

**Placer County Water Agency  
Middle Fork American River Project  
(FERC No. 2079)**

***FINAL***

**AQ 7 – ENTRAINMENT  
TECHNICAL STUDY REPORT – 2011**



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## 1.0 INTRODUCTION

This report describes the AQ 7 – Entrainment Technical Study conducted by Placer County Water Agency (PCWA) in accordance with the AQ 7 – Entrainment Technical Study Plan (AQ 7 – TSP) (PCWA 2007a) and Entrainment Direct Sampling Approach (Contingency Study) (PCWA 2008a). The AQ 7 – TSP was included in the Supporting Document (SD) H of the Pre-Application Document (PAD) for the Middle Fork American River Project (MFP or Project) (PCWA 2007b).

The AQ 7 – TSP specified a process for the Aquatic Technical Working Group (TWG) to collaboratively determine if direct sampling of entrainment was needed to supplement the indirect entrainment estimates developed for Project intake/diversion facilities. A working draft whitepaper report (Whitepaper Report) (Attachment A) that contained indirect entrainment calculation information identified in the AQ 7 – TSP was distributed to the Aquatic TWG on July 3, 2008. The Whitepaper Report was discussed during the July 8, 2008 Aquatic TWG meeting. During the meeting, the Aquatic TWG determined that direct entrainment sampling was necessary to complete the AQ 7 – TSP. The Aquatic TWG also concluded that additional work did not need to be expended on the Whitepaper Report because it adequately addressed the indirect sampling study elements outlined in the AQ 7 – TSP. Further, the Aquatic TWG determined that the Whitepaper Report should remain a "Draft" document.

PCWA, in collaboration with the Aquatic TWG, developed a scope of work and schedule for direct entrainment sampling (AQ 7 – Entrainment Direct Sampling Approach (Contingency Study) [AQ 7 – Contingency TSP; PCWA 2008a]). The draft scope of work was discussed at the September 8, 2008 TWG. It was then revised to reflect comments discussed during the meeting and distributed to the Aquatic TWG by e-mail on September 16, 2008 for review and approval. No additional comments were received. Accordingly, as agreed to by the Aquatic TWG, the scope of work was deemed final.

This report includes: (1) a Project facilities characterization in relation to fish entrainment; (2) a feasibility level diversion intake screening cost assessment; (3) indirect method entrainment estimates; and (4) direct entrainment sampling results and estimates. The draft indirect entrainment study includes information from the Whitepaper Report and from a power point presentation made to the Aquatic TWG on June 2, 2008 (Attachment A and Attachment B, respectively).

Direct entrainment sampling at the Duncan Creek Diversion Intake is provided in this report and was used to estimate entrainment potential at the North Fork and South Fork Long Creek diversion intakes and Middle Fork Interbay (Ralston Powerhouse Intake). Direct sampling of the large reservoir intakes (sonar) and fry emergence at the small diversion streams is also reported as it relates to entrainment potential. Direct entrainment sampling at Ralston Afterbay and Middle Fork Interbay, as described in the direct sampling contingency study and reported here, was not successful. An alternative study approach for sampling these locations is provided in Section 3.4 Proposed Modifications to Technical Study Plan.

The purpose of the AQ 7 – Entrainment Technical Study is to characterize potential fish mortality or translocation associated with MFP flow diversion, intake structures, or powerhouse facilities.

The draft report was distributed to the MFP Plenary on December 15, 2010 for a 30-day comment period. The comment period ended on January 15, 2011, with no comments received.

The following sections provide a description of the study objectives, study implementation, extent of the study area, study approach, study results, summary, and literature cited.

## **2.0 STUDY OBJECTIVES**

The objectives of the entrainment study in the AQ 7 – TSP and the AQ 7 – Contingency TSP include the following:

- Characterize Project facilities (diversions, intake structures and intakes, and powerhouse turbines) and operations in relation to factors (e.g., velocity fields) that may affect entrainment or mortality.
- Develop the information necessary to assess the feasibility of screening intake structures (technical feasibility, feasibility level cost estimates, and maintenance requirements of screens).
- Indirectly estimate the potential for entrainment and mortality using the Project facility characterizations and literature information.
- Directly sample mortality and entrainment at selected Project facilities.
  - Sample fish distribution and abundance near power tunnel intakes in French Meadows Reservoir and Hell Hole Reservoir.
  - Directly sample entrainment at Ralston Afterbay, Middle Fork Interbay, and Duncan Creek Diversion.
  - Sample young-of-the-year (YOY) fish abundance and emergence timing upstream of the Duncan Creek Diversion.

Figure AQ 7-1 shows the AQ 7 – TSP study objectives and the study elements associated with each objective. It also shows where information developed is documented.

## **3.0 STUDY IMPLEMENTATION**

Study elements described in the AQ 7 – TSP (PCWA 2007a) and the Contingency Study were initiated in 2008 and the final report will be completed in 2011. A summary of the study elements that have been completed, outstanding study elements, and any

deviations or proposed modifications to the AQ 7 – TSP are discussed in the following subsections.

### **3.1 STUDY ELEMENTS COMPLETED**

The following study elements were completed and are included in this report:

- Characterized Project diversion structures and intakes, diversion operations, and powerhouse turbines. Provided either calculated or measured intake velocity fields at each intake structure over the range of potential inflows.
- Developed the information necessary to assess the cost of screening intake structures.
- Indirectly estimated entrainment and mortality potential at Project facilities.
- Collaborated with the Aquatic TWG to determine whether direct measurements of entrainment and mortality were warranted.
- Developed an approach for directly sampling entrainment at selected locations in collaboration with the Aquatic TWG.
  - Sampled fish distribution and abundance throughout the water column in French Meadows and Hell Hole reservoirs.
  - Directly sampled entrainment at Ralston Afterbay, Middle Fork Interbay, and Duncan Creek Diversion
  - Sampled YOY fish abundance and emergence timing upstream of the Duncan Creek Diversion.
  - Monitored Ralston Powerhouse and Oxbow Powerhouse intakes for entrainment using split-beam sonar.

### **3.2 DEVIATIONS FROM TECHNICAL STUDY PLAN**

The entrainment studies were conducted as outlined in the AQ 7 – TSP and the AQ 7 – Contingency Study with the following enhancement:

- Additional sampling for YOY fish abundance and emergence timing upstream of North Fork Long Canyon Diversion and South Fork Long Canyon Diversion was completed. These sampling locations were not included in the AQ 7 – Contingency TSP.

### **3.3 OUTSTANDING STUDY ELEMENTS**

The following study element will be completed in 2011:

- Characterize the technical feasibility of installing screens and maintenance requirements. This study element will be discussed and developed (if appropriate) in consultation with the Aquatic TWG during development of the Protection, Mitigation, and Enhancement (PM&Es).

### **3.4 PROPOSED MODIFICATION TO TECHNICAL STUDY PLAN**

There are no proposed modifications to the AQ 7 – TSP.

However, PCWA has committed to further study fish entrainment at Ralston Powerhouse and Oxbow Powerhouse intakes in consultation with USDA-FS, State Water Board, and CDFG (see Fish Population Monitoring Plan [PCWA 2011]).

### **4.0 EXTENT OF STUDY AREA**

The study area for characterization of the Project diversions, intake structures, and powerhouse turbines includes Duncan Creek Diversion, North Fork Long Canyon Diversion, South Fork Long Canyon Diversion, French Meadows Powerhouse, Hell Hole Powerhouse, French Meadow-Hell Hole Tunnel Intake, Hell Hole-Middle Fork Tunnel Intake, Middle Fork Powerhouse, Middle Fork-Ralston Tunnel Intake, Ralston Powerhouse, Ralston-Oxbow Tunnel Intake, and Oxbow Powerhouse (Map AQ 7-1).

The study area for sampling fish distribution and abundance near power tunnel intakes includes the French Meadows-Hell Hole Tunnel Intake at French Meadows Reservoir and the Hell Hole-Middle Fork Tunnel Intake at Hell Hole Reservoir. The study area for direct entrainment sampling includes the Ralston-Oxbow Tunnel Intake (at Ralston Afterbay), Middle Fork-Ralston Tunnel Intake (at Middle Fork Interbay), and the Duncan Creek Diversion Intake. The study area for sampling YOY abundance and emergence timing is the stream reaches above the Duncan Creek Diversion, North Fork Long Canyon Creek Diversion, and the South Fork Long Canyon Creek Diversion (Map AQ 7-1).

### **5.0 STUDY APPROACH**

The study approach contains the methods for the: (1) Project facilities characterization; (2) screening feasibility cost assessment; (3) indirect entrainment estimate; and (4) direct sampling entrainment estimate.

#### **5.1 PROJECT FACILITIES CHARACTERIZATION**

Characterization of the Project facilities with respect to entrainment consisted of the following:

- Maps of each of the Project diversions facilities;
- Pictures of each structure with labels identifying the intakes and outlets;

- Summaries of the monthly exceedance flows (10, 20, 50, 80, and 90%) at each diversion facility for both the inflows and outflows and for the percent of flow diverted;
- Characterization of diversion structures and intakes by hydraulic capacity, frequency of use, inlet/outlet type, inlet area, intake depth, and approach velocity over a wide range of flows;
- Estimates of the potential mortality rate of entrained fish for various types of infrastructure (e.g., Pelton and Francis turbines) based on studies in the literature.

In addition, at each of the Project facilities the sustained swimming performance capability of fish (trout, cyprinids) was compared to the intake velocity to evaluate non-volitional fish entrainment potential. For the analysis a swimming velocity of three body lengths per second was used to estimate the approximate threshold for non-volitional entrainment. Sustained swimming velocity for trout and cyprinids ranges from approximately 2 ft/s to 4 ft/s (PCWA 2008b). Two fish sizes were used for the analysis, juvenile fish < 6 in (used 4.5 in) and adult fish > 6 in (used 9 in). The sustained swimming velocity for juvenile and adult fish was 1.1 ft/s and 2.3 ft/s, respectively.

## **5.2 SCREENING FEASIBILITY COST ASSESSMENT**

A screening feasibility cost assessment was conducted for the Project diversion structures and intakes. Estimates of screen design and construction costs were based on 35 California screening projects completed from 1983 to 2005. The data were obtained from the National Oceanic and Atmospheric Administration (NOAA) and the United States Fish and Wildlife Service (USFWS). The costs also include estimated screening cost for the Yuba River (NMFS 2010). Screening costs were compiled for screens within four flow categories (50–100 cfs, 100–500 cfs, 500–1000 cfs, >1000 cfs). The historic screen costs were converted to approximately 2008 dollars using a 3% inflation rate. The current cost of these screens is uncertain due to recent large increases in steel and materials prices. The potential cost of installation of screens at each diversion intakes was estimated using the appropriate per cfs screening cost and the maximum volume of the diversion. Further detailed analysis (site specific cost estimates) would be required to refine the estimates.

It should be noted that the cost of screens based on data available from Washington State was also compiled; however, the costs were significantly lower than California screen costs. The California costs were used because they are considered to be more applicable to the MFP.

The AQ 7 – TSP also includes a characterization of the technical feasibility of installing screens and maintenance requirements. This study element, however, is not included in this report and will be discussed and developed (if appropriate) in consultation with the Aquatic TWG during development of the PM&Es.

### 5.3 INDIRECT ENTRAINMENT ESTIMATES

PCWA collaborated with the Aquatic TWG to develop an approach to estimate entrainment by indirect means (i.e., without direct sampling of entrainment). PCWA expanded upon a preliminary draft fish entrainment threshold calculation approach proposed by California Department of Fish and Game (CDFG 2007; Whitepaper Report). The approach was to estimate potential entrainment at the small to medium diversion pools (Duncan, North Fork Long Canyon, South Fork Long Canyon, and Middle Fork Interbay) by calculating:

- Downstream emigration/movement of two size categories: YOY and juvenile/adult; and
- Percent of fish entrained based on the percent of flow diverted (monthly 50% exceedance value 1975–2007) (Table AQ 7-1).

Three general indirect approaches were used to estimate downstream movement/entrainment at the small to medium size diversion pools:

- Empirical Data Set Extrapolation – Historic entrainment sampling data from West Panther Creek (Mokelumne River tributary), a nearby west slope Sierra Nevada stream, were used to estimate YOY and juvenile/adult fish downstream movement (and entrainment) in the bypass reaches associated with the MFP. The West Panther Creek diversion was sampled nearly continuously for entrainment (1983–1984) (Bozeman et al. 1987) using an inclined plane fish trap (1/8 inch slot spacing) to sample 100% of the diverted flow. The 1984 West Panther Creek entrainment data were summarized on a weekly basis. Any missing data were interpolated/extrapolated. The number of fish moving downstream was calculated by adjusting observed captures by trap effort and percent diversion (Table AQ 7-2). The data were then applied to streams associated with the MFP based on the fish population size present in the streams and the percent of flow diverted at MFP facilities (Tables AQ 7-3 and AQ 7-1).
- Literature Based Fish Movement Studies – Existing literature on resident trout movement were used to estimate downstream movement of juvenile/adult trout in the vicinity of MFP diversions. Studies of resident trout movement from small streams and from some nearby rivers (Gowen and Fausch 1996; Jenkins et al. 1999; Hilderbrand and Kershner 2000; Graf 2007) were fit to probability of dispersal distance distributions (dispersal curves) (Rodriguez 2002) (Table AQ 7-4). The dispersal probability distributions were used to predict the number of fish that would move downstream (Table AQ 7-5). The data were applied to the MFP diversions by scaling them to the population density upstream of each diversion (Table AQ 7-3). The percent of the fish potentially entrained was then calculated to be proportional to the percent of diverted flow.
- Canal Entrainment Empirical Data Sets – Data from previous canal or power tunnel entrainment studies (resident trout) were summarized as a source of

information on downstream fish movement. Data from the Bow River, Canada (Post et al. 2006); Smiths Fork River, WY (Carlson and Rahel 2007); Middle Fork Stanislaus River, CA (PG&E 2002); and three canals on the DeSabra Project, Butte Creek, CA (PG&E 2007) (Table AQ 7-6) were used. The information available for the canal data sets such as percent of flow diverted, fish population upstream of the canal intake, timing of the fish entrainment, etc. was variable/uncertain and had to be estimated; therefore the canal data were simply reported as the number of fish diverted and no attempt was made to scale the data to the MFP diversions.

The details of the development of each of the indirect methods are provided in the Whitepaper Report (Attachment A). In this report, the indirect entrainment methods identified above were updated. Updates to the indirect methods include using updated fish population densities, correcting errors found in the draft Whitepaper Report approaches, incorporating the dates when MFP diversions cease operations in developing YOY entrainment calculations, and simplifying the canal entrainment approach to better match the available data. The indirect entrainment estimates are supplemental to the direct sampling entrainment estimates described below.

#### **5.4 DIRECT SAMPLING ENTRAINMENT ESTIMATES**

Direct entrainment sampling as determined by the Aquatic TWG consisted of the following approach (PCWA 2008a):

- Sample fish distribution and abundance near power tunnel intakes in French Meadows Reservoir and Hell Hole Reservoir.
- Directly sample entrainment at Ralston Afterbay, Middle Fork Interbay, and Duncan Creek Diversion.
- Sample YOY fish abundance and emergence timing upstream of the Duncan Creek diversion.

The methods for collecting direct sampling data and using the data to estimate entrainment are provided below for the: (1) large reservoirs; (2) medium reservoirs; and (3) small diversions.

##### **5.4.1 Large Reservoirs**

Fish abundance/vertical distribution was sampled throughout the water column near the French Meadows-Hell Hole Tunnel Intake (French Meadows Reservoir) and near the Hell Hole-Middle Fork Tunnel Intake (Hell Hole Reservoir) to estimate the likelihood of fish entrainment at the intakes. Fish sampling was accomplished with a single beam sonar unit (Hummingbird 967c). Surveys were conducted both day and night in the fall, spring, summer, and late summer seasons (Table AQ 7-7). Excessive debris in the water column during the spring prohibited successful spring sonar data collection in Hell Hole Reservoir, despite repeated attempts (Table AQ 7-7).

Each survey consisted of a minimum of five transects that were approximately 200 m in length for a total sampling effort of at least one hour. In total, over 900 meters (linear transects) were sampled during each survey. Day surveys took place between 11:00 AM and 3:00 PM. All night surveys began at least 2 hours after sunset. Transects were oriented parallel to each other and spaced so that the bottom width of the sonar beams for each track did not overlap (approximately 20–80 meters depending on the water depth). The set of parallel sonar tracks was centered approximately on the intake Global Positioning System (GPS) coordinate location (Map AQ 7-7, Map AQ 7-8).

#### **5.4.2 Medium Reservoirs**

Scientific-grade split-beam echo sounders were installed at the Middle Fork-Ralston Tunnel Intake (Middle Fork Interbay) and the Ralston-Oxbow Tunnel Intake (Ralston Afterbay) to measure fish entrainment. Three BioSonics (Model DT-X 420 kHz) transducers (6° beam angle) were installed inside the trash rack at each intake and oriented towards the throat of the intake. The sonars ensonified approximately 50% of the intake opening. The sonars were deployed March 2009–July 2010. Data were stored on a hard drive and archived periodically.

A preliminary analysis of every 6th day (March to June 2009) was conducted in the late summer of 2009. The preliminary analysis included time periods when the powerhouses were operating and not operating. To determine the risk of entrainment, the direction that an assumed “fish” target traveled was taken into account and “fish” targets that were traveling at angles towards the intake and at the depth of the intake were assumed to be entrained. To eliminate the possibility of milling fish the number of fish moving upstream (from the intake) was subtracted from the number of fish moving downstream (toward the intake).

The preliminary analysis showed that velocity in the portion of the intake where the beams were sampling was below entrainment velocity. As a result, fish were freely milling about in the intakes and using the shade/shelter of the intakes as a habitat refuge. Data collected during no flow time periods (powerhouse off) and subsequent analyses of those data based on criteria described above provided estimates of significant positive entrainment (an incorrect conclusion). Settling debris and underestimation of fish moving away from the intake potentially caused this problem. The results from this assessment were determined to be unreliable because of the inability of the sonar approach to: (1) directly sample within the portion of the intake flow field with high enough velocity to entrain fish; (2) differentiate between debris and fish; (3) keep track of fish moving in and out of the multiple sonar fields (the three beams did not provide complete coverage); and (4) account for the behavioral milling of fish in the intakes.

A follow-up entrainment sampling test involving installation of a high resolution Dual-Frequency Identification Sonar (DIDSON) (July 24, 2010) concurrent with collection of the split-beam sonar data at Middle Fork Interbay was designed to do the following:

- Confirm that the objects identified in the split-beam sonar as fish or debris;

- Confirm milling behavior of fish; and
- Potentially identify fish ingress and egress routes into the intake opening that could be used to refine the split-beam sonar analysis.

The outcome of the follow-up entrainment sampling test is documented in the results section.

### **5.4.3 Small Diversions**

At the Duncan Creek Diversion, PIT tagging was used to estimate entrainment of juvenile and adult fish. These data in combination with abundance/emergence timing information for YOY (collected in Duncan, North Fork Long Canyon, and South Fork Long Canyon creeks) were used to estimate entrainment at each of the small to medium diversion pools (Duncan, North Fork Long Canyon, South Fork Long Canyon, Middle Fork Interbay)

#### **PIT Tagging Entrainment Estimate**

Entrainment of juvenile and adult fish at the Duncan Creek Diversion was sampled continuously from November 11, 2008 to June 22, 2009 (one complete diversion season) using passive integrated transponder (PIT) tags. Prior to the beginning of the diversion season (October 21–29, 2008), 997 fish (886 rainbow trout, 111 brown trout) were collected (electrofishing) and implanted with individually coded PIT tags. All tagged fish were approximately 60 mm or larger in fork length (FL) (size of the smallest fish in the stream during the sampling). Approximately 100 fish were collected and tagged at 0.2 mile increments over a 2-mile reach of Duncan Creek, starting immediately upstream of the diversion (RM 8.8 to RM10.6) (Map AQ 7-9). In total, the sample of tagged fish represented approximately 21% of the estimated fish population based on fish population estimates (see below) (PCWA 2009). The location, size, and species of each fish tagged were recorded. An effort was made to PIT tag fish with a similar size distribution to the populations at the AQ 2 – TSR study sites (AQ 2 – TSR (PCWA 2009). Photographs of the direct sampling are also provided.

A custom-made automatic PIT tag reader was fabricated and installed at the diversion intake on November 2–6, 2008. The PIT tag reader recorded the identifying code and number of PIT tagged fish that passed through the diversion intake during the monitoring period. The PIT tag reader was tested and calibrated by passing PIT tags through the reader at the beginning, middle, and end of the diversion season (December 5, 2008; February 27, 2009; April 1, 2009; and June 4, 2009) (at least 10 tags each time). All of the PIT tags were recorded each time (100% reading success).

The entrained fish from the PIT tag reader were used in combination with fish population density estimates in the creek to calculate total entrainment. Estimates of the total number of fish entrained and the percent of the total population entrained in the first two miles upstream of the diversion were calculated using a weighted density entrainment equation. Within the PIT tagging sampling reach, two study sites were

sampled for fish population estimates: (1) at RM 9.0 (D9.0); and (2) at RM 10.0 (D10.0) (PCWA 2009). The fish density data (fish per mile) from D9.0 were used for estimating the fish population in the first mile upstream of the diversion (RM 8.8–9.7), and the data from D10.0 were used for the second mile upstream of the diversion (RM 9.7–10.6). This was the most accurate way to represent the fish population in the two miles of stream. The following equation was used for the weighted calculation of total population entrainment:

$$N_{TE} = \left( \frac{\text{Entrained}_{8.8}}{\text{Tagged}_{8.8}} \times \frac{D_1}{5} \right) + \left( \frac{\text{Entrained}_{9.0}}{\text{Tagged}_{9.0}} \times \frac{D_1}{5} \right) + \dots + \left( \frac{\text{Entrained}_{10.6}}{\text{Tagged}_{10.6}} \times \frac{D_2}{5} \right)$$

$N_{TE}$  = Total number of fish entrained

$\text{Entrained}_{X.X}$  = Number of tagged fish entrained from river mile X.X

$\text{Tagged}_{X.X}$  = Number of total fish tagged at river mile X.X

$D_1$  = The estimated fish per mile from river mile 8.8–9.7

$D_2$  = The estimated fish per mile from river mile 9.7–10.6

For these estimates, survival of the PIT tagged fish in the stream through the diversion was assumed to be equal to that of untagged fish in the stream. In addition, PIT tag retention and tagging survivorship of implanted fish were assumed to be greater than 99% (McCutcheon 2008; Dare 2003).

The entrainment estimate for Duncan Creek Diversion (per two miles of stream) was used to estimate the level of entrainment at the North Fork Long Canyon, South Fork Long Canyon, and Middle Fork Interbay diversions. Fish population estimates at these sites (PCWA 2009) were combined with the percent of population entrained at Duncan Creek Diversion to calculate entrainment. Only 1.8 miles of habitable stream exist above the North Fork Long Canyon Creek Diversion and the entrainment estimate was adjusted accordingly. The following fish sampling sites were used for the population estimates above the diversions: North Long Canyon Creek NFLC3.8; Middle Fork Interbay MF36.2; and South Fork Long Canyon Creek SFLC4.2 and SFLC5.2.

### **YOY Abundance and Timing Sampling**

YOY sampling upstream of the Duncan Creek Diversion, North Fork Long Canyon Diversion, and South Fork Long Canyon Diversion began on May 14, 2009 prior to YOY emergence. At each stream, three locations above the diversion were sampled with electrofishing equipment and seine nets. The sampling sites were revisited until YOY were captured at all sites.

The timing of YOY emergence and timing of the greatest abundance of YOY fish were summarized. This information was then used to relate YOY emergence timing to the timing of diversion operation.

The date that newly emerged YOY were first observed was also used to estimate spawning timing. The time period from fertilization to hatching and from hatching to emergence is largely dependent on water temperature (Quinn 2005). The time period is

longer when temperatures are cooler and shorter when temperatures are warmer. Typically, rainbow trout eggs and fry spend approximately 630 degree-days within the gravel before emerging (Behnke 1992). The approximate spawning date was calculated as the sum of 24-hour daily average water temperatures ( $^{\circ}\text{C}$ ) back in time from the date when YOY were first observed.

## **6.0 STUDY RESULTS**

The results for the: (1) Project facilities characterization; (2) screening feasibility cost assessment; (3) indirect entrainment estimate; and (4) direct sampling entrainment estimate are provided below.

### **6.1 PROJECT FACILITIES CHARACTERIZATION**

Maps of each of the Project diversions facilities are shown in Maps AQ 7-2–7-6. Pictures of each structure with labels identifying the outlets are provided in Appendix A, and a summary of the monthly 10, 20, 50, 80, and 90% exceedance flows at each diversion facility for both the inflows and outflows and for the percent of flow diverted is in Appendix B. The Project diversion structures/intakes hydraulic characterization showing each potential entrainment location and the associated infrastructure is shown in Table AQ 7-8. The estimated survival rate of fish entrained in infrastructure and the potential for non-volitional entrainment are discussed below.

#### **6.1.1 Survival Rate of Entrained Fish in Project Infrastructure**

The potential survival rate of fish entrained in various infrastructures was ranked from low to high survival. Entrained fish that pass through Pelton turbines were assumed to have very low survival rates, nearly 100% mortality. Pelton turbines are located at the Middle Fork Powerhouse (Hell Hole-Middle Fork Tunnel Outlet) and Ralston Powerhouse (Middle Fork-Ralston Tunnel Ralston Powerhouse Outlet). Fish passing through cone or Howell-Bunger valves were also assumed to have low survival rates (nearly 100% mortality). Infrastructure with a cone or Howell-Bunger valve include the French Meadows Dam instream flow pipe, Hell Hole Dam low level outlet, and the Hell Hole Dam instream flow pipe.

Fish entrained and passing through Francis turbines can have moderate to high survival rates depending on the characteristics of the turbine (Winchell et al. 2000). Based on the literature summary in Winchell et al. (2000), the fate of entrained fish passing through MFP Francis turbines is summarized in Table AQ 7-9. Factors that potentially affect fish survival are peripheral runner velocity, blade and or wicket spacing/clearance, and fish size (Winchell et al. 2000; Table AQ 7-10). Francis turbines are located at the French Meadows Powerhouse (French Meadows-Hell Hole Tunnel outlet), Hell Hole Powerhouse, and the Oxbow Powerhouse (Ralston-Oxbow Tunnel outlet).

The Oxbow Powerhouse, in particular, has high estimated survival due primarily to the slow runner speed of the turbine. For fish less than 300 mm, the 48-hour survival was estimated to be 80% or greater (higher for smaller fish). The estimated survival rate for fish greater than 300 mm was 67%. The other two powerhouses with Francis turbines,

French Meadows and Hell Hole powerhouses, estimated survival rates were moderate for fish less than 200 mm (46–72%). For large fish, >300 mm, the estimated survival was low (6%).

For other facilities, such as fish passing through minimum flow pipes, over diversion structures, or entrained into other bodies of water (reservoirs) the survival of fish is assumed to be high (e.g., >80%).

### **6.1.2 Non-Volitional Entrainment**

Table AQ 7-8 shows the locations where the estimated velocity fields at Project intakes exceed the sustained swimming velocity (index velocity) selected for juvenile or adult fish. The analysis does not indicate whether entrainment will or will not occur. It simply identifies intakes where the velocity field is in the range that non-volitional entrainment could occur. Fish have short duration (e.g., 1 second) burst swimming capability much greater than the 3 body lengths per second used in the analysis (e.g., 8–12 body lengths per second or greater [PCWA 2008b]). However, if fish entered an intake velocity field and did not react by burst swimming and remained in the velocity field, the analysis indicates the locations where they may be susceptible to non-volitional entrainment.

## **6.2 SCREENING FEASIBILITY COST ASSESSMENT**

Potential screening cost estimates (2008 dollars) for diversion intakes ranged from \$9,000 to \$62,000 per cfs depending on screen size (i.e., maximum flow capacity). California screen installation costs by discharge range are shown in Table AQ 7-11. The average cost and the highest cost of the 35 California screens were summarized. The data used to create Table AQ 7-11 are provided in Appendix C. The potential screen costs do not include recent large increases in materials (e.g., steel) and construction costs.

The potential costs in 2008 dollars for screen installation at the MFP diversions range from \$1 million dollars (North Fork Long Canyon Diversion) to \$21 million dollars (Hell Hole-Middle Fork Tunnel Intake, Ralston-Oxbow Tunnel Intake). Table AQ 7-12 shows the maximum flow capacity of each of the MFP diversions and the estimated cost of screen installation based on the average and maximum screen costs in Table AQ 7-11. These estimated costs are only for installation of the screens based on ready available information and do not reflect costs based on site-specific engineering assessments or annual operation and maintenance costs.

## **6.3 INDIRECT ENTRAINMENT ESTIMATES**

Indirect method entrainment estimates for the Duncan Creek, North Fork Long Canyon Creek, South Fork Long Canyon and Middle Fork Interbay diversions for the empirical data set extrapolation and the literature based fish movement modeling approaches are shown in Table AQ 7-13. The estimates by month of the year are shown in Tables AQ 7-14a and b, respectively.

The entrainment estimates range from 51 to 237 fish per year or 0.9 to 4.3% of the fish population in the first two miles, depending on the diversion. The empirical data set (West Panther Creek) approach shows some potential entrainment of YOY, 6 to 757 depending on the diversion. YOY entrainment could only occur during the later part of June and during July in the few years when diversions overlap with YOY emergence (see Section 6.4.3 below).

The historical canal entrainment data are difficult to apply to the streams associated with the MFP (Table AQ 7-6). The canal data are based on entrainment year-round or throughout the spring/summer/fall and represent entrainment of downstream moving YOY fish, as well as juveniles/adults. The MFP small diversion pools (Duncan Creek, North Fork Long Canyon, South Fork Long Canyon) divert very little, if at all, during the summer/fall (Table AQ 7-1) and have very limited potential for entraining YOY (see Section 6.4.3 below).

The canal data are likely most applicable to the Middle Fork Interbay diversion (Ralston Powerhouse intake). This diversion operates year-around. Inferring from the canal data, up to approximately 440 to 4660 fish (YOY and juvenile/adult) could be entrained. The other indirect methods (Table AQ 7-13), estimate 127 to 237 juveniles/adults and 757 YOY (up to 994 fish total). The estimates are on the lower end of the canal data set range, but close to the canal data set median value of 1297 fish (Table AQ 7-6).

## **6.4 DIRECT SAMPLING ENTRAINMENT ESTIMATES**

### **6.4.1 Large Reservoirs**

More than 99% of fish detected with the sonar sampling transects (during all surveys) were located up in the water column away from the intake structures (Tables AQ 7-7 and AQ 7-15). During the surveys, the depths of the intakes were 74–143 feet at French Meadows Reservoir and 207–260 feet at Hell Hole Reservoir. In French Meadows Reservoir, 92% of observed fish were in the upper 40 feet of the water column; 96% of the fish were greater than 40 feet above the intake structure. In Hell Hole Reservoir, 90% of observed fish were detected in the upper 60 feet of the water column; 100% of the fish were observed greater than 95 feet above the intake (closest fish to the intake was 97 feet).

The abundance and depth distribution of fish detected near the intake structures in French Meadows and Hell Hole reservoirs varied between sampling efforts (Table AQ 7-7). Figures showing the fish observation depths compared to the intake depth are shown for each sample period in Appendix D (Figures D-1 and D-2). The low number of fish detected near the intake structures in both French Meadows and Hell Hole reservoirs indicate that the likelihood of fish entrainment is low.

### **6.4.2 Medium Reservoirs**

Previously installed split-beam sonar data collection and analysis provided unreliable results (see Section 5.4.2). The unreliability of results was due to milling of fish at the low velocity portion of the intakes and the inability of the split-beam sonar setup to

accurately track and differentiate milling fish from entrained fish and differentiate entrained debris (e.g., sticks and leaves) from fish. The follow-up entrainment sampling test involving installation of a DIDSON (July 24, 2010) and concurrent split-beam sonar data collection at Middle Fork Interbay (Ralston Powerhouse Intake) suffered a mechanical failure of the DIDSON; however, enough data were collected to clearly reiterate the unreliability of the split-beam sonar data analysis.

The original plan was to leave the DIDSON installed for three weeks in the intake while making concurrent data collection with the split-beam sonars. The DIDSON had a mechanical failure approximately 24 hours after installation. However, analysis of the DIDSON data that was successfully collected indicated that little additional information would be provided by repairing or installing a new DIDSON unit.

The DIDSON data that was collected included a period of when the powerhouse was turned off (no inflow) and a period of full powerhouse inflow (including a powerhouse startup period). The DIDSON data and visual observation at the site during the hours the DIDSON was operational showed the following:

- Numerous small inanimate objects (leaves, sticks) were visually observed being entrained from the surface of the water near the intake grate. These objects were also observed being entrained on the DIDSON and split-beam sonars, but based on the DIDSON and split-beam sonograms it was not possible to determine whether the objects were inanimate or fish.
- No entrained objects that could be clearly identified as fish were observed with the DIDSON. Objects were observed being entrained, but the objects had identical fall/entrainment characteristics as neutrally buoyant objects (2 inch long by 1 in diameter hotdog pieces) purposefully entrained for testing purposes.
- A few swimming fish were observed with the DIDSON, but these were not observed to be entrained. They were observed during the period the powerhouse was not operating. Either no fish were entrained during the period the powerhouse was operating or, if fish were entrained, they could not be differentiated from inanimate objects.
- The split-beam sonar beams and angle of orientation did not provide discrete coverage; therefore, objects were observed in multiple beams and could be counted multiple times.
- The split-beam sonar narrow beams did not provide complete coverage especially of the upper portion of the intake or the sides of the intake and, therefore, the likelihood of accurately tracking emigration/immigration routes of objects/fish was low.

The follow-up testing of the split-beam sonar setup using the DIDSON showed that the fish entrainment data collected or analyzed by the split-beam sonars was not reliable. The testing also showed that installation of a more sophisticated sonar approach

(DIDSON) also would likely not provide reliable fish entrainment data because the resolution was not good enough to positively identify if objects entrained were inanimate objects or fish. The DIDSON approach could reliably enumerate the number of entrained objects at the intakes, if a secondary method was available to positively identify which entrained objects were fish (e.g., high resolution video). For example, a subset of entrained objects that were positively identified as fish could be used to train analysts to discriminate fish from inanimate objects in the DIDSON video images.

An alternative direct entrainment study approach for the Ralston Powerhouse and Oxbow Powerhouse intakes would be needed to accurately estimate fish entrainment at these facilities.

### **6.4.3 Small Diversions**

The PIT tagging study entrainment estimates and YOY abundance and timing sampling results are provided below.

#### **PIT Tagging Entrainment Estimate**

At the Duncan Creek Diversion, over the course of one diversion season (November 7, 2008–June 22, 2009), a total of 12 PIT tagged fish (5 rainbow trout, 7 brown trout) were detected passing through the Duncan Creek Diversion Tunnel. A summary of the fish detections is provided in Table AQ 7-16. In general, PIT tagged fish released nearer to the diversion structure were more susceptible to being entrained. All 12 fish that were entrained were tagged and released within the first mile upstream of the diversion (Appendix E, Table E-1). Ten of the 12 fish that were entrained were captured and released within the first 0.4 mile upstream of the diversion. Approximately 2.1 and 9.7% of the rainbow and brown trout, respectively, PIT tagged within the first 0.6 mile upstream of the diversion were entrained. The probability of entrainment based on distance upstream of the diversion is shown in Appendix E, Figure E-1.

Of the total estimated population in the first 2 miles upstream of the Duncan Diversion, 1.4% (71 fish) were estimate to be entrained; 0.8% of rainbow trout were estimated to be entrained and 3.2% of brown trout were estimated to be entrained (Table AQ 7-17, Appendix E, Table E-2). The higher percentage of brown trout entrained was likely due to the differences in sample size and sample location between the two species, rather than behavioral movement patterns. The brown trout sample size was substantially smaller than the rainbow trout sample (111 brown trout versus 886 rainbow trout), and of the 111 tagged brown trout, 61 (55%) were tagged within the first 0.2 mile upstream of the diversion. In comparison, only 16% of all the rainbow trout sampled were from the first 0.2 mile upstream of the diversion (Appendix E, Table E-1).

The size distribution of tagged fish was similar to the population size distribution of captured fish during fish population studies (Figure AQ 7-2a and b). Of the 12 fish entrained only one, a 66 mm rainbow trout, was a juvenile/YOY (Table AQ 7-16). The remaining 11 fish entrained ranged in size from 124–212 mm (Table AQ 7-16).

The timing of entrainment, particularly for the detected rainbow trout, did not follow a discernible pattern. The detected fish were entrained during increasing, decreasing, and steady flows. Brown trout detections were relatively clustered, with entrainment of five of the seven entrained brown trout occurring during a one-week span in late January. Four of those five fish were entrained during a high flow event (Table AQ 7-16, Figure AQ 7-3).

Application of the Duncan Creek trout entrainment data to North Fork Long Canyon Creek, South Fork Long Canyon Creek, and Middle Fork Interbay diversions is shown in Table AQ 7-13. The estimated annual entrainment at the North Fork Long Canyon Diversion was 88 fish (1.4%) and at South Fork Long Canyon Diversion 82 fish (1.4%). At Middle Fork Interbay (Ralston Powerhouse intake) 134 fish (1.4%) were estimated to be entrained during the same diversion period. Because the Duncan Creek entrainment was based on approximately seven months of operation and because the percent of diversion was lower at Duncan Creek, the estimate for Middle Fork Interbay should be approximately double, 268 fish (2.8% of the population) (Table 7-13). This approximation assumes that fish at Middle Fork Interbay during the period that was not sampled at Duncan Creek (e.g., approximately mid-June – early November) are equally susceptible to being entrained to those during the Duncan Creek diversion season.

### **YOY Abundance and Timing Sampling**

The YOY trout emergence sampling (timing and abundance) on Duncan Creek, South Fork Long Canyon Creek, and North Fork Long Canyon Creek show that emergence of YOY occurred after the diversions stopped diverting in 2007 and 2009 (Table AQ 7-18 and 7-19).

In 2009, YOY rainbow trout were first observed upstream of the small diversion structures on June 23 in North Fork Long Canyon Creek. Approximately two weeks later (July 6), YOY were captured above the diversions in Duncan Creek and South Fork Long Canyon Creek. In all of the streams, the abundance of YOY captured was low; suggesting emergence occurred in late-June to early-July in 2009 (Table AQ 7-18 and 7-19). Estimated spawning dates in Duncan Creek, North Fork Long Canyon Creek, and South Fork Long Canyon Creek in 2009 were May 3, April 23, and May 11, respectively.

YOY were observed earlier (June) during the 2007 emergency studies (PCWA 2009). The difference in the timing of emergence between the study years likely reflects differences in the water temperatures. Average daily water temperatures were warmer in 2007 than in 2009 (Figure AQ 7-4). Water temperatures in 2009 in all three streams were within the range of water temperatures recorded during recent years (2004–2008) (Figure AQ 7-4).

The timing of the observed emergence in 2007 and 2009 coincided with the approximate timing of the end of the diverting season (Table AQ 7-19). Based on the period of record (1975–2007), diverting at all three diversion structures had ceased by July 1 in most years. In both 2007 and 2008, YOY were first observed in North Fork

Long Canyon Creek. North Fork Long Canyon Creek is the earliest stream to stop diverting; since 1975, diverting has not extended past June 27. At Duncan Creek, diverting sometimes continued into July, mainly during wet water years. In South Fork Long Canyon Creek, flow diversion typically ceased by mid-July in all but two of the last 34 years (Figure AQ 7-5). During the few wet years when the diversion operates later into summer there could be some overlap of diversion and YOY emergence. In 2006, PCWA committed to cease diversion by July 1 and has done so since.

## **7.0 SUMMARY**

- All Project facilities that could potentially entrain fish were characterized physically and in terms of hydrology, hydraulics (velocity), and swimming capabilities of fish.
- The potential survival rate of fish passing through Project facilities was ranked as follows:
  - Low Survival – Powerhouses with Pelton turbines and outlets with energy dissipating valves (Howell-Bunger, cone valves) including Middle Fork Powerhouse, Ralston Powerhouse, French Meadows Dam instream flow pipe, Hell Hole Dam low level outlet, Hell Hole Dam instream flow pipe.
  - Moderate Survival – Powerhouses with high velocity Francis turbines including Hell Hole Powerhouse and French Meadows Powerhouse.
  - High Survival – Powerhouses with slow velocity Francis turbines including Oxbow Powerhouse, and all other facilities where fish might go through minimum flow pipes, over diversion structures, or be entrained into other bodies of water.
- The potential costs for screen installation at the MFP diversions (2008 dollars) range from \$1 million dollars at the smallest diversion (North Fork Long Canyon Diversion) to \$21 million dollars at the largest diversions (Hell Hole-Middle Fork Tunnel Intake, Ralston-Oxbow Tunnel Intake). These estimated costs are only for installation of the screens based on ready available information and do not reflect costs based on site-specific engineering assessments or annual operation and maintenance costs
- Indirect entrainment calculations at the small and medium sized diversion pools indicate that less than approximately 0.9–4.2% (51 to 237 fish), depending on location) of the fish population in the 2-miles of stream above the diversions would be entrained on an annual basis (Duncan Creek, North Fork Long Canyon, South Fork Long Canyon, and Middle Fork Interbay diversion).
- The potential for fish entrainment at the deep water intake structures (French Meadows-Hell Hole Tunnel Intake and Hell Hole-Middle Fork Tunnel Intake) is

low. The sonar sampling showed that fish were in shallower water than the deep water intake structures.

- Direct sampling of entrainment at Duncan Creek Diversion (PIT tagging) produced an annual entrainment estimate of 1.4% (68 fish) of the fish population in the 2 miles of stream of the diversion. The data suggest that fish greater than 1.0 miles upstream of the diversion facility are very unlikely to be entrained.
- Application of the Duncan Creek direct sampling results (1.4%) to the other small and medium sized diversion pool locations produces annual entrainment estimates of 88, 82, and approximately 268 fish annually in the first 2 miles of stream above the diversions at the North Fork Long Canyon, South Fork Long Canyon, and Middle Fork Interbay diversions, respectively.
- Based on historical diverting schedules and the timing of YOY trout emergence in 2007 and 2009, emergence typically occurs after the end of the diversion season.
- Direct entrainment sampling at Middle Fork Interbay (Ralston Powerhouse Intake) and Ralston Afterbay (Oxbow Powerhouse Intake) was conducted according to the stakeholder-approved contingency study, but was not successful due to milling of fish at the low velocity portion of the intakes and the inability of the split-beam sonar setup to accurately track and differentiate milling fish from entrained fish and differentiate entrained debris (e.g., sticks and leaves) from fish.

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**TABLES**

**Table AQ 7-1. Percent of Flow Diverted (50% Exceedance) (1975 - 2007).**

Month	% Flow Diverted			
	Duncan Creek	North Fork Long Canyon Creek	South Fork Long Canyon Creek	Middle Fork Interbay
Jan	21%	0%	0%	89%
Feb	41%	40%	51%	92%
Mar	62%	72%	67%	86%
Apr	82%	77%	81%	84%
May	85%	54%	74%	89%
Jun	46%	0%	0%	95%
Jul	0%	0%	0%	97%
Aug	0%	0%	0%	97%
Sep	0%	0%	0%	97%
Oct	0%	0%	0%	86%
Nov	4%	0%	0%	97%
Dec	7%	0%	0%	93%
<b>Average</b>	<b>29%</b>	<b>20%</b>	<b>23%</b>	<b>92%</b>

**Table AQ 7-2. Summary Fish Moving Downstream at West Panther Creek (1984; Red Values are Extrapolated).**

Month	# YOY	# Juvenile/Adult
Jan	0	10
Feb	0	5
Mar	0	11
Apr	0	2
May	7	3
Jun	250	1
Jul	74	0
Aug	46	2
Sep	42	5
Oct	44	6
Nov	42	5
Dec	42	5
<b>Total</b>	<b>548</b>	<b>56</b>

**Table AQ 7-3. Fish Population Scaling Factors Versus West Panther Creek Population**

River Site	Trout (#/mile)	Population Scaling Factor <sup>1</sup>
West Panther Creek	2515	-
Duncan Creek above Diversion (DC9.0)	2418	0.96
North Fork Long Canyon Creek above Diversion (NFLC3.8)	3154	1.17
South Fork Long Canyon Creek above Diversion (SFLC4.2)	2946	1.25
Middle Fork American River above Middle Fork Interbay (MF36.2)	2798	1.11

<sup>1</sup>Population Scale Factor: # fish per mile in stream/# fish per mile in West Panther Creek

**Table AQ 7-4. Dispersal Functions and Derived Parameters for MFP Juvenile and Adult Trout Downstream Movement Modeling.<sup>1</sup>**

Source	$\lambda_s$	$\lambda_m$	p	Duration Days	Extent (m)	HSL (m)
Graf 2008	0.000178	0.002282	0.099315	365	6500	500
Jenkins et al. 1999	0.004389	0.075026	0.431598	270	745	13.8
Hilderbrand and Kershner 2000	0.000316	0.006390	0.317767	365	4500	500
Fausch et al. (1995; cited in Rodriguez 2002)	0.017670	0.001550	0.460000	365	1350	50

<sup>1</sup>Dispersal function describing decline in capture probability with distance from the home section:

$$f(x) = p\lambda_s e^{-\lambda_s x} + (1 + p)\lambda_m e^{-\lambda_m x}$$

where: p = proportion of stationary individuals; (1 - p) = proportion of mobile individuals; x = distance in meters away from the home section;  
HSL = home section length (in meters);  $\lambda_m$  and  $\lambda_s$  = displacement parameters (i.e., the inverse of the me

**Table AQ 7-5. Potential Number of Fish Moving Downstream by Year and by Month Scaled to a Population of 1,000 Fish/Mile.**

<b>Author</b>	<b>Species</b>	<b>No. Juv/Adult Per Year</b>	<b>Per Month</b>
Fausch et al. (1995; cited in Rodriguez 2002)	Brook Trout	108	9.00
Hilderbrand and Kershner (2000)	Cutthroat Trout	100	8.33
Jenkins et al (1999) <sup>1</sup>	Brown Trout	72	6.00
Graf (2008)	Rainbow Trout	89	7.42
<b>Average</b>		<b>92</b>	<b>7.69</b>
<b>Minimum</b>		<b>72</b>	<b>6.00</b>

<sup>1</sup>Based on 9 months of data

**Table AQ 7-6. Summary of Canal Entrainment Data for Trout.**

Parameter	River/Project - Canal Name					
	Bow River, Alberta, CA	Smith Fork River, WY	Stanislaus, CA	DeSabra, CA		
	Carseland	Covey, Whites Water, South Branch Irrigation	Stanislaus Power Tunnel & Forebay	Hendricks	Butte	Lower Centerville
Length of Diversion Period (months)	6	5	12	12	12	12
Number of Streams Entering Canal	1	1	1	4	5	4
Coarse Approximation % of Flow Diverted	≈73	≈32	≈85	≈80	≈76	≈72
Approximate Amount of Flow Diverted (cfs)	1018	61 <sup>1</sup>	500	125	91	183
Approximate Estimate Trout Fish Population Mainstem	2017 (>150 mm)	≈269	≈8233 <sup>2</sup>	≈892	≈389	≈1063
Total Estimated Number of Trout Diverted	4660 (1799 Trout >150 mm)	404	1872	1420	1102	1174
Reference	Post et al. 2006	Carlson and Rahel 2007	PG&E 2002	P&GE 2007	P&GE 2007	P&GE 2007

<sup>1</sup>Based on Average annual discharge<sup>2</sup>Based on 10 years of data

**Table AQ 7-7. Abundance and Depths of Fish Detected Near the Intake Structures in French Meadows and Hell Hole Reservoirs (2008).**

Season	Date	Survey Type	Number of Transects Surveyed	Total Length Surveyed (ft (m))	Number of Fish Observed	Total Number of Fish Per Transect Mile	Average Depth of Fish Observed (ft)	Maximum Depth of Fish Observed <sup>1</sup> (ft)	Depth of Intake (ft)	
<b>French Meadows Reservoir</b>										
Fall	10/16/08	Day	7	3432 (1047)	23	158.4	17.9	28.9	75.2	
	10/27/08	Day	7	4843 (1476)	42	67.6	20.4	126.0	73.5	
	10/27/08	Night	7	4843 (1476)	65	70.9	11.6	65.0	73.5	
Spring	05/13/09	Day	<i>No survey data obtained due to spring high flows and floating / suspended woody debris interfering with sonar</i>							
	05/14/09	Night								
	05/27/09	Day	6	4157 (1267)	10	12.7	2.7	4.7	143.2	
	05/27/09	Night	6	4157 (1267)	75	184.2	3.6	6.3	143.2	
Summer	08/05/09	Day	6	4108 (1252)	32	41.1	11.9	78.0	131.1	
	08/04/09	Night	6	4117 (1255)	7	9.0	32.4	39.0	131.5	
Later Summer	9/3/2009	Day	6	4184 (1275)	14	17.7	1.8	2.3	118.4	
	9/3/2009	Night	6	4042 (1232)	6	7.8	51.0	110.0	118.4	
<b>Hell Hole Reservoir</b>										
Fall	10/16/08	Day	5	3177 (968)	25	81.4	38.9	73.0	212.4	
	10/20/08	Night	7	6306 (1922)	41	34.3	36.1	83.3	209.7	
	10/22/08	Night	7	6142 (1872)	52	44.7	26.5	108.0	208.7	
	10/27/08	Day	7	6360 (1938)	45	37.4	27.7	57.8	206.7	
	10/27/08	Night	7	6372 (1942)	35	29.0	28.3	110.0	206.7	
Spring	05/13/09	Day	<i>No survey data obtained due to spring high flows and floating / suspended woody debris interfering with sonar</i>							
	05/14/09	Night								
	05/27/09	Day								
	05/27/09	Night								
	06/09/09	Day								
	06/09/09	Night								
Summer	08/05/09	Day	6	5701 (1738)	5	4.6	29.9	37.0	284.6	
	08/04/09	Night	6	5579 (1700)	14	13.2	23.2	79.0	285.3	
Later Summer	9/3/2009	Day	6	5517 (1682)	12	11.5	50.3	75.6	260.0	
	9/4/2009	Night	5	3932 (1198)	22	29.5	16.0	89.2	259.0	

<sup>1</sup>Some transect extended into deeper portions of the reservoir; therefore, some fish were observed at depths deeper than the intake.

Table AQ 7-8. Middle Fork Project Facilities Entrainment Characteristics.

Facility	Hydraulic Capacity (cfs)	Frequency of Use	Inlet/Outlet Type	Inlet Area (ft <sup>2</sup> )	Approach Velocity (fps)	Non-Volitional Velocity (Juvenile / Adult)	Intake Depth (ft)	Comments
<b>French Meadows Reservoir</b>								
French Meadows-Hell Hole Tunnel	400	Frequent during spring and summer	<u>Inlet</u> : 10-ft-diameter pipe  <u>Trashrack</u> : 2.6-in bar spacing  <u>Outlet</u> : vertical Francis turbine	<u>Inlet</u> : 78.5  <u>Trashrack</u> : 484	<u>Inlet</u> : 0–5.1  <u>Trashrack</u> : 0–0.8	Yes / Yes  No / No	145 <sup>1</sup>  --	
French Meadows Dam – Low Level Outlet	1,430	Infrequent	<u>Inlet</u> : 60-in pipe with slide gate  <u>Trashrack</u> : 6-in bar spacing  <u>Outlet</u> : 60-in Ring Jet Valve	<u>Inlet</u> : 28  <u>Trashrack</u> : 52	<u>Inlet</u> : 0–51  <u>Trashrack</u> : 0–28	Yes / Yes  Yes / Yes	211.5 <sup>2</sup>	Energy dissipating valve discharges to a plunge pool
French Meadows Dam – Instream Flow Pipe Intake	4–8	Continuous	<u>Inlet</u> : 8-in pipe  <u>Outlet</u> : 8-in Howell-Bunger Valve	<u>Inlet</u> : 0.35  <u>Trashrack</u> : 23	<u>Inlet</u> : 11.4–22.86  <u>Trashrack</u> : 0.2–0.4	Yes / Yes  No / No	194 <sup>1</sup>	Energy dissipating valve discharges to a plunge pool

Table AQ 7-8. Middle Fork Project Facilities Entrainment Characteristics (continued).

Facility	Hydraulic Capacity (cfs)	Frequency of Use	Inlet/Outlet Type	Inlet Area (ft <sup>2</sup> )	Approach Velocity (fps)	Non-Volitional Velocity (Juvenile / Adult)	Intake Depth (ft)	Comments
<b>Hell Hole Reservoir</b>								
Hell Hole-Middle Fork Tunnel	800	Frequent	<u>Inlet</u> : 11.5-ft-diameter pipe.  <u>Trashrack</u> : 2-in bar spacing  <u>Outlet</u> : Two Pelton Turbines	<u>Inlet</u> : 104  <u>Trashrack</u> : 705	<u>Inlet</u> : 0–7.8  <u>Trashrack</u> : 0–1.1	Yes / Yes  No / No	308.1 <sup>1</sup>	Powerhouse discharges into Middle Fork Interbay
Hell Hole Dam Outlet Works	6–848	<u>6–20 cfs</u> : Continuous low flow  <u>~65 cfs</u> : Infrequent during outages  <u>65–848 cfs</u> : Infrequent and would cause facility damage	Rectangular inlet (with trashrack) into horizontal 13-ft horseshoe shaped tunnel (original tunnel opening shut with stop logs)	<u>Inlet</u> : 76  <u>Trashrack</u> : 300.3	<u>Inlet</u> : 0.08–11.2  <u>Trashrack</u> : 0.02–2.82	Yes / Yes  Yes / Yes	342 <sup>3</sup>	Outlet works is a tunnel that leads to a 48-in-diameter pipe and 16-in-diameter pipe for the Hell Hole Powerhouse, instream flow pipe, and low level outlet
Hell Hole Dam Low Level Outlet <sup>5</sup>	Calculated maximum capacity 848	Infrequent (would cause facility damage)	<u>Inlet</u> : 48-in-diameter pipe with butterfly valve  <u>Outlet</u> : 48-in hollow-cone valve	12.6	48-in pipe opening  <u>Inlet</u> : 0–67.3 <sup>4</sup>	Yes / Yes	342 <sup>3</sup>	Energy dissipating valve discharges to a plunge pool

Table AQ 7-8. Middle Fork Project Facilities Entrainment Characteristics (continued).

Facility	Hydraulic Capacity (cfs)	Frequency of Use	Inlet/Outlet Type	Inlet Area (ft <sup>2</sup> )	Approach Velocity (fps)	Non-Volitional Velocity (Juvenile / Adult)	Intake Depth (ft)	Comments
<b>Hell Hole Reservoir (continued)</b>								
Hell Hole Power House <sup>5</sup>	Approx 45	Continuous except for maintenance	<u>Inlet</u> : 20-in-diameter pipe with control valve <u>Outlet</u> : horizontal Francis turbine	2.18	20-in pipe opening  <u>Inlet</u> : 0–20.6 <sup>4</sup>	Yes / Yes	342 <sup>3</sup>	20-in-diameter penstock for powerhouse “Y’s” off of 48-in-diameter pipe. Hell Hole Powerhouse discharges to plunge pool
Hell Hole Dam Instream Flow Pipe <sup>5</sup>	20	Infrequent (typically Instream flow compliance is provided by Hell Hole Powerhouse) discharge	<u>Inlet</u> : 16-in-diameter pipe with butterfly valve <u>Outlet</u> : 12-in hollow-cone valve	0.8	16-in pipe opening  <u>Inlet</u> : 0–25 <sup>4</sup>	Yes / Yes	342 <sup>3</sup>	Energy dissipating valve discharges to a plunge pool
<b>Middle Fork Interbay</b>								
Middle Fork - Ralston Tunnel	836	Frequent	<u>Inlet</u> : Tunnel with slide gate  <u>Trashrack</u> : 3-in bar spacing  <u>Outlet</u> : Pelton Turbine	<u>Tunnel Inlet</u> : 96  <u>Trashrack</u> : 680	<u>Inlet</u> : 0–8.71  <u>Trashrack</u> : 0–1.23	Yes / Yes  Yes / No	51 <sup>6</sup>	Ralston Powerhouse discharges into Ralston Afterbay
Middle Fork Interbay Dam Low Level Outlet	895	Infrequent	<u>Inlet</u> : 60-in-diameter with slide gate  <u>Grizzly</u> : 8-in bar opening  <u>Outlet</u> : Open pipe	<u>Pipe Inlet</u> : 19.6  <u>Grizzly</u> : 62	<u>Inlet</u> : 0–45.7  <u>Trashrack</u> : 0–14.4	Yes / Yes  Yes / Yes	68.5 <sup>6</sup>	Discharges to a plunge pool

Table AQ 7-8. Middle Fork Project Facilities Entrainment Characteristics (continued).

Facility	Hydraulic Capacity (cfs)	Frequency of Use	Inlet/Outlet Type	Inlet Area (ft <sup>2</sup> )	Approach Velocity (fps)	Non-Volitional Velocity (Juvenile / Adult)	Intake Depth (ft)	Comments
<b>Middle Fork Interbay (continued)</b>								
Middle Fork Interbay Dam Stream Maintenance Pipe	12–23	Continuous	<u>Inlet</u> : 20-in-diameter pipe with slide valve  <u>Trashrack</u> : 3-in bar opening  <u>Outlet</u> : Open pipe	<u>Pipe Inlet</u> : 2.18  <u>Trashrack</u> : 6.0	<u>Inlet</u> : 5.5–10.6  <u>Trashrack</u> : 2.0–3.8	Yes / Yes  Yes / Yes	39.84 <sup>6</sup>	Outlet discharges to a plunge pool
<b>Ralston Afterbay</b>								
Ralston - Oxbow Tunnel	1,088	Frequent	<u>Inlet</u> : Tunnel with slide gate  <u>Trashrack</u> with 3-in bar spacing  <u>Outlet</u> : vertical Francis turbine	<u>Tunnel Inlet</u> : 96  <u>Trashrack</u> : 590	<u>Inlet</u> : 0–11.3  <u>Trashrack</u> : 0–1.8	Yes / Yes  Yes / No	39 <sup>6</sup>	Oxbow Powerhouse discharges into the Middle Fork American River
Ralston Afterbay Dam Low Level Outlet	1,671	Infrequent	<u>Inlet</u> : 72-in-diameter with slide valve  <u>Grizzly</u> : 8-in bar opening  <u>Outlet</u> : 72-in-diameter slide gate	<u>Pipe Inlet</u> : 28.3  <u>Grizzly</u> : 82.6	<u>Inlet</u> : 0–59.1  <u>Trashrack</u> : 0–20.33	Yes / Yes  Yes / Yes	74 <sup>6</sup>	Discharges to a plunge pool

Table AQ 7-8. Middle Fork Project Facilities Entrainment Characteristics (continued).

Facility	Hydraulic Capacity (cfs)	Frequency of Use	Inlet/Outlet Type	Inlet Area (ft <sup>2</sup> )	Approach Velocity (fps)	Non-Volitional Velocity (Juvenile / Adult)	Intake Depth (ft)	Comments
<b>Ralston Afterbay (continued)</b>								
Ralston Afterbay Dam Stream Maintenance Pipe	75	10 cfs: Frequent  75 cfs: Infrequent	<u>Inlet</u> : 30-in-diameter pipe with slide valve  <u>Trashrack</u> : 3.88-in bar opening  <u>Outlet</u> : 30-in-diameter Ring Jet valve	<u>Pipe Inlet</u> : 4.9  <u>Trashrack</u> : 36.2	<u>Inlet</u> : 2.04–15.31  <u>Trashrack</u> : 0.3–2.1	Yes / Yes  Yes / No	41.25 <sup>6</sup>	Energy dissipating valve discharges to a plunge pool
Duncan Creek – Middle Fork Tunnel	400	Frequent	<u>Inlet</u> : Tunnel with stop logs.  <u>Trashrack</u> : 9-in bar spacing  <u>Outlet</u> : Open tunnel	<u>Tunnel Inlet</u> : 51  <u>Trashrack</u> : 51	<u>Inlet</u> : 0–7.84  <u>Trashrack</u> : 0–7.84	Yes / Yes  Yes / Yes	4.25 <sup>7</sup>	Discharges into French Meadows Reservoir
Duncan Creek Low Level Outlet	304	Infrequent	<u>Inlet</u> : 60-in-diameter pipe w/ slide gate  <u>Grizzly</u> : 10-in bar spacing  <u>Outlet</u> : Open pipe	<u>Pipe Inlet</u> : 19.6  <u>Grizzly</u> : 58.7	<u>Inlet</u> : 0–15.5  <u>Trashrack</u> : 0–5.2	Yes / Yes  Yes / Yes	13.5 <sup>8</sup>	Discharges to a plunge pool
Duncan Creek Stream Maintenance Pipe	4–8	Continuous	<u>Inlet</u> : 10-in-diameter pipe with slide gate  <u>Trash Screen</u> : 1.75-in openings)  <u>Outlet</u> : Discharge weir	<u>Pipe Inlet</u> : 0.55  <u>Trash Screen</u> : 12.2	<u>Inlet</u> : 7.3–14.6  <u>Trashrack</u> : 0.33–0.66	Yes / Yes  No / No	5 <sup>7</sup>	Outlet discharges to a plunge pool

Table AQ 7-8. Middle Fork Project Facilities Entrainment Characteristics (continued).

Facility	Hydraulic Capacity (cfs)	Frequency of Use	Inlet/Outlet Type	Inlet Area (ft <sup>2</sup> )	Approach Velocity (fps)	Non-Volitional Velocity (Juvenile / Adult)	Intake Depth (ft)	Comments
<b>North Fork Long Canyon Creek Diversion</b>								
North Fork Long Canyon Diversion Pipe	100	Frequently during winter and spring  No diversion after July 1	<u>Inlet</u> : Parshall Flume with slide gate to a 36-in-diameter pipe.  <u>Trashrack</u> : 2-in bar spacing  <u>Outlet</u> : 403-foot-deep drop inlet to the Hell Hole - Middle Fork Tunnel	<u>Inlet</u> : 16  <u>Trashrack</u> : 68.7	<u>Inlet</u> : 0–6.25  <u>Trashrack</u> : 0–1.46	Yes / Yes  Yes / No	6 <sup>9</sup>	Discharges to Hell Hole – Middle Fork Tunnel
North Fork Long Canyon Low Level Outlet	104	Infrequent	<u>Inlet</u> : 36-in-diameter pipe with slide gate  <u>Outlet</u> : open pipe	<u>Inlet</u> : 7.1	<u>Inlet</u> : 0–14.7	Yes / Yes	5.5 <sup>9</sup>	Discharges to streambed
North Fork Long Canyon Stream Maintenance Pipe	0–2	Continuous	<u>Inlet</u> : 12-in-diameter pipe with 12-in slide valve  <u>Outlet</u> : 25-in-wide concrete channel with weir	<u>Inlet</u> : 0.8	<u>Inlet</u> : 0–2.5	Yes / Yes	6 <sup>9</sup>	Discharges to streambed

Table AQ 7-8. Middle Fork Project Facilities Entrainment Characteristics (continued).

Facility	Hydraulic Capacity (cfs)	Frequency of Use	Inlet/Outlet Type	Inlet Area (ft <sup>2</sup> )	Approach Velocity (fps)	Non-Volitional Velocity (Juvenile / Adult)	Intake Depth (ft)	Comments
<b>South Fork Long Canyon Creek Diversion</b>								
South Fork Long Canyon Diversion Pipe	200	Frequently during winter and spring  No diversion after July 1	<u>Inlet</u> : 42-in-diameter pipe with inlet weir  <u>Trashrack</u> : 2.4-in bar spacing.  <u>Outlet</u> : 387-ft-deep drop inlet to Hell Hole - Middle Fork Tunnel	<u>Inlet</u> : 36  <u>Trashrack</u> : 107	<u>Inlet</u> : 0–5.6  <u>Trashrack</u> : 0–1.87	Yes / Yes  Yes / No	11 <sup>9</sup>	Discharges to Hell Hole – Middle Fork Tunnel
South Fork Long Canyon Low Level Outlet	136 136	Infrequent	<u>Inlet</u> : 36-in-diameter pipe with slide gate  <u>Outlet</u> : open pipe	<u>Inlet</u> : 7.1	<u>Inlet</u> : 0–19.5	Yes / Yes	12.2 <sup>9</sup>	Discharges to streambed
South Fork Long Canyon Stream Maintenance Pipe	2.5–5	Continuous	<u>Inlet</u> : 12-in-diameter pipe with 12-in slide valve  <u>Outlet</u> : 48-in-wide concrete channel with weir	<u>Inlet</u> : 0.8	<u>Inlet</u> : 3.1–6.25	Yes / Yes	6 <sup>9</sup>	Discharges to streambed

<sup>1</sup>Maximum reservoir operating surface elevation minus intake surface elevation.<sup>2</sup>Maximum reservoir operating surface elevation minus curb intake elevation.<sup>3</sup>Maximum reservoir operating surface elevation minus intake elevation invert of Hell Hole Dam Outlet Works.<sup>4</sup>Intake velocity calculated at the pipe inlet inside the tunnel. Intake velocity to the tunnel is much lower (see Hell Hole-Middle Fork Tunnel Intake)<sup>5</sup>Outlet branches off from tunnel. Inlet to tunnel is the Hell Hole Dam Outlet Works.<sup>6</sup>Maximum reservoir operating surface elevation minus intake elevation invert.<sup>7</sup>Diversion Dam Crest minus top of intake weir.<sup>8</sup>Diversion Dam Crest minus invert elevation.<sup>9</sup>Diversion Dam spillway crest minus invert elevation.

## AQ 7-9. Turbine Characteristics and Associated Estimated Mortality at Middle Fork American River Project Facilities

Name	Max. Hydraulic Capacity (cfs)	Turbine Type	Runner Speed (rpm)	Maximum Blade Velocity <sup>1</sup> (fps)	Static Head Max - Min (ft)	Fish Size (mm)	Approx. % Survival <sup>2</sup>	
							Immediate	48-Hour
French Meadows P.H.	400 <sup>3</sup>	Vertical Francis	450	150 - 170	654 - 517	<100	70 (31-98)	72 (63-86)
						100 - 199	60 (34-83)	46 (16-78)
						200 - 299	39 (23-83)	32 (12-65)
						300+	19 (4-35)	6 (4-8)
Hell Hole P.H.	65 <sup>4</sup>	Horizontal Francis	1200	62 - 94	391 - 101	<100	70 (31-98)	72 (63-86)
						100 - 199	60 (34-83)	46 (16-78)
						200 - 299	39 (23-83)	32 (12-65)
						300+	19 (4-35)	6 (4-8)
Oxbow P.H.	1025	Vertical Francis	200	66 - 76	90	<100	94 (86-100)	90 (81-101)
						100 - 199	92 (75-100)	88 (74-101)
						200 - 299	87 (59-100)	80 (47-96)
						300+	73 (36-100)	67 (34-94)
Middle Fork P.H. (2 units)	920 <sup>5</sup>	Pelton	400	NA	2,096 - 1,806	All	~0	~0
Ralston P.H.	924	Pelton	240	NA	1,344	All	~0	~0

<sup>1</sup>Approximate range based in diameter of scroll case and allowance for wicket gate assembly.

<sup>2</sup>Mean approximate mortality for all fish species combined. See Winchell et al. 2000 table.

<sup>3</sup>Nominal tunnel capacity.

<sup>4</sup>Maximum flow capacity when supporting instream flow requirements below Oxbow PH during fall maintenance outage.

<sup>5</sup>Nominal capacity of Hell Hole – Middle Fork Tunnel.

**Table AQ 7-10. Immediate and 48-Hour Fish Survival Rates for Francis Turbines by Fish Size.<sup>1</sup>**

Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	Average Immediate Survival <sup>2</sup> (all species combined)			
			N <sup>3</sup>	Minimum (%)	Maximum (%)	Mean (%)
<250	440-1,600	<100	13	85.9	100 <sup>(4)</sup>	93.9
	370-1,600	100-199	19	74.8	100.0	91.6
	370-2,450	200-299	18	59.0	100.0	86.9
	440-1,600	300+	14	36.1	100.0	73.2
>250	275-695	<100	6	31.0	97.6	70.1
	"	100-199	7	34.3	82.7	60.0
	"	200-299	7	22.8	82.9	39.3
	"	300+	3	3.5	35.4	19.1

Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	48-Hour Survival <sup>2</sup> (all species combined)			
			N <sup>3</sup>	Minimum (%)	Maximum (%)	Mean (%)
<250	440-1,600	<100	11	81	101 <sup>(4)</sup>	90
	370-2,450	100-199	17	74	101 <sup>(4)</sup>	88
	440-2,450	200-299	15	47	96	80
	440-1,600	300+	13	34	94	67
>250	275-695	<100	3	63	86	72
	275-695	100-199	5	16	78	46
	275-695	200-299	5	12	65	32
	275-450	300+	2	4	8	6

<sup>1</sup>From Winchell, F., S. Amaral and D. Dixon. 2000. Hydroelectric Turbine Entrainment and Survival Database: An Alternative to Field Studies. Paper presented at Hydrovision 2000.

<sup>2</sup>Average of all control-adjusted estimates provided in EPRI (1997) including all species and test conditions but excluding tests with less than 90% survival of control groups.

<sup>3</sup>Number of turbines for which survival estimates are available.

<sup>4</sup>Even with high rates of control survival, the true rate of survival may be under- or over-estimated. When the survival of treatment groups is higher than controls, the adjusted survival estimates will exceed 100%.

**Table AQ 7-11. Summary of Diversion Screening Costs (dollars per cfs) for California Projects.**

<b>Flow Range (cfs)</b>	<b>Average Cost<sup>1</sup> (dollars/cfs)</b>	<b>Highest Cost<sup>2</sup> (dollars/cfs)</b>
50-100	\$9,000	\$15,000
100-500	\$14,000	\$62,000
500-1000	\$15,000	\$23,000
>1000	\$11,000	\$19,000

<sup>1</sup>Average capital cost of 48 projects constructed in California between 1983 and 2012 (used cost estimates for 2009 dollars on uncompleted projects). Costs inflated at +/- 3% to 2008 dollars.

<sup>2</sup>Highest capital cost in range (2008 dollars).

**Table AQ 7-12. Estimated Installation Costs to Screen Selected Project Facility Intakes.**

Facility	Maximum Flow (cfs)	Average Cost <sup>1,4</sup> (dollars/cfs)	Maximum Cost <sup>1,4</sup> (dollars/cfs)	Range of Screen Cost (millions) <sup>4</sup>	
<b>Large Facilities</b>					
Duncan Creek - Middle Fork Tunnel Intake	400	\$14,000	\$62,000	\$6	\$25
Hell Hole - Middle Fork Tunnel Intake	920	\$15,000	\$23,000	\$14	\$21
Middle Fork - Ralston Tunnel Intake	836	\$15,000	\$23,000	\$13	\$19
Ralston - Oxbow Tunnel Intake	1,088	\$11,000	\$19,000	\$12	\$21
<b>Small Facilities</b>					
North Fork Long Canyon Diversion	100	\$9,000	\$15,000	\$1	\$2
South Fork Long Canyon Diversion	200	\$14,000	\$62,000	\$3	\$12

<sup>1</sup>Estimated costs per cfs are based on average and maximum costs from 35 previously constructed screening projects in California and the estimated costs for the Yuba River with a variety of screen designs, sizes, and design criteria.

<sup>2</sup>Current operations

<sup>3</sup>Utilizing maximum tunnel capacity

<sup>4</sup>Capital cost in 2008 dollars (±3% annual inflation)

**Table AQ 7-13. Estimated Number of Fish Entrained at Small and Medium Sized Diversions Based on Indirect Methods (Gray) and the Duncan Creek PIT Tagging Study Results (White).**

Site	Species	Fish Population Estimate in the First 2 Miles Upstream of Diversion <sup>1</sup>	Estimation Method	Estimated Number of Fish Entrained (range) [Young-Of-The-Year]	Estimated Percentage of Population Entrained
Duncan Creek Diversion	Rainbow and Brown Trout	4836	Empirical Data Set Extrapolation	51 [157]	1.1%
			Literature Based Fish Movement Studies	65 (50 - 76)	1.3%
			Duncan Creek PIT Tagging Study	68	1.4%
North Fork Long Canyon Creek Diversion	Rainbow Trout	6307	Empirical Data Set Extrapolation	60 [6]	1.0%
			Literature Based Fish Movement Studies	59 (46 - 69)	0.9%
			Duncan Creek PIT Tagging Study	88	1.4%
South Fork Long Canyon Creek Diversion	Rainbow Trout	5892	Empirical Data Set Extrapolation	58 [8]	1.0%
			Literature Based Fish Movement Studies	62 (48 - 72)	1.1%
			Duncan Creek PIT Tagging Study	82	1.4%
Ralston Powerhouse Intake <sup>2</sup>	Rainbow and Brown Trout	5596	Empirical Data Set Extrapolation	127 [757]	2.3%
			Literature Based Fish Movement Studies	237 (185 - 277)	4.2%
			Duncan Creek PIT Tagging Study	134 <sup>2</sup> (268) <sup>3</sup>	1.4%

<sup>1</sup>Data from fish population sampling conducted in 2007, 2008, and 2009 were used to estimate the fish population above the diversions. See Appendix D for entrainment estimation details.

<sup>2</sup>Results based on approximately 7 months empirical diversion at Duncan Creek.

<sup>3</sup>Based on doubling the Duncan Creek numbers to account for 12 month diversion and higher diversion rates.

**Table AQ 7-14a. Summary of Potential Fish Diverted using the West Panther Creek Data and the 50% Exceedance Percent Flow Diversion.**

Month	Duncan Creek		North Fork Long Canyon Creek		South Fork Long Canyon Creek		Middle Fork Interbay	
	# YOY <sup>1</sup>	# Juv/Ad <sup>2</sup>	# YOY	# Juv/Ad	# YOY	# Juv/Ad	# YOY	# Juv/Ad
Jan	0	5	0	0	0	0	0	22
Feb	0	5	0	6	0	7	0	12
Mar	0	28	0	42	0	37	0	44
Apr	0	3	0	4	0	4	0	4
May	6	10	4	8	5	11	9	12
Jun	144	1	3	0	3	0	358	1
Jul	7	0	0	0	0	0	112	0
Aug	0	0	0	0	0	0	65	3
Sep	0	0	0	0	0	0	55	7
Oct	0	0	0	0	0	0	51	7
Nov	0	0	0	0	0	0	55	7
Dec	0	0	0	0	0	0	53	7
<b>Total</b>	<b>157</b>	<b>51</b>	<b>6</b>	<b>60</b>	<b>8</b>	<b>58</b>	<b>757</b>	<b>127</b>

<sup>1</sup>YOY: young-of-the-year

<sup>2</sup>Juv/Ad: juvenile/adult

**Table AQ 7-14b. Potential Number of Fish Moving Downstream and Entrained per Month Based on the Literature Movement Data and the 50% Exceedance Percent Flow Diversion.**

Fish Moving or Entrained	Number of Fish Moving Downstream or Entrainment							
	DC 9.0		NFLC 3.8		SFLC 4.2		MF 36.2	
	Average	Range	Average	Range	Average	Range	Average	Range
<b>Per Month</b>	<b>18.6</b>	(14.5 - 21.8)	<b>24.2</b>	(18.9 - 28.4)	<b>22.6</b>	(17.7 - 26.5)	<b>21.5</b>	(16.8 - 25.2)
Jan (entrained)	<b>4.0</b>	(3.1 - 4.6)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>19.1</b>	(14.9 - 22.3)
Feb (entrained)	<b>7.6</b>	(5.9 - 8.9)	<b>9.8</b>	(7.6 - 11.4)	<b>11.5</b>	(9.0 - 13.5)	<b>19.7</b>	(15.4 - 23.1)
Mar (entrained)	<b>11.6</b>	(9.1 - 13.6)	<b>17.4</b>	(13.5 - 20.3)	<b>15.2</b>	(11.8 - 17.8)	<b>18.4</b>	(14.4 - 21.6)
Apr (entrained)	<b>15.2</b>	(11.9 - 17.8)	<b>18.7</b>	(14.6 - 21.9)	<b>18.3</b>	(14.3 - 21.4)	<b>18.0</b>	(14.0 - 21.0)
May (entrained)	<b>15.8</b>	(12.3 - 18.4)	<b>13.0</b>	(10.2 - 15.2)	<b>16.7</b>	(13.0 - 19.5)	<b>19.2</b>	(15.0 - 22.4)
Jun (entrained)	<b>8.6</b>	(6.7 - 10.0)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>20.5</b>	(16.0 - 24.0)
Jul (entrained)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>20.8</b>	(16.3 - 24.4)
Aug (entrained)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>20.9</b>	(16.3 - 24.5)
Sep (entrained)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>20.9</b>	(16.3 - 24.5)
Oct (entrained)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>18.4</b>	(14.4 - 21.6)
Nov (entrained)	<b>0.7</b>	(0.5 - 0.8)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>20.9</b>	(16.3 - 24.4)
Dec (entrained)	<b>1.3</b>	(1.0 - 1.6)	<b>0.0</b>	(0.0 - 0.0)	<b>0.0</b>	(0.0 - 0.0)	<b>20.0</b>	(15.6 - 23.5)
<b>Year Total (entrained)</b>	<b>65</b>	(50 - 76)	<b>59</b>	(46 - 69)	<b>62</b>	(48 - 72)	<b>237</b>	(185 - 277)

**Table AQ 7-15. Depth Distribution of Fish Detected Near the Intake Structures in French Meadows and Hell Hole Reservoirs (2008).**

Site	Time (Day/Night)	Total Number of Fish Observed									Intake Structure Depth (ft)
		Depth of Observed Fish (ft)									
		0 - 10'	10 - 20'	20 - 30'	30 - 40'	40 - 50'	50 - 60'	60 - 70'	70 - 100'	100-150'	
French Meadows Reservoir (French Meadows - Hell Hole Tunnel Intake)	Day	57	35	21	4	0	1	0	1	2	74-143
	Night	100	19	8	7	2	0	15	0	2	
Hell Hole Reservoir (Hell Hole - Middle Fork Tunnel Intake)	Day	9	3	12	28	16	14	2	3	0	207-260
	Night	73	11	13	27	8	8	11	9	4	

**Table AQ 7-16. Summary of Fish Entrained at the Duncan Creek Diversion Tunnel.**

<b>Fish Detected</b>	<b>Date</b>	<b>Time Detected</b>	<b>Fork Length (mm)</b>	<b>Location Tagged (river mile)</b>
Rainbow Trout	11/7/2008	15:43	212	D9.0
Brown Trout	1/19/2009	6:28	170	D9.0
Brown Trout	1/23/2009	1:16	175	D9.0
Brown Trout	1/23/2009	1:21	170	D9.0
Brown Trout	1/23/2009	21:38	147	D9.0
Brown Trout	1/24/2009	18:50	160	D9.0
Rainbow Trout	2/2/2009	19:33	130	D8.8
Rainbow Trout	3/10/09; 3/11/09; 5/21/09; 5/31/09; 6/1/09-6/11/09	21:31; throughout each day <sup>1</sup>	124	D9.2
Rainbow Trout	4/1/2009	5:23	66	D8.8
Brown Trout	5/5/2009	22:10	154	D9.0
Brown Trout	5/9/2009	1:57	138	D9.4
Rainbow Trout	5/24/2009; 6/1/09-6/11/09	6:01; throughout each day <sup>1</sup>	131	D8.8

<sup>1</sup>These fish stayed in the antenna range for these dates.

**Table AQ 7-17. Duncan Creek PIT Tagging Entrainment Study Results and Estimate of Percent of Fish Population Entrained.**

Species	Total Number of PIT Tagged Fish	Total Number of PIT Tagged Fish Entrained	Percent of Tagged Fish Entrained	Fall 2008 Fish Population Estimate in the First 2 Miles Upstream of Diversion	Calculated Number of Fish Entrained <sup>1</sup>	Calculated Percent of Study Reach Population Entrained <sup>1</sup>
<b>Calculated By Species Separate</b>						
Rainbow Trout	886	5	0.6%	4,801	37	0.8%
Brown Trout	111	7	6.3%	222	7	3.2%
Total				5,023	44	0.9%
<b>Calculated Species Combined</b>						
Trout	997	12	1.2%	5,023	71	1.4%

<sup>1</sup>See Appendix D for calculation details.

**Table AQ 7-18. 2009 Young-of-the-Year Emergence Timing and Abundance in Duncan Creek, North Fork Long Canyon Creek, and South Fork Long Canyon Creek Upstream of the Diversions.**

Survey Date	Species Captured	Young-of-the-Year Size Range	Total Number Captured	Stream Length Sampled (ft)	Water Temperature (C)	Estimated Spawning Date <sup>1</sup>
<b>Duncan Creek Above Diversion</b>						
5/14/2009	<i>No young-of-the-year captured</i>			400	5.5	
6/10/2009				400	12.5	
6/23/2009				400	13.8	
7/6/2009	Rainbow Trout	21 - 24 mm	13	400	14	5/3/2009
<b>North Fork Long Canyon Above Diversion</b>						
5/14/2009	<i>No young-of-the-year captured</i>			450	10	
6/10/2009				450	13.1	
6/23/2009				Rainbow Trout	20 - 34 mm	
<b>South Fork Long Canyon Above Diversion</b>						
5/14/2009	<i>No young-of-the-year captured</i>			400	10	
6/10/2009				400	13.1	
6/23/2009				400	13.9	
7/6/2009	Rainbow Trout	22 - 34 mm	7	400	17	5/7/2009

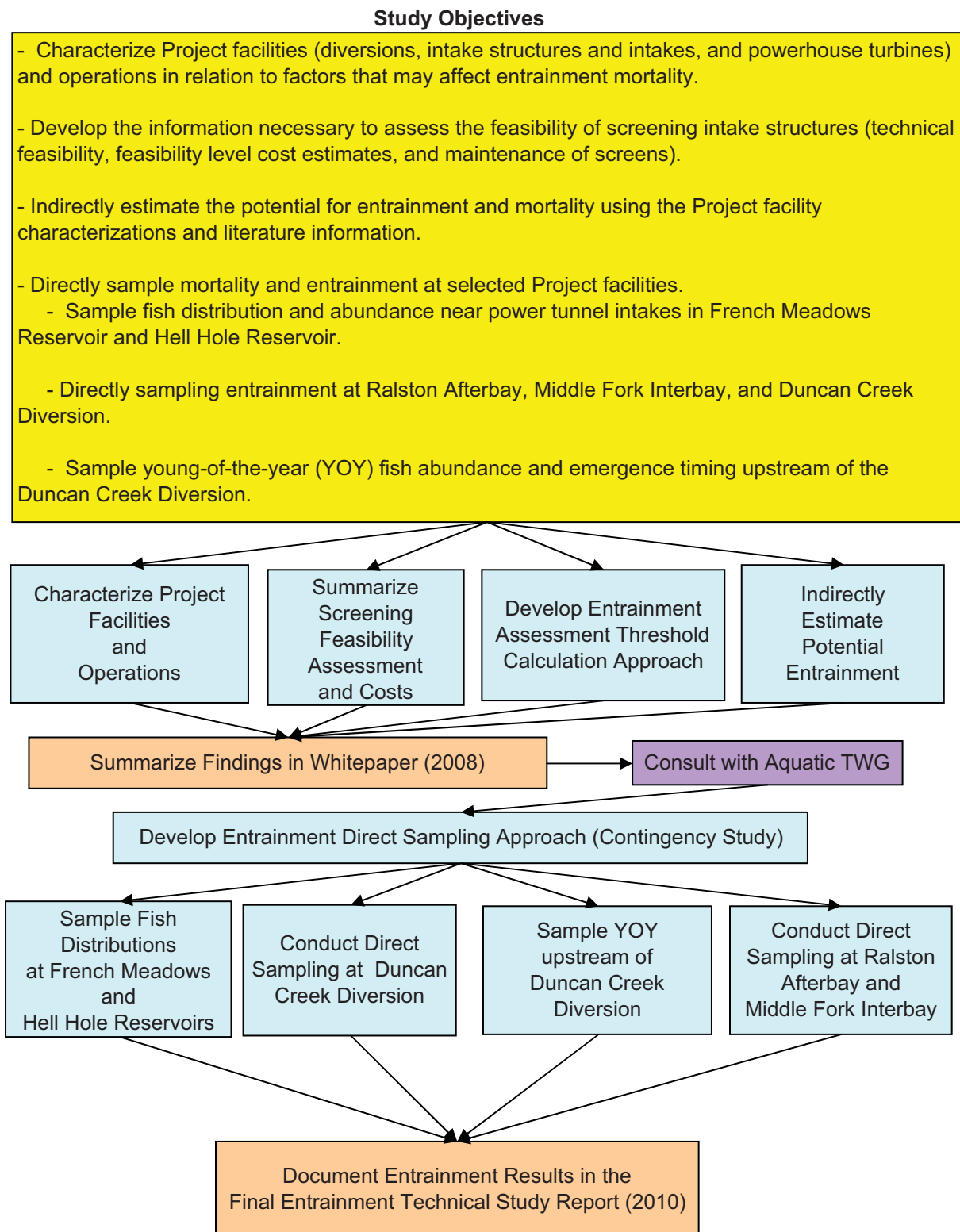
<sup>1</sup>Estimated based on 630 degree days from spawning to emergence.

**Table 7-19. Young-of-the-Year Observed Emergence Dates above the Small Stream Diversions.**

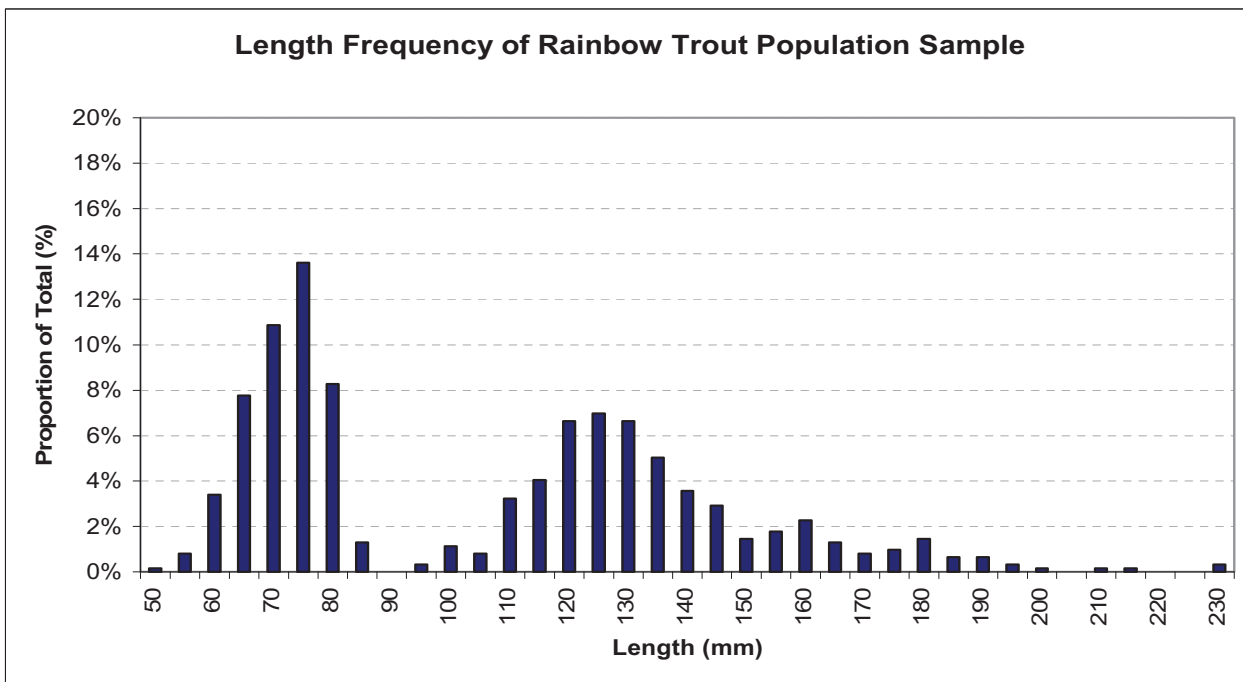
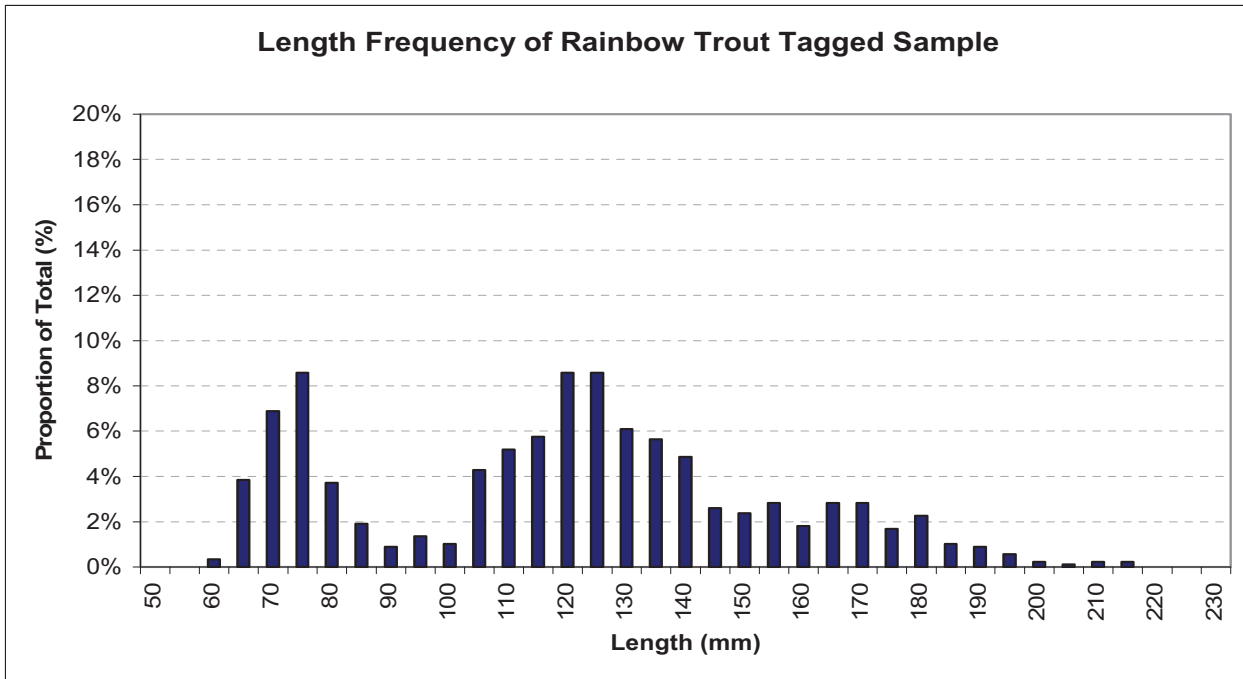
Site	Emergence Date	Date Diversion Ceased Diverting Water
<b>2009</b>		
Duncan Creek	7/6	6/16
North Fork Long Canyon Creek	6/23	5/30
South Fork Long Canyon Creek	7/6	6/9
<b>2007</b>		
Duncan Creek	6/26	5/29
North Fork Long Canyon Creek	6/5	5/20
South Fork Long Canyon Creek	6/26	5/28

**FIGURES**

**Figure AQ 7-1. Entrainment Study Objectives, Related Study Elements, and Reports.**



**Figure AQ 7-2a. Length Frequency of PIT Tagged Rainbow Trout (top) and All Rainbow Trout Captured During Fish Population Survey (2007 - 2008) (bottom) Above the Duncan Diversion.**



**Figure AQ 7-2b. Length Frequency of PIT Tagged Brown Trout (top) and All Brown Trout Captured During Fish Population Survey (2007 - 2008) (bottom) Above the Duncan Diversion.**

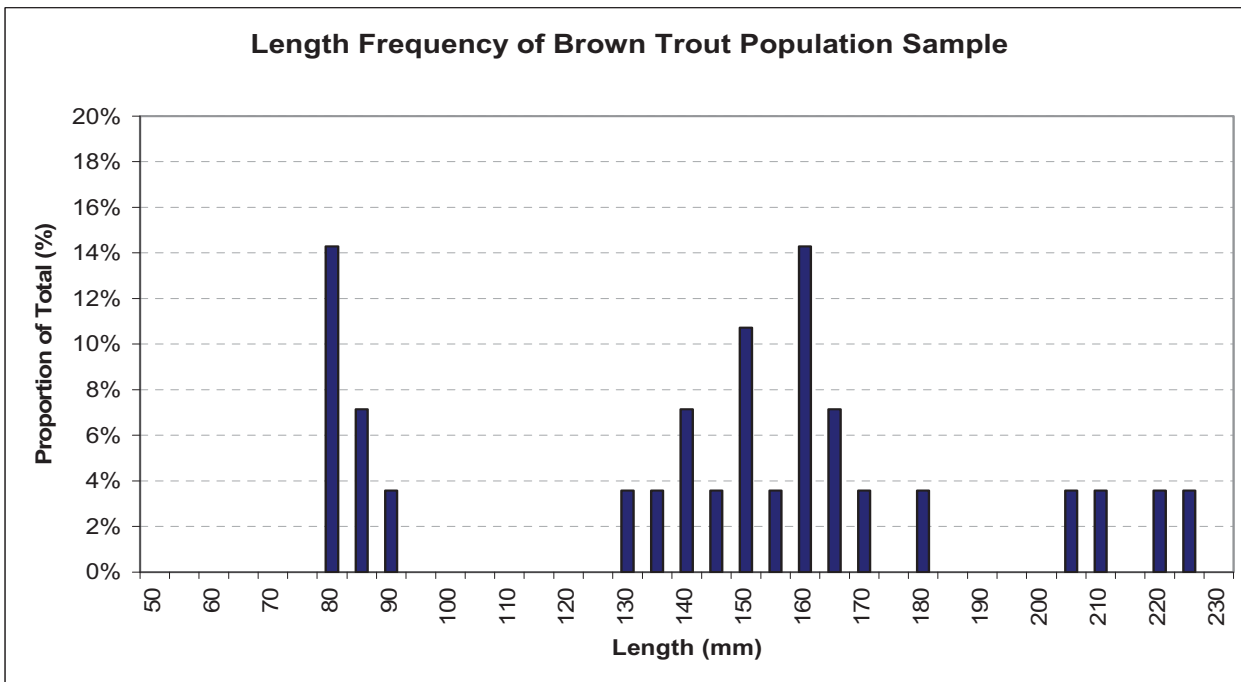
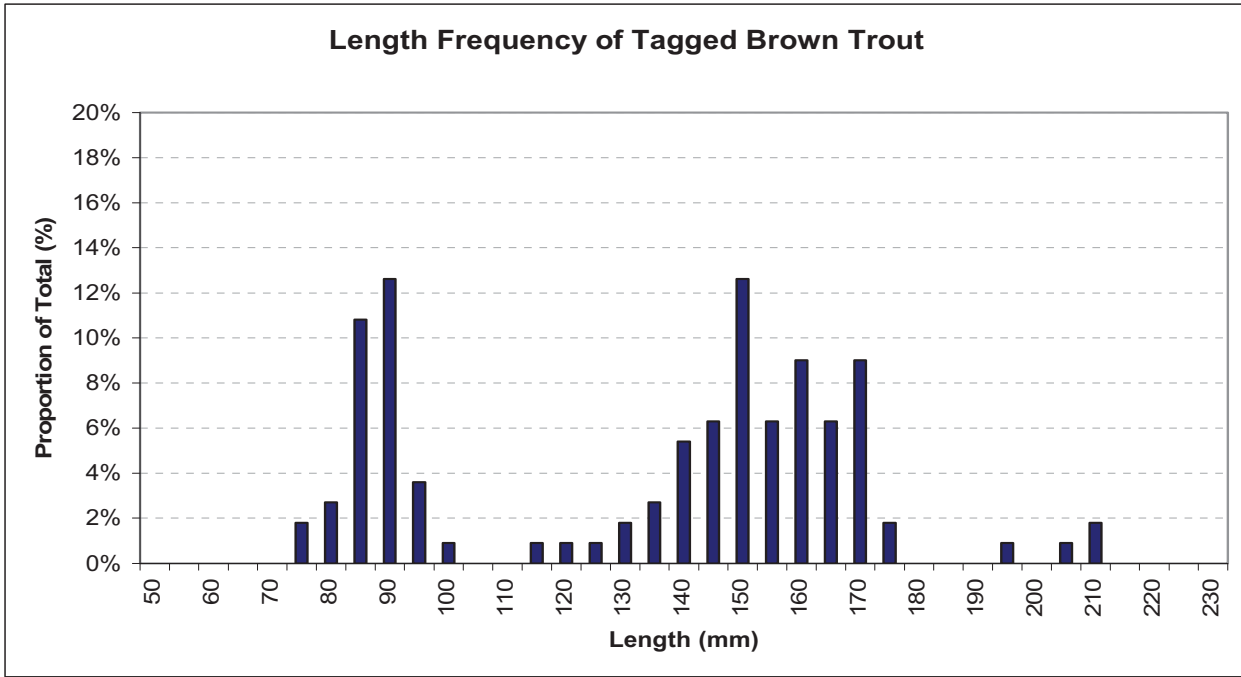
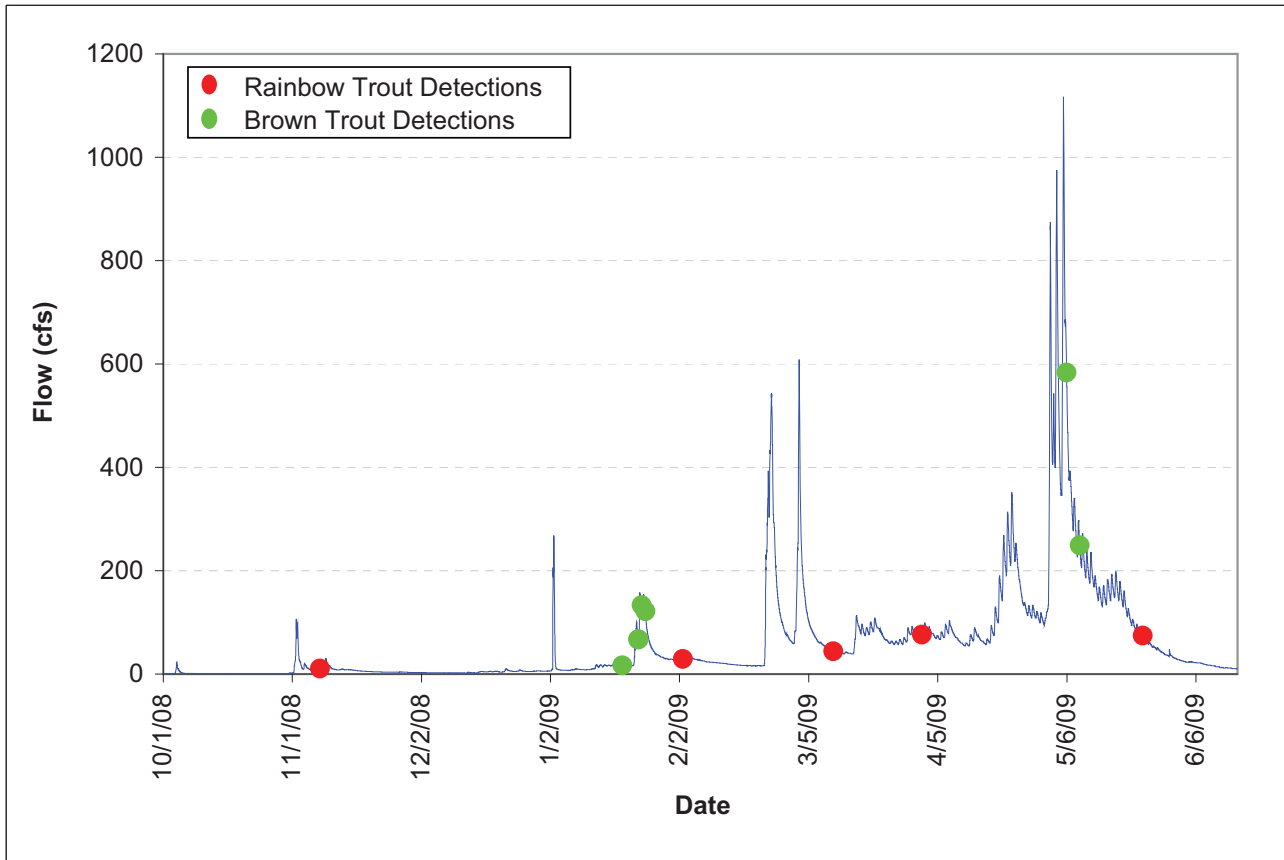


Figure AQ 7-3. Fish Entrainment in Relation to Flow at Duncan Creek Diversion.



Note: A single dot on the graph may represent more than one fish. Refer to Table AQ 7-8 for a list of fish entrained by date.

**Figure AQ 7-4. Daily Average Water Temperatures Above the Diversions in (A) Duncan Creek, (B) North Fork Long Canyon Creek , (C) South Fork Long Canyon Creek , and the (D) Middle Fork American River Upstream of Middle Fork Interbay from 2004 - 2009 and the Weekly Average Water Temperature in West Panther Creek (1984).**

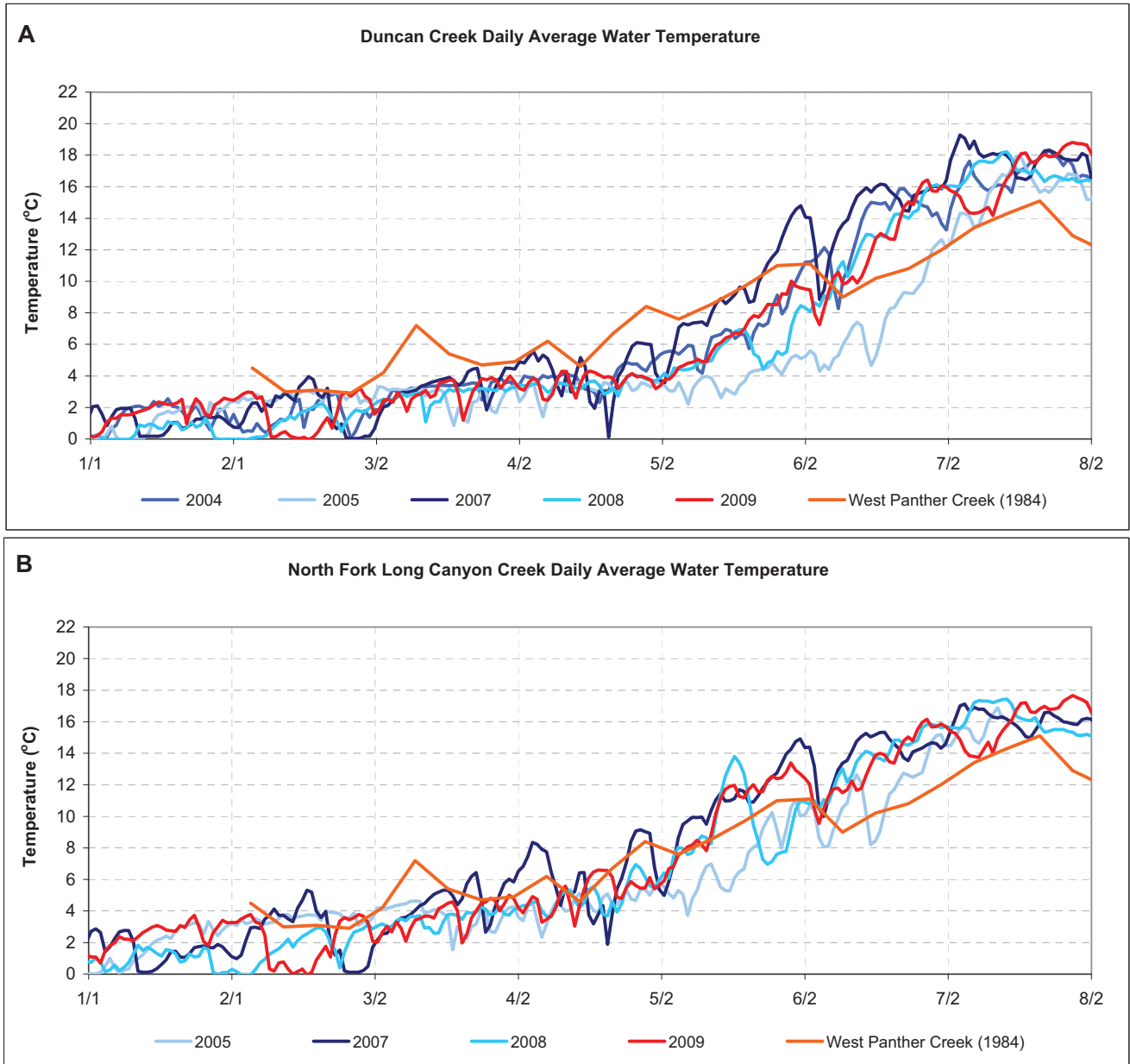


Figure AQ 7-4. Daily Average Water Temperatures Above the Diversions in (A) Duncan Creek, (B) North Fork Long Canyon Creek , (C) South Fork Long Canyon Creek , and the (D) Middle Fork American River Upstream of Middle Fork Interbay from 2004 - 2009 and the Weekly Average Water Temperature in West Panther Creek (1984) (continued).

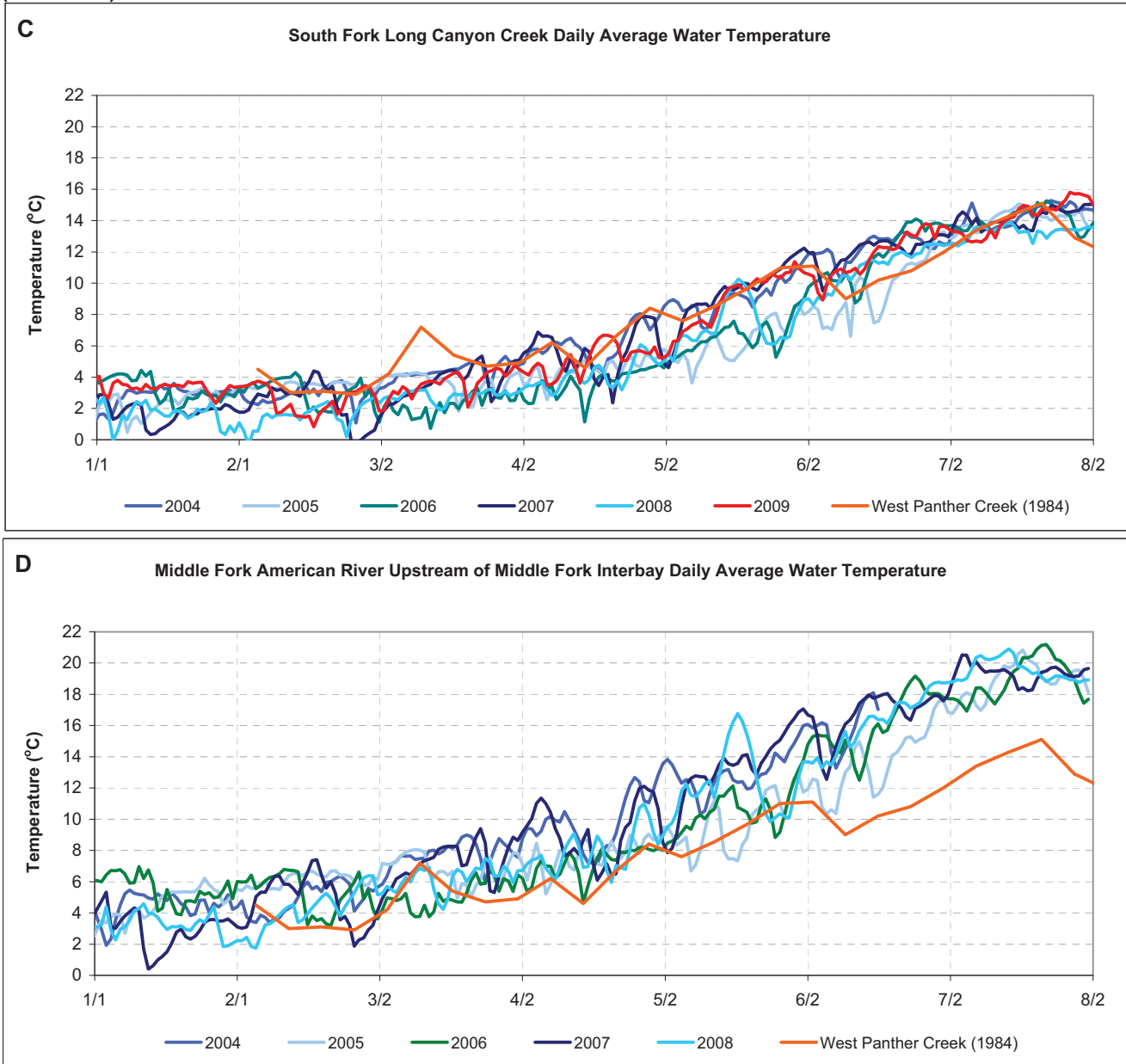
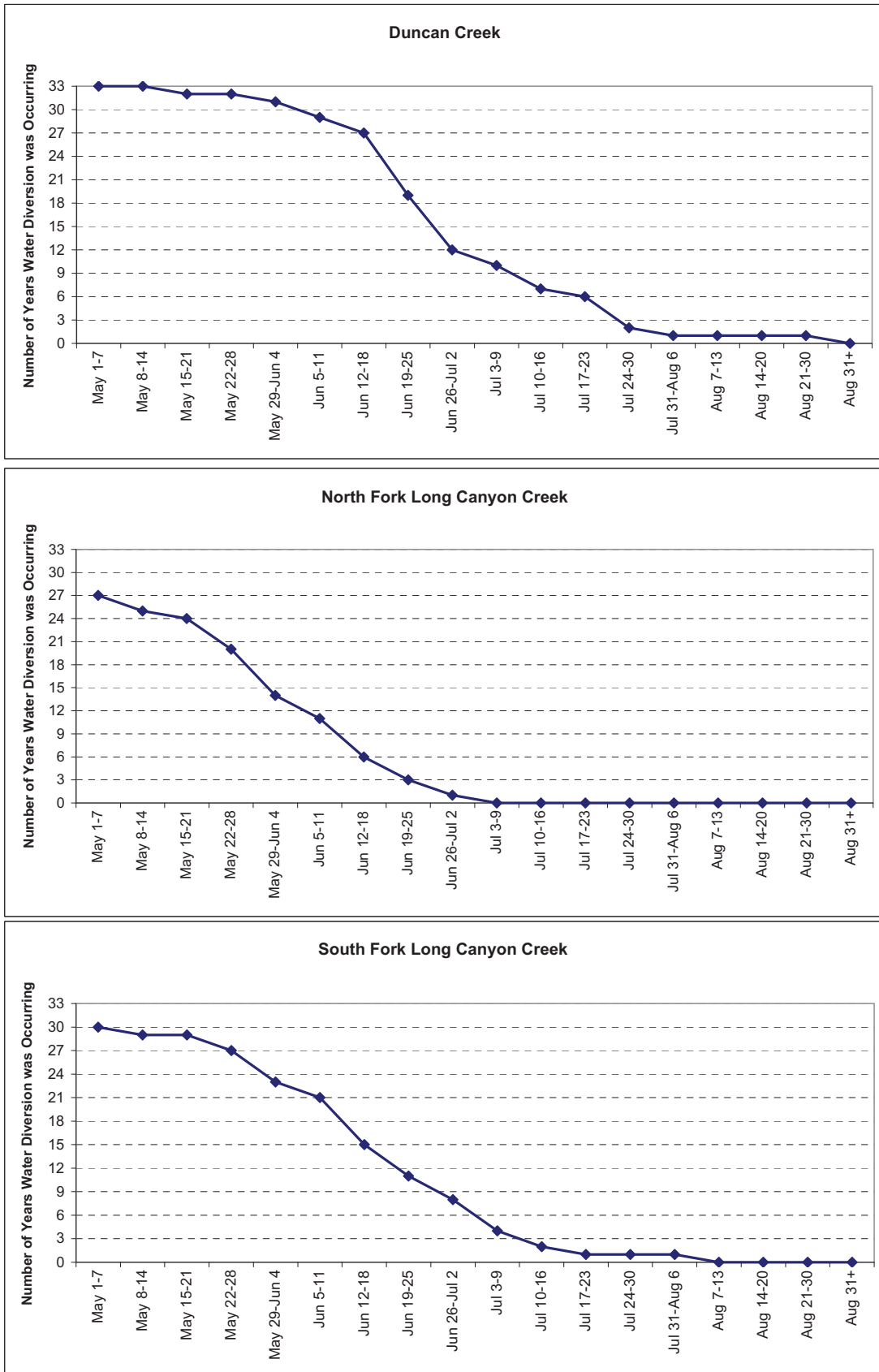


Figure AQ 7-5. The Cumulative Number of Years that Water Diversion was Occurring (1975-2007) at Duncan Creek (top), North Fork Long Canyon Creek (middle), and South Fork Long Canyon Creek (bottom).



**MAPS**

**APPENDIX A**  
**Diversion Photographs**

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## French Meadows Reservoir

### French Meadows Dam Outlet Works Photographs



French Meadows Outlet Works



French Meadows Outlet Works - Instream Flow Pipe and Low Level Outlet

## French Meadows Reservoir

### French Meadows – Hell Hole Tunnel Intake Photograph



French Meadows - Hell Hole Tunnel Inlet Gatehouse

## Hell Hole Reservoir

### French Meadows Powerhouse Photograph



French Meadows Powerhouse



French Meadows Powerhouse

## Hell Hole Reservoir

### Hell Hole Dam Outlet Works Photographs



Dam Outlet Works



Dam Low Level Discharge Ring Jet Valve

## Hell Hole Reservoir

### Hell Hole – Middle Fork Tunnel Intake Photograph



Hell Hole – Middle Fork Tunnel Intake Gatehouse

## Middle Fork Interbay

### Middle Fork – Ralston Tunnel Inlet Structure Photograph



Middle Fork – Ralston Tunnel Inlet Structure

## Middle Fork Interbay

### Middle Fork Interbay Low Level Outlet Photograph



Interbay Low Level Outlet

## Middle Fork Interbay

### Middle Fork Interbay Dam Photographs



Middle Fork Interbay Dam



Middle Fork Interbay Dam - Instream Flow Pipes



Interbay Dam Low Level Discharge



Instream Flow Pipes

## Middle Fork Interbay

### Middle Fork Powerhouse Photograph



Middle Fork Powerhouse



Middle Fork Interbay below Powerhouse

## Ralston Afterbay

### Ralston Afterbay Dam Photographs



Ralston Afterbay Dam



Ralston Afterbay Dam – Downstream

## Ralston Afterbay

### Ralston – Oxbow Tunnel Inlet Structure Photograph



Ralston – Oxbow Tunnel Inlet Structure

## Ralston Afterbay

### Ralston Powerhouse Photographs



Ralston Powerhouse



Ralston Powerhouse with Low Water Level

## Oxbow Powerhouse Photograph



Oxbow Powerhouse

## Duncan Creek

### Duncan Creek Diversion Dam Photographs



Duncan Creek Diversion Dam – Downstream Side



Inlet to Instream Flow Pipe

## Duncan Creek

### Duncan Creek – Middle Fork Intake and Trash Rack Photograph



Duncan Creek – Middle Fork Tunnel Intake

## North Fork Long Canyon

### North Fork Long Canyon Diversion Dam Photographs



North Fork Long Canyon Diversion – Downstream Side



North Fork Long Canyon Diversion – Instream Flow Pipe

## South Fork Long Canyon

### South Fork Long Canyon Diversion Dam Photographs



South Fork Long Canyon Diversion Dam



South Fork Long Canyon Diversion Dam – Downstream Side

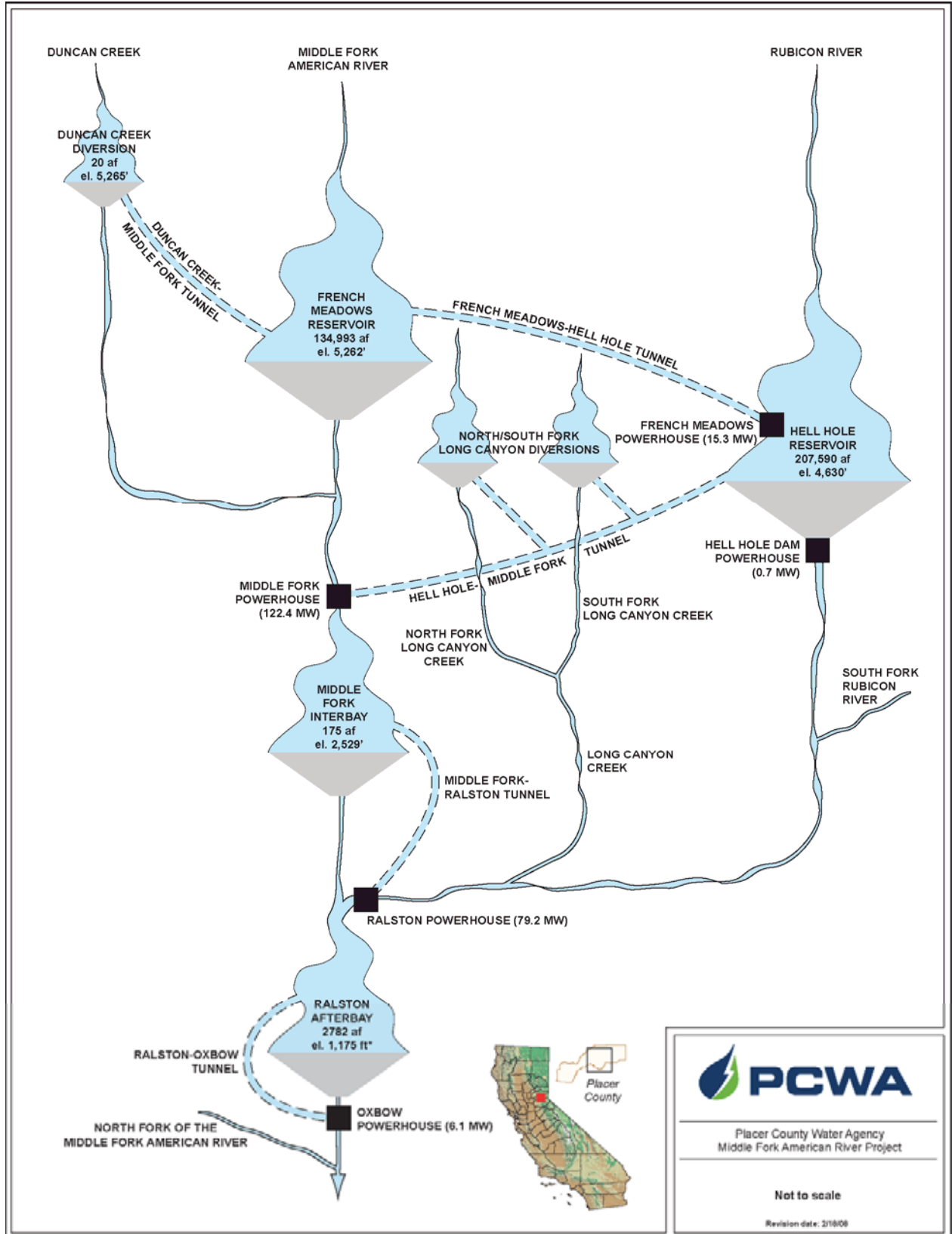
**APPENDIX B**  
**Water Diversion Diagrams and Flow Data**

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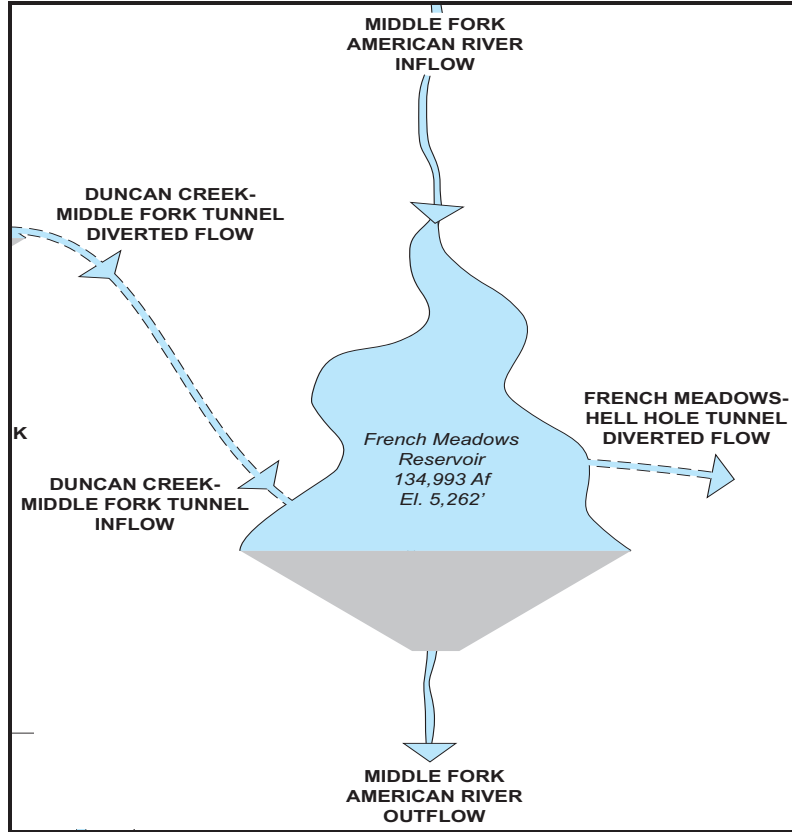
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# Middle Fork American Project Water Inflow-Outflow Diagram.



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## French Meadows Reservoir



French Meadows Water Budget.

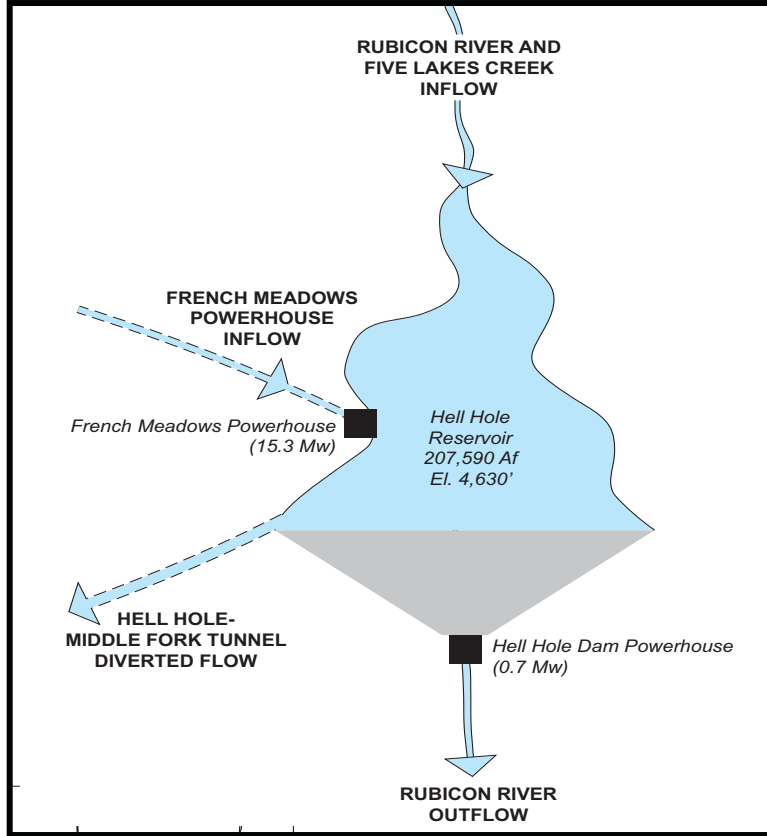
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Middle Fork American River Inflow</b>					
Oct	24	14	6	2	1
Nov	119	55	14	5	4
Dec	209	84	28	12	9
Jan	313	170	52	20	14
Feb	323	205	102	30	21
Mar	498	310	169	97	67
Apr	621	486	283	170	122
May	894	719	396	175	104
Jun	774	492	133	42	24
Jul	179	89	33	15	10
Aug	44	27	13	6	3
Sep	23	15	6	3	2
<b>Duncan Creek - French Meadows Tunnel Inflow</b>					
Oct	0	0	0	0	0
Nov	20	4	0	0	0
Dec	40	11	0	0	0
Jan	51	24	2	0	0
Feb	50	31	9	0	0
Mar	86	55	24	8	3
Apr	128	100	52	24	15
May	193	151	80	26	12
Jun	157	90	8	0	0
Jul	12	1	0	0	0
Aug	0	0	0	0	0
Sep	0	0	0	0	0

## French Meadows Reservoir

### French Meadows Water Budget (continued).

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Middle Fork American River Outflow</b>					
Oct	10	10	9	7	5
Nov	12	10	9	7	6
Dec	14	11	10	7	6
Jan	17	13	10	9	6
Feb	16	13	10	8	6
Mar	18	15	11	9	8
Apr	16	14	11	9	8
May	23	14	10	8	7
Jun	14	11	10	7	5
Jul	11	10	9	7	5
Aug	10	10	9	7	5
Sep	10	10	9	8	5
<b>French Meadows-Hell Hole Tunnel Diverted Flow</b>					
Oct	353	334	237	0	0
Nov	343	327	0	0	0
Dec	352	241	0	0	0
Jan	334	239	0	0	0
Feb	352	335	58	0	0
Mar	362	345	92	0	0
Apr	360	326	0	0	0
May	359	326	0	0	0
Jun	365	325	197	0	0
Jul	342	325	262	146	0
Aug	341	326	269	173	0
Sep	341	322	224	0	0
<b>Percent Diverted</b>					
Oct	6732	4890	1865	0	0
Nov	3903	1611	0	0	0
Dec	707	243	0	0	0
Jan	284	140	0	0	0
Feb	317	208	17	0	0
Mar	225	146	28	0	0
Apr	110	69	0	0	0
May	68	40	0	0	0
Jun	470	245	49	0	0
Jul	2193	1244	535	106	0
Aug	7553	3809	1400	598	0
Sep	9049	6349	2154	0	0

## Hell Hole Reservoir



Hell Hole Reservoir Water Budget.

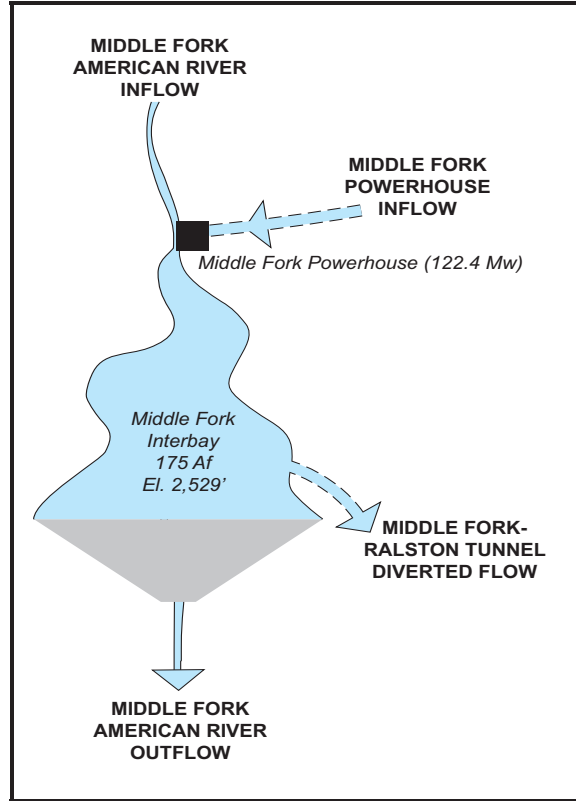
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Rubicon River and Five Lakes Creek Inflow</b>					
Oct	21	8	2	1	0
Nov	109	22	8	7	0
Dec	166	60	21	12	0
Jan	293	102	30	18	0
Feb	325	166	56	42	0
Mar	494	265	168	125	0
Apr	769	458	289	202	0
May	1199	697	311	189	0
Jun	856	214	58	32	0
Jul	111	32	9	2	0
Aug	36	16	5	3	0
Sep	20	8	4	2	0
<b>French Meadows Powerhouse Inflow</b>					
Oct	353	334	237	0	0
Nov	343	327	0	0	0
Dec	352	241	0	0	0
Jan	334	239	0	0	0
Feb	352	335	58	0	0
Mar	362	345	92	0	0
Apr	360	326	0	0	0
May	359	326	0	0	0
Jun	365	325	197	0	0
Jul	342	325	262	146	0
Aug	341	326	269	173	0
Sep	341	322	224	0	0

## Hell Hole Reservoir

### Hell Hole Reservoir Water Budget (continued).

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Rubicon River Outflow</b>					
Oct	43	29	22	10	8
Nov	24	23	22	14	8
Dec	23	22	15	12	8
Jan	26	17	13	12	11
Feb	25	20	14	12	11
Mar	24	21	15	12	11
Apr	25	21	15	13	12
May	38	24	21	14	12
Jun	138	24	22	19	12
Jul	23	23	22	17	11
Aug	23	23	21	11	9
Sep	30	23	22	11	9
<b>Hell Hole - Middle Fork Tunnel Diverted Flow</b>					
Oct	806	583	73	0	0
Nov	688	584	384	6	0
Dec	817	629	241	0	0
Jan	776	473	159	0	0
Feb	826	734	313	0	0
Mar	898	796	339	-13	-24
Apr	887	771	219	-17	-34
May	914	852	335	-3	-10
Jun	917	861	555	211	0
Jul	896	845	570	308	26
Aug	911	861	617	368	169
Sep	883	711	487	139	0
<b>Percent Diverted</b>					
Oct	668	253	55	0	0
Nov	3899	1397	173	4	0
Dec	1724	952	132	0	0
Jan	766	309	106	0	0
Feb	269	190	95	0	0
Mar	177	146	62	-6	-9
Apr	134	100	36	-4	-8
May	107	77	35	-1	-3
Jun	337	191	101	34	0
Jul	392	278	183	106	33
Aug	419	312	231	153	113
Sep	4477	438	216	88	0

## Middle Fork Interbay



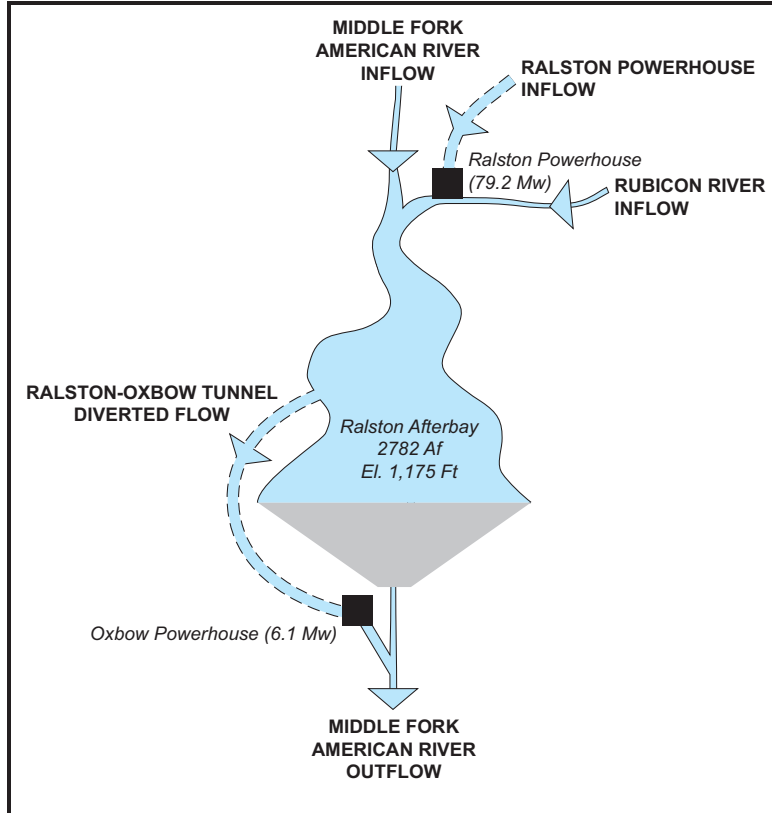
Middle Fork Interbay Water Budget.

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Middle Fork American River Inflow</b>					
Oct	25	21	17	13	10
Nov	62	37	19	16	14
Dec	160	69	31	20	17
Jan	248	158	55	22	19
Feb	278	179	89	37	25
Mar	328	228	123	74	58
Apr	241	196	122	66	50
May	372	224	76	41	32
Jun	222	76	42	22	18
Jul	46	37	25	16	12
Aug	26	23	18	13	10
Sep	21	19	16	12	10
<b>Middle Fork Powerhouse Inflow</b>					
Oct	800	673	133	0	0
Nov	800	719	517	196	12
Dec	920	781	478	223	67
Jan	920	595	114	0	0
Feb	920	769	203	0	0
Mar	936	920	234	0	0
Apr	940	927	333	0	0
May	940	940	541	0	0
Jun	925	920	414	85	35
Jul	920	830	565	218	67
Aug	800	726	565	295	119
Sep	740	628	246	39	0

**Middle Fork Interbay****Middle Fork Interbay Water Budget. (continued)**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Middle Fork American River Outflow</b>					
Oct	23	23	19	14	11
Nov	23	23	21	16	12
Dec	23	23	23	19	12
Jan	23	23	23	20	12
Feb	23	23	23	23	12
Mar	23	23	23	23	12
Apr	23	23	23	23	12
May	23	23	23	23	12
Jun	23	23	23	22	12
Jul	23	23	23	17	12
Aug	23	23	20	13	11
Sep	23	21	18	13	10
<b>Middle Fork - Ralston Tunnel Diverted Flow</b>					
Oct	800	674	133	0	0
Nov	803	739	532	209	32
Dec	924	814	497	238	75
Jan	924	781	180	10	1
Feb	924	879	286	31	15
Mar	924	924	461	71	47
Apr	924	924	498	55	37
May	924	924	657	24	16
Jun	924	924	443	105	67
Jul	924	841	571	223	69
Aug	800	726	566	295	119
Sep	741	628	247	39	0
<b>Percent Diverted</b>					
Oct	98%	98%	91%	0%	0%
Nov	98%	98%	97%	93%	61%
Dec	99%	98%	96%	90%	72%
Jan	102%	99%	88%	32%	6%
Feb	103%	101%	91%	63%	41%
Mar	105%	101%	91%	78%	72%
Apr	103%	101%	88%	77%	69%
May	98%	95%	81%	57%	46%
Jun	97%	97%	93%	82%	72%
Jul	98%	98%	96%	91%	83%
Aug	98%	98%	97%	95%	90%
Sep	98%	97%	94%	78%	0%

## Ralston Afterbay



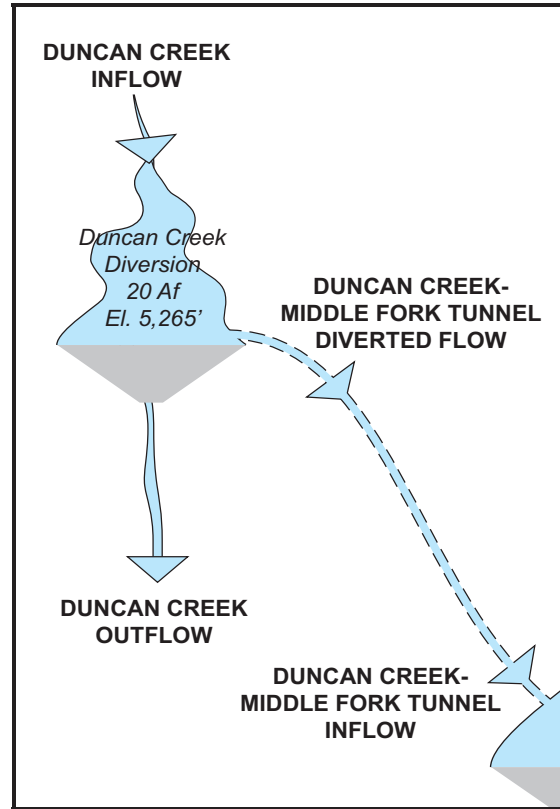
Ralston Afterbay Water Budget.

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Rubicon River Inflow</b>					
Oct	83	75	64	41	29
Nov	175	100	69	49	44
Dec	481	181	84	56	48
Jan	1102	588	159	65	49
Feb	1287	767	274	107	84
Mar	1358	918	424	185	129
Apr	1051	772	389	150	103
May	1041	630	198	100	82
Jun	600	225	126	63	52
Jul	151	113	76	44	33
Aug	93	78	56	38	26
Sep	83	73	52	37	26
<b>Middle Fork Amercian River Inflow</b>					
Oct	62	47	31	22	19
Nov	101	64	41	30	20
Dec	213	104	46	31	21
Jan	396	202	60	40	27
Feb	578	224	89	46	38
Mar	572	277	115	62	43
Apr	386	242	108	58	46
May	403	159	62	43	33
Jun	304	99	50	36	29
Jul	77	55	38	28	21
Aug	47	38	32	20	17
Sep	45	36	30	20	16

**Ralston Afterbay****Ralston Afterbay Water Budget (continued).**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Ralston Powerhouse Inflow</b>					
Oct	797	602	88	0	0
Nov	768	602	434	29	0
Dec	908	679	272	18	0
Jan	906	637	261	21	0
Feb	911	891	443	34	9
Mar	914	909	586	57	38
Apr	918	911	452	46	25
May	915	911	586	27	12
Jun	914	909	583	232	18
Jul	908	843	597	331	40
Aug	909	850	615	400	174
Sep	868	703	502	88	0
<b>Middle Fork American River Outflow</b>					
Oct	139	109	74	-1	-33
Nov	178	110	48	-14	-51
Dec	472	170	58	-9	-53
Jan	1184	597	86	19	-28
Feb	1636	860	132	33	-19
Mar	1731	1152	255	55	-32
Apr	1269	843	178	59	3
May	1419	562	139	53	13
Jun	950	253	81	-1	-31
Jul	166	114	34	-18	-40
Aug	93	68	19	-25	-48
Sep	102	87	16	-33	-55
<b>Ralston - Oxbow Tunnel Diverted Flow</b>					
Oct	861	730	0	0	0
Nov	910	758	544	51	0
Dec	958	877	459	77	17
Jan	971	942	570	103	34
Feb	978	968	834	197	85
Mar	981	969	907	309	196
Apr	983	975	841	188	102
May	984	971	843	120	60
Jun	976	961	724	351	76
Jul	950	914	708	428	69
Aug	939	907	730	462	197
Sep	914	808	604	154	0
<b>Percent Diverted</b>					
Oct	107	100	0	0	0
Nov	108	102	85	25	0
Dec	101	93	74	29	6
Jan	96	86	59	32	12
Feb	90	82	55	31	18
Mar	80	71	47	31	23
Apr	63	56	39	24	14
May	55	48	35	21	15
Jun	98	88	62	30	21
Jul	108	102	92	68	26
Aug	109	105	97	90	76
Sep	111	107	99	72	0

**Duncan Creek**



**Duncan Creek Diversion Water Budget.**

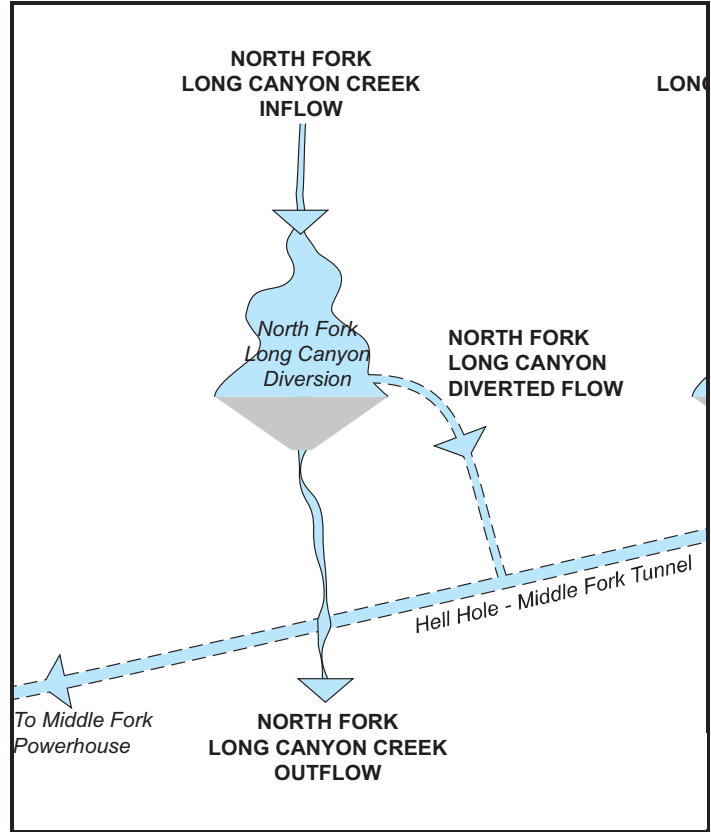
Month	Exceedances				
	10 %	20 %	50 %	80 %	90 %
<b>Duncan Creek Inflow</b>					
Oct	3.9	2.3	0.9	0.5	0.5
Nov	29.0	13.0	2.9	1.2	1.0
Dec	54.0	23.0	8.0	3.4	2.1
Jan	82.0	42.0	13.0	4.2	3.0
Feb	73.0	46.0	23.0	6.7	5.0
Mar	112.0	72.0	37.0	21.0	15.0
Apr	147.0	117.0	65.0	38.0	26.0
May	234.0	188.0	93.0	36.0	20.0
Jun	201.0	114.0	18.0	5.3	3.2
Jul	20.0	8.5	2.8	1.2	0.9
Aug	3.2	2.1	1.0	0.5	0.4
Sep	2.1	1.4	0.8	0.4	0.4
<b>Duncan Creek Outflow</b>					
Oct	3.3	2.2	0.9	0.5	0.4
Nov	12.0	7.3	2.5	1.1	1.0
Dec	15.0	13.0	6.5	2.9	1.8
Jan	20.0	15.0	10.0	4.1	2.7
Feb	21.0	15.0	11.0	5.5	4.7
Mar	21.0	17.0	13.0	10.0	9.0
Apr	19.0	16.0	12.0	9.0	7.0
May	42.0	18.0	11.0	8.2	5.4
Jun	16.0	12.0	8.7	4.4	3.1
Jul	9.6	6.8	2.7	1.2	0.8
Aug	2.8	1.9	1.0	0.5	0.4
Sep	2.0	1.3	0.8	0.4	0.3

## Duncan Creek

### Duncan Creek Diversion Water Budget (continued).

Month	Exceedances				
	10	20	50	80	90
<b>Duncan Creek - Middle Fork Tunnel Diverted Flow</b>					
Oct	0.2	0.0	0.0	0.0	0.0
Nov	19.7	4.0	0.1	0.0	0.0
Dec	40.0	11.0	0.2	0.0	0.0
Jan	51.0	24.1	2.0	0.0	0.0
Feb	50.0	31.0	9.0	0.0	0.0
Mar	86.0	55.0	24.0	8.0	3.1
Apr	128.0	100.0	51.6	24.4	14.5
May	193.0	151.0	80.0	25.7	11.5
Jun	157.0	90.0	8.1	0.0	0.0
Jul	12.0	0.6	0.0	0.0	0.0
Aug	0.2	0.1	0.0	0.0	0.0
Sep	0.1	0.0	0.0	0.0	0.0
<b>Percent Diverted</b>					
Oct	13%	3%	0%	0%	0%
Nov	71%	42%	4%	0%	0%
Dec	73%	55%	7%	0%	0%
Jan	76%	65%	21%	0%	0%
Feb	78%	71%	41%	0%	0%
Mar	84%	78%	62%	37%	22%
Apr	91%	89%	82%	67%	57%
May	94%	92%	85%	65%	49%
Jun	91%	87%	46%	0%	0%
Jul	62%	13%	0%	0%	0%
Aug	17%	8%	0%	0%	0%
Sep	13%	6%	0%	0%	0%

## North Fork Long Canyon Creek



North Fork Long Canyon Diversion Water Budget.

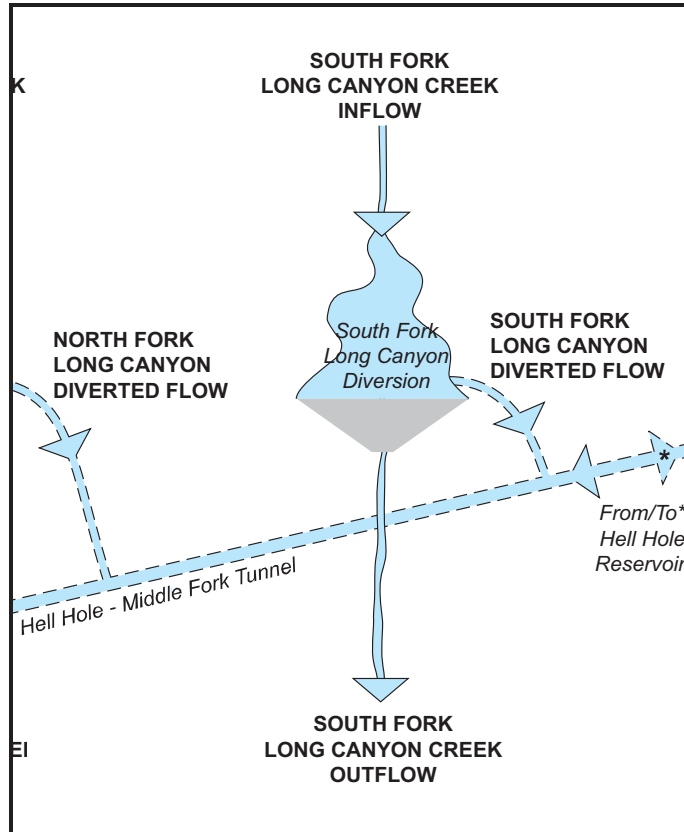
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>North Fork Long Canyon Creek Inflow</b>					
Oct	0.9	0.5	0.3	0.2	0.1
Nov	6.8	4.5	1.0	0.4	0.3
Dec	20.0	8.1	3.0	1.1	0.5
Jan	31.7	18.7	5.2	1.3	0.9
Feb	35.8	21.8	9.7	3.6	2.0
Mar	43.5	30.3	16.5	8.2	5.8
Apr	39.8	31.6	19.5	9.1	5.9
May	44.1	34.1	12.3	4.0	2.7
Jun	14.4	7.7	3.0	1.3	0.9
Jul	2.8	1.7	0.8	0.4	0.3
Aug	0.8	0.5	0.3	0.2	0.1
Sep	0.5	0.4	0.3	0.1	0.1
<b>North Fork Long Canyon Creek Outflow</b>					
Oct	0.9	0.5	0.3	0.2	0.1
Nov	5.9	3.3	1.0	0.4	0.3
Dec	11.1	5.5	2.3	1.1	0.5
Jan	15.2	8.1	2.9	1.3	0.9
Feb	15.9	5.9	3.3	2.0	2.0
Mar	22.9	9.9	3.7	2.6	2.0
Apr	13.8	6.0	3.4	2.0	2.0
May	20.7	5.0	3.3	2.0	2.0
Jun	7.4	4.5	2.5	1.3	0.9
Jul	2.8	1.7	0.8	0.4	0.3
Aug	0.8	0.5	0.3	0.2	0.1
Sep	0.5	0.4	0.3	0.1	0.1

**North Fork Long Canyon Creek**

**North Fork Long Canyon Diversion Water Budget (continued).**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>North Fork Long Canyon Diverted Flow</b>					
Oct	0.0	0.0	0.0	0.0	0.0
Nov	0.1	0.0	0.0	0.0	0.0
Dec	3.8	0.4	0.0	0.0	0.0
Jan	18.0	9.5	0.0	0.0	0.0
Feb	21.0	13.0	2.5	0.0	0.0
Mar	31.0	22.0	8.5	0.0	0.0
Apr	33.0	26.0	12.0	1.5	0.0
May	33.0	22.0	4.1	0.0	0.0
Jun	5.9	0.7	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0
<b>Percent Diverted</b>					
Oct	0%	0%	0%	0%	0%
Nov	6%	0%	0%	0%	0%
Dec	51%	11%	0%	0%	0%
Jan	84%	71%	0%	0%	0%
Feb	87%	81%	40%	0%	0%
Mar	90%	86%	72%	0%	0%
Apr	92%	89%	77%	21%	0%
May	93%	88%	54%	0%	0%
Jun	68%	14%	0%	0%	0%
Jul	0%	0%	0%	0%	0%
Aug	0%	0%	0%	0%	0%
Sep	0%	0%	0%	0%	0%

### South Fork Long Canyon Creek



South Fork Long Canyon Diversion Water Budget.

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>South Fork Long Canyon Creek Inflow</b>					
Oct	1.5	1.0	0.6	0.3	0.3
Nov	15.7	7.8	1.7	0.7	0.6
Dec	37.2	13.7	4.8	1.8	0.9
Jan	56.3	32.2	8.9	2.3	1.6
Feb	66.8	40.6	18.5	6.3	3.5
Mar	79.2	55.6	29.1	14.4	11.1
Apr	72.5	59.0	36.0	17.9	13.7
May	81.0	61.4	31.0	11.2	7.2
Jun	34.0	20.0	6.3	2.5	1.6
Jul	6.0	2.8	1.4	0.8	0.6
Aug	1.4	0.9	0.6	0.3	0.2
Sep	0.8	0.7	0.5	0.2	0.1
<b>South Fork Long Canyon Creek Outflow</b>					
Oct	1.5	1.0	0.6	0.3	0.3
Nov	9.3	5.2	1.7	0.7	0.6
Dec	16.8	8.3	4.2	1.8	0.9
Jan	20.6	7.8	5.0	2.3	1.6
Feb	23.0	7.8	6.0	3.9	2.8
Mar	40.7	14.2	6.3	5.0	4.0
Apr	20.3	6.7	6.0	5.0	3.9
May	34.9	6.5	5.8	5.0	2.9
Jun	8.5	6.1	5.0	2.5	1.6
Jul	5.0	2.8	1.4	0.8	0.6
Aug	1.4	0.9	0.6	0.3	0.2
Sep	0.8	0.7	0.5	0.2	0.1

**South Fork Long Canyon Creek**

**South Fork Long Canyon Diversion Water Budget (continued).**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>South Fork Long Canyon Diverted Flow</b>					
Oct	0.0	0.0	0.0	0.0	0.0
Nov	0.8	0.0	0.0	0.0	0.0
Dec	9.7	1.6	0.0	0.0	0.0
Jan	34.0	20.0	0.0	0.0	0.0
Feb	38.0	24.0	5.0	0.0	0.0
Mar	61.0	40.0	15.0	0.6	0.0
Apr	63.0	49.0	24.0	5.0	0.0
May	60.0	50.0	15.0	1.6	0.0
Jun	24.0	11.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0
<b>Percent Diverted</b>					
Oct	0%	0%	0%	0%	0%
Nov	21%	0%	0%	0%	0%
Dec	58%	27%	0%	0%	0%
Jan	86%	76%	0%	0%	0%
Feb	88%	81%	51%	0%	0%
Mar	91%	86%	67%	10%	0%
Apr	93%	90%	81%	50%	0%
May	92%	89%	74%	22%	0%
Jun	80%	67%	0%	0%	0%
Jul	0%	0%	0%	0%	0%
Aug	0%	0%	0%	0%	0%
Sep	0%	0%	0%	0%	0%

**APPENDIX C**  
**Summary of Fish Screening Unit Costs**

**List of Tables**

Table C-1. Summary of Fish Screening Unit Costs (dollars / cfs).

Table C-1. Summary of Fish Screening Unit Costs (dollars / cfs).

California Projects	Date	Maximum Diversion (cfs)	Design Criteria (approach velocity)	Screen Area	Design	Total Project Cost	2008 Cost with 3% Annual Inflation	2008 cost/cfs
<b>Flow Range 50-100 cfs</b>								
Coyote Canal Diversion	1999	50	0.33	-	Single flat plate	\$470,000	\$613,240	\$12,260
Anderson Cottonwood Irrigation District (Bonnyview Pumps)	1992	60	-	-	Cylindrical	\$330,000	\$529,550	\$8,830
Browns Valley ID	1999	65	-	-	-	\$298,287	\$389,200	\$5,990
Upper Toppenish	1987	72	-	144	Drum	\$264,720	\$492,460	\$6,840
Maxwell Irrigation District	1993	80	0.33	-	Cylindrical	\$794,000	\$1,237,000	\$15,460
Richland	1985	80	-	160	Drum	\$322,560	\$636,600	\$7,960
EBMUD Bixler Slough	1987	90	-	-	Cylindrical	\$50,000	\$93,015	\$1,030
Suisun Resource Conservation District	1997	93	-	-	-	\$900,000	\$1,245,800	\$13,400
<b>Average 2008 cost/cfs</b>								<b>\$8,971</b>

<b>Flow Range 100-500 cfs</b>								
Grizzly Island (CDFG)	1995	100	0.2	-	Cylindrical	\$300,000	\$440,560	\$4,410
Maxwell ID	1997	100	-	-	-	\$1,545,000	\$2,138,600	\$21,390
RD 999	2006	100	-	-	-	\$636,000	\$674,730	\$6,750
Adams Dam / Rancho Esquon Partners	1998	120	0.33	530	Single flat plate	\$558,700	\$750,850	\$6,260
Gorrell	1999	121.7	0.33	-	Single flat plate	\$1,515,955	\$1,978,000	\$16,250
Parrott-Phelan Irrigation Systems (M&T Ranch)	1997	150	0.33	-	Cylindrical	\$4,500,000	\$6,229,100	\$41,530
Dryden	1993	200	-	500	Single flat plate	\$2,394,000	\$3,729,800	\$18,650
Banton Carbona	2004	260	-	-	-	\$9,800,000	\$11,030,000	\$42,420
Reclamation District 104	1999	290	-	-	-	\$7,250,000	\$9,459,600	\$32,620
Potter Valley	1996	320	0.33	960	Inclined Plane	\$14,000,000	\$19,961,000	\$62,380
CCWD Rock Slough	1998	350	-	-	Single flat plate	\$6,600,000	\$8,869,800	\$25,340
Contra Costa Canal- Estimated	1992	350	-	1800	Single flat plate	\$3,000,000	\$4,814,100	\$13,750
Leaburg (a)	1983	470	-	675	Chevron	\$3,247,400	\$6,799,300	\$14,470
Jim Boyd	1987	500	-	345	Single flat plate	\$868,510	\$1,615,700	\$3,230
Wapatox	1993	500	-	1250	Single flat plate	\$3,150,000	\$4,907,600	\$9,820
<b>Average 2008 cost/cfs</b>								<b>\$21,285</b>

<b>Flow Range 500-1000 cfs</b>								
Princeton-Codora Glenn/ Prov ID	1999	605	-	-	-	\$10,957,887	\$14,298,000	\$23,630
Toppenish-Status	1986	650	-	1300	Drum	\$1,392,300	\$2,667,800	\$4,100
DWR Roaring River	1980	750	-	-	Single flat plate	\$1,500,000	\$3,431,900	\$4,580
RD 108 - Wilkins Slough	1998	800	0.33	2520	Single flat plate	\$11,600,000	\$15,589,000	\$19,490
Sutter Mutual	2007	960	-	-	-	\$21,500,000	\$22,145,000	\$23,070
Dalles North FERC	1991	1000	-	2000	Single flat plate	\$4,280,000	\$7,074,200	\$7,070
<b>Average 2008 cost/cfs</b>								<b>\$11,662</b>

<b>Flow Range 1000 &gt; cfs</b>								
Easton	1988	1170	-	2340	Drum	\$8,256,000	\$14,911,000	\$12,740
Sunnyside	1985	1300	0.4	2600	Drum	\$5,098,000	\$10,061,000	\$7,740
Chandler	1987	1500	-	3000	Drum	\$15,063,000	\$28,022,000	\$18,680
Wapato	1986	2000	0	4000	-	\$6,652,000	\$12,746,000	\$6,370
Roza	1988	2200	-	4600	Drum	\$19,860,000	\$35,869,000	\$16,300
Red Bluff	1990	3000	0.33	6000	Drum	\$17,202,000	\$29,285,000	\$9,760
<b>Average 2008 cost/cfs</b>								<b>\$11,932</b>

Source: NOAA Fisheries

Yuba River Projects	Date	Maximum Diversion (cfs)	Design Criteria (approach velocity)	Screen Area	Design	Total Project Cost <sup>1</sup>	2008 Cost with -3% Annual Inflation	2008 cost/cfs
<b>Flow Range 500-1000 cfs</b>								
Englebright-Narrows I <sup>2</sup>	2009	720	-	2400	Vertical plate	\$13,805,825	\$13,392,000	\$18,600
<b>Average 2008 cost/cfs</b>								<b>\$18,600</b>
<b>Flow Range &gt;1000 cfs</b>								
North Yuba River	2009	5000	0.33	7500	Vertical plate	\$60,000,000	\$58,200,000	\$11,640
Middle Yuba River	2009	2000	0.33	6000	Vertical plate	\$33,000,000	\$32,010,000	\$16,010
South Yuba River	2009	4000	0.33	6000	Vertical plate	\$55,000,000	\$53,350,000	\$13,340
Englebright-Narrows II <sup>2</sup>	2009	3400	0.33	5400	Vertical plate	\$65,194,175	\$63,238,000	\$18,600
<b>Average 2008 cost/cfs</b>								<b>\$14,898</b>

Source: National Marine Fisheries Service

<sup>1</sup>Total project costs are opinion of probable construction costs.

<sup>2</sup>Uncompleted project costs are listed in 2009 dollars, see next column for normalization to 2008 dollars for comparison.

<sup>3</sup>Total project cost estimate for Englebright fish screens is \$79 million. The total cost per unit (Narrows I and Narrows 2) was scaled by cfs.

Washington State Projects	Date	Maximum Diversion (cfs)	Design Criteria (approach velocity)	Screen Area	Design	Total Project Cost	2008 Cost with 3% Annual Inflation	2008 cost/cfs
<b>Flow Range 50-100 cfs</b>								
Upper WIP	1997	55	-	-	-	\$506,715	\$701,410	\$12,750
Union Gap	1997	76	-	-	-	\$279,984	\$387,560	\$5,100
<b>Average 2008 cost/cfs</b>								<b>\$8,925</b>
<b>Flow Range 100-500 cfs</b>								
Westside	1988	114	-	-	-	\$599,982	\$1,083,600	\$9,510
New Cascade	1992	147	-	-	-	\$541,401	\$868,790	\$5,910
Toppenish Pump	1995	100	-	-	-	\$532,400	\$781,850	\$7,820
Naches-Selah	1996	137	-	-	-	\$695,275	\$991,300	\$7,240
Yakima-Hieton	1998	350	-	-	-	\$799,750	\$1,074,800	\$3,070
<b>Average 2008 cost/cfs</b>								<b>\$6,710</b>
<b>Flow Range 1000 &gt; cfs</b>								
Chandler	1987	1500	-	-	-	\$3,849,000	\$7,160,300	\$4,770
<b>Average 2008 cost/cfs</b>								<b>\$4,770</b>

Source: WDFW: Washington State Fish Screening Unit Costs

## **APPENDIX D**

### **Detailed Results from the Deep Water Intake Sonar Surveys: Hell Hole and French Meadows Reservoirs**

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Photograph D-1. Debris in Hell Hole Reservoir During Spring Surveys.

Photograph D-2. Image of Sonar Disruption Due to Debris Suspended in Water Column.

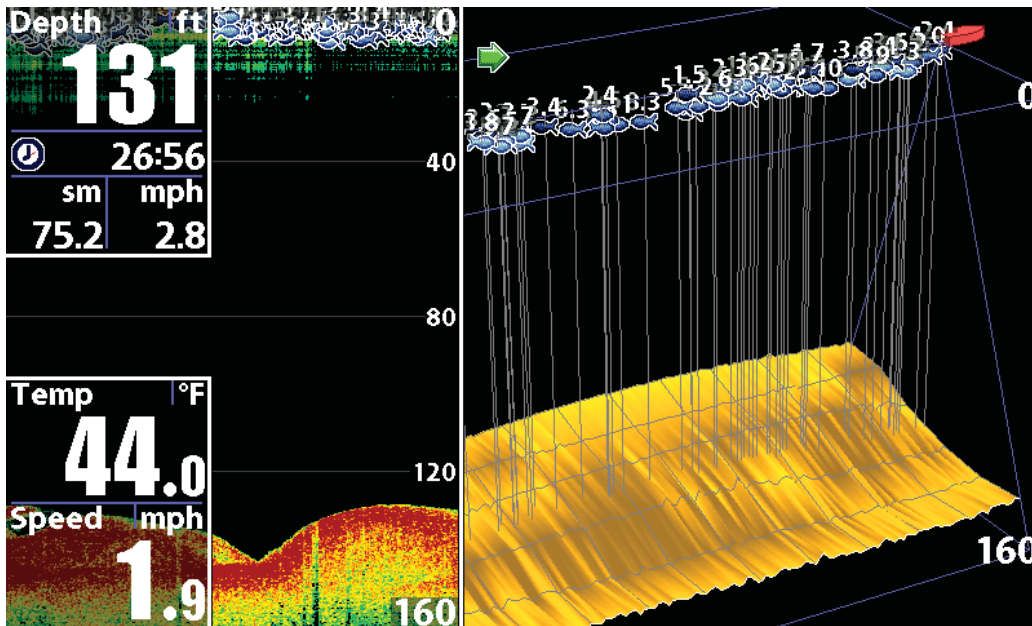
**List of Figures**

Figure D-1. Number and Depth of Fish Observed During Deep Intake Sonar Surveys (2008–2009) at French Meadows Reservoir.

Figure D-2. Number and Depth of Fish Observed During Deep Intake Sonar Surveys (2008–2009) at Hell Hole Reservoir.

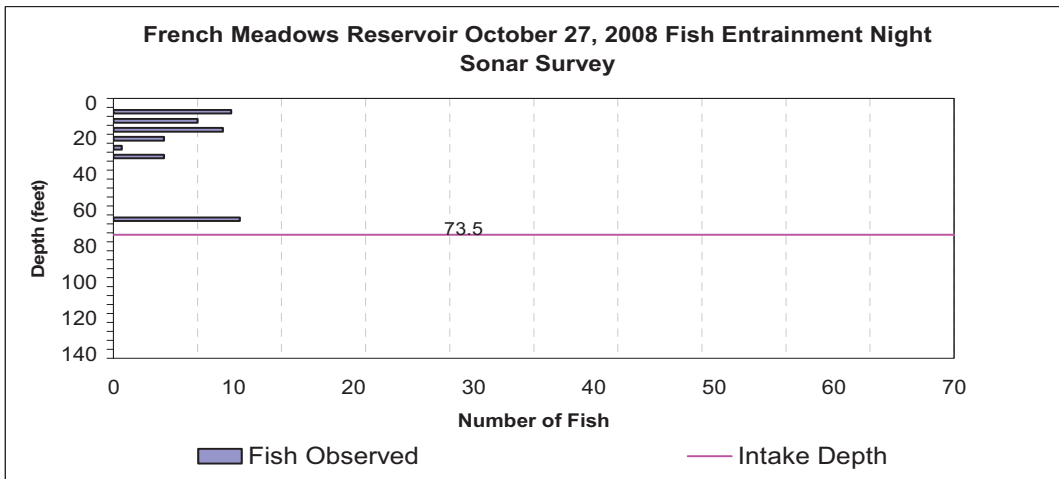
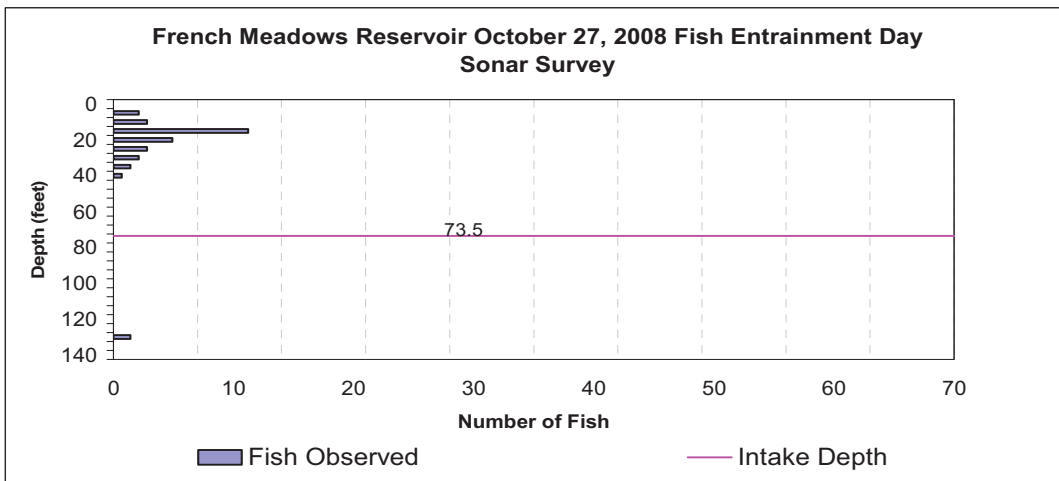
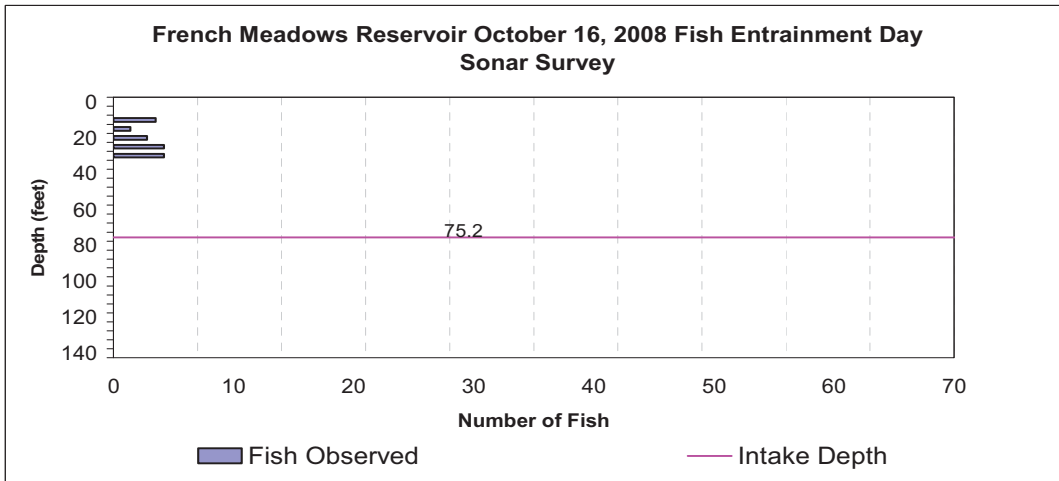


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**Figure D-1. Number and Depth of Fish Observed During Deep Intake Sonar Surveys (2008-2009) at French Meadows Reservoir (continued).**

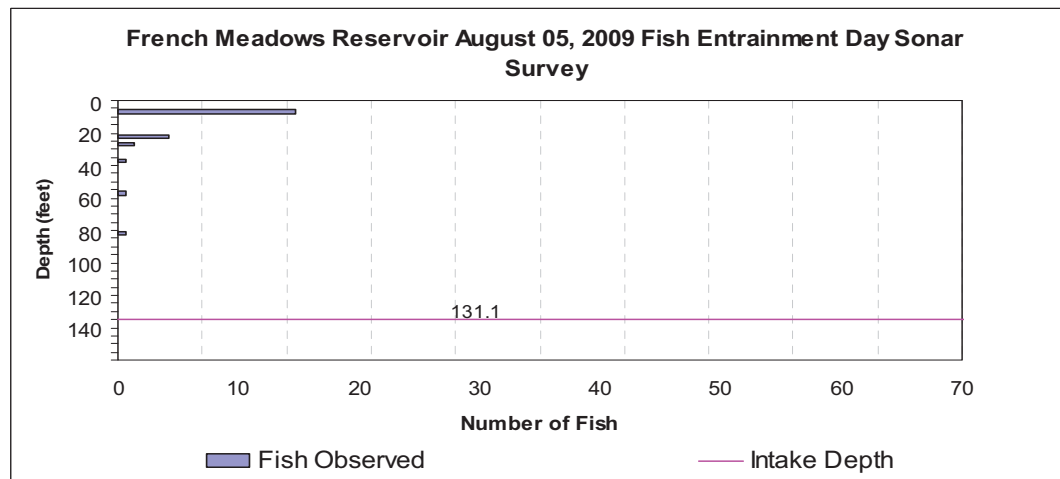
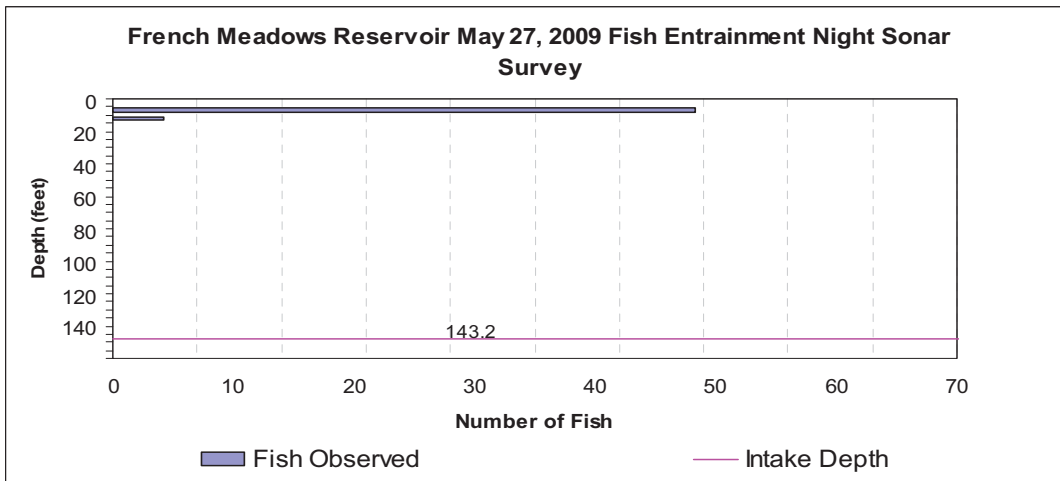
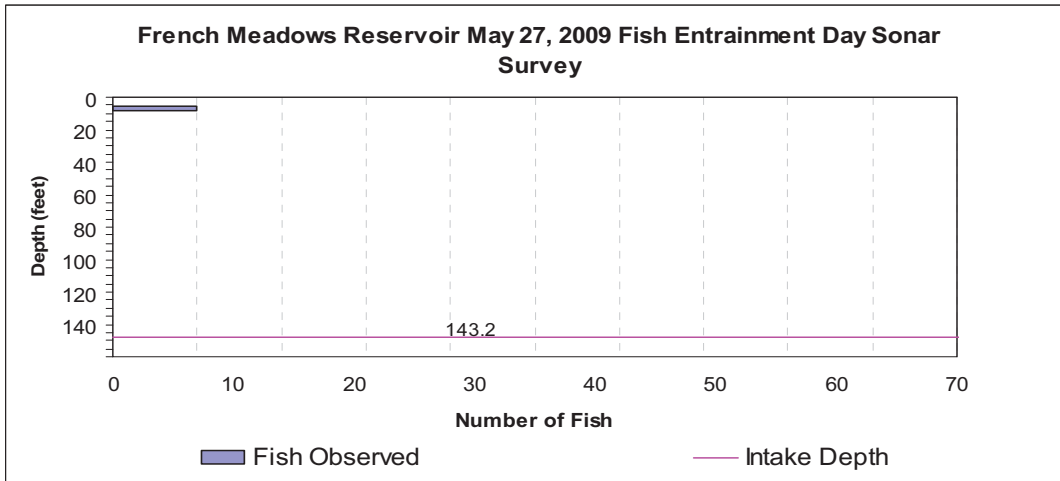


Figure D-1. Number and Depth of Fish Observed During Deep Intake Sonar Surveys (2008-2009) at French Meadows Reservoir (continued).

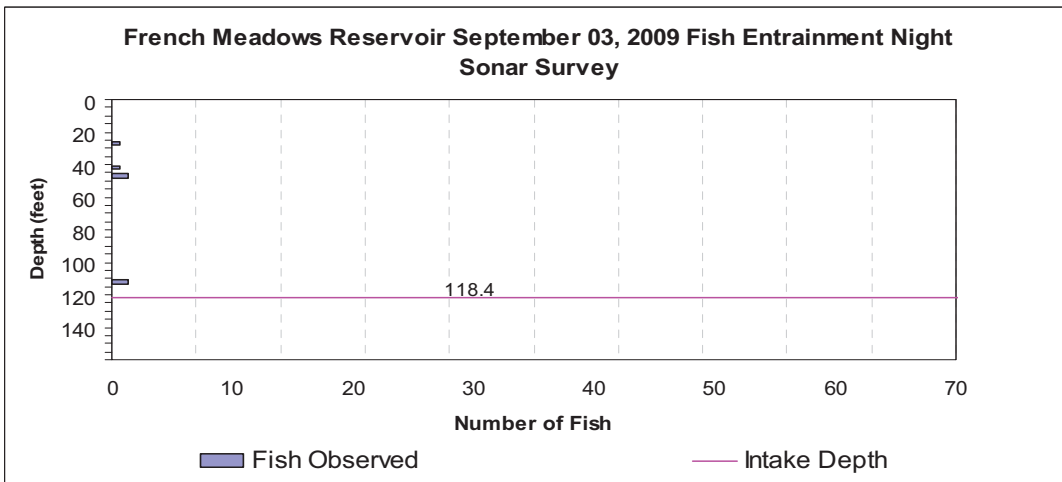
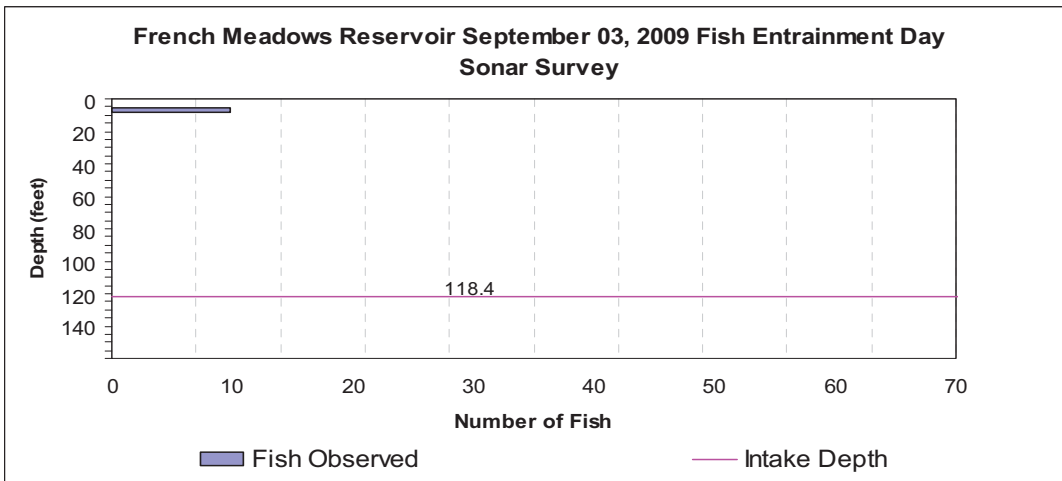
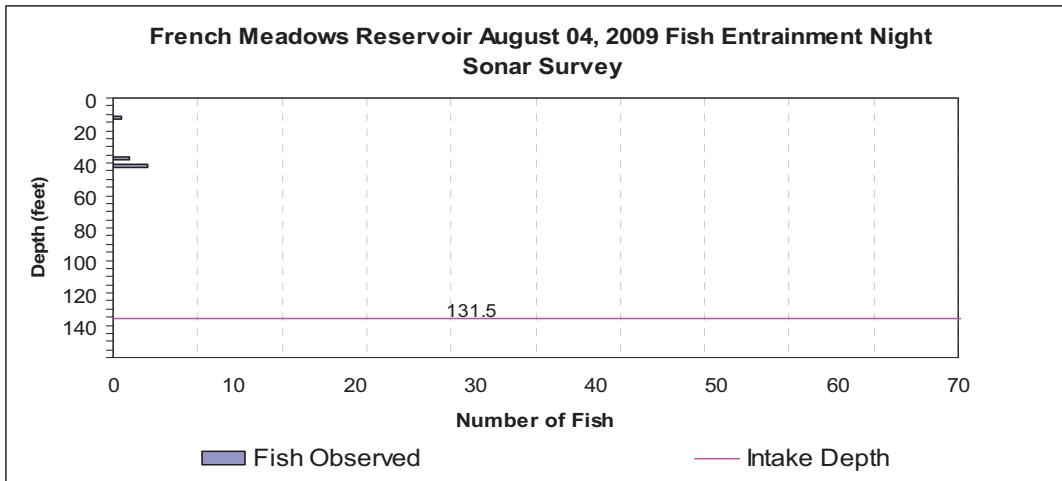
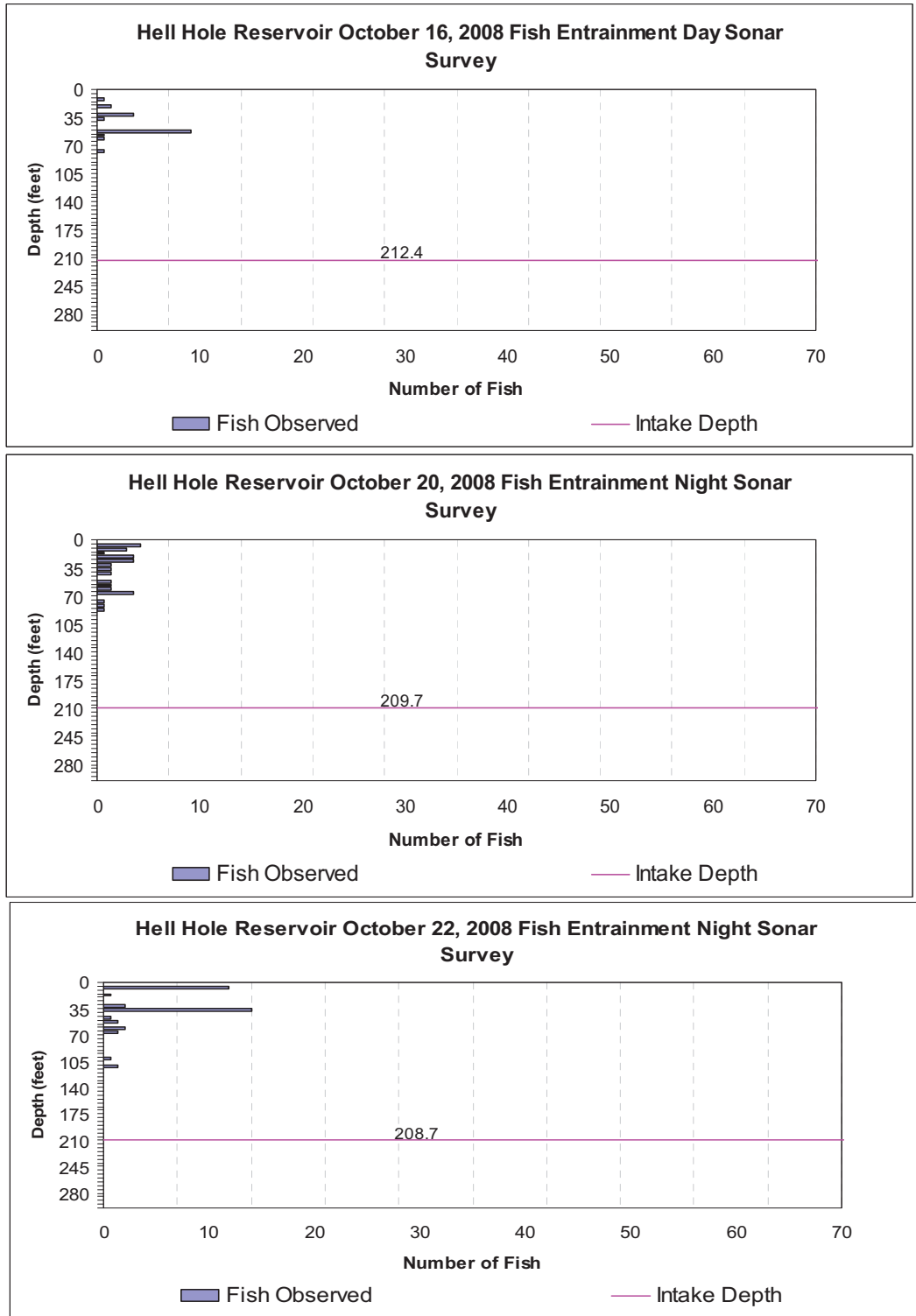
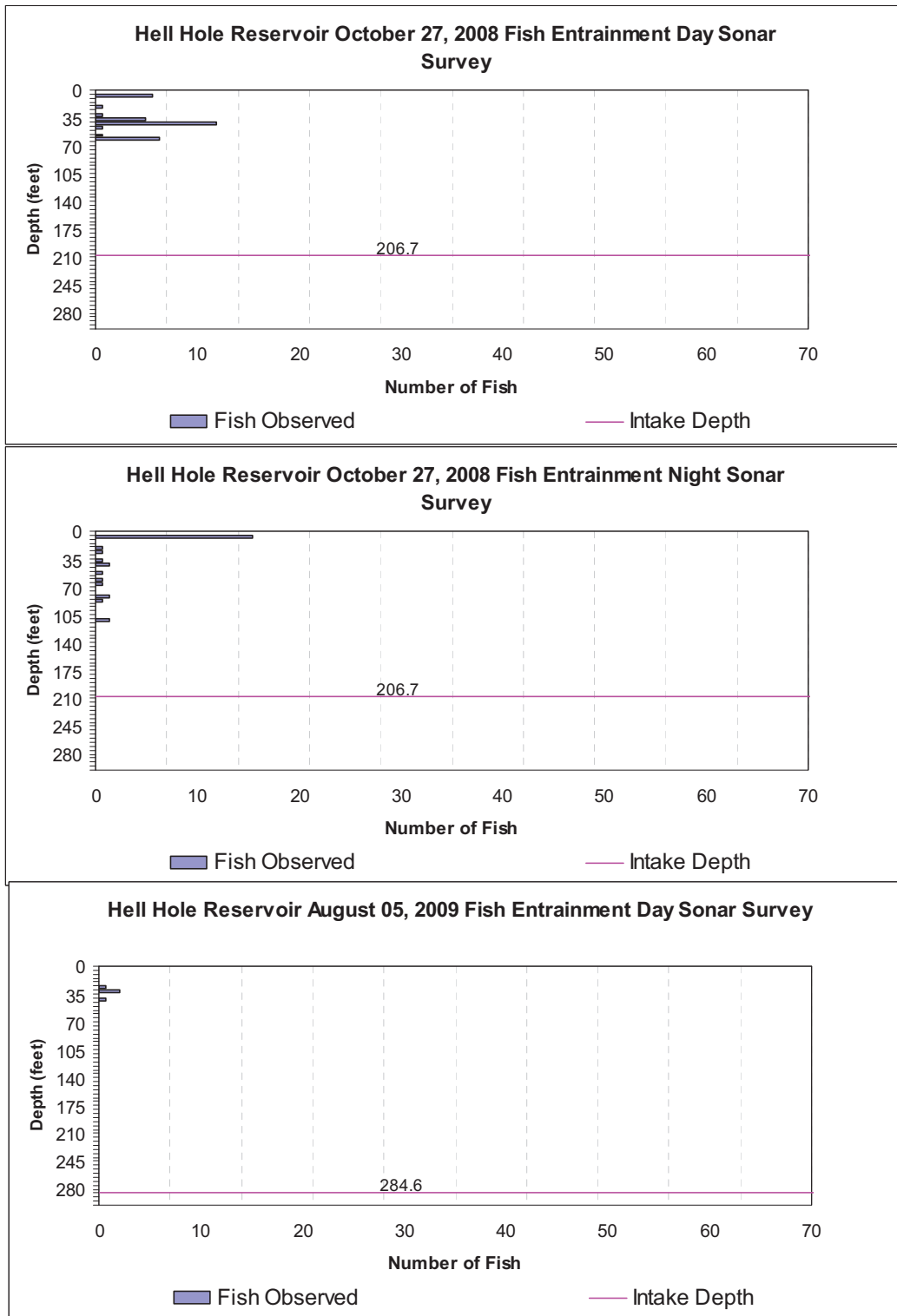


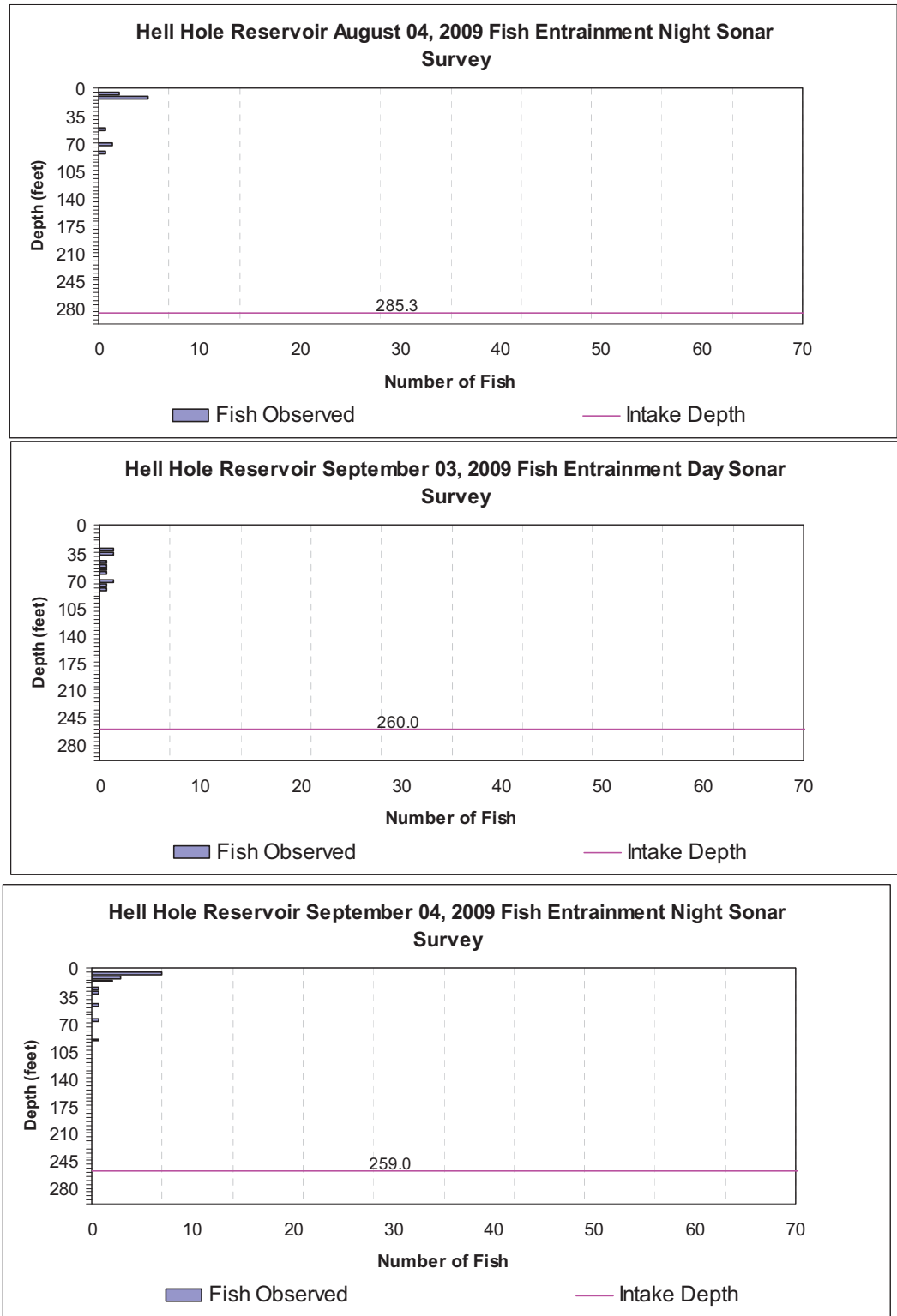
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**Figure D-2. Number and Depth of Fish Observed During Deep Intake Sonar Surveys (2008-2009) at Hell Hole Reservoir (continued).**



**Figure D-2. Number and Depth of Fish Observed During Deep Intake Sonar Surveys (2008-2009) at Hell Hole Reservoir (continued).**



## **APPENDIX E**

### **Detailed Results from the PIT Tagging Entrainment Study: Duncan Creek**

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Photograph E-2. Duncan Creek Antenna in Diversion Tunnel.

**Table E-1. Characteristics of Duncan Creek PIT Tagged Fish - October 21-29, 2008.**

Site	Species	Number Tagged	% of All PIT Tagged Fish	% of Tagged Fish by Species	Average Length (mm)	Maximum Length (mm)	Minimum Length (mm)	Standard Deviation (mm)
D8.8	Rainbow Trout	82	8.2%	9.3%	113	195	62	39
	Brown Trout	17	1.7%	15.3%	124	206	80	37
D9.0	Rainbow Trout	56	5.6%	6.3%	124	212	74	31
	Brown Trout	44	4.4%	39.6%	124	175	80	36
D9.2	Rainbow Trout	99	9.9%	11.2%	108	190	65	31
	Brown Trout	1	0.1%	0.9%	165	165	165	na
D9.4	Rainbow Trout	95	9.5%	10.7%	118	199	58	32
	Brown Trout	4	0.4%	3.6%	149	158	138	9
D9.6	Rainbow Trout	90	9.0%	10.2%	119	190	60	32
	Brown Trout	10	1.0%	9.0%	152	169	120	13
D9.8	Rainbow Trout	88	8.8%	9.9%	125	213	65	28
	Brown Trout	11	1.1%	9.9%	129	201	75	43
D10.0	Rainbow Trout	87	8.7%	9.8%	108	194	63	37
	Brown Trout	13	1.3%	11.7%	153	170	133	12
D10.2	Rainbow Trout	91	9.1%	10.3%	128	200	61	38
	Brown Trout	9	0.9%	8.1%	124	209	75	45
D10.4	Rainbow Trout	98	9.8%	11.1%	120	210	60	35
	Brown Trout	2	0.2%	1.8%	163	168	157	8
D10.6	Rainbow Trout	100	10.0%	11.3%	120	206	65	35
	Brown Trout	0	0.0%	0.0%	-	-	-	-
Total	Rainbow Trout	886	88.9%	-	118	213	58	34
	Brown Trout	111	11.1%	-	133	209	75	35
		997			120	213	58	35

Table E-2. Duncan Creek PIT Tag Sampling Results and Percent of Total Population Entrained by 0.2 Mile.

Number of Fish Tagged	Mile 1 (River Mile 8.8 - 9.6)					Mile 2 (River Mile 9.8 - 10.6)					Total
	8.8	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	
Rainbow Trout	82	56	99	95	90	88	87	91	98	100	886
Brown Trout	17	44	1	4	10	11	13	9	2	0	111
All Species	99	100	100	99	100	99	100	100	100	100	997

Number of Fish Entrained	Mile 1 (River Mile 8.8 - 9.6)					Mile 2 (River Mile 9.8 - 10.6)					Total
	8.8	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	
Rainbow Trout	3	1	1	0	0	0	0	0	0	0	5
Brown Trout	0	6	0	1	0	0	0	0	0	0	7
All Species	3	7	1	1	0	0	0	0	0	0	12

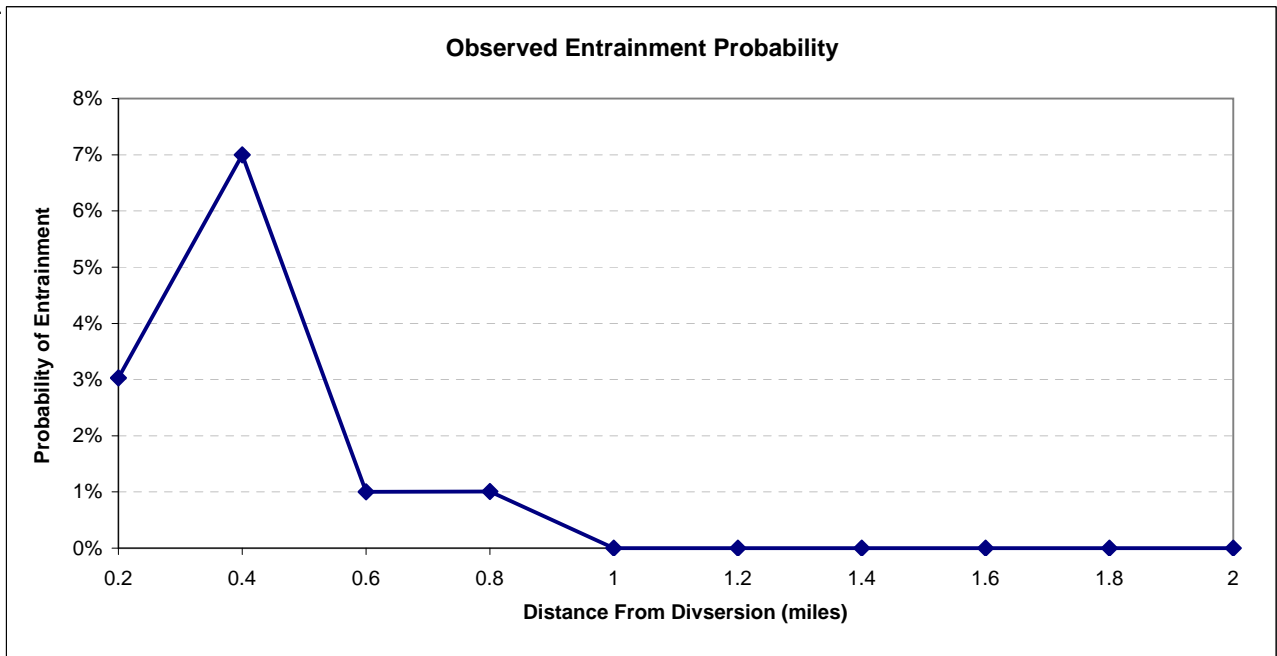
Percent of Tagged Fish Entrained	Mile 1 (River Mile 8.8 - 9.6)					Mile 2 (River Mile 9.8 - 10.6)					Total
	8.8	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	
Rainbow Trout	3.7%	1.8%	1.0%	0%	0%	0%	0%	0%	0%	0%	0.6%
Brown Trout	0%	13.6%	0%	25.0%	0%	0%	0%	0%	0%	0%	6.3%
All Species	3%	7%	1%	1%	0%	0%	0%	0%	0%	0%	1.2%

Study Reach Fish Population Estimate	Mile 1 (River Mile 8.8 - 9.6)					Mile 2 (River Mile 9.8 - 10.6)					Total
	8.8	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	
Rainbow Trout	572	572	572	572	572	388	388	388	388	388	4801
Brown Trout	18	18	18	18	18	26	26	26	26	26	222
All Species	590	590	590	590	590	414	414	414	414	414	5023

Calculated Number of Fish Entrained by Species	Mile 1 (River Mile 8.8 - 9.6)					Mile 2 (River Mile 9.8 - 10.6)					Total
	8.8	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	
Rainbow Trout Number	21	10	6	0	0	0	0	0	0	0	37
Rainbow Trout Percent	4%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0.8%
Brown Trout Number	0	3	0	5	0	0	0	0	0	0	7
Brown Trout Percent	0%	14%	0%	25%	0%	0%	0%	0%	0%	0%	3.2%

Calculated Number of Fish Entrained all Species Combined	Mile 1 (River Mile 8.8 - 9.6)					Mile 2 (River Mile 9.8 - 10.6)					Total
	8.8	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	
All Species Number	18	41	6	6	0	0	0	0	0	0	71
All Species Percent	3%	7%	1%	1%	0%	0%	0%	0%	0%	0%	1.4%

Figure E-1. The Observed Probability of Entrainment at the Duncan Creek Diversion.



**ATTACHMENT A**

**Working Draft, AQ 7 – Entrainment Whitepaper Report**

**Placer County Water Agency  
Middle Fork American River Project  
(FERC No. 2079)**

***Whitepaper Report***

***WORKING DRAFT***

**AQ 7 - Entrainment REPORT**

*This Whitepaper Report is for historical documentation purposes. It should not be cited nor should the data presented in the text, tables, figures, or appendices be used. The Whitepaper Report was discussed during the July 8, 2008 Aquatic TWG meeting. During the meeting, the Aquatic TWG determined that direct entrainment sampling was necessary to complete the AQ 7 –TSP. The Aquatic TWG also concluded that additional work did not need to be expended on the Whitepaper Report because it adequately addressed the indirect sampling study elements outlined in the AQ 7 – TSP. Further, the Aquatic TWG determined that The Whitepaper should remain a 'Draft' document.*



Placer County Water Agency  
P.O. Box 6570  
Auburn, CA 95604

**Preliminary Working Draft**  
**All Numbers Are Preliminary and Subject to Change -- Do Not Cite**  
July 2008

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## **1.0 INTRODUCTION**

This report describes the entrainment study conducted by the Placer County Water Agency (PCWA) in 2007 in accordance with the AQ 7 - Entrainment Technical Study Plan (AQ 7 - TSP) for the Middle Fork American River Project (MFP or Project). The stakeholder-approved TSP was included in Supporting Document (SD) H of the Pre-Application Document (PAD) filed with the Federal Energy Regulatory Commission (FERC or Commission) on December 13, 2007 (PCWA 2007).

The following sections provide a detailed description of the study objectives, study implementation, extent of the study area, study approach, study results, and literature cited.

## **2.0 STUDY OBJECTIVES**

The objectives of the entrainment studies in the AQ 7 - TSP include the following:

- Characterize Project facilities (diversions, intake structures and intakes, and powerhouse turbines) and operations in relation to factors that may affect entrainment or entrainment-related mortality.
- Develop the information necessary to assess the feasibility of screening intake structures (technical feasibility, feasibility level cost estimates, and maintenance requirements of screens).
- Indirectly estimate the potential for entrainment and entrainment-related mortality using the Project facility characterizations and literature information.
- Determine the need to directly sample entrainment and entrainment-related mortality at Project facilities in coordination with the Aquatic Technical Working Group (TWG).
- If appropriate, directly sample entrainment and entrainment-related mortality at selected Project facilities.

## **3.0 STUDY IMPLEMENTATION**

Figure AQ 7 - 1 shows the AQ 7 -TSP study (PCWA 2007) objectives and the study elements associated with each objective. It also shows how the information developed during the study will be documented and disseminated. The following sections summarize the study elements completed, any deviations from the TSP, outstanding study elements, and proposed modifications to the TSP.

### **3.1 STUDY ELEMENTS COMPLETED**

The following study elements have been completed unless indicated otherwise:

- Characterize Project diversions, intake structures, and powerhouse turbines and operations (**detailed data on some turbines is still being collected**).
- Develop feasibility level estimates of screen installation costs, characterized the technical feasibility of installing the screens (**Pending**), and describe the maintenance requirements of the screens (**Pending**) to assess the feasibility of screening intake structures.
- Indirectly estimate entrainment and mortality potential.
- Summarize fish entrainment and mortality literature.
- Develop fish entrainment threshold calculation approach in collaboration with the Aquatic TWG.

### **3.2 DEVIATIONS FROM TECHNICAL STUDY PLAN**

There are no deviations from the AQ 7 - TSP.

### **3.3 OUTSTANDING STUDY ELEMENT**

The following study element will be completed in 2008 and 2009 and presented in the 2010 Technical Study Report (TSR):

- Collaborate with the Aquatic TWG to determine whether or not direct measurements of entrainment and mortality are warranted.

### **3.4 PROPOSED MODIFICATION TO TECHNICAL STUDY PLAN**

There are no proposed modifications to the AQ 7 - TSP.

### **4.0 EXTENT OF STUDY AREA**

The study area for characterization of the Project diversions, intake structures, and powerhouse turbines includes Duncan Creek Diversion, North Fork Long Canyon Diversion, South Fork Long Canyon Diversion, French Meadows Powerhouse, Hell Hole Powerhouse, French Meadow-Hell Hole Tunnel Intake, Hell Hole-Middle Fork Tunnel Intake, Middle Fork Powerhouse, Middle Fork-Ralston Tunnel Intake, Ralston Powerhouse, Ralston-Oxbow Tunnel Intake, Oxbow Powerhouse, and the low level and instream flow release locations for each of the reservoirs and diversion pools (Map AQ 7-1).

### **5.0 STUDY APPROACH**

This section describes the approach to meet each of the study objectives: (1) characterize the Project facilities and operations in relation to factors that may affect entrainment or mortality; (2) develop information necessary to assess the feasibility of

screening intake structures; and (3) indirectly estimate the potential for entrainment and mortality.

## **5.1 PROJECT FACILITIES**

Maps of each of the project diversions facilities are shown in Maps AQ 7-2 to AQ 7-6. The Project diversion structures and intakes were characterized by hydraulic capacity, frequency of use, inlet/outlet type, inlet area, approach velocity over the range of flows, and intake depth (Table AQ 7-1). Pictures of each structure with labels identifying the outlets are provided in Appendix A and a summary of the monthly 10, 20, 50, 80, and 90 percent exceedance flows at each diversion facility for both the inflows and outflows and for the percent of flow diverted is provided in Appendix B. A spreadsheet with the daily flows and a plotting function for each diversion facility will be provided on CD upon request.

## **5.2 SCREENING FEASIBILITY ASSESSMENT AND COSTS**

A screening feasibility assessment was conducted for the Project diversion structures and intakes, diversion operations, and powerhouse turbines. This assessment included: (1) estimates of screen installation costs; (2) characterization of the technical feasibility of installing screens at each location (**Pending**); and (3) maintenance requirements of the screens (**Pending**).

### **5.2.1 Estimates of Screen Installation Costs**

The estimates of screen design and construction costs were based on 35 California screening projects completed from 1983 to 2005. The data were obtained from the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service (USFWS). Screening costs were compiled for screens within four flow categories (50-100, 100-500, 500-1000, >1000 cfs). The historic screen costs were converted to approximately 2008 dollars using a 3% inflation rate. The current cost of these screens is uncertain due to recent large increases in steel and materials prices. The potential cost of installation of screens at each diversion intakes was estimated using the appropriate per cfs screening cost and the maximum volume of the diversion. Further detailed analysis or site specific cost estimates would be required to refine the estimates.

It should be noted that the cost of screens based on data available on Washington State screen costs was also compiled; however, the costs were significantly lower than California screen costs. The California costs were used because they are considered to be more applicable to the MFP.

### **5.2.2 Technical feasibility of installing screens at each location**

**(Pending)**

### 5.2.3 Maintenance requirements of screens

(Pending)

### 5.3 ENTRAINMENT ASSESSMENT THRESHOLD CALCULATION APPROACH

A preliminary draft fish entrainment threshold calculation approach was initiated by California Department of Fish and Game (CDFG 2007) and further developed by PCWA in collaboration with the Aquatic TWG. The threshold calculation approach evaluated the potential amount of entrainment at Project facilities (reservoirs, diversions, and powerhouse facilities) using literature and Project specific data. Approximate fish entrainment calculations were based on the following data:

- Facility characteristics (e.g., location of intake);
- Project operations (hydrology, percent of flow diverted, and the timing and duration of diversions);
- Fish population estimates and qualitative fish data from the AQ 2 - Fish Population TSR (AQ 2 - TSR) (PCWA 2008a); and
- Entrainment and mortality information from the literature.

The approach estimated: (1) the potential number of fish entrained at Project facilities; (2) the fate of entrained fish; and (3) the potential threshold effect on fish populations at the seven MFP locations where entrainment could occur. There are five shallow water and two deep water diversion/water storage facilities where entrainment can occur, including:

#### **Shallow Water Intakes**

##### ***Small Diversion Pools***

Duncan Creek Diversion  
North Fork Long Canyon Diversion  
South Fork Long Canyon Diversion

##### ***Medium Diversion Pool***

Middle Fork Interbay

##### ***Large Diversion Pool***

Ralston Afterbay

#### **Deep Water Intakes**

##### ***Large Reservoirs***

French Meadows Reservoir  
Hell Hole Reservoir

### 5.3.4 Potential Number of Entrained Fish

The potential number of fish entrained was estimated differently for the small to medium diversion pool sites and the large reservoir sites. The approaches used to estimate the potential numbers of entrained fish at these locations are described below.

#### **Shallow Water Intakes with Small to Medium Diversion Pools**

Potential entrainment at the small to medium diversion pools (Duncan, North Fork Long Canyon, South Fork Long Canyon, Middle Fork Interbay) was calculated by estimating:

- Downstream emigration/movement of two size categories: young-of-the-year (YOY) and juvenile/adult; and
- Percent of fish entrained proportional to the percent of flow diverted.

#### ***Estimate of Downstream Movement***

Three general approaches were used to estimate downstream movement at the small to medium size diversion pools:

- Empirical entrainment data set
  - West Panther Creek (Mokelumne River tributary)
- Literature based mechanistic approach; and
  - Adult movement studies
  - YOY population modeling (in progress)
- Canal entrainment literature.

***Empirical Entrainment Data Set***—Historic entrainment sampling data from West Panther Creek, a nearby west slope Sierra Nevada stream, was used to provide an estimate of YOY and juvenile/adult fish downstream movement (and entrainment) for the MFP streams. The West Panther Creek diversion was sampled nearly continuously for entrainment for two years (1983-84) (Bozeman et al. 1987). An inclined plane fish trap (1/8 inch slot spacing) was used to sample 100 percent of the diverted flow. Several other small tributary stream diversions were also sampled at the same time, but West Panther Creek had the highest amount of fish entrainment and the fish population was most similar to the MFP streams (Duncan Creek, North Fork and South Fork Long Canyon creeks). West Panther Creek is located approximately 45 miles south of the MFP streams at an elevation of approximately 3,600 feet. The water temperature pattern of West Panther Creek is similar to the MFP streams (see below).

The second year data (1984) from West Panther Creek were selected to estimate downstream fish movement on a weekly basis for an entire year. The 1984 data showed the greatest amount of entrainment (downstream movement) and 1983 was one of the wettest years on record, potentially limiting its applicability. The West Panther Creek data were generalized (i.e., made applicable to the MFP streams of interest) using the following methods:

- Filling in missing data where necessary (extrapolation/interpolation);
- Scaling the fish capture data on a weekly basis by the weekly trap effort (Fish Caught \* 168 hr Week / # hrs Week Trap Effort);
- Estimating the total number of fish moving downstream by scaling the data to the percent of stream sampled (Fish Caught / % Flow Diverted); and
- Scaling the number of YOY and juvenile/adult fish moving downstream to the size of the juvenile/adult fish population (number moving downstream \* West Panther Creek fish per mile/ target stream fish per mile).

Figure AQ 7-2 shows the West Panther Creek data collected and the estimated number of fish moving downstream and the amount of flow and percent of flow diverted. The timing of YOY fish present in the West Panther Creek entrainment data coincides with the timing of YOY fish present in the small MFP streams (e.g., Duncan Creek) (see discussion below). Figure AQ 7-3 shows the West Panther Creek mean weekly water temperature overlaid with the 2007 water temperature for several MFP streams (Duncan Creek, North Fork Long Canyon Creek, South Fork Long Canyon Creek, and Middle Fork American River above Middle Fork Interbay).

**Literature Data**—Existing literature regarding trout movement and trout life history were used to estimate downstream movement of juvenile/adult trout and YOY in the vicinity of MFP diversions.

*Juvenile/Adult Fish*--Studies of resident juvenile/adult trout movement for periods of 9 to 12 months in small streams and nearby rivers (Gowen and Fausch 1996; Jenkins et al. 1999; Hilderbrand and Kershner 2000; Graf 2008) were fit to probability of dispersal distance distributions (dispersal curves) (Rodriguez 2002) (Table AQ 7-2). The dispersal probability distributions were used to predict how many fish would move downstream into the vicinity of diversions based on the population density upstream of the diversion.

For example, Figure AQ 7-4a shows a fitted annual probability distribution of fish distance from home section (Fausch et al. 1995 cited in Rodriguez 2002) based on 500 m home section lengths (HSL). Figure AQ7-4b shows the same dispersal distribution for multiple home sections along the length of a hypothetical river. The summed probabilities downstream of the zero location represent the probability of fish moving downstream into the vicinity of the diversion. The summed probabilities by 500 m home section upstream of the zero location, when multiplied by the original stream density of fish per 500 m, represent the number of fish remaining in the stream after one year in each 500 m home section (Figure AQ 7-5). This assumes all fish moving downstream are removed from the population (either went downstream over the diversion or were entrained). The difference between the original density and the density after one year is the estimated number of fish moving downstream.

*YOY Fish*—Modeling downstream movement of YOY resident trout was based on YOY behavior, mortality, and several assumptions regarding how these operate in Project streams. Table AQ 7-3 summarizes the assumptions for the YOY downstream movement modeling. A brief discussion of behavior and mortality issues related to the modeling is provided below.

The potential number of YOY present is based on the number of spawning sized adults greater than approximately 120 mm in length (Moyle 2002, Meyer et al 2003, Avery 1985), the fecundity (number of eggs) of the adult female fish, and the fraction of the eggs that actually get placed in the redd. Figure AQ 7-6 shows fecundity for trout in the 120 to 400 mm size range. Van Winkle et al (1988) found that approximately 90 percent of the eggs were actually deposited in redds.

Timing of spawning depends on photoperiod and water temperature (Lam 1988, cited in Van Winkle et al. 1998). Once the eggs are laid about 330 Celsius degree days is required for the eggs to hatch and another 300 Celsius degree days for emergence (Behnke 1992).

Qualitative sampling (seines and electrofishing) on Duncan, South Fork Long Canyon, and North Fork Long Canyon creeks above their respective diversions on May 17, June 6, and June 26, 2007 found the following: no rainbow trout fry were collected during the first sampling; 3 rainbow trout fry were collected on June 6 in North Fork Long Canyon Creek (23 mm FL) and no fry were found in the other streams; and a combined total of 51 rainbow trout fry were collected on June 26 in the three streams (28-43 mm FL) (PCWA 2008a). Based on this data and the data from West Panther Creek that show rainbow trout YOY entrainment did not start until the first week of June, we assume that emerged YOY fish typically are present and can potentially be entrained no sooner than approximately June 1.

Upon emergence from redds, YOY begin to disperse from the vicinity of the redd. Voluntary dispersal direction is genetically controlled and dispersing fish typically establish and defend group territories (e.g., 1-6 fish) in suitable unoccupied stream habitat (e.g., Elliott 1990). In some situations dispersal is adapted for resident stream rearing and some situations it is directed into lake or reservoir rearing habitats (e.g., Hayes 1988a and 1988b). For example, fish populations spawning in inlet or outlets of reservoirs or above waterfalls (barriers), potentially have hereditary adaptations (genetics) that control the direction of dispersal (Benke 1992). This happens because, over a long period of time, fish with the genetic disposition for dispersal in the wrong direction can be lost from the gene pool. Depending on the river system, dispersal can be directed upstream (e.g., lake outlet spawning fish), downstream, or both directions (Hunt 1965; Raleigh and Chapman 1971; Benke 1992; Lentsch 1985; Elliott 1986; Hayes 1988a and 1988b; Kahler et al. 2001), but it should be noted that rapid downstream dispersal in resident stream fish is potentially maladaptive (see examples of failed attempts to establish resident stream fish using downstream migrating lake inlet spawning fish in Raleigh and Chapman (1971)).

Dispersal of YOY from high density locations near redds to lower density locations potentially “seeds” sections of streams without YOY or spawning habitat (Crisp 1993; Close and Anderson 1992). Not all downstream dispersing YOY, however, are viable. Elliott (1993; 1986) found that for fry in his study stream, 22% emigrated downstream and that most of the emigrating fish, 93.7%, were moribund and that 87% of the older 0+ (parr) that emigrated downstream were moribund. These fish were dying and could not be revived with feeding in the laboratory.

Limited information exists on the distance resident YOY disperse. Kahler et al. (2001) found that rearing juvenile anadromous salmonids moved a maximum of 234 m over the summer. Close and Anderson (1992) and Hunt (1965) found that YOY steelhead and brook trout, respectively, moved as much as about 3 miles over the summer (approximately 1 mile/month) at lower densities. Both studies showed that more fish moved at high densities (e.g., greater than 1 fish per m<sup>2</sup>) and Close and Anderson (1992) found that YOY steelhead emigrated farther downstream at very high stocking densities.

High levels of natural mortality occur during the first 2-3 months for newly emerging YOY. Many of the YOY potentially die within close proximity to the spawning location (Elliott 1986) and it appears that many of the fish that are either emigrating or that die are YOY fish that did not or were prevented from establishing territories in suitable habitat (see Figure 1 in Elliott 1990). Mortality during the early 2-3 month “critical period” is as high as 96% (4% survivorship) and then declines (i.e., survivorship improves) (Elliott 1993, Allen 1951). One of the lowest percentages of mortality (highest survivorship values) we found in the literature was 77% (23% survivorship) (Mortenson 1977).

Few moribund or dead fry are observed in streams because they decompose quickly and are scavenged by invertebrates (e.g., caddis larvae and predatory stoneflies) (Elliott 1997) and are likely scavenged by numerous vertebrate predators (fish, birds, mammals).

**Canal Entrainment Empirical Data Sets**—Data from canal or power tunnel entrainment studies provides another source of information on downstream moving fish. Post et al. (2006) studied entrainment of rainbow and brown trout on the Bow River in Canada, Carlson and Rahel (2007) estimated cutthroat trout entrainment on the Smith Fork River in Wyoming, and some data exists on the entrainment of rainbow and brown trout for the Stanislaus Power Tunnel (PG&E 2002) and canals on the DeSabra Project (PG&E 2007). A summary of the canal entrainment data is provided in Table AQ 7-4.

Description of the rivers for each of the canal entrainment data sets and their applicability to the MFP streams (**to be completed**).

#### ***Percent of Fish Entrained Proportional to the Percent of Flow Diverted***

After estimating the downstream movement, the number of juvenile/adult fish and YOY entrained was calculated proportional to the amount of flow diverted. For example, if 75% of the flow was diverted, 75% of the fish were assumed to be entrained.

## **Shallow Water Intakes with Large Diversion Pools**

Ralston Afterbay is a relatively large diversion pool with a shallow diversion intake (powerhouse tunnel). Estimation of entrainment at Ralston Afterbay is pending discussions with the Aquatic TWG and collection of fish population data on Ralston Afterbay (June and September 2008).

## **Deep Water Intakes, Large Reservoirs**

Potential entrainment and potential effects on the fishery at the deep water intakes of the large reservoirs will be estimated by:

- Estimating the abundance of fish in the water column near the intake structure; and
- Reviewing stocking and fish sampling data.

French Meadows Reservoir and Hell Hole Reservoir each have dam outlets and tunnel diversion outlets that have deep water intake structures. The dam outlet depths for French Meadows Reservoir average 151 and 169 feet for the instream flow release and low level outlets, respectively (ranges are 92-198 feet and 110-215 feet, respectively) and the tunnel outlet depth averages 102 feet (range is 43-149 feet). The Hell Hole Reservoir dam outlet works depth averages 263 feet (range is 127-347) and the tunnel outlet depth averages 229 feet (range is 93-313). These depths are dependent on the water surface elevations of the reservoirs, which vary seasonally (e.g., higher water surface elevations are associated with deeper depths of intake facilities).

Entrainment is assumed to be low at these facilities because sonar data from other systems with relatively large, deep reservoirs typically shows that the majority of fish in deep water reservoirs reside in depths shallower than the intake structures (e.g., SCE 2007). The Aquatic TWG has agreed that PCWA will use sonar equipment (fish-finder) to estimate the abundance of fish throughout the water column in the vicinity of the reservoir deep water intake structures to assess the potential risk of fish entrainment. This will entail sampling at the structures four times: once during spring, twice during the summer, and once in the fall (road access to the reservoirs is restricted during the winter due to snow).

In addition to the low potential for entrainment at the deep water intakes, no special-status species are present in the reservoirs and annual fish stocking either supplements or supports the reservoir fishery, which may reduce the effect of potential entrainment on the reservoir fisheries. Limited opportunity exists for fish at Hell Hole Reservoir to migrate into tributaries for spawning due to natural barriers in the streams (PCWA 2008b). Most natural spawning would be confined to spawning in a very short segment of stream or within the reservoir itself. It is, therefore, likely that the fishery is primarily supported by stocking. This will be assessed by reviewing stocking records and fish sampling data from the reservoir (PCWA 2008a). At French Meadows Reservoir, the Middle Fork American River provides a potential spawning location for reservoir fish. PCWA will survey upstream of the reservoir to determine the length of river accessible to spawning fish from French Meadows Reservoir and will use this data and stocking records to characterize source of fish for the reservoir fishery.

### 5.3.5 Fate of Entrained Fish

The fate of entrained fish at a particular diversion depends on the type of facility to which the diversion leads (e.g., reservoir, release outlet, powerhouse, etc.). If the diversion leads to a powerhouse, then the characteristics of the powerhouse also affect mortality. Entrained fish that pass through Pelton turbines are assumed to have very high (nearly 100%) mortality. Fish passing through cone or Howell-Bunger valves are also assumed to have high mortality. Fish entrained and passing through Francis turbines are assumed to have low to moderate mortality depending on the characteristics of the turbine. Table AQ 7-5 shows the immediate and 48-hour fish survival rates for Francis turbines based on data presented in Winchell et al. 2000. Factors that potentially affect fish survival are peripheral runner velocity, blade and or wicket spacing/clearance, and fish size. High survival is assumed for fish passing through minimum flow pipes, over diversion structures, or entrained into other bodies of water (reservoirs).

Table AQ 7-6 shows each potential fish entrainment mortality location (powerhouse, reservoir) by diversion and relative mortality rankings (high, medium, low) for each diversion. Details on mortality are provided in the results section.

### 5.3.6 Threshold Fish Population Effects

The effect of entrainment on fish populations for the present was assessed conservatively and in a simplistic manner assuming that all mortality was additive (i.e., mortality was not compensatory). Entrainment of adult fish (2+ and older) was assumed to remove an equivalent number of reproductive age adult fish from the population. For potential future mitigation measures, it was assumed removal of two adults from the population was equivalent to the loss of one redd or, vice versa, that the addition of one redd was assumed to compensate for the loss of an adult pair.

Entrainment of YOY and juvenile fish was assumed to remove an equivalent number of YOY fish from the stream population and based on using the survivorship calculated for each stream, the equivalent number of redds or spawning adults lost was also calculated. Plots were developed relating the number of YOY of various ages to the number redds (or adult pairs) required to replace the YOY. The biomass and energy lost to other trophic levels from YOY or juvenile fish potentially lost to entrainment was also estimated.

Mortality based on the threshold analysis, at present, did not consider that mortality could be compensatory; where, removal of some fish from a population is compensated for by freeing up limited resources (food, space) for remaining fish, thereby increasing survivorship, increasing growth, and increasing reproductive capacity for the remaining fish. The concept of sustainable fishery harvest and surplus production is based on the fact that compensatory mortality occurs in fisheries. The implications and evidence for compensatory mortality in Sierra Nevada streams is briefly discussed in the results section.

## 6.0 STUDY RESULTS

### 6.1 OVERVIEW

To Be Completed.

### 6.2 SCREENING FEASIBILITY ASSESSMENT AND COSTS

Potential California screen installation costs by discharge range are shown in Table AQ 7-7. The average cost and the highest cost of the 35 California screens were summarized. The screen cost estimates range from \$8,300 to \$42,000 per cfs depending on screen size (maximum flow capacity). The data used to create the table are provided in Appendix C. The potential screen costs do not include recent large increases in steel and construction costs.

The potential cost for screen installation at the MFP diversions range from \$1 to \$21 million dollars. Table AQ 7-8 shows the maximum flow capacity of each of the MFP diversions and the estimated cost of installation based on the average and maximum screen costs in Table AQ 7-7.

### 6.3 ENTRAINMENT ASSESSMENT THRESHOLD CALCULATION APPROACH

#### 6.3.1 Potential Number of Entrained Fish

The potential number of entrained fish at shallow water intakes with small to medium diversion pools is described below. The results of entrainment analyses at the shallow water intakes at the large diversion pool and deep water intakes are pending additional planned data collection.

#### **Shallow Water Intakes with Small to Medium Diversion Pools**

The potential number of entrained fish at the shallow water intakes with small to medium size diversion pools determined by the three approaches is discussed below.

***West Panther Creek Empirical Data Set*** - The fish populations in North Fork Long Canyon Creek, South Fork Long Canyon Creek, Duncan Creek and the Middle Fork American River upstream of Middle Fork Interbay are summarized in Table AQ 7-9. The juvenile/adult fish populations were used to create a scaling factor to scale the data from West Panther Creek to the MPF diversions. The juvenile/adult fish population upstream of the West Panther Creek diversion was 870 fish/ mile (Table AQ 7-9). Weekly estimates of downstream movement of both YOY and juvenile/adult fish were multiplied by both the scale factor and the percent of flow diverted for each MFP diversion to estimate the potential number of fish entrained.

A summary of the daily 50% exceedance percent of flow diverted by month at each MFP diversion is shown in Table AQ 7-10. The calculated monthly YOY and juvenile/adult fish entrainment values, based on the percent of flow diverted, are shown in Table AQ 7-11. The annual YOY entrainment values range from 9 to 525 YOY. The annual juvenile/adult entrainment values range from 63 to 87 fish. Entrainment of YOY

was estimated to be very low at both the North and South Fork Long Canyon diversions because the diversions typically do not divert water during the summer time period when YOY were present and entrained at the West Panther Creek Diversion.

Appendix D shows plots of the estimated number fish moving downstream and estimated number entrained by month. The plots also include the amount of flow and the percent of flow diverted.

**Literature Data Modeling** – The estimated downstream movement of juvenile/adult trout and YOY in the vicinity of MFP diversions based on literature data and modeling is presented below.

*Juvenile/Adult Fish*—The estimated number of fish moving downstream based on four long-term trout movement data sets, scaled to a fish population of 1000 fish/mile, range from 72 to 108 fish annually (Table AQ 7-12). The monthly average was combined with the fish population and 50% exceedance percent of flow diverted at each MFP diversion site to estimate the potential number of entrained juvenile/adult fish (Table AQ 7-13). The annual number of fish potentially entrained at each MFP site ranges from 27 to 59 fish. These values are similar to those estimated by using the West Panther Creek empirical data.

*YOY Fish*—Survivorship data calculated for each of the fish populations above and below the diversions fall midway between the high and low survivorship data found in the literature for rainbow and brown trout populations. The initial values, beginning the first of June, are based on the estimated number of YOY emerging from redds (estimated from the fecundity and number of the adult females present) and the remaining fish density values are based on the 2007 fall sampling data (AQ 2 TSR PCWA 2008a). Figures AQ 7-7 to 7-10 show the survivorship curves for North Fork Long Canyon Creek, South Fork Long Canyon Creek, Duncan Creek and Middle Fork American River upstream of Middle Fork Interbay. The top figures show all four age classes (0+, 1+, 2+, 3+) and the bottom figures shows only age 0+ fish and indicate when the diversions stops diverting for the year.

The survivorship curves do not provide a direct way to estimate downstream YOY movement. A rough estimate of the potential “excess” number of YOY moving downstream was calculated by making two assumptions: (1) the observed survivorship curve represents equilibrium survivorship (observed numbers of fish are in equilibrium and no excess fish are available for downstream emigration); and (2) the high literature survivorship curve represents the maximum potential survivorship. The difference between the equilibrium and the high literature survivorship curve was used as an estimate of potential “excess” YOY available for downstream emigration. This is viewed as a simple scaling estimate of excess YOY. A potentially more accurate method for estimating excess YOY may be developed based on habitat availability once instream flow modeling is completed.

Table AQ 7-14 shows the difference between the equilibrium number of YOY at the end of the diversion period using the site specific survivorship compared to the number of

YOY assuming the highest literature survivorship (i.e., potential excess YOY emigrating that might be entrained). Included in the table is the number of equivalent adult pairs (or alternatively redds) that are represented by the number of emigrating YOY potentially entrained.

The survivorship curves can be used to estimate the potential population effect of entrainment of different age fish. Figures AQ 7-11 to 7-14 show the number of fish surviving per redd over a period of four years (0+, 1+, 2+, and 3+ age fish) for the fish populations above and below each diversion. Entrainment of an equivalent number of fish of a given age equates to the loss of one redd or alternatively the loss of a pair of adult fish.

It should be noted that, in general, there was little difference between the observed survivorship curves for the above and below diversion data sets.

**Canal Entrainment Empirical Data Sets** - The canal trout entrainment data sets integrate entrainment over the period of diversion operation. Where the throughput or number of fish actually passing through the canal is accounted for, the estimates represent the total number of fish entrained (Bow River, Smith Fork River). Where the throughput of fish is not accounted for, the canal entrainment data sets should be considered a minimum estimate of entrainment (DeSabra Canal and Stanislaus Tunnel data). As entrainment is integrated over time in these data sets, they do not provide information on the timing of the entrainment (e.g., what time of year YOY were entrained). Consequently, it is difficult to apply the data on a monthly basis to diversions that operate only during selected periods of time (see discussion below).

Entrainment estimates based on canal entrainment data result in higher entrainment than the other two methods used to estimate entrainment (i.e., West Panther Creek empirical data and literature data based modeling). A summary of the canal entrainment data is shown in Table AQ 7-4. The canal data were summarized in a manner that allowed application to downstream movement and entrainment in MFP streams on a monthly average basis (Table AQ 7-15). These data were scaled by the number of months flow was diverted, by the size of the juvenile/adult fish population, and the percent of flow diverted. The juvenile/adult entrainment data are more applicable for analysis and application to MFP diversions than the YOY data. Several of the MFP diversions have limited operations during the summer (North Fork Long Canyon, South Fork Long Canyon, Duncan Creek) when YOY entrainment would be expected to be highest, whereas the canal entrainment data sets all consist of high diversion amounts during the entire summer period.

These data were then used to estimate potential MFP entrainment by multiplying the scaled average canal entrainment data by the juvenile/adult fish population upstream at each MFP diversion and the average amount of flow diverted (50% exceedance value) at the diversion (Table AQ 7-16). The scaled Smith Fork River canal entrainment data for cutthroat trout was excluded from the analysis for the present time because scaling the data based on the low fish population in the Smith Fork River produced average

entrainment values that seem unreasonable. This will be revisited in the next revision of this document.

### **Shallow Water Intakes with Large Diversion Pool**

Estimation of entrainment at Ralston Afterbay is pending: (1) discussions with the Aquatic TWG; (2) collection of fish population data on Ralston Afterbay (June and September 2008); and (3) a refined estimate of potential fish mortality at Oxbow Powerhouse.

### **Deep Water Intakes with Large Reservoirs**

Estimates of potential entrainment at French Meadows Reservoir and Hell Hole Reservoir are pending sonar data collection of fish density near intake structures.

### **6.3.2 Fate of Entrained Fish**

Table AQ 7-17 shows the estimated survival for each of the MFP powerhouses. Additional information will be added to this section in a future revision as more detailed information of powerhouse facilities is obtained.

### **6.3.3 Threshold Fish Population Effects**

Table AQ 7-18 shows a summary of potential numbers of YOY and juvenile/adult fish potentially entrained in MFP diversions. The most conservative approach to estimating the effects of the potential number of fish entrained is to assume the mortality is additive. That is, that fish entrained represent a one-to-one loss to the population upstream and/or downstream of the diversion (i.e., one entrained fish equals one lost fish to the population). YOY numbers can be back calculated to determine the equivalent number of redds or adult pairs lost from the stream based on the data provided in this report (see Figures AQ 6-11 to AQ 6-14).

Table showing conversion of YOY numbers to equivalent redds and adults **(to be completed)**.

There is a high likelihood that some of the mortality based on entrainment would be compensatory. That is, removal of some fish from the population would free up food and space resources for remaining fish and as a result growth would increase, over winter survival might increase, fecundity of the remaining fish would increase because of larger size (see Figure AQ 7-6), and the reproduction of the remaining fish would be enhanced (i.e., compensating for some portion of the lost fish). Jenkins et al. (1999) found a strong inverse relationship between growth and fish density in two Sierra Nevada streams (Convict Creek and Mammoth Creek) at fish densities less than about  $1/m^2$  and assumed that the effect would result in compensatory reproductive capacity for fish populations at lower densities.

Discussion of the density of fish in MFP streams compared to Jenkins et al. (1999) and other sources and to reference fish populations **(to be completed)**.

Calculations of biomass and energy lost to different trophic levels due to potential entrainment (**to be completed**).

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**DRAFT**

**TABLES**

**Table AQ 7-1. Middle Fork Project Facilities – Entrainment Characteristics.**

Facility	Hydraulic Capacity (cfs)	Frequency of Use (cfs)	Inlet/Outlet Type	Inlet Area (ft. <sup>2</sup> )	Approach Velocity (fps)	Intake Depth (ft)	Comments
<b>French Meadows Reservoir</b>							
French Meadows-Hell Hole Tunnel	Existing Project: 400 Betterment: 800	Frequent during spring and summer	Inlet: 10 ft. dia. pipe. Trash rack with 2.6 in. bar spacing. Outlet: vertical Francis turbine	Inlet: 78.5 Trash Rack: 484	Inlet/Exist: 0-5.1 Inlet/Better: 0-10.2 Trash Rack/Exist: 0-0.8 Trash Rack/Better: 0-1.6	145 <sup>(1)</sup>	Betterment – French Meadows Powerhouse capacity upgrade.  French Meadows Powerhouse discharges into Hell Hole Reservoir.
French Meadows Dam – Low Level Outlet	1,430	Infrequent	Inlet: 60 in. pipe with slide gate. Trash rack with 6 in. bar spacing. Outlet: 60 in. Ring Jet Valve	Inlet: 28 Trash Rack: 52	Inlet: 0-51 Trash Rack: 0 - 28	211.5 <sup>(2)</sup>	Energy dissipating valve discharges to a plunge pool
French Meadows Dam – Instream Flow Pipe Intake	4 - 8	Continuous	Inlet: 8 in. pipe. Outlet: 8 in. Howell-Bunger Valve	Inlet: 0.35 Trash Rack: 23	Inlet: 11.4 – 22.86 Trash Rack: 0.2 – 0.4	194 <sup>(1)</sup>	Energy dissipating valve discharges to a plunge pool

<sup>1</sup>Maximum reservoir operating surface elevation minus intake surface elevation.

<sup>2</sup>Maximum reservoir operating surface elevation minus curb intake elevation.

**AQ 7-1. Middle Fork Project Facilities – Entrainment Characteristics (cont.).**

Facility	Hydraulic Capacity (cfs)	Frequency of Use (cfs)	Inlet/Outlet Type	Inlet Area (ft. <sup>2</sup> )	Approach Velocity (fps)	Intake Depth (ft)	Comments
<b>Hell Hole Reservoir</b>							
Hell Hole-Middle Fork Tunnel	800	Frequent	Inlet: 11.5 ft. dia. pipe. Trash rack with 2 in. bar spacing Outlet: Two Pelton Turbines	Inlet: 104 Trash Rack: 705	Inlet: 0-7.8 Trash Rack: 0-1.1	308.1 <sup>(1)</sup>	Powerhouse discharges into Middle Fork Interbay
Hell Hole Dam Outlet Works	6-848	Continuous low flow (6-20); Infrequent during outages (approx. 65); Infrequent and would cause facility damage (65-848)	Rectangular inlet (with trash rack) into horizontal 13 ft. horseshoe shaped tunnel (original tunnel opening shut with stop logs).	Inlet: 76 Trash Rack: 300.3	Inlet: 0.08-11.2 Trash Rack: 0.02-2.82	342 <sup>(2)</sup>	Outlet works is a tunnel that leads to a 48 in. dia. pipe and 16 in. dia. pipe for the Hell Hole Powerhouse, instream flow pipe, and low level outlet.
Hell Hole Dam Low Level Outlet <sup>(4)</sup>	Calculated maximum capacity 848	Infrequent (would cause facility damage)	Inlet: 48 in. dia. pipe with butterfly valve. Outlet: 48 in. hollow-cone valve	12.6	48 in. pipe opening inlet: 0-67.3 <sup>(3)</sup>	342 <sup>(2)</sup>	Energy dissipating valve discharges to a plunge pool
Hell Hole Power House <sup>(4)</sup>	Approx 45	Continuous except for maintenance	Inlet: 20 in. dia. pipe with control valve Outlet: horizontal Francis turbine	2.18	20 in. pipe opening inlet: 0-20.6 <sup>(3)</sup>	342 <sup>(2)</sup>	20 in. dia. penstock for powerhouse “Y’s” off of 48 in. dia pipe. Hell Hole Powerhouse discharges to plunge pool
Hell Hole Dam Instream Flow Pipe <sup>(4)</sup>	20	Infrequent (typically instream flow compliance is provided by Hell Hole Powerhouse) discharge	Inlet: 16 in. dia. pipe with butterfly valve. Outlet: 12 in. hollow-cone valve.	0.8	16 in. pipe opening inlet: 0-25 <sup>(3)</sup>	342 <sup>(2)</sup>	Energy dissipating valve discharges to a plunge pool

<sup>1</sup>Maximum reservoir operating surface elevation minus intake surface elevation.

<sup>2</sup>Maximum reservoir operating surface elevation minus intake elevation invert of Hell Hole Dam Outlet Works.

<sup>3</sup>Intake velocity calculated at the pipe inlet inside the tunnel. Intake velocity to the tunnel is much lower (see Hell Hole-Middle Fork Tunnel Intake)

<sup>4</sup>Outlet branches off from tunnel. Inlet to tunnel is the Hell Hole Dam Outlet Works.

**AQ 7-1. Middle Fork Project Facilities – Entrainment Characteristics (cont.).**

Facility	Hydraulic Capacity (cfs)	Frequency of Use (cfs)	Inlet/Outlet Type	Inlet Area (ft. <sup>2</sup> )	Approach Velocity (fps)	Intake Depth (ft)	Comments
<b>Middle Fork Interbay</b>							
Middle Fork – Ralston Tunnel	836	Frequent	Inlet: Tunnel with slide gate and trash rack with 3 in. bar spacing Outlet: Pelton Turbine	Tunnel Inlet: 96 Trash Rack: 680	Inlet: 0-8.71 Trash Rack: 0-1.23	51 <sup>(1)</sup>	Ralston Powerhouse discharges into Ralston Afterbay
Middle Fork Interbay Dam Low Level Outlet	895	Infrequent	Inlet: 60 in. dia. with slide gate and Grizzly (8 in. bar opening) Outlet: Open pipe	Pipe Inlet: 19.6 Grizzly: 62	Inlet: 0-45.7 Trash Rack: 0-14.4	68.5 <sup>(1)</sup>	Discharges to a plunge pool
Middle Fork Interbay Dam Stream Maintenance Pipe	12-23	Continuous	Inlet: 20 in dia. pipe with slide valve and trash rack (3 in. bar opening) Outlet: Open pipe	Pipe Inlet: 2.18 Trash Rack: 6.0	Inlet: 5.5-10.6 Trash Rack: 2.0-3.8	39.84 <sup>(1)</sup>	Outlet discharges to a plunge pool

<sup>1</sup>Maximum reservoir operating surface elevation minus intake elevation invert.

**AQ 7-1. Middle Fork Project Facilities – Entrainment Characteristics (cont.).**

Facility	Hydraulic Capacity (cfs)	Frequency of Use (cfs)	Inlet/Outlet Type	Inlet Area (ft. <sup>2</sup> )	Approach Velocity (fps)	Intake Depth (ft)	Comments
<b>Ralston Afterbay</b>							
Ralston – Oxbow Tunnel	1,088	Frequent	Inlet: Tunnel with slide gate and trash rack with 3 in. bar spacing Outlet: vertical Francis turbine	Tunnel Inlet: 96 Trash Rack: 590	Inlet: 0-11.3 Trash Rack: 0-1.8	39 <sup>(1)</sup>	Oxbow Powerhouse discharges into the Middle Fork American River
Ralston Afterbay Dam Low Level Outlet	1,671	Infrequent	Inlet: 72 in. dia. with slide valve and Grizzly (8" bar opening) Outlet: 72 in. dia. slide gate	Pipe Inlet: 28.3 Grizzly: 82.6	Inlet: 0-59.1 Trash Rack: 0-20.33	74 <sup>(1)</sup>	Discharges to a plunge pool
Ralston Afterbay Dam Stream Maintenance Pipe	75	Frequent – 10 cfs Infrequent – 75 cfs	Inlet: 30 in. dia. pipe with slide valve and trash rack (3.88 in. bar opening) Outlet: 30 in. dia. Ring Jet valve	Pipe Inlet: 4.9 Trash Rack: 36.2	Inlet: 2.04-15.31 Trash Rack: 0.3-2.1	41.25 <sup>(1)</sup>	Energy dissipating valve discharges to a plunge pool

<sup>1</sup>Maximum reservoir operating surface elevation minus intake elevation invert.

**AQ 7-1. Middle Fork Project Facilities – Entrainment Characteristics (cont.).**

Facility	Hydraulic Capacity (cfs)	Frequency of Use (cfs)	Inlet/Outlet Type	Inlet Area (ft. <sup>2</sup> )	Approach Velocity (fps)	Intake Depth (ft)	Comments
<b>Duncan Creek Diversion</b>							
Duncan Creek – Middle Fork Tunnel	400	Frequent	Inlet: Tunnel with stop logs. Trash Rack (with 9 in. bar spacing.) Outlet: Open tunnel	Tunnel Inlet: 51 Trash Rack: 51	Inlet: 0-7.84 Trash Rack: 0-7.84	4.25 <sup>(1)</sup>	Discharges into French Meadows Reservoir
Duncan Creek Low Level Outlet	304	Infrequent	Inlet: 60 in. dia. pipe w/ slide gate and grizzly with 10 in. bar spacing. Outlet: Open pipe	Pipe Inlet: 19.6 Grizzly: 58.7	Inlet: 0-15.5 Trash Rack: 0-5.2	13.5 <sup>(2)</sup>	Discharges to a plunge pool
Duncan Creek Stream Maintenance Pipe	4 - 8	Continuous	Inlet: 10 in. dia. pipe with slide gate and trash screen (with 1.75 in. openings) Outlet: Discharge weir.	Pipe Inlet: 0.55 Trash Screen: 12.2	Inlet: 7.3-14.6 Trash Rack: 0.33-0.66	5 <sup>(1)</sup>	Outlet discharges to a plunge pool

<sup>1</sup>Diversion Dam Crest minus top of intake weir.

<sup>2</sup>Diversion Dam Crest minus invert elevation.

**AQ 7-1. Middle Fork Project Facilities – Entrainment Characteristics (cont.).**

Facility	Hydraulic Capacity (cfs)	Frequency of Use (cfs)	Inlet/Outlet Type	Inlet Area (ft. <sup>2</sup> )	Approach Velocity (fps)	Intake Depth (ft)	Comments
<b>North Fork Long Canyon</b>							
North Fork Long Canyon Diversion Pipe	100	Frequently during winter and spring. No diversion after July 1.	Inlet: Parshall Flume with slide gate to a 36 in. dia pipe. Trash rack w/ 2 in. bar spacing. Outlet: 403 foot deep drop inlet to the Hell Hole - Middle Fork Tunnel	Inlet: 16 Trash Rack: 68.7	Inlet: 0 – 6.25 Trash Rack: 0 – 1.46	6 <sup>(1)</sup>	Discharge to Hell Hole – Middle Fork Tunnel
North Fork Long Canyon Low Level Outlet	104	Infrequent	Inlet: 36 in. dia. pipe with slide gate Outlet: open pipe	Inlet: 7.1	Inlet: 0 – 14.7	5.5 <sup>(1)</sup>	Discharge to streambed
North Fork Long Canyon Stream Maintenance Pipe	0 - 2	Continuous	Inlet: 12 in. dia pipe with 12 in. Slide valve Outlet: 25 in. wide concrete channel with weir	Inlet: 0.8	Inlet: 0 - 2.5	6 <sup>(1)</sup>	Discharge to streambed

<sup>1</sup>Diversion dam spillway crest minus invert elevation.

**AQ 7-1. Middle Fork Project Facilities – Entrainment Characteristics (cont.).**

Facility	Hydraulic Capacity (cfs)	Frequency of Use (cfs)	Inlet/Outlet Type	Inlet Area (ft. <sup>2</sup> )	Approach Velocity (fps)	Intake Depth (ft)	Comments
<b>South Fork Long Canyon</b>							
South Fork Long Canyon Diversion Pipe	200	Frequently during winter and spring. No diversion after July 1	Inlet: 42 in. dia. pipe with inlet weir. Trash rack w/2.4 in. bar spacing. Outlet: 387 foot deep drop inlet to Hell Hole-Middle Fork Tunnel	Inlet: 36 Trash Rack: 107	Inlet: 0 – 5.6 Trash Rack: 0 – 1.87	11 <sup>(1)</sup>	Discharge to Hell Hole – Middle Fork Tunnel
South Fork Long Canyon Low Level Outlet	136 136	Infrequent	Inlet: 36 in. dia. pipe with slide gate Outlet: open pipe	Inlet: 7.1	Inlet: 0 – 19.5	12.2 <sup>(1)</sup>	Discharge to streambed
South Fork Long Canyon Stream Maintenance Pipe	2.5 - 5	Continuous	Inlet: 12 in. dia pipe with 12 in. Slide valve Outlet: 48 in. wide concrete channel with weir	Inlet: 0.8	Inlet: 3.1 – 6.25	6 <sup>(1)</sup>	Discharge to streambed

<sup>1</sup>Diversion dam spillway crest minus invert elevation.

**Table AQ 7-2. Dispersal Functions and Derived Parameters for PCWA Juvenile and Adult Trout Modeling<sup>1</sup>.**

Source	$\lambda_s$	$\lambda_m$	p	Duration Days	Extent (m)	HSL (m)
Graf 2008	0.000177806	0.002281752	0.099314901	365	6500	500
Jenkins et al. 1999	0.004388637	0.075026033	0.431597998	270	745	13.8
Jenkins et al. 1999	0.000316486	0.006390323	0.317766589	365	4500	500
Fausch et al. (1995; cited in Rodriguez 2002)	0.01767	0.00155	0.46	365	1350	50

<sup>1</sup> Dispersal function describing decline in capture probability with distance from the home section:

$$f(x) = p\lambda_s e^{-\lambda_s x} + (1 - p)\lambda_m e^{-\lambda_m x}$$

where: p = proportion of stationary individuals; (1 - p) = proportion of mobile individuals; x = distance in meters away from the home section;

HSL = home section length (in meters);  $\lambda_m$  and  $\lambda_s$  = displacement parameters (i.e., the inverse of the mean displacement distance; in units of  $m^{-1}$ ) and subscripts 'm' is mobile and 's' is stationary.

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**Table AQ 7-3. Assumptions for YOY Modeling.**

Not Yet Completed

Table AQ 7-4. Summary of Canal Entrainment Data.

River/Project	Bow River, Alberta, CA	Smiths Fork, WY	Stanislaus, CA	DeSabra, CA		
	Carseland	Covey, Whites Water, South Branch Irrigation	Stanislaus Power Tunnel and Forebay	Hendricks	Butte	Lower Centerville
Canal Name						
Length of Diversion Period (months)	4	5	12	12	12	12
Number of Streams Entering Canal	1	1	1	4	5	4
Approximate % of Flow Diverted	73	32	85	80	76	72
Approximate Amount of Flow Diverted	1018	61 <sup>2</sup>	500	125	91	183
Estimate of All Trout Fish Population Main stem	--	--	8233 <sup>6</sup>	892	389	1063
Estimate of Adult Fish Population Mainstem	2017	269	3264	892	389	1063
Number of Trout Diverted <sup>1</sup>	4660	404	1872	1420	1102	1174
% RBT	86	65	50	42	65	93
% YOY	62	--	54	43	61	61
Reference	Post et al. 2006	Carlson and Rahel 2007	PG&E 2002	P&GE 2007	P&GE 2007	P&GE 2007

<sup>1</sup>Minimum Entrained

<sup>2</sup>Based on Average annual discharge

<sup>3</sup>Butte Creek - total of 4 tribs, 3 with fish population

<sup>4</sup>3 tribs with no fish population data

<sup>5</sup>Averaged the 3 mainstem Fish Population Sites, above the diversion

<sup>6</sup>Based on 10 years of data

**Table AQ 7-5. Immediate and 48-Hour Fish Survival Rates for Francis Turbines by Fish Size.<sup>1</sup>**

Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	Average Immediate Survival <sup>2</sup> (all species combined)			
			N <sup>3</sup>	Minimum (%)	Maximum (%)	Mean (%)
<250	440-1,600	<100	13	85.9	100 <sup>4</sup>	93.9
"	370-1,600	100-199	19	74.8	100.0	91.6
"	370-2,450	200-299	18	59.0	100.0	86.9
"	440-1,600	300+	14	36.1	100.0	73.2
>250	275-695	<100	6	31.0	97.6	70.1
"	"	100-199	7	34.3	82.7	60.0
"	"	200-299	7	22.8	82.9	39.3
"	"	300+	3	3.5	35.4	19.1
Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	Average 48-Hour Survival <sup>2</sup> (all species combined)			
			N <sup>3</sup>	Minimum (%)	Maximum (%)	Mean (%)
<250	440-1,600	<100	11	81	101 <sup>(4)</sup>	90
"	370-2,450	100-199	17	74	101 <sup>(4)</sup>	88
"	440-2,450	200-299	15	47	96	80
"	440-1,600	300+	13	34	94	67
>250	275-695	<100	3	63	86	72
"	275-695	100-199	5	16	78	46
"	275-695	200-299	5	12	65	32
"	275-450	300+	2	4	8	6

<sup>1</sup>From Winchell, F., S. Amaral and D. Dixon. 2000. Hydroelectric Turbine Entrainment and Survival Database: An Alternative to Field Studies. Paper presented at Hydrovision 2000.

<sup>2</sup>Average of all control-adjusted estimates provided in EPRI (1997) including all species and test conditions but excluding tests with less than 90% survival of control groups.

<sup>3</sup>Number of turbines for which survival estimates are available.

<sup>4</sup>Even with high rates of control survival, the true rate of survival may be under- or over-estimated. When the survival of treatment groups is higher than controls, the adjusted survival estimates will exceed 100%.

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**Table AQ 7-6. Entrainment Locations by Diversion and Potential Mortality Rankings.**

To be completed

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**Table AQ 7-7. Summary of Screen Costs - California.**

<b>Flow Range (cfs)</b>	<b>Average Cost Dollars/CFS<sup>1</sup></b>	<b>Highest Cost Dollars/CFS<sup>2</sup></b>
50-100	\$8,300	\$15,000
100-500	\$21,000	\$42,000
500-1000	\$12,000	\$23,000
>1000	\$12,000	\$19,000

Notes

<sup>1</sup>Average capital cost of 35 projects constructed in California between 1983 and 2005. Costs inflated at 3% to 2008 dollars.

<sup>2</sup>Highest capital cost in range (2008 dollars).

**Table AQ 7-8. Estimated Installation Costs to Screen Selected Project Facility Intakes.**

Facility	Maximum Flow (CFS)	Average Cost \$/CFS <sup>1,4</sup>	Maximum Cost \$/CFS <sup>1,4</sup>	Range of Screen Cost (millions) <sup>4</sup>	
<b>Small Facilities</b>					
North Fork Long Canyon Diversion	100	\$8,300	\$15,000	\$1	\$2
South Fork Long Canyon Diversion	200	\$21,000	\$42,000	\$4	\$8
<b>Large Facilities</b>					
Duncan Creek - Middle Fork Tunnel Intake	400	\$21,000	\$42,000	\$8	\$17
French Meadows - Hell Hole Tunnel Intake <sup>(2)</sup>	400	\$21,000	\$42,000	\$8	\$17
French Meadows - Hell Hole Tunnel Intake <sup>(3)</sup>	800	\$12,000	\$23,000	\$10	\$18
Hell Hole - Middle Fork Tunnel Intake	920	\$12,000	\$23,000	\$11	\$21
Middle Fork - Ralston Tunnel Intake	836	\$12,000	\$23,000	\$10	\$19
Ralston - Oxbow Tunnel Intake	1,088	\$12,000	\$19,000	\$13	\$21

<sup>1</sup>Estimated costs per cfs are based on average and maximum costs from 35 previously constructed screening projects in California with a variety of screen designs, sizes, and design criteria.

<sup>2</sup>Current operations

<sup>3</sup>Utilizing maximum tunnel capacity

<sup>4</sup>Capital cost in 2008 dollars (3% annual inflation)

**Table AQ 7-9. Fish Population Scaling Factors Versus West Panther Creek Population.**

<b>River Site</b>	<b>Juvenile/Adult Trout (#/mile)</b>	<b>Population Scaling Factor</b>
West Panther Creek	870	-
Duncan Creek above Diversion (DC9.0)	1021	1.17
South Fork Long Canyon Creek above Diversion (SFLC4.2)	1380	1.59
North Fork Long Canyon Creek above Diversion (NFLC3.8)	1577	1.81
Middle Fork American River above Middle Fork Interbay (MF36.2)	696	0.80

**Table AQ 7-10. Fifty Percent Exceedance Diversion Percent.**

Month	% Flow Diverted			
	NF Long Canyon Creek	SF Long Canyon Creek	Duncan Creek	Middle Fork Interbay
Jan	0%	0%	21%	89%
Feb	40%	51%	41%	92%
Mar	72%	67%	62%	86%
Apr	77%	81%	82%	84%
May	54%	74%	85%	89%
Jun	0%	0%	46%	95%
Jul	0%	0%	0%	97%
Aug	0%	0%	0%	97%
Sep	0%	0%	0%	97%
Oct	0%	0%	0%	86%
Nov	0%	0%	4%	97%
Dec	0%	0%	7%	93%
<b>Average</b>	<b>20%</b>	<b>23%</b>	<b>29%</b>	<b>92%</b>

**Table AQ 7-10. Fifty Percent Exceedance Diversion Percent.**

<b>Month</b>	<b>NFLC 3.8</b>	<b>SFLC 4.2</b>	<b>DC 9.0</b>	<b>MF 36.2</b>
<b>Jan</b>	0	0	21	89
<b>Feb</b>	40	51	41	92
<b>Mar</b>	72	67	62	86
<b>Apr</b>	77	81	82	84
<b>May</b>	54	74	85	89
<b>Jun</b>	0	0	46	95
<b>Jul</b>	0	0	0	97
<b>Aug</b>	0	0	0	97
<b>Sep</b>	0	0	0	97
<b>Oct</b>	0	0	0	86
<b>Nov</b>	0	0	4	97
<b>Dec</b>	0	0	7	93
<b>Average</b>	20	23	29	92

**Table AQ 7-11. Summary of Potential Fish Diverted using the West Panther Creek Data and the 50% Exceedance Percent Flow Diversion.**

Month	NF Long Canyon Creek		SF Long Canyon Creek		Duncan Creek		Middle Fork Interbay	
	# YOY <sup>1</sup>	# Juv/Ad <sup>1</sup>	# YOY	# Juv/Ad	# YOY	# Juv/Ad	# YOY	# Juv/Ad
Jan	0	0	0	0	0	6	0	16
Feb	0	9	0	10	0	6	0	9
Mar	0	60	0	49	0	34	0	32
Apr	0	6	0	5	0	4	0	3
May	5	12	6	14	7	12	7	9
Jun	4	0	5	0	176	1	257	1
Jul	0	0	0	0	8	0	80	0
Aug	0	0	0	0	0	0	47	2
Sep	0	0	0	0	0	0	40	5
Oct	0	0	0	0	0	0	36	5
Nov	0	0	0	0	0	0	39	5
Dec	0	0	0	0	0	0	38	5
<b>Total</b>	<b>9</b>	<b>87</b>	<b>11</b>	<b>79</b>	<b>192</b>	<b>63</b>	<b>544</b>	<b>91</b>

<sup>1</sup>YOY - young-of-the-year; Juv/Ad = juvenile/ adult

**Table AQ 7-12. Total Potential Number of Fish Moving Downstream by Year and by Month Scaled to a Population of 1,000 Fish/Mile.**

<b>Author</b>	<b>Species</b>	<b>Juv/Adult Total</b>	<b>Per Month</b>
Fausch et al. (1995; cited in Rodriguez 2002)	Brook Trout	108	9.00
Hilderbrand and Kershner (2000)	Cutthroat Trout	100	8.33
Jenkins et al (1999) <sup>1</sup>	Brown Trout	72	6.00
Graf (2008)	Rainbow Trout	89	7.42
<b>Average</b>		<b>92</b>	<b>7.69</b>
<b>Minimum</b>		<b>72</b>	<b>6.00</b>
<b>Maximum</b>		<b>108</b>	<b>9.00</b>

<sup>1</sup>Based on 9 months of data.

**Table AQ 7-13. Potential Number of Fish Moving Downstream and Entrained per Month Based on the Literature Movement Data and the 50% Exceedance Percent Flow Diversion.**

	NFLC 3.8		SFLC 4.2		DC 9.0		MF 36.2	
<b>Fish Moving or entrained</b>	<b>Average</b>	<b>(Min-Max)</b>	<b>Average</b>	<b>(Min-Max)</b>	<b>Average</b>	<b>(Min-Max)</b>	<b>Average</b>	<b>(Min-Max)</b>
<b>Fish Moving / Month</b>	<b>12.1</b>	<b>(9.5 - 14.2)</b>	<b>10.6</b>	<b>(8.3 - 12.4)</b>	<b>7.8</b>	<b>(6.1 - 9.2)</b>	<b>5.3</b>	<b>(4.2 - 6.3)</b>
Jan (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	1.7	(1.3 - 2.0)	4.7	(3.7 - 5.6)
Feb (entrained)	4.9	(3.8 - 5.7)	5.4	(4.2 - 6.3)	3.2	(2.5 - 3.8)	4.9	(3.8 - 5.7)
Mar (entrained)	8.7	(6.8 - 10.2)	7.1	(5.5 - 8.3)	4.9	(3.8 - 5.7)	4.6	(3.6 - 5.4)
Apr (entrained)	9.4	(7.3 - 11.0)	8.6	(6.7 - 10.0)	6.4	(5.0 - 7.5)	4.5	(3.5 - 5.2)
May (entrained)	6.5	(5.1 - 7.6)	7.8	(6.1 - 9.1)	6.7	(5.2 - 7.8)	4.8	(3.7 - 5.6)
Jun (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	3.6	(2.8 - 4.2)	5.1	(4.0 - 6.0)
Jul (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	5.2	(4.0 - 6.1)
Aug (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	5.2	(4.1 - 6.1)
Sep (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	5.2	(4.1 - 6.1)
Oct (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	4.6	(3.6 - 5.4)
Nov (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.3	(0.2 - 0.3)	5.2	(4.1 - 6.1)
Dec (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.6	(0.4 - 0.7)	5.0	(3.9 - 5.8)
<b>Year Total (entrained)</b>	<b>29.4</b>	<b>(23.0 - 34.5)</b>	<b>28.9</b>	<b>(22.5 - 33.8)</b>	<b>27.3</b>	<b>(21.3 - 32.0)</b>	<b>58.9</b>	<b>(46.0 - 69.0)</b>

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**FIGURES**

**Figure AQ 7-1. Entrainment Objectives, Related Study Elements, and Reports.**

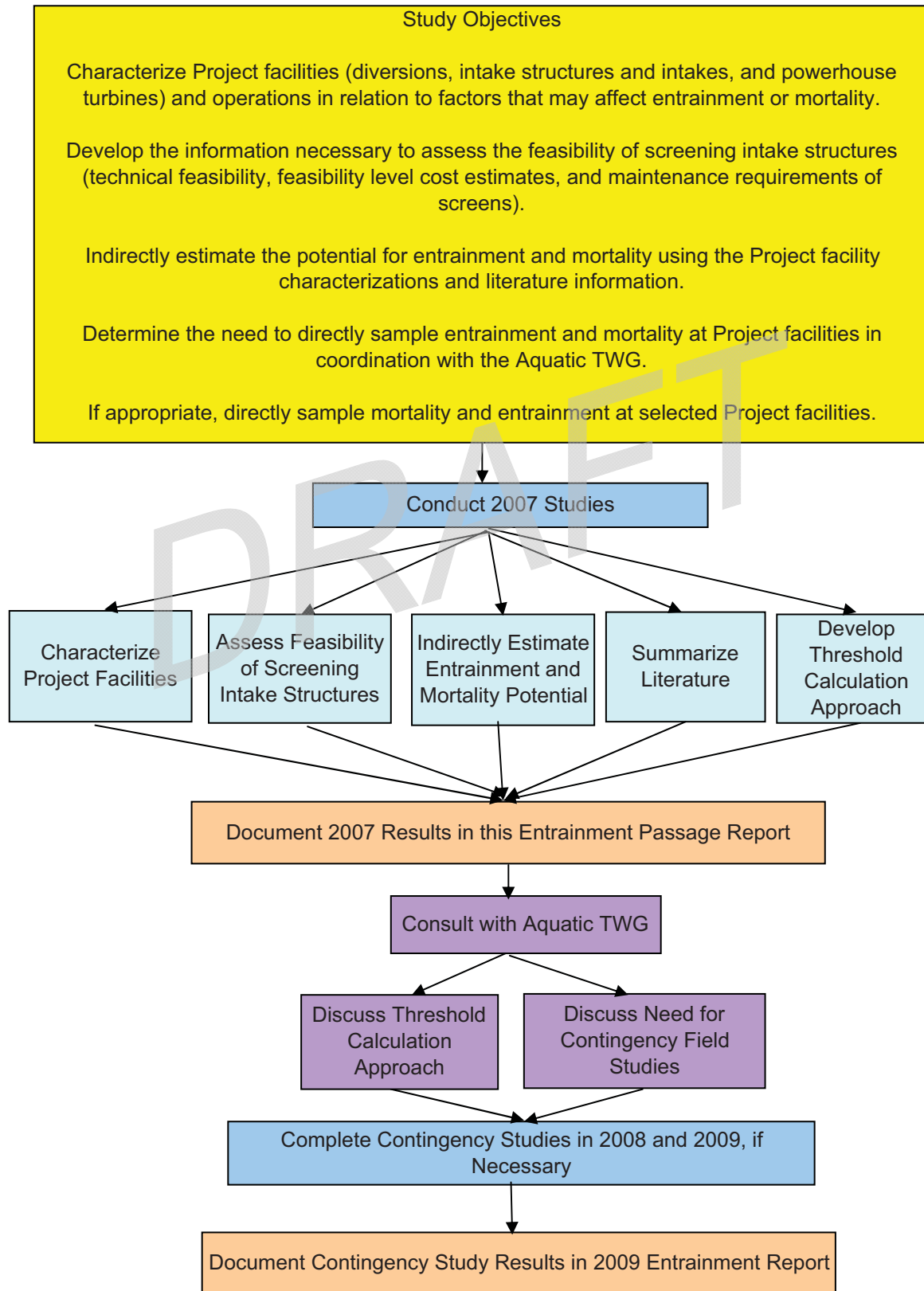


Figure AQ 7-2. Relationship between Number of Fish Moving Downstream, Number of Fish Entrained, the Amount of Flow and Percent of Flow Diverted on West Panther Creek.

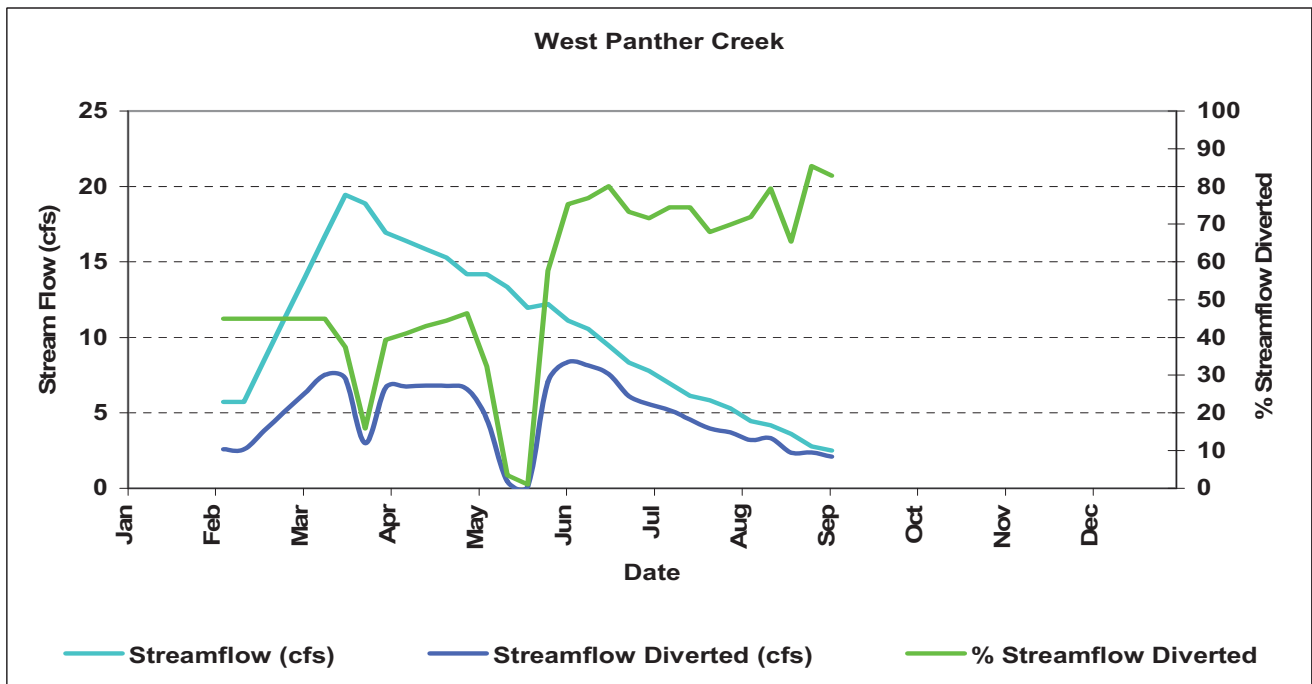
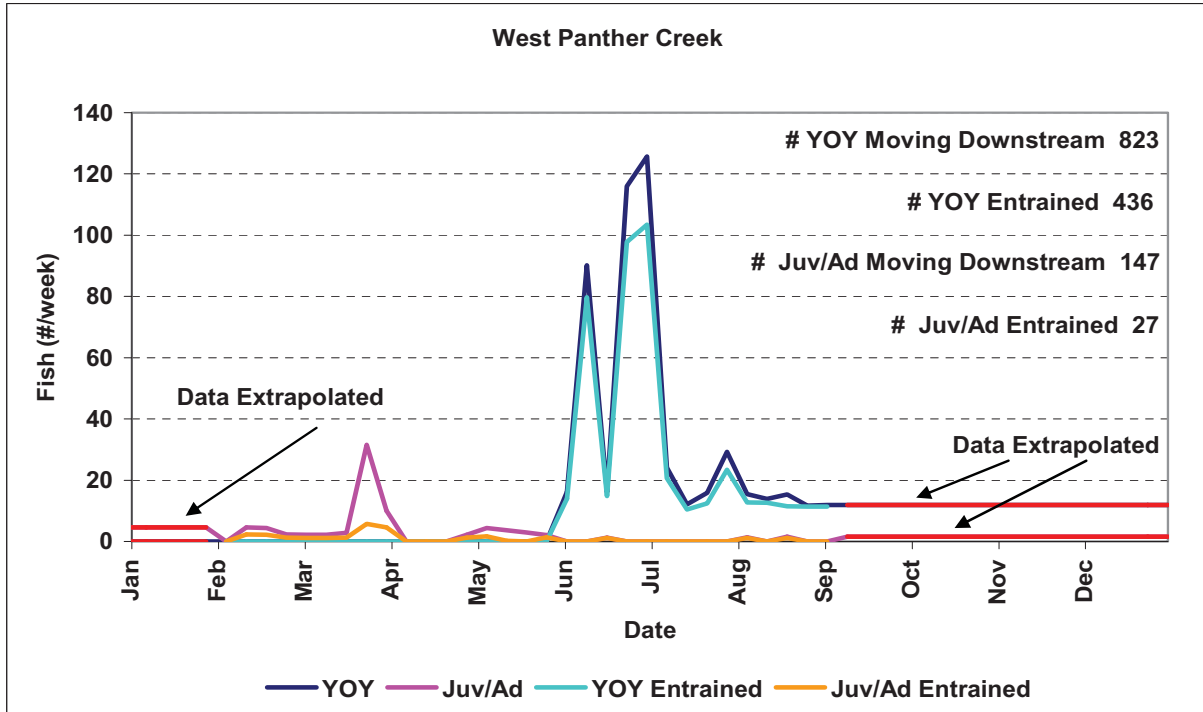


Figure AQ 7-3. Comparison of Mean Weekly Water Temperatures on West Panther Creek and Middle Fork Project Streams.

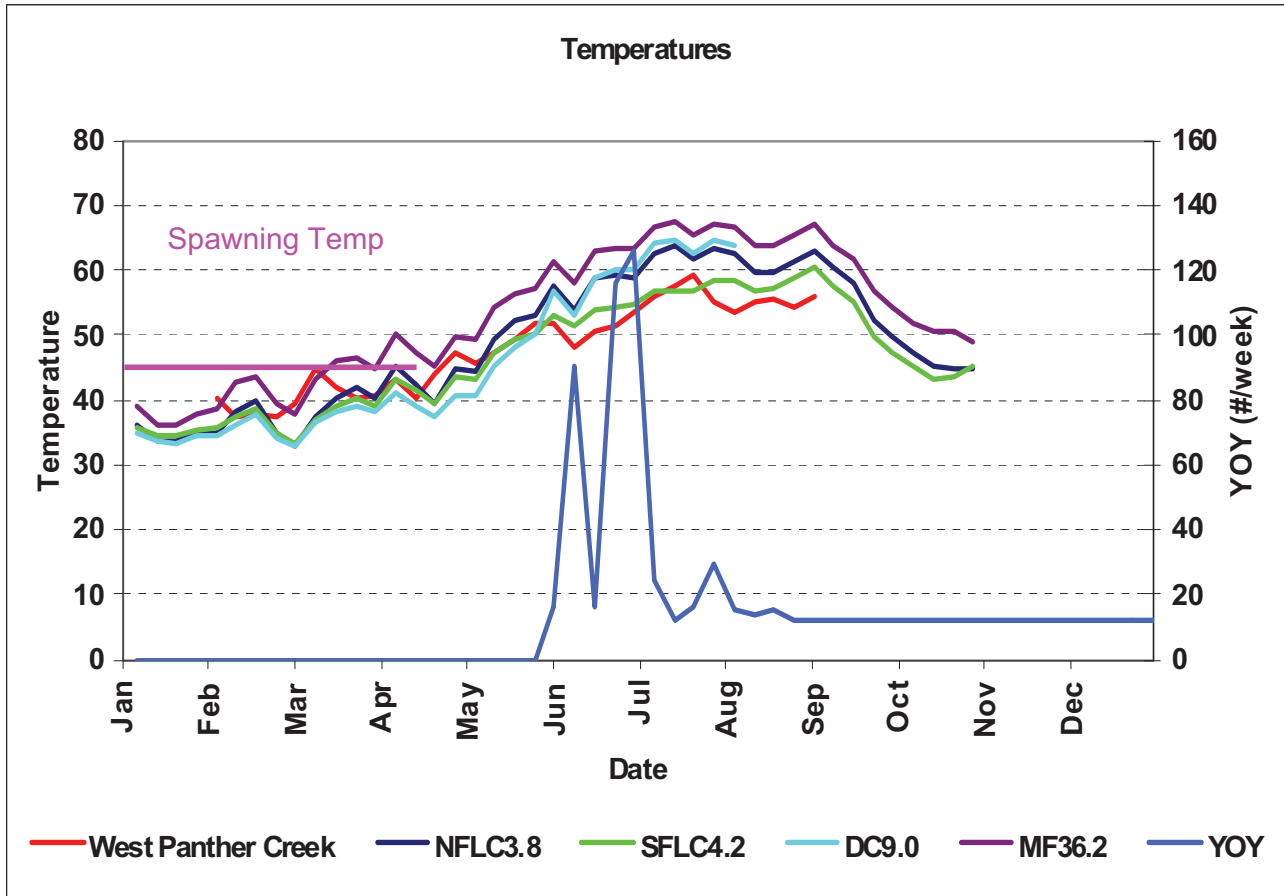


Figure AQ 7-4. Example Fitted Annual Probability Distribution of Fish Distance from Home Section.

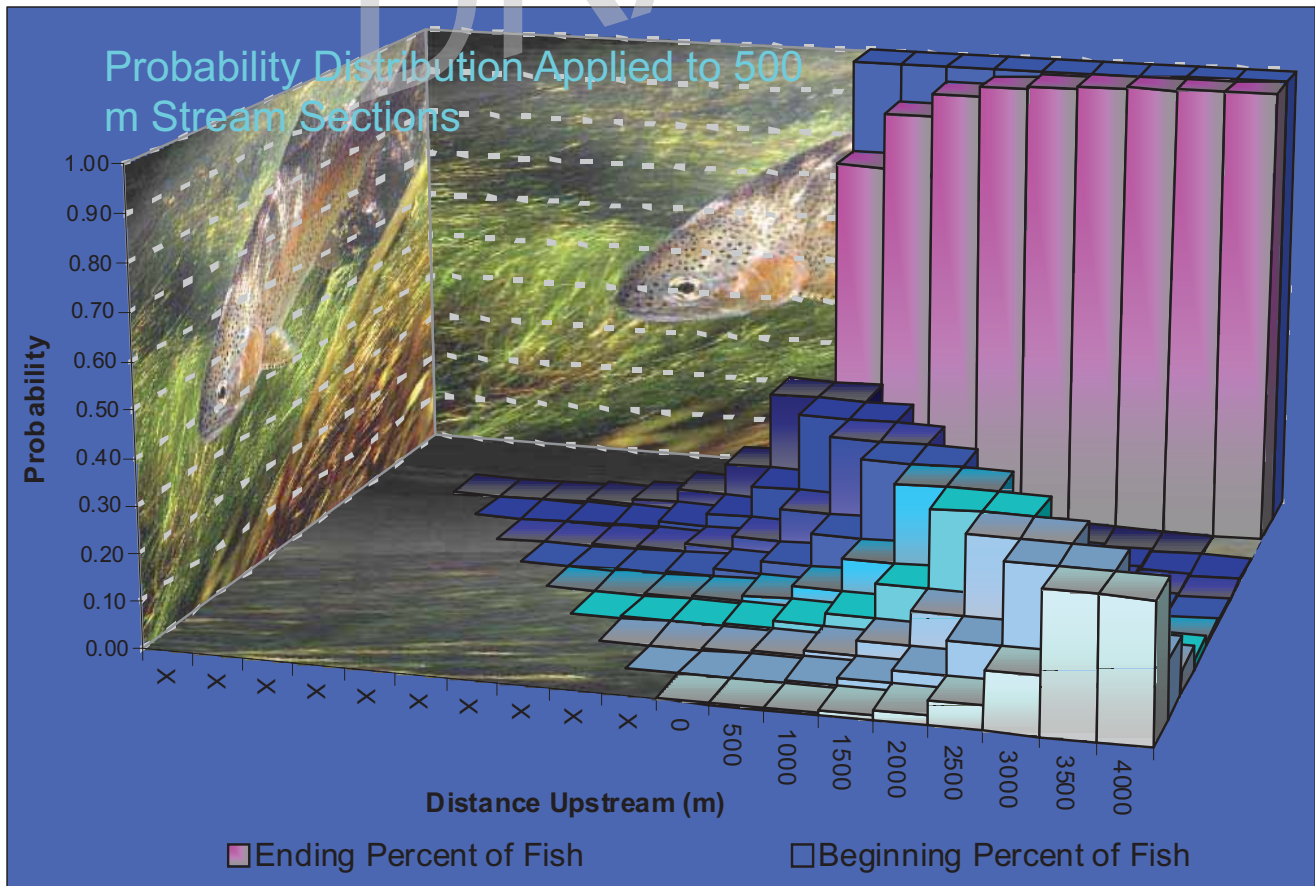
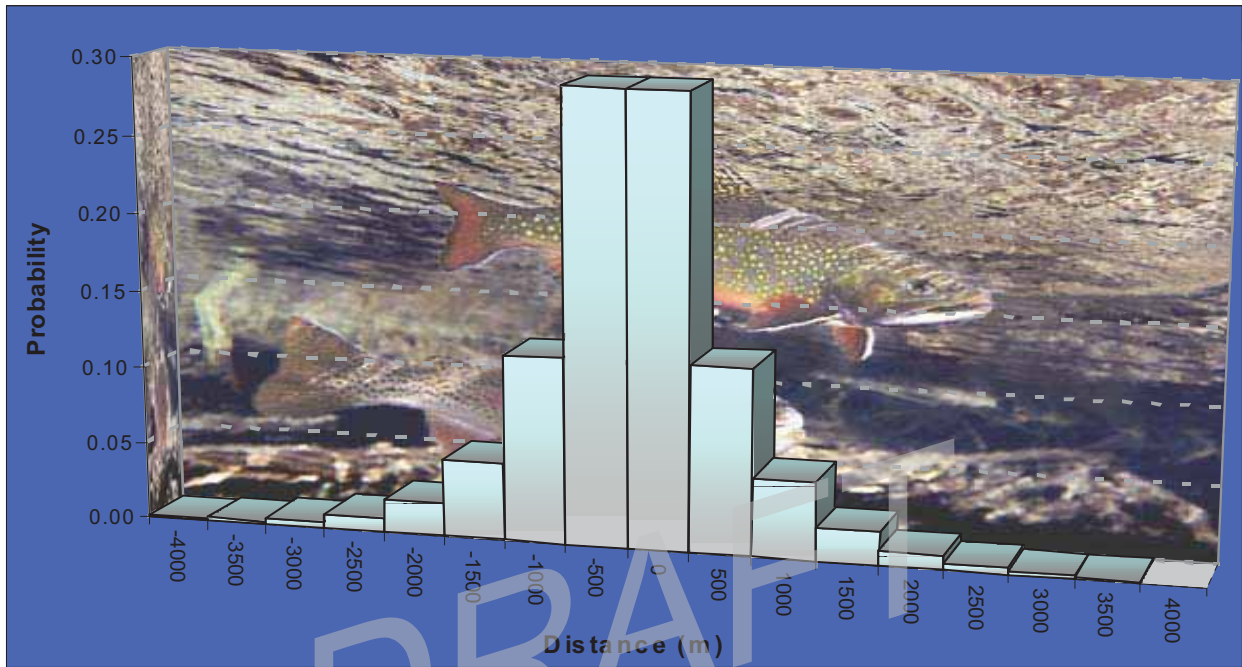


Figure AQ 7-5. Example Number of Fish Remaining in Stream After One Year.

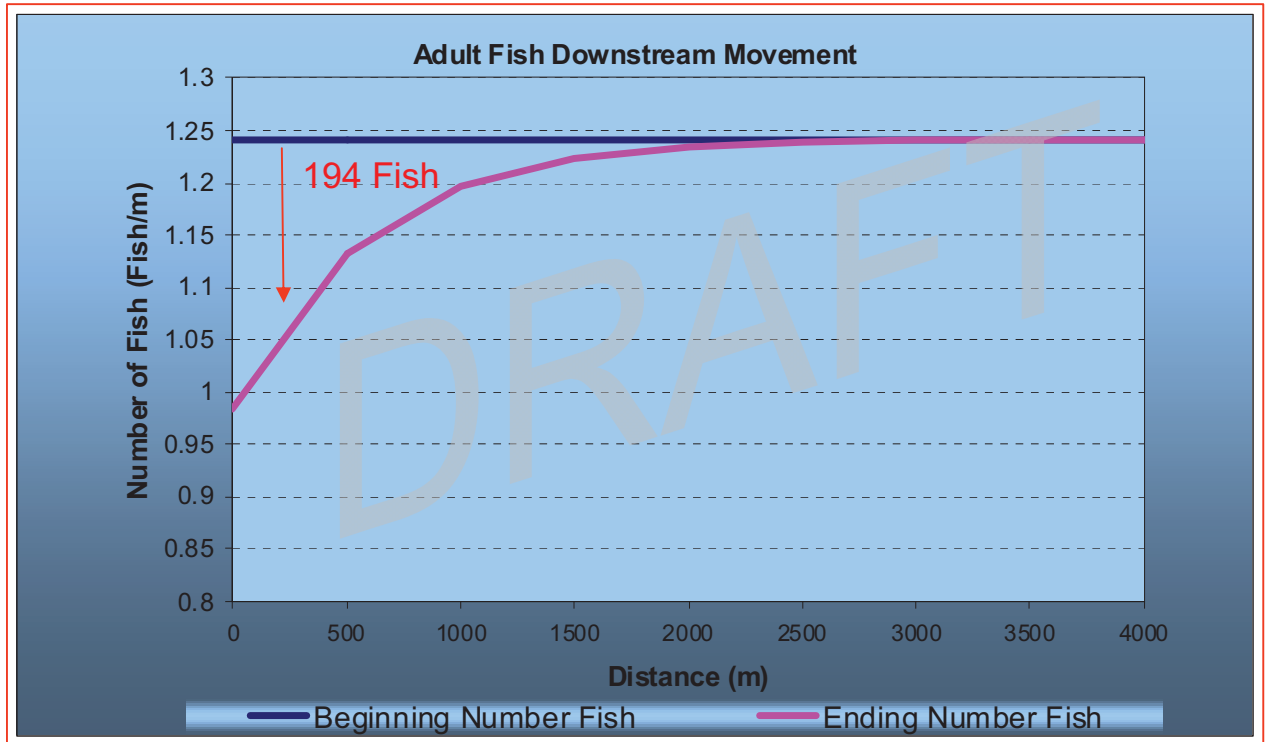


Figure AQ 7-6. Fecundity for Trout in the 120 to 400 mm Size Range.

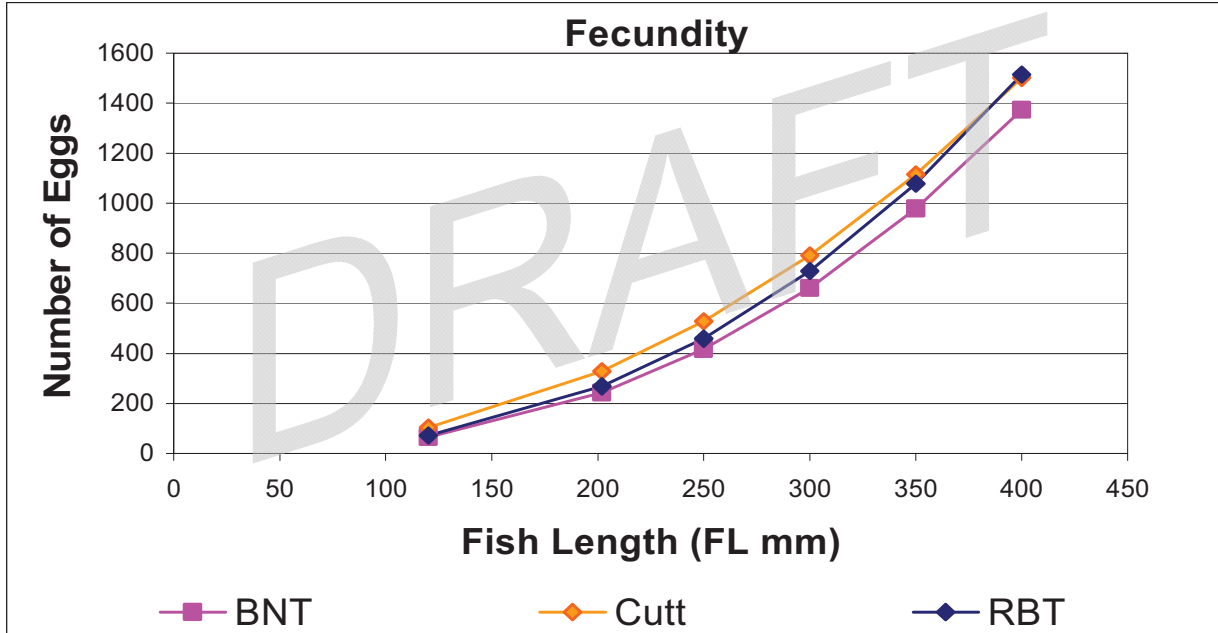


Figure AQ 7-7. Survivorship Curves for North Fork Long Canyon Creek Compared to Literature Survivorship Curves.

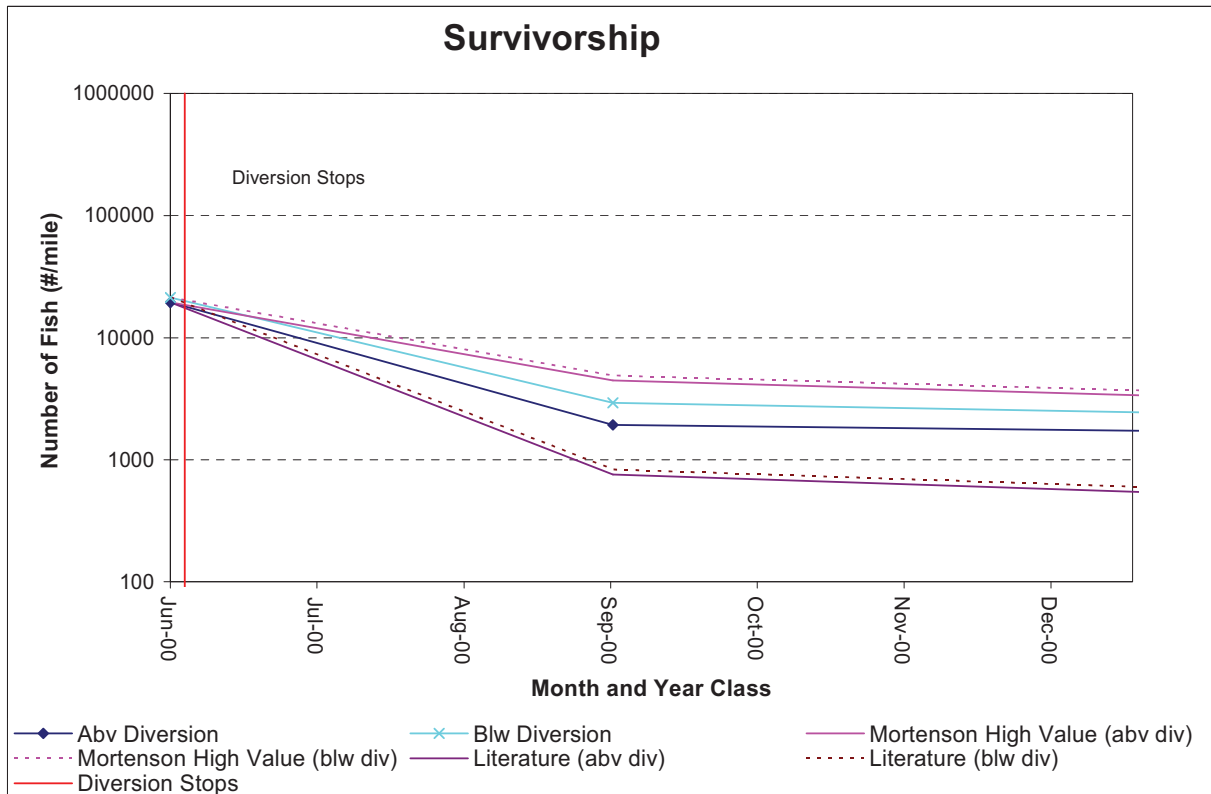
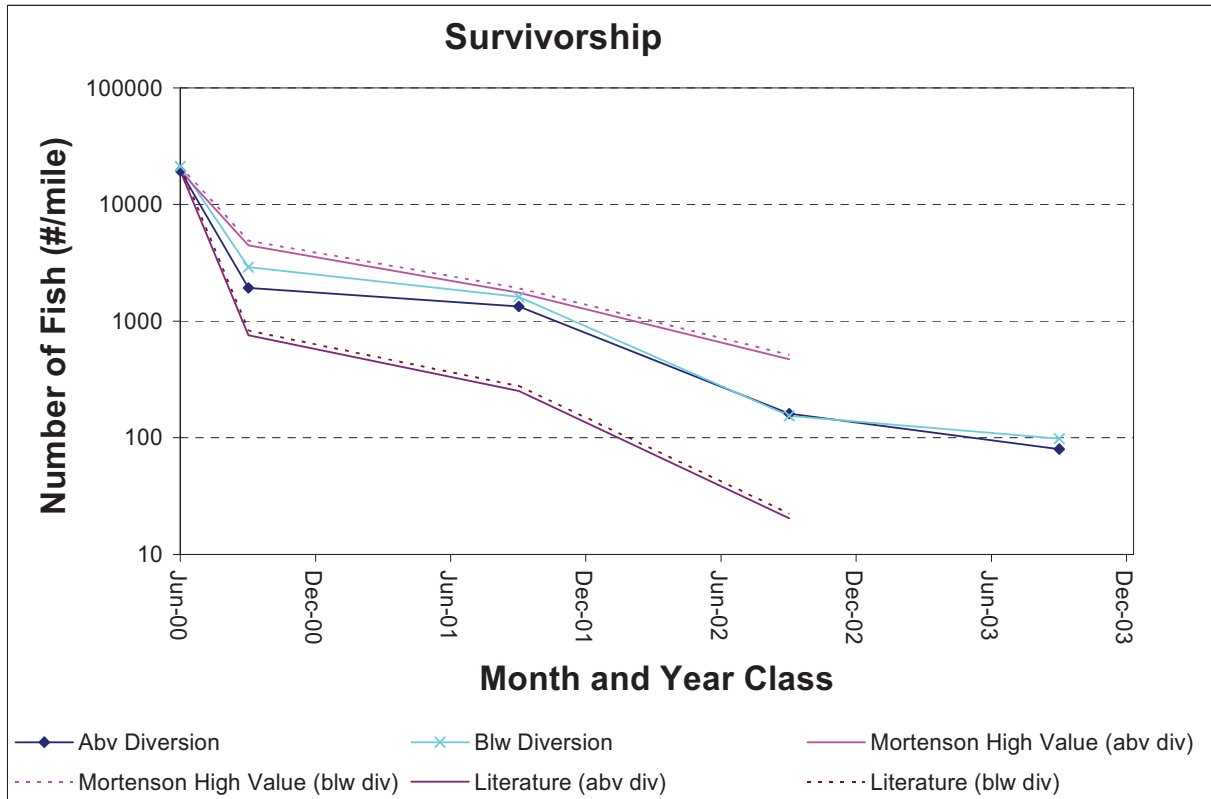


Figure AQ 7-8. Survivorship Curves for South Fork Long Canyon Creek Compared to Literature Survivorship Curves

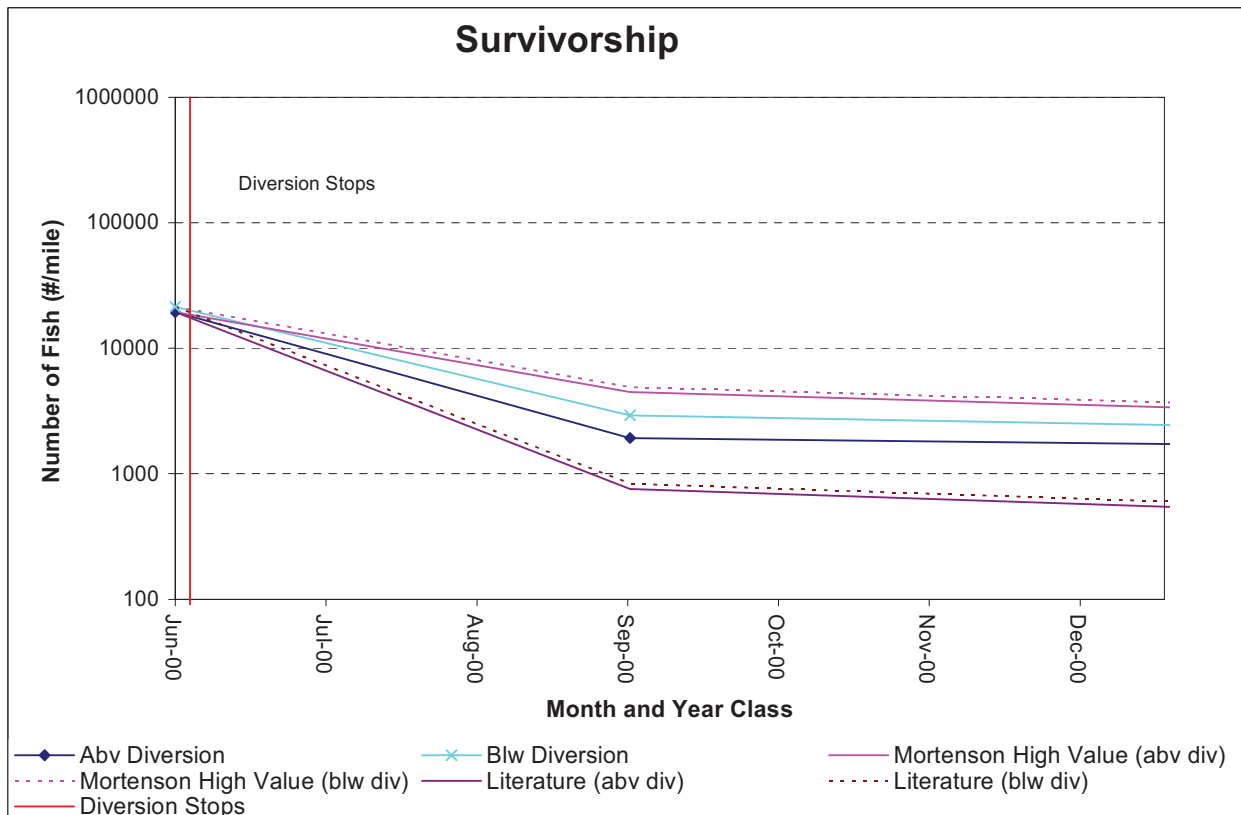
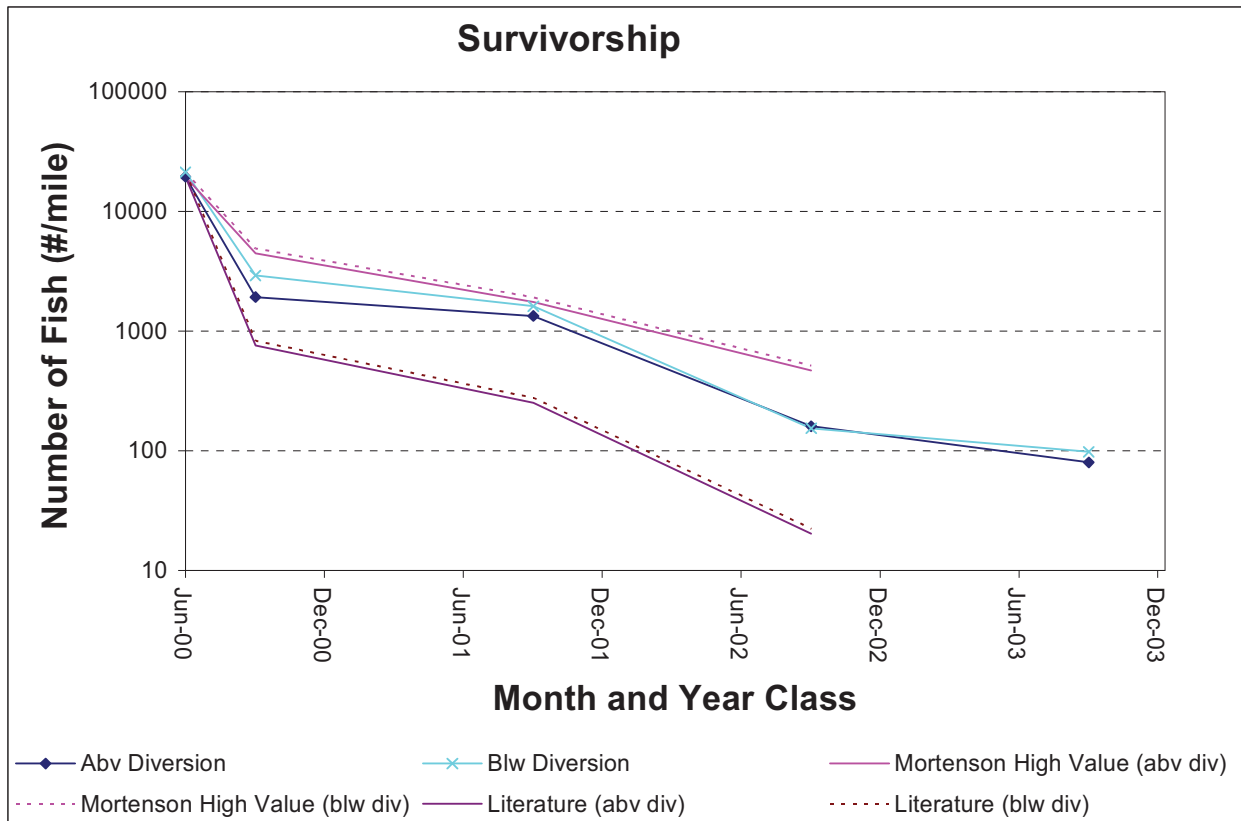


Figure AQ 7-9. Survivorship Curves for Duncan Creek Compared to Literature Survivorship Curves.

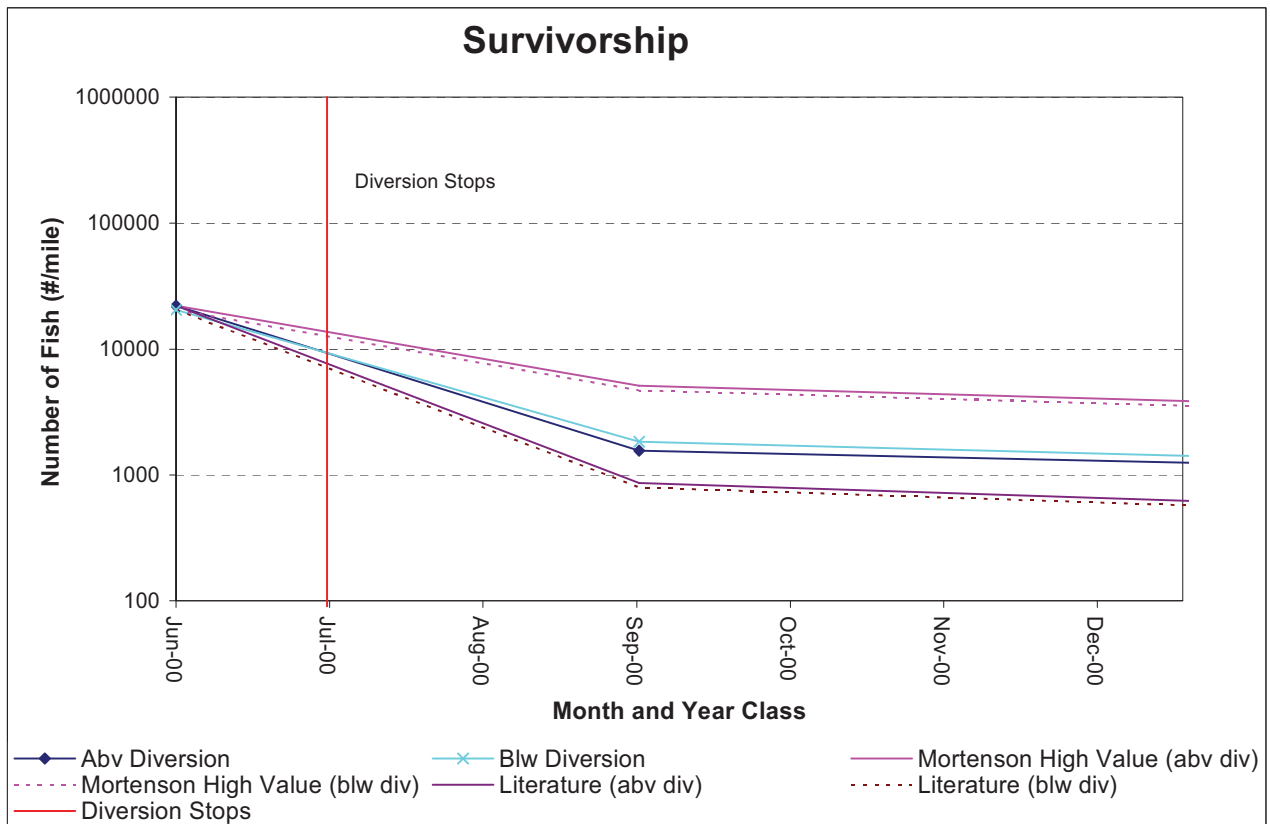
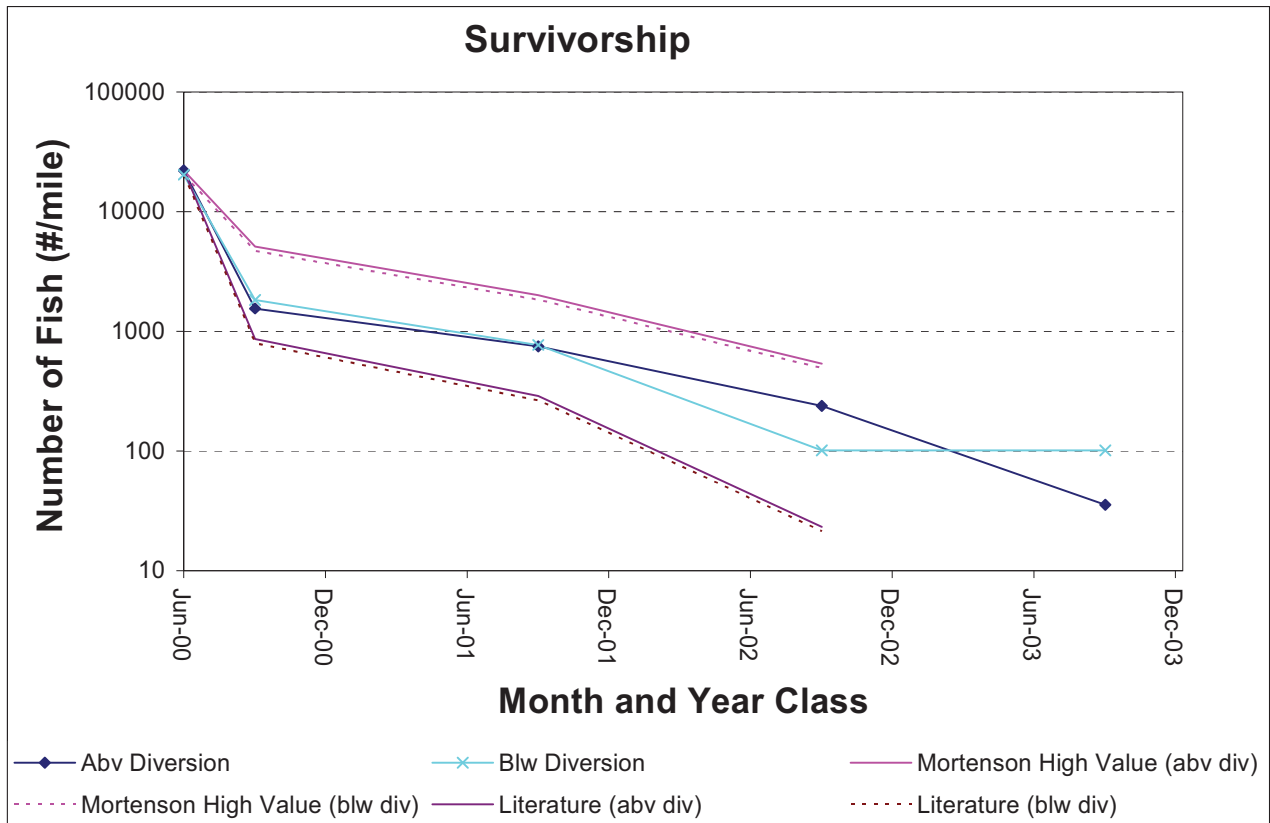


Figure AQ 7-10. Survivorship Curves for Middle Fork American River upstream of Middle Fork Interbay Compared to Literature Survivors

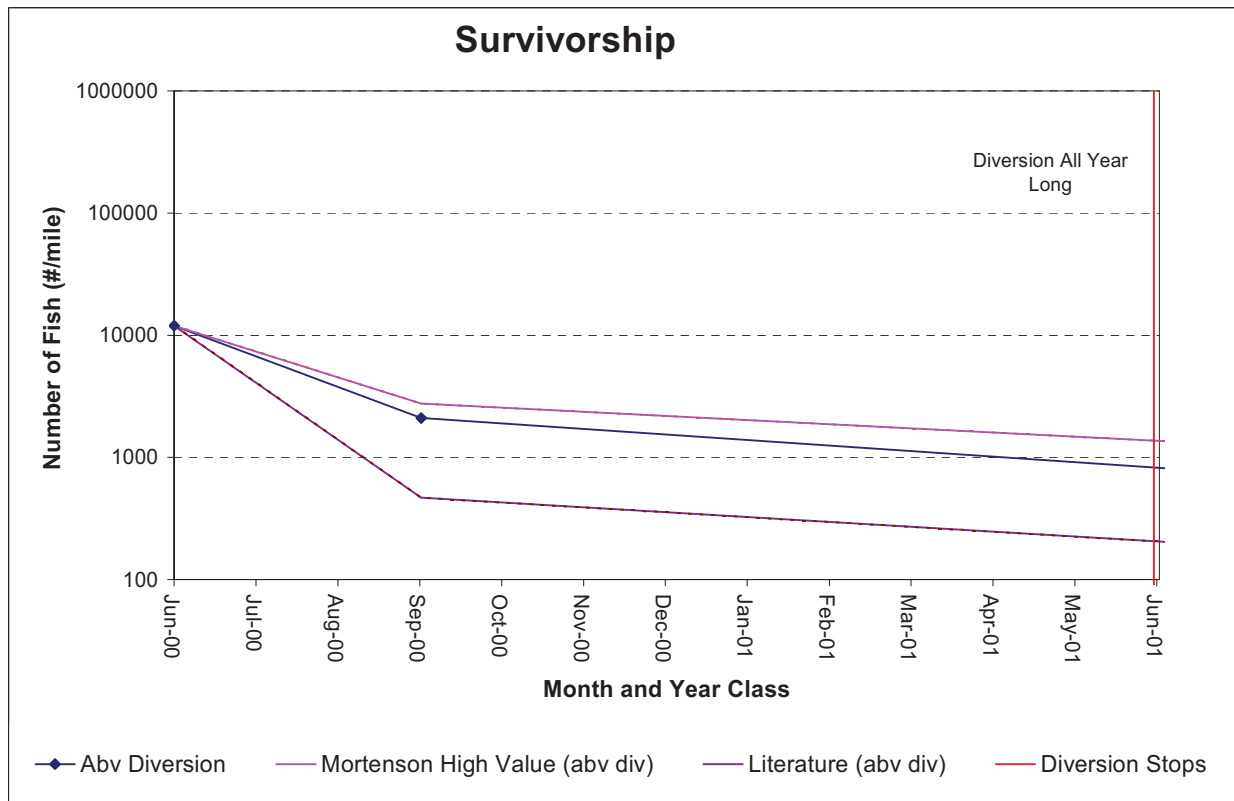
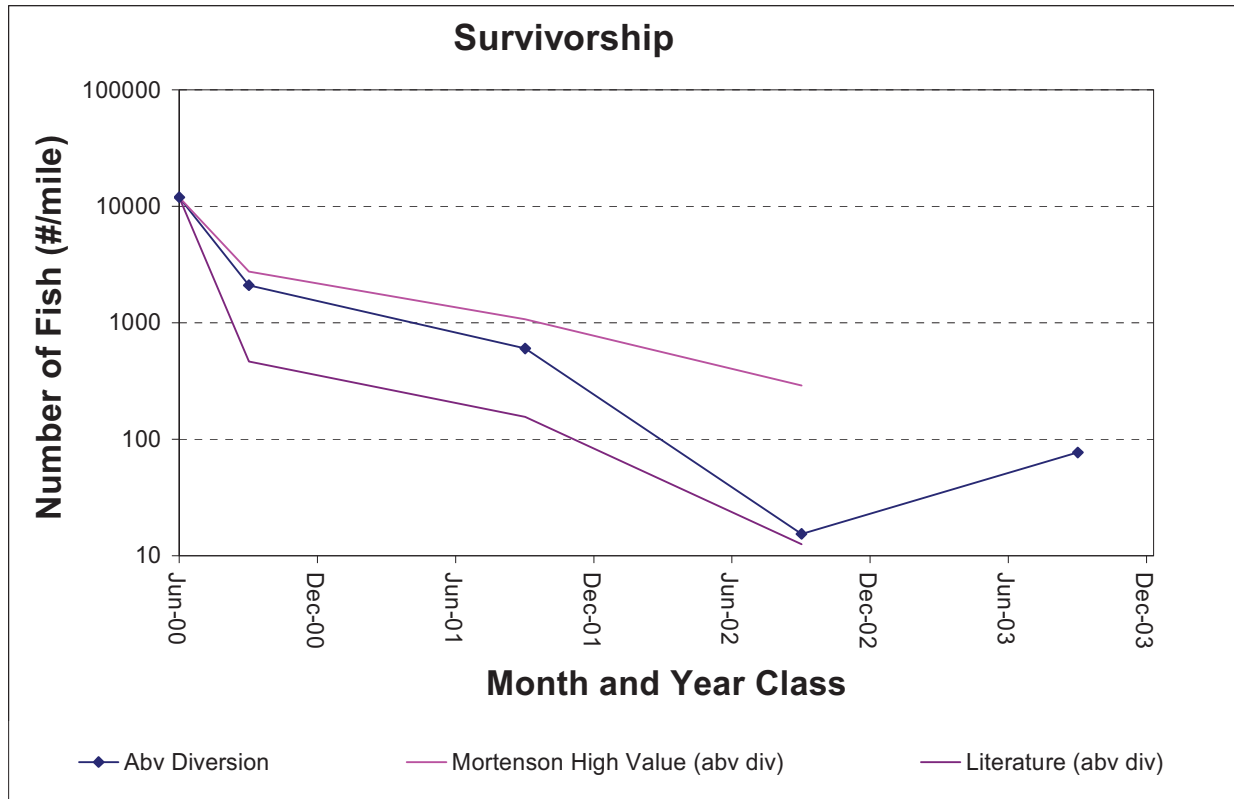


Figure AQ 7-11. Estimated Survivorship per Redd for Fish Populations Above and Below the North Fork Long Canyon Creek Diversion.

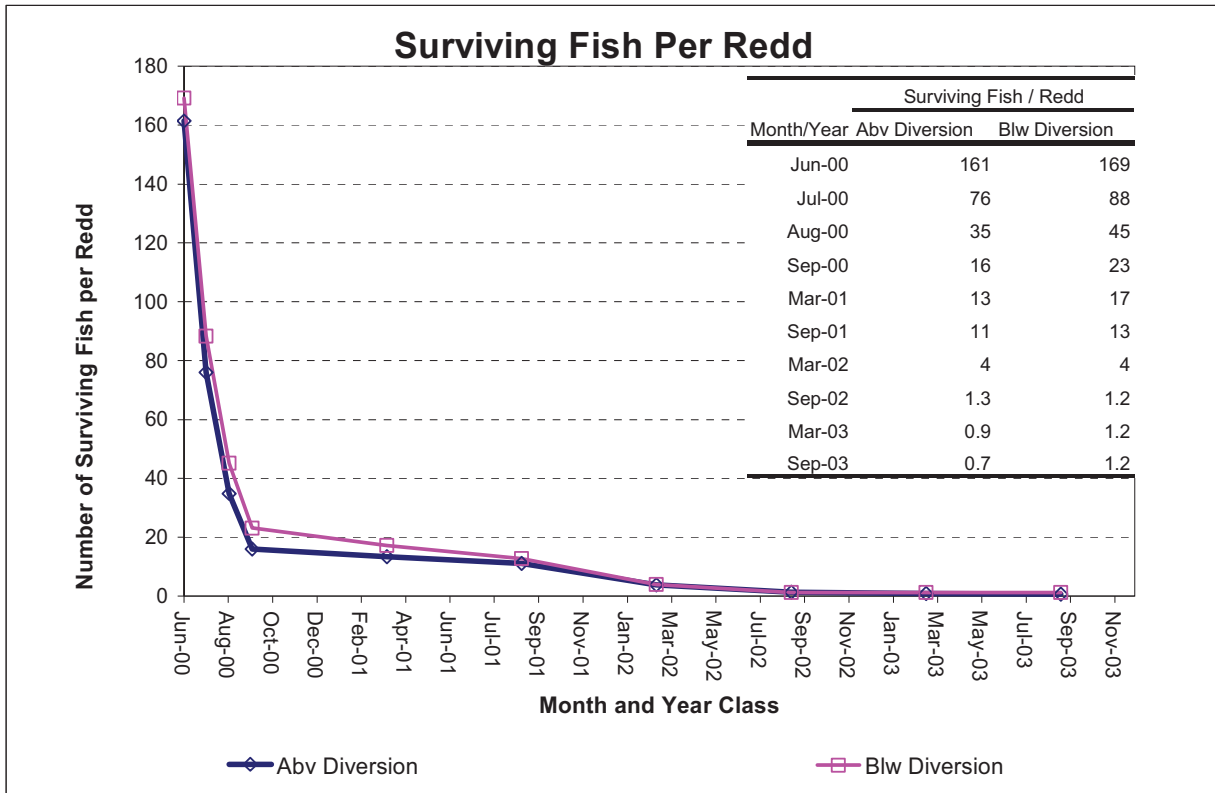


Figure AQ 7-12. Estimated Survivorship per Redd for Fish Populations Above and Below the South Fork Long Canyon Creek Diversion.

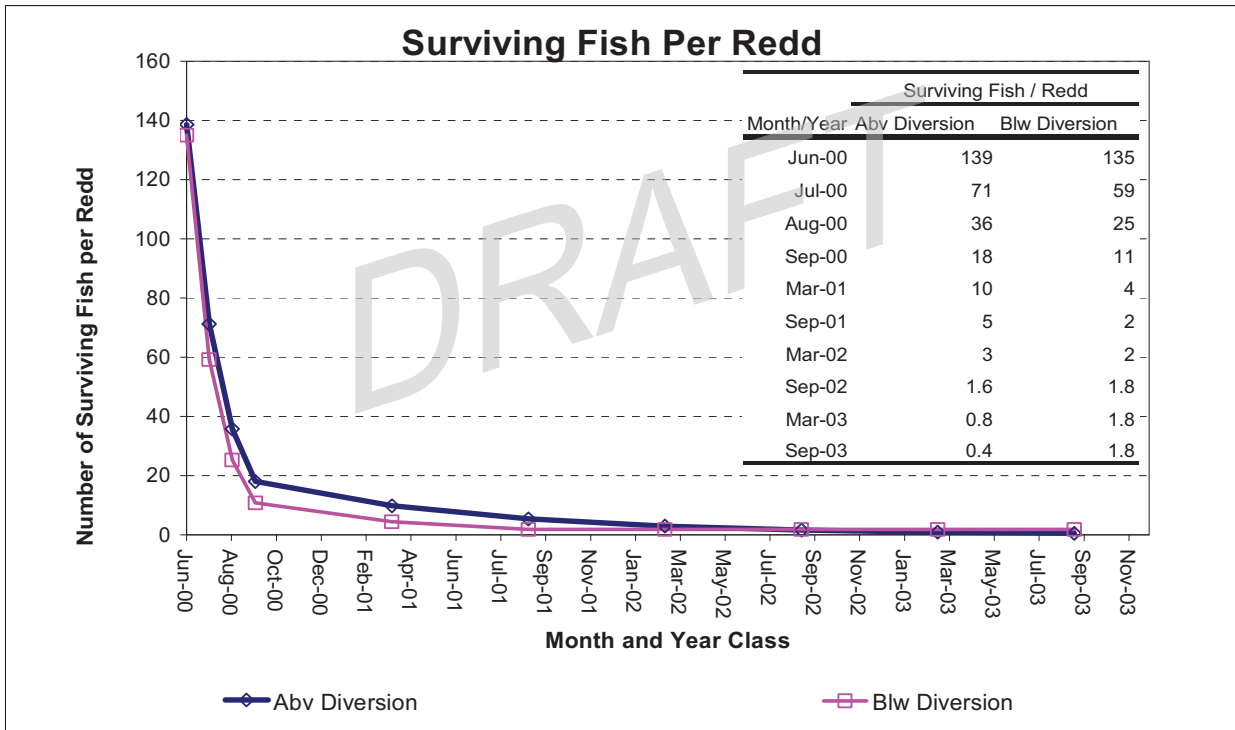


Figure AQ 7-13. Estimated Survivorship per Redd for Fish Populations Above and Below the Duncan Creek Diversion.

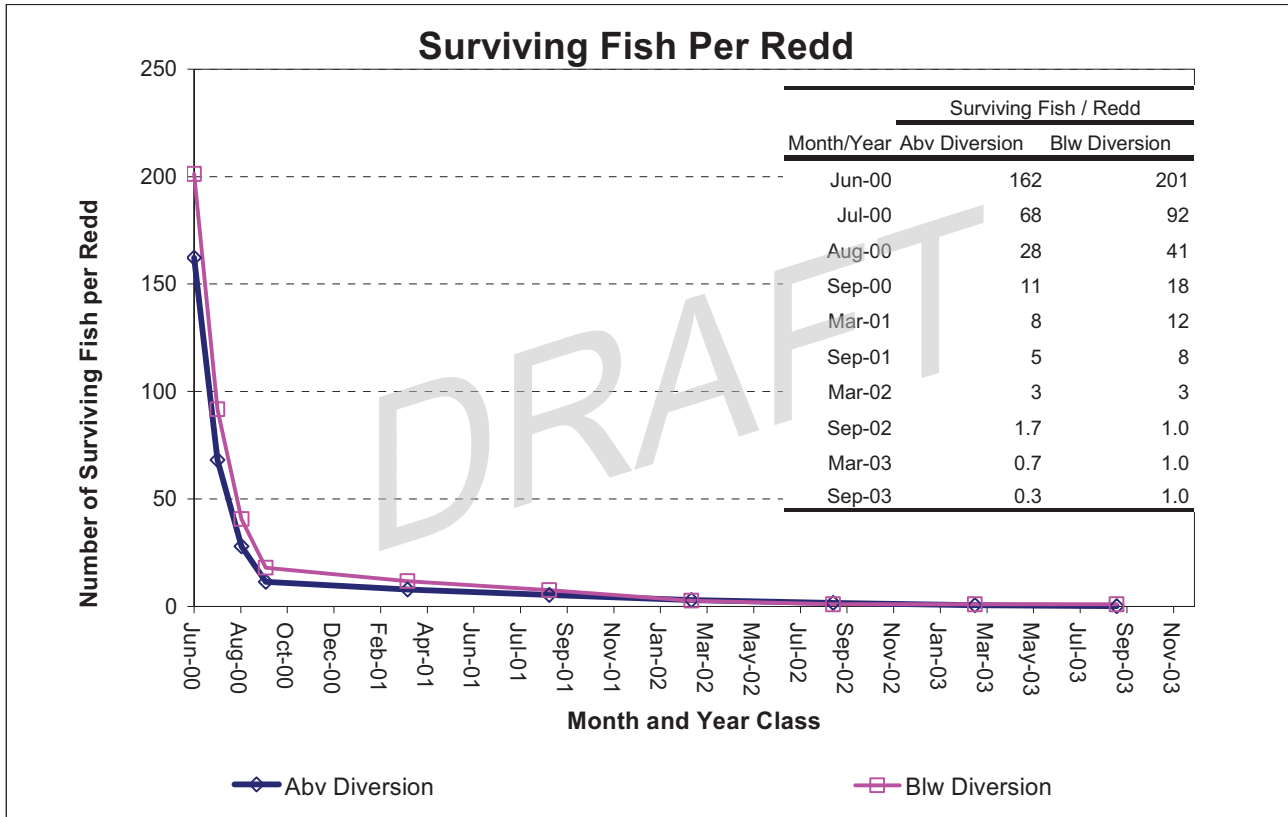
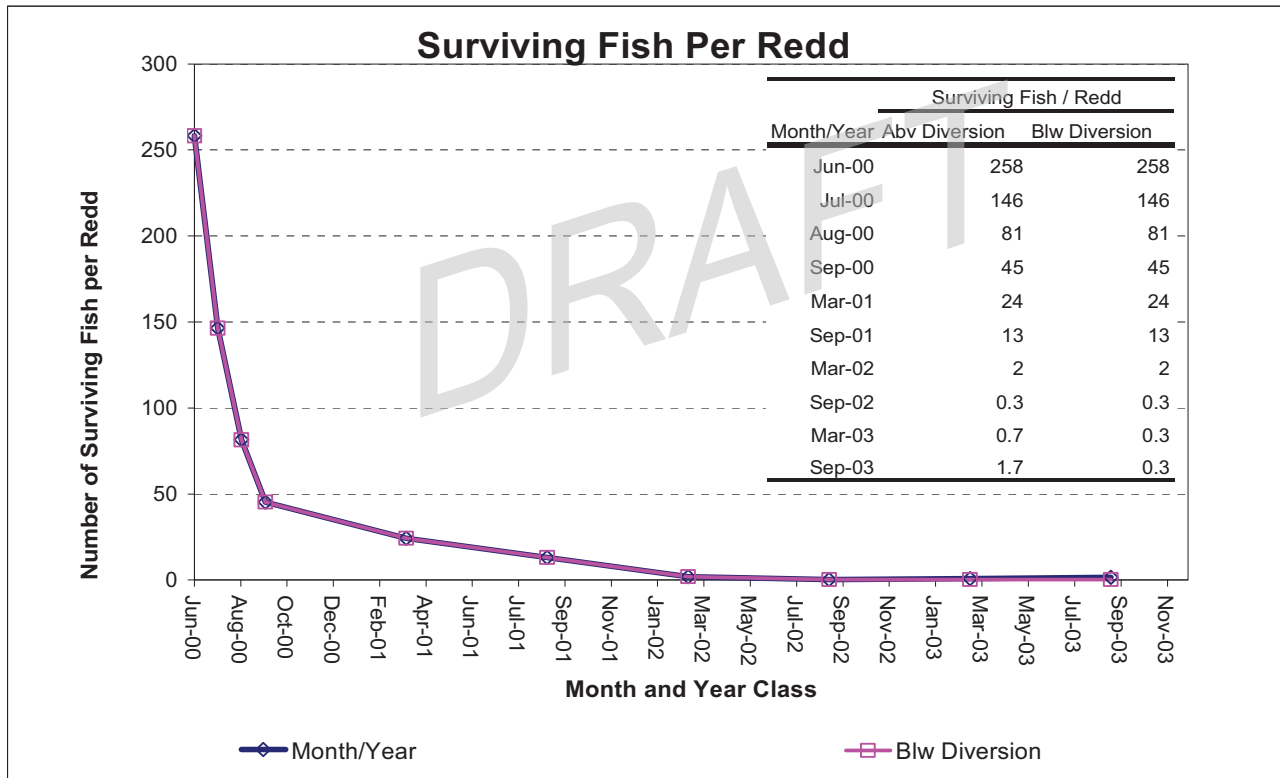


Figure AQ 7-14. Estimated Survivorship per Redd for Fish Populations Above and Below Middle Fork Interbay



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**MAPS**

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**APPENDIX A**  
**Diversion Photographs**

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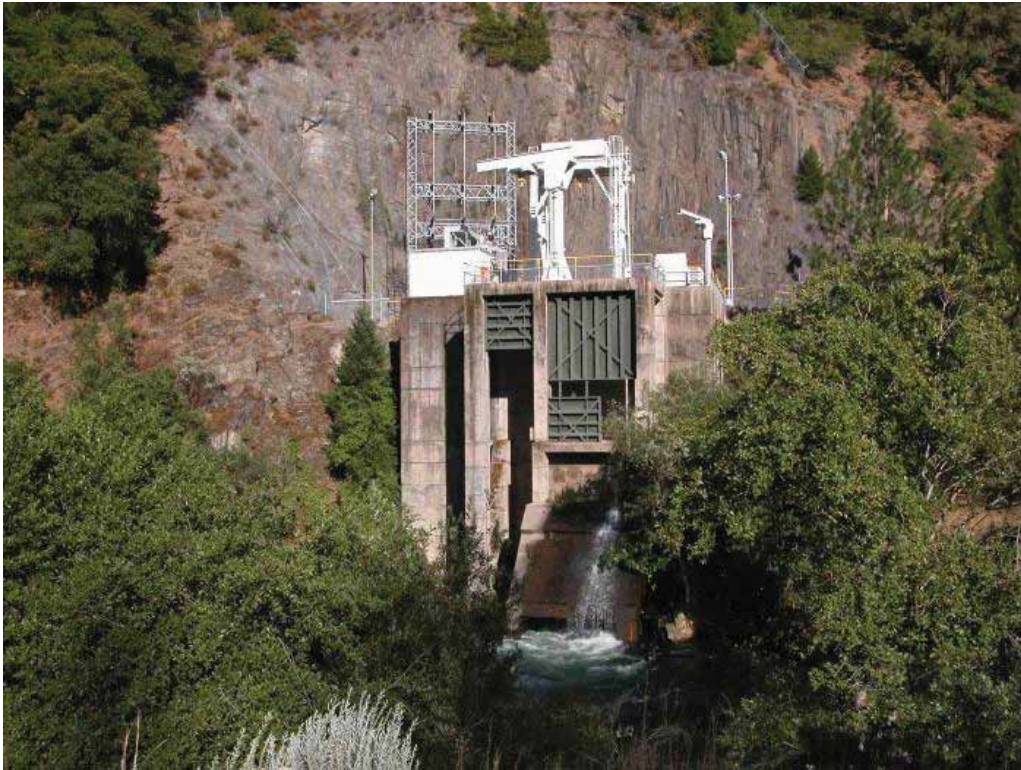
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## Ralston Afterbay

### Oxbow Powerhouse Photograph



Oxbow Powerhouse

## Ralston Afterbay

### Ralston Afterbay Dam Photographs



Ralston Afterbay Dam



Ralston Afterbay Dam - Downstream

## Ralston Afterbay

### Ralston - Oxbow Tunnel Inlet Structure Photograph



Ralston-Oxbow Tunnel Inlet Structure

## Ralston Afterbay

### Ralston Powerhouse Photographs



Ralston Powerhouse



Ralston Powerhouse with Low Water Level

**Middle Fork Interbay**

**Middle Fork - Ralston Tunnel Inlet Structure Photograph**



Middle Fork - Ralston Tunnel Inlet Structure

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## Middle Fork Interbay

### Interbay Low Level Outlet Photograph



Interbay Low Level Outlet

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Middle Fork Interbay

Middle Fork Interbay Dam Photographs



Middle Fork Interbay Dam



Middle Fork Interbay Dam - Instream Flow Pipes



Interbay Dam Low Level Discharge



Instream Flow Pipes

## Middle Fork Interbay

### Middle Fork Powerhouse Photograph



Middle Fork Powerhouse



Middle Fork Interbay below Powerhouse

## French Meadows Reservoir

### French Meadows Dam Outlet Works Photographs



French Meadows Outlet Works



French Meadows Outlet Works - Instream Flow Pipe and Low Level Outlet

## French Meadows Reservoir

### French Meadows - Hell Hole Tunnel Intake Photograph



French Meadows - Hell Hole Tunnel Inlet Gatehouse

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## Hell Hole Reservoir

### French Meadows Powerhouse Photograph



French Meadows Powerhouse



French Meadows Powerhouse

## Hell Hole Reservoir

### Hell Hole Dam Outlet Works Photographs



Dam Outlet Works



Dam Low Level Discharge Ring Jet Valve

## Hell Hole Reservoir

### Hell Hole - Middle Fork Tunnel Intake Photograph



Hell Hole - Middle Fork Tunnel Intake Gatehouse

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## North Fork Long Canyon

### North Fork Long Canyon Diversion Dam Photographs



North Fork Long Canyon Diversion - Downstream Side



North Fork Long Canyon Diversion - Instream Flow Pipe

## South Fork Long Canyon

### South Fork Long Canyon Diversion Dam Photographs



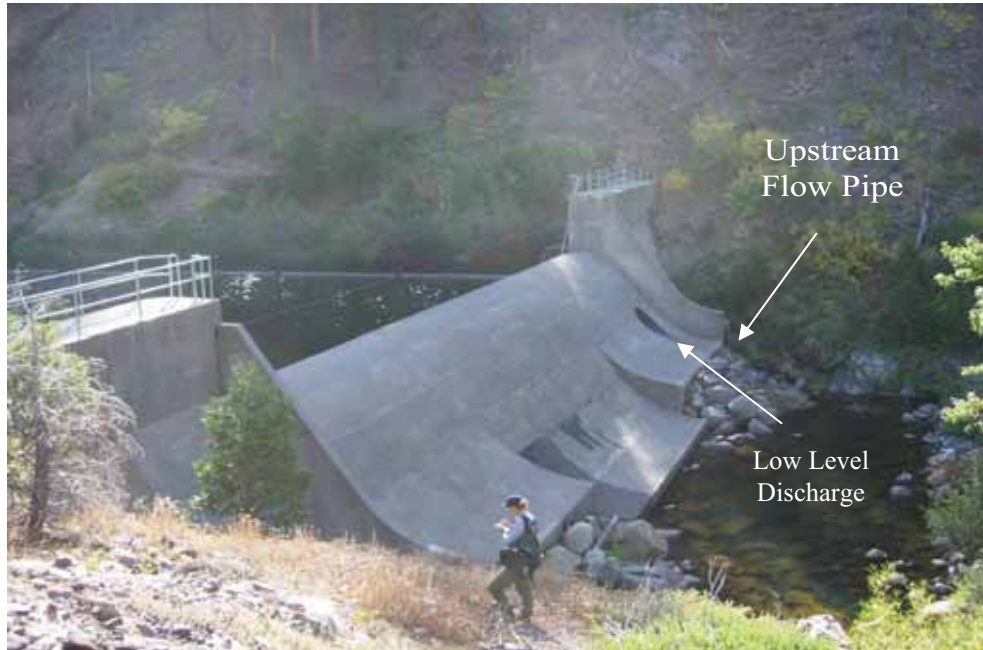
South Fork Long Canyon Diversion Dam



South Fork Long Canyon Diversion Dam - Downstream Side

## Duncan Creek

### Duncan Creek Diversion Dam Photographs



Duncan Creek Diversion Dam - Downstream Side



Inlet to Upstream Flow Pipe

## Duncan Creek

### Duncan Creek - Middle Fork Intake and Trash Rack Photograph



Duncan Creek - Middle Fork Tunnel Intake

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**APPENDIX B**

**Water Diversion Flows and Diagrams**

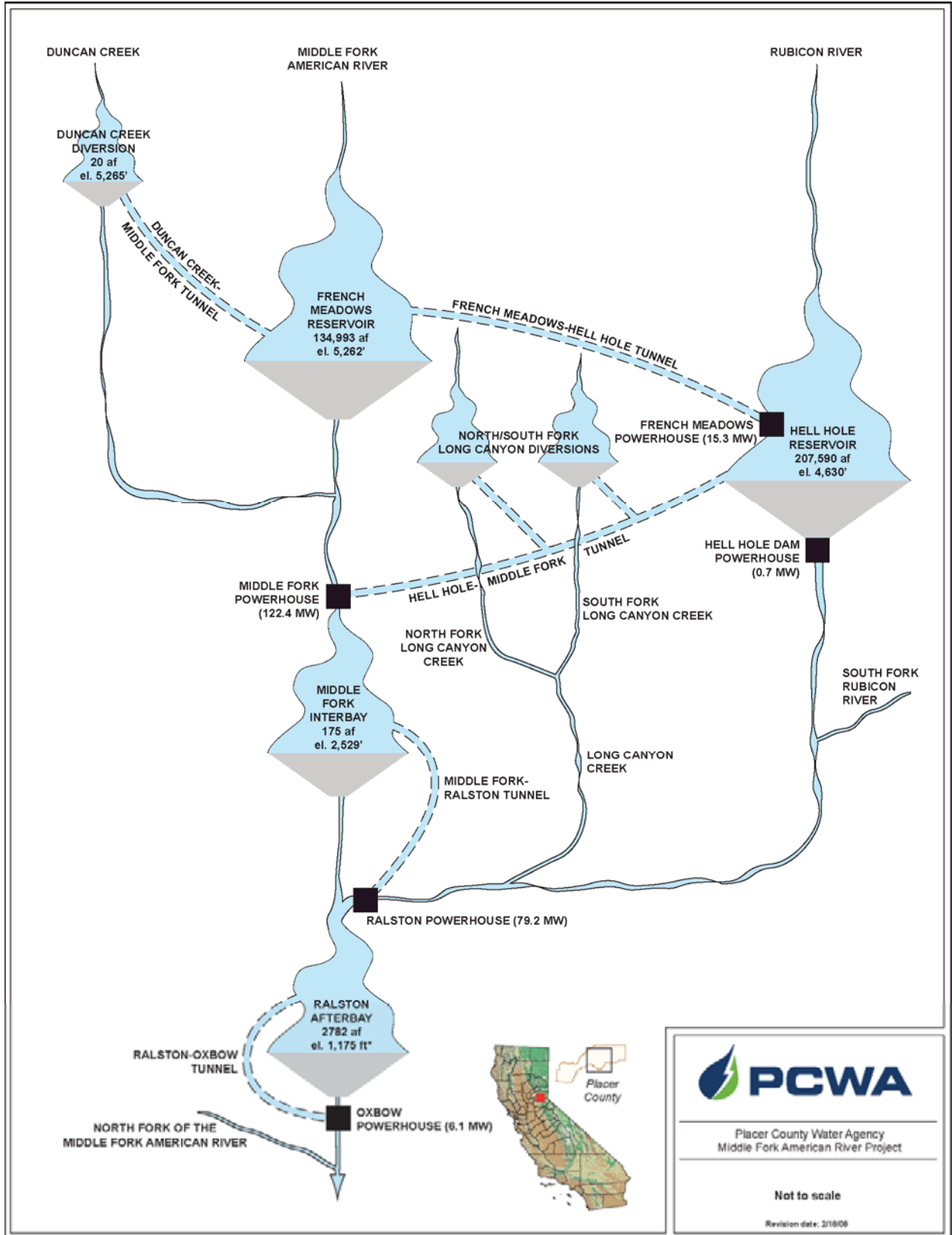
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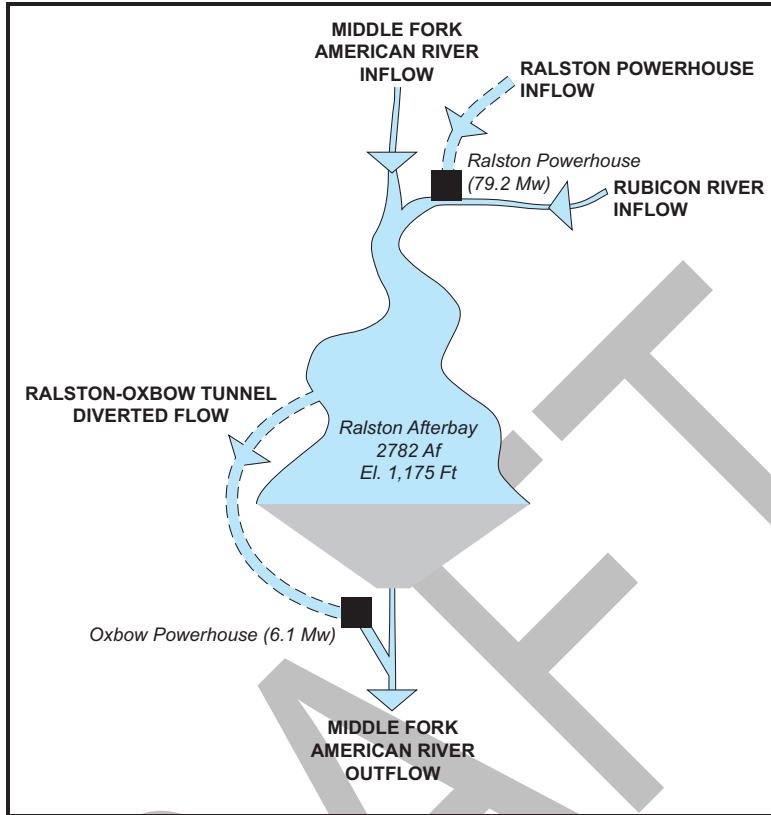
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### Middle Fork American Project Water Inflow-Outflow Diagram.



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Ralston Afterbay



Ralston Afterbay Water Budget.

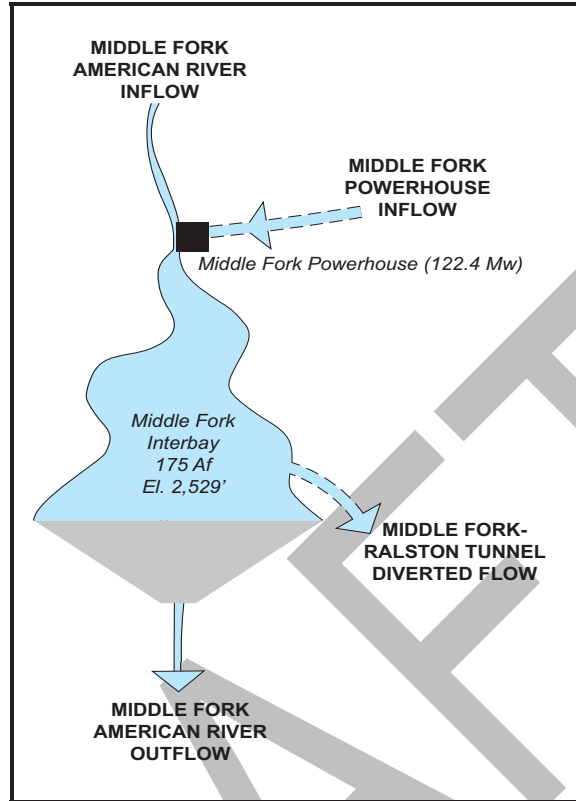
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Rubicon River Inflow</b>					
Oct	83	75	64	41	29
Nov	175	100	69	49	44
Dec	481	181	84	56	48
Jan	1102	588	159	65	49
Feb	1287	767	274	107	84
Mar	1358	918	424	185	129
Apr	1051	772	389	150	103
May	1041	630	198	100	82
Jun	600	225	126	63	52
Jul	151	113	76	44	33
Aug	93	78	56	38	26
Sep	83	73	52	37	26
<b>Middle Fork Amercian River Inflow</b>					
Oct	62	47	31	22	19
Nov	101	64	41	30	20
Dec	213	104	46	31	21
Jan	396	202	60	40	27
Feb	578	224	89	46	38
Mar	572	277	115	62	43
Apr	386	242	108	58	46
May	403	159	62	43	33
Jun	304	99	50	36	29
Jul	77	55	38	28	21
Aug	47	38	32	20	17
Sep	45	36	30	20	16

**Ralston Afterbay**

**Ralston Afterbay Water Budget (continued).**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Ralston Powerhouse Inflow</b>					
Oct	797	602	88	0	0
Nov	768	602	434	29	0
Dec	908	679	272	18	0
Jan	906	637	261	21	0
Feb	911	891	443	34	9
Mar	914	909	586	57	38
Apr	918	911	452	46	25
May	915	911	586	27	12
Jun	914	909	583	232	18
Jul	908	843	597	331	40
Aug	909	850	615	400	174
Sep	868	703	502	88	0
<b>Middle Fork American River Outflow</b>					
Oct	139	109	74	-1	-33
Nov	178	110	48	-14	-51
Dec	472	170	58	-9	-53
Jan	1184	597	86	19	-28
Feb	1636	860	132	33	-19
Mar	1731	1152	255	55	-32
Apr	1269	843	178	59	3
May	1419	562	139	53	13
Jun	950	253	81	-1	-31
Jul	166	114	34	-18	-40
Aug	93	68	19	-25	-48
Sep	102	87	16	-33	-55
<b>Ralston - Oxbow Tunnel Diverted Flow</b>					
Oct	861	730	0	0	0
Nov	910	758	544	51	0
Dec	958	877	459	77	17
Jan	971	942	570	103	34
Feb	978	968	834	197	85
Mar	981	969	907	309	196
Apr	983	975	841	188	102
May	984	971	843	120	60
Jun	976	961	724	351	76
Jul	950	914	708	428	69
Aug	939	907	730	462	197
Sep	914	808	604	154	0
<b>Percent Diverted</b>					
Oct	107	100	0	0	0
Nov	108	102	85	25	0
Dec	101	93	74	29	6
Jan	96	86	59	32	12
Feb	90	82	55	31	18
Mar	80	71	47	31	23
Apr	63	56	39	24	14
May	55	48	35	21	15
Jun	98	88	62	30	21
Jul	108	102	92	68	26
Aug	109	105	97	90	76
Sep	111	107	99	72	0

### Middle Fork Interbay



Middle Fork Interbay Water Budget.

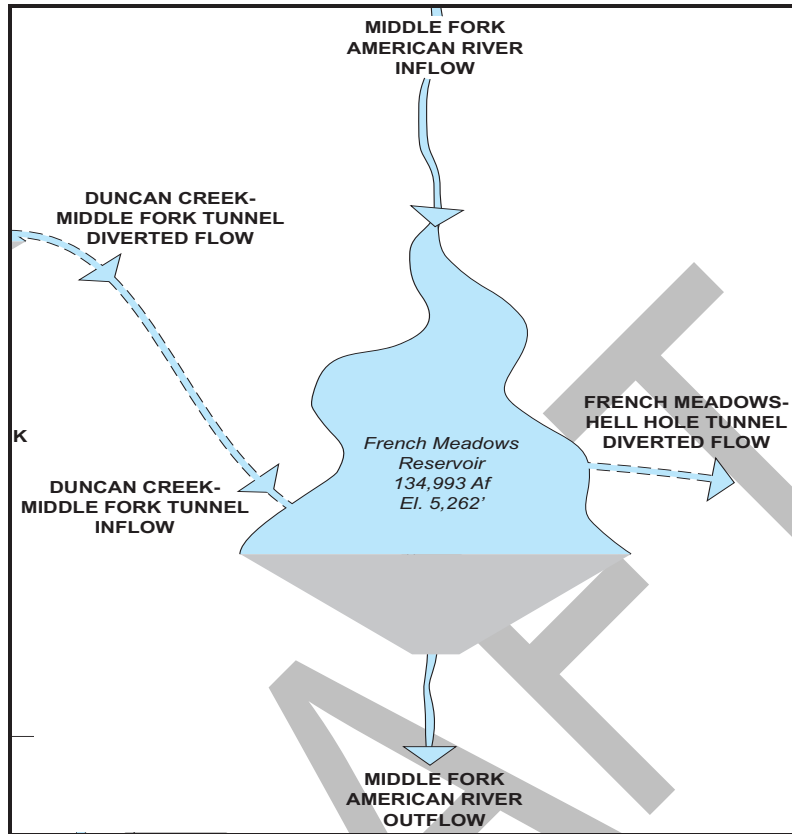
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Middle Fork American River Inflow</b>					
Oct	25	21	17	13	10
Nov	62	37	19	16	14
Dec	160	69	31	20	17
Jan	248	158	55	22	19
Feb	278	179	89	37	25
Mar	328	228	123	74	58
Apr	241	196	122	66	50
May	372	224	76	41	32
Jun	222	76	42	22	18
Jul	46	37	25	16	12
Aug	26	23	18	13	10
Sep	21	19	16	12	10
<b>Middle Fork Powerhouse Inflow</b>					
Oct	800	673	133	0	0
Nov	800	719	517	196	12
Dec	920	781	478	223	67
Jan	920	595	114	0	0
Feb	920	769	203	0	0
Mar	936	920	234	0	0
Apr	940	927	333	0	0
May	940	940	541	0	0
Jun	925	920	414	85	35
Jul	920	830	565	218	67
Aug	800	726	565	295	119
Sep	740	628	246	39	0

**Middle Fork Interbay**

**Middle Fork Interbay Water Budget. (continued)**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Middle Fork American River Outflow</b>					
Oct	23	23	19	14	11
Nov	23	23	21	16	12
Dec	23	23	23	19	12
Jan	23	23	23	20	12
Feb	23	23	23	23	12
Mar	23	23	23	23	12
Apr	23	23	23	23	12
May	23	23	23	23	12
Jun	23	23	23	22	12
Jul	23	23	23	17	12
Aug	23	23	20	13	11
Sep	23	21	18	13	10
<b>Middle Fork - Ralston Tunnel Diverted Flow</b>					
Oct	800	674	133	0	0
Nov	803	739	532	209	32
Dec	924	814	497	238	75
Jan	924	781	180	10	1
Feb	924	879	286	31	15
Mar	924	924	461	71	47
Apr	924	924	498	55	37
May	924	924	657	24	16
Jun	924	924	443	105	67
Jul	924	841	571	223	69
Aug	800	726	566	295	119
Sep	741	628	247	39	0
<b>Percent Diverted</b>					
Oct	98%	98%	91%	0%	0%
Nov	98%	98%	97%	93%	61%
Dec	99%	98%	96%	90%	72%
Jan	102%	99%	88%	32%	6%
Feb	103%	101%	91%	63%	41%
Mar	105%	101%	91%	78%	72%
Apr	103%	101%	88%	77%	69%
May	98%	95%	81%	57%	46%
Jun	97%	97%	93%	82%	72%
Jul	98%	98%	96%	91%	83%
Aug	98%	98%	97%	95%	90%
Sep	98%	97%	94%	78%	0%

**French Meadows Reservoir**



**French Meadows Water Budget.**

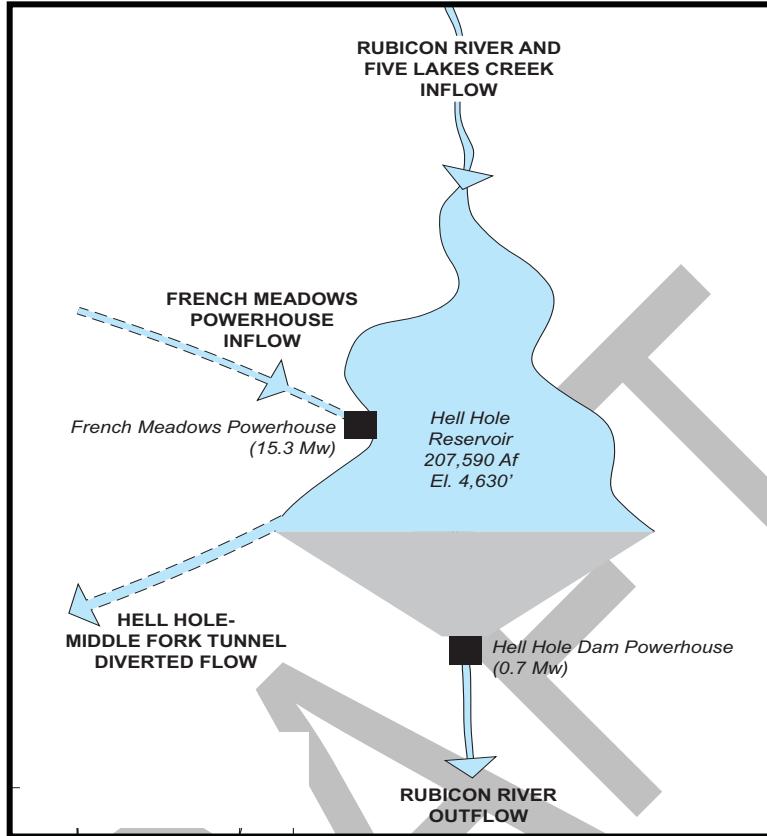
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Middle Fork American River Inflow</b>					
Oct	24	14	6	2	1
Nov	119	55	14	5	4
Dec	209	84	28	12	9
Jan	313	170	52	20	14
Feb	323	205	102	30	21
Mar	498	310	169	97	67
Apr	621	486	283	170	122
May	894	719	396	175	104
Jun	774	492	133	42	24
Jul	179	89	33	15	10
Aug	44	27	13	6	3
Sep	23	15	6	3	2
<b>Duncan Creek - French Meadows Tunnel Inflow</b>					
Oct	0	0	0	0	0
Nov	20	4	0	0	0
Dec	40	11	0	0	0
Jan	51	24	2	0	0
Feb	50	31	9	0	0
Mar	86	55	24	8	3
Apr	128	100	52	24	15
May	193	151	80	26	12
Jun	157	90	8	0	0
Jul	12	1	0	0	0
Aug	0	0	0	0	0
Sep	0	0	0	0	0

**French Meadows Reservoir**

**French Meadows Water Budget (continued).**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Middle Fork American River Outflow</b>					
Oct	10	10	9	7	5
Nov	12	10	9	7	6
Dec	14	11	10	7	6
Jan	17	13	10	9	6
Feb	16	13	10	8	6
Mar	18	15	11	9	8
Apr	16	14	11	9	8
May	23	14	10	8	7
Jun	14	11	10	7	5
Jul	11	10	9	7	5
Aug	10	10	9	7	5
Sep	10	10	9	8	5
<b>French Meadows-Hell Hole Tunnel Diverted Flow</b>					
Oct	353	334	237	0	0
Nov	343	327	0	0	0
Dec	352	241	0	0	0
Jan	334	239	0	0	0
Feb	352	335	58	0	0
Mar	362	345	92	0	0
Apr	360	326	0	0	0
May	359	326	0	0	0
Jun	365	325	197	0	0
Jul	342	325	262	146	0
Aug	341	326	269	173	0
Sep	341	322	224	0	0
<b>Percent Diverted</b>					
Oct	6732	4890	1865	0	0
Nov	3903	1611	0	0	0
Dec	707	243	0	0	0
Jan	284	140	0	0	0
Feb	317	208	17	0	0
Mar	225	146	28	0	0
Apr	110	69	0	0	0
May	68	40	0	0	0
Jun	470	245	49	0	0
Jul	2193	1244	535	106	0
Aug	7553	3809	1400	598	0
Sep	9049	6349	2154	0	0

### Hell Hole Reservoir



Hell Hole Reservoir Water Budget.

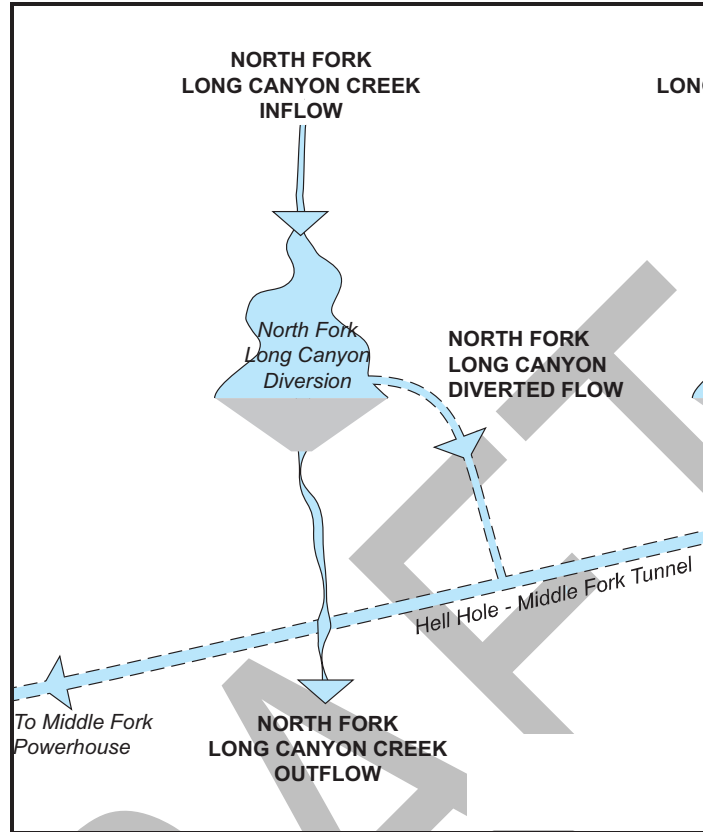
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Rubicon River and Five Lakes Creek Inflow</b>					
Oct	21	8	2	1	0
Nov	109	22	8	7	0
Dec	166	60	21	12	0
Jan	293	102	30	18	0
Feb	325	166	56	42	0
Mar	494	265	168	125	0
Apr	769	458	289	202	0
May	1199	697	311	189	0
Jun	856	214	58	32	0
Jul	111	32	9	2	0
Aug	36	16	5	3	0
Sep	20	8	4	2	0
<b>French Meadows Powerhouse Inflow</b>					
Oct	353	334	237	0	0
Nov	343	327	0	0	0
Dec	352	241	0	0	0
Jan	334	239	0	0	0
Feb	352	335	58	0	0
Mar	362	345	92	0	0
Apr	360	326	0	0	0
May	359	326	0	0	0
Jun	365	325	197	0	0
Jul	342	325	262	146	0
Aug	341	326	269	173	0
Sep	341	322	224	0	0

**Hell Hole Reservoir**

**Hell Hole Reservoir Water Budget (continued).**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>Rubicon River Outflow</b>					
Oct	43	29	22	10	8
Nov	24	23	22	14	8
Dec	23	22	15	12	8
Jan	26	17	13	12	11
Feb	25	20	14	12	11
Mar	24	21	15	12	11
Apr	25	21	15	13	12
May	38	24	21	14	12
Jun	138	24	22	19	12
Jul	23	23	22	17	11
Aug	23	23	21	11	9
Sep	30	23	22	11	9
<b>Hell Hole - Middle Fork Tunnel Diverted Flow</b>					
Oct	806	583	73	0	0
Nov	688	584	384	6	0
Dec	817	629	241	0	0
Jan	776	473	159	0	0
Feb	826	734	313	0	0
Mar	898	796	339	-13	-24
Apr	887	771	219	-17	-34
May	914	852	335	-3	-10
Jun	917	861	555	211	0
Jul	896	845	570	308	26
Aug	911	861	617	368	169
Sep	883	711	487	139	0
<b>Percent Diverted</b>					
Oct	668	253	55	0	0
Nov	3899	1397	173	4	0
Dec	1724	952	132	0	0
Jan	766	309	106	0	0
Feb	269	190	95	0	0
Mar	177	146	62	-6	-9
Apr	134	100	36	-4	-8
May	107	77	35	-1	-3
Jun	337	191	101	34	0
Jul	392	278	183	106	33
Aug	419	312	231	153	113
Sep	4477	438	216	88	0

North Fork Long Canyon



North Fork Long Canyon Diversion Water Budget.

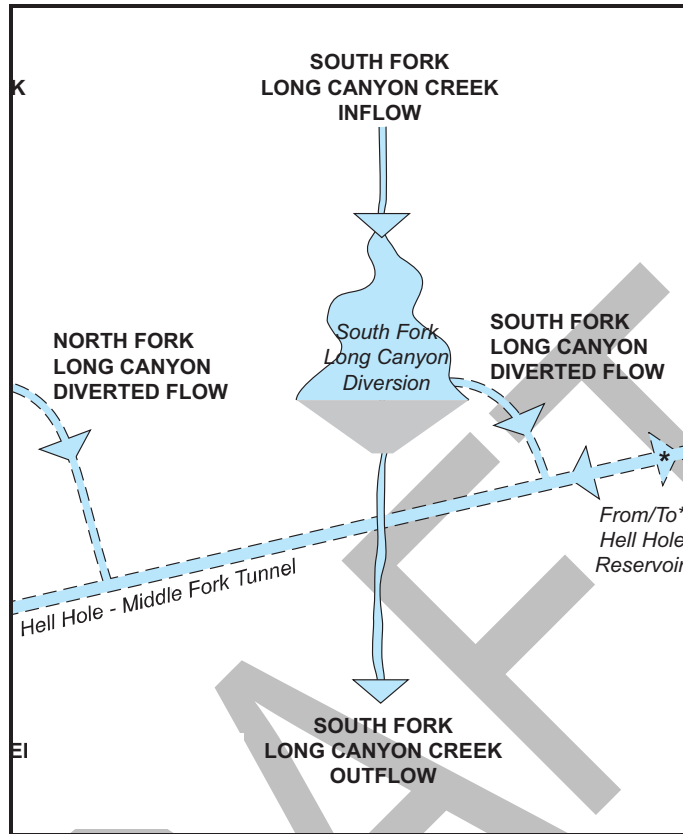
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>North Fork Long Canyon Creek Inflow</b>					
Oct	0.9	0.5	0.3	0.2	0.1
Nov	6.8	4.5	1.0	0.4	0.3
Dec	20.0	8.1	3.0	1.1	0.5
Jan	31.7	18.7	5.2	1.3	0.9
Feb	35.8	21.8	9.7	3.6	2.0
Mar	43.5	30.3	16.5	8.2	5.8
Apr	39.8	31.6	19.5	9.1	5.9
May	44.1	34.1	12.3	4.0	2.7
Jun	14.4	7.7	3.0	1.3	0.9
Jul	2.8	1.7	0.8	0.4	0.3
Aug	0.8	0.5	0.3	0.2	0.1
Sep	0.5	0.4	0.3	0.1	0.1
<b>North Fork Long Canyon Creek Outflow</b>					
Oct	0.9	0.5	0.3	0.2	0.1
Nov	5.9	3.3	1.0	0.4	0.3
Dec	11.1	5.5	2.3	1.1	0.5
Jan	15.2	8.1	2.9	1.3	0.9
Feb	15.9	5.9	3.3	2.0	2.0
Mar	22.9	9.9	3.7	2.6	2.0
Apr	13.8	6.0	3.4	2.0	2.0
May	20.7	5.0	3.3	2.0	2.0
Jun	7.4	4.5	2.5	1.3	0.9
Jul	2.8	1.7	0.8	0.4	0.3
Aug	0.8	0.5	0.3	0.2	0.1
Sep	0.5	0.4	0.3	0.1	0.1

**North Fork Long Canyon**

**North Fork Long Canyon Diversion Water Budget (continued).**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>North Fork Long Canyon Diverted Flow</b>					
Oct	0.0	0.0	0.0	0.0	0.0
Nov	0.1	0.0	0.0	0.0	0.0
Dec	3.8	0.4	0.0	0.0	0.0
Jan	18.0	9.5	0.0	0.0	0.0
Feb	21.0	13.0	2.5	0.0	0.0
Mar	31.0	22.0	8.5	0.0	0.0
Apr	33.0	26.0	12.0	1.5	0.0
May	33.0	22.0	4.1	0.0	0.0
Jun	5.9	0.7	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0
<b>Percent Diverted</b>					
Oct	0%	0%	0%	0%	0%
Nov	6%	0%	0%	0%	0%
Dec	51%	11%	0%	0%	0%
Jan	84%	71%	0%	0%	0%
Feb	87%	81%	40%	0%	0%
Mar	90%	86%	72%	0%	0%
Apr	92%	89%	77%	21%	0%
May	93%	88%	54%	0%	0%
Jun	68%	14%	0%	0%	0%
Jul	0%	0%	0%	0%	0%
Aug	0%	0%	0%	0%	0%
Sep	0%	0%	0%	0%	0%

South Fork Long Canyon



South Fork Long Canyon Diversion Water Budget.

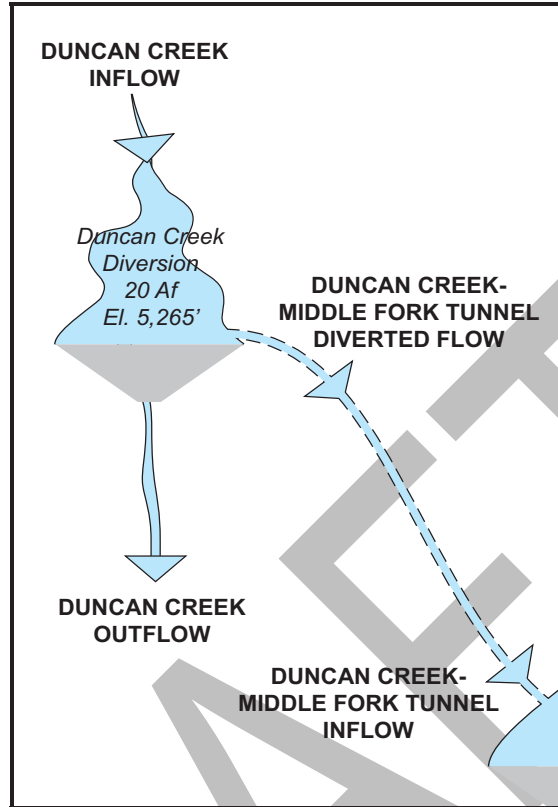
Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>South Fork Long Canyon Creek Inflow</b>					
Oct	1.5	1.0	0.6	0.3	0.3
Nov	15.7	7.8	1.7	0.7	0.6
Dec	37.2	13.7	4.8	1.8	0.9
Jan	56.3	32.2	8.9	2.3	1.6
Feb	66.8	40.6	18.5	6.3	3.5
Mar	79.2	55.6	29.1	14.4	11.1
Apr	72.5	59.0	36.0	17.9	13.7
May	81.0	61.4	31.0	11.2	7.2
Jun	34.0	20.0	6.3	2.5	1.6
Jul	6.0	2.8	1.4	0.8	0.6
Aug	1.4	0.9	0.6	0.3	0.2
Sep	0.8	0.7	0.5	0.2	0.1
<b>South Fork Long Canyon Creek Outflow</b>					
Oct	1.5	1.0	0.6	0.3	0.3
Nov	9.3	5.2	1.7	0.7	0.6
Dec	16.8	8.3	4.2	1.8	0.9
Jan	20.6	7.8	5.0	2.3	1.6
Feb	23.0	7.8	6.0	3.9	2.8
Mar	40.7	14.2	6.3	5.0	4.0
Apr	20.3	6.7	6.0	5.0	3.9
May	34.9	6.5	5.8	5.0	2.9
Jun	8.5	6.1	5.0	2.5	1.6
Jul	5.0	2.8	1.4	0.8	0.6
Aug	1.4	0.9	0.6	0.3	0.2
Sep	0.8	0.7	0.5	0.2	0.1

**South Fork Long Canyon**

**South Fork Long Canyon Diversion Water Budget (continued).**

Month	Exceedances				
	10 %	20%	50%	80%	90%
<b>South Fork Long Canyon Diverted Flow</b>					
Oct	0.0	0.0	0.0	0.0	0.0
Nov	0.8	0.0	0.0	0.0	0.0
Dec	9.7	1.6	0.0	0.0	0.0
Jan	34.0	20.0	0.0	0.0	0.0
Feb	38.0	24.0	5.0	0.0	0.0
Mar	61.0	40.0	15.0	0.6	0.0
Apr	63.0	49.0	24.0	5.0	0.0
May	60.0	50.0	15.0	1.6	0.0
Jun	24.0	11.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0
<b>Percent Diverted</b>					
Oct	0%	0%	0%	0%	0%
Nov	21%	0%	0%	0%	0%
Dec	58%	27%	0%	0%	0%
Jan	86%	76%	0%	0%	0%
Feb	88%	81%	51%	0%	0%
Mar	91%	86%	67%	10%	0%
Apr	93%	90%	81%	50%	0%
May	92%	89%	74%	22%	0%
Jun	80%	67%	0%	0%	0%
Jul	0%	0%	0%	0%	0%
Aug	0%	0%	0%	0%	0%
Sep	0%	0%	0%	0%	0%

Duncan Creek



Duncan Creek Diversion Water Budget.

Month	Exceedances				
	10 %	20 %	50 %	80 %	90 %
<b>Duncan Creek Inflow</b>					
Oct	3.9	2.3	0.9	0.5	0.5
Nov	29.0	13.0	2.9	1.2	1.0
Dec	54.0	23.0	8.0	3.4	2.1
Jan	82.0	42.0	13.0	4.2	3.0
Feb	73.0	46.0	23.0	6.7	5.0
Mar	112.0	72.0	37.0	21.0	15.0
Apr	147.0	117.0	65.0	38.0	26.0
May	234.0	188.0	93.0	36.0	20.0
Jun	201.0	114.0	18.0	5.3	3.2
Jul	20.0	8.5	2.8	1.2	0.9
Aug	3.2	2.1	1.0	0.5	0.4
Sep	2.1	1.4	0.8	0.4	0.4
<b>Duncan Creek Outflow</b>					
Oct	3.3	2.2	0.9	0.5	0.4
Nov	12.0	7.3	2.5	1.1	1.0
Dec	15.0	13.0	6.5	2.9	1.8
Jan	20.0	15.0	10.0	4.1	2.7
Feb	21.0	15.0	11.0	5.5	4.7
Mar	21.0	17.0	13.0	10.0	9.0
Apr	19.0	16.0	12.0	9.0	7.0
May	42.0	18.0	11.0	8.2	5.4
Jun	16.0	12.0	8.7	4.4	3.1
Jul	9.6	6.8	2.7	1.2	0.8
Aug	2.8	1.9	1.0	0.5	0.4
Sep	2.0	1.3	0.8	0.4	0.3

**Duncan Creek**

**Duncan Creek Diversion Water Budget (continued).**

Month	Exceedances				
	10	20	50	80	90
<b>Duncan Creek - Middle Fork Tunnel Diverted Flow</b>					
Oct	0.2	0.0	0.0	0.0	0.0
Nov	19.7	4.0	0.1	0.0	0.0
Dec	40.0	11.0	0.2	0.0	0.0
Jan	51.0	24.1	2.0	0.0	0.0
Feb	50.0	31.0	9.0	0.0	0.0
Mar	86.0	55.0	24.0	8.0	3.1
Apr	128.0	100.0	51.6	24.4	14.5
May	193.0	151.0	80.0	25.7	11.5
Jun	157.0	90.0	8.1	0.0	0.0
Jul	12.0	0.6	0.0	0.0	0.0
Aug	0.2	0.1	0.0	0.0	0.0
Sep	0.1	0.0	0.0	0.0	0.0
<b>Percent Diverted</b>					
Oct	13%	3%	0%	0%	0%
Nov	71%	42%	4%	0%	0%
Dec	73%	55%	7%	0%	0%
Jan	76%	65%	21%	0%	0%
Feb	78%	71%	41%	0%	0%
Mar	84%	78%	62%	37%	22%
Apr	91%	89%	82%	67%	57%
May	94%	92%	85%	65%	49%
Jun	91%	87%	46%	0%	0%
Jul	62%	13%	0%	0%	0%
Aug	17%	8%	0%	0%	0%
Sep	13%	6%	0%	0%	0%

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**APPENDIX C**

**Summary of Fish Screening Unit Costs (Dollars/ CFS)**

Appendix C. Summary of Fish Screening Unit Costs (Dollars/ CFS)

Project	Date	Maximum Diversion (cfs)	Design Criteria (approach velocity)	Screen Area	Design	Total Project Cost	2008 Cost with 3% Annual Inflation	2008 cost/cfs
<b>Flow Range 50-100 cfs</b>								
Coyote Canal Diversion	1999	50	0.33		Single flat plate	\$470,000	\$613,240	\$12,260
Anderson Cottonwood Irrigation District (Bonnyview Pumps)	1992	60			Cylindrical	\$330,000	\$529,550	\$8,830
Browns Valley ID	1999	65				\$298,287	\$389,200	\$5,990
Upper Toppenish	1987	72		144	Drum	\$264,720	\$492,460	\$6,840
Maxwell Irrigation District	1993	80	0.33		Cylindrical	\$794,000	\$1,237,000	\$15,460
Richland	1985	80		160	Drum	\$322,560	\$636,600	\$7,960
EBMUD Bixler Slough	1987	90			Cylindrical	\$50,000	\$93,015	\$1,030
Suisun Resource Conservation District	1997	93				\$900,000	\$1,245,800	\$13,400
<b>Average 2008 cost/cfs</b>								<b>\$8,339</b>

<b>Flow Range 100-500 cfs</b>								
Grizzly Island (CDFG)	1995	100	0.2		Cylindrical	\$300,000	\$440,560	\$4,410
Maxwell ID	1997	100				\$1,545,000	\$2,138,600	\$21,390
RD 999	2006	100				\$636,000	\$674,730	\$6,750
Adams Dam / Rancho Esquon Partners	1998	120	0.33	530	Single flat plate	\$558,700	\$750,850	\$6,260
Gorrill	1999	121.7	0.33		Single flat plate	\$1,515,955	\$1,978,000	\$16,250
Parrott-Phelan Irrigation Systems (M&T Ranch)	1997	150	0.33		Cylindrical	\$4,500,000	\$6,229,100	\$41,530
Dryden	1993	200		500	Single flat plate	\$2,394,000	\$3,729,800	\$18,650
Banton Carbona	2004	260				\$9,800,000	\$11,030,000	\$42,420
Reclamation District 104	1999	290				\$7,250,000	\$9,459,600	\$32,620
Potter Valley	1996	320	0.33	960	Inclined Plane	\$14,000,000	\$19,961,000	\$62,380
CCWD Rock Slough	1998	350			Single flat plate	\$6,600,000	\$8,869,800	\$25,340
Contra Costa Canal- Estimated	1992	350		1800	Single flat plate	\$3,000,000	\$4,814,100	\$13,750
Leaburg (a)	1983	470		675	Chevron	\$3,247,400	\$6,799,300	\$14,470
Jim Boyd	1987	500		345	Single flat plate	\$868,510	\$1,615,700	\$3,230
Wapatox	1993	500		1250	Single flat plate	\$3,150,000	\$4,907,600	\$9,820
<b>Average 2008 cost/cfs</b>								<b>\$21,285</b>

<b>Flow Range 500-1000 cfs</b>								
Princeton-Codora Glenn/ Prov ID	1999	605				\$10,957,887	\$14,298,000	\$23,630
Toppenish-Status	1986	650		1300	Drum	\$1,392,300	\$2,667,800	\$4,100
DWR Roaring River	1980	750			Single flat plate	\$1,500,000	\$3,431,900	\$4,580
RD 108 - Wilkins Slough	1998	800	0.33	2520	Single flat plate	\$11,600,000	\$15,589,000	\$19,490
Sutter Mutual	2007	960				\$21,500,000	\$22,145,000	\$23,070
Dalles North FERC	1991	1000		2000	Single flat plate	\$4,280,000	\$7,074,200	\$7,070
<b>Average 2008 cost/cfs</b>								<b>\$11,662</b>

<b>Flow Range 1000 &gt; cfs</b>								
Easton	1988	1170		2340	Drum	\$8,256,000	\$14,911,000	\$12,740
Sunnyside	1985	1300	0.4	2600	Drum	\$5,098,000	\$10,061,000	\$7,740
Chandler	1987	1500		3000	Drum	\$15,063,000	\$28,022,000	\$18,680
Wapato	1986	2000	0	4000		\$6,652,000	\$12,746,000	\$6,370
Roza	1988	2200		4600	Drum	\$19,860,000	\$35,869,000	\$16,300
Red Bluff	1990	3000	0.33	6000	Drum	\$17,202,000	\$29,285,000	\$9,760
<b>Average 2008 cost/cfs</b>								<b>\$11,932</b>

Source: NOAA Fisheries

Project	Date	Maximum Diversion (cfs)	Design Criteria (approach velocity)	Screen Area	Design	Total Project Cost	2008 Cost with 3% Annual Inflation	2008 cost/cfs
<b>Flow Range 50-100 cfs</b>								
Upper WIP	1997	55				\$506,715	\$701,410	\$12,750
Union Gap	1997	76				\$279,984	\$387,560	\$5,100
<b>Average 2008 cost/cfs</b>								<b>\$8,925</b>

<b>Flow Range 100-500 cfs</b>								
Westside	1988	114				\$599,982	\$1,083,600	\$9,510
New Cascade	1992	147				\$541,401	\$868,790	\$5,910
Toppenish Pump	1995	100				\$532,400	\$781,850	\$7,820
Naches-Selah	1996	137				\$695,275	\$991,300	\$7,240
Yakima-Tieton	1998	350				\$799,750	\$1,074,800	\$3,070
<b>Average 2008 cost/cfs</b>								<b>\$6,710</b>

<b>Flow Range 1000 &gt; cfs</b>								
Chandler	1987	1500				\$3,849,000	\$7,160,300	\$4,770
<b>Average 2008 cost/cfs</b>								<b>\$4,770</b>

Source: WDFW: Washington State Fish Screening Unit Costs

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**APPENDIX D**

**Plots of Monthly Entrainment Calculations**

Figure D-1. Duncan Creek

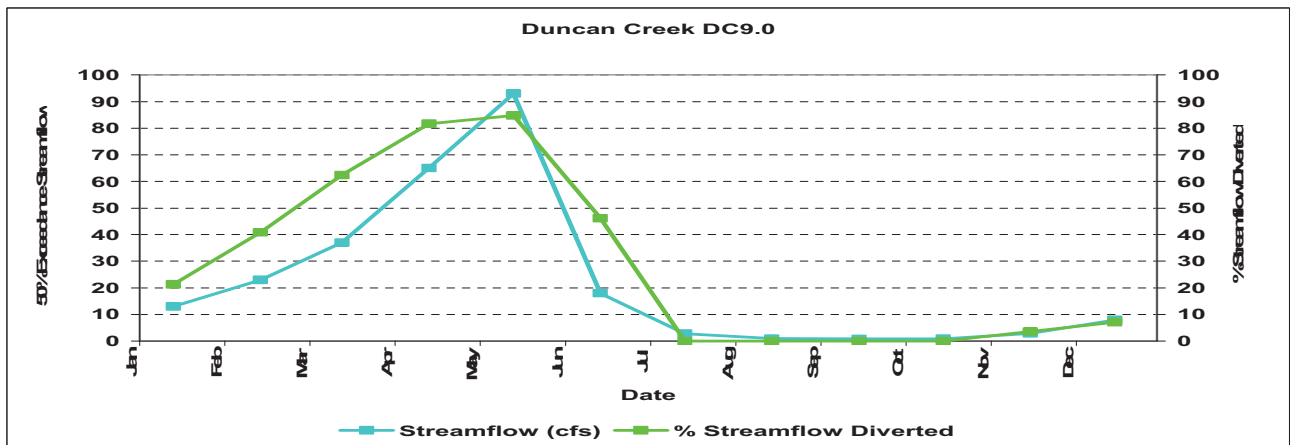
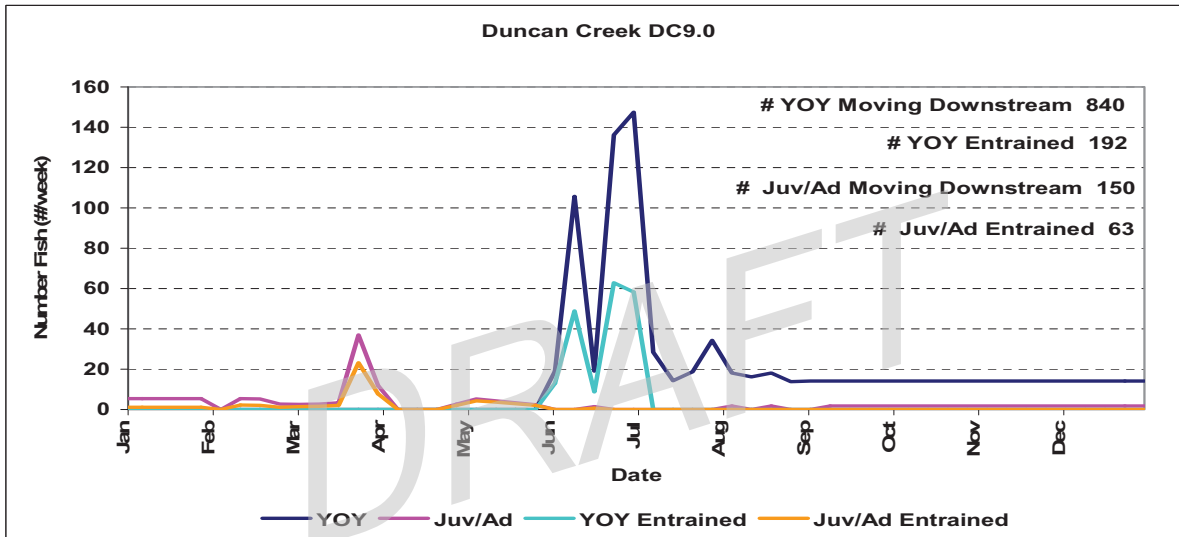


Figure D-2. North Fork Long Canyon Creek

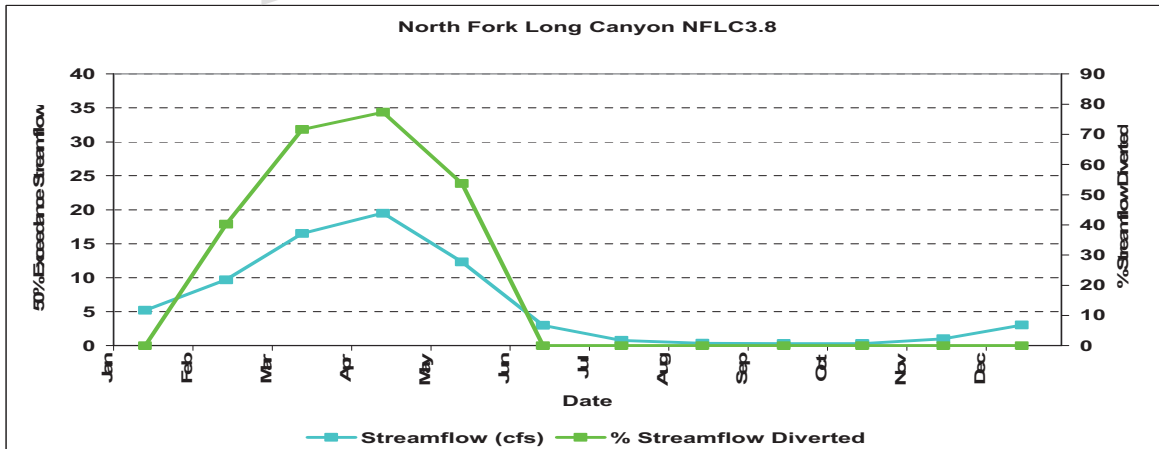
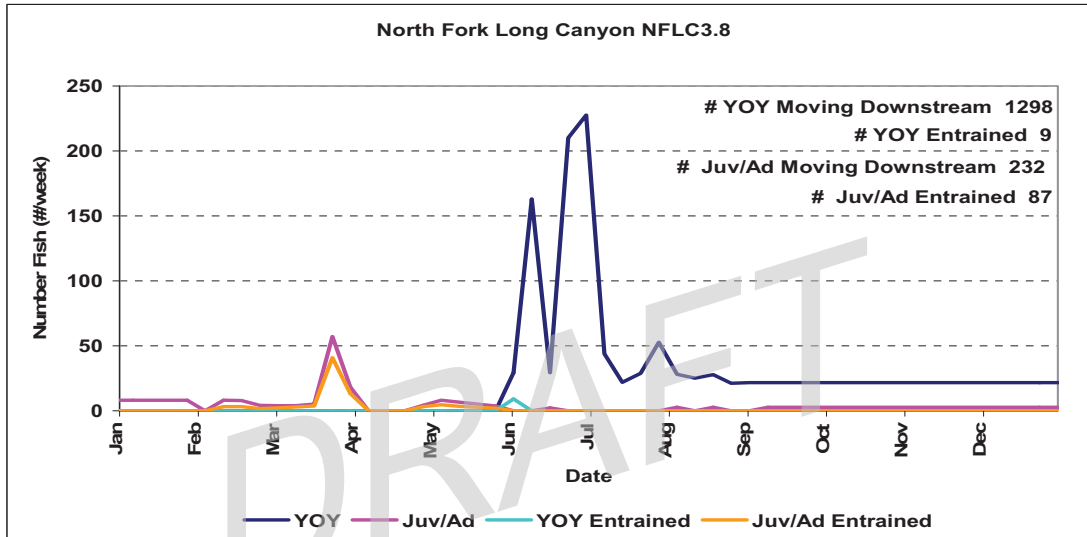


Figure D-3. South Fork Long Canyon Creek

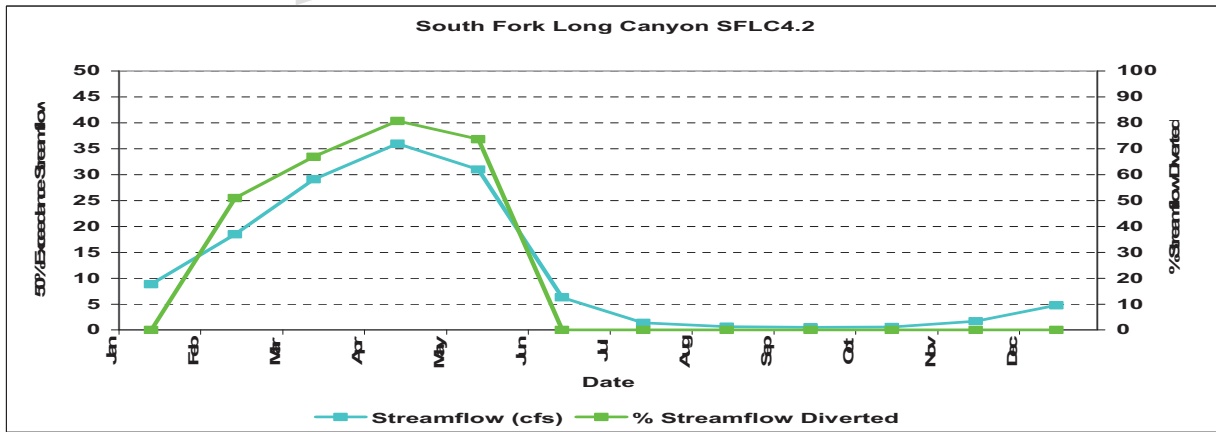
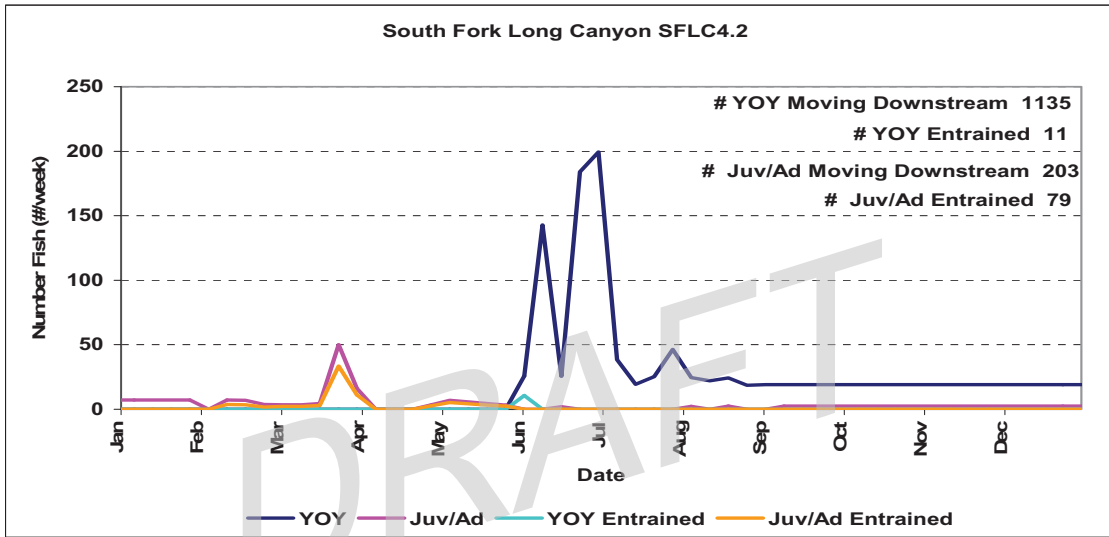
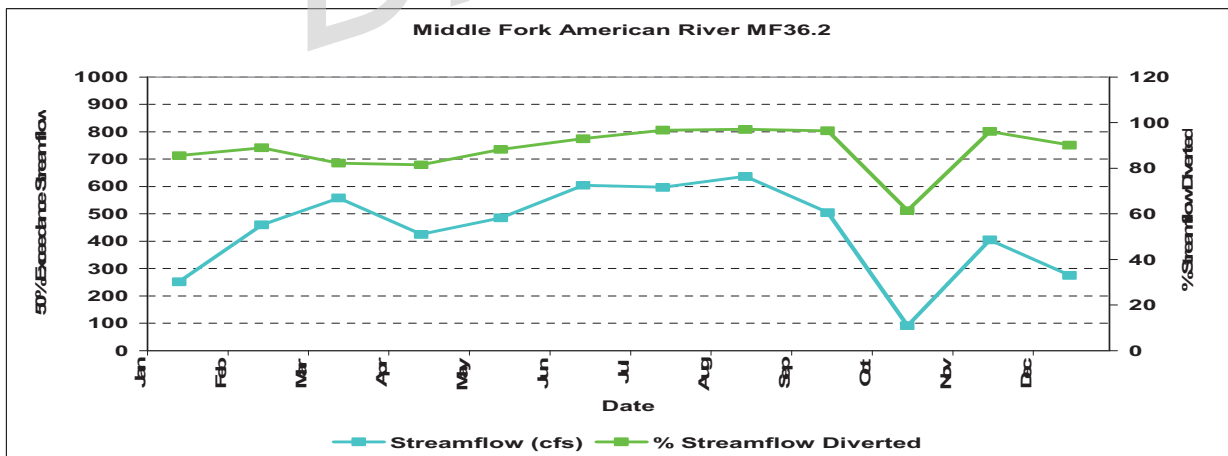
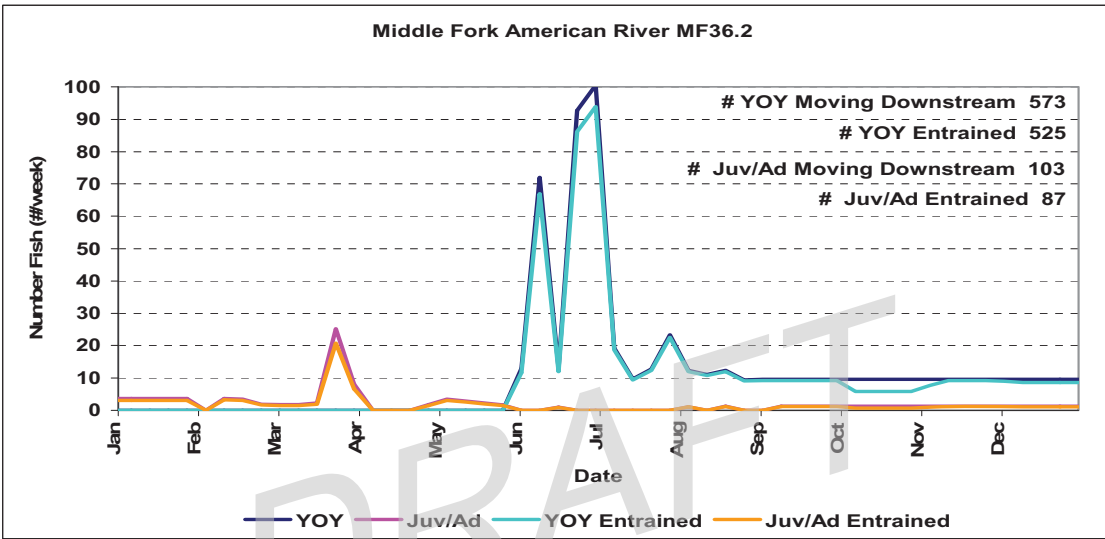


Figure D-4. Middle Fork American River above Interbay



**ATTACHMENT B**

**Middle Fork Project, Progress on Entrainment Approach,  
June 2, 2008 PowerPoint**

# Middle Fork Project

## Progress on Entrainment Approach

*This PowerPoint presentation is for historical documentation purposes. It should not be cited nor should the data presented in the presentation be used. The presentation was given during the July 8, 2008 Aquatic TWG meeting. During the meeting, the Aquatic TWG determined that direct entrainment sampling was necessary to complete the AQ 7 –TSP. The Aquatic TWG also concluded that additional work did not need to be expended on the Whitepaper Report or presentation.*



June 2, 2008

Preliminary Draft

All Numbers Are Preliminary and Subject to Change -- Do Not Cite

# AQ 7 -- Study Objectives

- **Characterize Project Facilities**

Characterize Project facilities (diversions, intake structures and intakes, and powerhouse turbines) and operations in relation to factors that may affect entrainment or mortality.

- **Screening Feasibility/Cost Assessment**

Develop the information necessary to assess the feasibility of screening intake structures (technical feasibility, feasibility level cost estimates, and maintenance requirements of screens).

- **Indirectly Estimate Entrainment**

Indirectly estimate the potential for entrainment and mortality using the Project facility characterizations and literature information.

# Study Objectives (cont.)

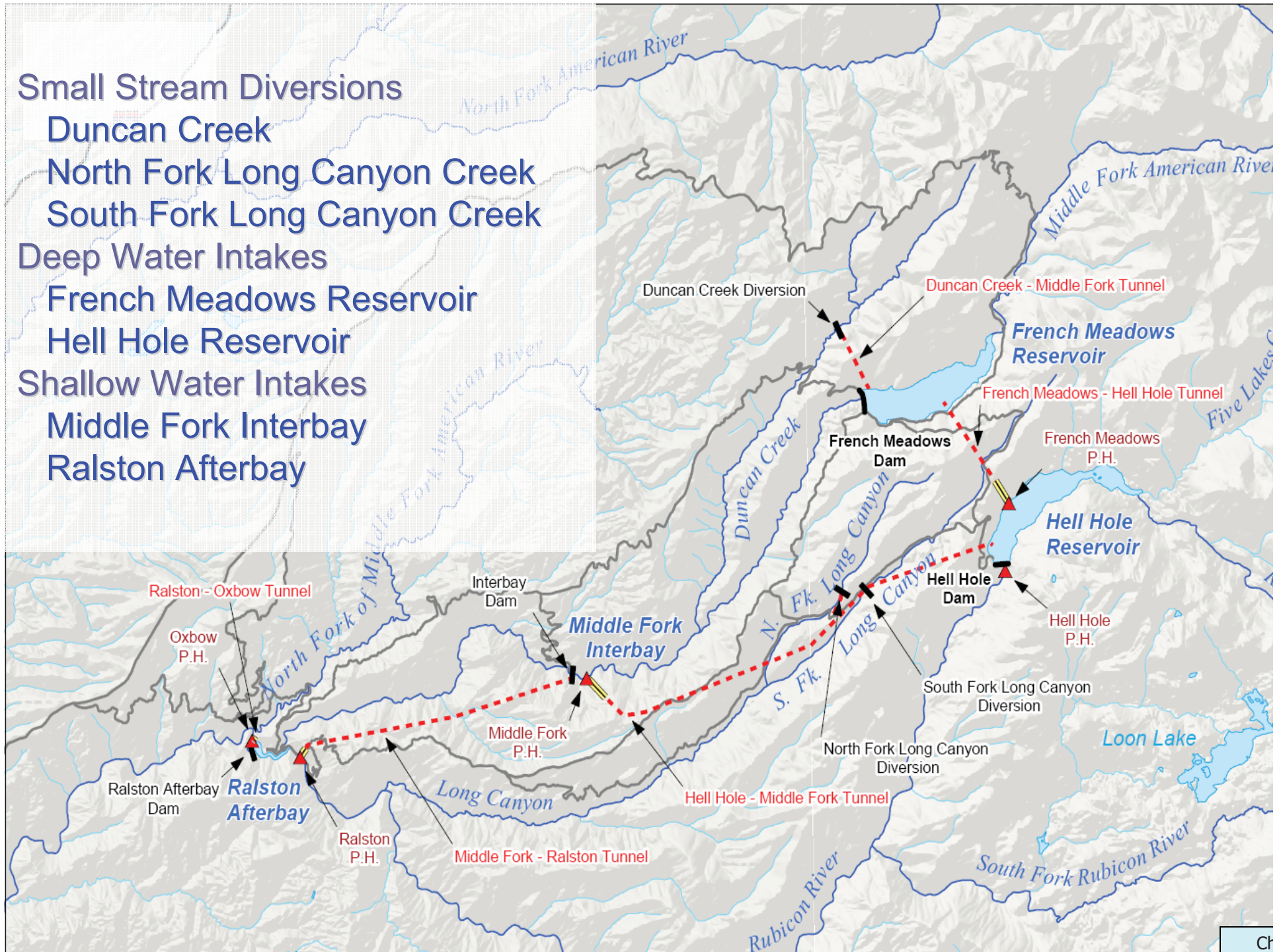
- Determine Need For Entrainment Sampling

Determine the need to directly sample entrainment and mortality at Project facilities in coordination with the Aquatic TWG.

- If Appropriate, Sample Entrainment

If appropriate, directly sample mortality and entrainment at selected Project facilities.

Small Stream Diversions  
 Duncan Creek  
 North Fork Long Canyon Creek  
 South Fork Long Canyon Creek  
 Deep Water Intakes  
 French Meadows Reservoir  
 Hell Hole Reservoir  
 Shallow Water Intakes  
 Middle Fork Interbay  
 Ralston Afterbay



# Characterization of Project Facilities

- Facility Characteristics -- Table AQ7-1
- Pictures and ~~Schematics~~\* -- Appendix A
- Flow Mass Balance -- Appendix B

\*Critical Energy Infrastructure Information  
(CEII)

# ■ Facility Characteristics -- Table AQ7-1

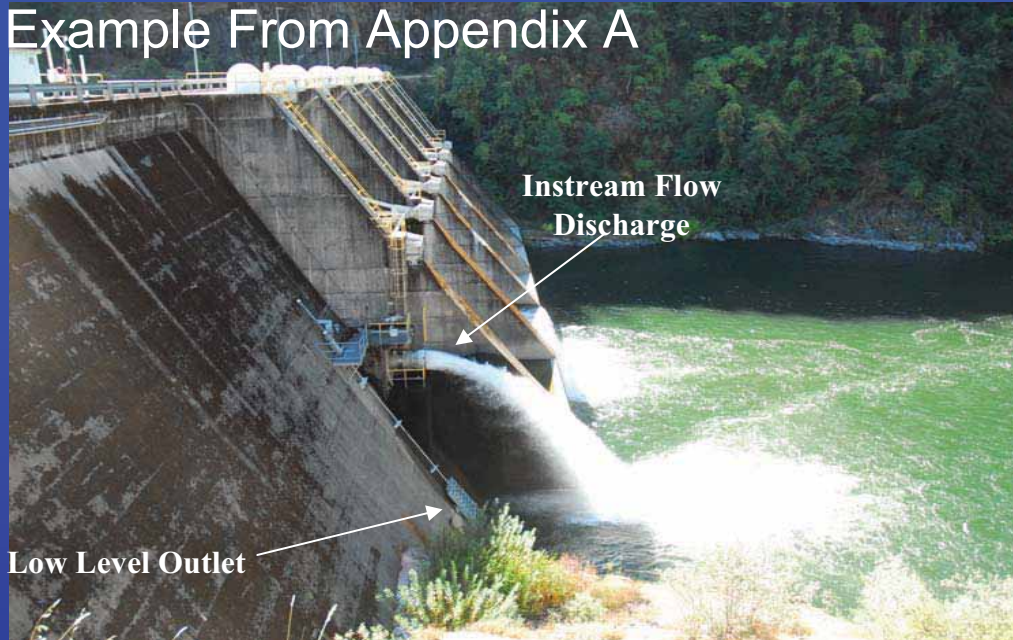
## Example From Table

Facility	Hydraulic Capacity (cfs)	Frequency of Use (cfs)	Inlet/Outlet Type	Inlet Area (ft. <sup>2</sup> )	Approach Velocity (fps)	Intake Depth (ft)	Comments
<b>Ralston Afterbay</b>							
Ralston – Oxbow Tunnel	1,088	Frequent	Inlet: Tunnel with slide gate and trash rack with 3 in. bar spacing Outlet: vertical Francis turbine	Tunnel Inlet: 96 Trash Rack: 590	Inlet: 0-11.3 Trash Rack: 0-1.8	39 <sup>(1)</sup>	Oxbow Powerhouse discharges into the Middle Fork American River
Ralston Afterbay Dam Low Level Outlet	1,671	Infrequent	Inlet: 72 in. dia. with slide valve and Grizzly (8" bar opening) Outlet: 72 in. dia. slide gate	Pipe Inlet: 28.3 Grizzly: 82.6	Inlet: 0-59.1 Trash Rack: 0-20.33	74 <sup>(1)</sup>	Discharges to a plunge pool
Ralston Afterbay Dam Stream Maintenance Pipe	75	Frequent – 10 cfs Infrequent – 75 cfs	Inlet: 30 in. dia. pipe with slide valve and trash rack (3.88 in. bar opening) Outlet: 30 in. dia. Ring Jet valve	Pipe Inlet: 4.9 Trash Rack: 36.2	Inlet: 2.04-15.31 Trash Rack: 0.3-2.1	41.25 <sup>(1)</sup>	Energy dissipating valve discharges to a plunge pool

(1) Maximum reservoir operating surface elevation minus intake elevation invert.

# ■ Pictures and Schematics (Appendix A)

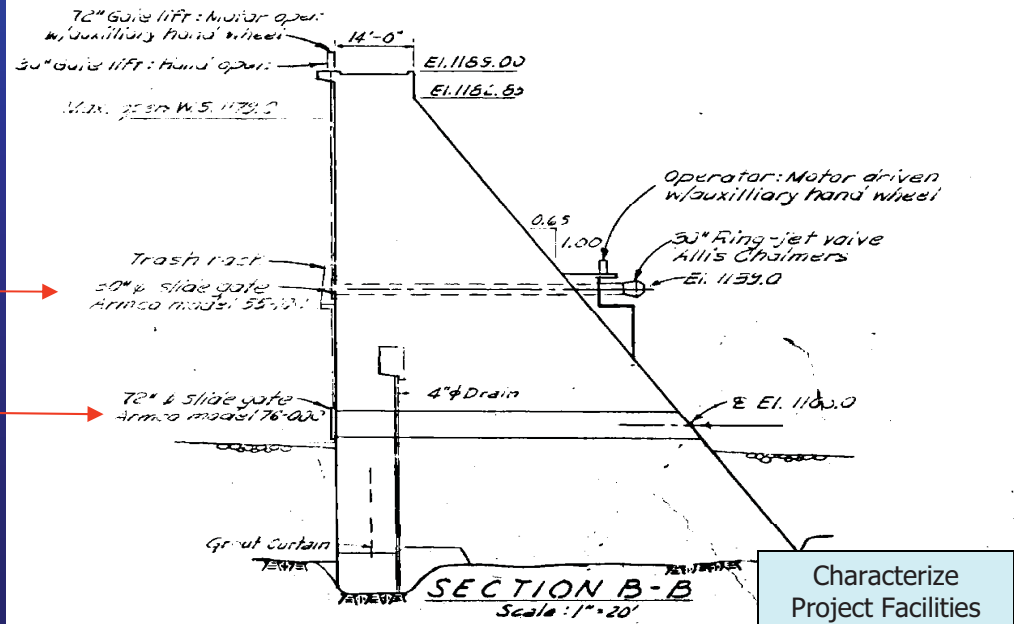
Example From Appendix A



Ralston Afterbay Dam – Down Stream Side

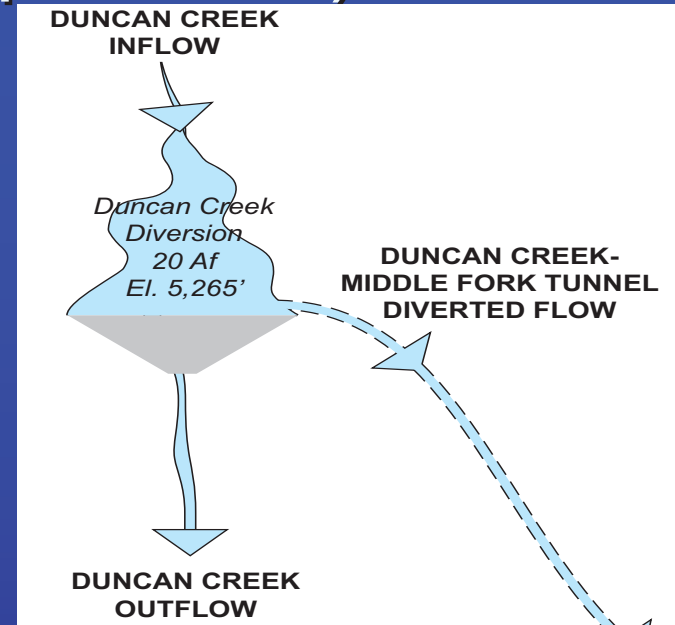
Instream  
Flow Pipe

Low  
Level  
Outlet



# ■ Flow Mass Balance (Appendix B)

- Inflows
- Outflows
- Percent Diverted  
(Daily % Exceedance  
by Month\*\*)



## Duncan Creek

Duncan Creek Diversion Water Budget (continued).

Month	Exceedances				
	10	20	50	80	90
<b>Duncan Creek Percent Diverted</b>					
Oct	13	3	0	0	0
Nov	71	42	4	0	0
Dec	73	55	7	0	0
Jan	76	65	21	0	0
Feb	78	71	41	0	0
Mar	84	78	62	37	22
Apr	91	89	82	67	57
May	94	92	85	65	49
Jun	91	87	46	0	0
Jul	62	13	0	0	0
Aug	17	8	0	0	0
Sep	13	6	0	0	0

# Fish Screen Feasibility Assessment and Costs

- Estimates of Screen Installation Costs
- Characterization of Technical Feasibility of Installing Screens (**pending**)
- Maintenance Requirements of Screens (**pending**)

# Fish Screen Costs

- 34 California Screening Projects (1983-2005)
  - Data from NOAA and USFWS
  - Binned into Four Flow Ranges (50-100, 100-500, 500-1000, >1000 cfs)
  - Converted to 2008 Dollars Using 3% Inflation Rate
  - Current Costs are Uncertain Due to Recent Large Increases in Steel Prices
- Washington State Screen Costs Reviewed, but Significantly Lower Than California Costs

# Approximate 2008 Screen Costs Per CFS

Table AQ7-2a Summary of Screen Costs - California		
Flow Range (cfs)	Average Cost Dollars/CFS <sup>(1)</sup>	Highest Cost Dollars/CFS <sup>(2)</sup>
50-100	\$8,300	\$15,000
100-500	\$21,000	\$42,000
500-1000	\$12,000	\$23,000
>1000	\$12,000	\$19,000
Notes		
(1) Average capital cost of 35 projects constructed in California between 1983 and 2005. Costs inflated at 3% to 2008 dollars.		
(2) Highest capital cost in range (2008 dollars).		

All Numbers Are Preliminary and Subject to Change -- Do Not Cite

# Estimates of Screen Installation Costs Based on CFS

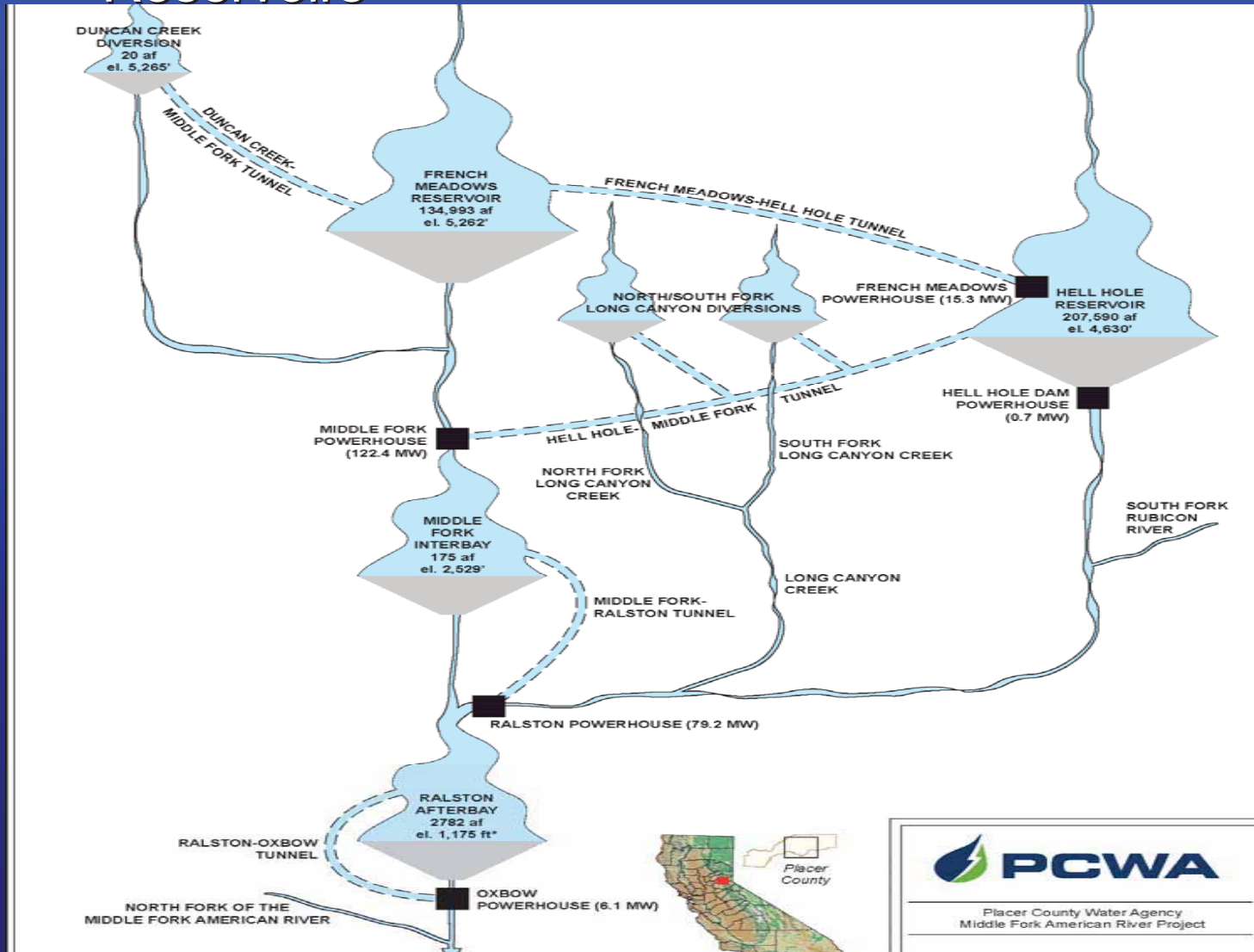
Facility	Maximum Flow (CFS)	Average Cost \$/CFS <sup>(1,4)</sup>	Maximum Cost \$/CFS <sup>(1,4)</sup>	Range of Screen Cost (millions) <sup>(4)</sup>	
<b>“Low” Flow Diversions</b>					
North Fork Long Canyon Diversion	100	\$8,300	\$15,000	\$1	\$2
South Fork Long Canyon Diversion	200	\$21,000	\$42,000	\$4	\$8
<b>“High” Flow Diversions</b>					
Duncan Creek - Middle Fork Tunnel Intake	400	\$21,000	\$42,000	\$8	\$17
French Meadows - Hell Hole Tunnel Intake <sup>(2)</sup>	400	\$21,000	\$42,000	\$8	\$17
French Meadows - Hell Hole Tunnel Intake <sup>(3)</sup>	800	\$12,000	\$23,000	\$10	\$18
Hell Hole - Middle Fork Tunnel Intake	920	\$12,000	\$23,000	\$11	\$21
Middle Fork - Ralston Tunnel Intake	836	\$12,000	\$23,000	\$10	\$19
Ralston - Oxbow Tunnel Intake	1,088	\$12,000	\$19,000	\$13	\$21

- (1) Estimated costs per cfs are based on average and maximum costs from 35 previously constructed screening projects in California with a variety of screen designs, sizes, and design criteria
- (2) Current operations
- (3) Utilizing maximum tunnel capacity
- (4) Capital costs in 2008 dollars (3% inflation)

All Numbers Are Preliminary and Subject to Change -- Do Not Cite

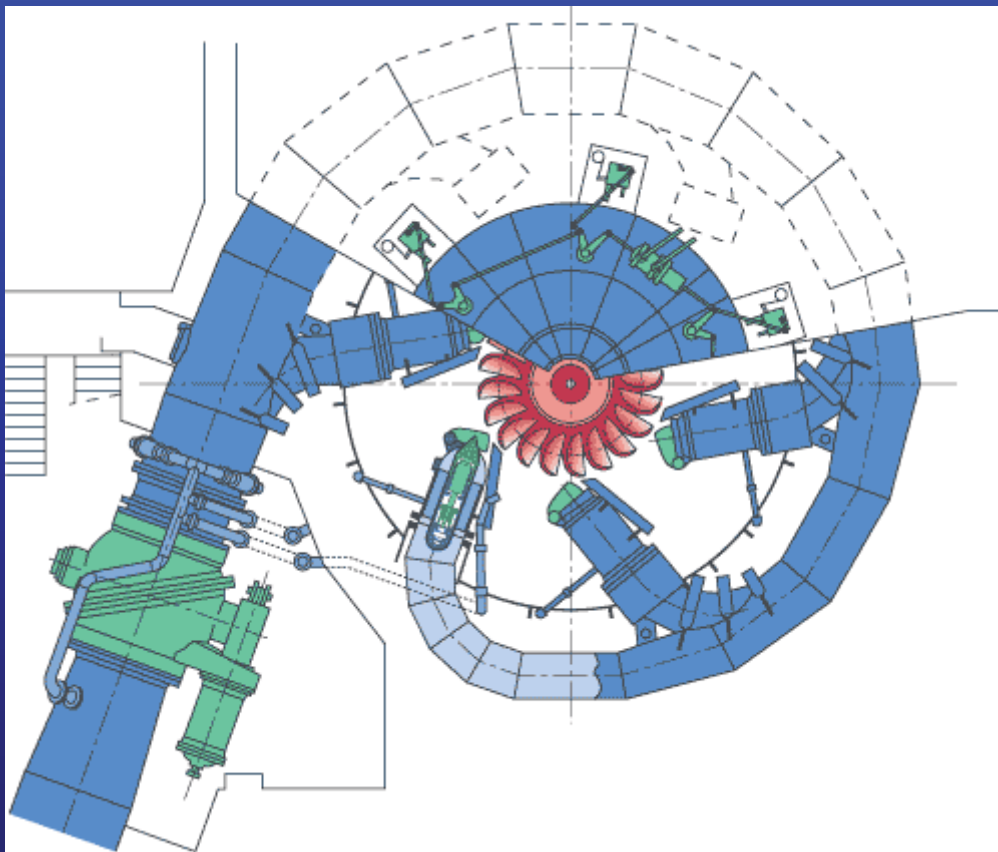
# Determine Fate of Entrained Fish

- Powerhouses (Francis and Pelton Turbines)
- Reservoirs



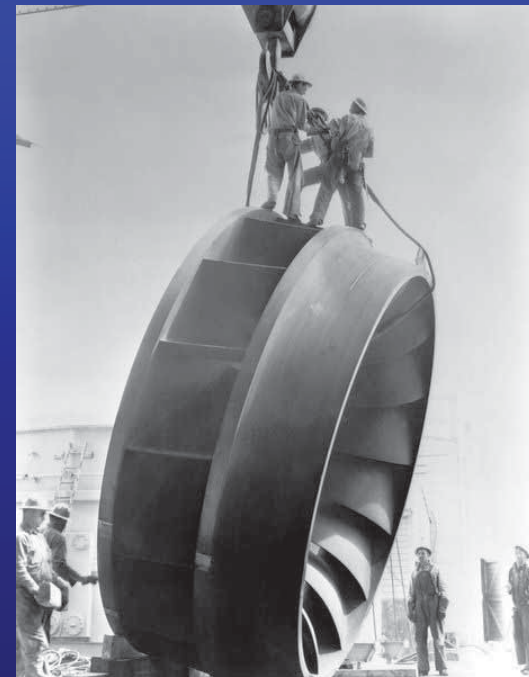
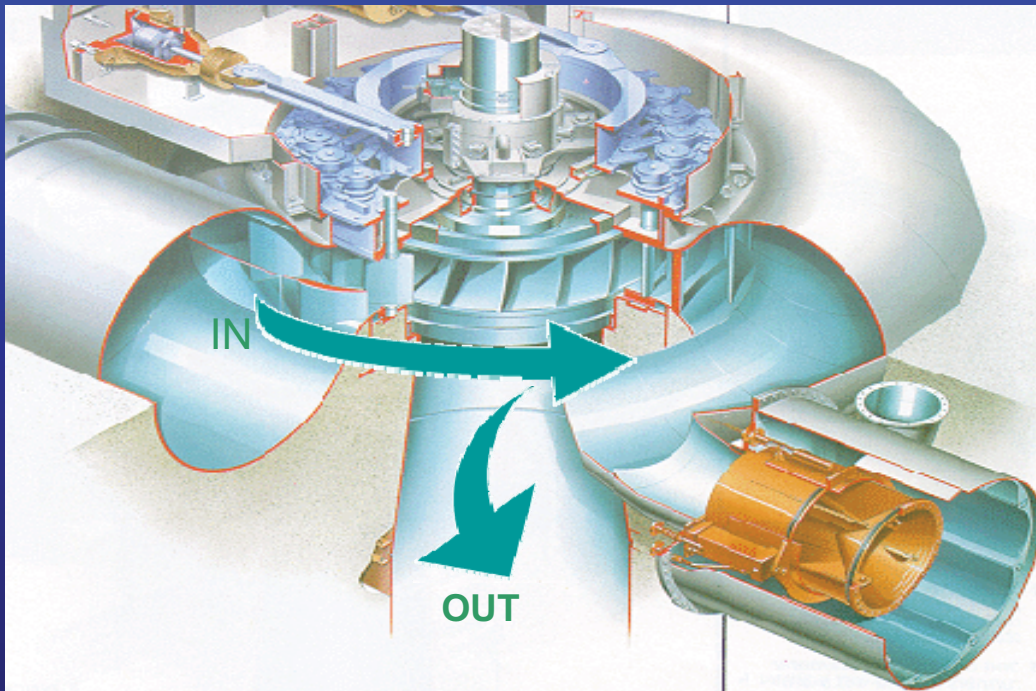
# Fate of Fish--Pelton Turbines

- High Mortality of Entrained Fish
  - Middle Fork Power House
  - Ralston Power House



# Fate of Fish--Francis Turbines

- Relatively Low Mortality of Entrained Fish
  - French Meadows Powerhouse
  - Hell Hole Powerhouse
  - Oxbow Powerhouse



# Francis Turbine (cont.)

- Primary Factors Affecting Fish Mortality
  - Peripheral Runner Velocity
  - Blade Spacing / Clearance
  - Fish Size
  - Others (e.g., wicket gate setting)



Small Horizontal Shaft Turbine



# Immediate and 48-Hour Fish Survival Rates in Francis Turbines by Fish Size and RPM (Winchell et al. 2000)

**Table A07-4. Immediate and 48-Hour Fish Survival Rates for Francis Turbines by Fish Size.<sup>(1)</sup>**

Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	Average Immediate Survival <sup>(2)</sup> (all species combined)			
			N <sup>(3)</sup>	Minimum (%)	Maximum (%)	Mean (%)
<250	440-1,600	<100	13	86	100 <sup>(4)</sup>	94
"	370-1,600	100-199	19	75	100	92
"	370-2,450	200-299	18	59	100	87
"	440-1,600	300+	14	36	100	73
>250	275-695	<100	6	31	98	70
"	"	100-199	7	34	83	60
"	"	200-299	7	23	83	39
"	"	300+	3	4	35	19
Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	Average 48-Hour Survival <sup>(2)</sup> (all species combined)			
			N <sup>(3)</sup>	Minimum (%)	Maximum (%)	Mean (%)
<250	440-1,600	<100	11	81	101 <sup>(4)</sup>	90
"	370-2,450	100-199	17	74	101 <sup>(4)</sup>	88
"	440-2,450	200-299	15	47	96	80
"	440-1,600	300+	13	34	94	67
>250	275-695	<100	3	63	86	72
"	275-695	100-199	5	16	78	46
"	275-695	200-299	5	12	65	32
"	275-450	300+	2	4	8	6

(1) From Winchell, F., S. Amaral and D. Dixon. 2000. Hydroelectric Turbine Entrainment and Survival Database: An Alternative to Field Studies. Paper presented at Hydrovision 2000.

(2) Average of all control-adjusted estimates provided in EPRI (1997) including all species and test conditions but excluding tests with less than 90% survival of control groups.

(3) Number of turbines for which survival estimates are available.

(4) Even with high rates of control survival, the true rate of survival may be under- or over-estimated. When the survival of treatment groups is higher than controls, the adjusted survival estimates will exceed 100%.

All Numbers Are Preliminary and Subject to Change -- Do Not Cite

Indirectly Estimate Entrainment and Mortality Potential

# Powerhouse Characteristics and Preliminary Estimates of % Mortality

Table AQ7-5. Turbine Characteristics and Associated Mortality for Middle Fork American River Project

Name	Max. Hydraulic Capacity (cfs)	Turbine Type	Runner Speed (rpm)	Maximum Blade Velocity <sup>(1)</sup> (fps)	Static Head Max - Min (ft)	Fish Size (mm)	Approx. % Survival <sup>(2)</sup> Average (Range)	
							Immediate	48-Hour
French Meadows P.H.	400 <sup>(3)</sup>	Vertical Francis	450	150 - 170	654 - 517	<100	70 (31-98)	72 (63-86)
						100 - 199	60 (34-83)	46 (16-78)
						200 - 299	39 (23-83)	32 (12-65)
						300+	19 (4-35)	6 (4-8)
Hell Hole P.H.	65 <sup>(4)</sup>	Horizontal Francis	1200	62 - 94	391 - 101	<100	70 (31-98)	72 (63-86)
						100 - 199	60 (34-83)	46 (16-78)
						200 - 299	39 (23-83)	32 (12-65)
						300+	19 (4-35)	6 (4-8)
Oxbow P.H.	1025	Vertical Francis	200	66 - 76	90	<100	94 (86-100)	90 (81-101)
						100 - 199	92 (75-100)	88 (74-101)
						200 - 299	87 (59-100)	80 (47-96)
						300+	73 (36-100)	67 (34-94)
Middle Fork P.H. (2 units)	920 <sup>(5)</sup>	<u>Pelton</u>	400	NA	2,096 - 1,806	All	~ 0	
Ralston P.H.	924	<u>Pelton</u>	240	NA	1,344	All	~ 0	
(1) Approximate range based in diameter of scroll case and allowance for wicket gate assembly. (2) Mean approximate mortality for all fish species combined. See Winchell et al. 2000 table. (3) Nominal tunnel capacity. (4) Maximum flow capacity when supporting instream flow requirements below Oxbow PH during fall maintenance outage. (5) Nominal capacity of Hell Hole – Middle Fork Tunnel.								

All Numbers Are Preliminary and Subject to Change -- Do Not Cite

Indirectly Estimate Entrainment and Mortality Potential

# Entrainment at Deep Water Reservoir Intakes: Hell Hole Reservoir French Meadows Reservoir

- Relatively Low Potential for Entrainment due to Water Depth
  - Fish Typically in Shallower Water
  - Intakes in Deeper Water
- No Species of Special Concern Present
- Fish Stocking Supports Fisheries

# Hell Hole Reservoir



Hell Hole-Middle Fork Tunnel Outlet Depth = Average **229 feet (93-313)**

Dam Outlet Works Depth =Average **263 feet (127-347)**

**All Numbers Are Preliminary and Subject to Change -- Do Not Cite**

# French Meadow Reservoir



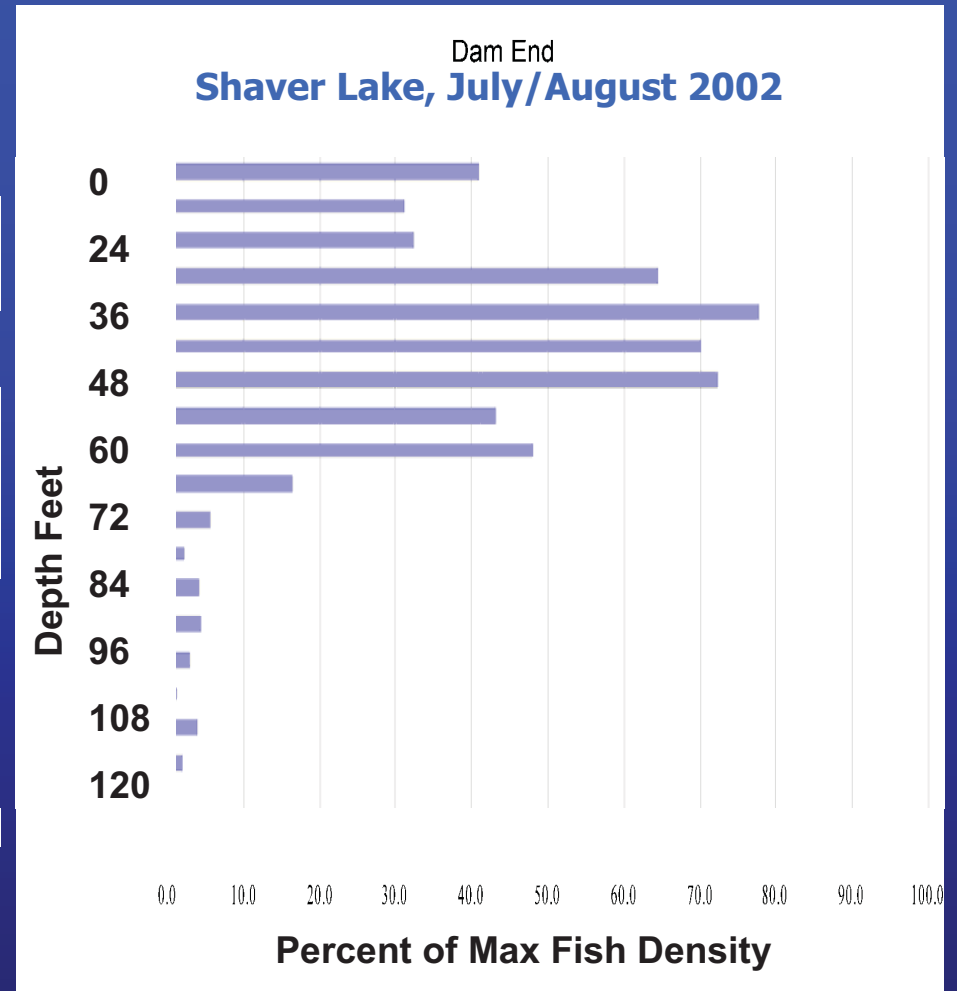
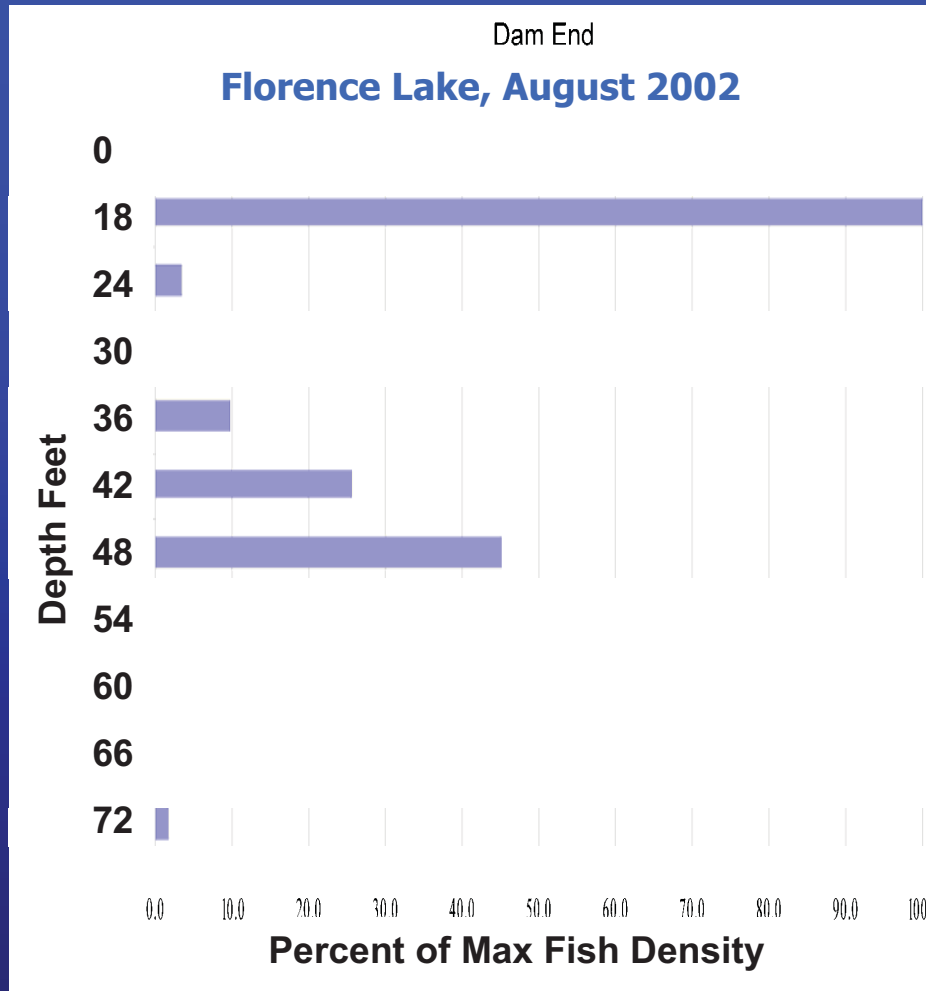
French Meadows-Hell Hole Tunnel Intake Depth = Average **102 feet (43-149)**

Dam Instream Flow Outlet Depth = Average **151 feet (92-198)**

Dam Low Level Outlet = Average **169 Feet (110-216)**

**All Numbers Are Preliminary and Subject to Change -- Do Not Cite**

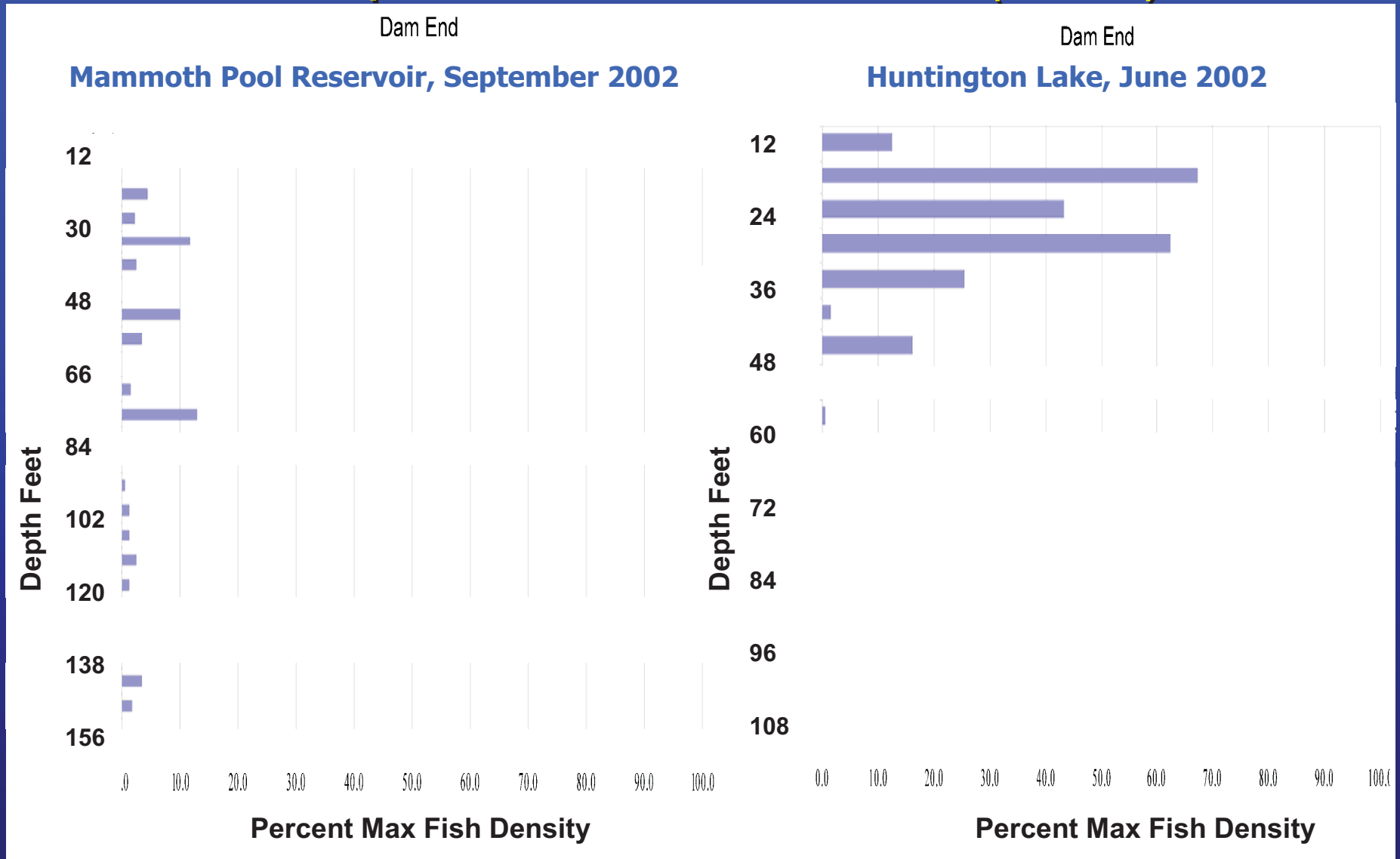
# Deep Water Reservoir Intakes Example Fish Distributions



From Combined Aquatics Working Group – 9 Entrainment

Indirectly Estimate Entrainment  
and Mortality Potential

# Deep Water Reservoir Intakes Example Fish Distributions (cont.)

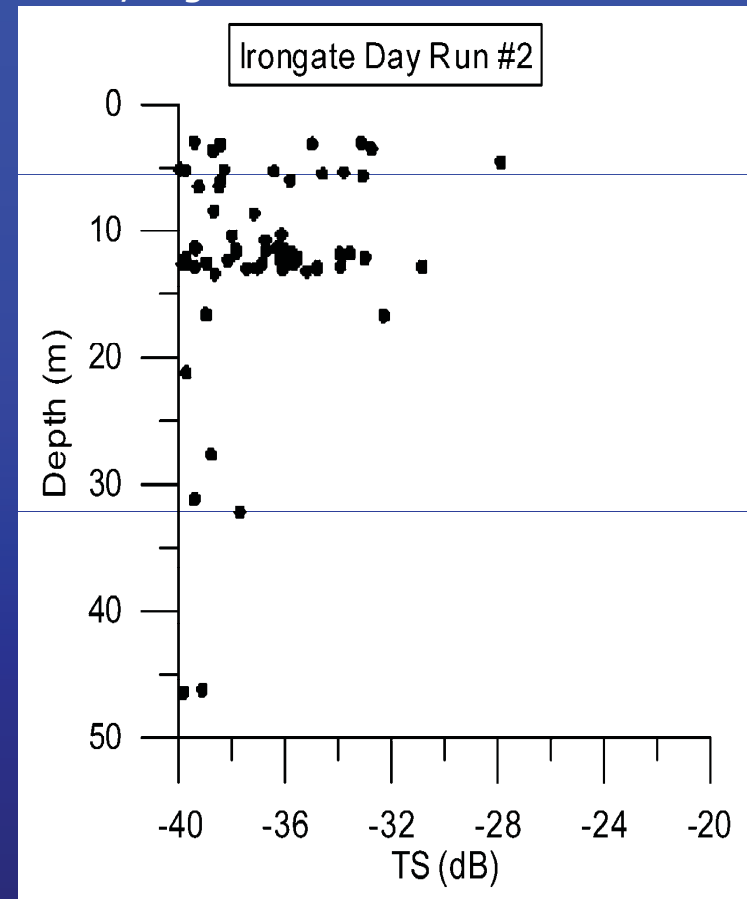
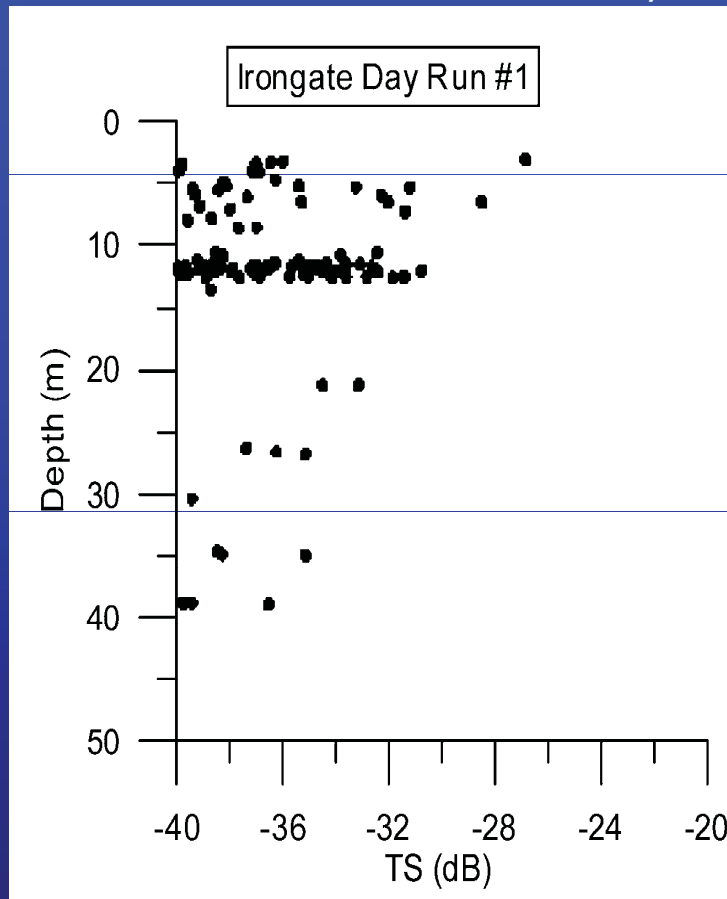


From Combined Aquatics Working Group – 9 Entrainment

Indirectly Estimate Entrainment  
and Mortality Potential

# Deep Water Reservoir Intakes Example Fish Distributions (cont.)

Iron Gate Reservoir, Klamath River, August 2003



TS = Target strength from hydroacoustic analysis

From Eilers J.M. and B.J. Eilers. 2004. Hydroacoustic Analysis of Fish Populations in Copco and Iron Gate Reservoirs. Klamath Hydroelectric Project FERC Project No. 2082. Prepared for PacifiCorp, Portland OR by MaxDepth Aquatics, Inc., Bend OR.

Indirectly Estimate Entrainment  
and Mortality Potential

# Indirectly Estimate Entrainment and Mortality Potential:

- Estimate Downstream Emigration/Movement
  - Young-of-the-Year (YOY)
  - Juvenile/Adult
- Estimate Fish Entrained Using Percent Flow Diverted

# Entrainment Threshold Calculation Approaches: Duncan Creek, NF Long Canyon Creek, SF Long Canyon Creek, Middle Fork Interbay

- 1. Empirical Entrainment Data Set
  - West Panther Creek (Mokelumne River Trib)
- 2. Mechanistic Approaches
  - Adult Movement Studies
  - YOY Population Modeling (in progress)
- 3. Canal Entrainment Literature

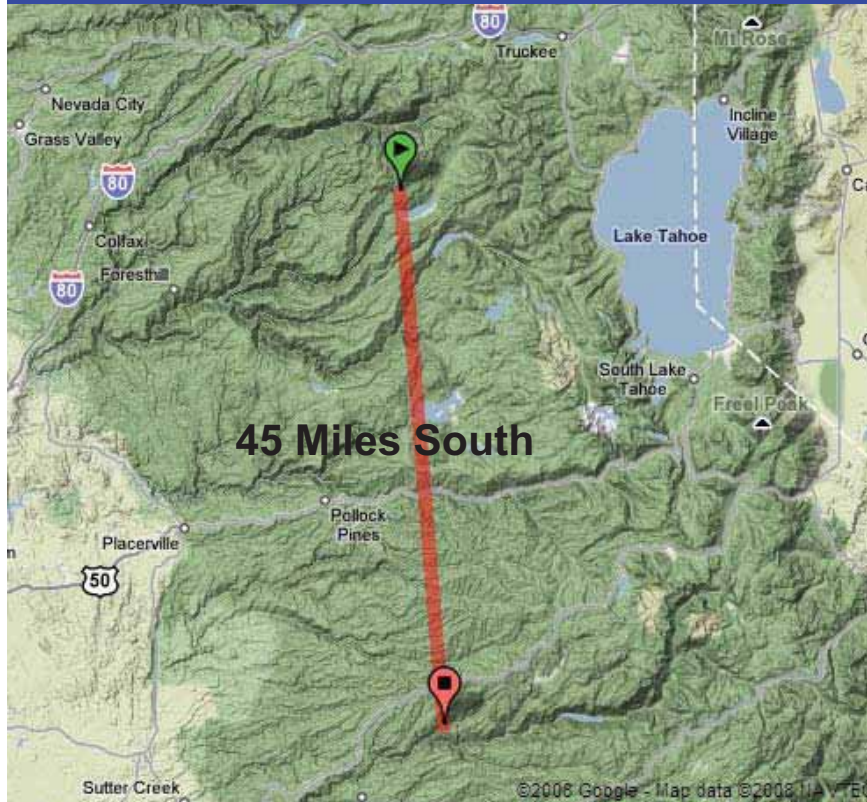
# Entrainment Threshold Calculation Approaches (Cont.)

## Project Specific Data

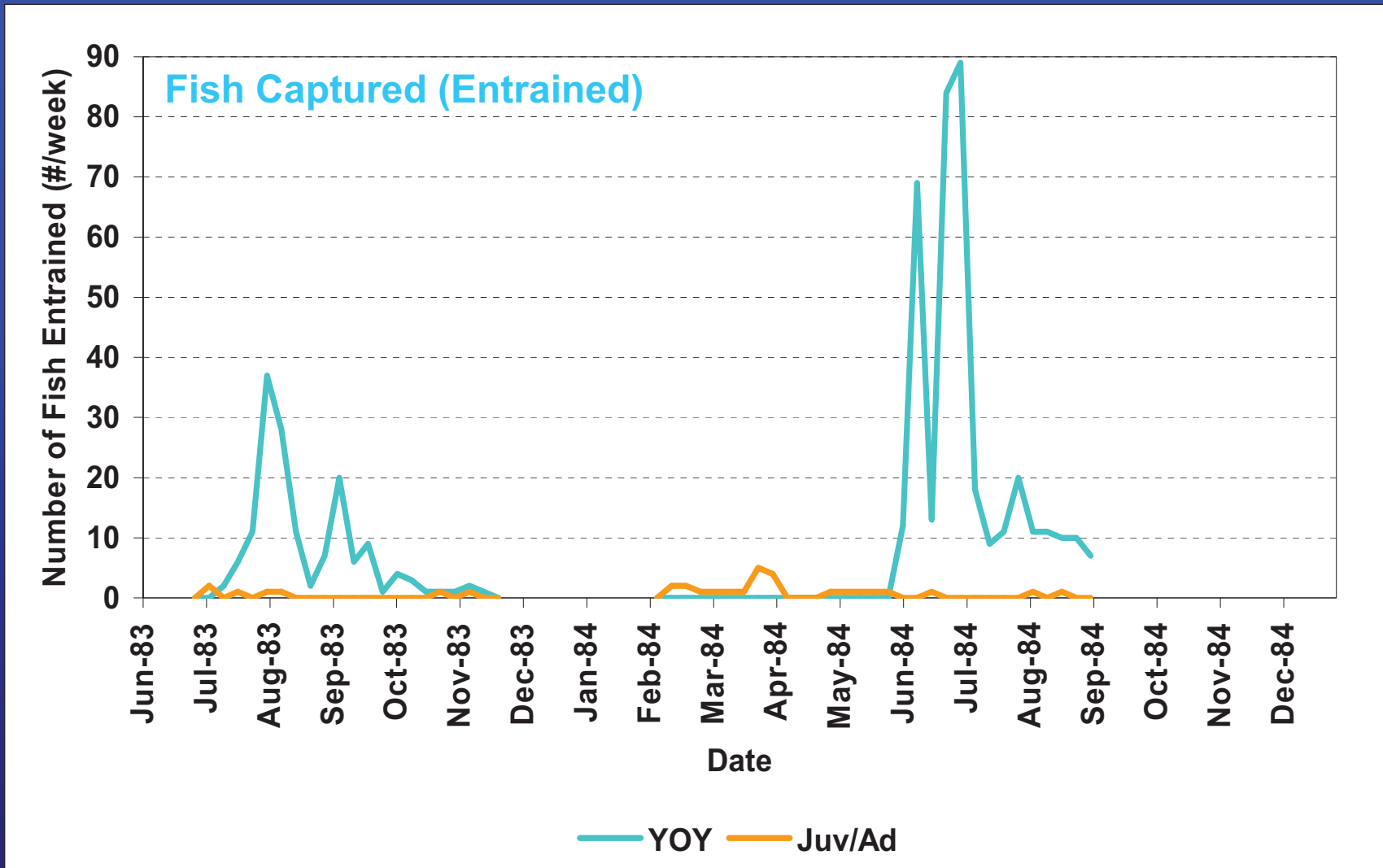
- Project Operations (amount and dates of diversions)
- PCWA Fish population data (AQ 2 2007 studies)
- PCWA Spring Qualitative Fish Sampling
  - Duncan Creek and North and South Forks of Long Canyon Creek

# West Panther Creek 1983-84 Empirical Data

- Tributary to Mokolumne River, Elevation 3600 ft, 45 Miles South of MFP
- Inclined Plane Fish Traps
- Sampled all Diverted Flow
- Sampled Approximately 24 hrs/day during Diversion Period
- Other Streams Sampled, but not Best Comparison to MFP (low fish density)

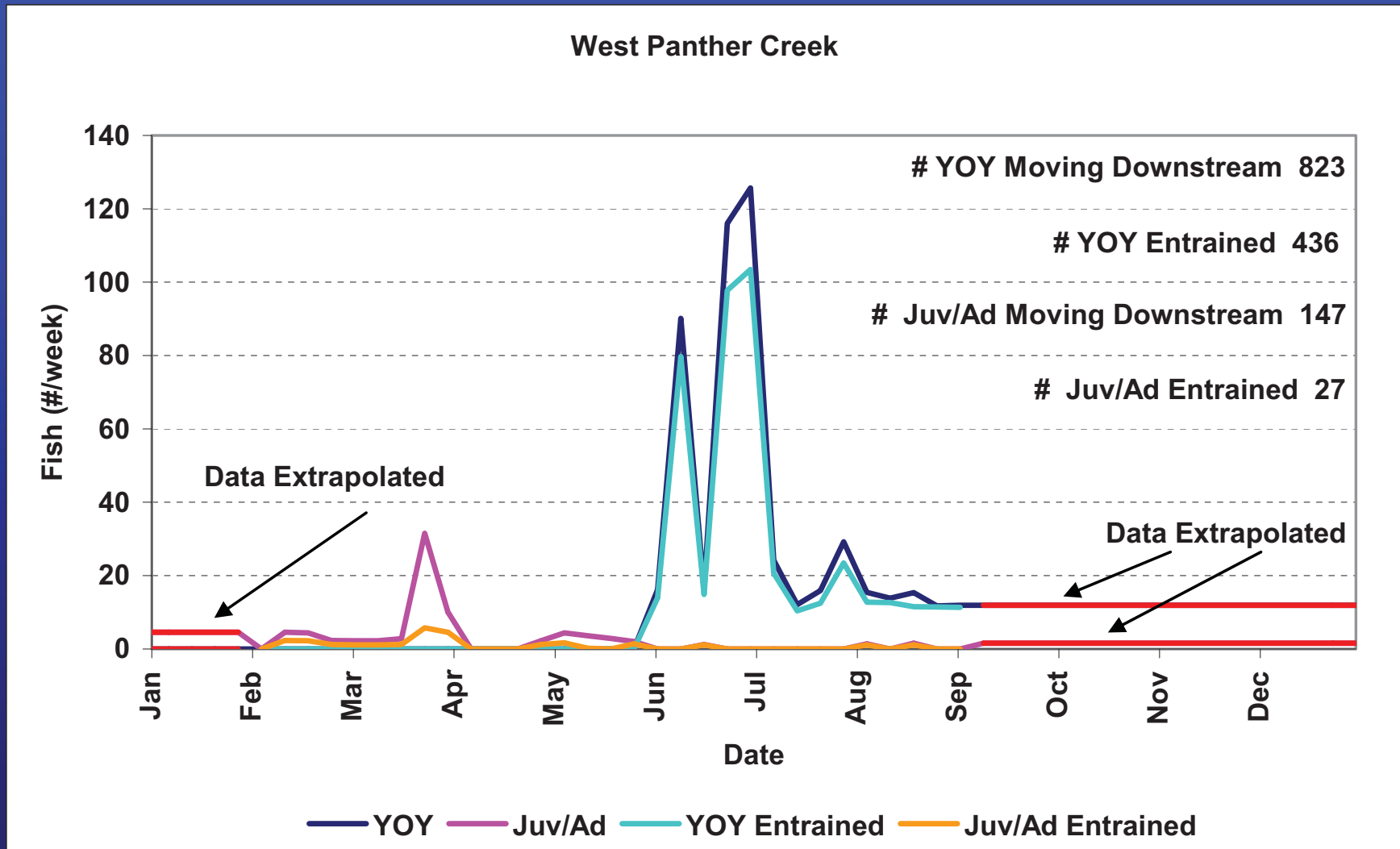


# West Panther Creek 1983-84 Data



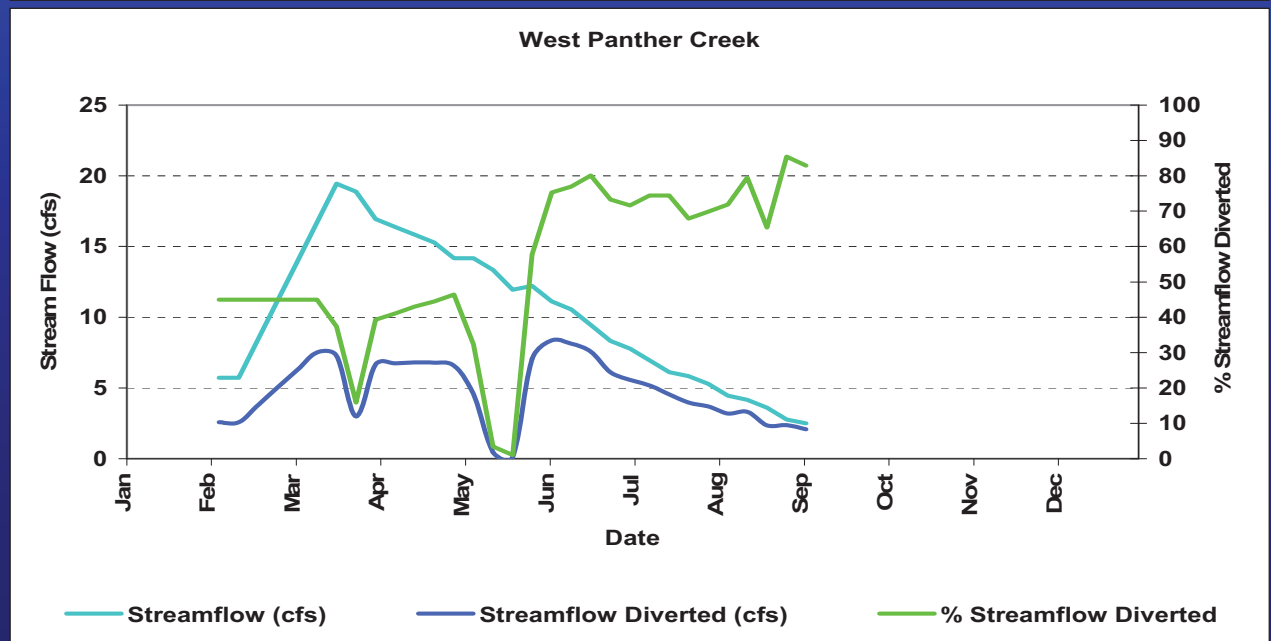
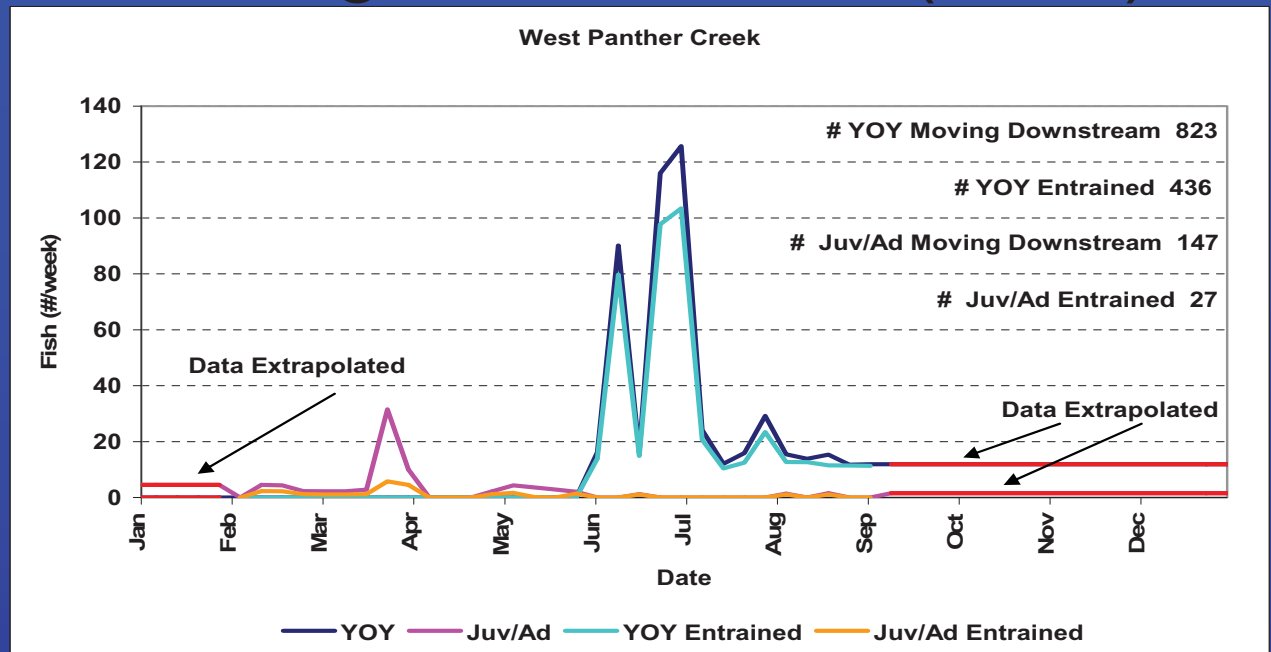
# West Panther Creek 1984 Data

## ■ Extrapolated Data to Fall and Winter



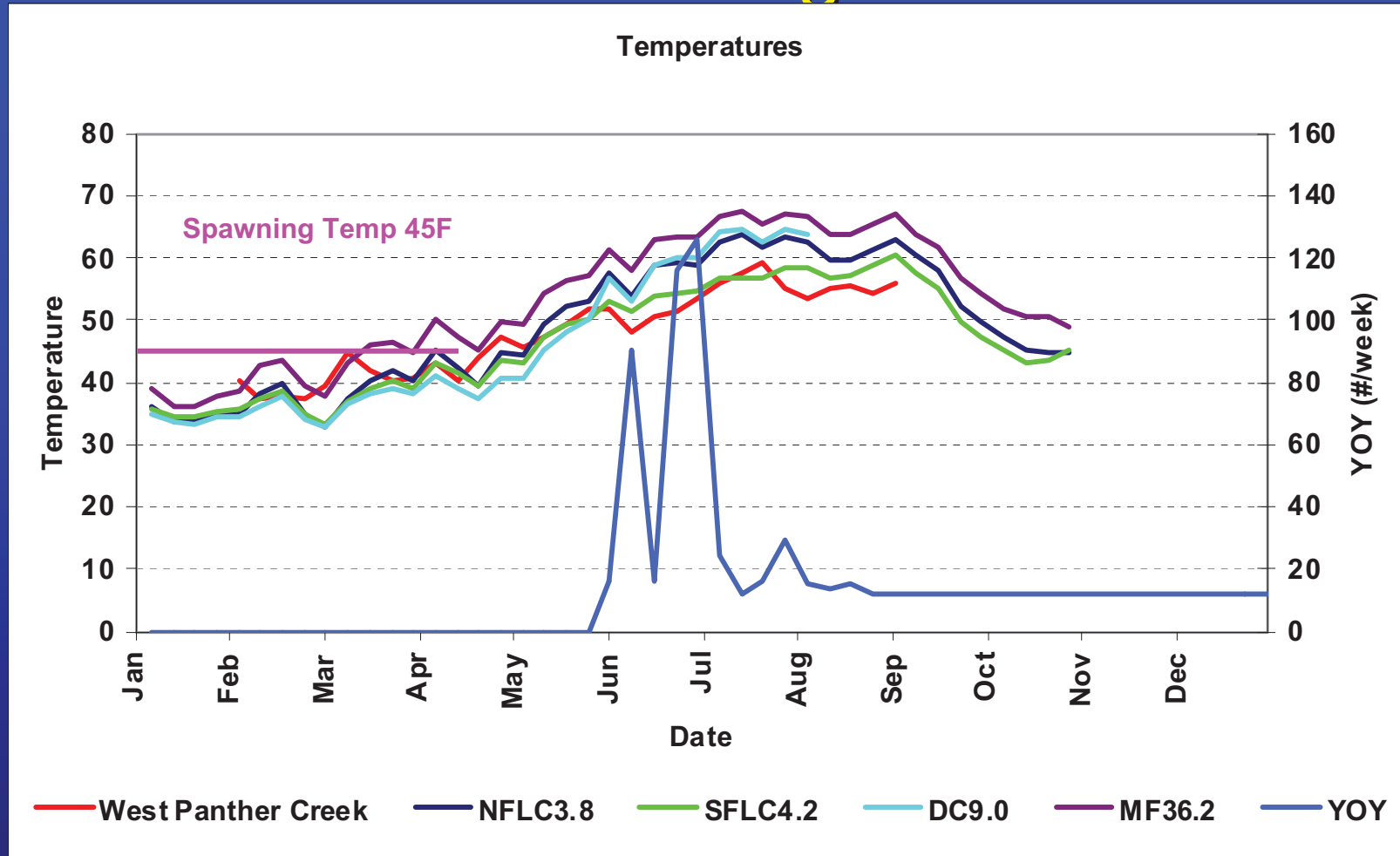
# W Panther Fish Moving Downstream (cont.)

- Scale by Trap Effort  
(Fish Caught\*168 hr week /#hrs week Trap Effort)
- Scale to Total Fish Moving Downstream  
(Fish Caught /% Q Diverted)



# W Panther Fish Moving Downstream (cont.)

## Timing



- Temperature Similar to PCWA Streams up to June Emergence
- Early June Emergence of Trout Fry Matches PCWA Qualitative Sampling Data

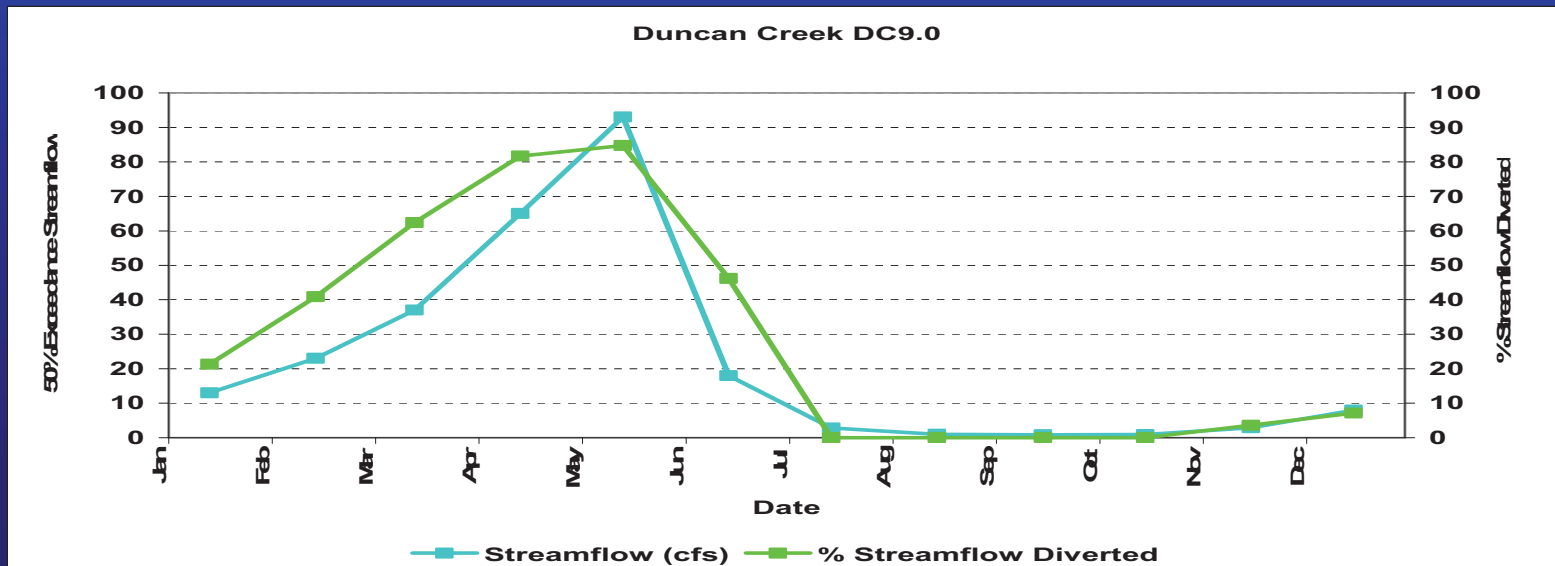
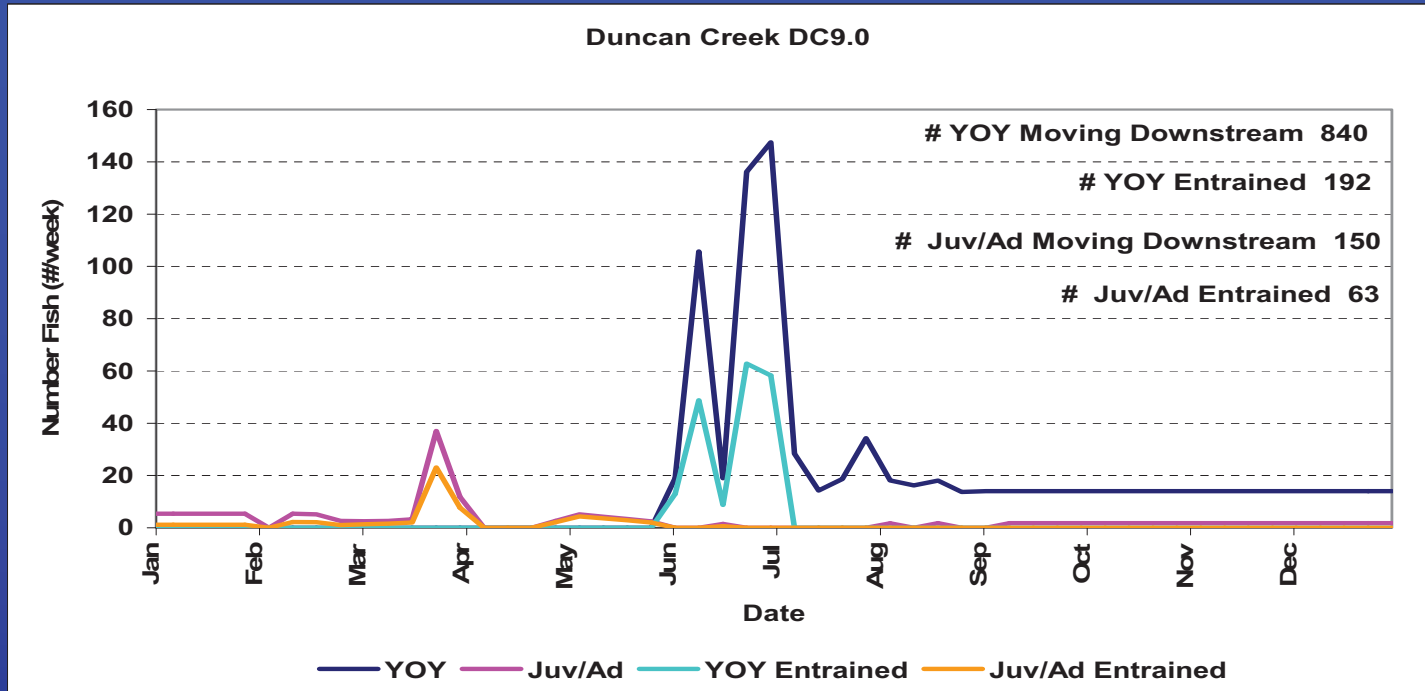
## W Panther Fish Moving Downstream (cont.)

- Scaled Number of Fish Moving Downstream to the Size of the Juvenile/Adult Fish Population of each Individual Stream

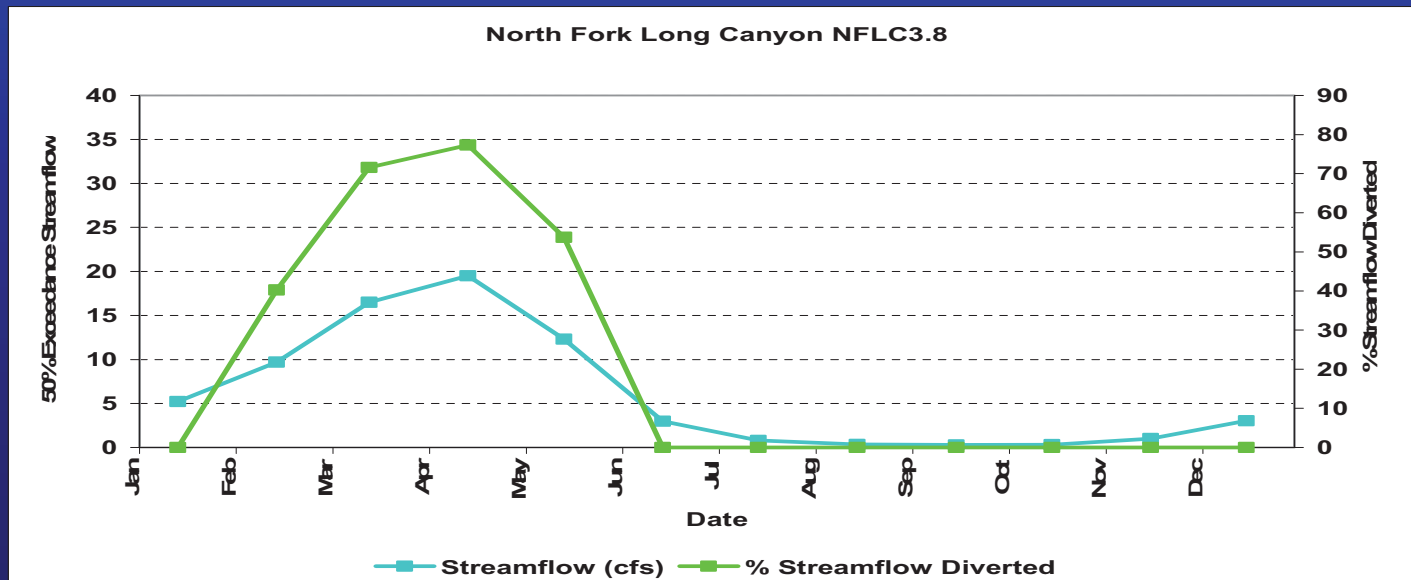
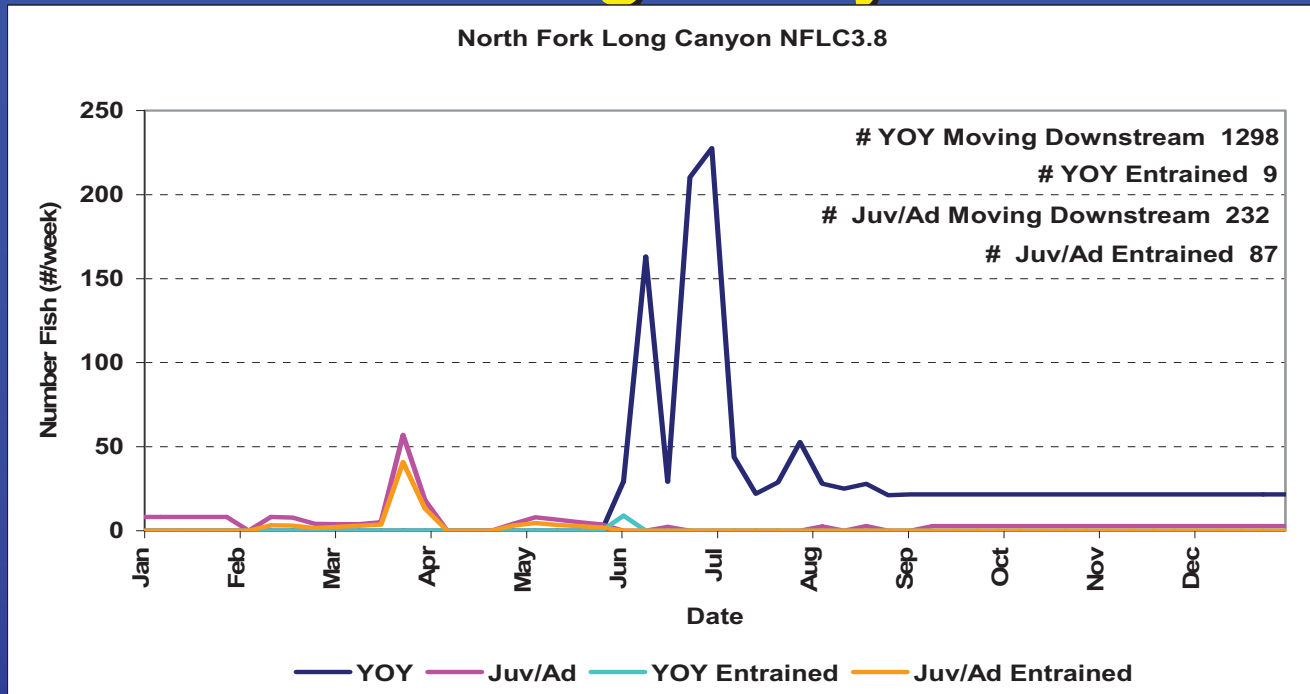
Population Scale Factor = (# Fish per mile in Stream / # Fish per Mile in W. Panther Creek)

River Site	Juvenile/Adult Trout (#/mile)	Population Scale Factor
West Panther Creek	870	1.0
Duncan Creek abv Diversion (DC9.0)	1021	1.17
South Fork Long Canyon Creek abv Diversion (SFLC4.2)	1380	1.59
North Fork Long Canyon Creek abv Diversion (NFLC3.8)	1577	1.81
Middle Fork American River abv Interbay (MF36.2)	696	0.80

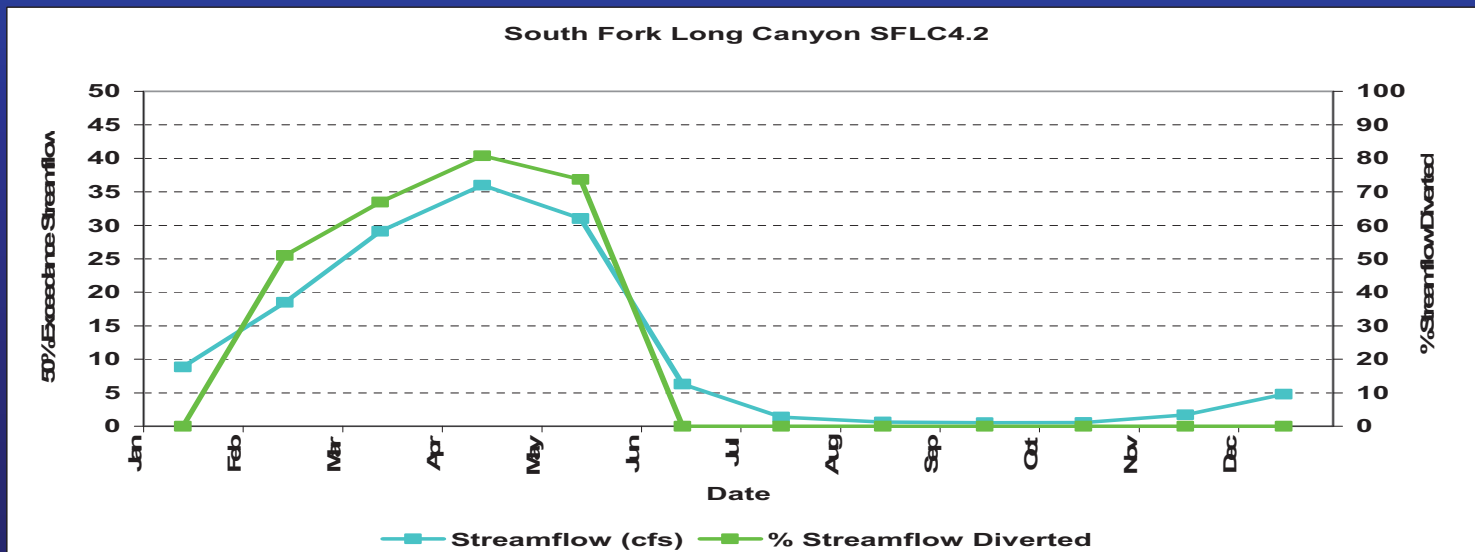
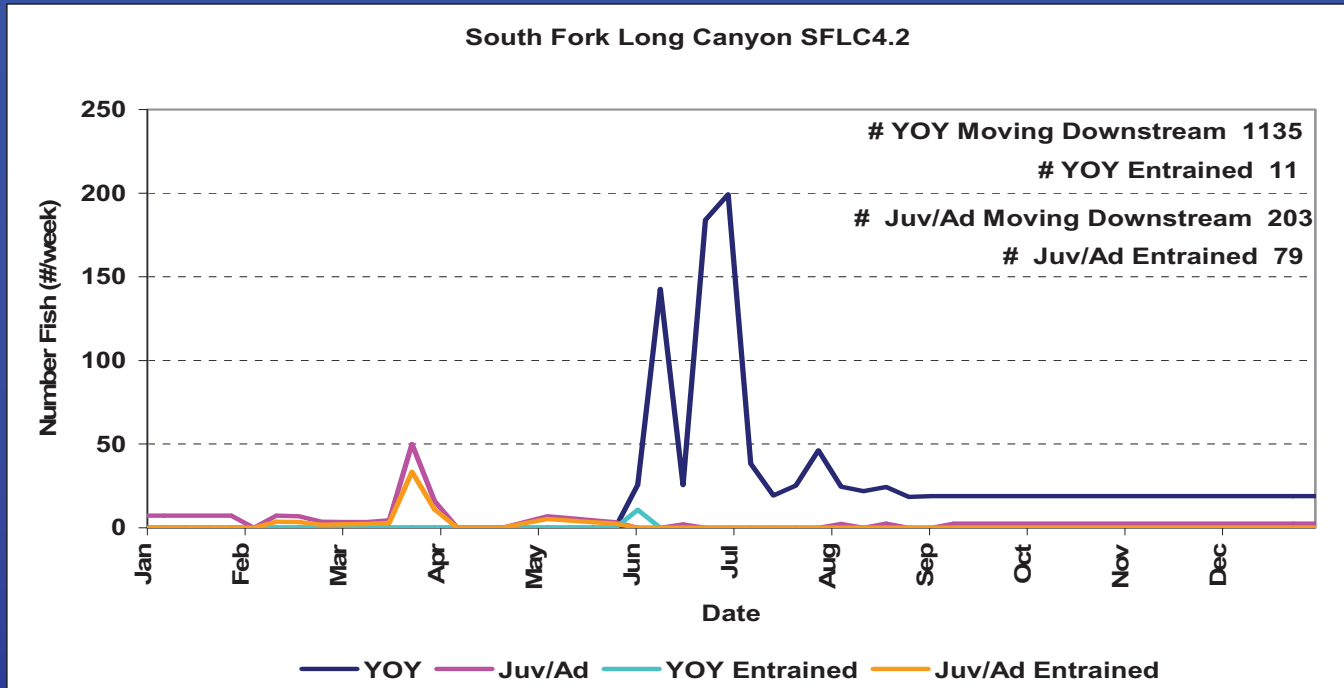
# Duncan Creek



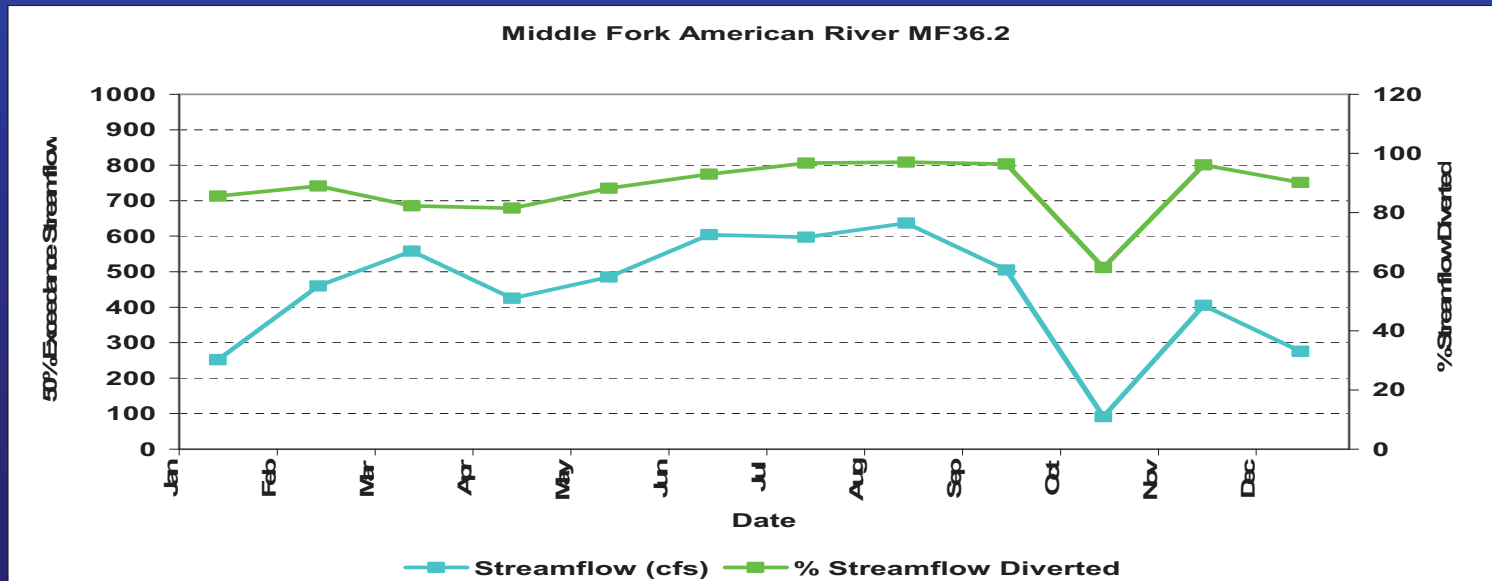
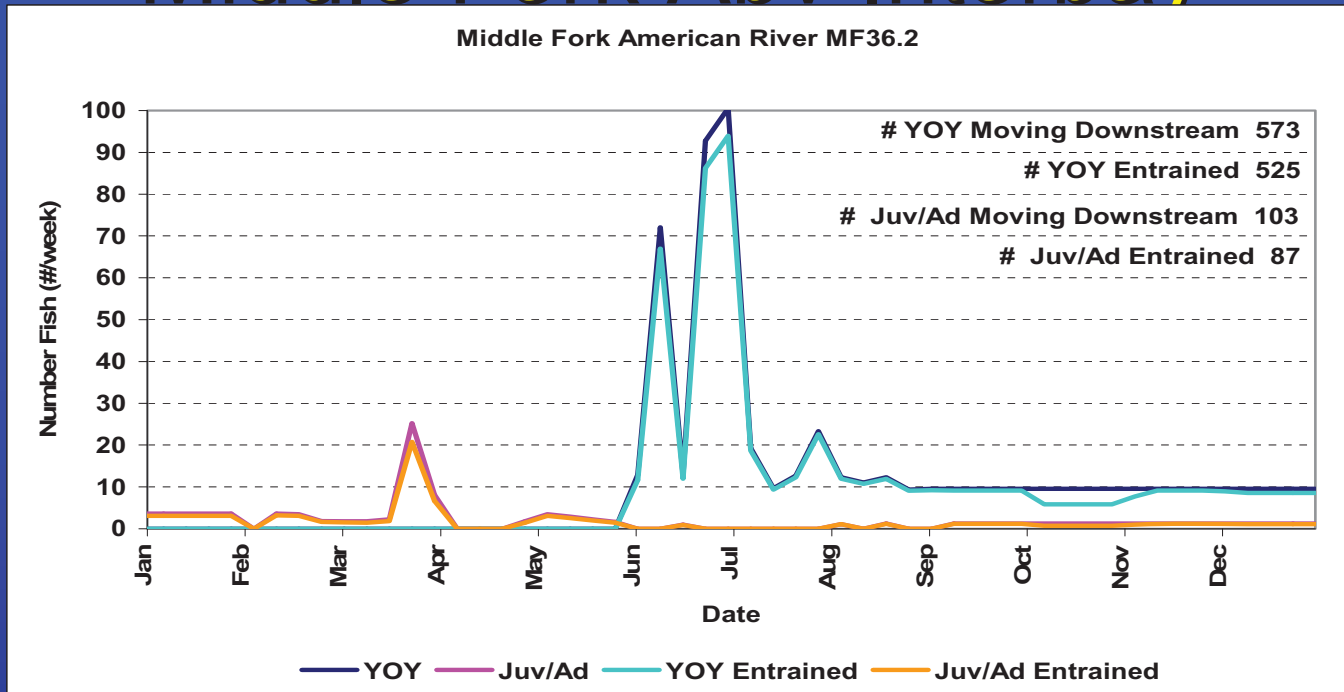
# North Fork Long Canyon Creek



# South Fork Long Canyon Creek



# Middle Fork Abv Interbay

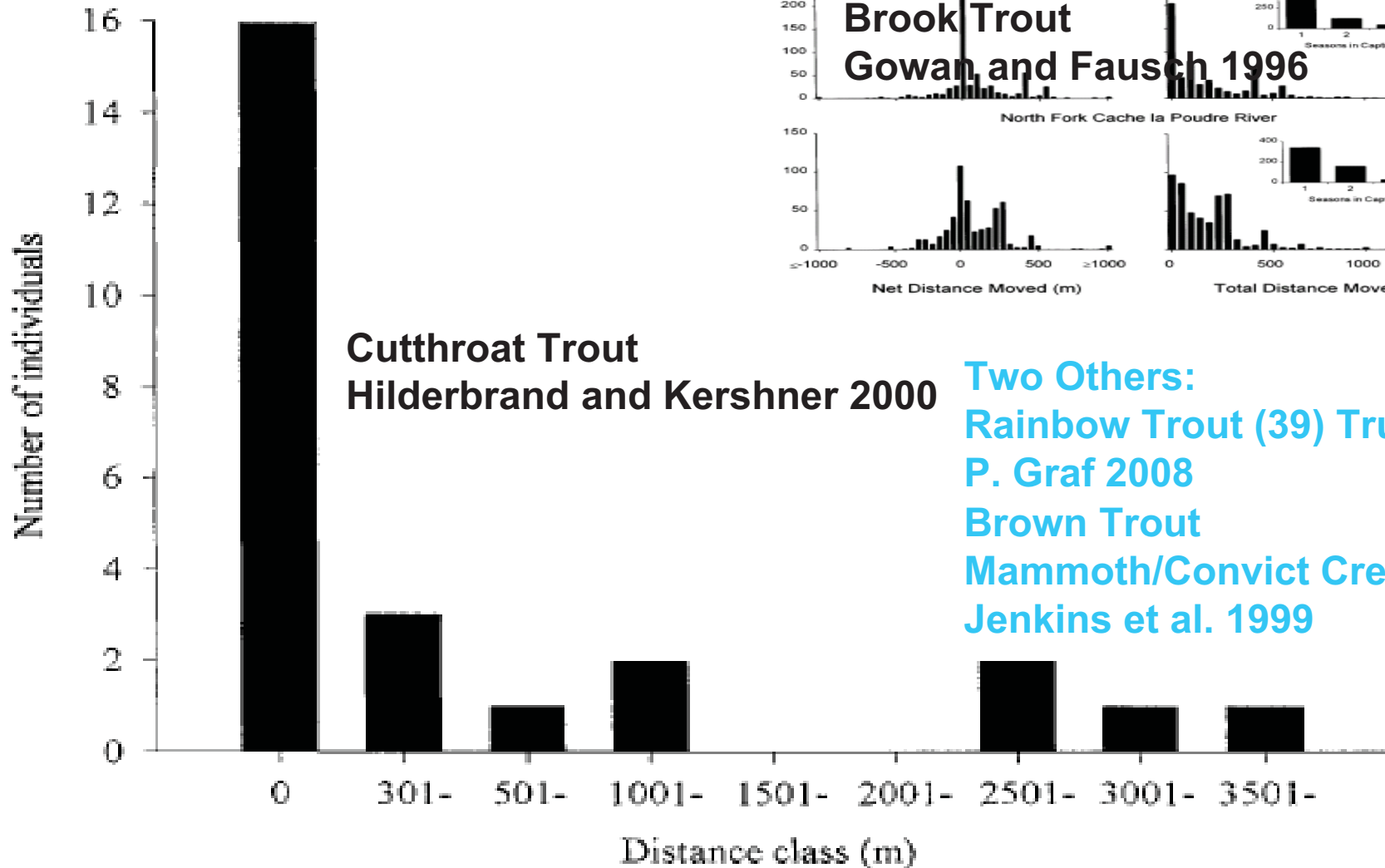


# Summary of Empirical Entrainment Results

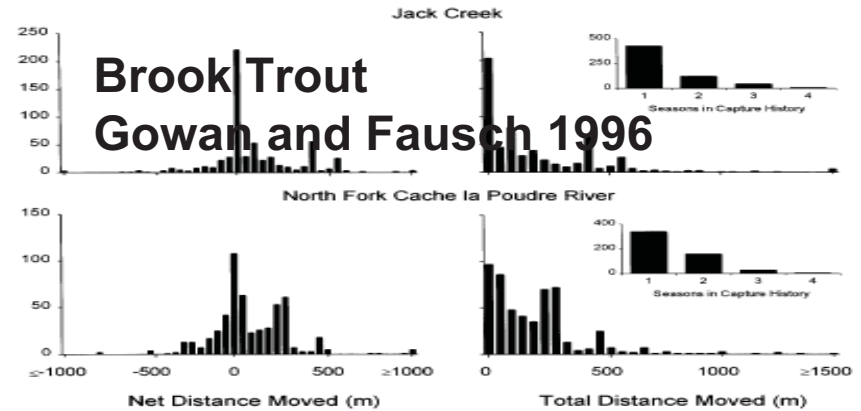
	NF Long Canyon		SF Long Canyon		Duncan Creek		MFAR Abv Interbay	
	# YOY	# Juv/Ad	# YOY	# Juv/Ad	# YOY	# Juv/Ad	# YOY	# Juv/Ad
Jan	0	0	0	0	0	6	0	16
Feb	0	9	0	10	0	6	0	9
Mar	0	60	0	49	0	34	0	31
Apr	0	6	0	5	0	4	0	3
May	5	12	6	14	7	12	7	9
Jun	4	0	5	0	176	1	251	1
Jul	0	0	0	0	8	0	80	0
Aug	0	0	0	0	0	0	47	2
Sep	0	0	0	0	0	0	39	5
Oct	0	0	0	0	0	0	27	3
Nov	0	0	0	0	0	0	38	5
Dec	0	0	0	0	0	0	37	5
<b>Total</b>	<b>9</b>	<b>87</b>	<b>11</b>	<b>79</b>	<b>192</b>	<b>63</b>	<b>525</b>	<b>87</b>

	% Flow Diverted			
	NF Long Canyon Ck	SF Long Canyon Ck	Duncan Ck	MFAR Abv Interbay
Jan	0%	0%	21%	86%
Feb	40%	51%	41%	89%
Mar	72%	67%	62%	82%
Apr	77%	81%	82%	82%
May	54%	74%	85%	88%
Jun	0%	0%	46%	93%
Jul	0%	0%	0%	97%
Aug	0%	0%	0%	97%
Sep	0%	0%	0%	96%
Oct	0%	0%	0%	61%
Nov	0%	0%	4%	96%
Dec	0%	0%	7%	90%

# Juvenile/Adult Trout Movement (Literature)



**Cutthroat Trout**  
Hilderbrand and Kershner 2000



**Two Others:**  
Rainbow Trout (39) Truckee  
P. Graf 2008  
Brown Trout  
Mammoth/Convict Creeks  
Jenkins et al. 1999

# Tagging and Tracking (Graf 2008)

39 Rainbow Trout

Relocate every 1-2 weeks for 1 year

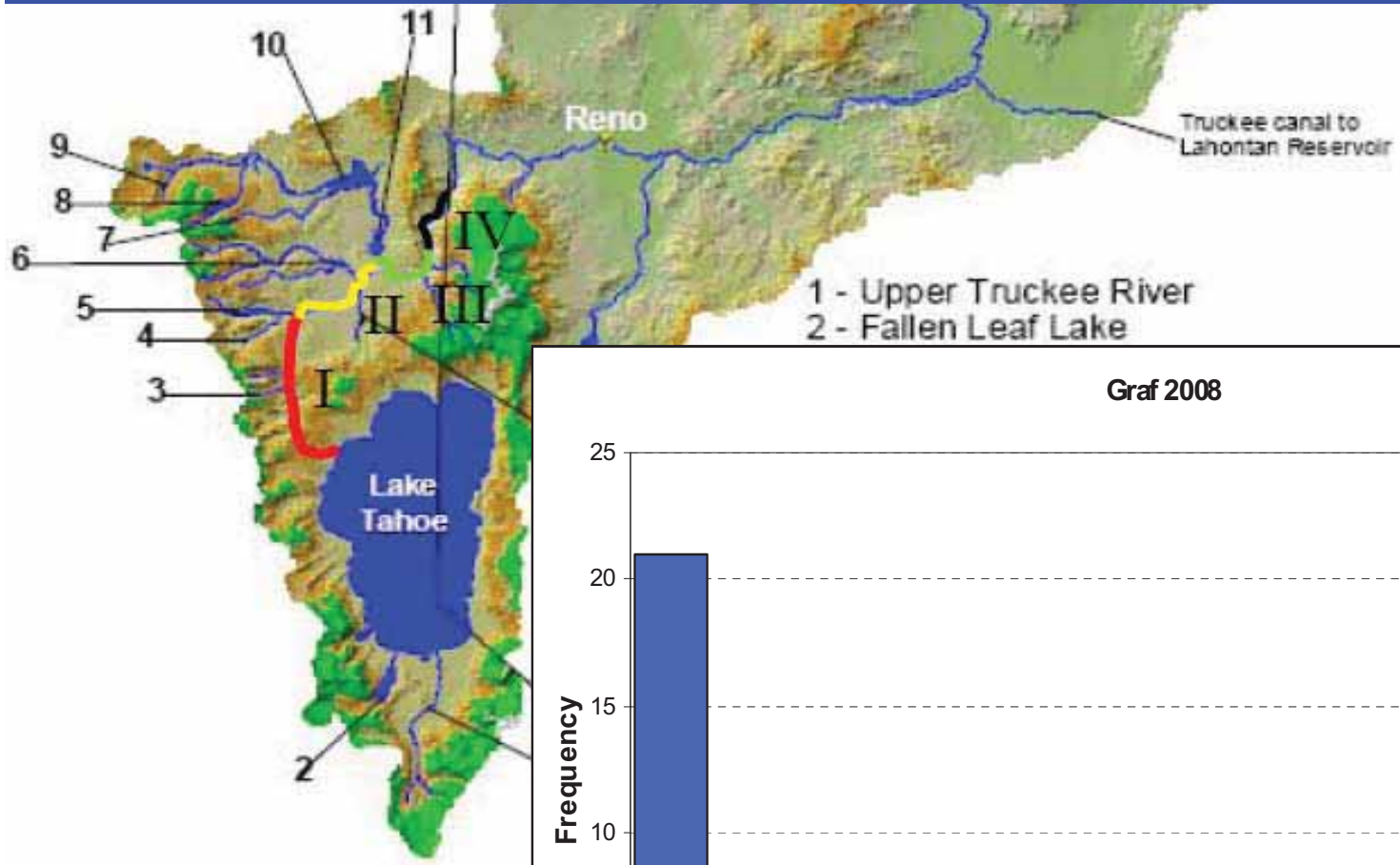
Mark with GPS

- 10 – 20 m accuracy

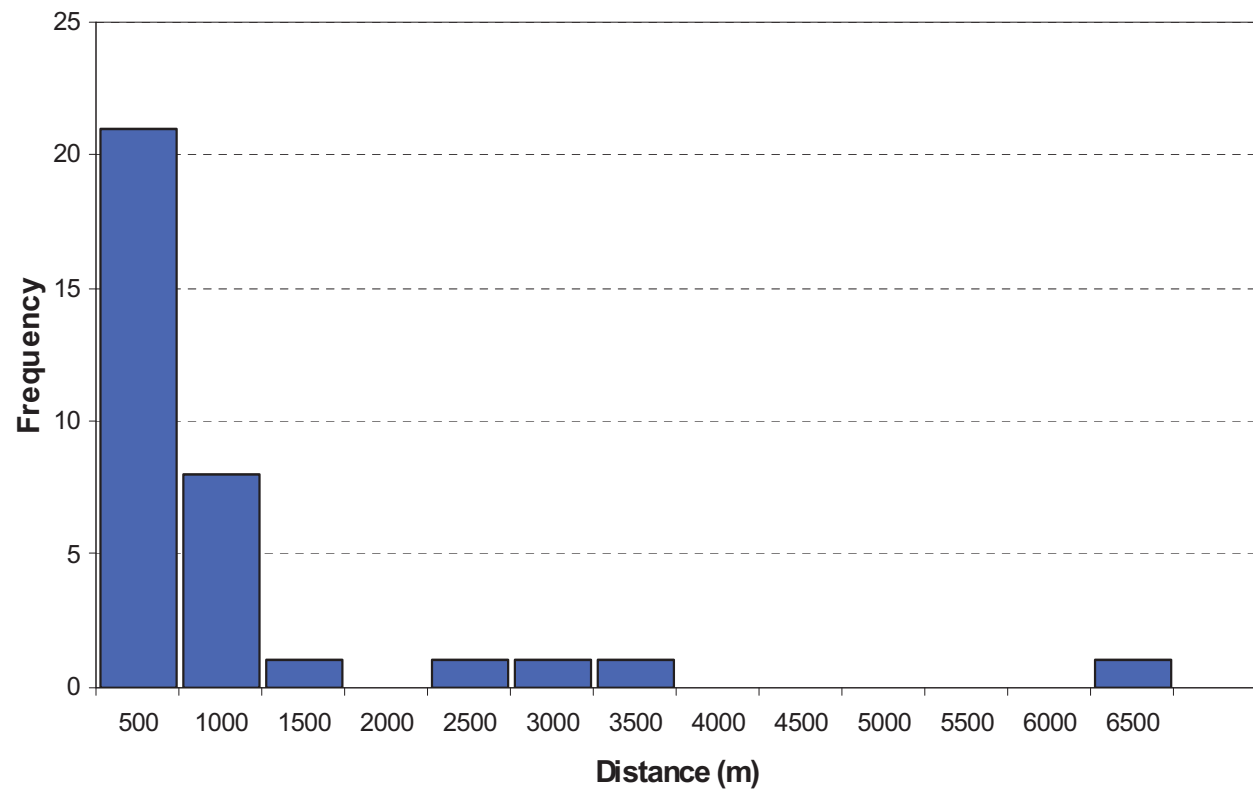
Staggered tagging = all 4 seasons captured



# Methods: Study Reaches (Graf 2008)

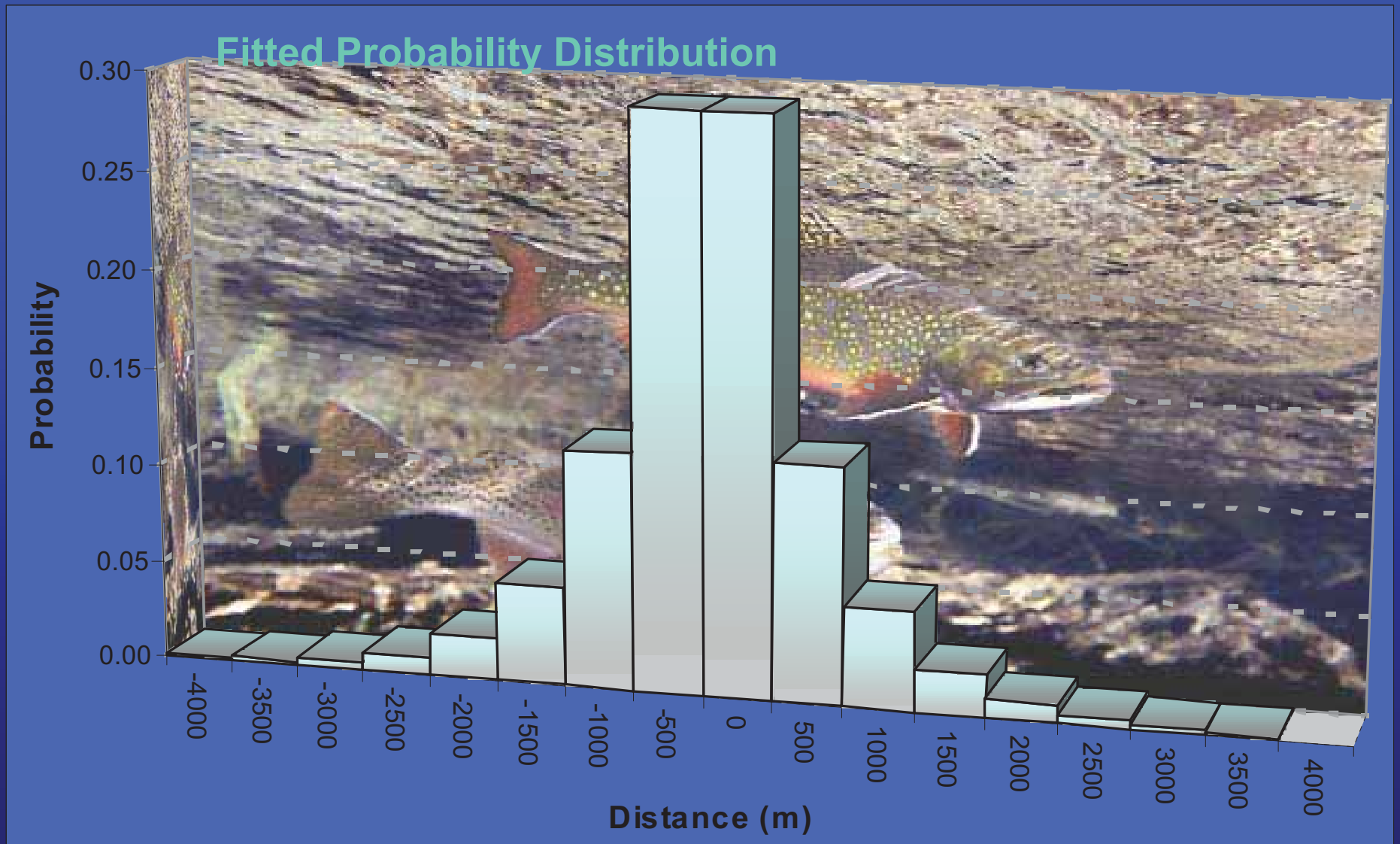


Graf 2008



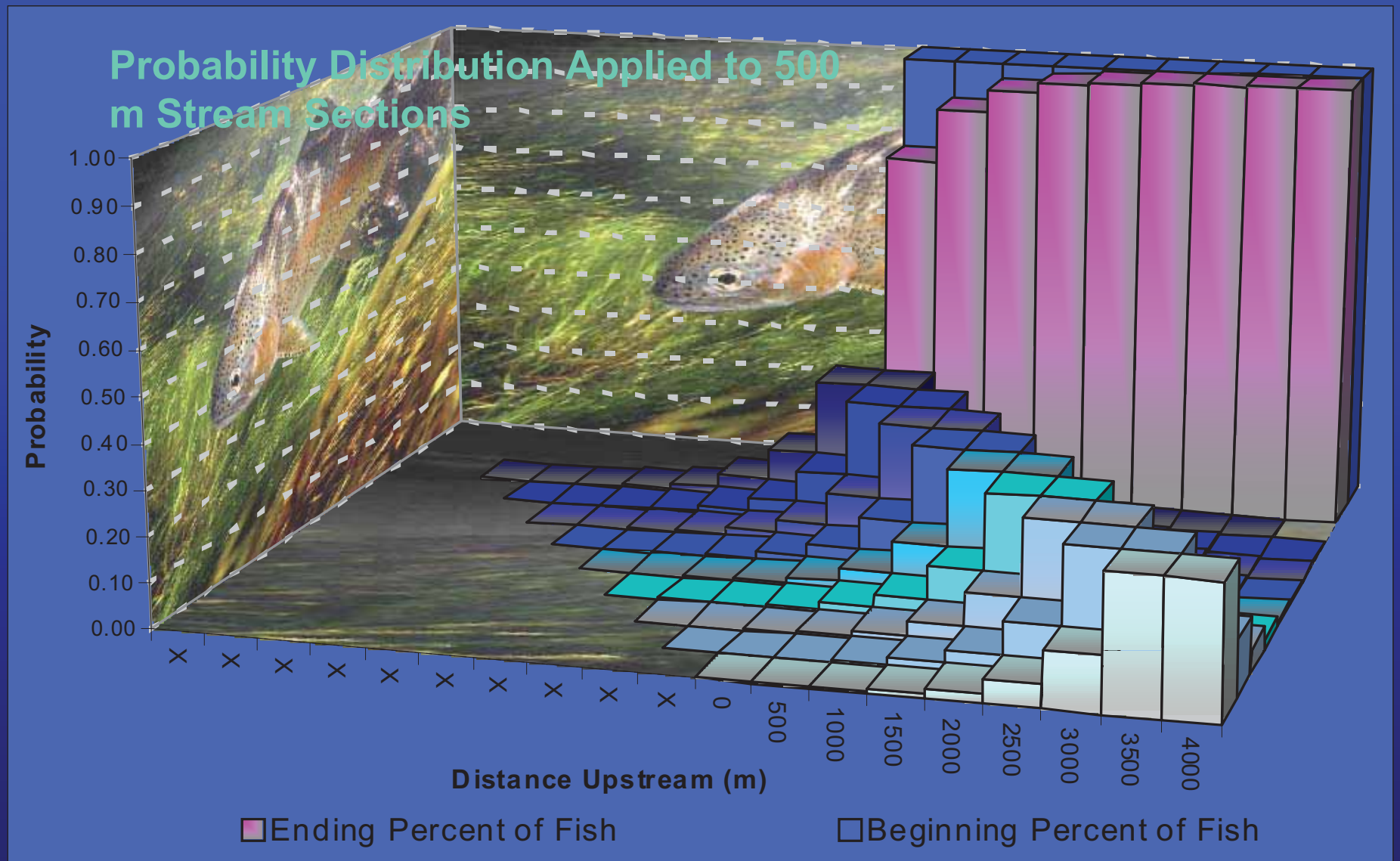
# Adult Movement Example

## Gowan Data



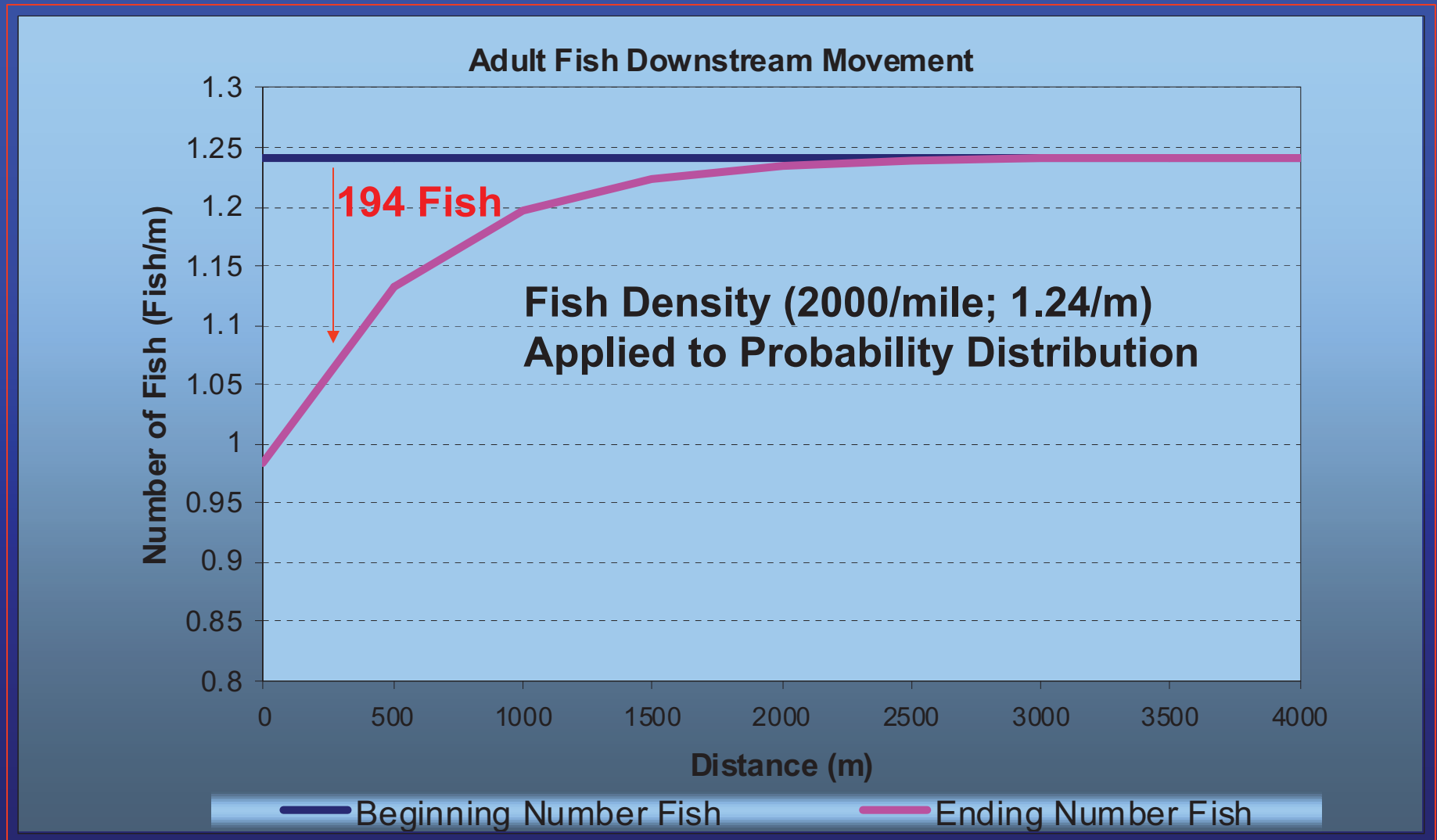
# Adult Movement Example

## Gowan Data (Continued)



Indirectly Estimate Entrainment  
and Mortality Potential

# Adult Movement Example Gowan Data (Continued)



# Summary of Adult Movement Results

**Table AQ 7-X. Total number of fish moving downstream by year and by month scaled to a population of 1000 fish/mile**

<b>Author</b>	<b>Species</b>	<b>Juv/Adult Total</b>	<b>Per Month</b>
<b>Gowan</b>	<b>Brook Trout</b>	<b>108</b>	<b>9.00</b>
<b>Hilderbrand</b>	<b>Cutthroat Trout</b>	<b>100</b>	<b>8.33</b>
<b>Jenkins *</b>	<b>Brown Trout</b>	<b>54</b>	<b>4.50</b>
<b>Graf</b>	<b>Rainbow Trout</b>	<b>89</b>	<b>7.42</b>
<b>Average</b>		<b>88</b>	<b>7.31</b>
<b>Minimum</b>		<b>54</b>	<b>4.50</b>
<b>Maximum</b>		<b>108</b>	<b>9.00</b>

\* Based on approximately 9 Months. All others include data from approximately a year.

# Summary of Adult Entrainment Results

Table AQ 7-X. Fish moving downstream and entrained per month.

Fish Moving or entrained	NFLC 3.8		SFLC 4.2		DC 9.0		MF 36.2	
	Average	(Min-Max)	Average	(Min-Max)	Average	(Min-Max)	Average	(Min-Max)
<b>Fish Moving / Month</b>	<b>11.5</b>	<b>(7.1 - 14.2)</b>	<b>10.1</b>	<b>(6.2 - 12.4)</b>	<b>7.5</b>	<b>(4.6 - 9.2)</b>	<b>5.1</b>	<b>(3.1 - 6.3)</b>
Jan (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	1.6	(1.0 - 2.0)	4.4	(2.7 - 5.4)
Feb (entrained)	4.6	(2.9 - 5.7)	5.1	(3.2 - 6.3)	3.1	(1.9 - 3.8)	4.5	(2.8 - 5.6)
Mar (entrained)	8.3	(5.1 - 10.2)	6.8	(4.2 - 8.3)	4.7	(2.9 - 5.7)	4.2	(2.6 - 5.2)
Apr (entrained)	8.9	(5.5 - 11.0)	8.1	(5.0 - 10.0)	6.1	(3.8 - 7.5)	4.1	(2.6 - 5.1)
May (entrained)	6.2	(3.8 - 7.6)	7.4	(4.6 - 9.1)	6.3	(3.9 - 7.8)	4.5	(2.8 - 5.5)
Jun (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	3.4	(2.1 - 4.2)	4.7	(2.9 - 5.8)
Jul (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	4.9	(3.0 - 6.1)
Aug (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	4.9	(3.0 - 6.1)
Sep (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	4.9	(3.0 - 6.0)
Oct (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	3.1	(1.9 - 3.8)
Nov (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.3	(0.2 - 0.3)	4.9	(3.0 - 6.0)
Dec (entrained)	0.0	(0.0 - 0.0)	0.0	(0.0 - 0.0)	0.5	(0.3 - 0.7)	4.6	(2.8 - 5.6)
<b>Year Total (entrained)</b>	<b>28.0</b>	<b>(17.2 - 34.5)</b>	<b>27.5</b>	<b>(16.9 - 33.8)</b>	<b>26.0</b>	<b>(16.0 - 32.0)</b>	<b>53.8</b>	<b>(33.1 - 66.2)</b>

Table AQ 7-X. Fifty percent exceedance diversion percent.

Month	NFLC 3.8	SFLC 4.2	DC 9.0	MF 36.2
Jan	0	0	21	86
Feb	40	51	41	89
Mar	72	67	62	82
Apr	77	81	82	82
May	54	74	85	88
Jun	0	0	46	93
Jul	0	0	0	97
Aug	0	0	0	97
Sep	0	0	0	96
Oct	0	0	0	61
Nov	0	0	4	96
Dec	0	0	7	90

# YOY Trout Mortality and Movement (Literature)

- Critical Period (2-3 Months) of High Early Mortality Followed by Lower, but still High Mortality
- First Year only 10% or Fewer (Sometimes <1%) Survive

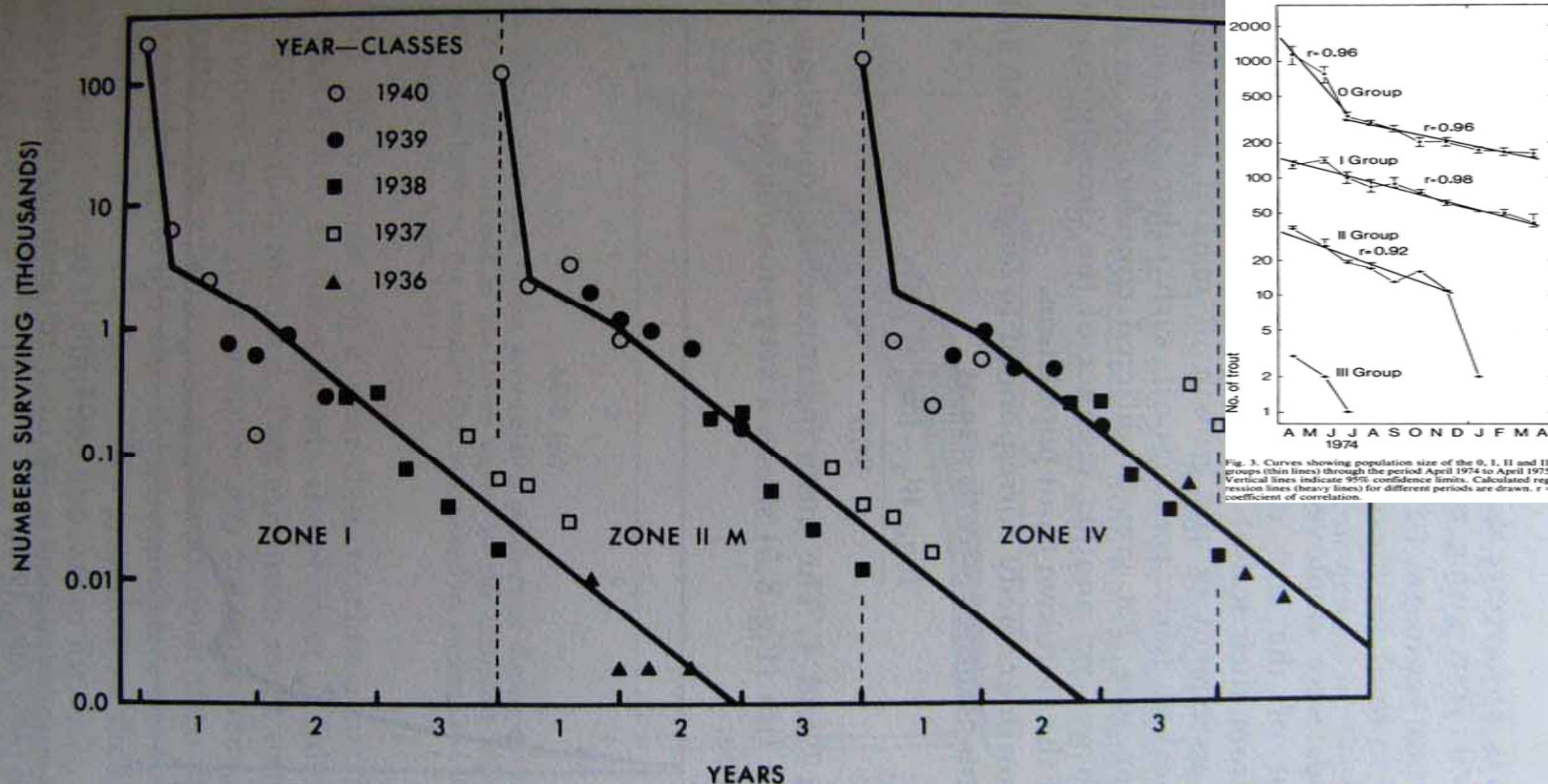


Fig. 8.4. The estimated number of trout surviving to each age in three zones—I, IIM and IV in the Horokiwi Stream. The points for successive year-classes have been combined to represent a composite year-class in each zone. The vertical scale for number of fish is logarithmic. (After Allen, 1951.)

# YOY Trout Mortality and Movement (Literature) (cont.)

- Elliott (Brown Trout) During Critical Period Mortality Density Dependent (Compensatory Mortality), but Depends on Density

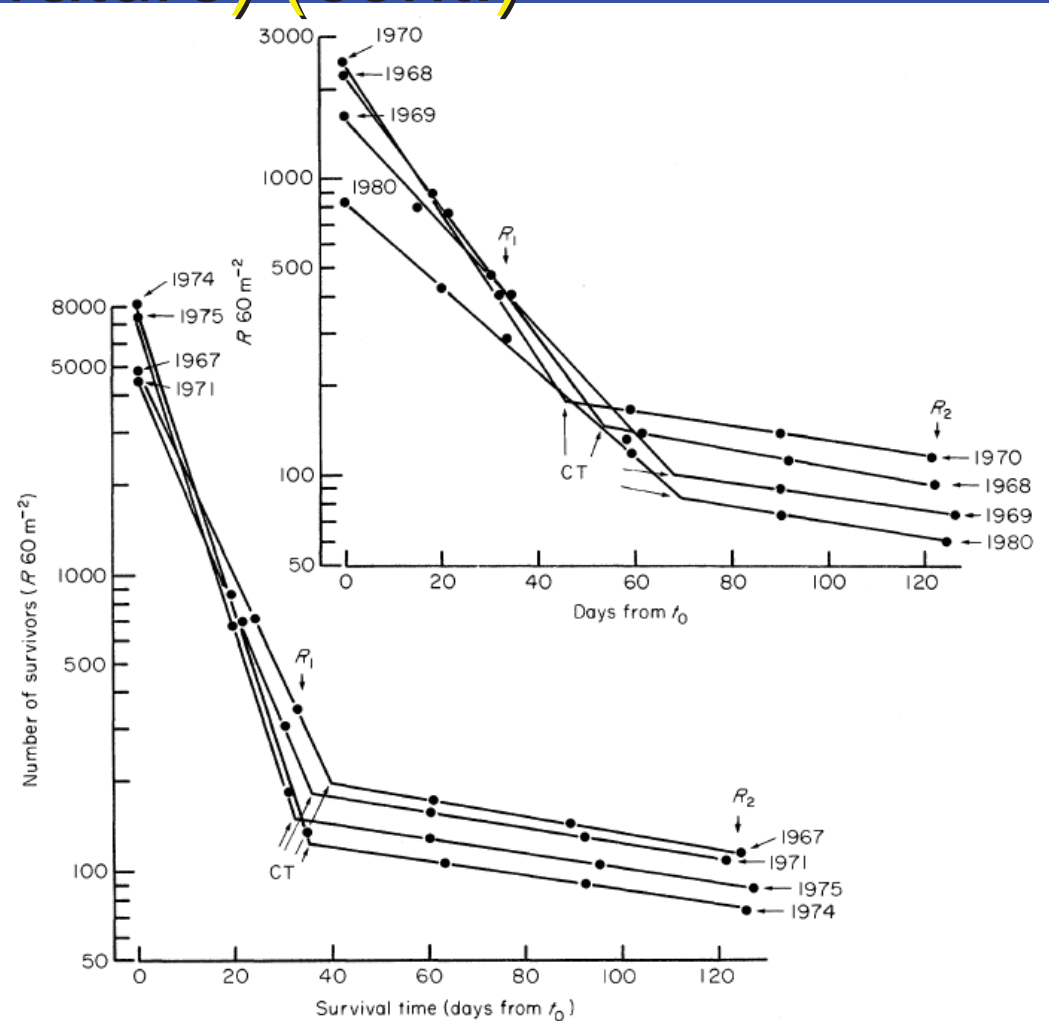
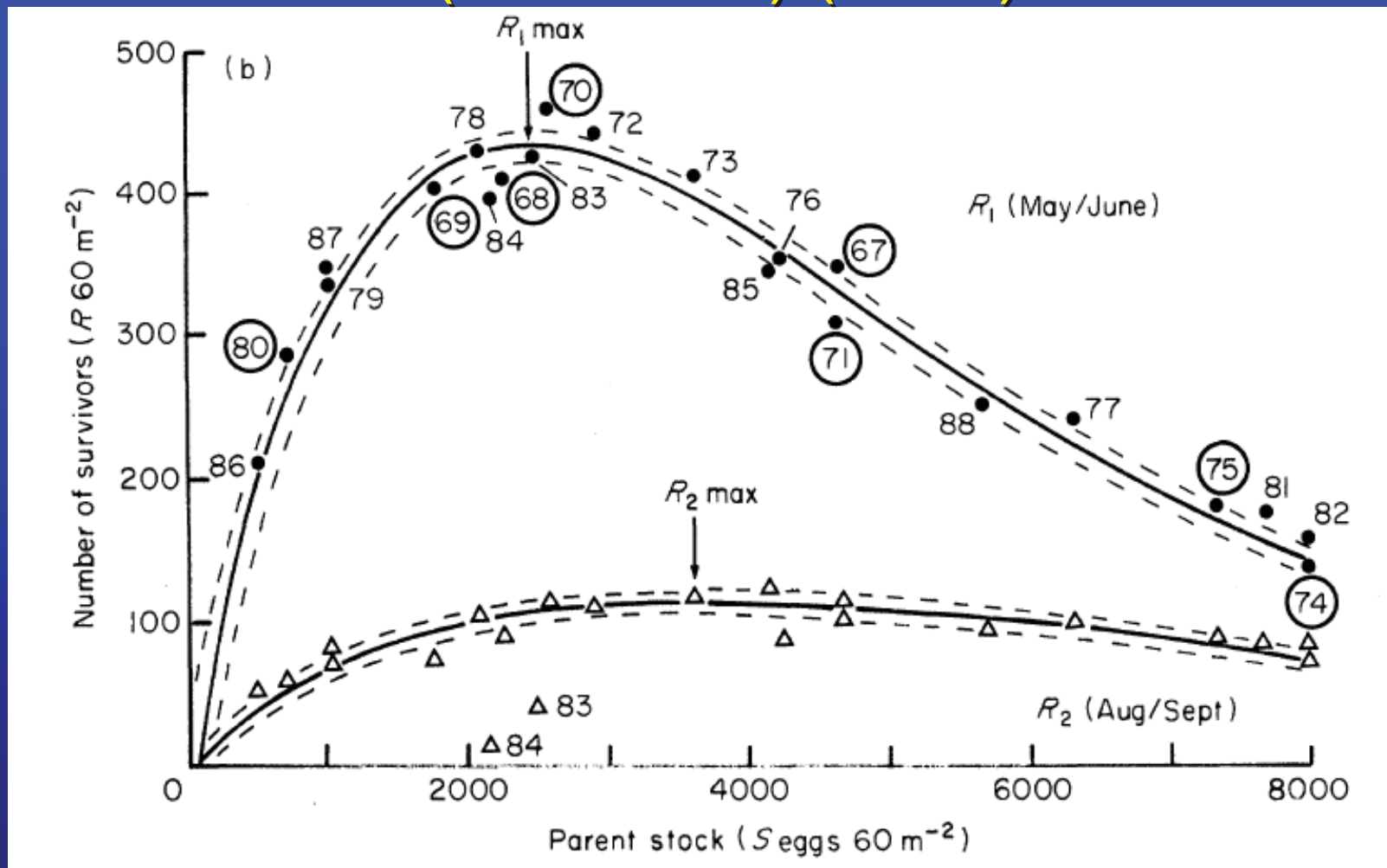


FIG. 3. Relationship between number of survivors ( $R$  fish per  $60 \text{ m}^2$ ) and survival time ( $t$  days from  $t_0$ ) for the eight year-classes sampled frequently by electrofishing; samples used in long-term study indicated as  $R_1$  and  $R_2$  (linear regression before and after critical survival time (CT):  $\ln R = a - bt$ , where values of  $a$  and  $b$  are given in Table 1).

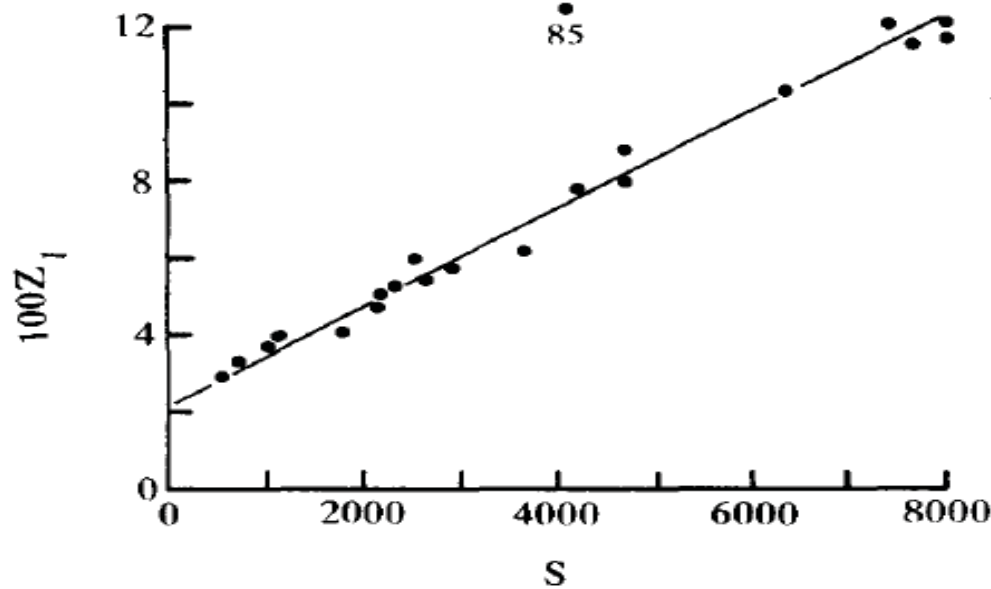
# YOY Trout Mortality and Movement (Literature) (cont.)



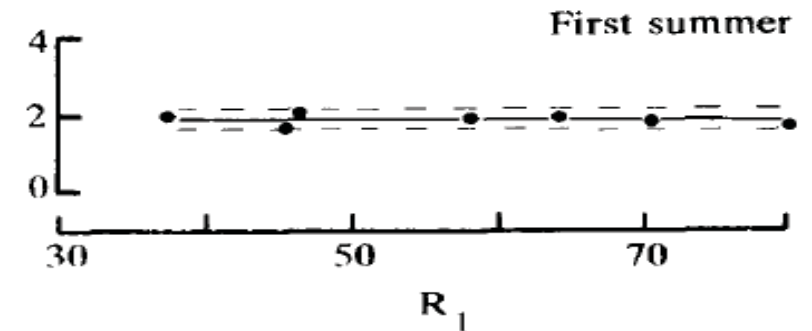
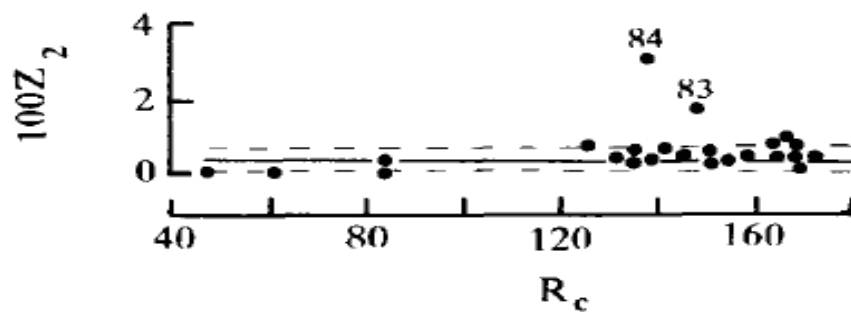
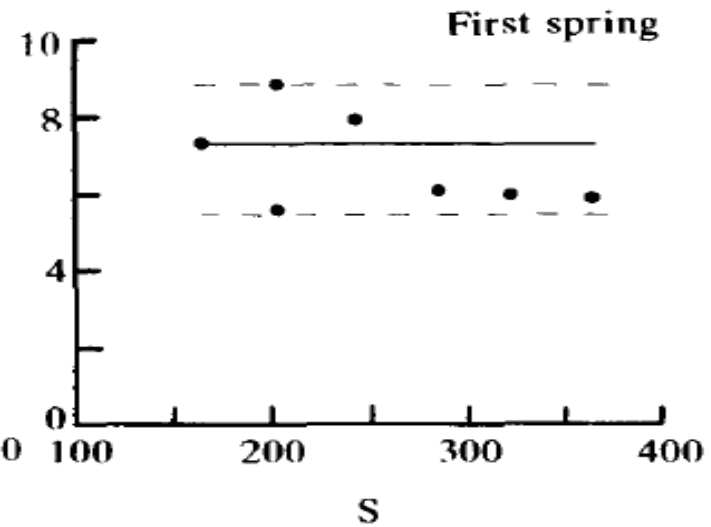
- Elliott (Brown Trout) Density Dependent Mortality

# YOY Trout Mortality (Literature)

(a) BLACK BROWS BECK

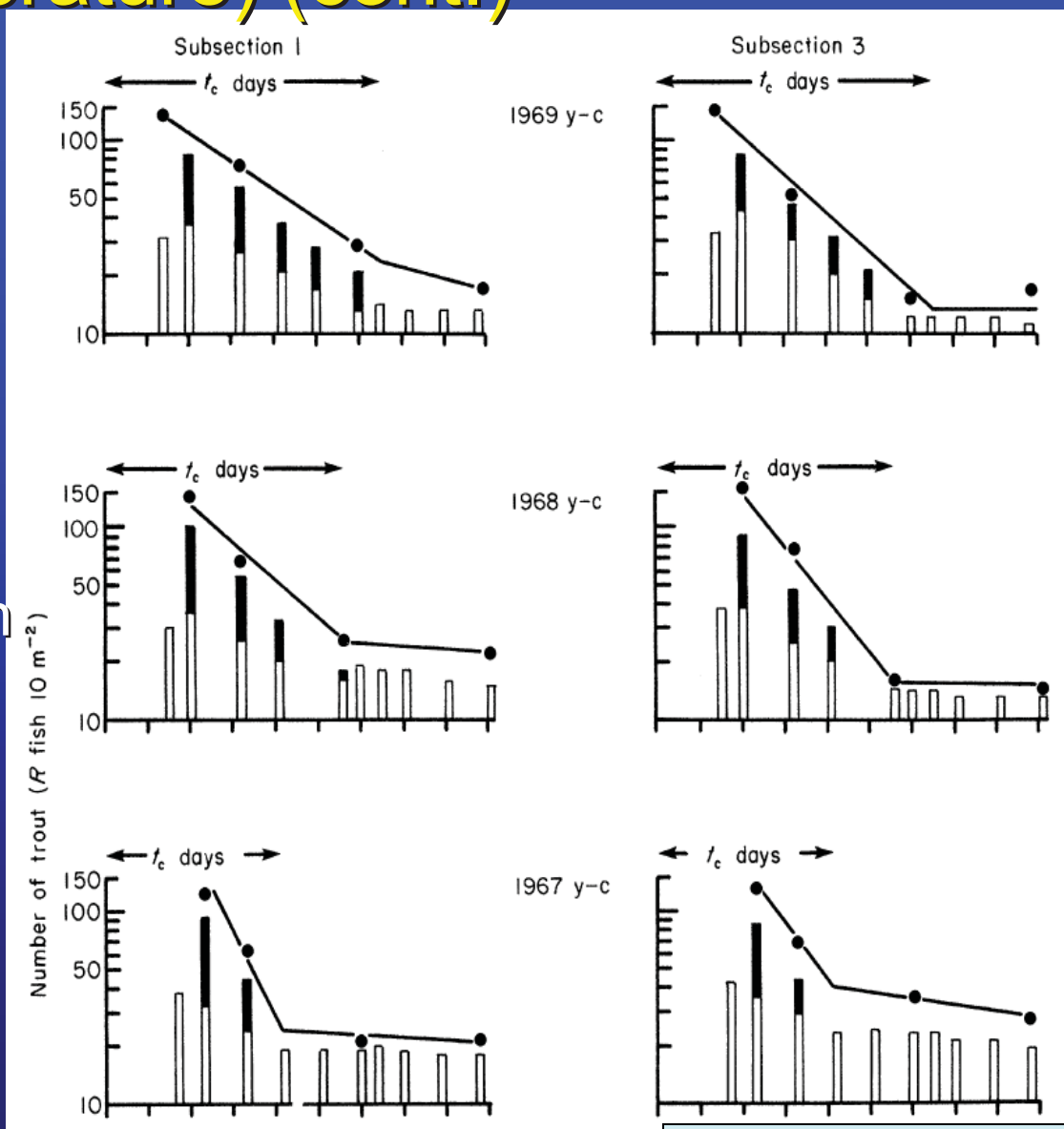


(b) WILFIN BECK



# YOY Trout Mortality and Movement (Literature) (cont.)

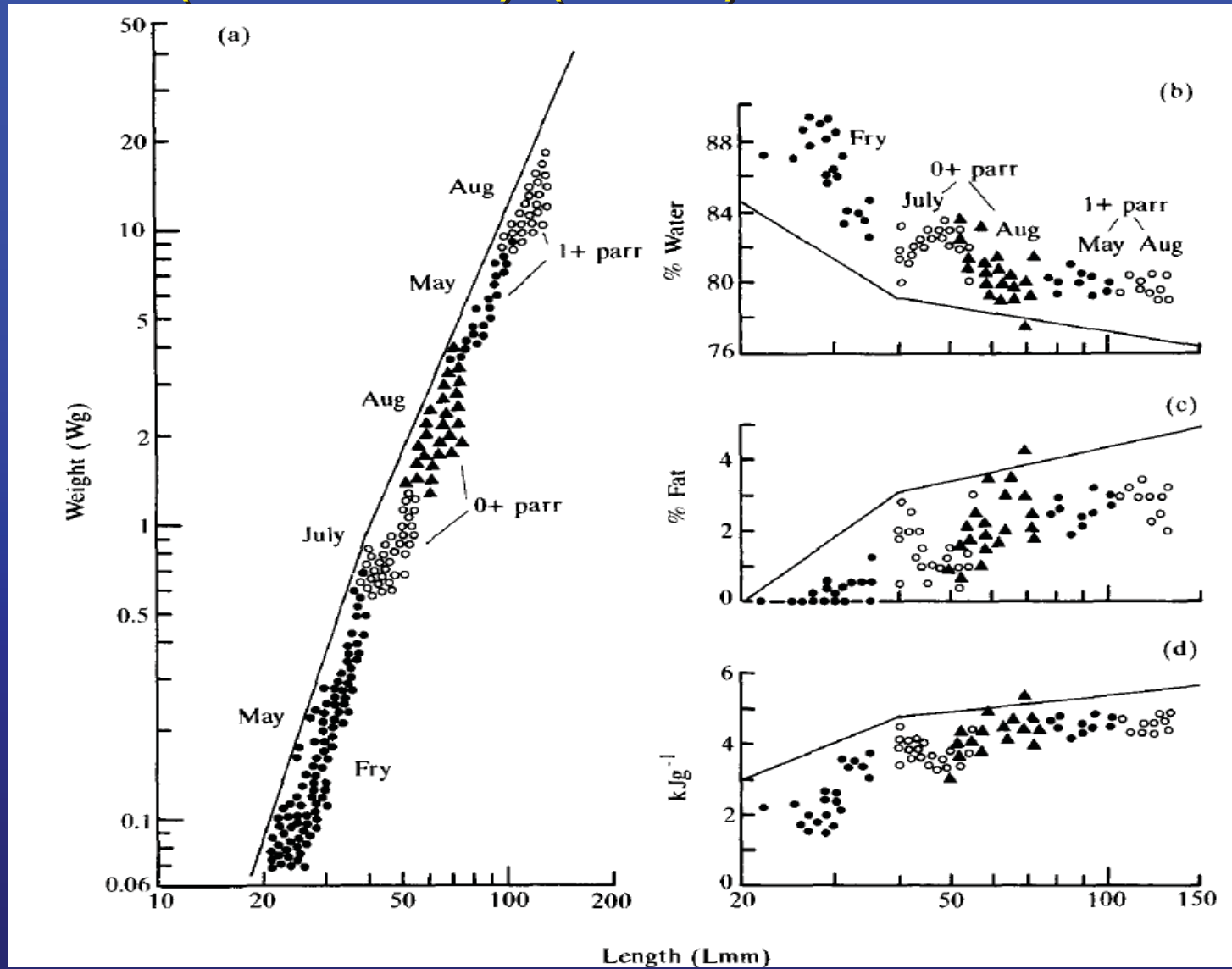
- Elliott (Brown Trout) During Critical Period Fry (1-6) Defend a Territory and Those Without Territories Lost From Population (Die or Migration)
- Vast Majority Died Within Site (Elliott) and of Those Emigrating Vast Majority Moribund
- Other Situations Can Provide Downstream Seeding



Indirectly Estimate Entrainment and Mortality Potential

# YOY Trout Mortality and Movement (Literature) (cont.)

- Moribund Emigrating Fry



# YOY Trout Mortality and Movement (Literature) (cont.)

## Downstream Seeding

- Steelhead Fry Point Stocking (Lake Superior Tribs) (500-1000 / 100 m<sup>2</sup>)

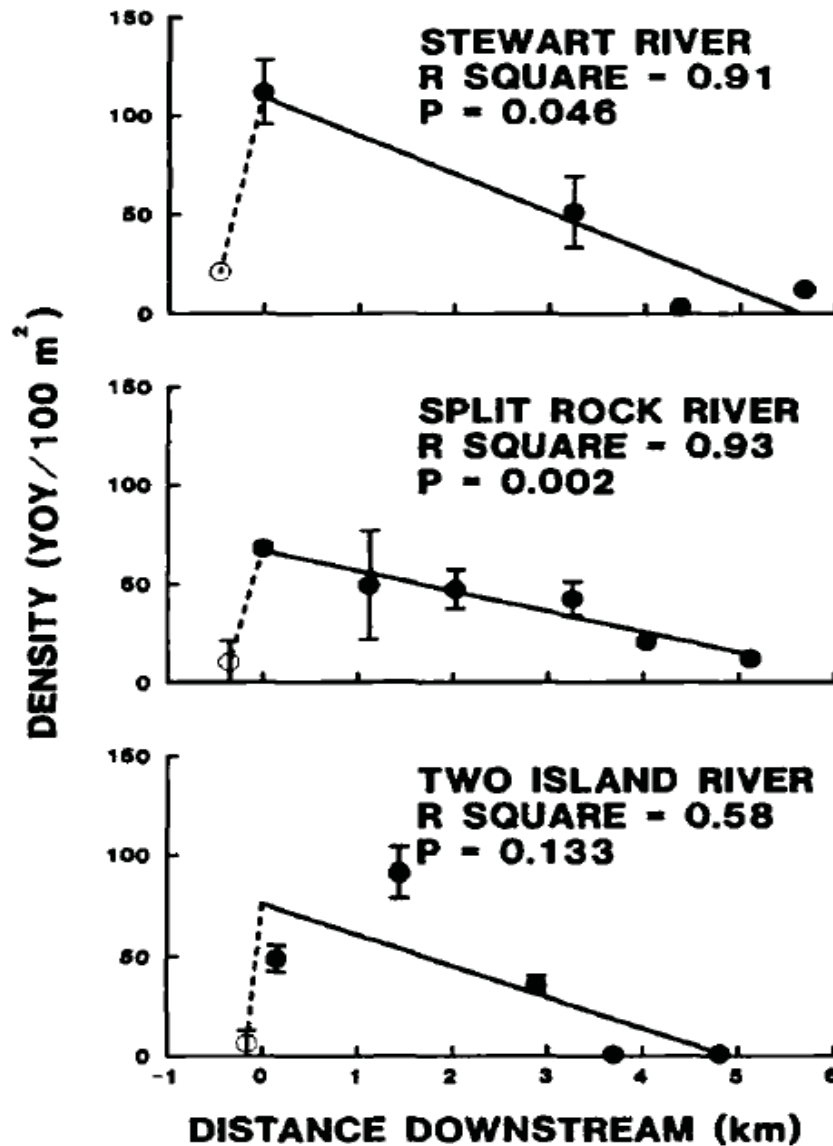


FIGURE 1.—Densities of age-0 steelhead (young-of-the-

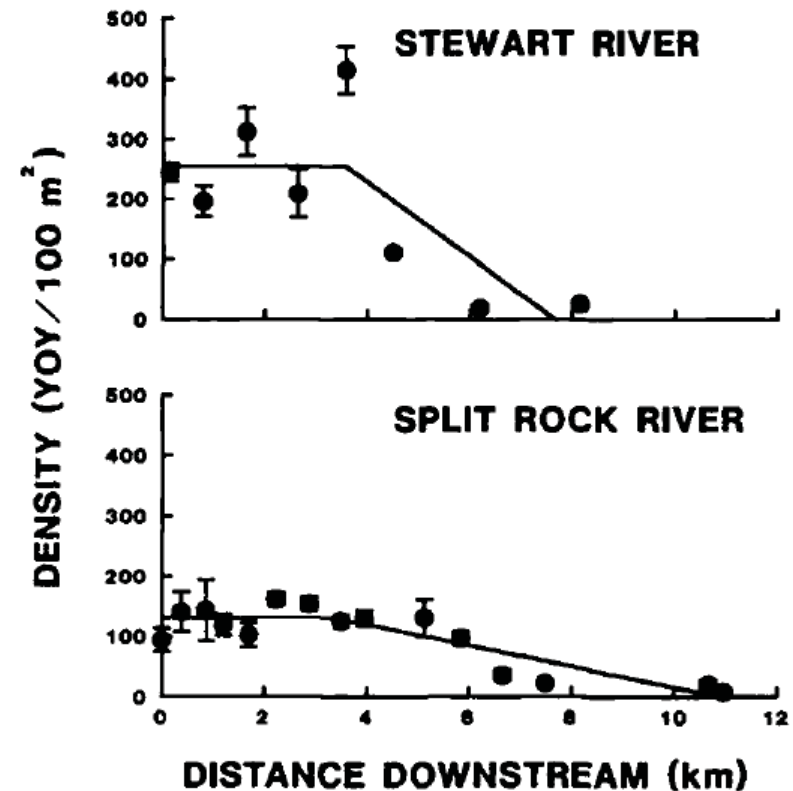
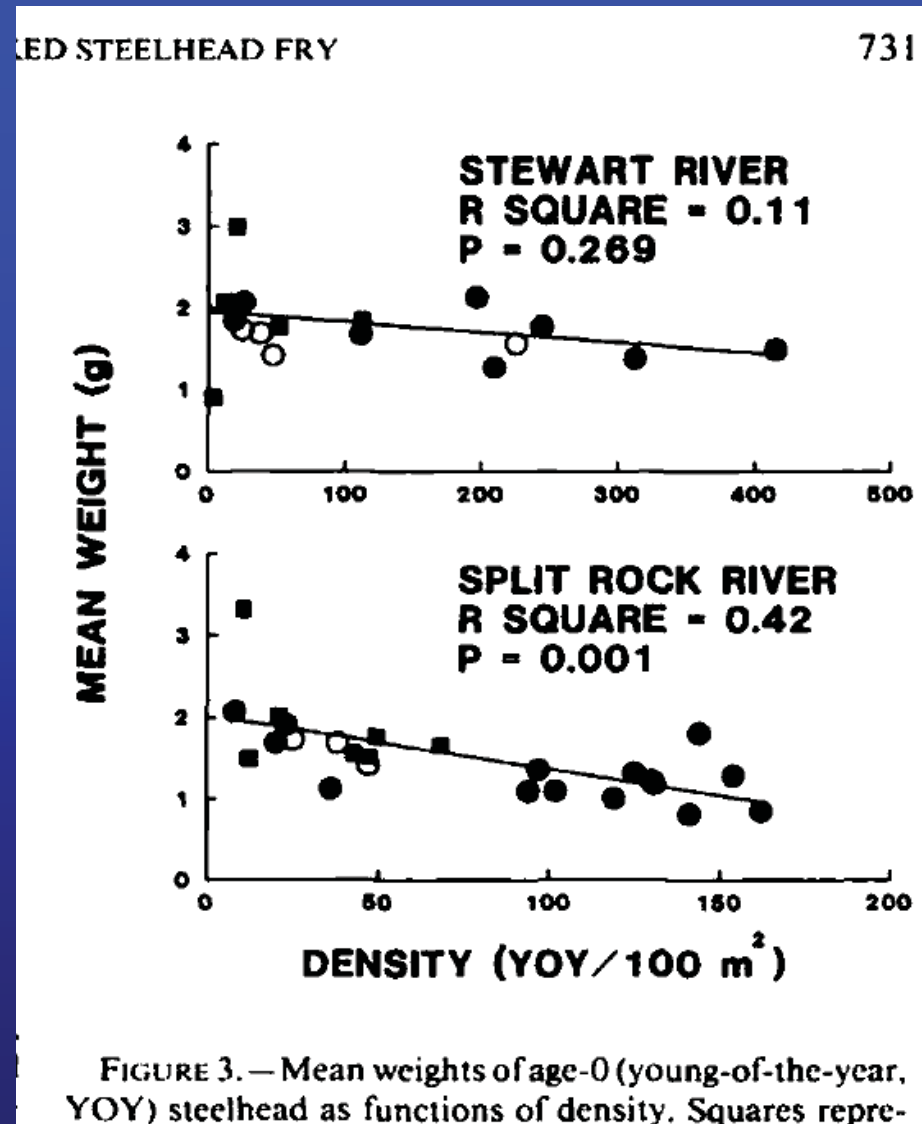


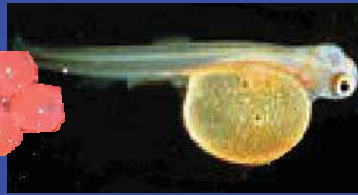
FIGURE 2.—Densities of age-0 (young-of-the-year,

University of Minnesota  
and Mortality Potential

# YOY Trout Mortality and Movement (Literature) (cont.)

- Also Density Dependent Growth—Which Can Lead to Density Dependent Overwinter Survival





**Eggs and Alevins In Gravel**  
4+ Weeks



**Fry Emerge**  
Early June:  
Critical Period  
2-3 Months



**2+ and 3+**  
(>158 mm Fall)  
**Adult Spawning**  
(>120+ mm; 7- 8 C)

**Mechanistic YOY Entrainment:**

1. Number of Each Lifestage
2. Number Moving Downstream
3. Fraction Entrained In Diversion



**YOY <100 mm (Fall)**

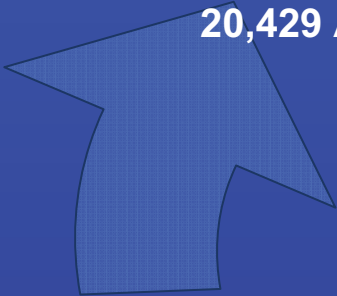


**Juvenile**  
**1+ <158 mm (Fall)**

Indirectly Estimate Entrainment  
and Mortality Potential



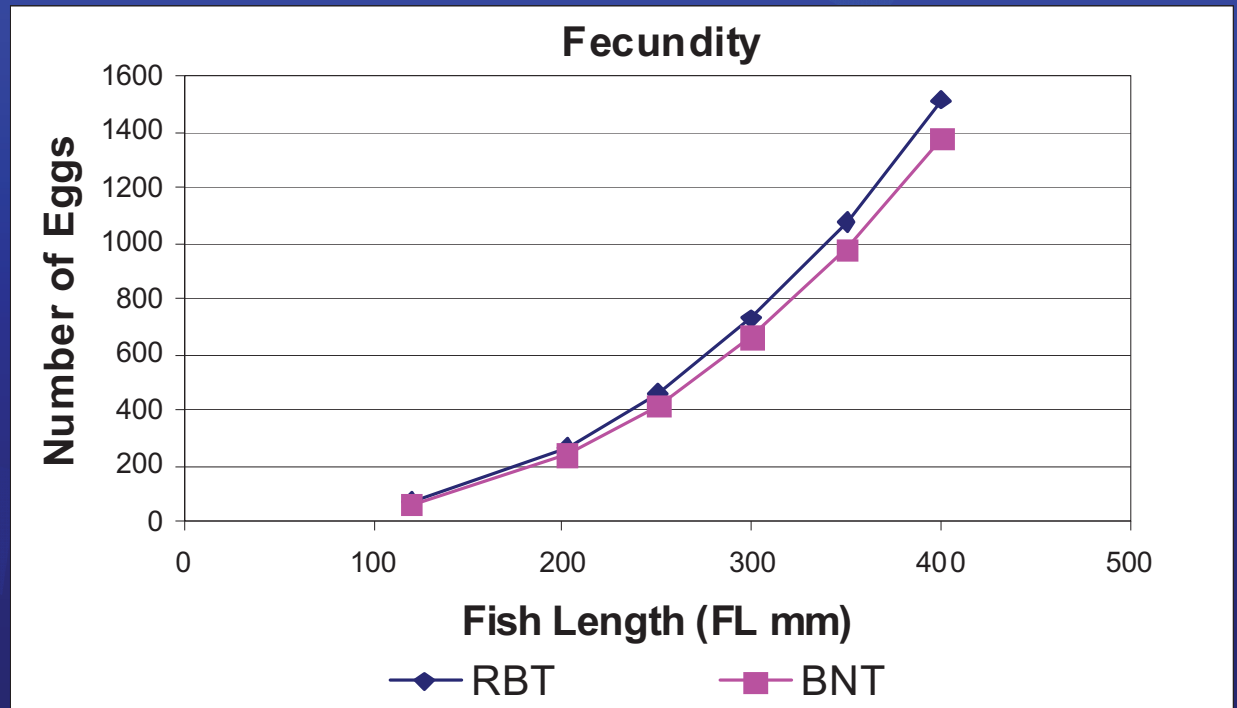
90% Eggs Deposited in Redds  
20,429 Alevins / Mile



**Duncan Creek Abv Diversion:**  
137 Adult Females / Mile  
166 Eggs / Female (average)  
90% Eggs Deposited in Redds  
20,429 Alevins / Mile @ 100 Survival

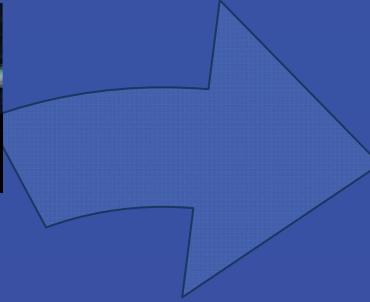


2+ and 3+  
137 Adult Females / Mile  
166 Eggs / Female

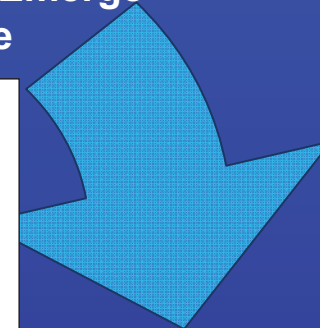




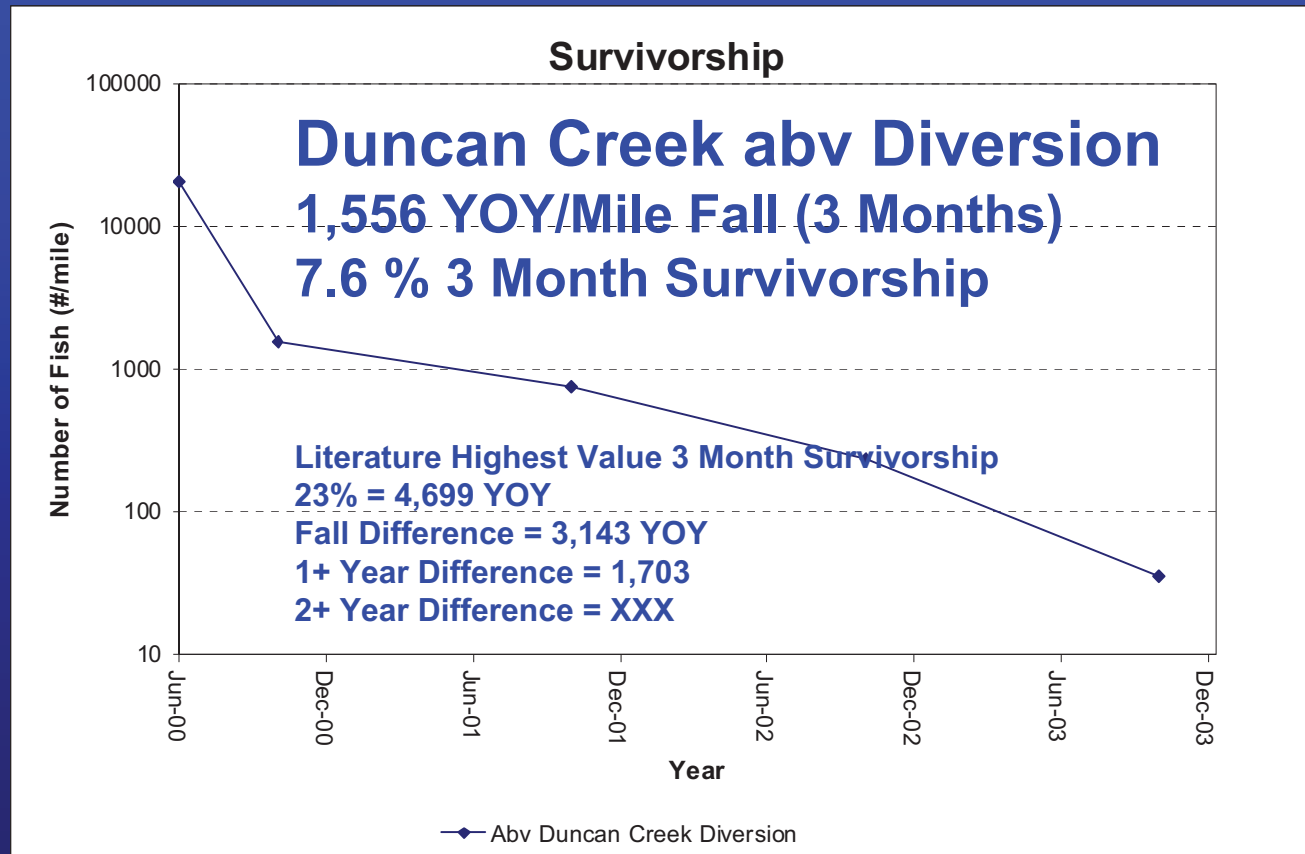
20,429 Alevins / Mile



20,429 Fry / Mile Emerge  
Early June

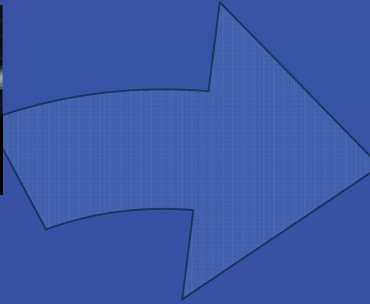


1,556  
Y <100 mm (Fall)

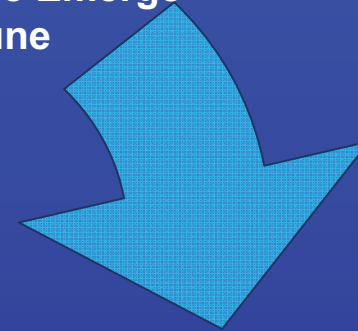




20,429 Alevins / Mile



20,429 Fry / Mile Emerge  
Early June



1,556  
YOY <100 mm (Fall)

To Be Continued.....

- Estimate Maximum Number YOY Moving Downstream (some difficulties inherent in assessment)
- Estimate if Downstream Needs Seeding (some assumptions inherent in assessment)
- Estimate Amount of YOY Nutrient Transport (lbs of fish) and/or Eventual Number of 1+, 2+, 3+ Produced
- Estimate Number of Redds Required to Replace Entrained Fish



Indirectly Estimate Entrainment  
and Mortality Potential

# Entrainment Assessment Threshold Calculation Approach

- Canal Entrainment Data (appear higher)
  - Two Literature Papers
    - Bow River Canada..1683 RBT during irrigation period
    - Smith River Wyoming.. 403 Cutt/BNT during irrigation Period
  - DeSabla (working on)
  - Stanislaus (?)
- Currently Working on This

# Entrainment Assessment Threshold Calculation Approach

Also To Be Continued.....

- Ralston Afterbay
  - Fish Sampling June and September
  - Refined Powerhouse Survivorship Estimates