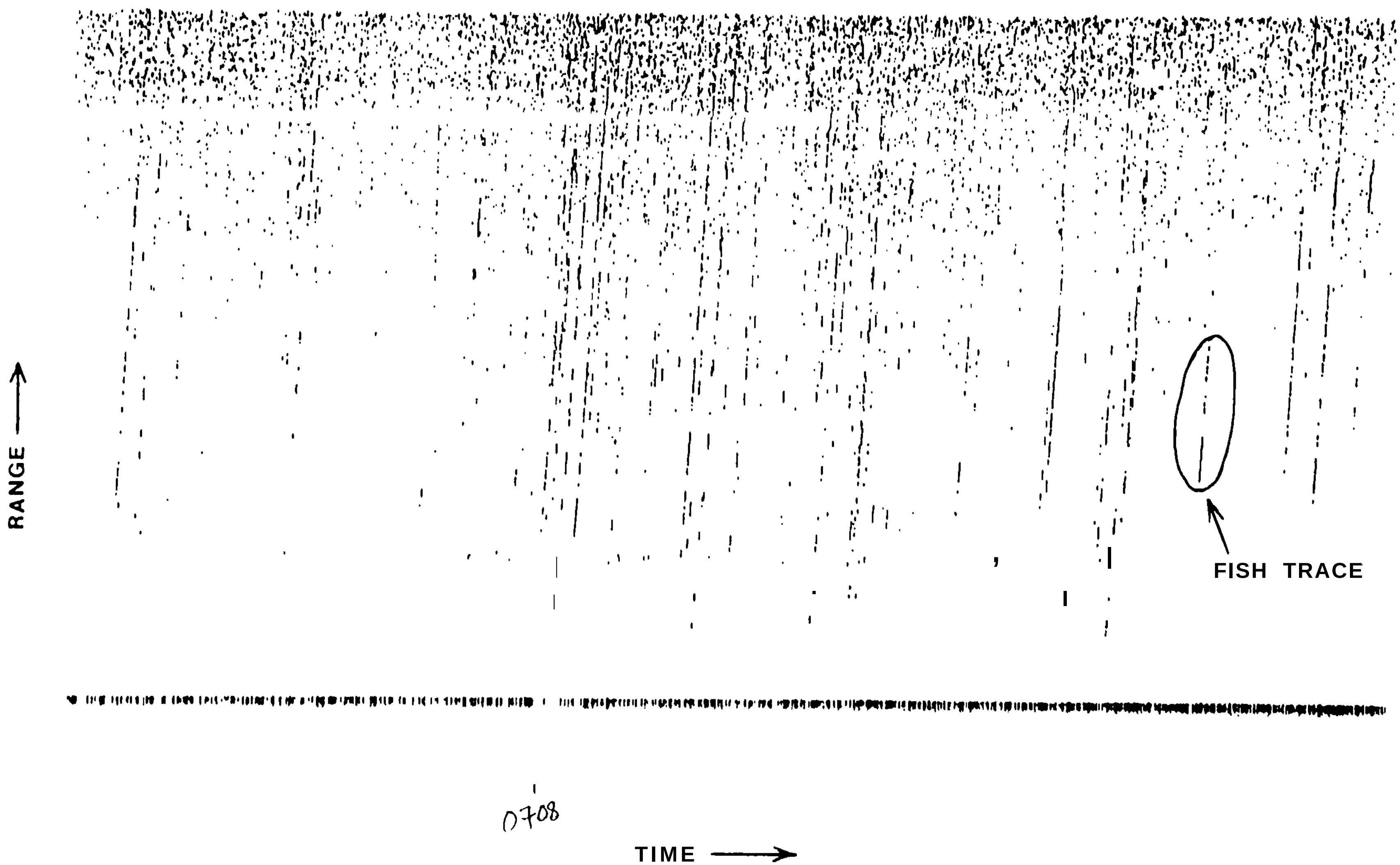

Figure 3. Examplefo penstock sonar chart recording.

mean target strength value, and fitting a frequency distribution around the mean. The mean target strength value was based on the length of the fish and its general position as it went through the penstock--head first, tail first, sideways, etc. Both the length and orientation were chosen by the program user as described below in input values #2 and 7. The frequency distribution associated with the mean was assumed to be that of a Rayleigh probability density function (Peterson et al. 1976). With each ping from the echosounder, the program randomly chose a target strength value from the Rayleigh distribution.

The program (using Monte Carlo techniques) simulated the progression of each fish through the penstock, and considered a fish to be detected if: 1) it travelled through the ensonified portion of the penstock (calculated from the beam width value for each fish); and 2) its return signal exceeded the 20 mV threshold at least three times (so that it created a "trace" on the chart paper). The program determined the ratio of detected to undetected fish in the simulation, and provided a scalar as output. This scalar was then multiplied by the number of targets detected on the chart paper (within the maximum effective range) to obtain an estimate of total number of fish going through the penstock.

The user was able to specify the following input values for the program:

1) Maximum effective range of transducer. Due to the geometry of the transducer beam, we expected that the number of targets would increase linearly with range. However, the tendency of the chart recordings to be more heavily marked with range (by amplification of background electrical noise) affected this relationship, and there was always a range at which our ability to detect targets began to diminish. The "maximum effective range" was therefore defined as the range at which the linear increase no longer occurred (Figure 4).

2) Length-frequency distribution of fish going through the penstock. The number of fish in each 10-mm length interval was used. Numbers were based on catches from the draft-tube nets at the time the sonar was operating, or in the absence of draft-tube netting, from the most recent sampling in the forebay with vertical gillnets.

3) Trigger interval (pings/second).

4) Transmitter source level (dB).

5) Other gains (voltage gains or losses due to changes in cable length or receiver gain setting).

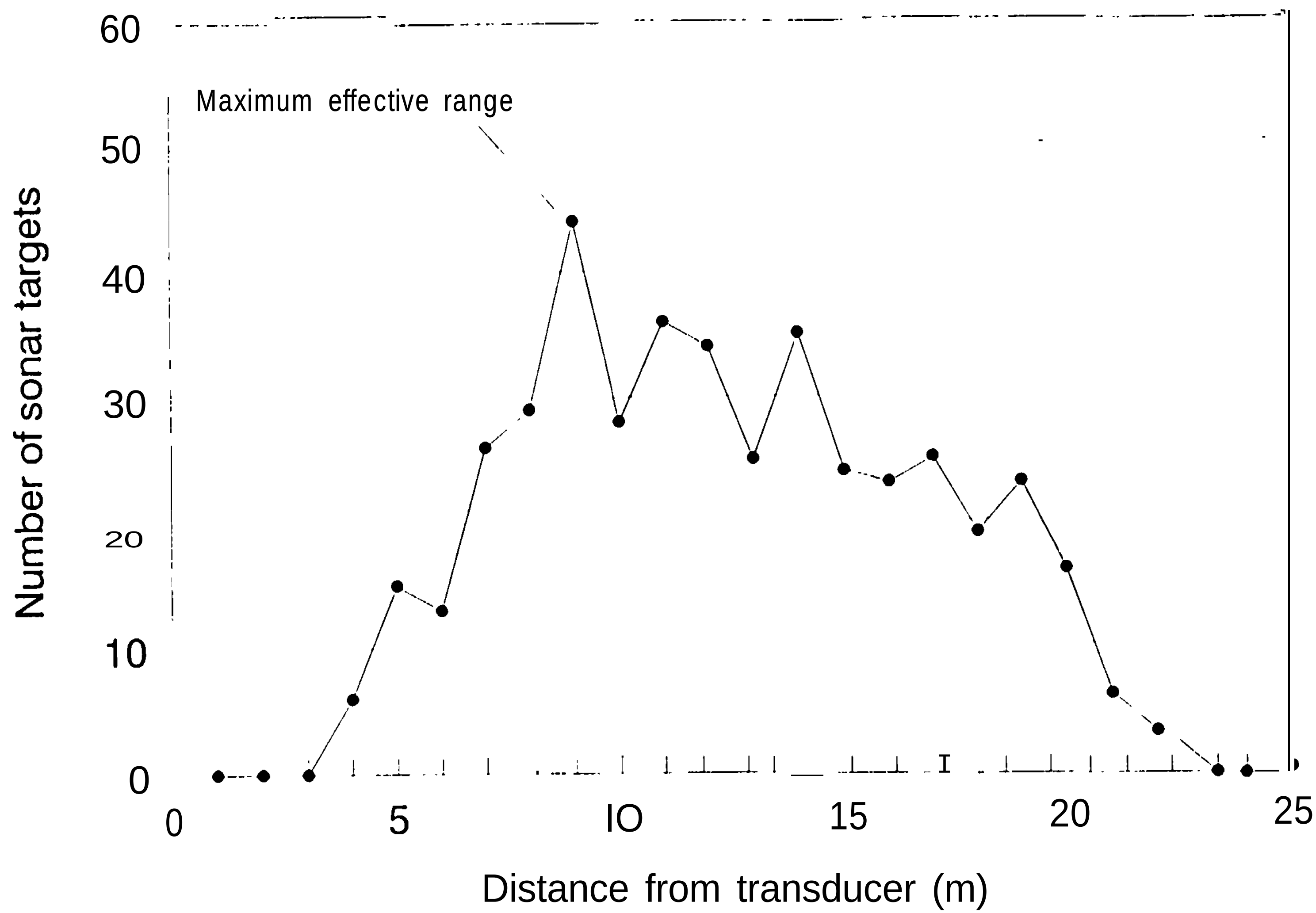

Figure 4. Distribution of sonar targets at range recorded on th penstock sonar charts. "Maximum effectiv range" is indicated.

6) Discharge for unit 3 (cfs). This was used to estimate the speed of the fish, and consequently the number of times it could be detected by the transducer.

7) Intercept point of a regression line drawn through a total fish length-target strength plot. This was used to assign target strength values to fish of various lengths (as entered for input value #2). The equation was:

$$TS=20*\log_{10}(\text{fish length in cm}) - X$$

where TS=target strength (dB) and X=intercept value. Using target strength values obtained from prior dual-beam surveys on Libby Reservoir, we determined that X = -74.7 when kokanee are detected from a dorsal aspect. A fish oriented with its head or tail toward the beam would have an intercept of about -94.7 dB. We chose to use a value of -87.7 dB, assuming that most fish in the penstock were likely to be at an orientation intermediate between the two extremes. Our use of -87.7 dB was also justified because this is the value that provided the best correlation between sonar estimates and draft-tube estimates (see paragraph below).

8) Number of simulations. Input on this line determined the number of simulations for each 10 mm length interval. For example, if there were six fish in the 160-170 mm size interval (based on netting), an input of 100 would make the program run 600 simulations for that interval.

Computer estimates for penstock entrainment were found to be somewhat lower than estimates generated from draft-tube netting. Using data from five sessions where both sampling methods were operated concurrently, we found the correlation between the two variables to be high (r^2 = 0.97), and the relationship to be described by the equation: (Y - 27.2)/0.85 = X, where Y = penstock sonar number and X = draft-tube net number. We assumed that draft-tube estimates were the more accurate of the two, and therefore adjusted all penstock estimates with the equation. The penstock estimates (Y) were inserted into the equation, which was solved for (X)--the "corrected" penstock sonar number.

Estimation of fish entrainment rates on an hourly basis. In order to make meaningful comparisons between the hourly intervals, all targets (including those beyond the maximum effective range) were used to calculate the number of targets per hour. This was necessary because the number of targets detected per hour was typically two or less (Appendix E), and frequently none of the targets were within the maximum effective range. As an example of this procedure, assume the following: there were 10 targets on the chart paper within maximum effective range, the program gave us a scalar of 100, and the total targets on the chart paper was 25 (10 targets between 0600-0700 h, 3 targets from 0700-0800 h and 12 targets from 0800-0900 h). Total estimated number of targets is 10 x 100 = 1,000. This total is apportioned among the hourly intervals as follows: 1,000/25 = 40 fish per target detected on chart paper; 40 x 10 = 400 fish from 0600-0700, 40 x 3 = 120 fish from 0700-0800 and 40 x 12 = 480 fish from 0800-0900.

Due to our inability to quantify the loss of signal strength as the covering on the transducer cable wore away, we were unable to directly compare hourly entrainment rates between many of the recording sessions. To compensate for this, we converted all hourly rates to percentages, calculated by dividing the rate for the hourly interval by the average entrainment rate for the entire recording session. In this way, the value for each hourly interval reflected its relative importance in the recording session, and could be directly compared to other recording sessions.

Draft-tube netting

Entrainment was also quantified by netting fish in the draft tubes of Libby Dam (Figure 5). In order to withstand the rigorous hydraulic conditions of the draft tubes, we designed and constructed a tubular-steel net frame. The rectangular frame had an outside dimension of 4.6 m x 7.3 m and had two vertical and one horizontal crosspieces, dividing the frame into six equally-sized openings or cells (Figure 6). Fyke nets (6-mm [1/4-inch] knotless mesh, 2.1 m x 2.0 m mouth dimension and 5.0 m in length) were attached to circular tubular-steel frames and fastened to the downstream face of the large frame with short lengths of chain. Typically three fyke nets were fished simultaneously. When fished, the entire rectangular tubular-steel frame, with fyke nets attached, was lowered into the gateslot of the draft tube using the powerhouse crane.

In order to determine the best conditions'under which to deploy the nets, we measured the water velocity at the center of each of the six draft-tube frame cells using a General Oceanics flowmeter. We took measurements in both the left and right (facing downstream) draft tubes of units 1 and 3 at 113.4 cms (4,000 cfs) (Table 2, Figure 7). Conditions in the draft tubes of the two units were quite similar, and with one exception (D-right), cell discharge measurements were within 15% of each other.

We decided to fish the nets in the left tube because velocities were lower than in the right tube, where preliminary tests produced conditions that tore the nets and bent the steel frames. We also chose to fish at 113.4 cms, because this is the normal minimum operating discharge for this turbine, and because velocities in the left tube increased markedly **as** the discharge was increased from 113.4 to 155.9 cms (5,500 cfs) (data on file).

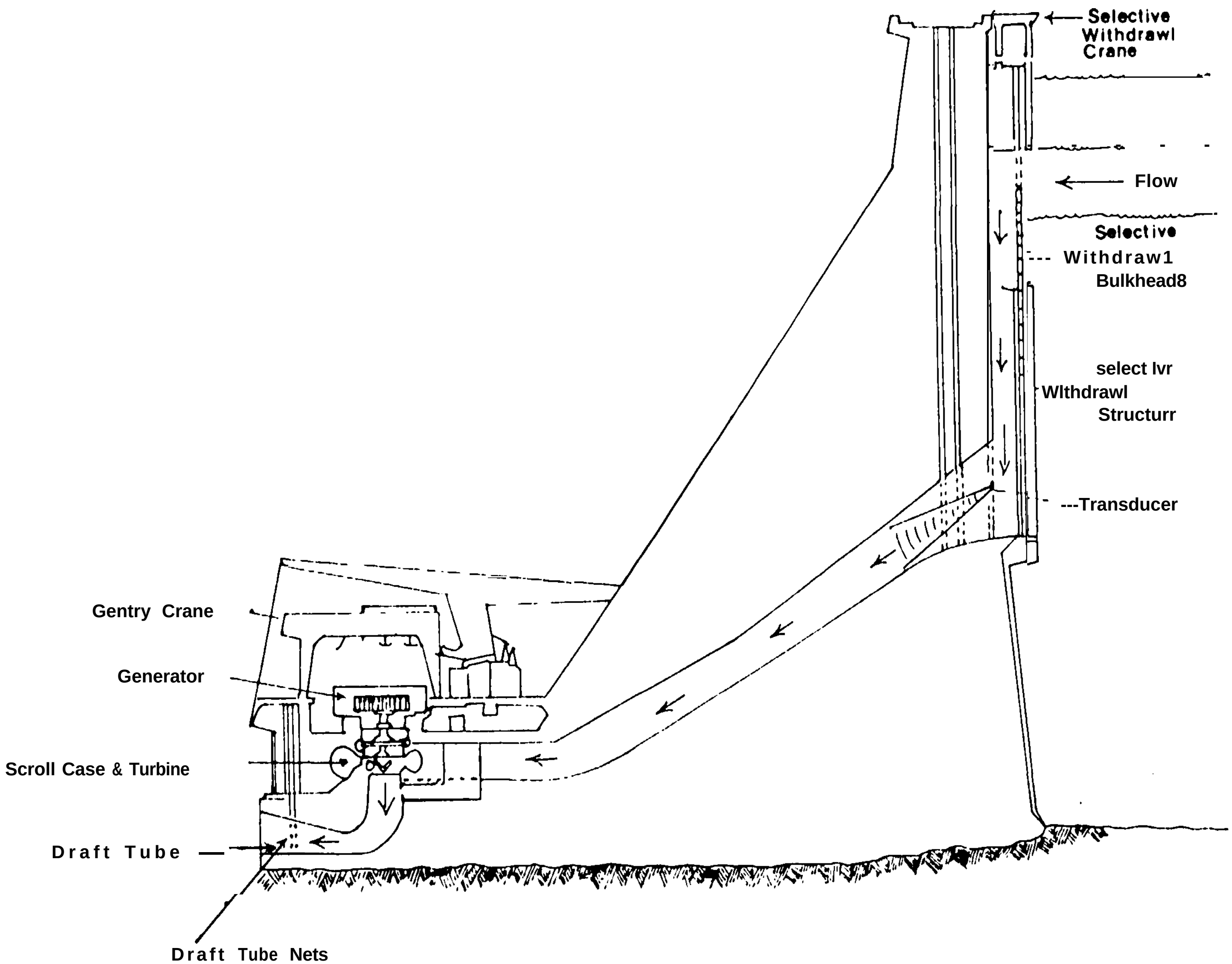

Figure 5. Cross-sectional view of Libby Dam, showing location of deployment for penstock sonar and draft-tube nets.

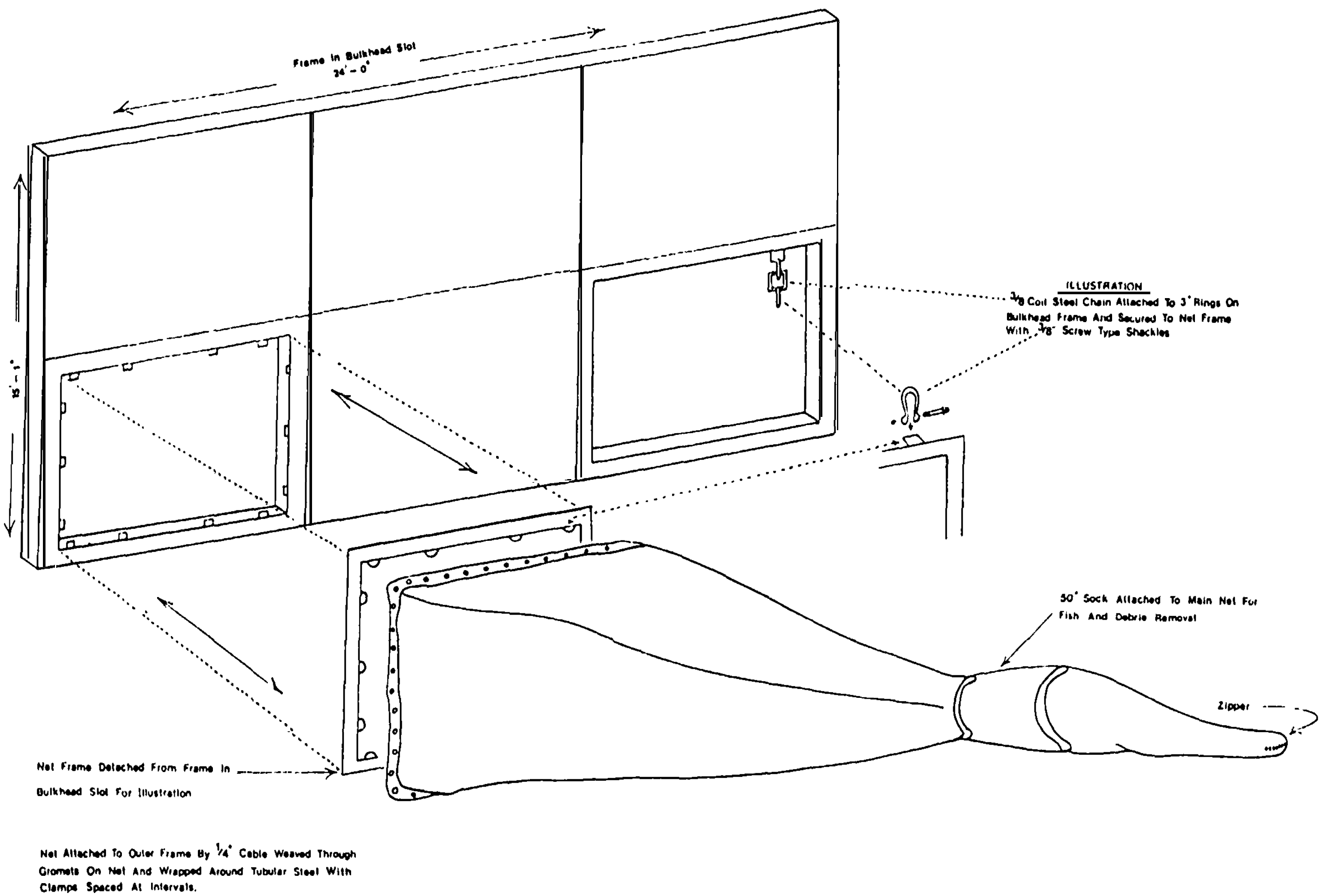

Figure 6. Drawing of draft-tube netting apparatus.

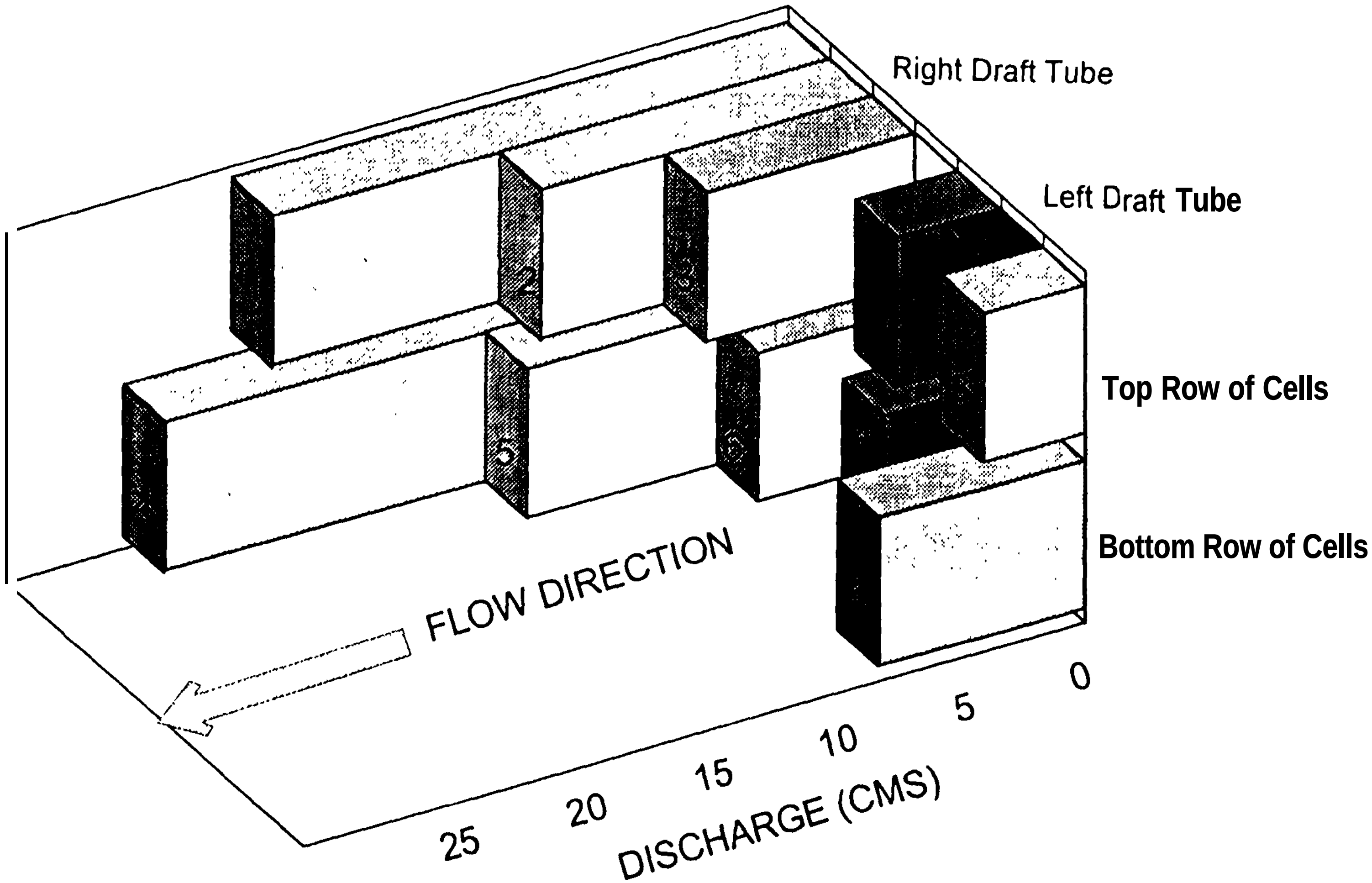

Figure 7. Graphic representation of the discharge of water through the draft tubes of unit 3 at 113 cms (4,000 cfs). View is looking to the east. Bars represent discharge in individual cells of the draft-tube net frame. Individual cells are identified by the numbers l-6 and correspond to those useh in Table 2.

Table 2. Discharge of water (cms) through net-frame cells when placed in the draft tubes of units 1 and 3 at a turbine discharge of 113 cms. The position of cells is displayed in Figure 7.

Cell	Unit 1	Unit 3	Ratio of unit l/unit 3
	Left draft tube[a]		
1	3.66	3.97	0.92
2	2.46	2.26	1.09
3	3.32	3.89	0.85
4	4.49	4.43	1.01
5	3.79	3.92	0.97
6	7.87	7.88	1.00
	Right Draft Tube[a]		
1	19.63	21.38	0.92
2	14.10	12.74	1.11
3	10.62	8.06	1.32
4	22.31	25.54	0.87
5	14.05	13.27	1.06
6	7.07	6.02	1.17

[a]Left or right determined by facing downstream.

The fyke nets were fished in the left draft tube of units 1, 2 or 3. Unit 3 was used exclusively from January 1991 through January 1993. In May 1993, unit 3 was damaged and taken out of operation; we then netted in unit 2 on May 25 and in unit 1 through the month of June and again in 1994. Nets were typically fished from about 1600-2300 hr and then again from about 2330-0700 hr.

Fish were examined for external and internal injuries immediately after removal from the draft-tube nets. Very small fish (primarily age 0+ kokanee) were not examined, due to the likelihood that many of their injuries were net-induced rather than turbine-induced. All larger fish (>125 mm TL) that were still alive were examined, as were a representative sample of dead fish.

Estimation of fish entrainment rates. Entrainment rates (fish/cubic meter of water) were summarized for each sampling session. The catch rate in each fyke net was calculated by multiplying the number of seconds the nets were fished by the discharge for that net cell (from Table 2). A mean catch rate for the sampling session was determined by averaging the catch rates for all fyke nets.

Mobile sonar in the forebay

We used boat-mounted sonar to estimate densities of fish in the forebay on a biweekly basis from December 4, 1990 to June 25, 1993. A Lowrance X-16 Depth Sounder with a paper chart recorder was used, and operated at a pulse width of 0.50 msec and a Surface Clarity Control setting of 1. The gain setting was standardized, although the actual voltage strength of this setting is not known. Ping rate was variable, and decreased with depth. We estimated it to be about 5.5 pings/second at a depth of 100 m. Nominal beam width of the transducer was 8°, although we calculated an actual beam width of using the duration-in-beam technique (Thorne 1988). Due to apparent inconsistencies in the time-varied gain (TVG) function, beam width did not stay constant at depths greater than 30 m. Estimated beam widths at specific depth intervals are as follows: O-30 m (4.92°), 30-40m (3.78°), 40-50 m (2.04°), 50 m and deeper (1.9°).

Soundings were made along predetermined transect lines. The entire water column was ensonified and the boat speed was maintained at a constant 2.5-3-O knots. We sounded the portion of the forebay extending from the dam upstream about 2 km to the mouth of Canyon Creek. A stratified random sampling design was used to select transects within this area. Six transects were established at fixed locations in each of two sub-areas. The near-dam area extended from the dam upstream to the weather station on the west shore, while the far-dam area extended from the weather station to the north bank of Canyon Creek at its confluence with the reservoir (Figure 2). During each 24-hour sampling period, soundings were made along two transects in each sub-area at sunrise, midday, sunset and midnight--for a total of 16 transects. We adjusted our sampling so that the transects would be sounded around the center of the time period. For example, for the sunrise sampling, we would try to have two transects completed by sunrise and begin the second two immediately after sunrise. Echoes from the soundings were recorded on chart paper, and the chart paper was visually inspected for targets.

Target densities (no./m^3 of water) along the transects were determined for each 10-m depth stratum. The number of targets in each stratum was determined by visually inspecting the chartpaper and counting the marks that were interpreted to be targets. The volume of ensonified water in each stratum was calculated by multiplying the transect distance (m) by the cross-sectional area (m^2) of the transducer beam in the stratum. Cross-sectional area was calculated by multiplying the average beam diameter of the stratum by the thickness of the stratum. Beam diameter (b) was calculated by the equation:

$$b= [2R\tan(\theta)]*a,$$

where theta is the half-beam angle in degrees, a is thickness of the stratum in meters, and R is the mid-range of the stratum from the transducer.

Vertical gillnetting and temperature measurements

Vertical gillnets were fished overnight once a month from December 1990 to August 1992 in conjunction with the mobile sonar surveys. The nets were set off the forebay buoy, which is located between transects 6 and 7. Four nets (50-m deep by 3.7-m wide) of square-mesh sizes 19, 25, 32 and 38 mm were used from December 1990 through May 1991, while a 12-mm mesh net was also used beginning in June 1991. The size and species of fish caught in these nets were assumed to be representative of fish detected with the mobile sonar and of fish entrained through the dam.

Water temperatures were measured monthly from December 1990 through August 1992 at the forebay buoy using a Cole-Parmer digital thermometer. Temperatures were taken at depths of surface, 3, 6, 9, 12, 15, 20, 25 and 30 meters. Occasionally temperatures were taken to depths of 40 meters.

Estimates of total entrainment through Libby Dam

For each day of sampling, entrainment through the entire dam was estimated in the following way: 1) For the draft-tube nets, we applied the entrainment rate for the netted draft-tube to the unnetted tube of the same unit as well as to draft-tubes of other units. For the time of day that we did not measure (always sometime between sunrise and sunset), we assumed that the entrainment rate was 28% of the measured rate. This was based on nocturnal/diurnal differences in entrainment measured by the penstock sonar (Table 20); and 2) For the penstock sonar, we assumed that entrainment rates for unit 3 were the same as for all other units.

We also estimated total entrainment for days that we did not sample. We developed two estimation procedures, with the purpose of yielding both a conservative (low) and a liberal (high) estimate. The high estimate was determined by assuming that the rates measured in one session were applicable to half the duration of time to the next or previous sampling session. The low estimate was determined by assuming that the entrainment rate during days not sampled was equal to the mean rate for all sampling sessions. Because the distribution plot of entrainment rates was skewed strongly to the left, we transformed values to the square-root or fourth-root before calculating a mean.

Reservoir-wide Fish Population Estimates

Estimates of the fish population in Libby Reservoir were made in August 1989 and August 1991. Sample design approximated that used by Shepard (1985) and Chisholm et al. (1989). The reservoir was divided into four areas for sampling purposes. The Tenmile area extended from the dam to above Tenmile Creek. The Peck area extended from the Tenmile Creek area to near Sutton Creek. The Rexford area extended from Sutton Creek to the Canada border, and the Canada section extended to the Kootenai River inlet (Figure 1).

Dual-beam hydroacoustics

We used dual-beam hydroacoustic equipment to estimate the total fish population in the reservoir. Acoustic data were collected along established transects during moonless nights in August. Data were collected with a 420 kHz BioSonics dual-beam echosounder (6° and 15° circular transducers) and recorded on tape in a digital format. The digital files were then processed with a BioSonics Model 281 Echo Signal Processor and converted to ASCII text files for further analysis. Density estimates were made for two size groupings of fish ("large" fish--mainly age class 1+ and 2+ kokanee, and "small" fish--mainly age class 0+ kokanee), for each 10-m depth stratum, and for each transect. Transect densities were weighted by their length, and combined to calculate a weighted average density for each area. The number of fish in each area was calculated by multiplying the weighted density for each depth stratum by the total volume of water in the stratum for the area. The numbers for each depth stratum were summed to come up with a total number of fish for that area. The number of fish for all four areas were summed to produce a reservoir-wide population estimate.

Vertical gillnetting

Vertical gill nets were fished overnight during August for one night in each of the four areas. The net mesh sizes that were used (19-, 25-, 32- and 38-mm square mesh) allowed us to sample fish in the "large" group. A ratio of kokanee/non-kokanee were calculated and applied to the total fish number from hydroacoustics in order to estimate the number of kokanee and other fish.

Fixed-frame trawling

A fixed-frame trawl (1.83 m x 1.83 m mouth dimension, 20-mm mesh at the mouth, 6-mm mesh at the cod end, 7.4 m in length) was fished along the sonar transects in the Tenmile, Peck and Rexford areas in August. At least one trawl was made within each depth stratum down to a depth of 45 meters. Catches from trawling allowed us to apportion the "small" fish category into kokanee and non-kokanee components.

Kokanee Spawner Surveys

We conducted kokanee spawner surveys in Kikomun Creek from 1989-1994. This spring-fed creek is one of the major spawning tributaries for the kokanee population in Libby Reservoir. It is ideally suited for visual surveys because of its small size (3-10 m wide and less than 1 m deep), excellent visual clarity and short length (less than 5 km of suitable spawning habitat).

Surveys were typically conducted at 7-14 day intervals from mid September through October. The entire stream was surveyed from the mouth upstream to the abandoned dam. A two-person crew conducted the surveys on foot, each person covering different reaches of the stream. All fish were directly counted, or if they were in large groups, estimates of group size were made. All counts were totaled to estimate spawner escapement.

RESULTS AND DISCUSSION

Dam Operations/Libby Reservoir Conditions

Water supply, power needs, flood control and Pacific salmon/white sturgeon flows all were prominent factors in determining Libby Dam operations from 1991-1994. Inflow to Lake Koocanusa was high (139% of normal using the October-September water year) and prolonged in 1991, with peak runoff greater than 1,800 cms and exceeding 1,000 cms for much of May, June and July (Appendix Figure Al). Outflow during 1991 was typical in that high discharges were released during fall and winter months. However, due to the high volume of runoff, discharges exceeding 500 cms were necessary during June, July and August. Inflow during 1992 was only 76% of normal, barely exceeded 1,000 cms at its peak, and quickly dropped below 250 cms by August. Due to the low reservoir elevations, outflow during 1992 rarely exceeded 500 cms (Appendix Figure A2). Highest discharges were mainly during the fall months, although **a** brief burst of water was provided for white sturgeon in late May and early June. Inflow during 1993 was slightly below normal (87%), with snowpack runoff peaking at over 1,500 cms in late May-early June (Appendix Figure A3). A second surge in inflow occurred during July, as heavy rains increased inflows back above 500 cms Outflow for the first seven months of 1993 was kept almost exclusively at the normal minimum level (113 cms), with the exception of brief spikes to around 500 cms from January through March, and a block of water for white sturgeon/Pacific salmon in June. Consistently high discharges (at or above 500 cms) were released from October through December. Inflow during 1994 was once again lower than average (83%) and peaked at just over 1,200 cms (Appendix Figure A4). Somewhat unusual was a brief surge above 700 cms during late April, due to high air temperatures accelerating snowmelt. Outflows were high during the first week of 1994, but were dropped quickly to 113 cms when the snowpack forecasts were issued. Minimum outflows were maintained through July, with the exception of the large block of water for white sturgeon/Pacific salmon in May and June.

Libby Reservoir reached full pool (749.7 m) during 1991, but not in 1992 or 1993 (Appendix Figures Bl-B3). The drawdown in the spring of 1991 was the second deepest on record (46 m), and was partly in response to the high runoff prediction. Drawdown in spring 1992 **was** less than 30 meters, although low runoff and the dam releases for white sturgeon caused a reservoir refill failure of about 6 meters. Drawdown in 1993 was 40 meters, and the reservoir rose to within 3 meters of full pool by September 1 (Appendix Figure B4). Drawdown **was** again less than 30 meters in spring 1994, and pool elevation rose slowly to within 5 meters of full pool by August 1.

Operation of the selective withdrawal gates was similar in all four years. Gates were typically installed beginning in late

April-early May as reservoir waters started to warm. Gates were then installed or removed through the spring, summer and fall in order to achieve the temperature rule curve (USACOE 1984) for the Kootenai River. All gates were typically removed by late November-early December (Appendix Figures Bl-B4).

Water temperatures measured at the forebay buoy in 1991 and 1992 showed a dimictic pattern typical of temperate region lakes (Wetzel 1975), and also similar to patterns previously described for the reservoir by Chisholm et al. (1989) (Appendix Figures Cl-2). In both years, isothermal conditions occurred in spring (April to early June) and fall (late October through December). Winter temperatures dropped below 4°C in both winters briefly from January to March. Thermal stratification was weak, but seemed to be strongest between the 16 and 18°C isotherms. Temperatures exceeded 15°C during July, August and September, but only exceeded 20°C briefly during July and August.

Forebay Fish Density and Distribution

Hydroacoustics

Acoustic data were collected along 711 transects in the forebay between December 4, 1990 and June 24, 1993. Effort was fairly well distributed among individual transects and periods of day (Table 3). An average of 59.2 and 177.7 surveys were conducted for each transect and time period, respectively. For each period of day, an average of 14.8 surveys (range 7-23) were conducted for each transect.

We found no indication of longterm or sustained differences in target densities from one part of the forebay to another. Kruskal-Wallis rank tests showed that there was no significant difference ($P<0.05$) in target densities between transects, either on an area1 basis or on a volumetric basis when 10 meter depth strata were considered individually (Table 4).

The area1 density of sonar targets was highest during May and June 1991, peaking at 63.4 targets/100 m^2 at midnight May 20 (Table 5). High densities also occurred in May and June of 1992 and 1993 and November through December 1992 (Figure 8). An unknown percentage of the targets during May and June were probably echoes from air bubbles and/or woody debris carried into the reservoir by snowpack runoff. This was corroborated by draft-tube net catches of large quantities of woody debris during May and June of 1992 and 1993 (Table lo), and by penstock sonar which detected debris-like traces in the spring of 1991 and 1992 (Appendix D). Lowest target densities were detected from April 29-30, 1992, when the densities averaged 0.085 targets/100 m^2 for all four periods of the day.

Table 3. Number of sonar surveys conducted for individual transects and periods of day in the forebay, December 4, 1990 to June 24, 1993.

Transect	Period: Sunrise	Midday	Sunset	Midnight	Total
1	21	13	13	15	62
2	14	21	13	17	65
3	16	9	14	13	52
4	16	14	18	15	63
5	15	17	15	16	63
6	11	15	17	13	56
7	11	23	14	11	59
8	18	21	7	19	65
9	15	11	19	16	61
10	12	15	17	15	59
11	20	7	16	15	58
12	10	10	17	11	48
Total	179	176	180	176	711

On most dates, densities were higher at midnight than any other period of day (Appendix E). Overall, area1 densities at midnight averaged 12.0 targets/100 m^2, about twice the levels at sunrise (5.52/100m^2) and sunset (7.28/100m^2), and over three times greater than levels recorded at midday (3.62/100 m^2) (Table 5). These differences are probably an anomaly, resulting from the tendency of kokanee to school during the day and not at night. Echoes from schools were usually large and amorphous, and we were rarely able to distinguish the traces of more than 4 to 6 individuals from a school. Consequently, we believe that many individual fish were unaccounted for during periods of schooling. For this reason, midday transect densities were usually the lowest. Sunrise and sunset densities were intermediate in density levels, because these were the periods of day when schools were breaking up (dusk) or forming (dawn), and only some of the schools were detected. Midnight transects were therefore considered to be the best indicator of actual forebay fish densities.

The vertical distribution of sonar targets varied with the period of day and the season (Table 5, Figure 9). In the spring, nearly all the targets were found in the top 20 meters of the water column. Even at midnight, when a slight movement to deeper water occurred, there were still 83% of the targets in the top 20 meters. This preference for shallow water could be due to: 1) Fish seeking the warmer surface waters in order to optimize growth conditions;

Table 4. Results from Kruskal-Wallis rank tests showing the mean rank of sonar target densities for individual transects in the forebay, December 4, 1990-June 25, 1993. Total number of transects=711.

Transect	Areal Density	Volumetric Density in 10 m depth strata						
		0-10 m	10-20 m	20-30 m	30-40 m	40-50 m	50-60 m	60-70 m
1	345.17	352.98	340.77	338.05	351.88	369.00	362.31	367.73
2	379.72	391.08	365.96	356.21	351.82	369.02	355.69	350.17
3	371.54	349.40	385.14	387.45	377.94	354.73	364.04	345.76
4	363.00	350.87	372.29	391.48	352.95	356.84	366.63	361.32
5	372.80	377.42	367.17	346.07	337.47	342.27	344.00	350.08
6	346.70	366.98	350.97	318.85	316.27	325.22	342.82	339.00
7	328.68	329.78	326.15	325.03	355.46	343.65	341.13	351.54
8	371.64	377.18	370.15	356.46	383.18	356.25	360.79	361.28
9	384.15	374.43	389.91	391.33	375.79	369.39	350.92	356.22
10	296.01	305.08	297.32	332.64	340.14	367.55	368.30	362.79
11	366.30	358.54	358.42	378.09	389.55	363.03	365.07	363.36
12	338.57	324.89	344.04	349.21	335.55	350.90	347.75	361.27
H Value	10.04	10.03	10.41	10.44	8.37	4.74	5.06	8.07
Significance Level	0.5268	0.5275	0.4942	0.4910	0.6796	0.9432	0.9282	0.7068

Table 5. Summary of sonar target densities in the forebay, December 4, 1990-June 25, 1993.

Season[1]	N	Period	Mean Areal Density (no./100 m^2)	Mean volumetric density (no./10^4 m^3) within depth stratum (m) 0-10	10-20	20-30	30-40	40-50	50-60	60-70
Spring	51	Sunrise	9.08	49.7	36.0	4.41	0.65	0.05	0	0
	52	Midday	6.41	45.9	16.2	1.77	0.10	0.08	0	0
	52	Sunset	15.9	122	28.1	5.60	2.69	0.04	0.23	0.10
	52	Midnight	21.1	102	84.1	18.8	5.27	0.64	0.20	0.24
Summer	40	Sunrise	5.93	24.5	20.2	9.56	2.72	1.44	0.79	0.05
	40	Midday	4.72	26.7	14.0	2.16	1.73	1.29	0.89	0.45
	40	Sunset	5.71	28.0	20.2	6.37	1.35	0.33	0.51	0.33
	40	Midnight	9.14	14.5	23.3	33.2	12.9	6.14	1.25	0.13
Fall	44	Sunrise	5.07	14.6	16.8	9.04	6.85	2.76	0.53	0.11
	40	Midday	1.90	7.62	6.04	2.34	1.59	1.01	0.31	0.12
	44	Sunset	5.13	18.6	17.7	7.30	4.38	2.70	0.48	0.10
	40	Midnight	12.1	28.4	18.5	22.0	22.5	19.4	9.36	0.97
Winter	44	Sunrise	1.46	4.00	4.77	3.96	1.33	0.50	0	0
	44	Midday	0.90	6.02	1.44	0.78	0.34	0.25	0.10	0.04
	44	Sunset	0.69	1.72	3.39	0.89	0.51	0.19	0.07	0.10
	44	Midnight	3.73	20.9	8.49	4.17	3.19	0.57	0	0.06
All	179	Sunrise	5.52	24.3	20.1	6.59	2.80	1.14	0.31	0.04
	176	Midday	3.62	22.9	9.70	1.74	0.87	0.61	0.30	0.14
	180	Sunset	7.28	46.5	17.8	5.03	2.27	0.79	0.31	0.15
	176	Midnight	12.0	45.0	36.5	19.1	10.4	6.12	2.47	0.34

[1]Season definitions are: Spring (late April through early July), when water temperatures are between 6-15°C and weak thermal stratification or isothermal conditions exist. Turbidity levels may be high; Summer (late June through early October), when water temperatures reach at least 15°C and thermal stratification exists; Fall (October through December), when isothermal conditions exist and water temperature is 6-15°C; Winter (January through April), when water temperatures are <6°C.

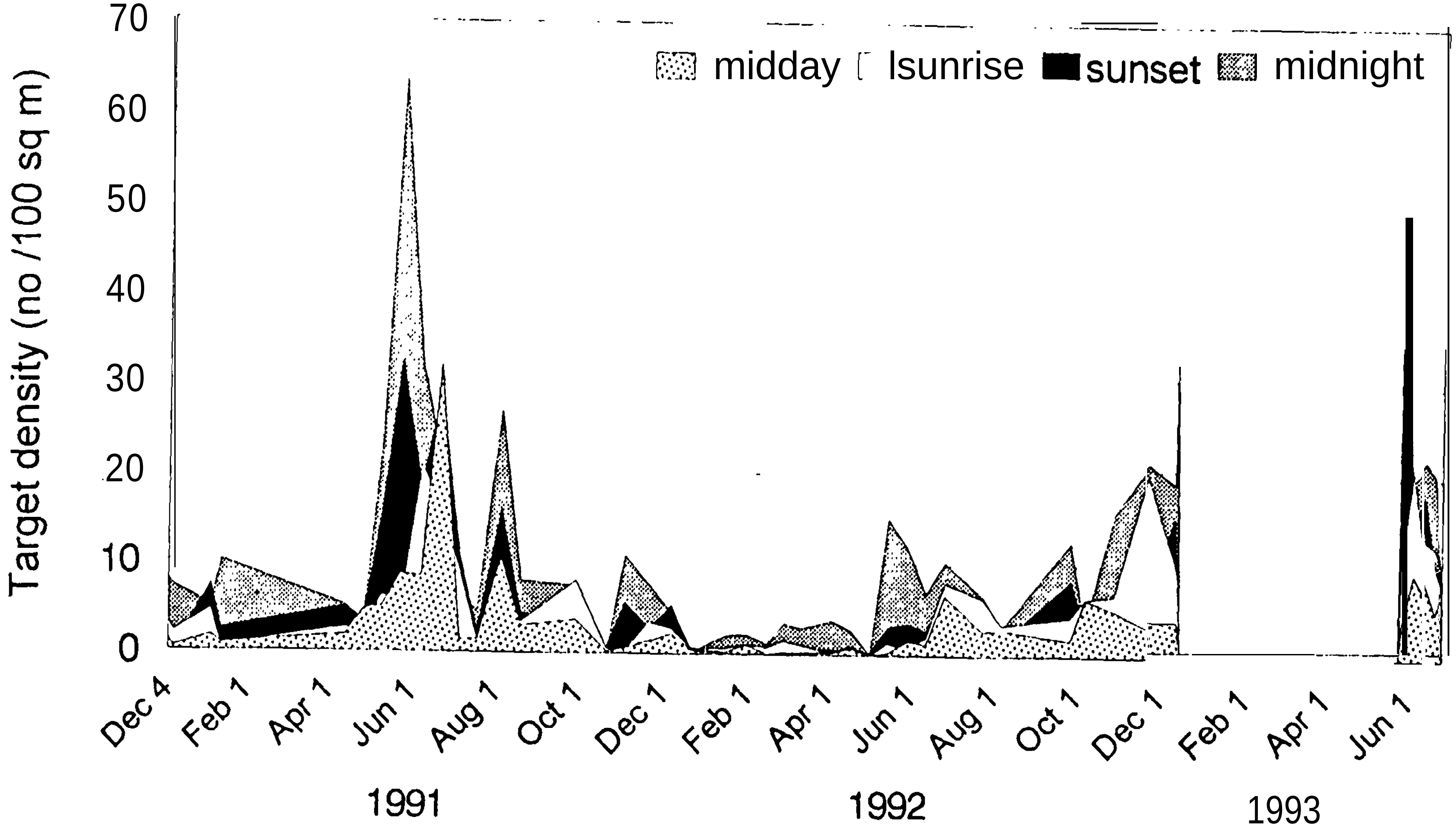

Figure 8. Seasonal distribution of forebay sonar targets.

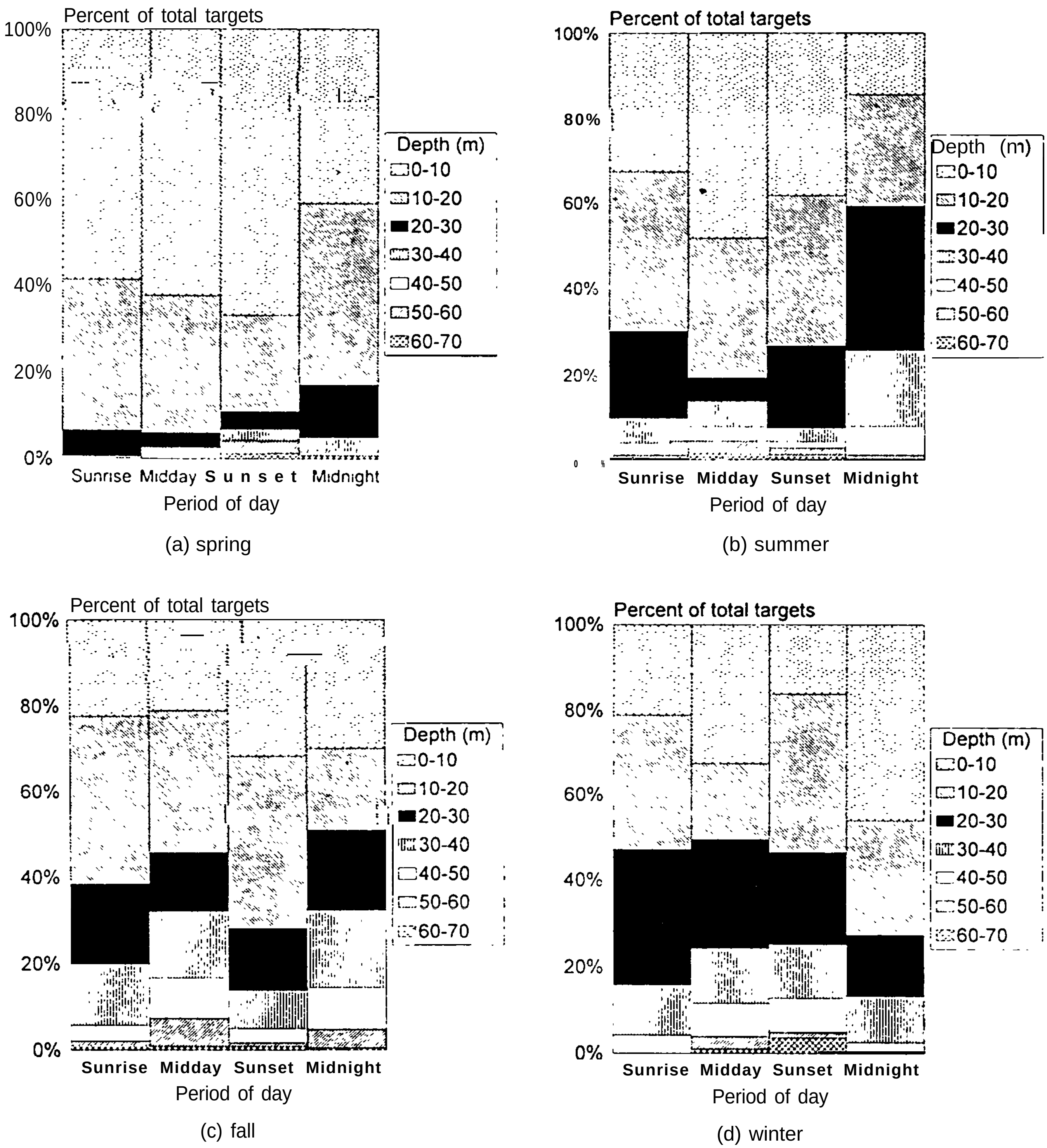

Figure 9. Vertical distribution of **forebay** sonar targets during spring, summer, fall and winter.

or 2) High levels of turbidity reducing light penetration and therefore reducing the ability of the fish (primarily kokanee) to forage in deep water. In the summer, a marked die1 vertical migration was seen. At midday, about 48% of the fish were in the top 10 meters, but at midnight only 14% were in the top 10 meters and 69% were below 20 meters. Examination of individual sampling sessions showed a tendency for the concentrations of fish at midnight to be at or below the 15°C isotherm--the upper limit of the optimal temperature range for kokanee (Piper et al. 1982). The movement down to this temperature at night may be for purposes of metabolic efficiency (Bevelhimer and Adams, 1993). In the fall, fish seemed to be somewhat shallower at sunrise and sunset that at midday and midnight, although the differences were slight. For all periods of day, the general tendency was for a slight concentration of fish in the top 20 meters (49-72% of total), but a substantial number of fish between 20 and 50 meters (an additional 26-46%). Winter distributions were similar to those in fall: 51-73% in the top 20 meters and an additional 27-47% between 20 and 50 meters. The most notable difference from the fall was the tendency for fish in winter to concentrate heavily in the top 10 meters at midnight (46% in this layer compared to 16-33% for the other times of day).

Vertical gillnetting

Vertical gillnets were fished on 17 nights between December 1990 and July 1992 in order to verify the species composition and vertical distribution of sonar targets. Species composition was dominated by kokanee, (81.1% of the catch), followed in abundance by peamouth (9-0%), redside shiner (6.8%), northern squawfish (1.8%), bull trout (0.6%), westslope cutthroat trout (0.4%) and rainbow trout (0.4%) (Table 6). The shallow waters were dominated by redside shiners and peamouth, whereas deeper net captures were predominantly kokanee. Peamouth and redside shiners were caught in the nets exclusively from May through September. All of the redside shiners were caught in the top 6 m of the water column (85% were in the top 2 meters), while 80% of the peamouth were found in the top 6 meters. Kokanee comprised only 17% of the catch in the top two meters, 43% of the catch throughout the top six meters, and 94.8% of the catch in water deeper than six meters. Kokanee were found in shallow water in April and May of both 1991 and 1992, moved to deeper water in August and September, and were distributed throughout the water column during fall and winter. This distribution for kokanee was fairly consistent with the distribution indicated in Figure 9 for seasonal distribution of all sonar targets. This is as expected, particularly since the sonar charts were typically unreadable in the top 2-3 meters, meaning that most of the species other than kokanee were not represented in the chart recordings. The sample size was often insufficient to

Table 6. Vertical distribution of fish captured in vertical gillnets in the forebay, December 4, 1990 to July 21, 1992. Each cell indicates number of kokanee captured within that depth interval. Abbreviations used for other species: NSQ=northern squawfish, RSS=redside shiner, CRC= peamouth, DV=bull trout, RBT=rainbow trout, WCT=westslope cutthroat trout. Only one individual fish was caught for species other than kokanee unless specified.

Depth (m) / Date	12 4 90	1 22 91	4 11 91	5 20 91	6 18 91	7 15 91	8 16 91	9 26 91	10 31 91	12 4 91	1 13 92	2 12 92	3 10 92	4 15 92	5 12 92	6 10 92	7 21 92
0-2				1 CRC-6	1 CRC RSS	RSS-4 CRC	RSS-7	CRC-5 RSS NSQ	NSQ				3		6	CRC-7 RBT NSQ RSS	RSS-15
2-4	1		2	1 CRC	3 CRC-2	RSS-2 CRC	RSS		1	2	1	3	1	1	2 CRC-2	CRC-5	CRC RSS
4-6	2		2	2 CRC-2		5	RSS CRC		4	4	2 RBT	24			2	1 RSS	CRC RSS
6-8	DV	1	2	2	3	7	1		3	1	2	2	7	1	CRC	6	
8-10		2	2			2 NSQ		CRC-4	2	4	1		28	1	1	1	
10-12	1	1			1	2 NSQ	1		2	4		4	2		CRC	2	
12-14		2	NSQ	1		4	3		1	1	1 NSQ	1	3		1	2 CRC	WCT
14-16				1		4	7	1	1	3	3	4	4			3	1
16-18	2		1			1	7			1	1	4				1	WCT
18-20	1 NSQ			3		1	4		1			2	2			2	2
20-22		NSQ				2	1		2		3	2	2				2
22-24	4			1			2	1	1		3					2	2
24-26	2			1		1	2		1	1	1	1				3	5
26-28	2 DV						3	7		2	1	1	1			1	2
28-30	1			1			5	2	1	1	1	1					3
30-32					CRC		1	4	DV	1	1	2	1			CRC	4
32-34							4	2		2		3		1			3
34-36								2	1			4					1
36-38	2	1						2		1	1	1	1				1
38-40							1	1	2			1	1				4
40-42								2	1	1		2	1		1		1
42-44	1						1	1				1					1
44-46	1						1	1	1								
46-48								1									2
48-50									1			1					

characterize the vertical distribution of the other species. Bull trout and northern squawfish were often found next to other fishes in the nets, and may have been caught as they attempted to prey on fish already caught in the nets.

Length-frequency analysis was used to separate the age classes of kokanee captured in the vertical gill nets. The 1988 year class was never distinct in the catches, but was most easily recognized in late summer/fall 1991, when most of the fish were probably over 300 mm TL (Table 7). The 1989 year class was first clearly detected in July 1991, when these fish had a modal value of 250-260 mm. As age 2+ fish in July 1992, only three of these fish were captured, ranging in size from 340-360 mm. The first obvious capture of 1990 year-class fish was in December 1991, when they had attained lengths between 170 and 220 mm. These fish were probably present in the forebay in the winter of 1990-1991, but the 12-mm mesh net had not as yet been used, and so these fish went undetected. The 1990 year-class fish were strongly represented in the nets in July 1992, when the modal length increment was 240-250 mm. The 1991 year class **was** first captured in October 1991, when they had a modal value of 120-130 mm. By March 1992, this same year class had grown to have a modal value of 130-140 mm.

The sample size of net catches was usually insufficient to characterize the vertical distribution of the different age classes of kokanee. However, there were four netting series (October 31, 1991-February 12, 1992) in which a comparison of depth selection was possible. When fish distribution was examined by lo-meter depth intervals, age class 1 and 2+ fish (combined) were found most frequently in the top 10 m of the water column (50% of total), while the IO-20 m depth interval was most frequently occupied by age 0+ fish (40% of total) (Table 8).

Comparisons to lakewide dual-beam sonar surveys

Differences in the vertical distribution of kokanee age classes were less distinct in lakewide sonar surveys than they were in the vertical gill net comparisons. In the lakewide estimates conducted in 1989 and 1991, fish were also grouped into large (age class 1+ and 2+) and small (age 0+) groups. The vertical distributions of these two size groups were determined for the 12 transects extending from the dam to Tenmile Creek (Table 9). As shown above in Table 6, kokanee are not the most abundant species in the 2-10 meter stratum in August. Therefore, the percentages given for the 2-10 m interval probably do not reflect actual kokanee densities. Below 10 meters however, the sonar targets can be assumed to represent kokanee. Excluding the 2-10 meter stratum, the percentage of large fish in the 1989 survey was highest in the

Table 7. Length-frequency distribution of kokanee captured in forebay vertical gill nets, December 5, 1990 to July 22, 1992. 12-mm mesh net first used on June 18, 1991. TL=total length.

TL (mm)	12 90	1 23 91	4 91	5 20 91	6 18 91	7 18 91	8 16 91	9 26 91	10 30 91	12 14 91	1 24 92	2 12 92	3 10 92	‖:	a:	It	It
100																	
110									2				1				
120									8	9	6	9	7				
130									1	2	5	19	37	1			
140											1	9	16	3			
150													1				
160																	
170		1		1						1							
180				3	1					2		1					
190					3		1			2	2	2			1	2	
200	1				2	1		1	1	2	1	1			2	7	
210	12		1			1				1						4	
220	6	2	2	4		1									1	3	1
230	1	1	4	4		2									1	3	5
240				2	1	8									4		15
250		2			1	13									2		6
260						3	1										4
270			1				1	3	3	2							
280		1	1				3	3	3	1	1						
290							3	3	3	3	2						
300							6	1	1	2	3						
310							4	3	3	2						1	
320							6	2	2	1						2	
330							1									3	
340																2	1
350							1										2
360																	
370																	1

30-40 meter stratum and ranged from 26-34% of the total fish (Table 9) In 1991, the greatest percentage of large fish was in the 10-20 meter stratum (40.2451, while percentages tended to drop with depth and were lowest in the 40-50 meter stratum (14.92%).

Table 8. Percentage of large (age class l+ and 2+) and small (age class 0+) kokanee in forebay vertical gillnet catches, October 31, 1992 to February 12, 1992.

Depth stratum (m)	Large Fish Percent	Large Fish no.	Small Fish Percent	Small Fish no.
O-10	80.0	24	20.0	6
10-20	26.0	10	74.0	28
20-30	30.0	6	70.0	14
30-40	30.0	6	70.0	14
40-50	20.0	2	80.0	8

Table 9. Percentages of small (age class 0+) and large fish (age class l+ and 2+) in Tenmile sonar transects, August 1989 and August 1991.

Depth stratum (m)	August 1989[a] Large fish	August 1989[a] Small fish	August 1991[b] Large fish	August 1991[b] Small fish
2-10	25.0	75.0	1.73	98.17
10-20	26.0	74.0	40.24	59.76
20-30	30.0	70.0	39.34	61.66
30-40	34.0	66.0	30.72	69.28
40-50	28.0	72.0	14.92	85.08
50-60	28.0	72.0	17.72	82.28
60-70	--	--	16.25	83.75
70-80	28.0	72.0		

[a]Thorne 1989
[b]McClain and Thorne 1991

Fish Entrainment

Draft Tube Netting

A total of 13,186 fish were captured during 501 hours of draft-tube net sampling between January 29, 1992 and June 30, 1994 (Table 10). Kokanee composed 97.5% of the catch, of which 74.1% were age 0+ (TL 40-160 mm), 12.7% were age l+ (TL 120-250 mm) and 13.2% were age 2+ (TL 200-360 mm). Notable surges in age 0+ fish were seen during June in all years. Peak numbers of this age class were netted in the evening of January 13, 1993, when 1,246 were captured, yielding an entrainment rate of 41.99 fish/10^4 m^3 of water. High numbers of age l+ fish were captured in June of both 1993 and 1994, with the peak number of 330 fish netted on the morning of June 4, 1993 (Table 10). Age 2+ fish were netted from June through October 1992 and again in June of both 1993 and 1994. The peak number of this age class was reached on June 2, 1994 when 244 fish were netted between 1930-0718 hrs.

Next to kokanee, the most abundant species in the draft-tube nets was the largescale sucker, which composed 44.6% of the remainder of the catch (Table 11). Some of the suckers were probably swept into the penstocks while feeding on algae on the face of the dam. Most of the suckers, however, were believed to have intruded into the nets from downstream during spawning runs in early summer. A number of sexually mature fish were found in the nets and they may have had the motivation to challenge the water velocities and swim up into the draft-tubes, only to be washed back into the nets. Similar intrusions by spawning fish were suspected in a few instances by mountain whitefish in the late fall and by kokanee in late summer. Several large (>5 kg) rainbow and bull trout were captured unharmed during the study, and these were also likely intruders from downstream. Burbot were captured most frequently during summer and fall, with juvenile fish outnumbering adults. The entrainment of burbot was surprising, given their demersal orientation. However, the extensive fields of rip-rap immediately above the dam may serve as an attractant to burbot for spawning and/or rearing. The two hatchery cutthroat trout captured in the nets on August 12, 1992 and January 14, 1993 probably do not serve as a reliable indication of the extent of entrainment of this species. This is because many hatchery cutthroat trout that were stocked into the reservoir in mid summer 1992 were captured later that year during electrofishing surveys below the dam (MDFWP, unpublished file data). Kamloops rainbow trout are also stocked into the reservoir on an annual basis, but none were captured in the nets during the course of the study.

Table 10. Numbers of fish and woody debris caught in draft-tube nets, January 29, 1992 to June 30, 1994.

Date	Time	Number of nets"	Number of kokanee": Age 0+	Age I+	Age II+ & older	Number other species	Total number fish	Number woody debris	Entrainment rate[c]: Number fish per 10' X m^3 water
01-29-92	0647-1053	2	0	0	0	0	0	0	0
01-29-92	1109-1235	3	0	0	0	0	0	0	0
02-13-92	0650-0952	3	4	0	0	0	4	0	0.311
02-25-92	1610-0005	3	20	0	0	0	20	0	0.596
02-26-92	0020-0845	3	44	0	0	0	44	0	1.232
03-10-92	1600-2341	3	12	0	0	0	12	0	0.367
03-11-92	2351-0810	3	16	0	0	0	16	0	0.455
04-61-92	1630-2356	2	0	3	0	0	3	0	0.143
04-02-92	0010-0640	3	0	7	0	0	7	0	0.254
04-15-92	1632-2355	3	1	6	1	1	9	0	0.288
04-16-92	0010-0758	3	0	3	0	2	5	0	0.151
04-29-92	1600-0001	3	0	0	0	0	0	47	0
04-30-92	0010-0737	3	0	0	0	0	0	9	0
05-12-92	1600-2330	3	0	0	2	16	18	50	0.063
05-13-92	2345-0650	3	0	0	0	0	0	245	0
05-27-92	1600-2400	3	0	0	0	13	13	12	0.236
05-28-92	0015-0730	3	0	2	5	5	12	23	0.357
06-09-92	1600-2400	3	1	0	4	29	34	60	0.147
06-10-92	0015-0800	3	3	0	3	7	13	17	0.213
06-23-92	1600-2353	3	10	0	29	1	40	10	1.168
06-24-92	0027-0805	3	60	0	3	7	70	2	2.036
06-30-92	1600-2400	3	11	0	51	5	67	0	1.944
07-21-92	1600-2356	3	15	1	37	5	58	1	1.666
07-22-92	0010-0728	3	52	0	9	5	66	1	2.131
08-04-92	1600-2401	3	8	0	18	4	30	3	0.854
08-05-92	0016-0807	3	33	0	4	1	38	0	1.143
08-12-92	1600-2400	2	0	0	15	2	17	0	0.702
08-25-92	1600-2400	3	19	0	28	1	48	1	1.415
08-26-92	0020-0812	3	78	0	42	0	120	1	3.599

Table 10, continued.

Date	Time	Number of nets'	Number of kokanee" Age 0+	Age I+	Age II+ & older.	Number other species	Total number fish	Number woody debris	Entrainment rate' Number fish per 10^4 X m^3 water
09-10-92	0020-0800	3	69	2	25	3	99	4	3.042
09-24-92	1600-2400	3	46	3	52	31	132	0	3.183
09-25-92	0020-0815	3	46	5	49	1	101	1	3.006
10-05-92	1600-0010	3	32	0	11	3	46	0	1.299
10-06-92	0020-0800	3	32	3	14	4	53	0	1.630
10-26-92	1600-2300	3	168	4	13	3	188	1	6.334
10-27-92	2325-0810	3	42	2	8	6	58	0	1.563
11-18-92	1600-2310	3	283	17	0	2	302	0	9.951
11-19-92	2332-0755	3	291	14	0	1	306	0	8.610
12-08-92	1600-2310	3	1,088	13	0	0	1,101	0	36.24
12-09-92	2337-0700	3	766	11	1	0	778	0	24.84
12-09-92	1600-2304	3	717	36	6	3	762	1	25.44
12-10-92	2320-0710	3	498	8	0	1	507	0	15.28
01-13-93	1600-2300	3	1,246	0	0	0	1,246	0	41.99
01-14-93	2325-0710	3	1,098	0	0	1	1,099	0	33.45
01-27-93	1600-2300	3	66	1	0	0	67	0	2.258
01-28-93	2305-0715	3	29	0	0	0	29	0	0.836
05-25-93	1600-2300	2	0	23	11	4	38	0	1.750
05-26-93	2335-0730	2	0	214	0	5	219	2	9.840
06-03-93	1630-2315	3	86	124	31	8	249	198	9.460
06-04-93	2345-0700	2	78	330	36	6	450	36	22.30
06-10-93	1600-2300	3	354	97	50	6	507	--	18.70
06-11-93	0010-0700	3	718	223	43	8	992	--	37.44
06-17-93	1600-2305	3	204	43	120	27	394	63	13.59
06-18-93	2320-0705	3	436	99	46	16	597	38	19.76
06-24-93	1535-2305	3	193	22	81	3	299	24	10.27
06-25-93	2337-0700	3	390	59	13	7	469	20	16.37

Table 10, continued.

Pull Date	Time	Number of nets[a]	Number of kokanee[b]: Age 0+	Age I+	Age II+ & older	Number other species	Total number fish	Number woody debris	Entrainment rate[c]: Number fish per 10^{1} X m^{3} water
05-16-94	0700-1925	3	0	0	49	14	63	44	1.332
05-17-94	1935-0710	3	0	1	24	5	30	21	0.663
05-25-94	0700-1925	3	0	1	9	4	14	23	0.306
05-26-94	1930-0715	2	0	14	35	4	53	18	1.764
06-01-94	0700-1915	3	0	10	53	17	80	42	1.683
06-02-94	1930-0718	3	0	109	244	8	361	49	7.890
06-08-94	0700-1915	2	0	2	28	1	31	80	0.932
06-09-94	1956-0707	2	0	23	67	2	92	30	3.024
06-15-94	0700-1900	3	0	1	12	3	16	--	0.336
06-16-94	1920-0700	3	43	61	117	8	229	82	4.940
06-22-94	0700-1914	1	0	2	14	4	20	183	1.214
06-23-94	1940-0715	2	25	25	132	1	183	19	5.865
06-29-94	0730-1915	2	0	2	24	1	27	35	0.854
06-30-94	1952-0714	2	98	11	26	0	135	56	4.410
TOTAL FISH			9,529	1,637	1,695	325	13,186		

*Nets were fished in unit 3 on all dates except 5/25-26, 1993 when unit 2 was used, and from 6/3-25, 1993 and all of 1994 when unit 1 was used. Nets were fished in right draft tube on l-29-92; nets fished in left draft tube after l-29-92. Nets were fished in cells 1,3, and 5 for all dates.

[b]April I is assumed to be the birthdate of all kokanee.

'Does not include fish considered to be intruding into nets from downstream.

Table 11. Summary of species other than kokanee caught in draft-tube nets, January 29, 1992 to June 30, 1994.

Species	Number caught	Percent of total
Largescale sucker (Catostomus macrocheilus)	145	44.6
Peamouth chub (Mvlocheilus caurinus)	57	17.5
Mountain whitefish (Prosopium williamsoni)	30	9.2
Longnose sucker (Catostomus catostomus)	26	8.0
Burbot (Lota lota)	24	7.4
Rainbow trout (Oncorhvnchus mykiss)	9	2.8
Yellow perch (Perca flavescens)	9	2.8
Westslope cutthroat trout (O.clarki lewisi) (includes 2 hatchery WCT)	7	2.2
Redside shiner (Richardsonius balteatus)	7	2.2
Bull trout (Salvelinus confluentus)	6	1.8
Rainbow/cutthroat trout	3	0.9
Longnose date (Rhinichthvs cataractae)	1	0.3
Northern squawfish (Ptvchocheilus oregonensis	1	0.3
TOTAL	325	**100.0**

Entrainment during Spring Runoff

Entrainment of age 0+ kokanee was very high in May and June 1993 relative to the same time period in 1992 and 1994 (Figure 10). Numbers in 1993 peaked on June 10-11 when 1,072 fish were captured. The large number of fish in 1993 relative to the other two years cannot be explained by differences in the size of the spawner class the previous year, because the 1992 spawner class was apparently fewer in number than either of the other two years. We hypothesize that following winters with high snowpack, reservoir inflow is very turbid and kokanee will move down-reservoir seeking clear water in which to feed. When the kokanee reach the dam, they continue downstream through the turbines of the dam. In support of this hypothesis, light transmission at the forebay buoy in 1993 was much lower than in 1992 or 1994 (Table 12).

While less well documented, the situation in 1991 also supports the hypothesis. Light transmission values were the lowest of all four years while the number of penstock sonar targets was higher than in 1992. Unfortunately, it was not possible to directly compare entrainment rates between the two years, because many of the penstock sonar targets during May, June and July in 1991 may have been debris. Nonetheless, the targets we speculated to be fish were consistently greater in number than they were in 1992 (Appendix El and E4). Forebay sonar target densities were also much higher during this period in 1991 than in 1992 (Table 5).

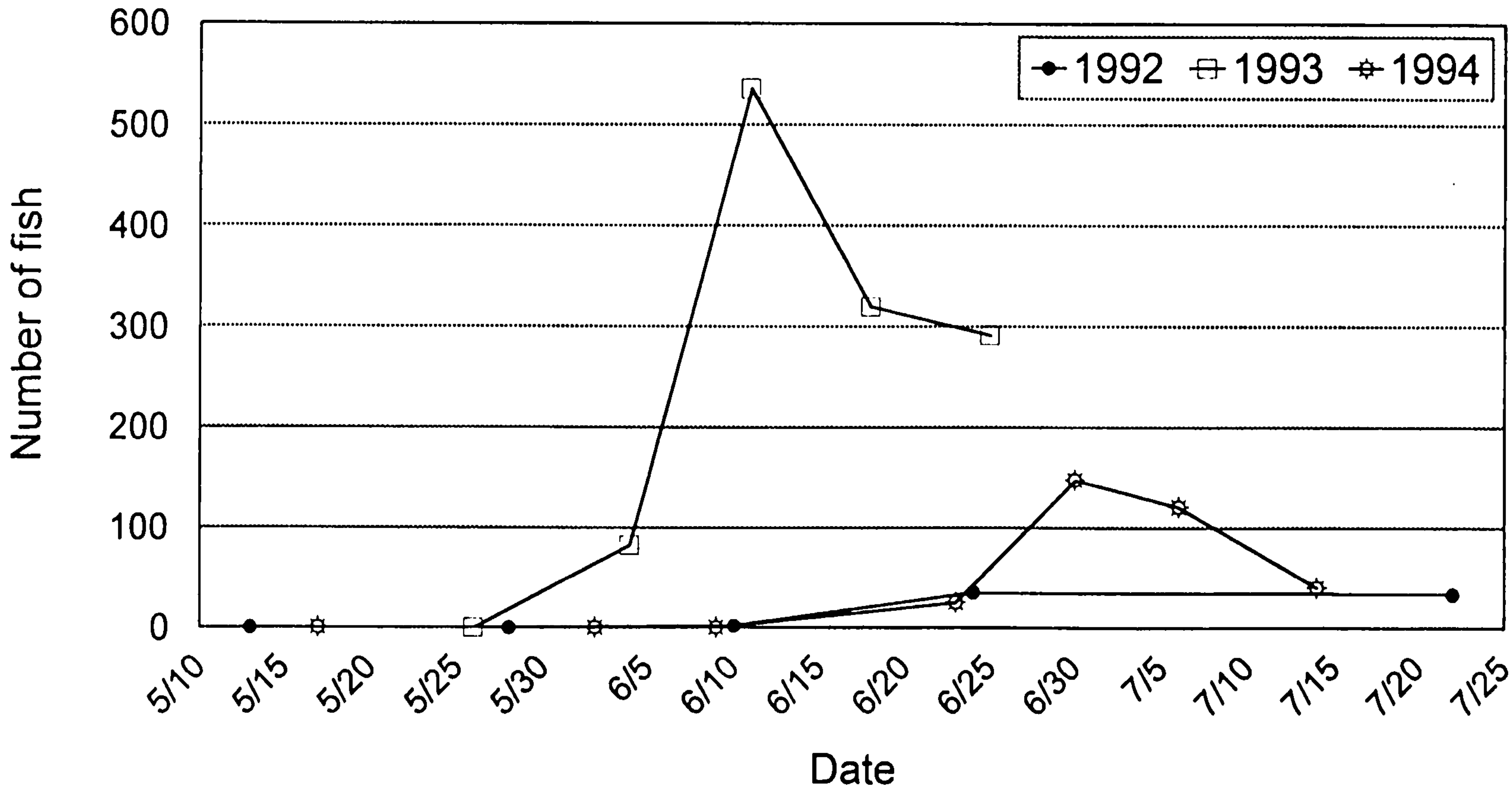

Figure 10. Number of age 0+ kokanee in draft-tube nets fished from ca 1600-0700 hrs.

Table 12. Minimum and maximum light transmission levels (%) measured at regular depth intervals within the water column from O-21 m (70 ft) at the forebay buoy, 1991-1994. Data from U.S. Geological Survey, Water Resources Data Summaries, **1991-1994.**

Date	Year 1991	1992	1993	1994
mid-May	3-4	8-14	4-7	9-27
mid-June	o-2	21-45	5-11	11-32
mid-July	30-50	25-33	14-32	24-33

Injuries to Entrained Fish

A total of 1,208 kokanee captured in draft-tube nets in 1992 and 1993 were examined for injuries (Table 13). Abrasions were the most common injury, found in 81% of examined fish ("combined" column). Other injuries, in decreasing order of occurrence were internal bleeding of unidentified source (40% of fish), inflated gas bladder (26%), eye damage (18%), contusions (lo%), soft and pulpy tissues (9%), lacerations (9%), body-cavity rupture (5%), damaged operculum (5%), decapitation (4%), ruptured or inverted gills (3%) and internal bleeding of spleen (2%).

Interpretation of the cause of these injuries is difficult, because damage may have occurred in the nets. Fish remained in the nets for up to 12 hours, and injuries or deaths may have resulted from being suffocated, crushed or disfigured by other fish and debris, or from the pounding action of the nets against the walls of the draft-tubes. To test for the effects of the nets alone, we placed yearling rainbow trout in the draft-tube nets and deployed the nets into the draft tube for varying amounts of time (Table **14)**. We found that the only injuries that occurred after 11.45 hours were abrasions **(100%** of the fish), hemorrhaging of lower intestine (80%), hemorrhage of unidentified source (80%) and soft and pulpy tissues (60%). To test for the effects of the turbines alone, we captured 38 kokanee from the tailrace of Libby Dam which had come through the turbines, but had not been netted (Table 15). Many of the same types of injuries were found as in the nets alone experiment: abrasions (40%), internal bleeding of unidentified source (45%), and soft and pulpy tissues (5%). However, more serious injuries were also found, such as lacerations (18%), decapitation (ll%), and body cavity rupture (5%).

To be conservative, we treated all abrasions, unidentified internal bleeding, and soft and pulpy tissues as being net-induced. Fish were grouped into one of three mutually-exclusive categories based on the severity of their injuries (Table 13). Fish with

Table 13. A description of the types of injuries sustained by age class I+ and 2+ kokanee (TL > 124 mn) captured in draft-tube nets, February 13, 1992 to June 25, 1993.

Number of dead fish (percent of total)

Type of injury	Feb 13	Feb 25/26	March IO/II	April I/2	April 15/16	May 12	May 27/20	June 10	June 23/24	June 30
	1992									
1. Abrasions	I(50)	33(77)	9(82)	8(100)	3(60)	0 (0)	8(100)	6(86)	30(97)	52(100)
2. Contusions	0 (0)	2 (5)	2(18)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	II(21)
3. Decapitation	0 (0)	1 (2)	1 (9)	0 (0)	0 (0)	0 (0)	0 (0)	4(57)	2 (7)	0 (0)
4. Internal bleeding of unidentified source	I(50)	19(44)	5(46)	5(63)	2(40)	0 (0)	0 (0)	I(14)	0 (0)	24(46)
5. Internal bleeding of spleen	0 (0)	0 (0)	1 (9)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
6. Lacerat ions	I(50)	4 (9)	2(18)	2(25)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3)	0 (0)
7. Eye damage[a]	I(50)	7(16)	8(73)	2(25)	0 (0)	0 (0)	3(38)	I(14)	1 (3)	0 (0)
8. Tissue soft,pulpy	0 (0)	1 (2)	1 (9)	0 (0)	0 (0)	0 (0)	0 (0)	3(43)	18(58)	3 (6)
9. Ruptured or inverted gills	I(50)	0 (0)	4(36)	0 (0)	0 (0)	0 (0)	3(38)	0 (0)	0 (0)	1 (2)
10. Damaged operculun	I(50)	2 (5)	3(27)	0 (0)	0 (0)	0 (0)	0 (0)	I(14)	1 (3)	0 (0)
12. Bcdy cavity rupture	I(50)	5(12)	1 (9)	0 (0)	0 (0)	0 (0)	0 (0)	2(29)	1 (3)	0 (0)
13. Inflated gas bladder	0 (0)	0 (0)	2(18)	3(38)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Fish with no injuries, minor injuries or net induced injuries (#1,2,4,5,8)	I(50)	30(70)	2(18)	3(38)	4(80)	I(100)	5(63)	4(57)	27(87)	51(98)
Fish with turbine induced injuries (#6,7,10,13)	0 (0)	7 (16)	5(45)	5(63)	1(20)	0 (0)	3(38)	I(14)	2 (6)	0 (0)
Fish with lethal or soon to be lethal injuries (#3,9,12)	I(50)	6(14)	4(36)	0 (0)	0 (0)	0 (0)	0 (0)	2(29)	2 (6)	1 (2)
Total number dead fish	2	43	11	a	5	1	8	7	31	52
Total number fish	2	47	12	10		1	8	7	32	52
Dead fish as a percent of total fish	100	92	92	80	7:	100	100	100	97	100
Total length (range, mm)	125-136	125-176	125-170	124-150	125-335	288	148-220	124-360	125-360	125-374

‘Eye damage includes hemorrhaging, protrusion or removal.

Table 13, continued.

TYPE of injury	July 21/22	Aug 5	Aug 12	Aug 25/26	Sept 10	Sept 24/25	Oct 5/6	Oct 26/27	Nov 18/19	Dec 8/9
	Number of dead fish (percent of total)									
	1992									
1. Abrasions	40(89)	18(90)	14(100)	43(92)	8(33)	94(93)	24(96)	25(78)	45(87)	45(85)
2. Contusions	5(11)	IO(50)	2(14)	0 (0)	14(58)	20(20)	4(16)	4(13)	1 (2)	5 (9)
3. Decapitation	2 (4)	1 (5)	0 (0)	4 (9)	4(17)	7 (7)	3(12)	4(13)	6(12)	2 (4)
4. Internal bleeding of unidentified source	6(13)	8(40)	IO(71)	18(38)	20(83)	28(28)	8(32)	7(22)	16(31)	14(26)
5. Internal bleeding of spleen	0 (0)	1 (5)	0 (0)	0 (0)	0 (0)	0 (0)	5(20)	1 (3)	0 (0)	1 (2)
6. Lacerations	0 (0)	1 (5)	1 (7)	2 (4)	2 (8)	II(11)	4(16)	7(22)	6(12)	8(15)
7. Eye damage'	2 (4)	0 (0)	0 (0)	9(19)	5(21)	12(12)	7(28)	2 (6)	3 (6)	13(25)
8. Tissue soft,pulpy	0 (0)	0 (0)	0 (0)	16(34)	1 (4)	3 O)	7(28)	1 (3)	20(39)	3 (6)
9. Ruptured or inverted gills	2 (4)	1 (5)	1 (7)	0 (0)	6(25)	5 (5)	0 (0)	0 (0)	0 (0)	0 (0)
10. Damaged operculun	1 (2)	0 (0)	0 (0)	0 (0)	0 (0)	5 (5)	1 (4)	2 (6)	0 (0)	4 (8)
12. Body cavity rupture	1 (2)	0 (0)	0 (0)	5(11)	0 (0)	12(12)	2 (8)	8(25)	5(10)	1 (2)
13. Inflated gas bladder	1 (2)	0 (0)	0 (0)	12(26)	0 (0)	20(20)	1 (4)	8(25)	25(48)	14(26)
Fish with no injuries, minor injuries or net induced injuries (#1,2,4,5,8)	38(84)	18(90)	13(93)	25(53)	12(50)	47(47)	II(44)	12(38)	17(33)	24(45)
Fish with turbine induced injuries (#6,7,10,13)	2 (4)	0 (0)	0 (0)	17(36)	12(50)	45(45)	IO(40)	II(34)	27(52)	26(49)
Fish with lethal or soon to be Lethal injuries (#3,9,12)	5fII)	2(10)	1 (7)	5(11)	0 (0)	9 (9)	4(16)	9(28)	8(15)	3 (6)
Total number dead fish	45	20	14	47	24	101	25	32	52	53
Total number fish	48	23	14	69	28	107	27	33	57	72
Dead fish as a percent of total fish	94	87	100	68	86	94	93	97	91	74
Total length (range, mm)	125-136	125-362	125.360	125-368	125-285	125-359	125-372	125-326	125-282	125-363

[a] Eye damage includes hemorrhaging, protrusion or removal.

Table 13, continued.

Type of injuries	Jan 13/14	Jan 27/28	May 25/26	1993 June 3/4	June 11	June 17/18	June 24/25	Totals[b] (Dead Fish)	Totals" (Live Fish)	Combined[b] (Live+Dead)
	Number of dead fish (percent of total)									
1. Abrasions	9(24)	4(801	41(61)	120(92)	66(87)	81(60)	60(61)	894(82)	86(74)	980(81)
2. Contusions	1 (3)	0 (0)	1 (2)	22(17)	4 (5)	5 (4)	1 (1)	115(11)	6 (5)	121(10)
3. Decapitation	0 (0)	I(20)	1 (2)	4 (3)	4 (5)	3 (2)	0 (0)	54(5)	0 (0)	54 (4)
4. Internal bleeding of unidentified source	5(13)	2(40)	IO(15)	76(58)	28(37)	70(52)	65(66)	446(41)	33(28)	479(40)
5. internal bleeding of spleen	0 (0)	0 (0)	1 (2)	4 (3)	2 (3)	3 (2)	0 (0)	20(2)	1 (1)	21 (2)
6. Lacerations	0 (0)	0 (0)	3 (5)	19(15)	II(15)	13(10)	14(14)	113(10)	1 (1)	114 (9)
7. Eye damage*	8(21)	0 (0)	18(27)	37(28)	21(28)	25(19)	24(25)	205(19)	11 (9)	216(18)
8. Tissue soft,pulpy	0 (0)	0 (0)	3 (5)	1 (1)	4 (5)	3 (2)	2 (2)	95 (9)	10 (9)	105 (9)
9. Ruptured or inverted gills	0 (0)	0 (0)	4 (6)	9 (7)	1 (1)	0 (0)	3 (3)	38 (3)	2 (2)	40 (3)
10. Damaged operculun	0 (0)	0 (0)	6 (9)	14(11)	5 (7)	5 (4)	6 (6)	63 (6)	0 (0)	63 (5)
12. Body cavity rupture	0 (0)	0 (0)	0 (0)	9 (7)	2 (3)	5 (0)	1 (1)	62 (6)	0 (0)	62 (5)
13. Inflated gas bladder	9(24)	2(40)	17(25)	60(46)	39(51)	64(48)	61(62)	336(31)	26(22)	310(26)
Fish with no injuries, minor injuries or net induced injuries (#1,2,4,5,8)	15(39)	I(20)	36(54)	31(24)	19(25)	52(39)	18(18)	502(46)	80(69)	582(48)
Fish with turbine induced injuries (#6,7,10,13)	22(58)	3(60)	26(39)	79(60)	51(67)	74(55)	77(79)	465(43)	34(29)	4W(41)
Fish with lethal or soon to be lethal injuries (#3,5,12)	1 (3)	I(20)	5 (7)	21(16)	6 (8)	8 (6)	3 (3)	125(11)	2 (2)	127(11)
Total number dead fish	38	5	67	131	76	134	98	1092	(Live)116	
Total number fish	38	6	67	150	76	142	111	1208	1208	1208
Dead fish as a percent of total fish	100	83	100	87	100	94	88	90	(% Live)10	
Total length (range,mnm)	125-168	125-255	132-305	130-351	136-295	125-335	125-300	124-372	125-393	124-393

[a] Eye damage includes hemorrhaging, protrusion or removal.
"Data from January 13/14, 1993 excluded from "totals" column because many live fish were not measured during this sample period.

Table 14. A description of the types of injuries sustained by yearling Kamloops rainbow trout (TL 162-240 mm) placed in draft tube nets for varying amounts of time.

Type of injury	Number of fish (percent of total) 3.9 hours	6.0 hours	11.45 hours
1. Abrasions	14 (93)	10(100)	15(100)
2. Contusions	0 (0)	0 (0)	0 (0)
3. Decapitation	0 (0)	0 (0)	0 (0)
4. Internal hemorrhage of unidentified source			
a. Spots of blood--not lethal	3 (20)	4 (40)	1 (7)
b. Blood covers 1/4 to 1/2 body cavity--may be lethal	0 (0)	1 (10)	0 (0)
c. Blood covers 1/2 or more of body cavity--probably lethal	0 (0)	0 (0)	11 (73)
5. Hemorrhage of lower intestine			
a. Probably not lethal	2 (13)	1 (10)	12 (80)
b. Probably lethal	0 (0)	0 (0)	0 (0)
6. Lacerations			
a. Barely breaks flesh--not lethal	0 (0)	0 (0)	0 (0)
b. Deeper, might be lethal	0 (0)	0 (0)	0 (0)
c. Deep, probably lethal	0 (0)	0 (0)	0 (0)
7. Eye damage			
a. Hemorrhage	1 (7)	0 (0)	0 (0)
b. Protrusion	0 (0)	0 (0)	0 (0)
c. One eye missing	0 (0)	0 (0)	0 (0)
d. Two eyes missing	0 (0)	0 (0)	0 (0)
e. One eye crushed	0 (0)	0 (0)	0 (0)
f. Two eyes crushed	0 (0)	0 (0)	0 (0)
8. Tissues soft, pulpy	0 (0)	4 (40)	9 (60)
9. Hemorrhaged gills	0 (0)	0 (0)	0 (0)
10. Torn gill arch(es)	0 (0)	0 (0)	0 (0)
11. Damaged operculum			
a. torn or less than 1/2 missing	0 (0)	0 (0)	0 (0)
b. more than 1/2 missing	0 (0)	0 (0)	0 (0)
12. Body cavity rupture			
a. Hole tiny, probably not lethal	0 (0)	0 (0)	0 (0)
b. Hole large, organs exposed	0 (0)	0 (0)	0 (0)
13. Inflated swim bladder	0 (0)	1 (10)	0 (0)
Total number of fish	15	10	15

Table 15. A description of the types of injuries sustained by age class 1+ and 2+ kokanee (TL 140-307 mm) captured in the tailrace of Libby Dam on June 4, 1993.

Type of injury	Number of fish	Percent of total
1. Abrasions	15	40
2. Contusions	0	0
3. Decapitation	4	11
4. Internal bleeding of unidentified source	17	45
5. Internal bleeding of spleen	1	3
6. Lacerations	7	18
7. Eye damage[a]	13	34
8. Tissue soft, pulpy	2	5
9. Ruptured or inverted gills	0	0
10. Damaged operculum	1	3
12. Body cavity rupture	2	5
13. Inflated gas bladder	28	74
Fish with no injuries, minor injuries or net-induced injuries (#1,2,4,5 or 8)	3	8
Fish with turbine-induced injuries (#6,7,10 or 13)	29	76
Fish with lethal or soon to be lethal injuries (#3,9 or 12)		16
Total number of fish	38	

a Eye damage includes hemorrhaging, protrusion or removal.

"lethal or soon to be lethal injuries" (decapitation, ruptured or inverted gills, body cavity rupture) were found in 11% of examined fish. Fish with "turbine-induced injuries" (lacerations, eye damage, damaged operculum, inflated swim bladder) represented 41% of the fish. We could not confidently determine if the "turbine-induced injuries" were life-threatening because the injury categories included injuries with a wide range of severity. Eye damage, for example, included a fish with a slight hemorrhage in one eye as well as a fish with two eyes missing. All the remaining fish (48% of total) were placed in the "no injuries, minor injuries or net-induced injuries" group, which included abrasions, internal bleeding, soft and pulpy tissue injuries and contusions.

Although the 1992-1993 sampling allowed us to establish a minimum mortality rate (11%) resulting from turbine passage, we felt that a refinement of the injury classification would provide for a more accurate determination of the effects of turbines on the fish. In 1994, we expanded the number of types of injuries from 13 to 25. We then examined 405 fish captured in draft-tube nets between May 16 and June 30, 1994 (Table 16). Abrasions were again the most common injury (99% of total), followed in decreasing order of occurrence by internal hemorrhage of,unidentified source (56% divided in three categories), inflated swim bladder (47%), hemorrhage of specific organ (38% divided into two categories, and typically referred to kidney, spleen or intestine), eye damage (30% in six categories), hemorrhaged gills (26%), lacerations (18% in three categories), soft and pulpy tissues (18%), body cavity rupture (13% in two categories), torn gill arch(es) (8%), damaged operculum (4% in two categories), decapitation (4%), and contusions (2%). All fish were placed into one of four mutually-exclusive categories. Fish with "lethal or soon-to-be-lethal" injuries (including decapitation, deep lacerations, two eyes missing, two eyes crushed, torn gill arch(es), or large body cavity rupture) represented 21% of the total. Fish with "major/possibly lethal turbine-induced injuries" represented 28% of the total, and included the following injuries: intermediate depth lacerations, one eye missing, one eye crushed, hemorrhaged gills, more than l/2 operculum missing, or tiny body cavity rupture. Fish with "minor/non-lethal turbine-induced injuries" sustained minor lacerations, hemorrhaged eye(s), protruding eye(s), less than l/2 operculum missing, or inflated swim bladder, and represented 32% of the fish. The remainder of the fish were placed in the "net-induced injuries" category and represented 19% of the fish. As in 1992 and 1993, many of these injuries may have been caused by passage through the turbines, but we have no way to distinguish them from net-induced injuries.

Based on the 1994 sampling, the minimum estimate of mortality (21%) compares favorably with rates presented by Winchell et al. (1992) for other dams. They found an average mortality of 18.2% for salmonids going through Francis turbines (based on work at four separate dams). For all fish species (including salmonids,

Table 16. A description of the types of injuries sustained by age class 1 and 2 kokanee (TL >124mm) captured in draft-t&e nets during 1994.

Type of injury	May 16/17 Live	May 16/17 Dead	May 25/26 Live	May 25/26 Dead
	Number of fish (Percent of total)			
1. Abrasions	5(100)	43(100)	1(100)	42(100)
2. Contusions	0 (0)	0 (0)	0 (0)	0 (0)
3. Decapitation	0 (0)	1 (2)	0 (0)	0 (0)
4. Internal hemorrhage of unidentified source				
a. Spots of blood--not lethal	2 (40)	12 (28)	0 (0)	6 (14)
b. Blood covers l/4 to l/2 body cavity--msy be lethal	1 (20)	15 (35)	0 (0)	6 (14)
c. Blood covers l/2 or more of body cavity--probably lethal	0 (0)	6 (14)	0 (0)	8 (19)
5. Hemorrhage of specific organs				
a. Probably not lethal	0 (0)	1 (2)	0 (0)	1 (2)
b. Probably lethal	0 (0)	0 (0)	0 (0)	0 (0)
6. Lacerations				
a. Barely breaks flesh--not lethal	0 (0)	0 (0)	0 (0)	0 (0)
b. Deeper, might be lethal	0 (0)	0 (0)	0 (0)	2 (5)
c. Deep, probably lethal	0 (0)	0 (0)	0 (0)	5 (12)
7. Eye damage				
a. Hemorrhage	0 (0)	13 (30)	0 (0)	1 (2)
b. Protrusion	0 (0)	0 (0)	0 (0)	1 (2)
c. Dne eye missing	0 (0)	1 (2)	0 (0)	4 (10)
d. Two eyes missing	0 (0)	1 (2)	0 (0)	2 (5)
e. One eye crushed	0 (0)	0 (0)	0 (0)	1 (2)
f. Two eyes crushed	0 (0)	0 (0)	0 (0)	0 (0)
8. Tissues soft, pulpy	0 (0)	0 (0)	0 (0)	0 (0)
9. Hemorrhaged gills	4 (80)	9 (21)	1(100)	12 (29)
10. Torn gill arch(es)	D (0)	0 (0)	0 (0)	3 (7)
11. Damaged operculum				
a. Torn or less than l/2 missing	0 (0)	2 (5)	0 (0)	0 (0)
b. more than l/2 missing	0 (0)	2 (5)	0 (0)	0 (0)
12. Body cavity rupture				
a. Bole tiny, probably not lethal	0 (0)	1 (2)	0 (0)	0 (0)
b. Hole large, organs exposed	0 (0)	2 (5)	0 (0)	4 (10)
13. Inflated swim bladder	0 (0)	19 (44)	0 (0)	22 (52)
Net induced injuries (# 1,2,4a,4b,4c,Sa,Sb,8)	1 (2)	11 (26)	0 (0)	6 (14)
Minor/non-lethal turbine induced injuries (# 6a,7a,7b,lla,13)	0 (0)	18 (42)	0 (0)	18 (43)
Major/possibly lethal turbine induced injuries (# 6b,7c,7e,9,11b,12a)	4 (80)	12 (28)	l(100)	10 (24)
Lethal or soon to be lethal turbine induced injuries (# 3,6c,7d,7f,10,12b)	D (0)	2 (5)	0 (0)	8 (19)
Total number of fish	5	43	1	42
Total Length (range, mm)	206-228	183-245	217	152-253

Table 16, continued.

Type of injury	Number of fish (Percent of total)			
	June 1/2		June 8/9	
	Live	Dead	Live	Dead
1. Abrasions	131100)	85 (98)	2(100)	48 (96)
2. Contusions	0 (0)	1 (1)	0 (0)	4 (8)
3. Decapitation	0 (0)	3 (3)	0 (0)	1 (2)
4. Internal hemorrhage of unidentified source				
a. Spots of blood--not lethal	1 (8)	16 (18)	0 (0)	10 (20)
b. Blood covers 1/4 to 1/2 body cavity--may be lethal	1 (8)	28 (32)	0 (0)	8 (16)
c. Blood covers 1/2 or more of body cavity--probably lethal	0 (0)	13 (15)	0 (0)	5 (10)
5. Hemorrhage of specific organs				
a. Probably not lethal	2 (15)	51 (59)	0 (0)	15 (30)
b. Probably lethal	0 (0)	8 (9)	D (0)	3 (6)
6. Lacerations				
a. Barely breaks flesh--not lethal	0 (0)	3 (3)	1 (50)	0 (0)
b. Deeper, might be lethal	0 (0)	2 (2)	0 (0)	1 (2)
c. Deep, probably lethal	0 (0)	17 (20)	0 (0)	10 (20)
7. Eye damage				
a. Hemorrhage	2 (15)	13 (15)	2(100)	2 (4)
b. Protrusion	1 (8)	0 (0)	0 (0)	0 (0)
c. One eye missing	0 (0)	6 (7)	0 (0)	2 (4)
d. Two eyes missing	0 (0)	3 (3)	0 (0)	3 (6)
e. One eye crushed	0 (0)	4 (5)	0 (0)	5 (10)
f. Two eyes crushed	0 (0)	1 (1)	0 (0)	0 (0)
8. Tissues soft, pulpy	1 (8)	36 (41)	0 (0)	7 (14)
9. Hemorrhaged gills	7 (54)	41 (47)	1 (50)	2 (4)
10. Torn gill arch(es)	1 (8)	10 (11)	0 (0)	5 (10)
11. Damaged operculum				
a. Torn or less than 1/2 missing	0 (0)	3 (3)	0 (0)	4 (8)
b. more than 1/2 missing	0 (0)	0 (0)	0 (0)	0 (0)
12. Body cavity rupture				
a. Hole tiny, probably not lethal	0 (0)	1 (1)	0 (0)	0 (0)
b. Hole large, organs exposed	0 (0)	19 (22)	0 (0)	4 (8)
13. Inflated swim bladder	4 (31)	52 (60)	1 (50)	20 (40)
Net induced injuries (# 1,2,4a,4b,4c,5a,5b,8)	5 (38)	5 (6)	0 (0)	15 (30)
Minor/non-lethal turbine induced injuries (# 6a,7a,7b,11a,13)	3 (23)	23 (26)	1 (50)	17 (34)
Major/possibly lethal turbine induced injuries (# 6b,7c,7e,9,11b,12a)	4 (31)	36 (41)	1 (50)	6 (12)
Lethal or soon to be lethal turbine induced injuries (# 3,6c,7d,7f,10,12b)	1 (8)	23 (26)	0 (0)	12 (24)
Total number of fish	13	87	2	50
Total length (range, mm)	210-251	145-241	205-230	155-242

Table 16, continued.

Type of injury	Number of fish (Percent of total) June 15/16 Live	June 15/16 Dead	June 22/23 Live	June 22/23 Dead
1. Abrasions	6(100)	59(100)	3(100)	49(100)
2. Contusions	0 (0)	1 (2)	0 (0)	1 (2)
3. Decapitation	0 (0)	3 (5)	0 (0)	4 (8)
4. Internal hemorrhage of unidentified source				
a. Spots of blood--not lethal	0 (0)	12 (20)	0 (0)	9 (18)
b. Blood covers I/4 to I/2 body cavity--my be lethal	3 (50)	5 (8)	0 (0)	6 (12)
c. Blood covers I/2 or more of body cavity--probably lethal	0 (0)	16 (27)	0 (0)	15 (31)
5. Hemorrhage of specific organs				
a. Probably not lethal	2 (33)	22 (37)	1 (33)	18 (37)
b. Probably lethal	0 (0)	5 (8)	0 (0)	14 (29)
6. Lacerations				
a. Barely breaks flesh--not lethal	0 (0)	2 (3)	0 (0)	0 (0)
b. Deeper, might be lethal	0 (0)	1 (2)	0 (0)	3 (6)
c. Deep, probably lethal	0 (0)	11 (19)	0 (0)	11 (22)
7. Eye damage				
a. Hemorrhage	0 (0)	7 (12)	1 (33)	5 (10)
b. Protrusion	0 (0)	0 (0)	0 (0)	1 (2)
c. One eye missing	0 (0)	6 (10)	0 (0)	4 (8)
d. Two eyes missing	0 (0)	1 (2)	0 (0)	3 (6)
e. One eye crushed	0 (0)	3 (5)	0 (0)	3 (6)
f. Two eyes crushed	0 (0)	0 (0)	0 (0)	0 (0)
8. Tissues soft, pulpy	0 (0)	2 (3)	0 (0)	23 (47)
9. Hemorrhaged gills	0 (0)	4 (7)	1 (33)	21 (43)
10. Torn gill arch(es)	0 (0)	4 (7)	0 (0)	6 (12)
11. Damaged operculum				
a. Torn or less than I/2 missing	0 (0)	1 (2)	D (0)	2 (4)
b. more than I/2 missing	0 (0)	3 (5)	0 (0)	1 (2)
12. Body cavity rupture				
a. Hole tiny, probably not lethal	0 (0)	1 (2)	0 (0)	2 (4)
b. Hole large, organs exposed	0 (0)	9 (15)	0 (0)	6 (12)
13. Inflated swim bladder	4 (67)	23 (39)	2 (67)	28 (57)
Net induced injuries (# 1,2,4a,4b,4c,5a,5b,8)	2 (33)	16 (27)	1 (33)	1 (2)
Minor/non-lethal turbine induced injuries (# 6a,7a,7b,lla,13)	4 (67)	21 (36)	1 (33)	11 (22)
Major/possibly lethal turbine induced injuries (# 6b,7c,7e,9,11b,12a)	0 (0)	9 (15)	1 (33)	21 (43)
Lethal or soon to be lethal turbine induced injuries (# 3,6c,7d,7f,10,12b)	0 (0)	13 (22)	0 (0)	16 (33)
Total number of fish	6	59	3	49
Total length (range, mm)	221-240	159-246	230-232	170-268

Table 16, continued.

Type of injury	June 29/30 Live	June 29/30 Dead	Total Live	Total Dead	Ueighted Combined TotalWd
	Number of fish (Percent of total)				
1. Abrasions	14(100)	311100)	44(100)	357 (99)	99
2. Contusions	0 (0)	0 (0)	0 (0)	7 (2)	2
3. Decapitation	0 (0)	1 (3)	0 (0)	1 3 (4)	4
4. Internal hemorrhage of unidentified source					
a. Spots of blood--not lethal	1 (7)	9 (29)	4 (9)	74 (20)	19
b. Blood covers l/4 to l/2 body cavity--may be lethal	1 (7)	4 (13)	6 (14)	72 (20)	20
c. Blood covers l/2 or more of body cavity--probably lethal	0 (0)	2 (6)	0 (0)	65 (18)	17
5. Hemorrhage of specific organs					
a. Probably not lethal	0 (0)	5 (16)	5 (11)	113 (31)	30
b. Probably lethal	0 (0)	0 (0)	0 (0)	3 0 (8)	8
6. Lacerations					
a. Barely breaks flesh--not lethal	0 (0)	0 (0)	1 (2)	5 (1)	1
b. Deeper, might be lethal	0 (0)	0 (0)	0 (0)	9 (2)	2
c. Deep, probably lethal	0 (0)	3 (10)	0 (0)	57 (16)	15
7. Eye damage					
a. Hemorrhage	1 (7)	2 (6)	12 (27)	43 (12)	13
b. Protrusion	0 (0)	0 (0)	1 12)	2 (1)	1
c. One eye missing	0 (0)	3 (10)	0 (0)	2 6 (7)	7
d. Two eyes missing	0 (0)	1 (3)	0 (0)	14 (4)	4
e. One eye crushed	0 (0)	0 (0)	0 (0)	1 6 (4)	4
f. Two eyes crushed	0 (0)	0 (0)	0 (0)	3 (1)	1
8. Tissues soft, pulpy	0 (0)	0 (0)	1 (2)	68 (19)	18
9. Hemorrhaged gills	1 (7)	5 (16)	12 (27)	94 (26)	26
10. Torn gill arch(es)	0 (0)	0 (0)	1 (2)	2 8 (8)	8
11. Damaged operculum					
a. Torn or less than l/2 missing	0 (0)	1 (3)	13 (30)	0 (0)	2
b. more than l/2 missing	0 (0)	1 (3)	0 (0)	7 (2)	2
12. Body cavity rupture					
a. Hole tiny, probably not lethal	0 (0)	0 (0)	0 (0)	5 (1)	1
b. Hole large, organs exposed	0 (0)	2 (6)	0 (0)	46 (13)	12
13. Inflated swim bladder	3 (21)	11 (35)	14 (32)	175 (48)	47
Net induced injuries (# 1,2,4a,4b,4c,5a,5b,8)	9 (64)	10 (32)	18 (41)	64 (18)	19
Minor/non-Lethal turbine induced injuries (# 6a,7a,7b,lla,13)	4 (29)	9 (29)	13 (30)	117 (32)	32
Major/possibly lethal turbine induced injuries (# 6b,7c,7e,9,11b,l2a)	1 (7)	8 (26)	12 (27)	102 (28)	28
Lethal or soon to be lethal turbine induced injuries (# 3,6c,7d,7f,10,12b)	0 (0)	4 (13)	1 (2)	78 (22)	21
Total number of fish	14	31	44	361	
Total length (range, mm)	155-239	170-242	155-251	145-268	

Only a representative sample of netted fish were inspected for injuries and summrized in this table. To determine injury rates for all fish, the following calculation was done for the weighted combined total column: (total dead kokanee in nets x % dead kokanee measured with specified injury(ies) + total live kokanee in nets x % live kokanee measured with specified injury(ies))/total live and dead kokanee in nets.

clupeids, centrarchids, percids, esocids, cyprinids and ictalurids), average mortality was 20.7% (37 dams).

The cause of injuries that we interpreted to be "turbine-induced" is poorly understood. Eicher et al. (1987) summarized turbine-mortality studies, and found that investigators in this field characterized injuries as being of three sources: mechanical (causing contusions, lacerations, skeletal fractures, scraped or cracked head, severed bodies, internai hemorrhaging, protruding or missing eyes), pressure (ruptured swim bladder, popped eyes, internal hemorrhaging) or shear (popped eyes, severing and decapitation, torn gill opercula). Much of this is speculation, as no one has actually observed injuries occurring in the turbine chamber. Regardless, mechanical injuries are thought to occur when the fish comes in contact with hard objects such as stay vanes, wicket gates or turbine blades. Water shear injuries result from conditions in turbines where water moves in different velocities or directions, creating a shear plane. Pressure injuries are assumed to occur as a result of the sudden drop in pressure as water crosses the face of the turbine buckets. Another cause of pressure-related effects may be cavitation, where sub-atmospheric pressure pockets of air form under turbine buckets and subsequently implode when the pockets are carried away from the turbine blades into above-atmospheric pressure areas. These implosions are enough to remove steel from the turbine blades and presumably can cause injuries or kill fish.

Much work has gone toward relating fish mortality rates to conditions associated with turbine operation. Eicher et al. (1987), Winchell et al. (1992) and Bell (1981) provided summaries of much of this work. Conditions relevant to the Francis turbines operated at Libby Dam are discussed below.

Eicher et. al. (1987) found a very strong relationship between peripheral runner velocity and fish mortality for Francis turbines (r=0.73, P<O.Ol, N=22). At Libby, peripheral runner velocity is 32.5 m/set toward the higher end of velocities used by Eicher et al. (1987) in their regression analysis. Other Francis units with velocities similar to Libby had mortalities in the 30-50% range. Unfortunately, runner velocity cannot be manipulated during normal dam operations, as it is tied to rate of revolution of the turbine, which must remain unchanged.

Changes in the operation of wicket gates have been linked to fish mortality (Eicher et al. 1987, Bell 1990). These gates are used to regulate the amount of water entering the turbine. At Libby Dam, low gate aperture is probably more likely to cause fish injuries and mortalities than is high gate aperture. Low gate apertures are believed to cause mortalities because of the narrow clearances between the adjacent wicket gates (Winchell et al. 1992). In addition, as wicket gate aperture is decreased, the angle at which water is directed against the turbine blades decreases away from the perpendicular. This is presumed to increase the chances of a fish striking the turbine blades and being injured or killed (Von Raben 1957 as cited in Cada 1990; Bell 1990). High gate settings may cause fish mortalities due to the-low clearances between the trailing edge of the wicket gates and the outer edge of the turbine buckets. If the opening between the gates and buckets becomes small enough, fish can be squeezed or crushed as they pass into the turbines (Eicher et al. 1987). This is probably not a problem at Libby Dam, as the minimum size of this opening is about 17 cm (6.6 in) --greater than the thickness of virtually all fish in the reservoir. Gate aperture ranged from 64-82% during the course of the study, which represents the range for typical operation of the dam (Table 17). No statistically significant correlations were found between wicket gate opening and incidence of different types of injuries (Table 18).

Unit efficiency (percent of power developed versus the theoretical amount) has also been related to fish mortality (Cramer and Oligher, 1961b; Eicher et al. 1987). Maximum unit efficiency at Libby Dam is about 93%, and is achieved with a particular hydraulic head and discharge (U.S. Army Corps of Engineers 1984). In this study, unit efficiency remained virtually unchanged and near its maximum the entire time (Table 17). It was therefore assumed that unit efficiency was not a factor affecting mortalities or injuries in this study. However, efficiencies between 80 and 90% are possible at Libby Dam, even when operating within the official generator output limits (data obtained from B. Chadwick, ACOE). Turbine efficiency values lower than 90% are not likely to develop at Libby Dam when turbine discharge is over 127.5 cms (4,500 cfs). At 113.4 cms (4,000 cfs) however, efficiency will drop below 90% when head drops below about 70 m (230 ft, about 110 ft below full pool). Efficiency drops to 85% when head drops to 61 m (200 ft, about 140 ft below full pool). At a discharge of 85 cms (3,000 cfs) efficiency is below 90% for any head elevation. When head is greater than 64 m (210 ft, about 130 ft below full pool), efficiency ranges from 86-89%. Below a head of 64 m, efficiency drops below 85%. The effect of low unit efficiencies on fish mortalities at Libby Dam is not known. However, tests at the Cushman No. 2 plant in Washington (Cramer and Oligher 1961b) showed that survival of steelhead trout and coho salmon was positively correlated with efficiency. Coho salmon survival increased from 32% to 74% as efficiency increased from 80 to 91%. It should be noted that wicket gate opening was modified in Cushman test in order to alter efficiency, and could have been a factor contributing to changes in survival.

Cramer and Oligher (1961a) observed decreased fish mortalities as tailwater elevation was increased relative to turbine runner elevation. This was presumably due to changes that occur in the pressure differential between penstock and turbine chamber, as well as the amount of cavitation that develops. As the tailwater elevation drops below the turbine runner elevation, the likelihood

Table 17. Incidence of types of injuries and their relationship to dam operation.

Date	Percent of dead fish with the following injuries: Decapi- tation	Decapitation, lacerations or body cavity rupture	Major and minor iniuries[1]	Inflated swim bladder	Hydraulic head (m)	Unit efficiency (%)	Turbine elevation minus tailwater elevation (m)	Wicket gate opening (%)
2-25/26-92	2	14	30	0	74.8	91	0.06	76
3-10/11-92	9	18	81	18	74.5	91	0.06	76
6-23/24-92	7	6	12	0	92.2	92	0.06	65
6-30-92	0	0	2	0	93.5	92	0.06	65
7-21/22-92	4	7	15	2	97.0	92	0.06	64
8-5-92	5	10	10	0	97.3	92	-0.79	64
8-12-92	0	7	7	0	97'0	92	-1.04	64
8-25/26-92	9	13	47	26	96.5	92	-0.46	64
g-10-92	17	25	50	0	94.3	92	-1.89	65
9-24/25-92	7	23	54	20	91.3	92	-1.62	66
10-5/6-92	12	28	56	4	90.8	92	-0.73	66
lo-26/27-92	13	34	62	25	88.2	92	-0.40	67
11-18/19-92	12	21	67	48	82.7	92	-1.68	67
12-8/9-92	4	19	55	26	76.9	91	-1.62	76
1-13/14-93	0	3	61	24	69.2	90	-1.62	82
5-25/26-93	2	6	46	25	79.2	92	0.03	73
6-3/4-93	3	21	76	46	82.6	92	0.06	67
6-11-93	5	18	75	51	83.8	92	-1.43	70
6-17/18-93	2	15	61	48	85.6	92	-0.24	70
6-24/25-93	0	15	82	62	87.9	92	0.06	67
5-16/17-94	2	7	75	44	86.9	92	-0.52	67
5-25/26-94	0	19	86	52	88.6	92	-0.91	67
6-1/2-94	3	28	93	60	90.1	92	-1.37	67
6-8/9-94	2	24	70	40	91.3	92	-1.46	68
6-15/16-94	5	27	73	39	92.5	92	-1.37	67
6-22/23-94	8	31	98	57	93.2	92	-1.46	65
6-29/30-94	3	13	68	35	94.5	92	-1.25	65

[1]Includes injuries #3,6,7,9,10 and 12 as denoted in Table 13.

Table 18. Correlation analysis of dam operation variables vs. injury rates.

Independent Variable	Dependent Variable	N	r	P
Wicket gate opening	Decapitation rate	27	-0.2382	0.232
	Major injury rate (decapitation, lacerations, body cavity rupture)	27	-0.1554	0.439
	Major & minor injuries"	27	0.1914	0.339
Head	Inflated swim bladder	27	-0.1594	0.427
	Decapitation	27	0.1668	0.406
	Major injuries	27	0.0857	0.671
	Major & minor injuries	27	-0.2953	0.135
Turbine elevation-tailwater elevation	Inflated swim bladder	27	-0.2315	0.245

"Major and minor injuries as described in Table 13.

that sub-atmospheric conditions can occur under the turbine blades will increase. In this study, the turbine/tailwater elevation difference ranged from 6.1 cm to -1.89 m, resulting from discharges ranging from 113.4 to 793.5 cms (4,000 to 28,000 cfs). The incidence of inflated swim bladders is a pressure-related injury that might be expected to result from changes in tailwater/turbine elevations. In this study, no significant relationship was found between these two variables (Table 18). However, several factors may have precluded us from accurately measuring the incidence of inflated swim bladders. Our own assessment of what constituted an inflated swim bladder was subjective, and was probably evaluated somewhat differently by individual field personnel. Also, some of the fish we handled may have experienced so much decompression that their swim bladders expanded to the point of rupture. Jones (1951) demonstrated this in the laboratory when he found that pressure reductions of 60% of the acclimated level could burst the swim bladders of 10 cm perch (*Perca fluviatilis*). In this study, however, we did not distinguish between a burst swim bladder and one that had simply not expanded.

Cada (1990) noted that the magnitude of decompression experienced by a fish passing through a turbine would be less for a fish acclimated to shallow water than for a fish acclimated to deep water. However, the magnitude of decompression would be the same for all fish if they were able to adjust to the changing pressure as they approached and were drawn into the penstocks. A physostomous fish, such as kokanee, is more likely to be able to adjust the contents of its swim bladder in this manner than is a physoclistis fish (such as yellow perch).

The magnitude of decompression for fish in the Libby forebay is not known. If fish are able to adjust the volume of their swim bladder prior to entering the penstocks, then measurements of hydraulic head should be a good indicator of the magnitude of decompression. During the course of normal dam operations, maximum decompression would occur when the reservoir is at full pool (hydraulic head of 104 m), which typically occurs during late summer and fall. Minimum decompression would occur when the reservoir is at its lowest level (hydraulic head of 60-80 m), which normally occurs during late winter. In this study, head ranged from 69.2-97.3 m, but no significant relationship was found between it and various types of injuries (Table 18). Eicher et al. (1987) found a strong correlation between head and mortality when comparing many sites. However, they felt that peripheral runner velocity, which was also strongly correlated with both mortality and head, was the truly important variable in determining mortality.

Penstock Sonar

A total of 821 hours of sonar chart recordings were made during 37 sessions between December 4, 1990 and August 4, 1992 (Appendix E). Sonar traces were divided into debris and non-debris targets, based on characteristics of the targets described in the Methods and Materials. Periods of heavy debris were encountered from May 6 to July 2, 1991 and April 29 to June 9, 1992 (Appendix E). Excluding the periods where debris contamination was suspected, the total number of targets detected during recording sessions ranged from 7 to 44. The one exception to this was February 28, 1991 when 213 targets were detected, 179 of them during a four hour period extending from one hour before sunrise to three hours after sunrise (Appendix E).

Twenty-four recording sessions were deemed suitable for use in describing die1 entrainment rates. Results show a distinct tendency for most of the fish to be entrained at night (Table 19, Figure 11). All hourly intervals between sunrise and sunset had median entrainment rates of 0% of the daily rate. The seven hour period extending from midday -1 to sunset -1 was especially low, in that five of the seven intervals had no targets detected 95% of the time. Entrainment increased immediately after sunset and reached a peak at 144% of the daily rate in the midnight -3 interval. Rates dropped for the next two hours, but then showed sustained high levels from midnight until sunrise. The peak interval was from one to two hours before sunrise, where the rate was 149% of daily rate and the 95% confidence intervals were 61-319.

In order to detect differences in entrainment between light and dark hours, the hourly intervals were grouped into two categories: diurnal (sunrise +l to sunset -1) and nocturnal (sunset +1 to sunrise -1). Nocturnal entrainment averaged 161% of daily rate, while diurnal entrainment average only 45% (Table 20). This same trend was seen for winter, summer and fall, with summer having the greatest difference between the two categories (222 to 49%) and fall the least difference (127% to 46%).

Thirteen chart-recording sessions were deemed suitable for the calculation of entrainment rates by way of computer simulation. The number of detected targets ranged from a low of three on April l-2, 1992 to a high of 44 on January 18-19, 1992 (Table 21). Scalars from the computer simulation ranged from 19.2 to 67.1; the wide range due to variability in the maximum effective sonar range and the size of fish. Based on computer simulations, the estimated number of targets through the entire penstock for the two dates mentioned above was 70 and 1,366, respectively. The highest calculated rate of entrainment was 1.535 targets/10^4 m^3 between 2400-0800 hrs on April 2, 1991. This rate is quite low compared to rates estimated for some periods of draft-tube netting (Table 10).

Table 19. Hourly rates of entrainment as determined by penstock sonar. Hourly rates are expressed as a percentage of daily rates.

Hourly interval[a]	N[b]	Median percentage of daily rate[c]	95% confidence intervals for median[d]
MIDNIGHT			
Midnight +1	22	127	0 - 231
Midnight +2	24	112	0 - 205
Midnight +3	19	92	0 - 185
Sunrise -3	15	149	0 - 357
Sunrise -2	20	149	61 - 319
Sunrise -1	21	111	0 - 190
SUNRISE			
Sunrise +1	23	0	0 - 188
Sunrise +2	22	0	0 - 125
Sunrise +3	14	0	0 - 82
Midday -3	14	0	0 - 147
Midday -2	19	0	0 - 61
Midday -1	20	0	0 - 0
MIDDAY			
Midday +1	20	0	0 - 76
Midday +2	20	0	0 - 0
Midday +3	13	0	0 - 0
Sunset -3	11	0	0 - 0
Sunset -2	21	0	0 - 50
Sunset -1	22	0	0 - 0
SUNSET			
Sunset +1	24	30	0 - 122
Sunset +2	24	100	0 - 245
Sunset +3	18	90	0 - 222
Midnight -3	17	144	46 - 309
Midnight -2	20	54	0 - 181
Midnight -1	22	59	0 - 188
MIDNIGHT			

[a] Hourly intervals are in relation to sunrise, midday, sunset and midnight. Example: Midnight +1 = one hour time interval beginning at midnight.

[b] Each sample consisted of one chart recording session. Chart recordings were used for this analysis if they were free of debris and if there were more than 5 targets for the entire session.

[c] Hourly rates calculated as the number of targets per minute; daily rates are the number of targets per minute for entire chart recording session (usually about 24 hours).

[d] Confidence limits are non-parametric tolerance limits (Dixon and Massey 1983).

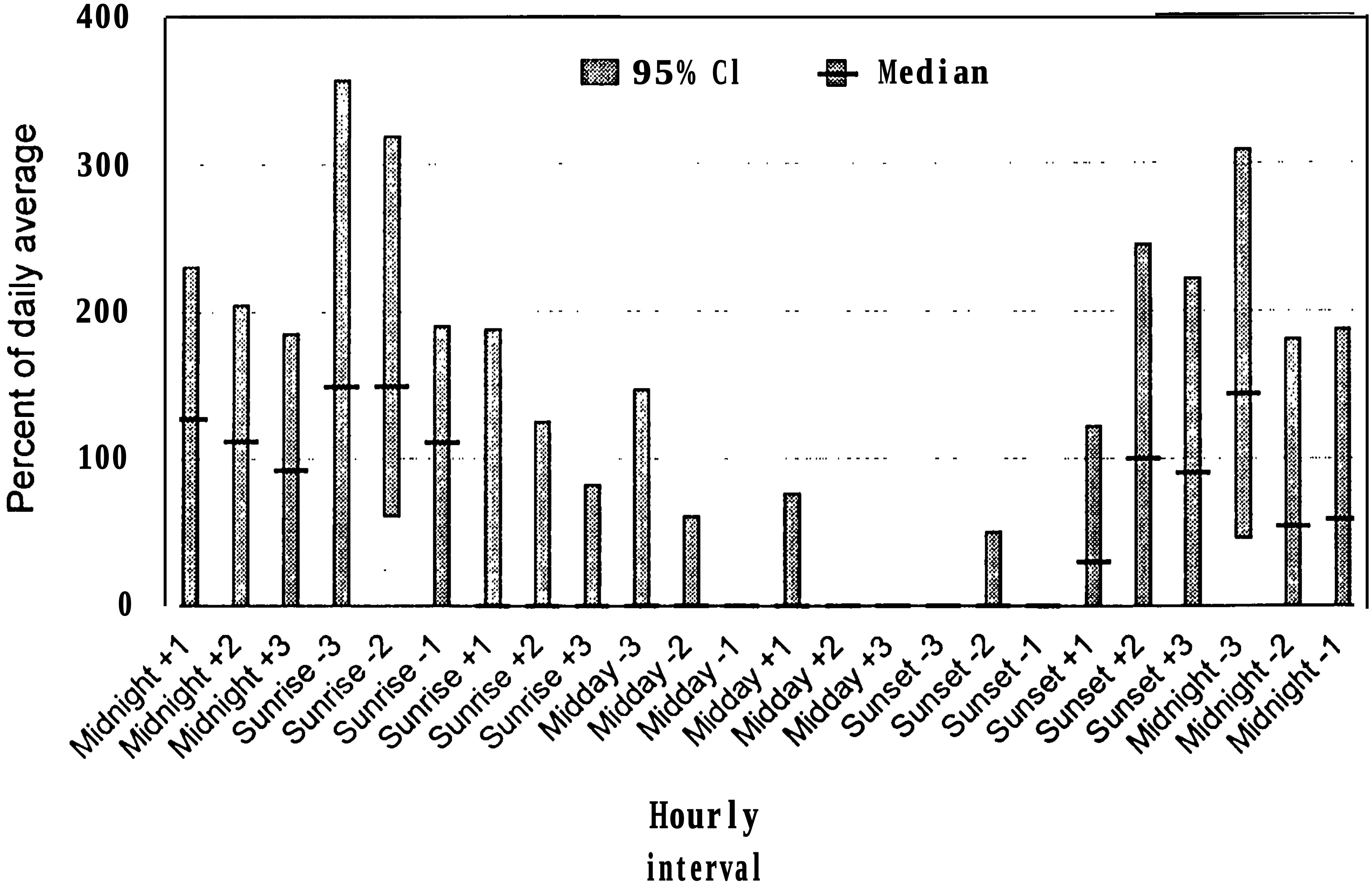

Figure 11. Hourly entrainment rates of fish through the penstock of unit 3. Hourly rates are expressed as a percentage of daily rate. Vertical bars represent 95% confidence intervals; short horizontal lines represent median values.

Table 20. Seasonal differences in diurnal and nocturnal rates of entrainment. Season definitions are the same as in Table 5.

Season	N	Period"	Period Rate/ Daily Rate (mean + S.D.)
Winter	13	Nocturnal	1.63 + 0.71
	13	Diurnal	0.34 + 0.39
Summer	4	Nocturnal	2.22 + 0.61
	4	Diurnal	0.49 + 0.27
Fall	6	Nocturnal	1.27 + 0.29
	6	Diurnal	0.46 + 0.33
All	24	Nocturnal	1.61 + 0.67
	24	Diurnal	0.45 + 0.41

'Nocturnal period includes hourly intervals from sunset +l to sunrise -1; diurnal period includes hourly intervals from sunrise +l to sunset -1.

Table 21. Penstock sonar operating conditions, number of detected targets, and estimated entrainment rates, April 1, 1991 to April 16, 1992.

Date	Time	Minutes of coverage	Maximum effective sonar range (m)	Number targets detected	Estimated total targets[a]	Estimated entrainment rate (no./10^4 m^3)[a] Entire Period	1600-2400 hr	2400-0800 hr
4-1/2-91	1745-1540	1,204	15.5	37	705	0.879	1.115	1.535
4-10/11-91	1100-1149	1,323	15.5	27	434	0.494	1.217	0.448
4-22/23-91	1932-1829	1,244	15.5	34	682	0.826	0.494	1.066
8-1/2-91	1145-1225	1,456	8.5	28	1,381	1.161	0.656	1.507
8-16/17-91	2400-0400	1,665	8.5	30	936	0.702	0.568	1.030
11-14/15-91	1509-2204	1,697	8.5	30	1,141	0.720	0.769	1.108
11-18/19-92	1205-0829	1,216	8.5	44	1,366	1.253	1.440	1.443
1-28/29-92	1220-1204	1,411	16.5	13	173	0.158	0.326	0.206
2-12/13-92	1150-1516	1,631	16.5	4	56	0.051	0.043	0.130
2-25/26-92	1145-1320	1,526	16.5	33	634	0.614	0.773	1.175
3-10/11-92	1220-1155	1,388	16.5	13	198	0.210	0.092	0.540
4-1/2-92	1245-1233	1,419	16.5	3	70	0.079	0.072	0.144
4-15/16-92	1339-1129	1,323	16.5	7	170	0.189	0	0.522

[a] Estimates based on computer simulation

The Effect of Entrainment on the Reservoir Population

High and low estimates of total fish entrainment were calculated for various periods of time (Tables 22 and 23). The longest of these periods was from January 1992 through January 1993, during which time about 4.5% of the total quantity of water through the dam was sampled during 25 nights of netting and sonar. The high estimate for this period was 4,469,969 fish, almost four times the low estimate of 1,146,513 fish. The reason these estimates differ so much is the extremely high entrainment rates measured during four sampling sessions between November 1992 and January 1993. For the high estimate, these four sessions were assumed to apply to the entire three month period between November and January. Conversely, the low estimation procedure vastly reduced the influence of the four sampling sessions by using a transformed mean value. The high and low estimates were much closer when applied to other periods of time. High and low estimates were 1,117,425 and 859,427 for the period May 26-June 25, 1993, and 487,083 and 380,630 for the period May 16-June 30, 1994 (Tables 22 and 23).

Of the two estimates, the low estimation procedure is probably the most biased. This is because it assumes that the entrainment rate during days not sampled is equal to the mean rate for all sampling sessions. This implies that the entrainment rate during one sampling session is independent of the next or previous session. This assumption may not be valid, however, based on the influence that discharge, depth of withdrawal and forebay fish density have been shown to have on entrainment (see section below on Regression Analysis of Factors Affecting Entrainment).

We estimated the proportion of fish in the reservoir that were lost to entrainment during the January 1992 to January 1993 period. Our dual-beam hydroacoustic estimate of the fish population in the reservoir in August 1991 provided an approximation of the number of fish that were alive during the entrainment sampling. The hydroacoustic equipment was unable to detect fish in waters shallower than 2 m and was not typically used closer than 15 m of shore, which probably eliminated many trout, suckers and peamouth from the estimate. Within the areas surveyed with this equipment, we estimated there to be about 4.8 million fish (Table 24). Our low and high estimates of entrainment during 1992 were 1.15 and 4.47 million fish, respectively, or about 23% and 92% of the reservoir estimate.

We also estimated the number of kokanee in the reservoir during 1991. Using vertical gillnet catches, we estimated that 89% of the "large" (>220 mm TL) sonar targets were kokanee (1,203,154 fish). This was partitioned into 193,000 age class 1+ fish and 1.007 million age class 2+ fish. The gill nets could not be used to determine the percent of the "small" (<220 mm TL) fish that were kokanee. However, trawl samples in 1989 showed that about 95% of

Table 22. Estimates of number of fish entrained through Libby Dam, using entrainment rates developed from penstock sonar (for dates prior to 2/25/92) or draft-tube netting (for dates after 2/13/92). Estimates are based on the assumption that measured rates apply to half the duration of time to the next or previous sampling session.

Expansion to entire dam for period of measurement			Expansion to other dates			
				For measured time period	For unmeasured time period"	Total no. fish (measured + unmeasured periods)
Date	Time	Number of fish	Dates	No. fish	No. fish	
4-l/2-91	1800-1600	1,723	4- to 4-6	3,953[b]	--	3,953
4-10/11-91	1100-1100	1,135	4-7 to 4-10	5,296	--	5,296
			4-11 to 4-16	4,588	--	4,588
4-22/23-91	1900-1800	3,108	4-17 to 4-23	12,531[b]	--	12,531
			Estimate for period 4-1 to 4-23-91			26,638
8-l/2-91	1200-1200	6,741	8-1 to 8-8	41,674	--	41,674
8-16/17-91	2400-2400	2,292	8-9 to 8-17	21,622	_-	21,622
			Estimate for period 8-l to 8-17-91			63,296
ll-14/15-91	1500-1500	3,007	11-14 to 11-16	15,133	--	15,133
ll-18/19-91	1600-0800	6,258	11-17 to 11-19	17,808	2,510	20,318
			Estimate for period 11-14 to 11-19-91			35,451
l-28/29-92	1200-1200	173	1-28 to 2-4	1,340	--	1,340

Table 22, continued.

Expansion to entire dam for period of measurement			Expansion to other dates			
Date	Time	Number of fish	Dates	For measured time period: No. fish	For unmeasured time period: No. fish	Total no. fish (measured + unmeasured periods)
2-12/13-92	1200-1200	56	2-5 to 2-12	468	--	468
			2-13 to 2-18	339	--	339
2-25/26-92	1600-0900	635	2-19 to 2-25	4,413	509	4,922
			2-26 to 3-3	4,434	510	4,944
3-lO/ll-92	1600-0800	267	3-4 to 3-10	1,885	260	2,145
			3-11 to 3-21	2,843	396	3,239
4-l/2-92	1600-0700	121	3-22 to 4-l	1,027	170	1,197
			4-2 to 4-8	726	135	861
4-15/16-92	1600-0800	199	4-9 to 4-15	1,281	261	1,542
			4-16 to 4-22	1,748	280	3,570
4-29/30-92	1600-0800	0	4-23 to 4-29	0	0	0
			4-30 to 5-5	0	0	0
5-12/13-92	1600-0700	19	5-6 to 5-12	221	38	259
			5-13 to 5-20	153	26	179
5-27/28-92	1600-0700	958	5-21 to 5-27	2,922	568	3,490
			5-28 to 6-2	5,081	696	5,777
6-9/10-92	1600-0800	175	6-3 to 6-9	3,163	454	3,617
			6-10 to 6-16	842	121	963
6-23/24-92	1600-0800	1,044	6-17 to 6-23	7,282	1,020	7,302
			6-24 to 6-27	4,159	583	4,742

Table 22, continued.

Expansion to entire dam for period of measurement			Expansion to other dates			
				For measured time period	For unmeasured time period	
Date	Time	Number of fish	Dates	No. fish	No. fish	Total no. fish (measured + unmeasured periods)
6-30-92	1600-2400	635	6-28 to 6-30[c]	3,780	528	4,308
			7-l to 7-10[c]	12,618	1,765	14,383
7-21/22-92	1600-0700	1,151	7-11 to 7-21	12,686	2,137	14,823
			7-22 to 7-28	8,075	1,359	9,434
8-4/5-92	1600-0800	1,333	7-29 to 8-4	4,486	627	9,741
			8-5 to 8-8	5,255	785	6,040
8-12-92	1600-2400	466	8-9 to 8-12[c]	3,160	642	3,802
			8-13 to 8-18[c]	5,972	988	6,960
8-25/26-92	1600-0800	1,867	8-19 to 8-25	40,129	6,497	46,626
			8-26 to 9-l	14,157	2,613	16,670
g-10-92	2400-0800	6,250	9-2 to 9-9[d]	33,928	6,423	40,351
			9-10 to 9-16[d]	68,641	9,030	77,671
9-24/25-92	1600-0800	9,366	9-17 to 9-24	81,131	11,512	92,643
			9-25 to 9-29	32,133	5,616	37,749
10-5/6-92	1600-0800	3,100	9-30 to 10-5	19,418	3,463	22,881
			10-6 to lo-15	28,647	6,269	34,916
10-26/27-92	1600-0800	7,743	lo-16 to lo-26	80,557	16,448	97,005
			lo-27 to 11-7	84,641	12,567	97,208

Table 22, continued.

Expansion to entire dam for period of measurement			Expansion to other dates			
Date	Time	Number of fish	Dates	For measured time period: No. fish	For unmeasured time period: No. fish	Total no. fish (measured + unmeasured periods)
11-18/19-92	1600-0800	30,377	11-8 to 11-18	327,198	48,524	375,722
			11-19 to 11-28	300,346	45,639	345,985
12-8/9-92	1600-0700	92,555	11-29 to 12-8	735,423	109,021	844,444
12-9/10-92	1600-0700	61,508	12-10 to 12-26	760,140	118,163	878,303
1-13/14-93	1600-0700	118,338	12-27 to 1-13	896,250	191,689	1,087,939
			1-14 to 1-20	205,676	38,422	244,098
1-27/28-93	1600-0700	1,042	1-21 to 1-28	8,033	1,338	9,371
			Estimate for period 1-28-92 to 1-28-93			4,469,969
5-25/26-93	1600-0700	3,713	5-25 to 5-29	23,034	3,560	26,594
6-3/4-93	1700-0700	34,965	5-30 to 6-3	105,075	23,171	128,246
			6-4 to 6-6	109,260	21,344	130,604
6-10/11-93	1600-0700	72,595	6-7 to 6-10	284,729	48,057	332,786
			6-11 to 6-13	220,651	36,929	257,580
6-17/18-93	1600-0700	10,406	6-14 to 6-17	132,014	23,140	155,154
			6-18 to 6-21	41,009	6,904	47,913
6-24/25-93	1600-0700	8,165	6-22 to 6-25	32,962	5,586	38,548
			Estimate for period 5-25 to 6-24-93			1.117.425

Table 22, continued.

Expansion to entire dam for period of measurement			Expansion to other dates			
Date	Time	Number of fish	Dates	For measured time period No. fish	For unmeasured time period No. fish	Total no. fish (measured + unmeasured periods)
5-16/17-94	0700-0700	1,887	5-16 to 5-20	12,306	--	12,306
5-25/26-94	0700-0700	2,790	5-21 to 5-25	13,866	--	13,866
			5-26 to 5-28	9,835	--	9,835
6-l/2-94	0700-0700	20,503	5-29 to 6-l	73,807	--	73,807
			6-2 to 6-4	63,379	--	63,379
6-8/9-94	0700-0700	8,712	6-5 to 6-8	35,966	--	35,966
			6-9 to 6-11	25,688	--	25,688
6-15/16-94	0700-0700	10,988	6-12 to 6-15	44,977	--	44,977
			6-16 to 6-18	32,703	--	32,703
6-22/23-94	0700-0700	16,611	6-19 to 6-22	64,678	--	64,678
			6-23 to 6-26	68,565	--	68,565
6-29/30-94	0700-0700	9,280	6-27 to 6-30	41,313	--	41,313
			Estimate for period 5-16 to 6-30-94			487,083

"Unmeasured (diurnal) rates assumed to be 28% of measured (nocturnal) rates.
"Measured time period assumed to apply to entire 24 hr period.
'Entrainment rate for 1600-2400 is assumed to also apply to 2400-0800.
*Entrainment rate for 2400-0800 is assumed to also apply to 1600-2400.

Table 23. Estimates of total number of fish entrained through Libby Dam for selected periods of time, based on the use of mean entrainment rates.

Time Period	Mean entrainment rate (10^4 m^3)	Estimated number for period not measured (rate x volume)	Expanded no. for entire dam for period of measurement'	Total entrainment
l-28-92 to l-28-93	1.44[b]	808,468	338,045	1,146,513
5-25 to 6-25-93	14.50[c]	729,583	129,844	059,427
5-16 to 6-30-94	2.07'	309.859	70,771	380,630

'Same numbers as shown in Table 22.
[b]Calculated after fourth-root transformation to achieve normality.
'Calculated after square-root transformation to achieve normality.

Table 24. Estimate of the number of fish in different areas of Libby Reservoir, August 1991. Estimates are expansions based on density calculations derived from 40 sonar transects. Raw data presented in McClain and Thome (1991).

		Estimated number of fish		
Area	Number transects	Large (>220 mm TL)	Small (<220 mm TL)	Total
Tenmile	12	450,790	1,542,995	1,993,785
Peck	10	90,832	350,887	441,719
Rexford	10	555,887	1,212,555	1,768,442
Canada	8	251,776	328,941	580,717
Total	40	1,349,285	3,435,378	4,784,663

fish in this size category were kokanee in the Tenmile, Peck and Rexford areas, but only 12% were kokanee in the Canada area. Applying these percentages to the small fish for 1991, we estimate that 2.99 million of these fish were age 0+ kokanee. Total kokanee in the reservoir was therefore estimated to be 2.99+1.20 = 4.19 million. We estimated the total kokanee entrainment during 1992 to be between 1.12 and 4.36 million, based on draft-tube net catches that showed kokanee to comprise 97.5% of the catch. These kokanee entrainment estimates were 27% and 104% of the calculated reservoir population, respectively.

High levels of kokanee entrainment have also been reported for Banks Lake, Washington (Stober et al. 1979). They found that most of the kokanee that were entrained were of ages 2, 3 or 4+. They estimated the number of fish in the reservoir in these age classes, based on creel census calculations and spawner surveys, and estimated that 60 and 75% of the population was entrained in 1975 and 1976, respectively. Weekly sampling of kokanee entrainment over a four year period showed the entrainment to be quite erratic. The authors postulated that this may have been partially due to the volume of irrigation water withdrawn, the effects of maturation, and the feeding movements of the fish in the portion of the lake near the withdrawal structure.

Regression Analysis of Factors Affecting Entrainment

We examined the statistical relationship between entrainment rates and a variety of potential predictors--including forebay fish densities (at different depths and distances from the dam), discharge and withdrawal depth and temperature. Entrainment rates were calculated for both the evening hours (typically 1600-2400 hrs) and morning hours (2400-0800 hrs) of each sampling session. A square-root transformation was performed on entrainment rates ("rate"), in order to increase the linearity of the relationship between rate and the predictor variables. Even when transformed, the relationship of rate to discharge was non-linear, so we added two additional variables in an attempt to explain the relationship as quadratic (discharge and discharge squared) or as binary (low discharge under 538 cms [19,000 cfs] and high discharge over 538 cms). Area1 fish densities were examined for the entire forebay area or for the near-dam area (transects l-6 combined) and the far-dam area (transects 7-12). Densities within discrete strata were also stratified by near- and far-dam areas, but also from 20 m below withdrawal depth to 20 m above withdrawal depth. Depth strata farther away from withdrawal depth (>20 m) were not used because of small sample size. Density values from sunset and midnight were averaged to make up an "evening" rate, and values from midnight and sunrise were averaged to make a "morning" rate. Sample sessions were not used for the analysis if the forebay density values were thought to include large amounts of woody debris (primarily during May and June).

Rate was significantly correlated (P<0.01) with three measures of discharge (DISCH (L-H), DISCHARGE and DISCH SQ) and seven fish density variables (DlOP (l-6), DlOL (l-6), D20L (l-61, D20L (7-12), ARE DEN (l-6), ARE DEN (7-12), AREAL DEN) (Table 25). At all depths, rate was better correlated with densities in transects l-6 than in transects 7-12. Correlations of densities in transects l-6 were greater between strata above or below the withdrawal depth (DlOP vs D20P = 0.789 and DlOL vs D20L = 0.889) than between strata straddling the withdrawal depth (DlOP vs. DlOL = 0.525). This suggests that hydraulic conditions at the depth of withdrawal create water currents that affect fish densities and distribution. Rate was very weakly correlated with withdrawal depth (r=-0.024) and withdrawal temperature (r=0.154).

We used the stepwise method of multiple regression to construct a model for explaining the variation in entrainment

Table 25. Pearson correlation coefficient matrix betueen entrainment rate, forebay fish densities and selective uithdraual system variables. RATE= square-root transformed entrairunent rate; DISCH (L-H)= discharge > or (than 19,000 cfs; DISCH SQ= discharge; AREAL DEN= areal density all transects combined; AREAL DEN (I-6)= area1 density transects 1-6 combined; AREAL DEN (7-12)= area1 density transects 7-12 combined; DIOP=density O-10 m above withdrawal depth; DZOP=density lo-20 m above withdrawal depth; DIOL= density O-10 m below uithdraual depth; D20L= density lo-20 m below uithdraual depth; WITH DEP= uithdraual depth; WITH TEMP= uithdraual temperature. N=40 for all correlations.

	RATE	DISCH (L-H)	DISCHARGE	DISCH SQ	AREAL DEN	AREAL DEN (I-6)	AREAL DEN (7-12)	DIOP (I-6)	DIOP (7-12)	DIOL (I-6)	DIOL (7-12)	D2OP (I-6)	D2OP (7-12)	D2OL (I-6)	DZOL (7-12)	WITH DEP	WI TEMP
RATE	—																
DISCH (L_H)	.758**	--															
DISCHARGE	.570**	.813**	--														
DISCH SQ	.549**	.856**	.981**	--													
AREAL DEN	.557**	.513**	.423**	.459**	--												
ARE DEN(I-6)	.676**	.580**	.435**	.464**	.975**	--											
ARE DEN(7-12)	.426**	.364*	.321*	.343*	.967**	.903**	--										
DIOP (I-6)	.498**	.338*	.280	.324*	.877**	.865**	.818**	--									
DIOP (7-12)	.301	.279	.309	.352*	.915**	.835**	.914**	.907**	--								
DIOL (I-6)	.764**	.747**	.625**	.636**	.655**	.715**	.531**	.525**	.462**	--							
DIOL (7-12)	.266	.455**	.585**	.632**	.602**	.509**	.557**	.526**	.681**	.638**	--						
D20P (I-6)	.292	.146	.073	.105	.862**	.821**	.892**	.789**	.a42**	.263	.270	--					
D20P (7-12)	.182	.086	.037	.067	.835**	.767**	.897**	.735**	.833**	.200	.263	.981**	--				
D20L (I-6)	.789**	.768**	.613**	.613**	.457**	.567**	.309	.267	.213	.889**	.399*	.158	.041	--			
D20L (7-12)	.593**	.600**	.555**	.541	.337*	.387*	.275	.160	.111	.726**	.367*	.044	-.008	.730**	--		
WITH DEPTH	-.024	.107	-.155	.130	-.365*	-.319*	-.371*	.'.476**	-.522**	-.271	-.399*	-.415**	-.380*	-.104	.133	--	
WITH TEMP	.154	.179	.361*	.330*	.259	.223	.246	.211	.300	.518**	.527**	.060	.050	.367*	.556*'	-.631**	- -

- p<0.05
- *p<0.01

rates. We restricted our model runs to four or fewer variables and in combinations that were logical or intuitively correct. This meant that we only used combinations of depth strata that were spatially adjacent to each other (either vertically or horizontally). Our preferred model (#l in Table 26) was chosen because it explained the largest percentage of variance (78%) and makes sense intuitively. No other combination of four or fewer variables explained as much of the variance. Diagnostics for this model were all acceptable. The residuals did not depart significantly (P=O.O5) from normality. Leverage values were within the P=O.O5 critical level for all but 3 of the 40 samples. Outliers were examined and felt to be legitimate and worthy of inclusion in the model. Scatterplots of rate and the four variables in this model show obvious trends, with a few outliers occurring at high fish densities (Figure 12). Using the preferred model, entrainment rate is estimated by the equation:

RATE = 1.3904*DISCH(L_H) + 0.0437*DlOP(l-6) - 0.0687*DlOP(7-12) + 0.l355*AREAL DEN - 0.8287, where

PATE = square-root of fish/10^4 m^3 discharged water
DISCH (L_H) = value of 1 assigned to discharge<19,000 cfs; value of 2 assigned to discharge>19,000 cfs.
DlOP(l-6) = density of fish/10^4 m^3 water
DlOP (7-12) = density of fish/10^4 m^3 water
AREAL DEN = density of fish/10^2 m^2 water.

When the equation was applied to entrainment rates measured in this study, the plot of predicted rates against measured rates was best described by the equation Y = 0.800X + 0.309 (Figure 13).

When using the model in the future to estimate entrainment rates, forebay fish densities (DlOP (l-6), DlOP (7-12) and AREAL DEN) can be obtained empirically, or estimated by using area1 densities (Table 5) and volumetric densities (Appendix F) summarized by season for this study. The model is most properly applied to periods from 1600-0800 hours, because this is the time period for which entrainment rates were typically measured. Predictors of diurnal entrainment should be determined empirically or else it should be assumed that the diurnal rate is 28% of the nocturnal rate.

More sampling is needed to improve the model, particularly during periods of high discharge. Only 9 of the 40 samples in the model were taken during high flows. The model also needs to incorporate more samples from the spring runoff period, when woody debris loads have rendered many of the forebay sonar density values unreliable. Corrections for debris should be based on trawling, where estimates of debris densities can be made.

Table 26. Multiple regressions of entrainment rate regressed on areal density, density within strata, and discharge. N=40 for all regressions. Variables defined in Table 25.

Model #	Variable	Coefficient	T	P	R^2
	(Suitable models determined by stepwise method)				
1.	DISCH (L-H)	1.3904	4.001**	<0.001	0.776
	D1OP (1-6)	0.0437	4.550**		
	D1OP (7-12)	-0.0687	-5.195**		
	AREAL DEN	0.1355	3.198**		
	Constant	-0.8287	-2.302*		
2.	DISCH (L H)	2.1102	7.110**	<0.001	0.719
	D1OP (1-6)	0.0492	4.658**		
	D1OP (7-12)	-0.0385	-3.711**		
	Constant	-1.3333	-3.676**		
3.	DISCH (L H)	1.3939	2.963**	<0.001	0.645
	D1OL (1-6)	0.0479	3.116**		
	Constant	-0.8003	-1.720		
4	DISCH (L_H)	1.2910	3.242**	<0.001	0.699
	AREAL DEN (1-6)	0.1662	3.959**		
	AREAL DEN (7-12)	-0.1070	-2.863**		
	Constant	-0.6526	-1.525		
	(Models determined by forced entry method, testing the suitability of using densities from other depths.)				
5.	DISCH (L H)	1.2861	3.171"	<0.001	0.738
	D1OL (1-6)	0.0644	3.999**		
	D1OL (7-12)	-0.0304	-3.807**		
	AREAL DEN	0.0364	1.924		
	Constant	-0.7477	-1.861		
6.	DISCH (L H)	1.5812	3.324**	<0.001	0.659
	D1OL (1-6)	0.0411	2.393*		
	D1OP (1-6)	0.0181	1.754		
	AREAL DEN	-0.0415	-1.109		
	Constant	-0.9916	-2.121*		
7.	DISCH (L-H)	0.9221	1.855	<0.001	0.674
	D1OL (1-6)	0.0132	0.617		
	D2OL (1-6)	0.0726	2.196*		
	AREAL DEN	0.0244	1.185		
	Constant	-0.3590	-0.725		
8.	DISCH (L H)	2.3458	4.328**	<0.001	0.604
	D1OP (1-6)	0.0194	1.742		
	D2OP (1-6)	0.0011	0.145		
	AREAL DEN	-0.0291	-0.457		
	Constant	-1.5523	-3.018**		

* $p<0.05$
** $p<0.01$

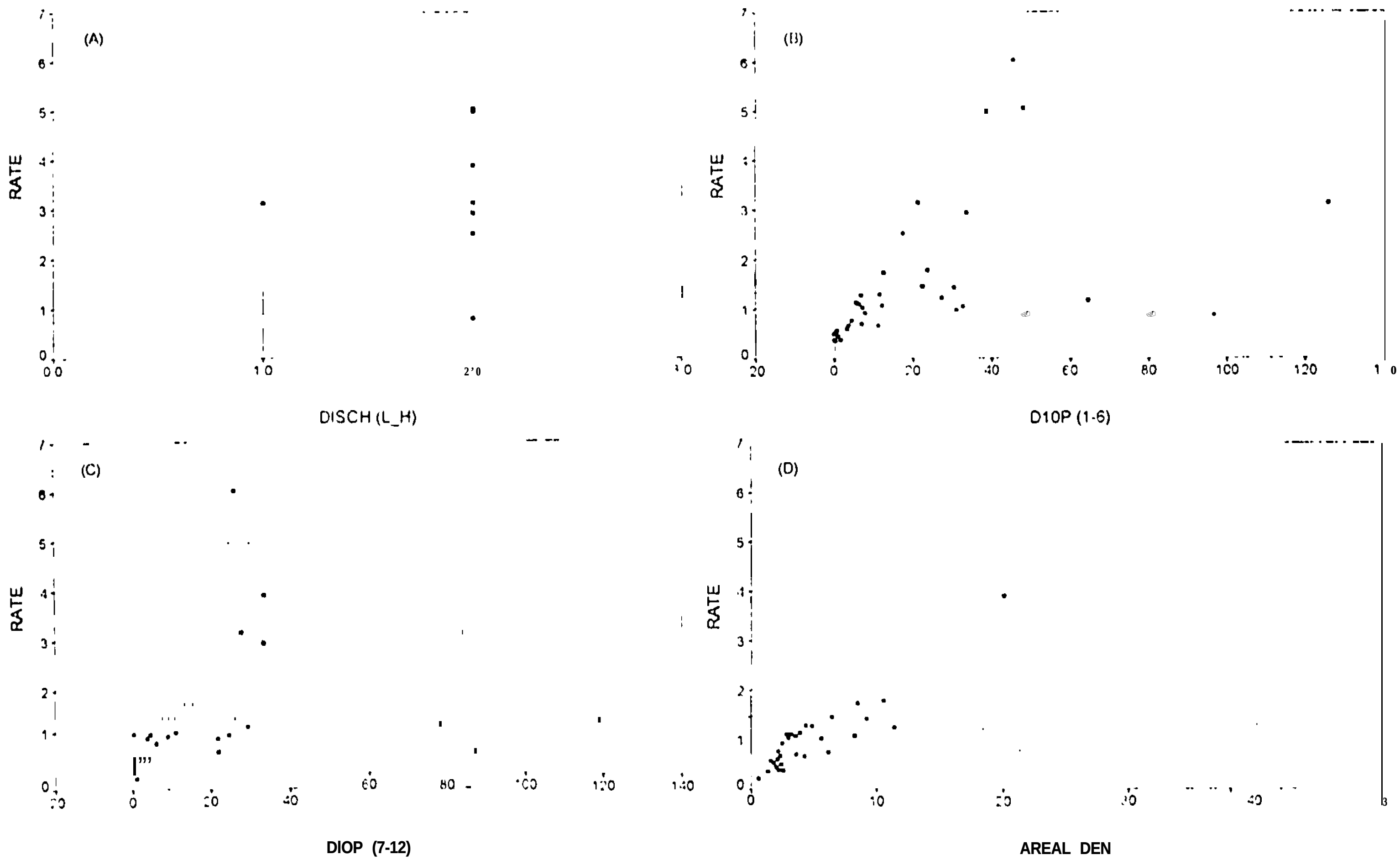

Figure 12. Scatterplots of entrainment rate (square-root transformed, and no./10^4 m^3 water) vs. discharge and fish density. (a) DISCH L-H = discharge, where 1 = flows c 19,000 cfs and 2 = flows > 19,000 cfs; (b) DEN 10P (l-6) = density (no./10^4 m^3 water) O-10 m above withdrawal depth in transects l-6; (c) DEN 10P (7-12) = density (no. /10^4 m^3 water) O-10 m above withdrawal depth in transects 7-12; (d) AREAL DEN = density (no./10^2 m^2 water) in all transects.

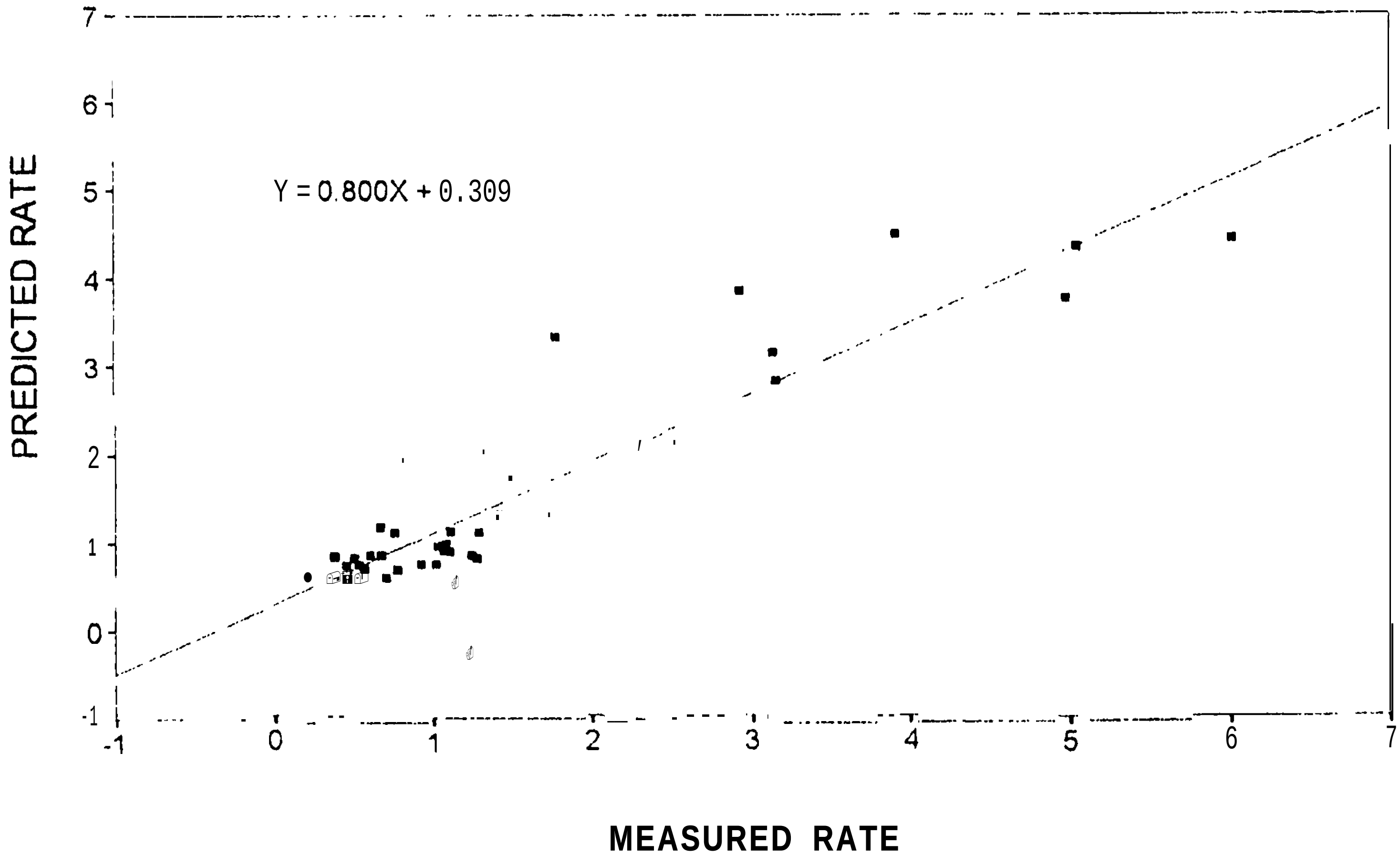

Figure 13. Relationship between predicted entrainment rates (Y) and measured entrainment rates (X) in this study evaluated with multiple regression model #l. Units for the rates are the square-root of rate (no./10^4 m^3 water).

Implications for Dam Operations and Fisheries Management

Our entrainment model shows that there is a relationship between entrainment rates and discharge, depth of withdrawal and forebay fish density. Entrainment can be expected to be high during times when high forebay fish densities coincide with high discharges and with withdrawal depths that are at or near the concentrations of fish. When "typical" dam operations are compared to trends in forebay fish densities, we can make some generalizations about the potential for entrainment on a seasonal basis (Table 27). Entrainment rates are likely to be lowest during the winter (January-March), due to low fish densities, low discharges and deep withdrawal depths. The highest potential for entrainment will be in spring (late April-early July) when withdrawal depth is shallow, discharge can be high (particularly if white sturgeon/salmon flows continue) and fish densities are highest. Fall (October-December) is the other likely season for high rates of entrainment to occur, based primarily on the likelihood of high discharges. Potential for entrainment during the summer (July-September) is likely to be greater than in winter but less than in spring and fall. This is because of intermediate levels of fish densities (12.1 fish/100 m^2), a low incidence of high discharges, and die1 vertical migration of kokanee through the depth of withdrawal.

One additional aspect of dam operations that will influence seasonal trends in entrainment is load following or "power peaking." The current practice at Libby Dam is to increase discharges at about 0600 or 0700 hours and maintain high levels throughout the day until cutting back at 2100 or 2200 hours. The effects of this load-following schedule on entrainment will change seasonally, because entrainment rates increase quickly after sunset and decrease quickly after sunrise. Therefore, during late fall to early spring, load following will begin before sunrise and end after sunset, increasing the potential for entrainment. Conversely, load following from late spring to early fall will typically begin after sunrise and end before sunset--thereby reducing the potential for entrainment.

The relationships between dam operations and entrainment, as well as the high levels of entrainment (23-92% of the 1991 population came out in 1992) suggest that it is feasible to manipulate entrainment rates for fish management purposes. A review of current management practices and the kokanee population trends should provide some insight into circumstances in which entrainment manipulation can be useful.

Current management practices for kokanee in Libby Reservoir are based on the assumption that the population is large and can sustain high levels of harvest. Fishing regulations are liberal, allowing 20 fish as a daily limit and 40 in possession; snagging is allowed September l-December 15. Kamloops rainbow trout are

Table 27. Seasonal dam operating conditions, fish distribution, and potential for entrainment through Libby Dam.

Period	Withdrawal Depth'	Midnight forebay fish densities (no./100 m^2)	Location of highest fish densities	Die1 vertical movement across depth of withdrawal?	Incidence of high (>19 kcfs) discharge'	Potential for entrainment
Winter (Jan-Mar)	usually 30-50 m	Low (3.73)	O-20 m	No	Occasional, but flows usually cut back for storage	Low, except during high discharge
Spring (late April to early July)	Starts at >30 m but ends close to 20 m	High (21.1)	O-20 m	No	Infrequent prior to 1992, but is now typical for sturgeon	High (especially in June) due to withdrawal depths, high discharges, and presence of age Ot kokanee.
Summer (July-September)	20-30 m	Intermediate (9.14)	O-30 m	Yes	Infrequent, except for September	Intermediate, due to die1 movement of fish[b]
Fall (October-December)	starts at ca. 30 m but ends >40 m	Intermediate (12.1)	O-20 m, but many fish from 20-40 m	No	Frequent	High, due primarily to high discharges'

'Based on dam operations from 1984-1994.
[b]Age class lt and 2t fish may be more susceptible to entrainment than age class Ot fish.
[c]Age class Ot fish may be more susceptible to entrainment than age class lt or 2t fish.

stocked by both the British Columbia Ministry of Environment (using Gerrard strain) and MDFWP (using Duncan River strain). These fish are piscivorous for much of their lives and have a preference for kokanee. However, there is reason to believe that the population cannot sustain high levels of predation or harvest in every year. Surveys have shown that the density and maximum size of kokanee has been quite variable since their introduction to the lake in the late 1970s. Total population densities between 1984 and 1991 have varied more than threefold, from 88.8 fish/ha in 1986 to 301.2/ha in 1988 (Table 28). The size of spawners since 1984 has ranged from 257 to 410 mm, and the spawner class of 1992 was particularly small, with peak counts of less than 1,700 in Kikomun Creek (Table 28). The year earlier, our dual-beam survey estimated this age class to number only 193,000 fish.

Table 28. Characteristics of the kokanee population in Libby Reservoir, 1984-1994. All population estimates conducted in August.

Year	Spawner total length (mm)	Peak spawner count in Kikomun Creek	Hydroacoustic surveys: Population estimate[a]	Hydroacoustic surveys: Density (no/ha)
1984	312	--	2,527,530	134.3
1985	352	--	2,047,911	108.8
1986	410	--	1,671,389	88.8
1987	356	--	1,875,513	99.7
1988	317	--	5,667,202	301.2
1989	278	21,860	3,302,578	175.5
1990	257	79,645	--	--
1991	316	9,803	4,193,742	222.9
1992	363	1,696	--[b]	--
1993	290	23,779	--[b]	--
1994	271	49,300	--[b]	--

[a] Estimates from 1984-1988 were with single-beam Honda Sitex. Estimates in 1989 and 1991 were with dual-beam BioSonics equipment.
[b] Data have been collected and are under analysis.

The inverse relationship between size and density in the kokanee spawner surveys of Kikomun Creek is highly correlated (r=0.975) (Figure 14). This logarithmic relationship is consistent with the models developed by Reiman and Myers (1990) for kokanee populations in Idaho lakes. Their models suggest that for lakes with a given productivity, size will decrease rapidly and logarithmically as density increases from 0 to around 40-60 fish/hectare (for each of the age classes 2+ and 3+). As densities

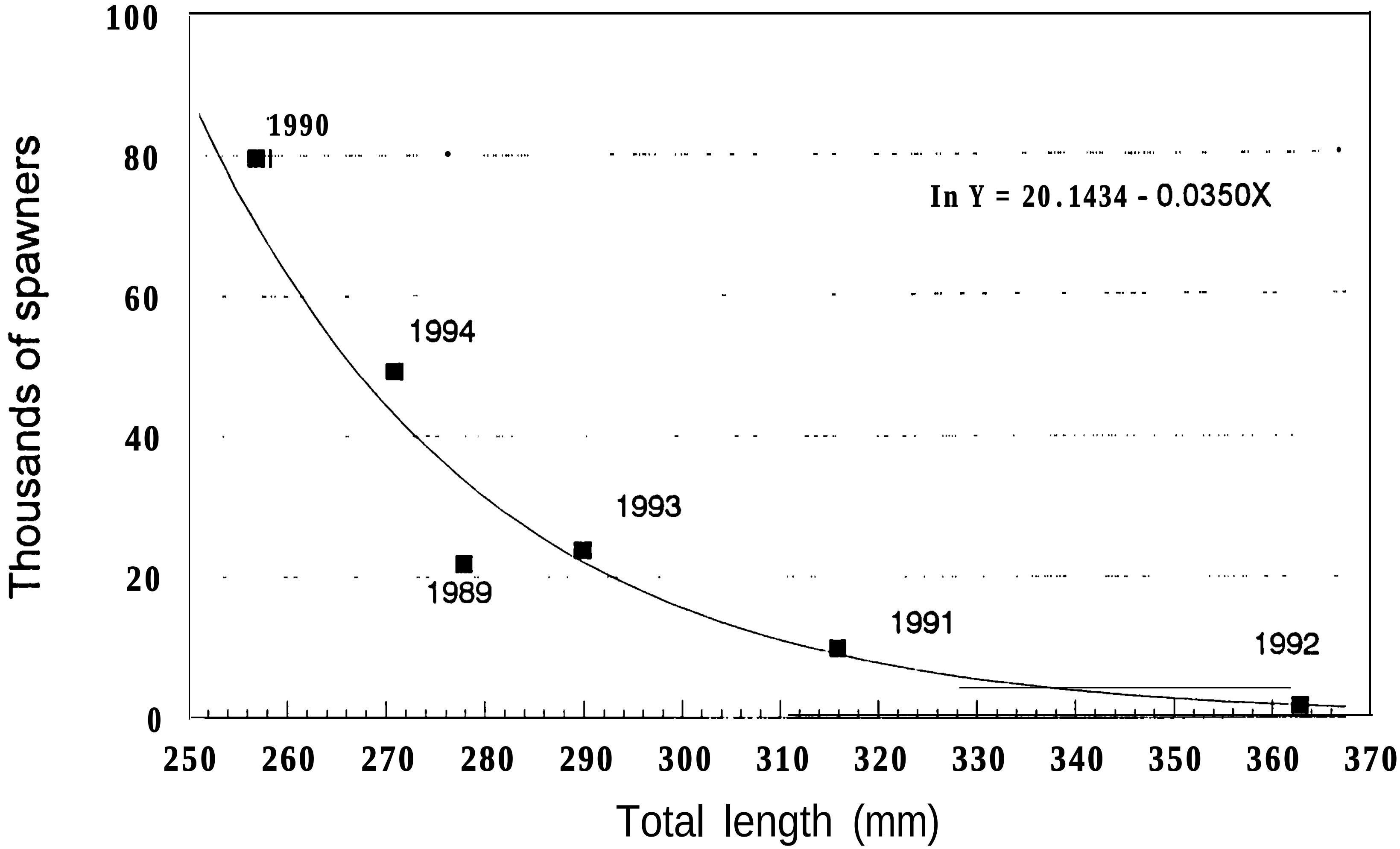

Figure 14. Plot of kokanee spawner size against numbers of spawners in Kikomun Creek, 1989-1994.

increase beyond this level, size will decrease much more slowly. At Libby, the density/size relationship is clearly in the dynamic zone of Reiman and Myer's models.

By manipulating entrainment rates, it may be possible to achieve two objectives: 1) stabilize the population, so there is less annual variation in spawner-class size and density. This objective would reduce the boom-and-bust aspect of the sport fishery, and would probably be more satisfactory to anglers and businesses supporting the fishery. It would also provide a more dependable basis for which to judge changes in regulations and changes in stocking levels of Kamloops trout; and 2) lower kokanee densities in order to increase size. This would generate more interest from anglers, but a note of caution is in order. In order to produce a 350 mm kokanee, densities would probably be quite low. Reiman and Myers (1990) data show that catch rates drop markedly from 1.0-1.5/hr to below 0.5/hr as kokanee densities drop from 50/ha to 25/ha or lower. Furthermore, severely reducing the population may make it unstable and subject to collapse from catastrophic events or from overharvest. If entrainment is used to manipulate kokanee numbers, age 0+ fish should be targeted, because they typically occur in higher densities than older age classes and are not sought by anglers. Removal of age 0+ fish will also reduce competition for food with the older age classes. A controlled entrainment program would require a clearly defined monitoring schedule and population objectives. The population of each age class should be quantified immediately after its immigration to the reservoir. Population objectives, indicating the desired standing crop of each age class in April or May of their second and third years, should then be established. Estimates of survival from age 0+ to 1+ and then from l+ to 2+ should incorporate desired levels of entrainment as well as estimates of harvest and predation.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH MONITORING AND EVALUATION

1. Accurately describe the timing of kokanee fry emigration from tributary streams and their subsequent movement in the reservoir downstream toward the dam. Further investigate the effect of turbidity and inflow volume and temperature on the movement of age 0+ fish.

2. Describe the effect of changes in kokanee size and density on angler satisfaction and catch rates.

3. Establish and quantify the relationship between entrainment rates and the magnitude of kokanee spawning runs in the Kootenai River below Kootenai Falls and in Lake Creek.

4. Measure entrainment through the dam with draft-tube nets during May, June and July to better assess the effects of white sturgeon flows.

5. Continue to conduct annual reservoir-wide population estimates. Partition population estimates by age class of kokanee.

6. Investigate fish mortalities and injuries when turbines are run at less than 90% efficiency.

7. Strengthen the entrainment model through additional draft-tube netting and forebay sonar measurements. Data during periods of high discharge and/or high rates of entrainment are needed the most.

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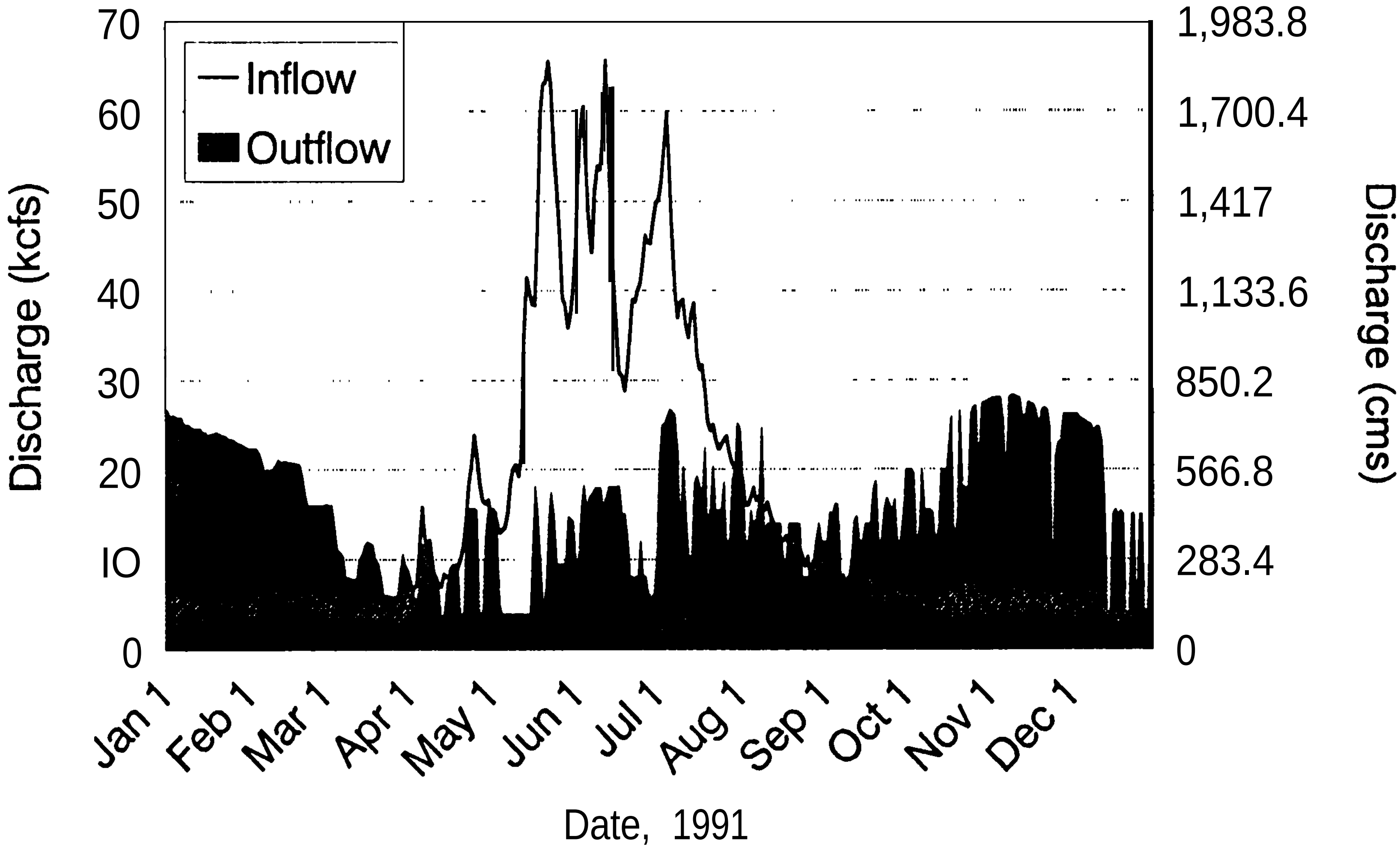
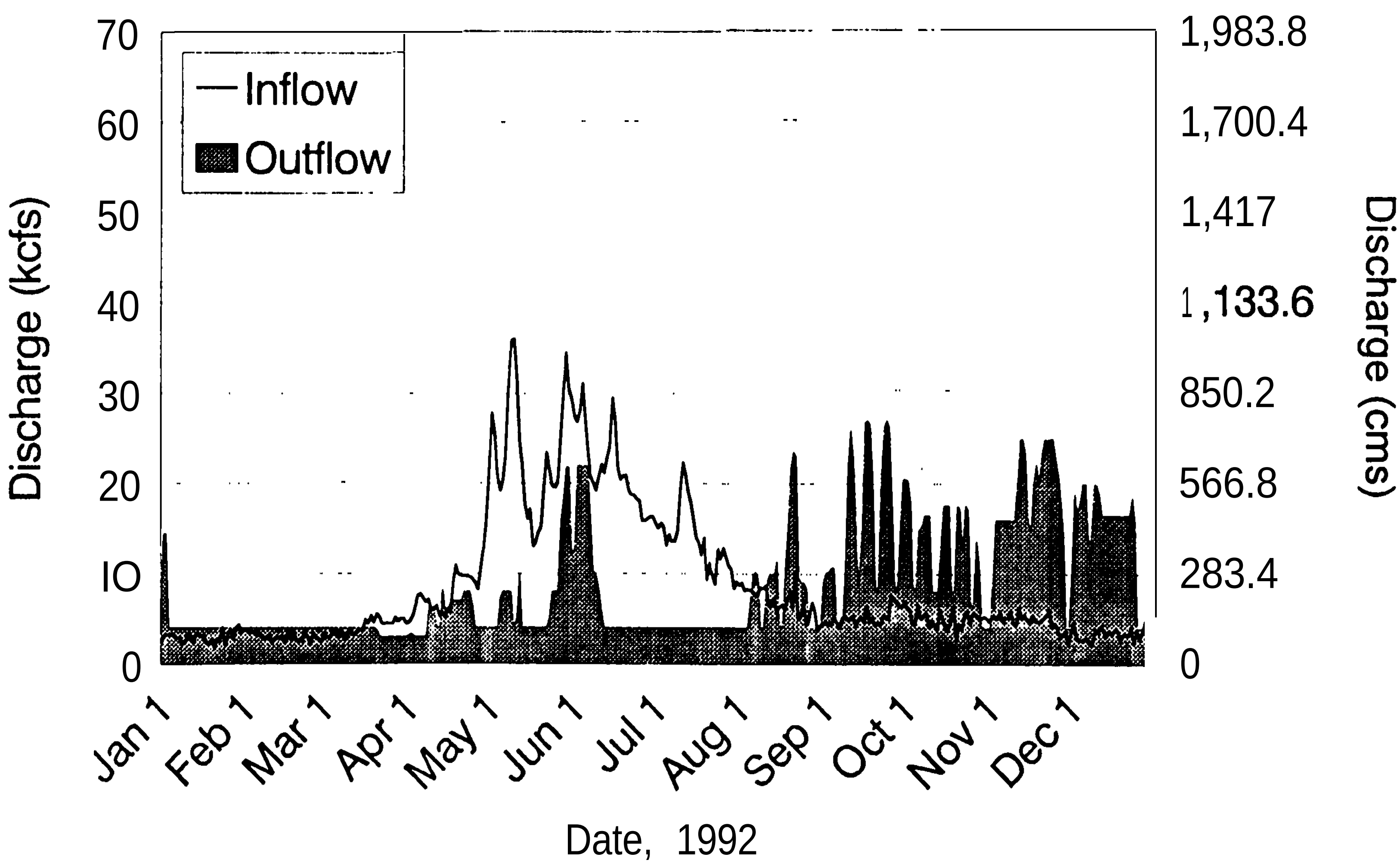
APPENDIX A

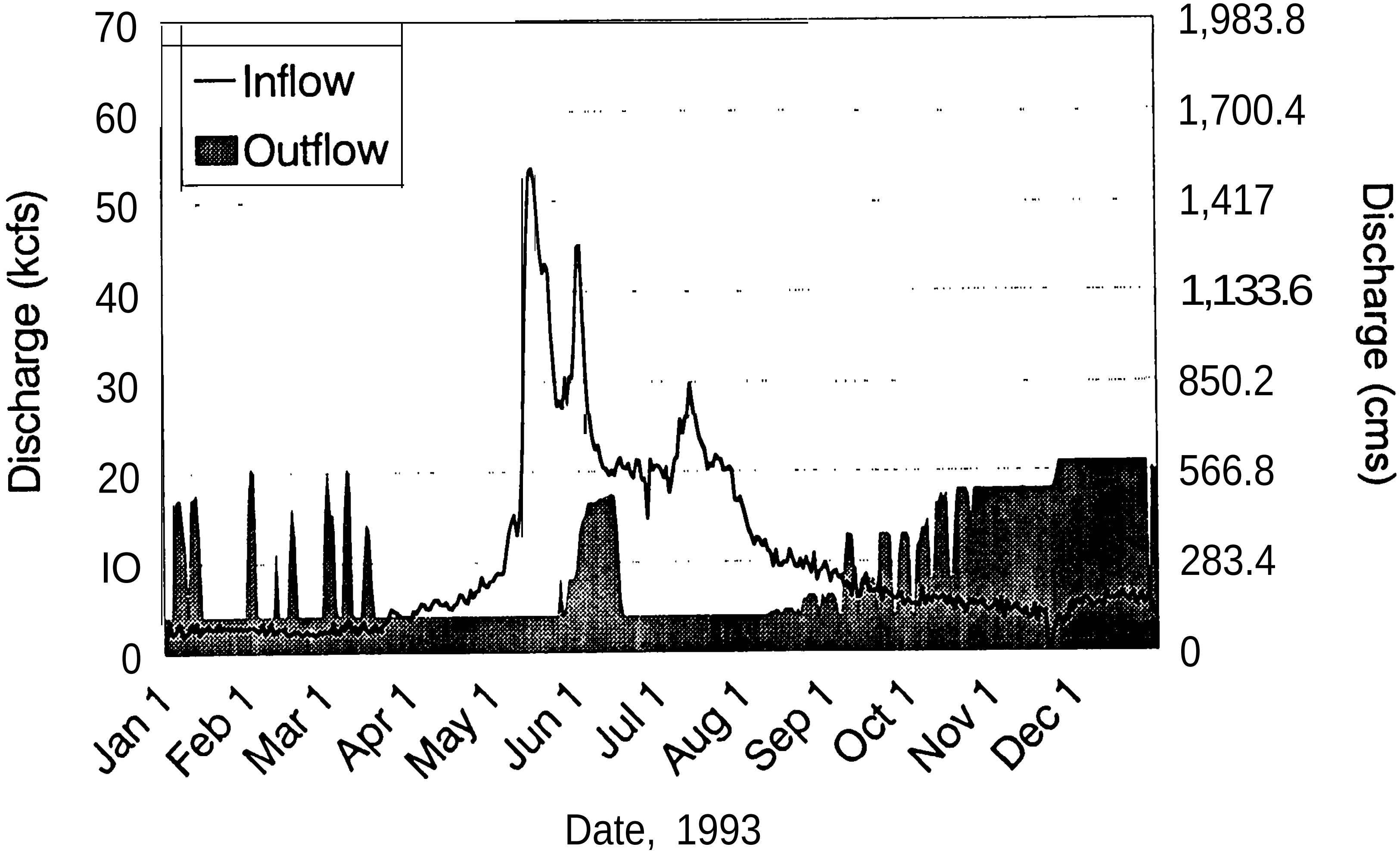
Plot of daily inflow and outflow measurements for Libby Reservoir, 1991-1994



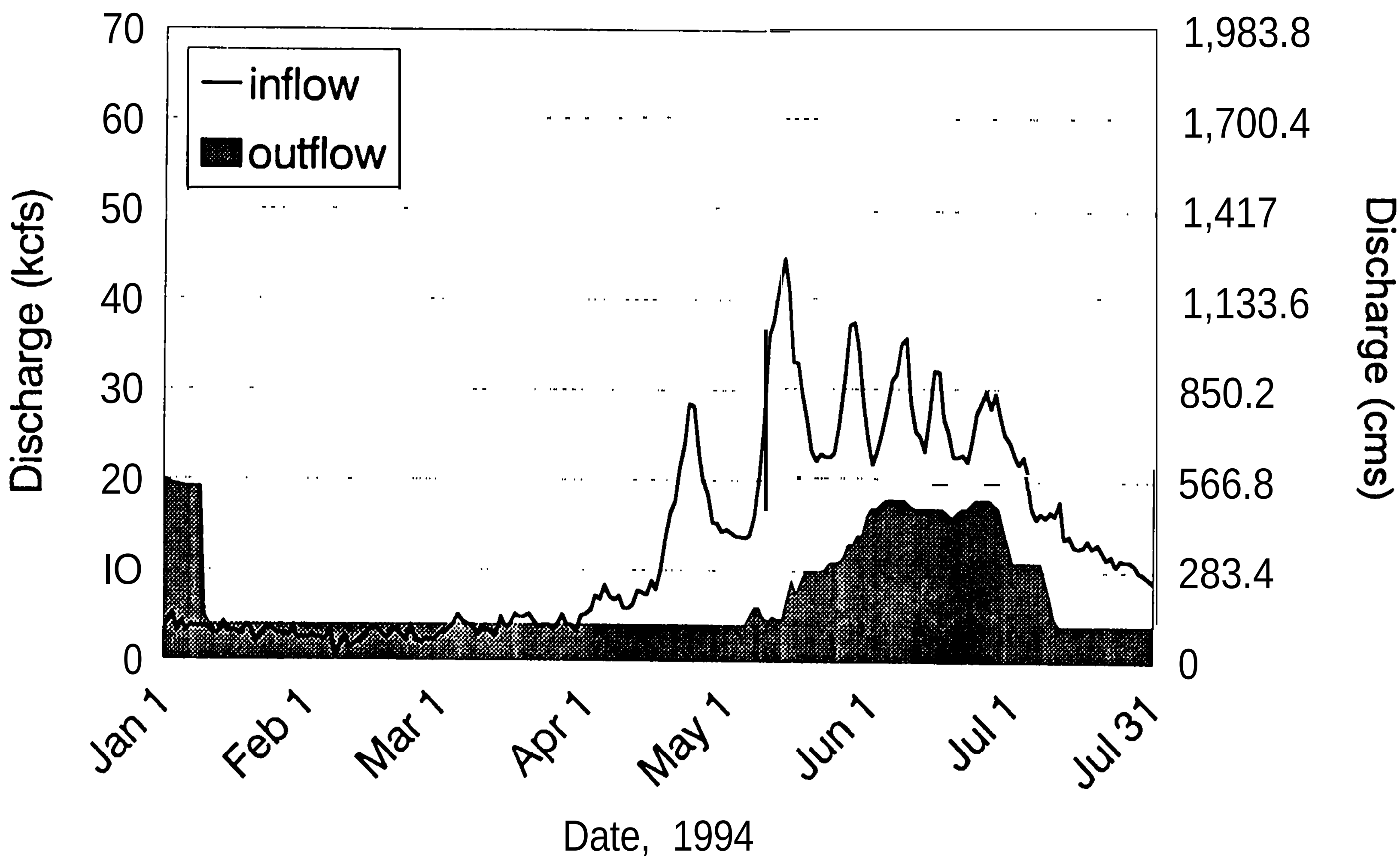
Appendix Figure **Al.** Plot of daily inflow and outflow measurements for Libby Reservoir, 1991



Appendix Figure A2. Plot of daily inflow and outflow measurements for Libby Reservoir, 1992.



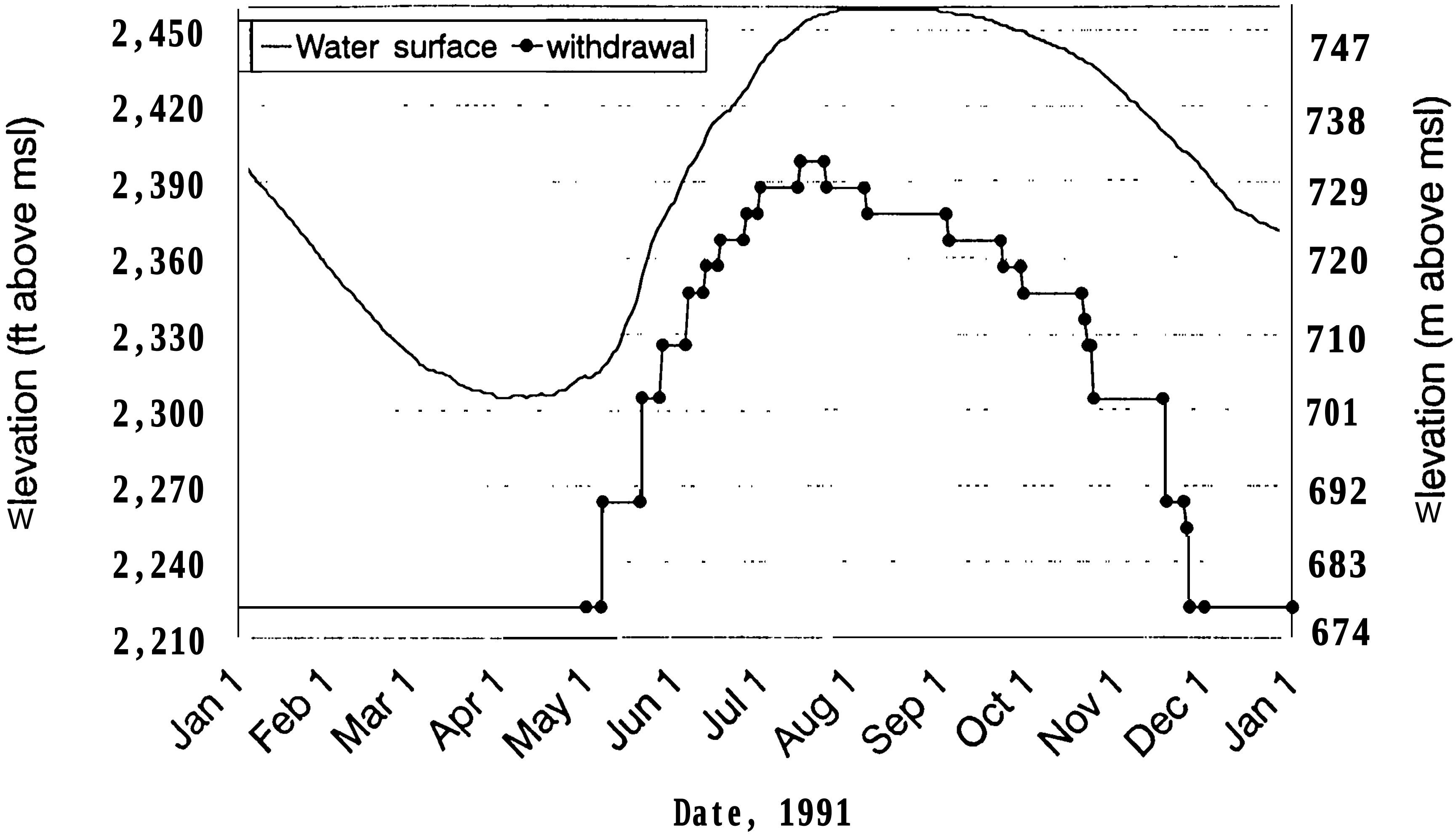
Appendix Figure A3. Plot of daily inflow and outflow measurements for Libby Reservoir, 1993.



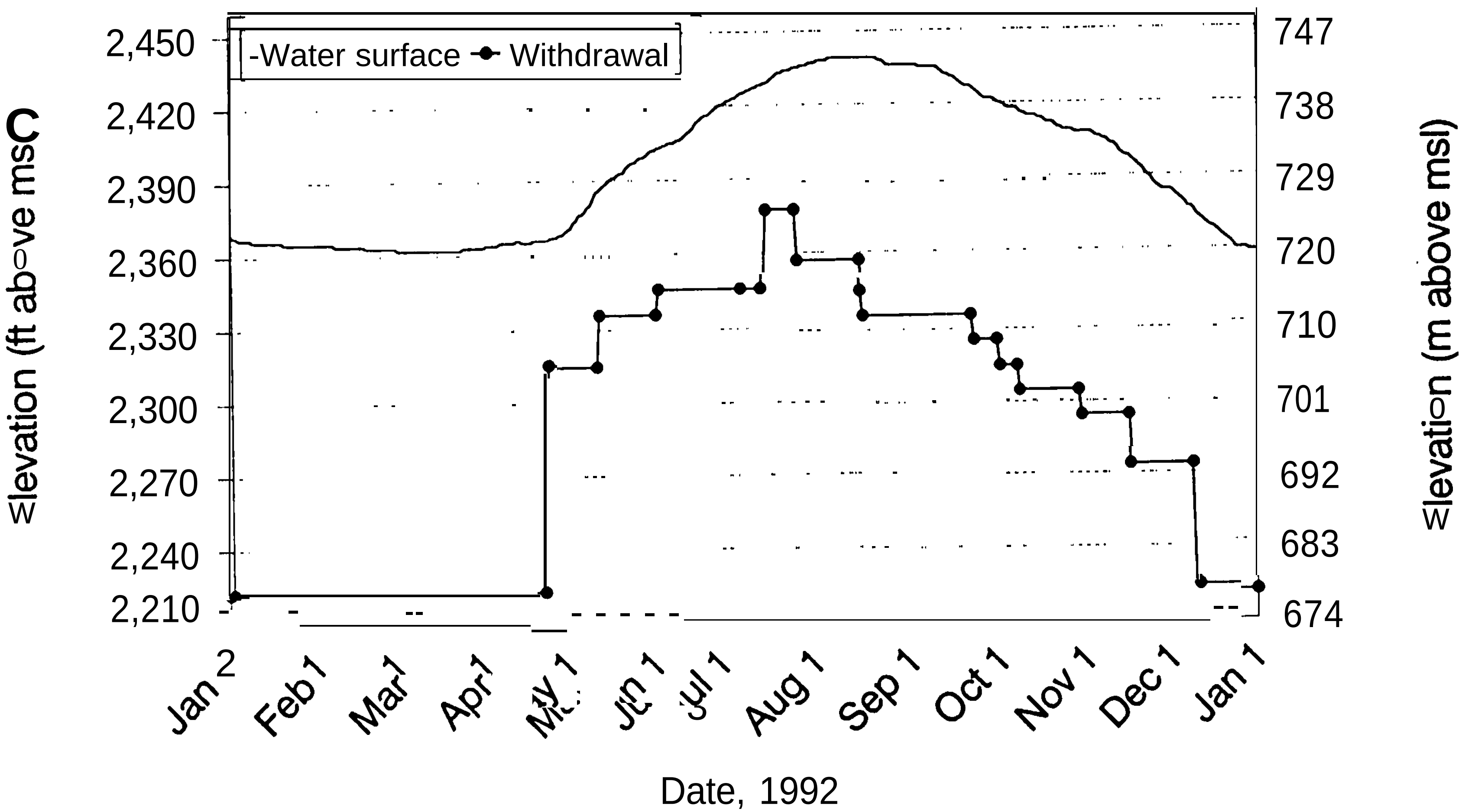
Appendix Figure A4. Plot of daily inflow and outflow measurements for Libby Reservoir, 1994.

APPENDIXB

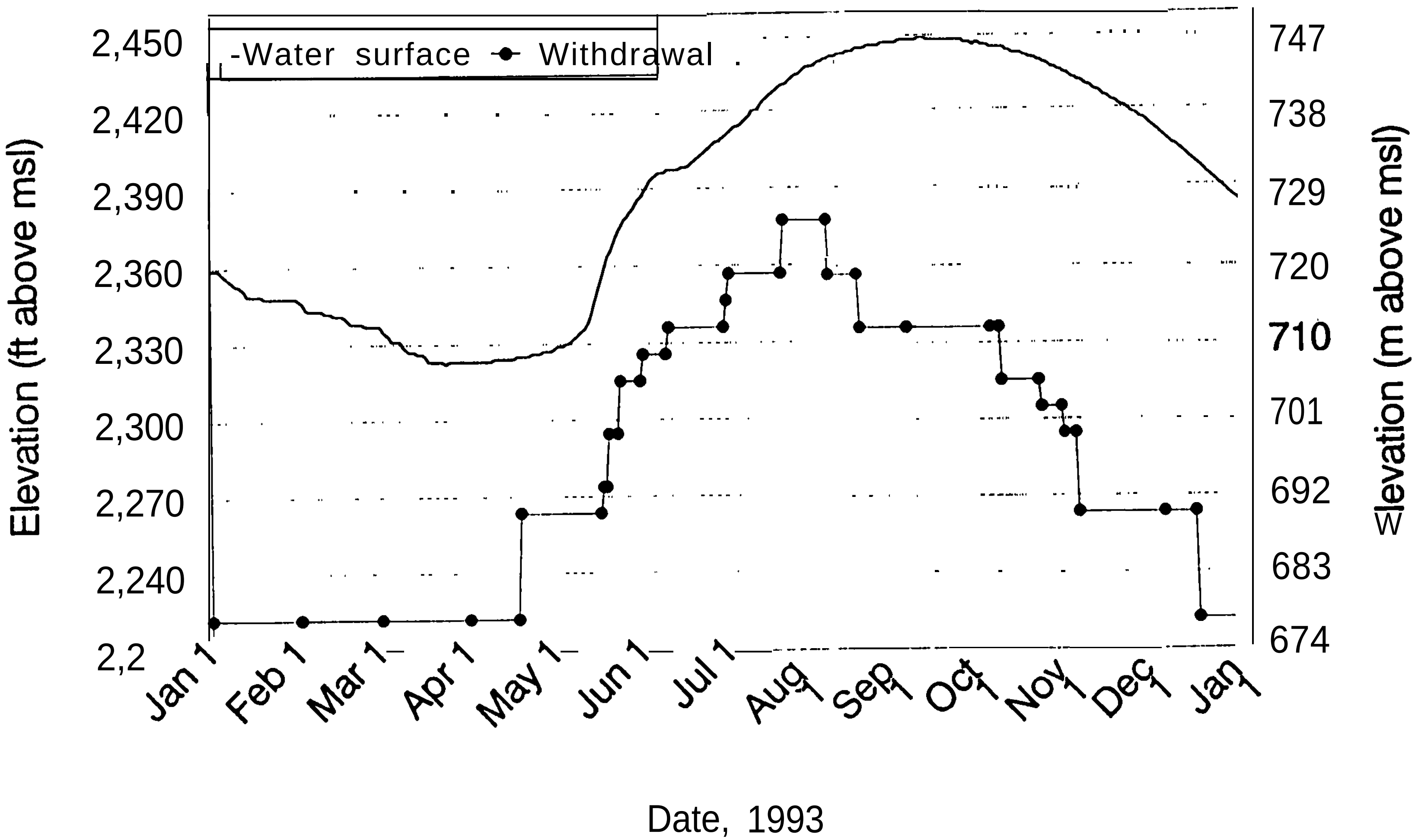
Plot of water surface elevations and withdrawal depths for Libby Reservoir, 1991-1994



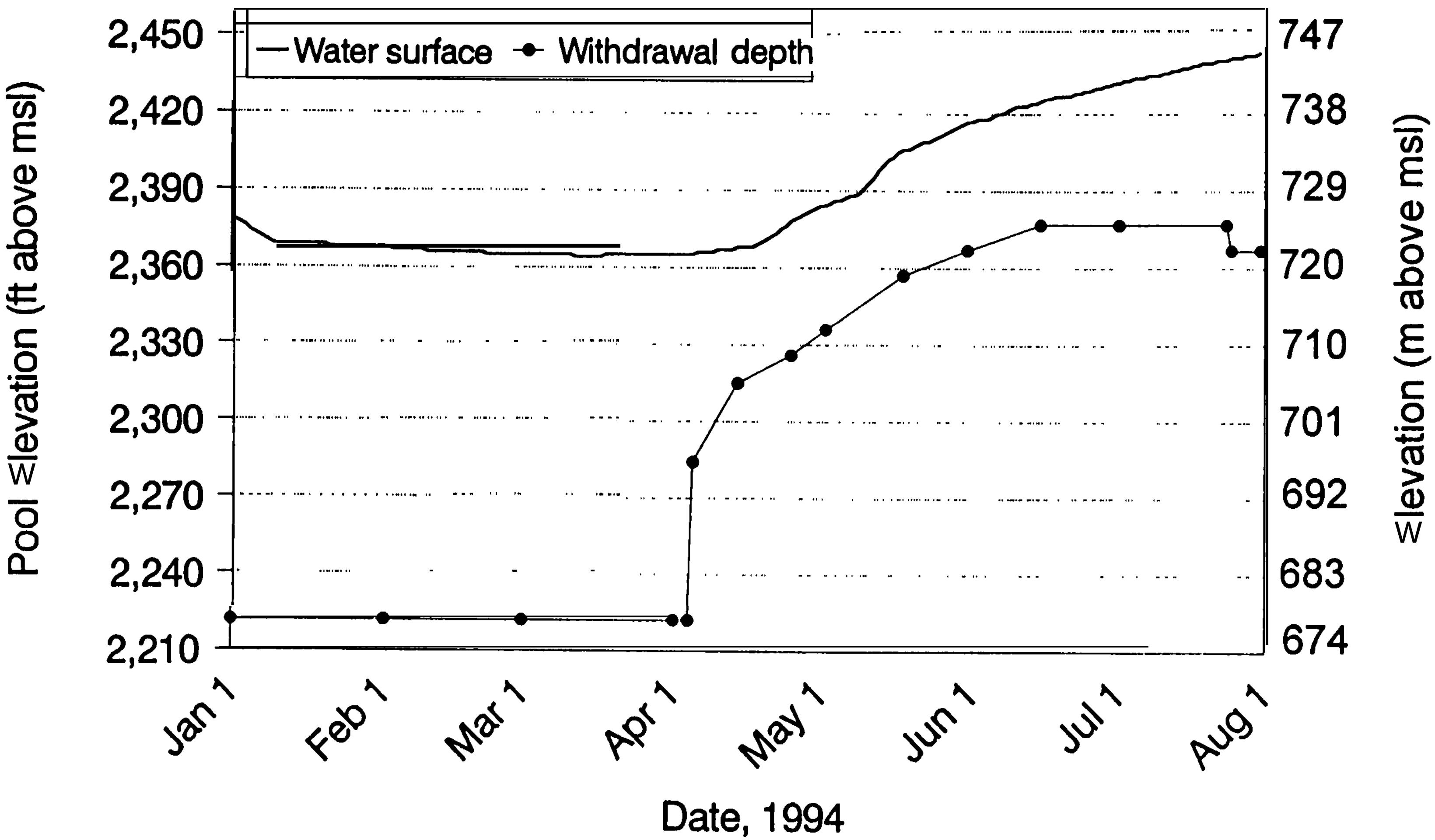
Appendix Figure Bl. Plot of water surface elevations and withdrawal depths for Libby Reservoir, 1991.



Appendix Figure B2. Plot of water surface elevations and withdrawal depths for Libby Reservoir, 1992.



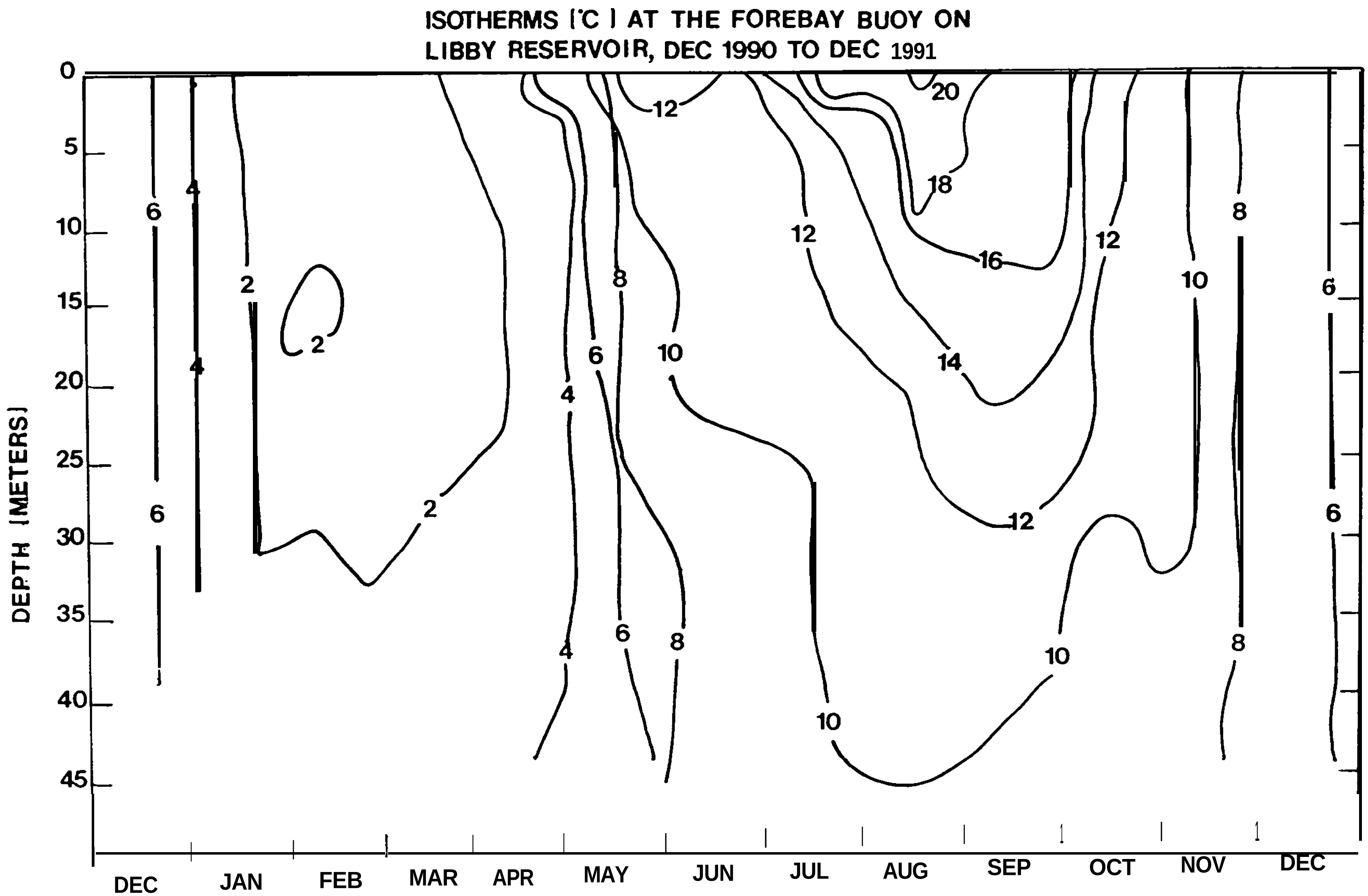
Appendix Figure B3. Plot of water surface elevations and withdrawal depths for Libby Reservoir, 1993.



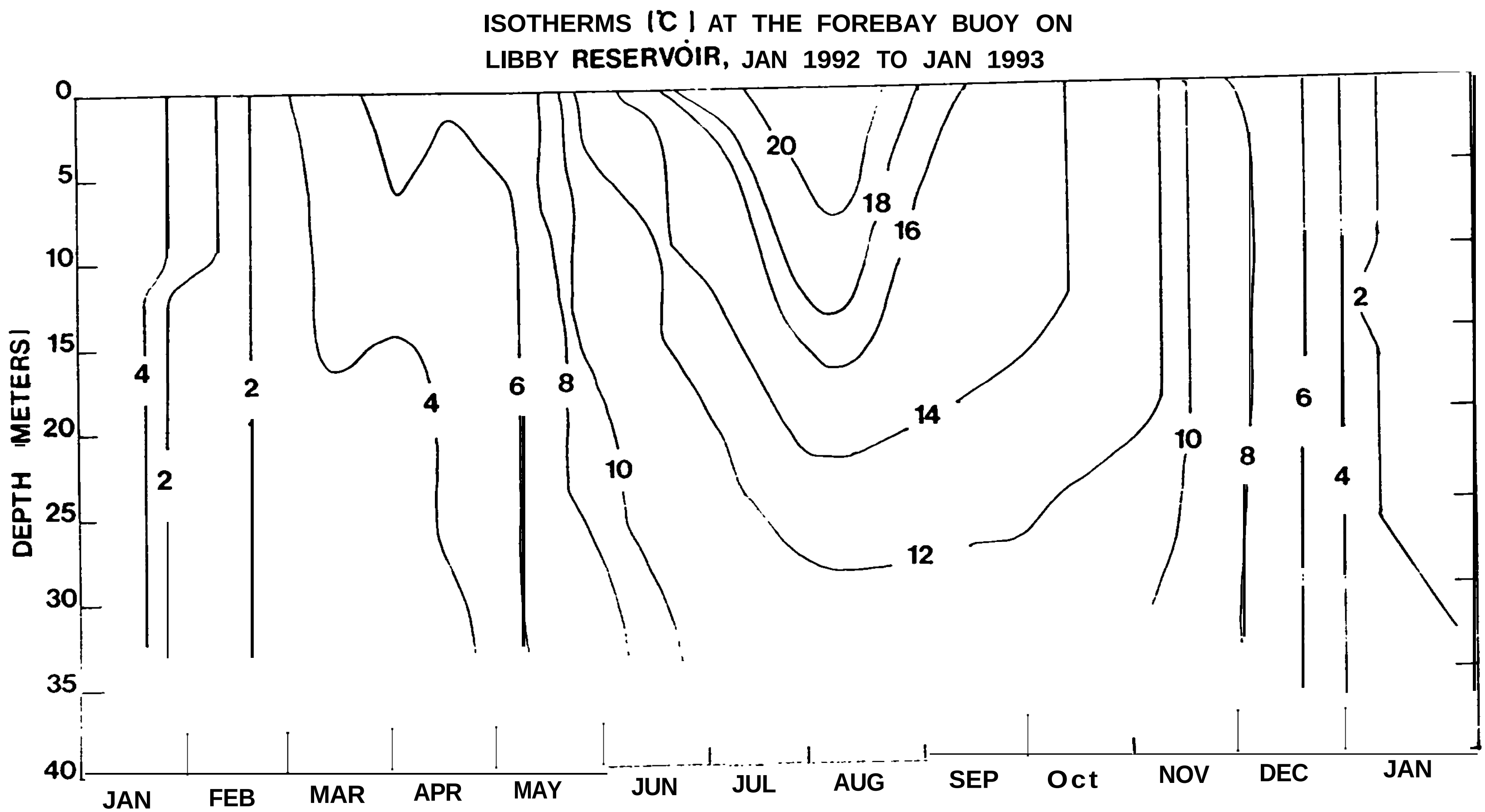
Appendix Figure B4. Plot of water surface elevations and withdrawal depths for Libby Reservoir, 1994.

APPENDIX c

Libby Reservoir forebay water temperatures, 1990-1993



Appendix Figure Cl. Libby Reservoir forebay water temperatures, 1990-1991.



Appendix Figure C2. Libby Reservoir forebay water temperatures, 1992.

Appendix D. Density of sonar targets in forebay, December 4, 1990-June 25, 1993. N=4 for all periods except sunrise, May 20, 1991 where N=3.

Date	Period	Mean Areal Density (no./100 m²)	Mean volumetric density (no./10⁴ m³) within depth stratum (m) 0-10	10-20	20-30	30-40	40-50	50-60	60-70
Dec 4-5, 1990	Sunrise	0.59	0	4.86	0.69	0.33	0	0	0
	Midday	0.82	1.16	4.49	1.14	0.36	0.22	0.79	0
	Sunset	2.47	8.38	12.61	2.74	0.22	0.75	0	0
	Midnight	10.1	50.8	16.2	13.8	14.9	2.34	3.20	0
Dec 12-13, 1990	Sunrise	4.50	20.2	15.5	7.82	0.96	0	0.53	0
	Midday	1.69	3.25	8.56	4.02	1.09	0	0	0
	Sunset	7.37	44.2	14.3	9.70	3.49	0.71	1.32	0
	Midnight	5.09	17.8	13.1	14.0	4.38	0.20	1.42	0
Jan 8-9, 1991	Sunrise	2.14	9.89	6.79	3.32	0.98	0.38	0	0
	Midday	0.44	1.57	0.88	0.77	0.66	0.14	0	0.41
	Sunset	0.13	0	0.73	0.58	0	0	0	0
	Midnight	7.19	55.2	12.1	4.71	0	0	0	0
Jan 22-23, 1991	Sunrise	3.19	1.66	16.3	8.63	2.74	2.51	0	0
	Midday	1.10	4.55	1.95	2.80	1.24	0.16	0.27	0
	Sunset	1.58	4.78	5.09	3.01	2.65	0.29	0	0
	Midnight	7.81	30.0	24.8	9.06	10.6	3.64	0	0
Apr 10-11, 1991	Sunrise	2.64	11.0	7.77	7.60	0	0	0	0
	Midday	1.85	16.0	1.17	0.61	0	0.75	0	0
	Sunset	0.49	0.88	3.02	0.55	0.48	0	0	0
	Midnight	5.07	30.1	12.0	7.35	1.25	0	0	0
Apr 23-24, 1991	Sunrise	2.08	10.5	6.40	3.65	0.32	0	0	0
	Midday	4.73	35.4	9.47	2.44	0	0	0	0
	Sunset	3.36	7.05	22.8	3.20	0.56	0	0	0
	Midnight	3.03	15.5	13.0	1.50	0.28	0	0	0
May 6-7, 1991	Sunrise	6.31	32.9	26.7	3.52	0	0	0	0
	Midday	5.05	32.2	9.86	7.57	0.88	0	0	0
	Sunset	15.5	82.4	57.2	12.3	3.55	0	0	0
	Midnight	23.4	81.3	138	12.6	1.06	0.72	0	0

Appendix D, continued.

Date	Period	Mean Area1 Density (no./100 m^2)	Mean volumetric density (no. /10^4 m^3) within depth stratum (m)						
			O-10	10-20	20-30	30-40	40-50	SO-60	60-70
May 20-21, 1991	Sunrise	5.57	48.8	6.88	0	0	0	0	0
	Midday	8.66	72.1	13.6	0.94	0	0	0	0
	Sunset	32.2	250	63.8	6.75	0.25	0	1.46	0
	Midnight	63.4	365	242	27.1	0.33	0	0	0
Jun 4-5, 1991	Sunrise	20.6	194	11.7	0	0	0	0	0
	Midday	8.35	82.9	0.59	0	0	0	0	0
	Sunset	18.3	180	2.39	0	0	0	0	0
	Midnight	31.9	309	10.2	0	0	0	0	0
Jun 18-19, 1991	Sunrise	16.4	130	33.7	0.33	0	0	0	0
	Midday	31.8	204	105	8.87	0.19	0	0	0
	Sunset	28.4	265	17.4	0.83	0.68	0	0	0
	Midnight	21.9	177	40.9	1.45	0.13	0	0	0
Jul 2-3, 1991	Sunrise	9.07	28.9	47.2	13.5	1.11	0	0	0
	Midday	1.43	5.21	7.50	1.54	0	0	0	0
	Sunset	10.8	78.5	25.6	3.61	0	0	0	0
	Midnight	7.57	29.8	42.9	2.93	0.12	0	0	0
Jun 15-16, 1991	Sunrise	1.78	2.26	8.87	6.39	0.32	0	0	0
	Midday	1.49	5.68	5.35	2.12	1.58	0.17	0	0
	Sunset	2.05	9.24	10.28	0.97	0	0	0	0
	Midnight	4.51	6.10	25.8	13.0	0.19	0	0	0
Aug 1-2, 1991	Sunrise	9.95	45.5	45.6	4.28	1.30	2.08	0.77	0
	Midday	10.5	55.0	26.4	8.42	5.86	6.10	3.24	0
	Sunset	15.8	56.0	85.6	11.2	5.28	0	0	0
	Midnight	26.8	52.9	77.0	128	8.84	0.68	0	0
Aug 16, 1991	Sunrise	3.42	4.66	19.3	7.96	2.10	0.14	0	0
	Midday	3.02	5.48	12.6	4.42	5.63	1.75	0.58	0.17
	Sunset	4.36	1.83	32.1	9.20	0.51	0	0	0
	Midnight	7.93	5.30	20.8	38.7	13.5	1.12	0	0

Appendix D, continued.

Date	Period	Mean Area1 Density (no./100 m²)	Mean volumetric density (no./10⁴ m³) within depth stratum (m)						
			0-10	10-20	20-30	30-40	40-50	50-60	60-70
Sep 25-26, 1991	Sunrise	8.03	16.0	33.1	6.97	5.83	10.8	7.13	0.46
	Midday	3.66	14.6	6.05	0.36	1.99	4.57	4.59	4.36
	Sunset	2.98	11.7	0.50	2.84	3.69	2.72	5.05	3.33
	Midnight	7.43	30.0	1.87	9.34	9.93	15.9	6.62	0.69
Oct 17-18, 1991	Sunrise	0.50	0.92	1.52	0.14	1.07	0	0.56	0.28
	Midday	0.23	0	0.31	0	0.64	1.34	0	0
	Sunset	0.74	3.15	1.09	1.03	1.02	0.14	0.50	0.49
	Midnight	2.74	19.7	2.66	1.50	2.89	0.69	0	0
Oct 30-31, 1991	Sunrise	0.28	0	0.92	0.89	0.53	0	0	0.44
	Midday	0.56	0	0.67	0	1.69	0.87	1.92	0.42
	Sunset	5.62	30.4	17.1	4.00	2.69	1.69	0.34	0
	Midnight	10.8	78.0	9.67	6.97	7.52	3.34	2.09	0.75
Nov 18-19, 1991	Sunrise	3.50	10.7	8.67	10.5	3.58	1.60	0	0
	Midday	1.40	0	7.77	2.01	2.57	1.61	0	0
	Sunset	2.74	13.0	7.79	3.31	1.92	1.47	0	0
Dec 4-5, 1991	Sunrise	2.73	17.7	5.82	3.11	0.71	0	0	0
	Midday	2.19	15.5	2.78	1.79	0.14	0.55	0.38	0.77
	Sunset	5.32	37.6	9.82	2.48	0.87	2.04	0.45	0
	Midnight	4.60	20.9	2.28	14.1	8.46	0.29	0	0
Dec 19-20, 1991	Sunrise	0.57	3.38	1.71	0.45	0	0.20	0	0
	Midday	0.41	1.01	1.55	0.63	0.61	0.27	0	0
	Sunset	0.25	0.96	1.36	0.13	0	0	0	0
	Midnight	0.11	0	0.66	0	0.43	0	0	0
Jan 13-14, 1992	Sunrise	0.63	0	2.56	2.92	0.86	0	0	0
	Midday	0.18	0.73	0	0.76	0.29	0	0	0
	Sunset	0.36	0	2.43	0.84	0.35	0	0	0
	Midnight	2.07	8.21	6.22	4.00	1.13	0.48	0	0.67

Appendix D, continued.

Date	Period	Mean Areal Density (no./100 m²)	Mean volumetric density (no./10⁴ m³) within depth stratum (m)						
			0-10	10-20	20-30	30-40	40-50	50-60	60-70
Jan 28-29, 1992	Sunrise	1.02	2.01	2.71	4.02	0.96	0.52	0	0
	Midday	0.10	0	0.34	0	0.70	0	0	0
	Sunset	0.16	0.73	0.23	0.38	0.23	0	0	0
	Midnight	2.16	5.93	7.46	5.79	2.38	0	0	0
Feb 12-13, 1992	Sunrise	0.76	0	2.54	4.08	1.02	0	0	0
	Midday	0.03	0	0.26	0	0	0	0	0
	Sunset	0.09	0	0.24	0	0	0.64	0	0
	Midnight	1.10	2.21	5.17	1.62	1.56	0.48	0	0
Feb 25-26, 1992	Sunrise	1:46	0	5.28	5.55	3.27	0.52	0	0
	Midday	0.18	0	1.28	0.37	0.17	0	0	0
	Sunset	0.11	0	0.34	0	0	0.28	0	0.45
	Midnight	3.36	8.74	3.89	7.72	12.1	1.16	0	0
Mar 10-11, 1992	Sunrise	0.95	4.74	0.79	1.25	2.06	0.73	0	0
	Midday	0.23	0	0	0.69	0.68	0.93	0	0
	Sunset	0.59	3.63	0.96	0.27	0.81	0.28	0	0
	Midnight	2.87	11.6	7.77	3.76	5.18	0.34	0	0
Apr l-2, 1992	Sunrise	0.24	0.99	1.26	0.13	0	0	0	0
	Midday	0.29	2.63	0.22	0	0	0	0	0
	Sunset	0.56	1.88	1.23	0.42	0	0.65	0.77	0.65
	Midnight	3.73	37.0	0.36	0	0	0	0	0
Apr 15-16, 1992	Sunrise	0.90	3.33	0.03	2.36	2.41	0.89	0	0
	Midday	0.76	5.44	0.33	0.14	0	0.82	0.86	0
	Sunset	0.13	0	0.27	0.50	0.51	0	0	0
	Midnight	2.67	24.9	0.64	0.35	0.63	0.19	0	0
Apr 29-30, 1992	Sunrise	0	0	0	0	0	0	0	0
	Midday	0.02	0	0	0	0.17	0	0	0
	Sunset	0.28	0	0	0	0	1.49	1.28	0
	Midnight	0.04	0	0.29	0.15	0	0	0	0

Appendix D, continued.

Date	Period	Mean Areal Density (no./100 m²)	Mean volumetric density (no./10⁴ m³) within depth stratum (m)						
			0-10	10-20	20-30	30-40	40-50	50-60	60-70
May 12-13, 1992	Sunrise	1.26	10.1	2.06	0.23	0.25	0	0	0
	Midday	0.26	0.60	1.89	0	0.15	0	0	0
	Sunset	3.14	28.1	3.24	0	0	0	0	0
	Midnight	15.1	45.7	75.8	13.0	6.87	4.26	2.28	3.08
May 27-28, 1992	Sunrise	0.58	3.89	0.65	1.28	0	0	0	0
	Midday	1.54	13.0	2.15	0	0	0.25	0	0
	Sunset	3.53	25.7	9.33	0.13	0	0.24	0	0
	Midnight	11.8	67.0	34.9	15.8	0.66	0	0	0
Jun 9-10, 1992	Sunrise	1.89	11.4	7.22	0	0	0.26	0	0
	Midday	1.17	2.85	8.48	0.38	0	0	0	0
	Sunset	2.71	16.4	10.7	0	0	0	0	0
	Midnight	6.77	40.8	18.5	7.80	0	0.25	0.32	0
Jun 23-24, 1992	Sunrise	8.03	46.8	19.2	12.7	1.58	0	0	0
	Midday	6.60	32.1	33.4	0.55	0	0	0	0
	Sunset	6.19	49.8	11.6	0.49	0	0	0	0
	Midnight	10.3	7.37	37.5	44.3	13.0	0.47	0	0
Jul 21-22, 1992	Sunrise	6.28	15.3	12.0	25.8	9.30	0.43	0	0
	Midday	2.66	16.6	7.07	1.20	1.22	0	0.50	0
	Sunset	2.21	10.7	2.35	7.05	1.92	0.13	0	0
	Midnight	6.54	14.1	2.07	34.6	14.1	0.13	0.33	0.18
Aug 4-5, 1992	Sunrise	3.37	5.53	8.72	16.7	2.53	0.21	0	0
	Midday	2.86	19.2	7.94	0.45	0.30	0.29	0.36	0
	Sunset	1.19	1.13	5.52	5.29	0	0	0	0
	Midnight	2.92	1.54	2.03	14.6	10.4	0.56	0	0
Sep 24-25, 1992	Sunrise	4.27	19.1	18.4	3.80	1.45	0	0	0
	Midday	1.71	9.80	6.64	0.47	0.19	0	0	0
	Sunset	8.44	38.6	26.6	16.8	1.98	0.47	0	0
	Midnight	12.6	2.03	12.2	22.1	48.9	34.2	5.58	0.41

Appendix D, continued.

Date	Period	Mean Areal Density (no./100 m^2)	Mean volumetric density (no./10^4 m^3) within depth stratum (m)						
			0-10	10-20	20-30	30-40	40-50	50-60	60-70
Oct 5-6, 1992	Sunrise	6.36	36.7	13.3	9.97	2.83	0.74	0	0
	Midday	6.36	42.7	20.0	0.37	0.49	0	0	0
	Sunset	3.59	9.48	16.4	9.83	0.15	0	0	0
	Midnight	3.39	3.94	6.63	7.69	7.35	8.33	0	0
Oct 26-27, 1992	Sunrise	6.75	12.4	41.9	6.50	4.41	2.00	0.35	0
	Midday	5.09	36.5	10.6	2.25	0.69	0.76	0	0
	Sunset	7.16	26.5	33.3	8.79	2.47	0.56	0	0
	Midnight	15.9	12.7	20.1	40.5	43.7	27.4	14.5	0.21
Nov 18-19, 1992	Sunrise	19.5	65.2	53.9	31.8	22.2	17.1	4.91	0
	Midday	3.34	3.33	19.8	6.08	3.01	1.22	0	0
	Sunset	6.78	19.2	29.2	14.0	4.20	0.97	0.32	0
	Midnight	20.9	37.7	30.0	30.3	47.0	49.9	12.3	2.18
Dec 8, 1992	Sunset	14.8	17.9	59.3	28.3	21.9	19.1	1.54	0.64
	Midnight	18.6	16.8	54.0	45.6	30.1	31.6	7.87	0.29
Dec 9, 1992	Sunrise	9.03	20.3	25.0	16.3	23.5	5.26	0	0
	Midday	3.31	15.4	3.84	5.51	5.06	3.28	0	0
	Sunset	3.05	3.38	8.76	5.88	9.41	2.28	0.82	0
	Midnight	32.2	30.0	36.8	53.2	65.6	77.9	52.2	6.29
Dec 10, 1992	Sunrise	7.80	10.3	24.6	21.3	18.0	3.76	0	0
May 25-26, 1993	Sunrise	10.9	43.9	65.3	0	0	0	0	0
	Midday	3.70	35.1	1.87	0	0	0	0	0
	Sunset	48.8	458	27.7	1.83	0	0	0	0
	Midnight	31.5	161	145	8.04	0	0	0	0
Jun 3-4, 1993	Sunrise	20.8	32.1	158	17.7	0.43	0	0	0
	Midday	9.47	72.9	20.3	0.87	0	0.58	0	0
	Sunset	16.2	50.3	72.8	29.7	9.34	0	0	0
	Midnight	19.8	12.1	99.3	62.2	24.3	0	0	0

Appendix D, continued.

Date	Period	Mean Areal Density (no./100 m²)	Mean volumetric density (no./10⁴ m³) within depth stratum (m)						
			0-10	10-20	20-30	30-40	40-50	50-60	60-70
Jun 10-11, 1993	Sunrise	12.3	51.5	62.8	8.65	0	0.18	0	0
	Midday	7.45	51.4	21.9	1.14	0	0	0	0
	Sunset	17.1	117	47.8	2.74	3.26	0	0	0
	Midnight	21.1	17.1	144	40.1	7.52	2.85	0	0
Jun 17-18, 1993	Sunrise	11.6	58.3	39.5	11.1	6.52	0.15	0	0
	Midday	4.32	23.7	17.8	1.67	0.12	0	0	0
	Sunset	9.56	35.0	27.7	15.0	18.0	0.28	0	0
	Midnight	19.6	14.7	101	53.7	27.5	0	0	0
Jun 24-25, 1993	Sunrise	8.04	55.5	23.7	1.10	0	0	0	0
	Midday	8.34	65.6	14.5	3.28	0	0	0	0
	Sunset	10.3	91.5	11.0	0	0	0	0	0
	Midnight	9.02	21.7	46.3	18.9	3.26	0	0	0

APPENDIX E

Number of fish and debris detected and time monitored by penstock sonar, December 4, 1990 - August 4, 1992

Appendix Table E1. Number of non-debris sonar targets, December 4, 1990-August 4, 1992 at Libby Dam.

Date Hour interval	12 4 90	12 12 90	1 8 91	1 22 91	2 4 91	2 21 91	2 28 91	4 1 91	4 10 91	4 22 91	5 6 91	5 23 91	6 4 91	6 18 91	7 2 91	7 15 91	8 1 91	8 16 91	11 14 91
Sunrise +1	1	0	0	0	0		52	0	1	1	1	2	0	4	4	3	1	0	2
Sunrise +2	0	0	0	0	1	0	15	0	0	0	6	3	5	0	3	2	0	2	0
Sunrise +3		0	0	0	0	0	27	0	0	1	3	1	3	2	5	7	1	0	0
Sunrise +4	--	--	--	--	--	--	--	0	1	5	2	0	0	0	1	9	0	0	--
Midday -4	--	--	--	--	--	--	--	0	0	0	1	2	0	4	1	10	0	0	--
Midday -3		0	0	0	1	0	0	0	0	0	0	2	0	8	3	14	1	0	0
Midday -2		0	1	0	0	0	2	0	0	1		8	0	1	1	26	4	1	0
Midday -1	1	0	0	0	0	0	0	0	0	1		0	0	4	4	4	3	0	0
Midday +1	0	0	0	0	0	0	0	0	0	1		2	0	6	6	16	2	1	1
Midday +2	0		0		1	0	0	0	0	4		2	0	1	0	13	0	1	0
Midday +3	0		0	0	0	0	0	0	0	0		2	0	4	1	19	0	0	1
Midday +4	--	--	--	--	--	--	--		0	1	0	4	0	1	2	19	0	0	--
Sunset -4	--	--	--	--	--	--	--		0	0	2	2	0	0	1	15	0	0	--
Sunset -3	0		0	0	0	1	0		0	0	0	0	0	2	1	2	0	0	0
Sunset -2	0	0	0	1	0	1	1	0	1	0		2	0	1	7	1	1	0	1
Sunset -1	0	0	0	0	1	1	0	0	0	1		8	1	4	9	2	0	0	0
Sunset +1	1	0	0	4	1	0	0	2	2	1		12	2	3	4	2	1	5	3
Sunset +2	4	1	0	2	4	1	1	2	3	0	0	10	6	4	4	3	3	0	1
Sunset +3	4	0	0	1	1	0	3	3	6	1	6	0	--	--	--	1	0	1	3
Sunset +4	1	0	0	3	1		0	--	--	--	--	--	--	--	--	--	--	--	3
Midnight -4	3	1	1	1	1		2	--	--	--	--	--	--	--	--	--	--	--	2
Midnight -3	2	1	0	1	1		0	4	6	3	3	0	--	--	--	0	0	1	1
Midnight -2	0	1	0	0	0		1	2	1	1	15	7	8	5	3	4	0	4	2
Midnight -1	0	1	1	1	0		6	4	0	4	9	11	7	3	5	5	3	1	2
Midnight +1	1	0	1	5	2		1	6	1	3	14	8	3	2	8	3	4	4	3
Midnight +2	1	2	1	5	0	2	7	0	3	2	12	9	5	4	5	2	1	2	4
Midnight +3	0	0	0	3	2	2	4	7	0	1	3	2	--	--	--	0	0	3	1
Midnight +4	0	0	2	3	0	1	2	--	--	--	--	--	--	--	--	--	--	--	1
Sunrise -4		1	1	0	0	2	1	--	--	--	--	--	--	--	--	--	--	--	0
Sunrise -3		1	2	0	0	6	2	3	0	0	1	1	--	--	--	0	0	1	1
Sunrise -2	0	2	1	1	2	1	1	3	1	1	3	5	5	3	3	0	1	3	
Sunrise -1	0	0	0	3	1		85	1	1	1	1	5	4	3	6	4	2	0	0
Total number targets	19	11	11	34	20	18	213	37	27	34	82	110	49	69	87	186	28	30	30

Appendix Table E2. Number of debris sonar targets, December 4, 1990 to November 14, 1991 at Libby Dam.

Hour interval \ Date	12 4 90	12 12 90	1 8 91	1 22 91	2 4 91	2 21 91	2 28 91	4 1 91	4 10 91	4 22 91	5 6 91	5 23 91	6 4 91	6 18 91	7 2 91	7 15 91	8 1 91	8 16 91	11 14 91
Sunrise +1	0	0	0	0	0		0	0	0	0	3	0	0	2	0	0	0	0	0
Sunrise +2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Sunrise +3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
Sunrise +4	--	--	--	--	--	--	--	0	0	0	0	0	1	0	0	1	0	0	--
Midday -4	--	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	0	0	--
Midday -3		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Midday -2		0	0	0	0	0	0	0	0	0		0	1	26	0	0	0	0	0
Midday -1	0	0	0	0	0	0	0	0	0	0		0	3	14	9	0	0	0	0
Midday +1	0	0	0	0	0	0	0	0	0	0		0	0	0	2	1	0	0	0
Midday +2	0		0		0	0	0	0	0	0		0	5	1	0	0	0	0	0
Midday +3	0		0	0	0	0	0	0	0	0		0	1	0	0	5	0	0	0
Midday +4	--	--	--	--	--	--	--		0	0	0	0	10	0	0	0	0	0	--
Sunset -4	--	--	--	--	--	--	--		0	0	0	0	4	0	0	0	0	0	--
Sunset -3	0		0	0	0	0	0		0	0	0	6	3	0	2	4	0	0	0
Sunset -2	0	1	0	0	0	0	0	0	0	0		3	7	0	0	0	0	0	0
Sunset -1	0	29	0	0	0	0	0	0	0	0		3	6	0	7	0	0	0	0
Sunset +1	0	5	0	0	0	0	0	0	0	0		0	11	0	2	0	0	0	0
Sunset +2	0	5	0	0	0	0	0	0	0	0	0	0	4	0	0	4	0	0	0
Sunset +3	0	0	0	0	0	0	0	0	0	0	0	0	--	--	--	0	0	0	0
Sunset +4	0	0	0	0	0		0	--	--	--	--	--	--	--	--	--	--	--	0
Midnight -4	0	0	0	0	0		0	--	--	--	--	--	--	--	--	--	--	--	0
Midnight -3	0	0	0	0	0		0	0	0	0	0	0	--	--	--	0	0	0	0
Midnight -2	0	0	0	0	0		0	0	0	0	0	8	8	0	0	0	0	0	0
Midnight -1	0	0	0	0	0		0	0	0	0	2	0	0	0	0	4	0	0	0
Midnight +1	0	0	0	0	0		0	0	0	0	4	0	0	0	5	0	0	0	0
Midnight +2	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0
Midnight +3	0	0	0	0	0	0	0	0	0	0	2	0	--	--	--	0	0	0	0
Midnight +4	0	0	0	0	0	0	0	--	--	--	--	--	--	--	--	--	--	--	0
Sunrise -4		0	0	0	0	0	0	--	--	--	--	--	--	--	--	--	--	--	0
Sunrise -3		0	0	0	0	0	0	0	0	0	0	0	--	--	--	0	0	0	0
Sunrise -2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sunrise -1	0	0	0	0	0		0	0	0	0	12	0	0	3	0	0	0	0	0
Total number targets	0	40	0	0	0	0	0	0	0	0	23	20	64	50	31	22	0	0	0

Appendix Table E3. Minutes of coverage by penstock sonar in hourly intervals, December 4, 1990 - November 14, 1991 at Libby Dam.

Date Hour interval	12 4 90	12 12 90	1 8 91	1 22 91	2 4 91	2 21 91	2 28 91	4 1 91	4 10 91	4 22 91	5 6 91	5 23 91	6 4 91	6 18 91	7 2 91	7 15 91	8 1 91	8 16 91	11 14 91
Sunrise +1	60	60	60	60	60	0	60	60	41	60	60	60	60	60	60	60	60	60	60
Sunrise +2	42	60	60	60	60	60	60	60	60	6	60	60	60	60	53	60	60	60	60
Sunrise +3	0	5	6	16	50	39	45	60	60	41	60	60	50	60	59	60	60	60	18
Sunrise +4	--	--	--	--	--	--	--	9	20	31	52	53	59	60	60	57	45	36	--
Midday -4	--	--	--	--	--	--	--	10	20	31	52	53	59	60	60	56	46	35	--
Midday -3	0	5	6	16	50	39	45	60	60	60	5	38	60	60	60	60	62	60	17
Midday -2	0	60	60	60	96	60	60	49	102	60	0	60	60	61	60	101	98	50	60
Midday -1	37	60	60	52	60	60	54	40	66	30	0	60	60	60	60	61	60	60	60
Midday +1	60	25	58	18	50	53	60	60	60	60	0	60	60	60	60	60	60	60	60
Midday +2	60	0	63	0	60	55	60	60	60	60	0	60	60	60	60	60	60	60	60
Midday +3	7	0	6	9	25	38	45	51	60	60	0	60	60	60	60	60	60	60	18
Midday +4	--	--	--	--	--	--	--	0	20	31	20	53	60	42	60	56	46	35	--
Sunset -4	--	--	--	--	--	--	--	0	20	31	42	53	60	24	60	56	46	36	--
Sunset -3	7		7	15	23	39	44	0	11	46	24	60	60	60	60	60	60	60	17
Sunset -2	60	60	60	60	47	47	60	25	45	10	0	60	98	60	109	60	60	60	112
Sunset -1	52	60	60	60	60	60	8	60	60	60	0	60	120	60	120	60	60	60	120
Sunset +1	60	60	60	60	60	60	60	60	60	60	0	60	120	60	120	60	60	60	120
Sunset +2	60	60	60	60	60	60	60	60	60	60	2	46	120	57	80	60	40	60	120
Sunset +3	60	60	60	60	60	34	60	49	39	28	17	0	--	--	--	3	13	23	120
Sunset +4	52	55	52	43	35	0	15	--	--	--	--	--	--	--	--	--	--	--	82
Midnight -4	46	56	53	43	34	0	15	--	--	--	--	--	--	--	--	--	--	--	84
Midnight -3	60	34	44	60	60	0	60	50	40	28	17	0	--	--	--	3	13	24	99
Midnight -2	60	60	60	6	60	0	58	27	27	60	60	58	89	58	58	46	60	104	60
Midnight -1	60	60	60	41	53	0	54	50	55	59	60	60	60	60	60	60	60	120	60
Midnight +1	60	60	60	60	55	0	60	60	60	60	60	60	60	60	60	60	60	120	60
Midnight +2	60	60	60	60	60	54	60	60	60	60	60	60	60	58	60	60	60	120	60
Midnight +3	60	60	60	60	60	60	60	49	38	28	17	6	--	--	--	3	13	39	60
Midnight +4	32	54	53	43	35	20	14	--	--	--	--	--	--	--	--	--	--	--	22
Sunrise -4	0	54	53	44	34	20	14	--	--	--	--	--	--	--	--	--	--	--	21
Sunrise -3	0	28	61	50	60	60	60	49	38	28	17	6	--	--	--	2	14	23	16
Sunrise -2	58	60	60	60	48	16	11	60	60	60	14	60	60	57	60	60	60	60	0
Sunrise -1	60	60	60	60	60	0	60	26	21	36	60	60	60	60	60	60	60	60	51
Total minutes coverage	1173	1276	1420	1182	1475	934	1321	1204	1323	1244	759	1386	1675	1367	1619	1464	1460	1665	1697

Appendix Table E4. Non-debris sonar targets from November 18, 1991 to August 4, 1992 at Libby Dam.

IWM:,~;~~	11 18	12 4 91	12 19	1 13	1 28	2 12	2 25	3 10	4 1 92	4 15	4 29	5 12	5 27	8 92	6 23	6 30	7 21	8 4 92
Sunrise +1	0	1	0	1	0	0	0	0	0	0	2	3	0	2	2		2	1
Sunrise +2		4	1	0	0	0	0	0	0	0	0	4	0	0	0		2	0
Sunrise +3		0	0	0	0	0	0	0	0	0	3	0	0	0	0		0	0
Sunrise +4	--	--	--	--	--	--	--	--	1	0	0	3	0		1		1	0
Midday -4	--	--	--	--	--	--	--	--	0	0	1	0	0		0		0	0
Midday -3		0	0	0	0	0	0	2	0	0	0	2	0		0		0	0
Midday -2		0	0	0	0	0	1	0	0	0	0	0	0			0	0	0
Midday -1	1	0	0	1	0	0	0	0	0		1		0			0	0	0
Midday +1	4	1	0	0	0	0	0	0	0	0	3		0			0	0	0
Midday +2	0	1	0	1	0	0	0	0	0	0	1		0			0	0	0
Midday +3	0	0		0	0	0	0	0	0	0	1	1	1	5	1	0	0	0
Midday +4	--	--	--	--	--	--	--	--	0	0	0	5	0	20	0	1	0	0
Sunset -4	--	--	--	--	--	--	--	--	0	0	2	2	0	3	0	0	0	0
Sunset -3	0	0	0	0	0	0	0	0	0	0	0	5	0	3	0	0	0	0
Sunset -2	0	0		0	0	0	0	0	0	0	2	4	0	0	1	0	0	1
Sunset -1	2	0	0	0	0	0	0	0	0	0	1	16	0	0	0	1	0	0
Sunset +1	3	0	1	0	0	0	1	0	0	0	0	18	0	0	0	0	0	0
Sunset +2	5	0	5	0	2	0	1	0	0	0	2	15	2	1	0	0	2	0
Sunset +3	1	2	1	0	2	1	5	0	0	0	0	6	0	--	--	--	--	0
Sunset +4	2	2	4	1	2	0	0	0	--	--	--	--	--	--	--	--	--	--
Midnight -4	4	0	0	1	0	0	0	0	--	--	--	--	--	--	--	--	--	--
Midnight -3	1	0	1	1	1	0	4	2	1	0	2	6	0	--	--	--	--	1
Midnight -2	1	2	0	0	1	0	2	0	0	0	3	12	0	1	0	0	2	1
Midnight-I	1	0	0	0	2	0	2	0	0	0	0	2	1	2	0		1	2
Midnight +1	2	1	1	0	0	0	3	0	0	0	4	1	0	2	0		1	2
Midnight +2	0	0	0	0	0	2	3	3	0	2	1	11	0	1	0		0	2
Midnight +3	2	1	0	0	0	0	1	2	0	2	0	2	0	--	--		--	1
Midnight +4	2	1	0	0	0	0	1	0	--	--	--	--	--	--	--		--	--
Sunrise -4	1	4	0	1	0	0	1	0	--	--	--	--	--	--	--		--	--
Sunrise -3	7	0	1	0	1	0	2	2	0	2	2	0	0	--	--		--	0
Sunrise -2	3	2	0	0	2	0	1	2	0	0	0	1	0	0	2		2	5
Sunrise -1	2	1	0	0	0	1	5	0	1	1	0	3	2	0	0		2	5
Total number targets	44	23	15	7	13	4	33	13	3	7	31	122	6	40	7	2	15	21

Appendix Table E5. Debris sonar targets from November 18, 1991 to August 4, 1992 at Libby Dam.

Date / Hour interval	11 18 91	12 4 91	12 19 91	1 13 92	1 28 92	2 12 92	2 25 92	3 10 92	4 1 92	4 15 92	4 29 92	5 12 92	5 27 92	6 9 92	6 23 92	6 30 92	7 21 92	8 4 92
Sunrise +1	0	0	0	0	0	0	0	0	0	0	8	21	0	0	0		0	0
Sunrise +2		0	0	0	0	0	0	0	0	0	10	31	1	0	0		0	0
Sunrise +3		0	0	0	0	0	0	0	0	0	33	38	1	0	0		0	0
Sunrise +4	--	--	--	--	--	--	--	--	0	0	4	50	0		0		0	0
Midday -4	--	--	--	--	--	--	--	--	0	0	19	23	2		0		0	0
Midday -3		0	0	0	0	0	0	0	0	0	16	29	1		0		0	0
Midday -2		0	0	0	0	0	0	0	0	0	0	14	1			0	0	0
Midday -1	0	0	0	0	0	0	0	0	0		0		4			0	0	0
Midday +1	1	0	0	0	0	0	0	0	0	0	0		1			0	0	0
Midday +2	5	0	0	0	0	0	0	0	0	0	0		6			0	0	0
Midday +3	3	0		0	0	0	0	0	0	0	0	2	3	8	0	0	0	0
Midday +4	--	--	--	--	--	--	--	--	0	0	0	7	3	0	0	0	0	0
Sunset -4	--	--	--	--	--	--	--	--	0	0	0	32	3	0	0	0	0	0
Sunset -3	5	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	0
Sunset -2	0	0		0	0	0	0	0	0	0	0	4	2	0	0	0	0	0
Sunset -1	0	0	0	0	0	0	0	0	0	0	0	5	3	0	0	0	0	0
Sunset +1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Sunset +2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Sunset +3	0	0	0	0	0	0	0	0	0	0	0	0	1	--	--	--	--	0
Sunset +4	0	0	0	0	0	0	0	0	--	--	--	--	--	--	--	--	--	--
Midnight -4	0	0	0	0	0	0	0	0	--	--	--	--	--	--	--	--	--	--
Midnight -3	0	0	0	0	0	0	0	0	0	0	0	0	0	--	--	--	--	0
Midnight -2	0	0	0	0	0	0	0	0	0	0	0	50	5	0	0	0	0	0
Midnight -1	0	0	0	0	0	0	0	0	0	0	0	25	3	0	0		0	0
Midnight +1	0	0	0	0	0	0	0	0	0	0	0	44	4	0	0		0	0
Midnight +2	0	0	0	0	0	0	0	0	0	0	0	66	0	0	0		0	0
Midnight +3	0	0	0	0	0	0	0	0	0	0	0	13	1	--	--		--	0
Midnight +4	0	0	0	0	0	0	0	0	--	--	--	--	--	--	--		--	--
Sunrise -4	0	0	0	0	0	0	0	0	--	--	--	--	--	--	--		--	--
Sunrise -3	0	0	0	0	0	0	0	0	0	0	0	5	0	--	--		--	0
Sunrise -2	0	0	0	0	0	0	0	0	0	0	0	79	3	0	0		0	0
Sunrise -1	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0		0	0
Total number targets	14	0	0	0	0	0	0	0	0	0	90	558	55	8	0	0	0	0

Appendix Table E6. Minutes of coverage by penstock sonar on an hourly basis from November 18, 1991 to August 4, 1992 at Libby Dam.

Date Hour interval	11 18 91	12 4 91	12 19 91	1 13 92	1 28 92	2 12 92	2 25 92	3 10 92	4 1 92	4 15 92	4 29 92	5 12 92	5 27 92	6 9 92	6 23 92	6 30 92	7 21 92	8 4 92
Sunrise +1	34	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	60	52
Sunrise +2	0	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	60	60
Sunrise +3	0	8	4	10	20	31	41	52	60	60	60	60	60	58	60	0	60	60
Sunrise +4	--	--	--	--	--	--	--	--	10	25	35	45	55	0	60	0	58	38
Midday -4	--	--	--	--	--	--	--	--	9	25	35	46	55	0	60	0	57	38
Midday -3	0	7	3	10	20	31	41	53	60	60	27	60	60	0	31	0	60	60
Midday -2	0	60	60	60	60	65	70	60	60	47	38	10	11	0	0	44	6	29
Midday -1	20	60	60	60	43	120	120	34	47	0	60	0	60	0	0	60	60	60
Midday +1	60	88	60	46	60	120	86	60	60	2	60	0	60	0	0	60	60	53
Midday +2	60	120	28	60	60	120	60	60	60	60	60	0	60	0	0	60	60	60
Midday +3	15	12	0	8	18	50	40	53	60	60	60	52	60	25	41	60	60	60
Midday +4	--	--	--	--	--	--	--	--	10	24	36	46	55	60	60	60	60	43
Sunset -4	--	--	--	--	--	--	--	--	10	25	37	47	56	60	60	60	58	44
Sunset -3	16	14	0	9	18	31	41	53	60	60	60	60	60	60	60	60	60	60
Sunset -2	60	65		60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sunset -1	60	60	16	60	60	60	60	60	60	60	60	60	60	60	60	60	60	50
Sunset +1	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sunset +2	60	60	60	60	60	60	60	60	60	60	60	60	60	58	58	58	52	60
Sunset +3	60	60	60	60	60	60	60	60	49	54	22	12	3	--	--	--	--	15
Sunset +4	43	52	56	50	40	29	18	6	--	--	--	--	--	--	--	--	--	--
Midnight -4	44	52	55	50	40	28	19	6	--	--	--	--	--	--	--	--	--	--
Midnight -3	60	60	60	60	60	60	60	60	50	55	23	13	4	--	--	--	--	16
Midnight -2	60	60	60	60	60	60	60	60	60	60	50	50	60	58	57	58	60	60
Midnight -1	56	49	60	51	54	50	54	38	56	60	59	60	48	48	54	0	60	29
Midnight +1	60	60	60	60	60	60	60	60	60	48	60	60	60	60	60	0	60	20
Midnight +2	60	60	53	60	60	60	60	60	60	60	60	60	60	60	57	0	60	60
Midnight +3	60	60	60	60	60	60	60	60	49	34	22	14	4	--	--	--	--	21
Midnight +4	44	52	55	49	39	28	18	7	--	--	--	--	--	--	--	--	--	--
Sunrise -4	44	52	56	50	39	28	18	6	--	--	--	--	--	--	--	--	--	--
Sunrise -3	60	60	60	60	60	60	60	60	49	34	22	13	4	--	--	--	--	21
Sunrise -2	60	60	60	60	60	60	60	60	60	60	60	60	60	60	58	0	60	60
Sunrise -1	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	60	60
Total number targets	1216	1531	1286	1413	1411	1631	1526	1388	1419	1323	1366	1188	1375	967	1136	760	1371	1309

Appendix F. Summary of sonar target densities in forebay, December 4, 1990 - June 25, 1993. Target densities are stratified by near-dam (transects I-6) and far-dam (transects 7-12) areas. Density values in this Appendix are intended to be used to estimate AREAL DEN, DIOP (I-6) and DIOP (7-12) values for the nultiple regression model.

Season[a]	Transects	N	Period	Mean volunetric density (no./10⁴ m³) within depth stratun (m) O-10	10-20	20-30	30-40	40-50	SO-60	60-70
Spring	I-6	14	Sunrise	38.1	60.1	6.12	0.52	0	0	0
		14	Midday	49.6	12.7	2.56	0.25	0	0	0
		14	Sunset	142.1	42.3	14.5	6.50	0.08	0.42	0
		14	Midnight	124.4	117.3	28.5	10.3	0.62	0	0
Spring	7-12	13	Sunrise	46.4	59.6	10.1	1.91	0.10	0	0
		14	Midday	34.0	13.9	1.37	0.04	0.16	0	0
		14	Sunset	164.1	49.9	6.00	3.32	0		0
		14	Midnight	70.4	143.3	30.6	7.09	0.40	8	0
Summer	I-6	22	Sunrise	26.9	19.2	12.2	2.84	1.86	1.31	0.05
		21	Midday	33.5	17.4	20.5	1.67	1.31	0.18	0
		20	Sunset	28.1	21.7	6.72	1.47	0.39	0.54	0.41
		20	Midnight	15.2	24.9	25.2	11.8	4.91	1.04	0.14
Summer	7-12	18	Svlris	22.1	21.5	6.36	2.58	0.93	0.15	0.04
		19	Midday	19.1	10.2	2.28	1.79	1.26	1.67	0.95
		20	Sunset	27.9	18.7	6.01	1.24	0.27	0.47	0.25
		20	Midnight	13.8	21.7	41.1	14.1	7.37	1.47	0.11
Fall	I-6	22	Sunrise	21.8	20.3	11.9	9.12	4.15	1.06	0.22
		20	Midday	9.95	7.67	2.40	1.31	1.60	0.34	0.15
		22	Sunset	20.5	22.3	8.65	5.71	4.01	0.60	0
		20	Midnight	31.6	21.4	18.8	21.7	23.8	9.31	0.41
Fall	7-12	22	Sunrise	7.44	13.2	6.18	4.58	1.38	0	0
		20	Midday	5.28	4.41	2.29	1.87	0.43	0.28	0.08
		22	S w e t	16.7	13.1	5.96	3.06	1.39	0.36	0.21
		20	Midnight	25.3	15.6	25.1	23.3	14.9	9.42	1.53
Winter	I-6	23	Sunrise	5.44	5.29	5.07	1.40	0.53	0	0
		22	Midday	7.63	2.00	1.12	0.41	0.10	0.16	0.08
		22	Sunset	2.50	1.92	1.01	0.53	0.32	0.06	0.12
		23	Midnight	18.6	9.45	4.19	3.48	0.78	0	0
Uinter	7-12	21	Sunrise	2.43	4.19	2.72	1.26	0.48	0	0
		22	Midday	4.42	0.89	0.43	0.27	0.41	0.05	0
		22	Sunset	0.94	4.86	0.77	0.49	0.07	0.08	0.08
		21	Midnight	23.3	7.43	4.15	2.87	0.35	0	0.13

'Spring sample sessions are a sub-set of those indicated for Spring in Table 5, and are the sessions thought to be relatively free of woody debris.