# 2009 Population Size Estimates for Adult Rainbow Trout (*Oncorhynchus mykiss*) in San Antonio and Calaveras Reservoirs

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**Water Enterprise**
Natural Resources and Lands Management Division
Fisheries and Wildlife Section
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San Antonio Reservoir (Figure 1), located in Alameda County, and Calaveras Reservoir (Figure 2), located in Alameda and Santa Clara counties, are owned by the City and County of San Francisco and operated by the San Francisco Public Utilities Commission (SFPUC). Both water storage reservoirs collect local runoff from the Sunol Drainage Unit of the Southern Alameda Creek Watershed. San Antonio Reservoir is also plumbed to accept waters from the SFPUC's Hetch Hetchy Reservoir and the State Water Project. The maximum storage capacity of San Antonio Reservoir is 50,500 acre-feet, while the capacity of Calaveras is 96,850 acre-feet.

When San Antonio and Calaveras reservoirs were constructed on Alameda Creek tributaries, in the mid- and early 1900's, respectively, they effectively blocked the upstream movements of both resident and transient fishes. Reservoir fishes are also not able to move downstream of the two dams during most years, although there is evidence of some downstream movement when the reservoirs spill. Today, there are self-sustaining populations of native cold and warm water fishes, along with non-native warm water species, in both reservoirs and their tributaries (SFPUC 2007).

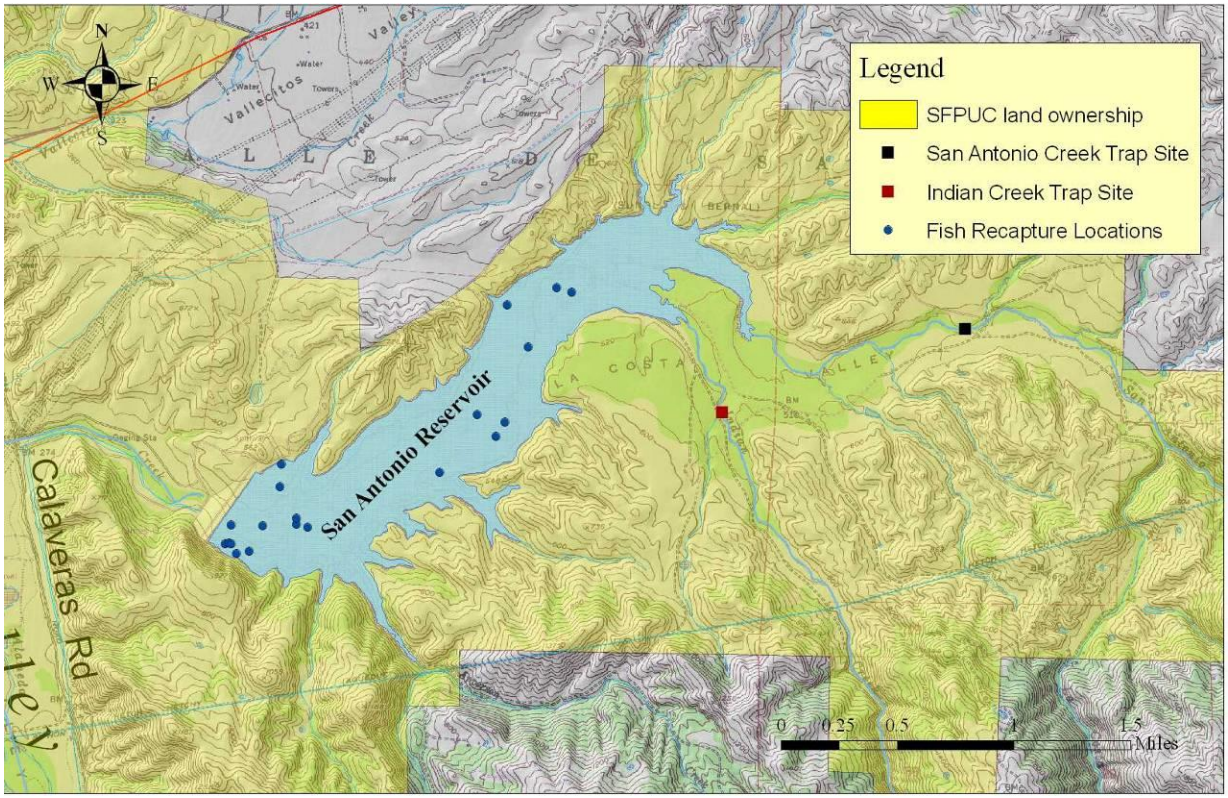


**Figure 1.** *Fish trapping stations on San Antonio and Indian creeks and San Antonio Reservoir fish recapture site.*

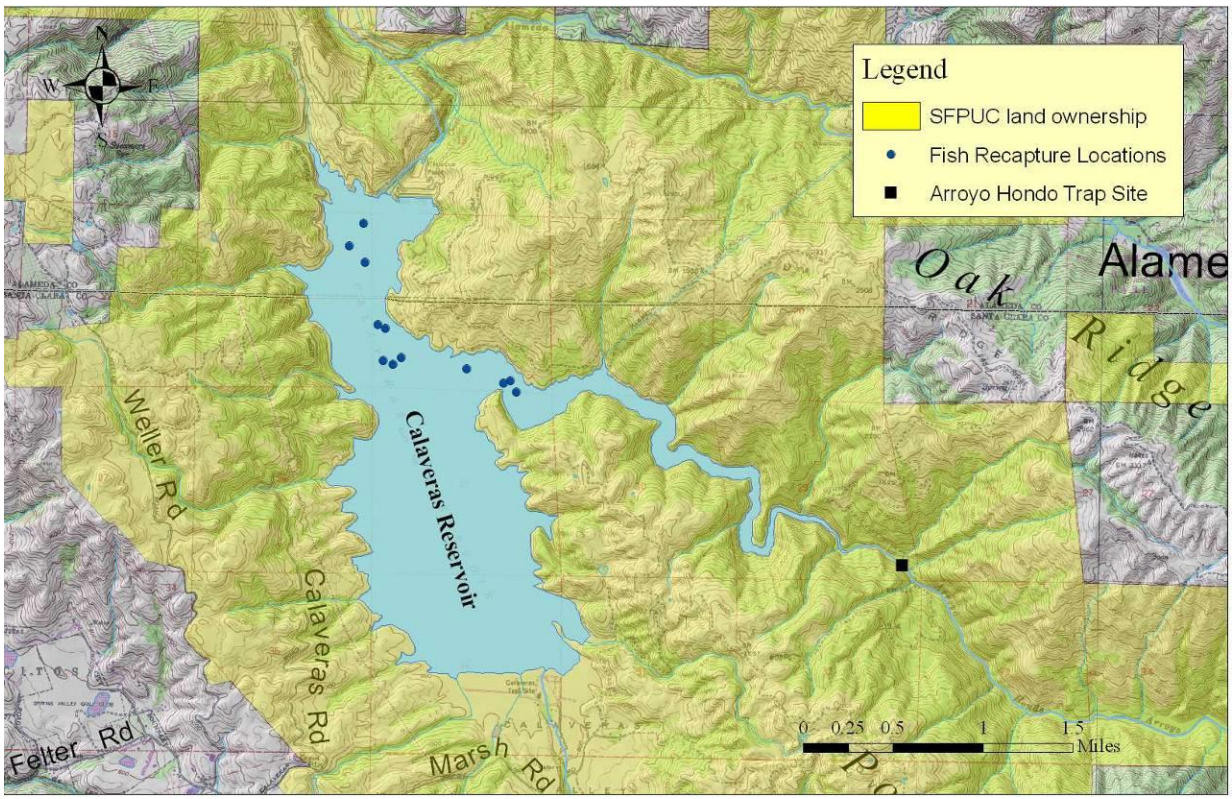


**Figure 2.** *Fish trapping station on Arroyo Hondo and fish recapture sites on Arroyo Hondo (some sites indicate multiple recaptures).*

In recent years there has been increased public interest in adfluvial rainbow trout (*Oncorhynchus mykiss*) populations in San Antonio and Calaveras reservoirs. The Alameda Creek Fisheries Restoration Workgroup has proposed using rainbow trout from the reservoirs to help jumpstart a steelhead run in the ocean-accessible portions of Alameda Creek and its tributaries (Gunther *et al.* 2000).

In 2001the California Department of Water Resources' Division of Safety of Dams placed an upper-limit restriction of 705.5 feet on Calaveras Reservoir. The California Department of Fish and Game has expressed concerns regarding the effects of an extended reservoir drawdown on the adfluvial rainbow trout population (SFPUC, 2004 and 2005a).

The Natural Resources and Lands Management Division leads the SFPUC's efforts to manage the Alameda Creek watershed lands. The division is responsible for monitoring, protecting, and restoring those lands and ecological resources under the management of the SFPUC, as well as environmental regulatory compliance for operations of the SFPUC water supply system. Protecting and conserving the resident rainbow trout that are currently in and upstream of San Antonio and Calaveras reservoirs, to both fulfill a portion of the SFPUC's mission and address other issues raised by private and public entities, requires at minimum a basic understanding of their population dynamics, biology, and behavior.

Fundamental to understanding rainbow trout in the San Antonio and Calaveras reservoir systems is determining species abundance. The goal of this long-term project is to establish a series of estimates of the number of adult rainbow trout supported by each body of water,

quantifying population sizes approximately once every five years. This report represents the second effort to estimate population sizes in these reservoirs, following the first estimates reported in Technical Memorandum No. 2-04-006 (SFPUC, 2005b).

## PROCEDURE

Population sizes of adult rainbow trout in San Antonio and Calaveras reservoirs were estimated using Schnabel's multiple census mark-and-recapture method, as modified by Chapman (Ricker 1975). The formula, $N=\Sigma(C_iM_i)/(R+1)$ was used, where N is the estimated population size, $C_i$ is the total number of fish caught during the $i^{th}$ recapture trip, $M_i$ is the size of the marked fish sub-population (number of initially marked fish, plus new fish marked during previous recapture trips, minus mortalities from previous recapture trips) at the time of the $i^{th}$ recapture trip, and R is the total number of recaptures. This equation is best suited to situations in which too few fish are collected during a single recapture outing to make a reliable population size estimate. It relies on a series of recapture trips in which all fish collected are returned to the population after the non-marked fish are marked. All observed mortalities were recorded and subtracted from the known number of tagged fish prior to population size calculations.

This study took advantage of the migratory nature of the reservoir's resident adult rainbow trout. Upstream and downstream moving trout were captured in San Antonio Creek from March 12 through May 27, 2009; in Indian Creek from March 13 through May 16, 2009; and in Arroyo Hondo from March 20 through June 15, 2009 (Figures 1-3). Adult trout were marked with Floy tags (SFPUC, *in prep*). Fish that were marked on their way upstream were not re-marked if captured again moving downstream. To document tag losses and increase the reliability of marked fish identifications, a portion of each tagged fish's adipose fin was clipped.

Weekly recapture trips were initiated August 13, 2009, alternating between the two reservoirs (Figures 1, 2 & 4). After the September 25, 2009 recapture trip on Calaveras, each weekly recapture trip took place on San Antonio Reservoir through October 22, 2009. This was due to the difficulty in launching the fishing vessel at the Calaveras boat ramp, and to the lower catch rate at San Antonio. Downriggers were used to target rainbow trout with a variety of flashers, spoons, and plugs trolled in the vicinity of the thermocline. In most cases, SFPUC biologists stayed in an area once a concentration of trout was located. Biologists landed hooked fish on the boat, took length measurements, looked for Floy tags, tag scars or clipped adipose fins, tagged and clipped non-tagged trout, and released fish as quickly as possible. Rainbow trout that died during the process, whether on board the boat or after being released, were kept for training purposes.

**Figure 3.** *Rainbow trout were initially captured for marking at San Antonio Creek, Indian Creek and Arroyo Hondo migrant traps.*


**Figure 4.** *Rainbow trout were recaptured at San Antonio and Calaveras reservoirs by trolling.*

FINDINGS

San Antonio Reservoir – Thirty-five and 28 adult rainbow trout were tagged, and fin clipped in San Antonio and Indian creeks, respectively, during the 2009 fish trapping study, for a total of 63 marked fish (SFPUC, *in prep*). There were no documented mortalities of tagged trout during the trapping study or prior to recapture trips. There were no high flow interruptions in trapping during the trapping study. However, nine of the tagged fish remained upstream of the trap sites following the completion of the study. It was assumed that these fish were not capable of returning to San Antonio Reservoir following the study because the surface water flow was seasonally disconnected by that time. Consequently, reservoir population estimate calculations were based on an initial marked sub-population of 54 rainbow trout.

There were six recapture trips made to San Antonio Reservoir between August 13 and October 22, 2009 (Table 1). Fish were captured between 30 and 70 feet, at an average depth of 54 feet. 20 fish were captured during 46 hours of fishing, at a capture rate of 0.4 fish / hour. One of the fish captured had a previously inserted tag, while one partially clipped adipose fin identified a trout that had lost a Floy tags. There were four adult trout mortalities during the recapture portion of the study, with the condition of all other released fish being reported as "fair" (four fish), "good" (five fish) or "excellent" (six fish).

**Table 1.** 2009 *Rainbow trout reservoir recapture trip summary.*

**San Antonio Reservoir**

| Sampling Date | Number of Fish | | | | |
|---|---|---|---|---|---|
| | Total Captured | Tagged | Adipose Clip | Total Marked | Mortalities |
| 13-Aug-09 | 3 | 0 | 0 | 0 | 0 |
| 27-Aug-09 | 1 | 1 | 1 | 1 | 0 |
| 17-Sep-09 | 4 | 0 | 0 | 0 | 1 |
| 02-Oct-09 | 5 | 0 | 0 | 0 | 0 |
| 09-Oct-09 | 4 | 0 | 1 | 1 | 1 |
| 22-Oct-09 | 3 | 0 | 0 | 0 | 2 |
| **Totals** | 20 | 1 | 2 | 2 | 4 |

**Calaveras Reservoir**

| Sampling Date | Number of Fish | | | | |
|---|---|---|---|---|---|
| | Total Captured | Tagged | Adipose Clip | Total Marked | Mortalities |
| 20-Aug-09 | 8 | 0 | 0 | 0 | 0 |
| 01-Sep-09 | 21 | 0 | 1 | 1 | 2 |
| 25-Sep-09 | 11 | 0 | 2 | 2 | 0 |
| **Totals** | 40 | 0 | 3 | 3 | 2 |

Based on the Chapman modified Schnabel formula, it is estimated that San Antonio Reservoir had a population of 408 adult rainbow trout ($P^{1}$(149[N[1020)=0.95) in 2009. According to the population estimate model, this population estimate should be considered negatively biased (underestimate). The relatively large confidence interval is a result of low number of recaptures.

[1] 95 percent confidence intervals are based on a binomial distribution with R as the Poisson variable.

Calaveras Reservoir – A total of 33 adult rainbow trout were tagged and clipped in Arroyo Hondo during the SFPUC's 2009 fish trapping study (SFPUC *in prep*), with one documented mortality. Six tagged, upstream-moving fish remained upstream of the trap sites following conclusion of the trapping study on June 15, 2009. Although there were no tagged adult rainbow trout observed in pools in Arroyo Hondo during summer snorkel surveys (SFPUC *In prep.*), there were adult trout present in each of four pools surveyed. Additionally, surveys conducted in the reach of Arroyo Hondo located downstream of the spillway elevation of Calaveras Reservoir on May 18 and June 10, 2009 indicated that surface water conditions at critical riffles downstream of the trap sites already appeared impassable by adult outmigrants prior to the end of the trapping study. Consequently, reservoir population estimate calculations were based on an initial marked sub-population of 26 rainbow trout.

Three recapture trips were made to Calaveras Reservoir, between August 20 and September 25, 2009 (Table 1). Trout were captured in Calaveras Reservoir at an average depth of 22.4 feet and ranging from depths of 15 to 40 feet. Forty fish were captured during 22 hours of fishing. The Calaveras catch rate of 1.8 fish / hour was 4.5 times the catch rate at San Antonio. None of the captured fish bore tags, but three individual fish were captured with partially clipped adipose fins, indicating fish which had shed their Floy tags. Except for a single mortality, recaptured fish were released in conditions reported as "poor" (one fish), "fair" (three fish), "good" (19 fish), and "excellent" (15 fish).

The Chapman modified Schnabel formula estimated that Calaveras Reservoir had a population of 373 adult rainbow trout ($P^2$(152[N[934)=0.95) in 2009. According to the model, the estimate should be considered unbiased.

## DISCUSSION

A mark-and-recapture study estimates the size of a population at the time that individual members of that population are marked, regardless of the amount of time between marking and subsequent recapture attempts (Everhart and Youngs 1981). The time lag between marking and recapture, however, combined with fish movement, requires that a set of assumptions be met when estimating population sizes using this method. Although mark-and-recapture estimates are not as accurate as direct counts, they can be used with confidence when the following assumptions are adequately addressed:

Assumption 1: Marked fish are identifiable. The rainbow trout in this study were double marked to minimize the possibility of missing marked fish. Floy tags, which were inserted in the back of captured trout next to their dorsal fin, are readily observable, but are sometimes shed after several days when not inserted properly. During the 2009 recapture trips, only one of the five fish identified as previously marked (in both reservoirs, combined) had a tag remaining, indicating an 83 % tag loss rate. In contrast, during the 2003 study, 16 of the 19 fish captured and identified as previously marked retained their tags, indicating a 16 % tag loss rate. As an additional measure, the adipose fins of tagged trout were partially clipped. Adipose fin clipping of adult trout can also be problematic, however, because the fins tend to grow back over time. Although SFPUC biologists observed partial re-growth of adipose fins in tag recaptures, they were confident in their ability to identify adult rainbow trout that had lost their Floy tags. If fish were incorrectly identified by biologists during recapture trips as

[2] 95 percent confidence intervals are based on a binomial distribution with R as the Poisson variable.

previously marked (e.g., a misleading adipose deformity), this error would lead to an underestimate of the population. If, however, fish were incorrectly identified as previously unmarked (e.g., re-growth of an adipose clip), this would lead to overestimate of fish population.

Assumption 2: The marking method and marks do not affect marked fish. There exists the potential for affecting the health and/or behavior of a relatively sensitive species, like rainbow trout, when capturing, handling, and physically manipulating them. In extreme cases, where there is delayed mortality, a population size can be over-estimated because the number of fish in the marked sub-population is actually lower than that used in the calculations. Regardless of the care given by biologists during handling, fish marked during migrant trapping must successfully travel distances as much as two miles (on Arroyo Hondo) to rejoin the reservoir population. The assumption that all marked fish released traveling downstream are able to rejoin the reservoir population can either have no bias on the population estimate (if this assumption is true) or lead to overestimate in population size (if the assumption is false), because failure to complete this journey would reduce the marked population.

The same outcome is possible when marked individuals are more susceptible to predation than unmarked fish. Every effort was made to reduce delayed mortality by handling trout as little and as gently as possible during both the SFPUC's trapping program and the recapture sampling. Floy tagging, when performed correctly, is relatively benign. This study also used low-visibility gray tags to ensure that tagged trout were no more obvious to predators than untagged fish. Adipose fin clipping has been shown to have little, if any, affect on trout health or behavior. There was no evidence of delayed mortality based on biologists' observations.

Assumption 3: The sampling is random. Marked and unmarked fish must be equally susceptible to being collected during the recapture phase of the sampling. Both reservoirs are closed systems, with no inflow or outflow during the time of year when recapture trips were conducted; so, emigration was not a concern. Stratification tends to create metalimnetic waters that balance the temperature and oxygen preferences of trout. This concentration of both marked and unmarked adult rainbow trout reduces the nonrandom vertical distributions of fish. There was no evidence to support or refute the idea that tagged rainbow trout are more or less likely to be captured using trolling gear than untagged trout.

Assumption 4: There are no additions to the population during the project. In 2009, as in most years, the connection between San Antonio Reservoir and its tributaries became dry shortly after the end of the wet-weather season. Consequently, any rainbow trout remaining in the streams following the conclusion of the fish trapping study (trapping ends when flows at the trapping site are too low to capture fish) could not re-enter the reservoir population prior to the recapture phase of this project. Although Calaveras Reservoir and its primary tributary, the Arroyo Hondo, typically remain connected throughout the year, biologists surveying the Arroyo Hondo between the trap site and Calaveras Reservoir determined critical riffles to be impassable at the conclusion of the trapping study. It is therefore unlikely that additional adults entered the reservoir population after the recapture phase of this study began. This assumption is reinforced by the observation of adult trout in Arroyo Hondo during summer snorkel surveys. SFPUC waters are closed to the general public, and there is no stocking or legal take of adult rainbow trout to affect estimates. An issue that does need further investigation; however, is the potential for sub-adults that are too small to be

considered part of the adult population at the time of the initial marking, but that grow enough to be deemed adults by the end of the recapture phase.

With minor exceptions, the generally satisfied assumptions inherent to mark-and-recapture studies suggest that the population size estimates generated for adult rainbow trout in San Antonio and Calaveras reservoirs are reliable. Based on the model, the population estimate at Calaveras Reservoir is considered unbiased due to a relatively large sample size. At San Antonio the relatively small number of rainbow trout caught during the recapture phase of the project resulted in a negative bias (underestimate)

Water quality conditions in the reservoirs may help explain some fish health and distribution observations during fishing in 2009. Trout generally congregate in strata with the best combination of food supply, cold water, and dissolved oxygen for their survival. Figures 5 – 8 characterize the temperature and dissolved oxygen concentrations in San Antonio and Calaveras Reservoirs during recapture trips. In San Antonio Reservoir, the strata where trout were captured contained cooler waters preferable for trout but relatively low concentrations of dissolved oxygen. Biologists noted that a disproportionate number of the San Antonio Reservoir fish were infested with black spot disease (larval trematode) and/or parasitic copepods (Figure 9). The relatively poor condition of trout collected at San Antonio Reservoir and the low catch rate (relative to Calaveras Reservoir) may reflect water quality conditions that are unfavorable to trout.

No fish captured in Calaveras Reservoir were reported infested with copepods or black spot disease. In contrast to the water quality conditions encountered in San Antonio Reservoir, the temperature and dissolved oxygen concentrations in Calaveras Reservoir during recapture trips in 2009, with water strata below the thermocline in Calaveras at or near dissolved oxygen saturation. A Hypolimnetic Oxygenation System (HOS) has been operating in Calaveras in recent years and can be attributed with improving oxygen conditions in the reservoir, especially at depths below the thermocline while the reservoir remains in a stratified condition. The healthier condition of fish captured in Calaveras Reservoir may be a result of more favorable oxygen conditions below the thermocline.

Based on the two years of population estimates available, it would be difficult to establish any trends in estimated population size at either Calaveras or San Antonio reservoirs. Although population estimates from 2003 to 2009 increased in Calaveras and decreased in San Antonio (Figure 10); the broad confidence intervals, small number of recaptured tagged fish, and the negative bias in the 2003 Calaveras and 2009 San Antonio estimates make it difficult to claim this with statistical certainty. Further estimates with larger sample sizes would be necessary to accurately characterize any trends in population size.

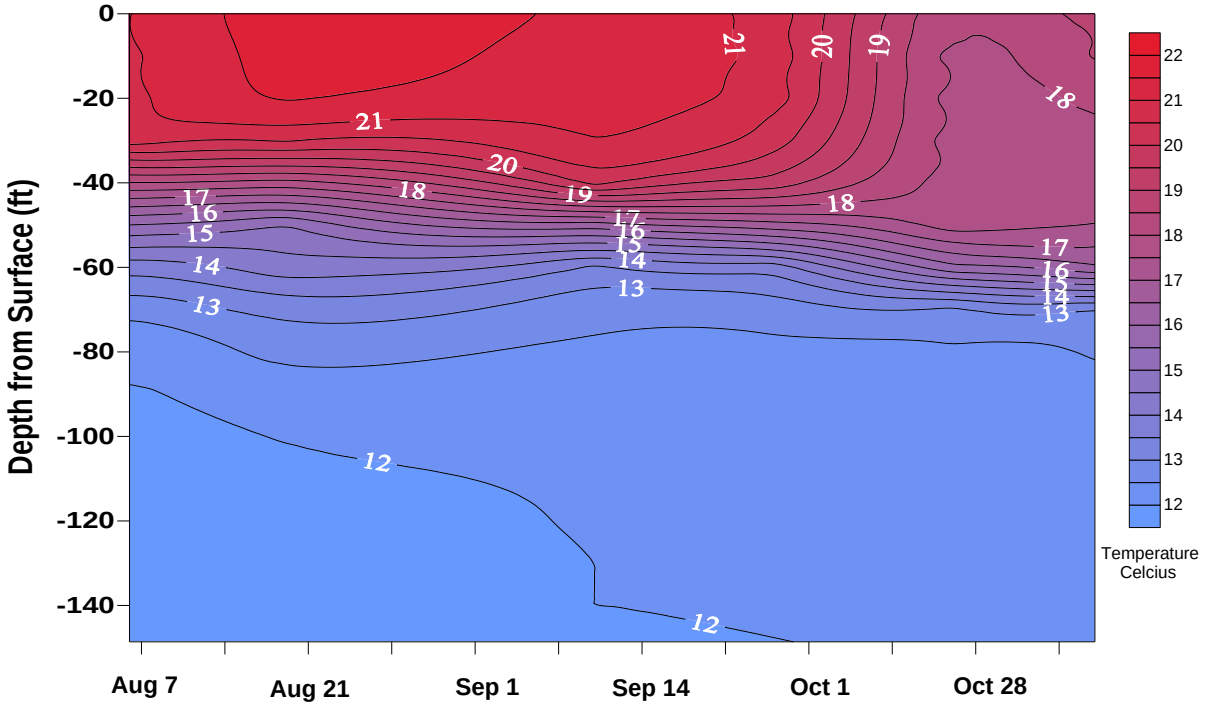


**Figure 5.** *San Antonio Reservoir water temperature during 2009 recapture trips.*

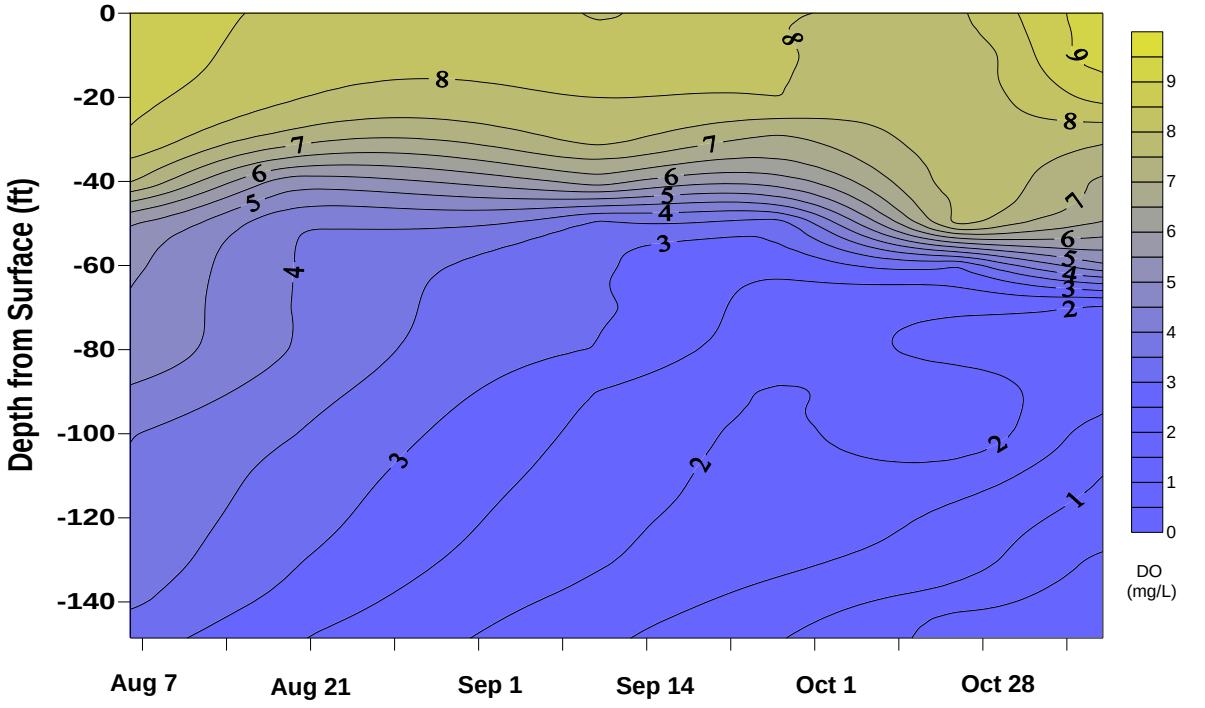


**Figure 6.** *San Antonio Reservoir water temperature during 2009 recapture trips.*

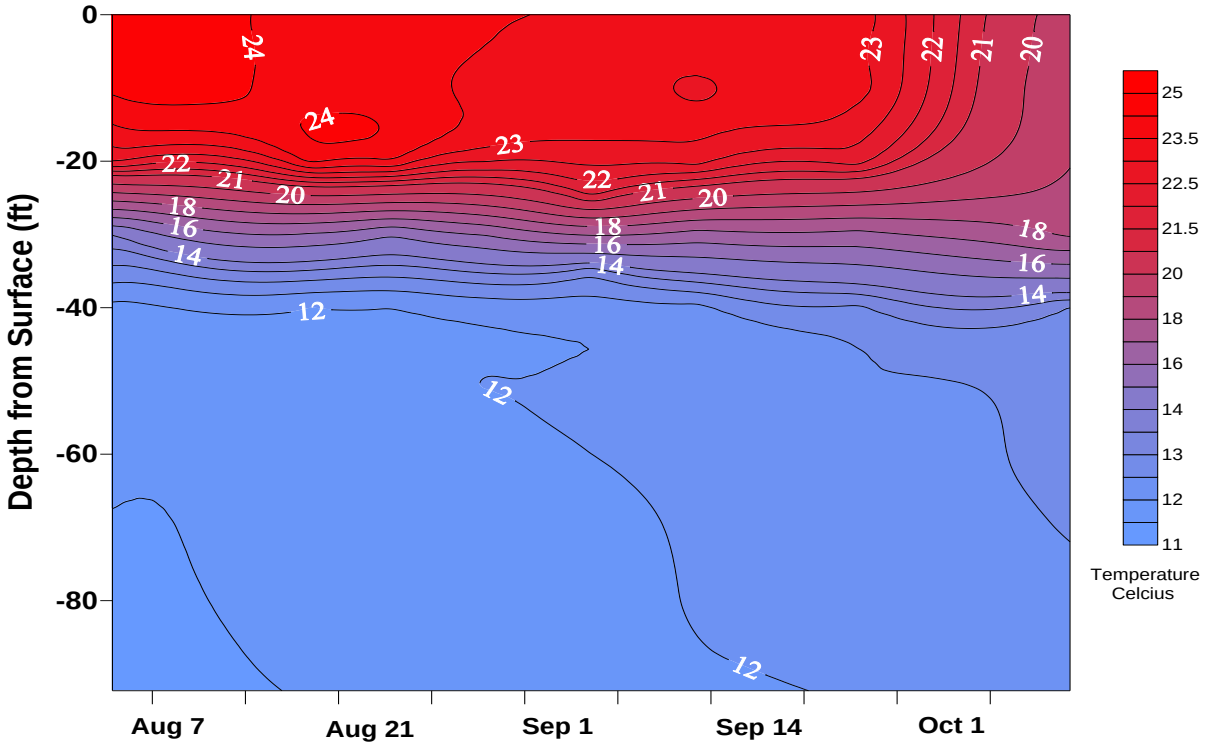


**Figure 7.** *Calaveras Reservoir water temperature during 2009 recapture trips.*

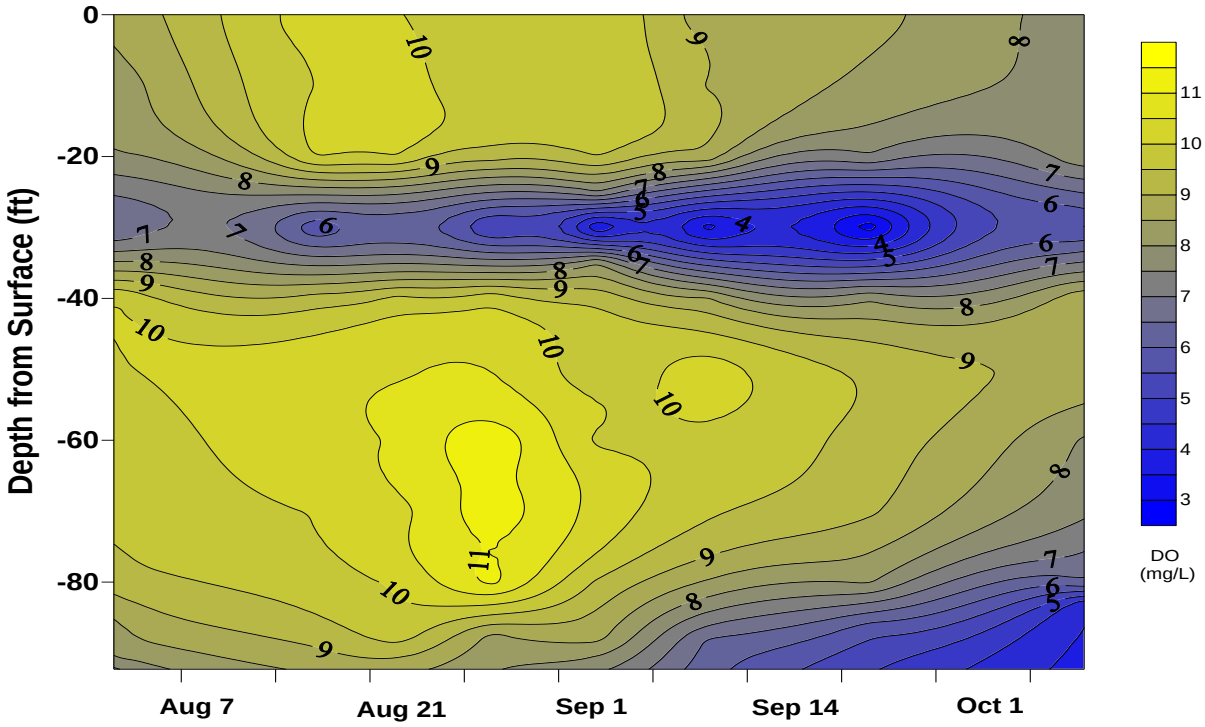


**Figure 8.** *Calaveras Reservoir water temperature during 2009 recapture trips.*

**Figure 9.** *Adult trout collected in Calaveras Reservoir without parasitic copepods (above), and adult trout typical of those collected in San Antonio Reservoir with infestation of parasitic copepods.*

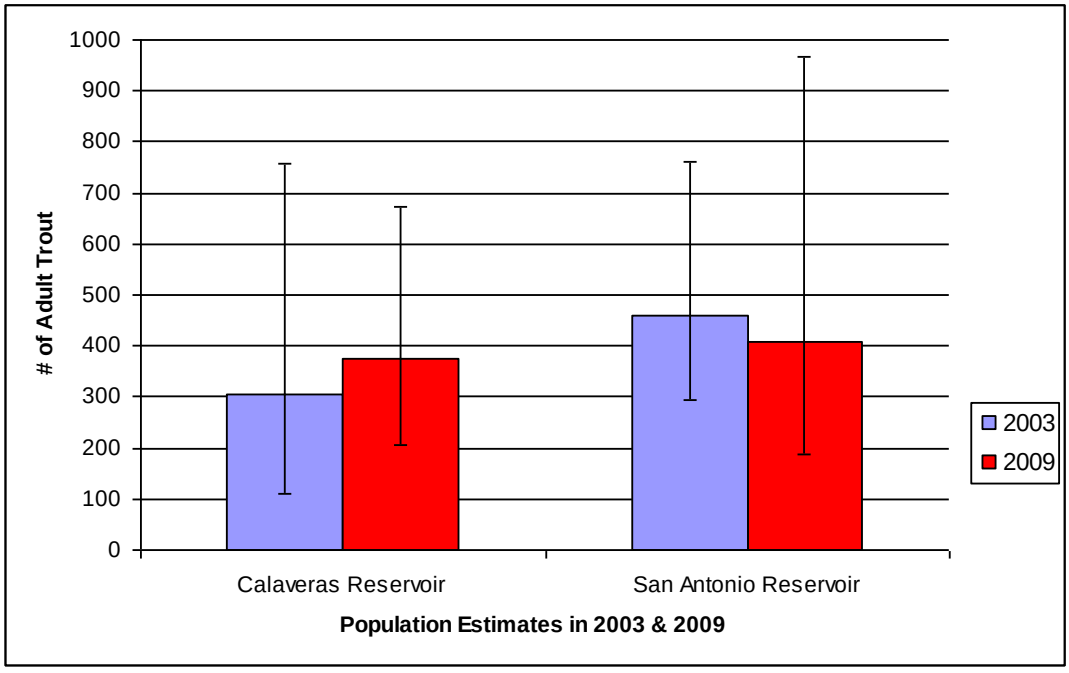


**Figure 10.** *Population estimates performed in 2003 (blue bars) and 2009 (red bars) in San Antonio Reservoir and in Calaveras Reservoir; error bars indicate population estimate confidence intervals.*

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