Fall-run chinook salmon and steelhead trout spawning survey, September 1999 through January 2000 Mokelumne River, California.

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Abstract: Weekly fall-run chinook salmon *Oncorhynchus tshawytscha* and steelhead trout *O. mykiss* spawning surveys were conducted in the lower Mokelumne River from September 1, 1999 through January 18, 2000. The estimated escapement during this period was 5,338 chinook salmon and 56 steelhead. The estimated number of in-river chinook salmon spawners was 2,185 fish. During the survey period 627 chinook salmon and 20 steelhead trout redds were observed. Sixty-two (10.0%) salmon redds were superimposed. The reach from Camanche Dam to Mackville Road contained 514 salmon redds (82.6%) and the reach from Mackville Road to Elliott Road had 109 redds (17.4%). An additional four redds were located above the fishway at Woodbridge Dam. Two hundred thirty-four redds (37.3%) were constructed in enhancement areas.

INTRODUCTION

The 627 sq. mile Mokelumne River watershed ranges from the Sierran Crest to the Sacramento - San Joaquin Delta. Pardee and Camanche reservoirs, located on the Mokelumne River (Figure 1), are owned and operated by East Bay Municipal Utility District (EBMUD), which provides water for 1.2 million customers in Alameda and Contra Costa Counties. Additionally, there are reservoirs and power generation facilities located upstream of Pardee Reservoir owned and operated by Pacific Gas & Electric Company (PG&E). Downstream of Camanche Dam, Woodbridge Irrigation District (WID) operates Woodbridge Dam (WD) and an associated system of irrigation canals near Lodi, CA.

The lower Mokelumne River (LMR) is used by fall-run chinook salmon *Oncorhynchus tshawytscha* and steelhead trout *O. mykiss* for spawning and rearing. Adult chinook salmon ascend the river as early as late August and may begin spawning in late September. The peak of the run usually occurs in November and tapers off through the month of December (Marine and Vogel 1994, Hartwell 1996, Setka 1997). The Mokelumne River Fish Hatchery (hatchery), constructed in 1964 to mitigate for spawning habitat lost with the construction of Camanche Dam, receives approximately 45.4% of the total run per year (1990-1998 average). EBMUD has conducted annual spawning surveys in the lower Mokelumne River (LMR) since 1990 (Hagar 1991, Hartwell 1996, Setka 1997). Concurrent with these surveys, EBMUD enumerates chinook salmon escapement at Woodbridge Dam (Biosystems 1992, Natural Resource Scientists Inc. 1996). Data generated from WD monitoring and hatchery returns allow for an estimation of the number of chinook salmon within the LMR at any time during the spawning season.

OBJECTIVES

The primary objective of the 1999 spawning survey was to enumerate chinook salmon redds in the LMR. With the escapement data from WD and the hatchery, an estimate was obtained for the total escapement to the river. The escapement estimate was used to associate the number of redds and their characteristics with population structure or density. Additional objectives included:

- Map locations of individual redds
- Determine specific preferences of spawning chinook with cover (overhanging vegetation, canopy, undercut banks, water depth and turbulence, etc.), habitat type, and large organic debris (LOD)
- Enumerate redds impacted by superimposition
- Determine use of enhancement gravel areas

The following were noted:

- Visible injuries to salmon, attached fishing gear, adipose clips or tags
- Behavior and numbers of salmon associated with redds

Environmental parameters and flow during the spawning period were summarized. An emergence timeline was constructed based on an egg model developed by Vogel (1993) from Piper et al. (1982).

EBMUD has developed a Geographic Information System (GIS) for the LMR. This year's results were compared to past year's in order to further develop spawning preference criteria, analyze differences between the years due to densities, and summarize the data-set collected to date. The GIS was used to spatially display and analyze much of the current data. The results generated by the GIS included:

- Spatial distribution of redds
- Total area used by spawners
- Relationship of redd spatial distribution to run size or age composition
- Habitat associations for spawning salmon

METHODS

SURVEYS

The lower Mokelumne River is divided into 6 reaches between Camanche Dam and the confluence with the Sacramento-San Joaquin Delta. The reach designations are based on gradient, substrate and tidal influence. Reaches 5 and 6 cover a 15.8 km (9.8 mile) section of the river from Camanche Dam to Elliott Road. Beginning September 22, 1999 weekly redd surveys were conducted in the LMR from Camanche Dam to Elliott Road (Figure 2). The last survey was conducted January 18, 2000. The reaches were surveyed over a 1 to 2 day period each week. Surveys consisted of three individuals walking abreast down the river (water depths to 4 feet) and searching for signs of redd construction. This method has been used in past Mokelumne River spawning surveys and in other rivers and streams (Keefe et al. 1994, Fritsch 1995, Hartwell 1996, Setka 1997). A boat was used to transport surveyors between spawning areas. During flows greater than 325 cubic feet per second (cfs) some areas were surveyed from the boat. Redds were marked using fluorescent yellow, numbered bricks and locations were recorded using a hand-held Global Positioning System (GPS) unit (Trimble Pro XR) and a laser range finder. Individuals positioned themselves directly behind redds (on the tailspill) to have positions recorded with the laser range finder. Care was taken to avoid impacts to redds during the survey and with placement of bricks. A prototype tag was used to mark 15 redds during the survey. The tags consist of a 6 to 8 inch bolt with a cattle ear tag attached to the head end. Tags were inserted into the tailspill areas of selected redds.

DATA COLLECTION

Location data for each redd were stored in the GPS unit and later downloaded to an ArcView (ESRI) data base. In addition to redd locations, notations were made regarding the characteristics and locations of redds. These measurements included cover type, number of fish associated with each redd, and other information, such as recruitment of LOD into specific areas, that could influence redd construction.

Levels of superimposition were recorded as follows (Hartwell 1996):

> Level C = egg pocket of one redd superimposed on estimated location of egg pocket of a second redd. The percent of superimposition range (<25%, 25-50%, 51-75%, 76-100%) is estimated
>
> Level D = egg pocket of one redd superimposes egg pocket of two or more redds

Water temperatures were measured using hand-held thermometers, Campbell data loggers (Campbell Scientific Inc., USA), and a dissolved oxygen/temperature meter (YSI Inc., USA). The Campbell data loggers also measured gauge heights from which river flows are computed.

Habitat types were based on a geomorphic type habitat mapping scheme designed for the lower American River (Snider et al. 1992). There are four tiers to the mapping scheme: study reach, major channel features, channel feature types and habitat units. Full descriptions of the various components to these tiers are listed in Table 1.

DATA ANALYSIS

Data analysis was performed using ArcView, Arc/Info (ESRI) systems and EBMUD LMR GIS. The lower river GIS is based on two data sets: regional USGS maps with a 1:24,000 scale and local maps based on orthorectified photos (taken February 28, 1994, at a release of 202cfs from Camanche Dam) with a 1:4,800 scale.

RESULTS

ESCAPEMENT AND REDD NUMBERS

The total observed escapement to the Mokelumne River from August 16, 1999 through January 23, 2000 was 5,338 chinook salmon (adults and grilse). Counts were based on video monitoring, trapping and salmon rescued from spillbay basins (methodologies detailed in Marine and Vogel 1994). The composition of the run was as follows:

1,349 adult females (25.2% of total escapement)

1,556 adult males (29.1% of total escapement)

151 unknown adults (2.8% of total escapement)

2,282 unknown grilse (42.8% of total escapement)

In addition to chinook salmon, 56 adult steelhead trout (3 female, 14 male, 39 unknown sex) were observed. The California Department of Fish and Game uses a length criteria to differentiate between steelhead and resident rainbows, with steelhead being greater than 40cm fork length. The 1999 salmon run peaked during the last week in October and the first week in November (Figure 3). The highest single-day migration took place on November 2 when 433 salmon passed WD.

Hatchery staff recorded 3,153 (59.1% of run) chinook salmon entering the hatchery during the 1999 spawning season. The sex and age composition of salmon returning to the hatchery was 819 adult females (25.9%), 792 adult males (25.1%) and 1,542 grilse (48.9%). By subtracting the hatchery count from the observed escapement at WD, there were an estimated 2,185 in-river spawners during the 1999 season. There were 4,112 in-river spawners in 1998. Extrapolating the known sex ratio obtained from trapping at WD to the unknown fish at WD and subtracting the hatchery returns resulted in an in-river sex composition of 568 adult females (41.3% of adults), 808 adult males (58.7% of adults) and 809 grilse (37.0% of total in-river estimate and assumed to be greater than 90% male).

During the 1999/2000 survey period 627 redds were observed. The first redd was observed on October 8, 1999. Redd construction peaked during the third week of November and lasted through January (Figure 4). Due to increased flows (>800cfs), surveys were discontinued at the beginning of February. Reach 6 contained 514 (82.5%) redds, while Reach 5 contained 109 (17.5%) redds. An additional 4 redds were located in the area of WD. The season's redd count was less than the 1,116 redds observed in 1998.

Twenty steelhead trout redds were observed during the 1999/2000 surveys. The first trout redd was observed on December 22, 1999. Sixteen of the redds were located in Reach 6 and 4 were within Reach 5.

ENHANCEMENT GRAVEL USAGE

Since 1992 the District has conducted gravel enhancement projects in the lower Mokelumne River in cooperation with federal and state agencies. In 1999 234 (37.3%)

redds were constructed in habitat enhancement areas (Figure 5). Habitat enhancement areas are depicted in Figure 6. One gravel enhancement project was conducted just above the Murphy Creek inflow (Reach 6) in 1999. Since 1990 no redds had been observed within the site. As of the end of the 1999/2000 survey one redd had been observed in the enhanced site. Figure 7 depicts the percentage of total redds that were constructed in areas enhanced from 1990-1996. The use of areas enhanced since 1996 is presented in Figure 8. The overall percent use of enhancement areas decreased in 1999 compared to 1998 (45.2%), as did the number of in-river spawners.

SUPERIMPOSITION

During the 1999 season 62 redds (10.0%) were superimposed. Ninety-four percent of redd superimposition (SI) occurred in Reach 6, while the remaining 6% occurred in Reach 5. During the peak of the run, weekly SI levels were 8% to 15% (Figure 9). Site specific superimposition levels varied from 24% at Catwalk to 0% at MRDUA (Figure 5). The 1999 level of SI is a decrease from the 16.5% of 1998 (Figure 10).

ENVIRONMENTAL DATA

Water temperatures below Camanche Dam during the period of October 1, 1999 to January 31, 2000 ranged from 14.4°C to 11.6°C (Figure 11). During the same time period, water temperatures at Mackville Road ranged from 14.4°C to 11.4°C. All redds were constructed in water temperatures under 14.5°C. Releases from Camanche Dam during the survey period ranged from 330cfs on October 1, 1999 to 873cfs on February 1, 2000 (Figure 12). All of the observed redds were constructed at a flow of 330cfs.

REDD PHYSICAL CHARACTERISTICS AND HABITAT PREFERENCES

The number of in-river spawners in 1999 (2,185) was almost half of the 1998 total (4,112). The percentage use of key (lateral, transverse, mid-channel and channel spanning bars) habitat in 1999 increased from 1998 (Figure 13).

There were 666 instances where cover was associated with individual redds (Figure 14). Many of these instances involved one redd associated with multiple cover types. The most common cover types used were canopy (35.0%), overhanging vegetation (29.0%) and LOD (20.0%).

Very few natural boulders are present within the channel of the LMR. As part of habitat enhancement projects from 1996 to 1999, boulders were placed in specific locations with spawning gravels. The boulders may provide refugia for salmonids and add stability to the gravel berms. Two percent (12) of redds constructed in 1999 were associated with boulders.

BEHAVIOR AND TAGS/MARKS

The number of salmon associated with a single redd ranged from 0 to 6. Of the 627 redds observed, 185 (29.5% of total redds) were active with at least one fish. There were 18 (2.9%) instances of more than 2 salmon on a single redd.

Two adipose fin-clipped salmon carcasses were observed. The heads were removed and bagged along with a label detailing size, sex and location of each fish. The specimens were given to hatchery staff for coded wire tag recovery and reading.

EMERGENCE TIMELINE

Using the egg model it was predicted that fry began emerging from redds the week of December 7, 1999 and continued through April 12, 2000 (Figure 15). The peak of fry emergence was estimated to be the week of January 23, 2000. The first fry captured in the rotary screwtraps at WD occurred on December 15, 1999 (traps installed December 14th).

DISCUSSION

The 1999-2000 escapement of 5,338 salmon was 144% of the historical 1940-1998 average (Figure 16). Flow increases in late January 2000 did not allow for continued redd surveys and likely resulted in steelhead trout redd numbers being under counted.

Run composition can play a significant role in the habitat use patterns and density of spawning salmonids (van de Berghe and Gross 1989, Vronskii and Leman 1991, Wilson 1997). The composition of a run is expressed as the ratio of males to females; total population; temporal density; and the grilse component. The male to female ratio from 1994-1999 is depicted in Figure 17. This year's male to female ratio was 2.8:1, while in 1997 it was 0.5:1. The grilse component varied from 10% in 1997 to 42.8% in 1999.

The level of use of key channel feature types since 1994 has varied with changes in run composition (Figure 13). The number of adult in-river spawners decreased in 1999 from 1998 by nearly 50%, while the number of in-river grilse was 85% of the 1998 total. Between 1998 and 1999 there is not significant ($p=>0.10$) variation between the percentage of key habitat types used. However, use levels between 1994 and 1997 differ from 1998 and 1999. These differences in habitat use can be attributed to a number of run composition factors. Adult female salmon are responsible for the construction of redds, while both male and female salmon defend the territory. The number of in-river females directly effects the number of redds observed in the river in any given year. The total number of in-river spawners does not necessarily serve as an indicator for the amount of spawning habitat used. Grilse make up a certain percentage of the in-river population. This percentage has varied from approximately 34% in 1999 to 14% in 1997. Grilse use already constructed redds by satellite spawning (males) or by superimposing (females) (Crisp and Carling 1989, van de Berghe and Gross 1989, Healy 1991, Wilson 1997). Therefore, as the grilse component of the run increases the number of redds and amount of habitat used decreases. This relationship was evident when comparing 1997 to 1998, when there were more grilse in 1998 (Figure 13). Although there was an increase in the grilse percentage in 1999, the total in-river spawning population was nearly half of the 1998 total.

Superimposition levels decreased from 16.5% in 1998 to 10.0% in 1999 (Figure 9). The estimated number of in-river spawners was 2,185 fish in 1999, which is a decrease of 47% from 1998. Analysis of nine years of data indicates a correlation between SI levels, redds and the number of in-river males (R^2=79.5). It would be expected that there would be a relationship between SI levels and the number of redds (R^2=77). However, the addition of in-river males to the multiple regression increases the R-squared value to 79.5. The increase in males can lead to increased competition for space. Females defend their immediate redd site, while males defend larger territories and can displace other salmon (Healy 1991, Wilson 1997).

The addition of enhancement gravels may also reduce superimposition through the expansion of spawning habitat. Until 1999 enhancement areas, especially in Reach 6, had experienced consistent increases in the percentage of total redds built within the sites (Figures 7 and 8). Spawning habitat enhancement is a relatively low cost way of reducing reliance on hatchery production, while increasing the quality and survival of natural production. Enhancement gravel projects provide high-quality spawning habitat with transition zones resulting in higher substrate permeability desirable for spawning chinook salmon (Healy 1991, Vronskii and Leman 1991, Merz 1996). These same areas provide rearing habitat for juvenile fish and substrate for invertebrate production.

In 1999, as with past years, spawning salmon in the Mokelumne River showed preferences for structure and cover in the form of LOD, various bars, boulders, overhanging vegetation, undercut banks, and water depth, presumably to provide cover from predators, sunlight, and flows. Additionally, LOD and boulders provide structural enhancement in gravel bars, assist in preserving the bars and berms, and allow for pool formation that provides thermal refugia for fish (Bisson et al.1987, Beechie and Sibley 1997). Structure is particularly important in streams below dams where natural gravel and LOD recruitment have been eliminated or reduced (Maser and Sedell 1994). Not only do gravel bars provide cover, they are used extensively by spawning chinook salmon due to their high permeability (Leman 1988). In 1994 and 1997 redds associated with LOD were deeper than those without (Merz 1996). LOD may provide distinct advantages in areas that would otherwise be too deep for chinook spawners. In addition to the benefits listed above, velocities would be increased in areas surrounding LOD as would substrate permeability. It is clear that structure is an integral part of salmonid spawning habitat in the LMR and should continue to be part of any enhancement project.

Survey results from this year indicate the positive effect of enhancing habitat within areas of high spawning densities. Fifty percent of spawning activity from 1994 to 1999 occurred in the approximately 1.6 mile section below Camanche Dam. The heavy use of this section is likely the result of the behavioral aspects of the salmon in which individuals try to go as far up a river system as they can. Enhancement areas in Reach 6 have shown consistent increases in their use while those in Reach 5 have had more variable usage. Therefore, to reduce competition for spawning habitat, a majority of the spawning habitat enhancement effort should be focused on the two-mile section below Camanche Dam.

ACKNOWLEDGEMENTS

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Table 1. Descriptions of Major Channel Features, Channel Feature Types and Habitat Units within the lower Mokelumne River, CA.

Classification	Abbreviations	Definition
Major Channel Feature	**MCF**	
Flatwater	FW	Areas where primary channel is uniform and without gravel bars or any channel controls.
Bar Complex	BC	River areas in which submerged and emergent bars are primary channel features.
Off-channel	OC	Areas separate from main channel (backwaters and isolated secondary channels).
Channel Feature Type	**CFT**	
Island Complex	IC	Area located in main channel that is more built-up and stable than other bar types. Generally supports established riparian vegetation.
Mid-Channel Bar	MCB	Located within main channel and surrounded by water or submerged; generally less built-up than an island complex and lacking established riparian vegetation.
Lateral Bar	LB	Bar contiguous with one main channel bank but does not span entire channel; less built up than island complex and lacks established riparian vegetation. Groins fall under this category.
Channel Spanning Bar	CSB	Bar spans entire channel at an approximate right angle.
Transverse Bar	TB	Bar spans entire channel at an approximate acute angle.
Channel Bend	CB	Main channel primarily curved.
Straight Channel	STC	Main channel without curve.
Split Channel	SC	Main channel split into two or more channels.
Contiguous Off-Channel	COC	Off-channel area contiguous with main channel.
Non-Contiguous	NC	Off-channel area not contiguous with main channel.
Chevron Bar (enhancement)	CVB	Enhancement bars placed in river at approximately acute angles. Aggregation of bars resembles chevron stripes.
Habitat Unit	**HU**	
Riffle	RF	Relative high gradient area with substrate of gravel and cobble; above average velocities, below average depths and turbulence. Also includes protuberance of bottom substrate.
Run	RU	Areas of moderate gradient with gravel/cobble substrate; above average velocities, below average depths and some turbulence. Generally associated with downstream extent of riffles.
Glide	GL	Areas of relatively low gradients with substrates of small gravel and sand; below average velocities and depths, no turbulence. Generally associated with heads of riffles or tails of pools.
Pool	PL	Low gradient area with substrates of fine material; below average velocities and above average depths.

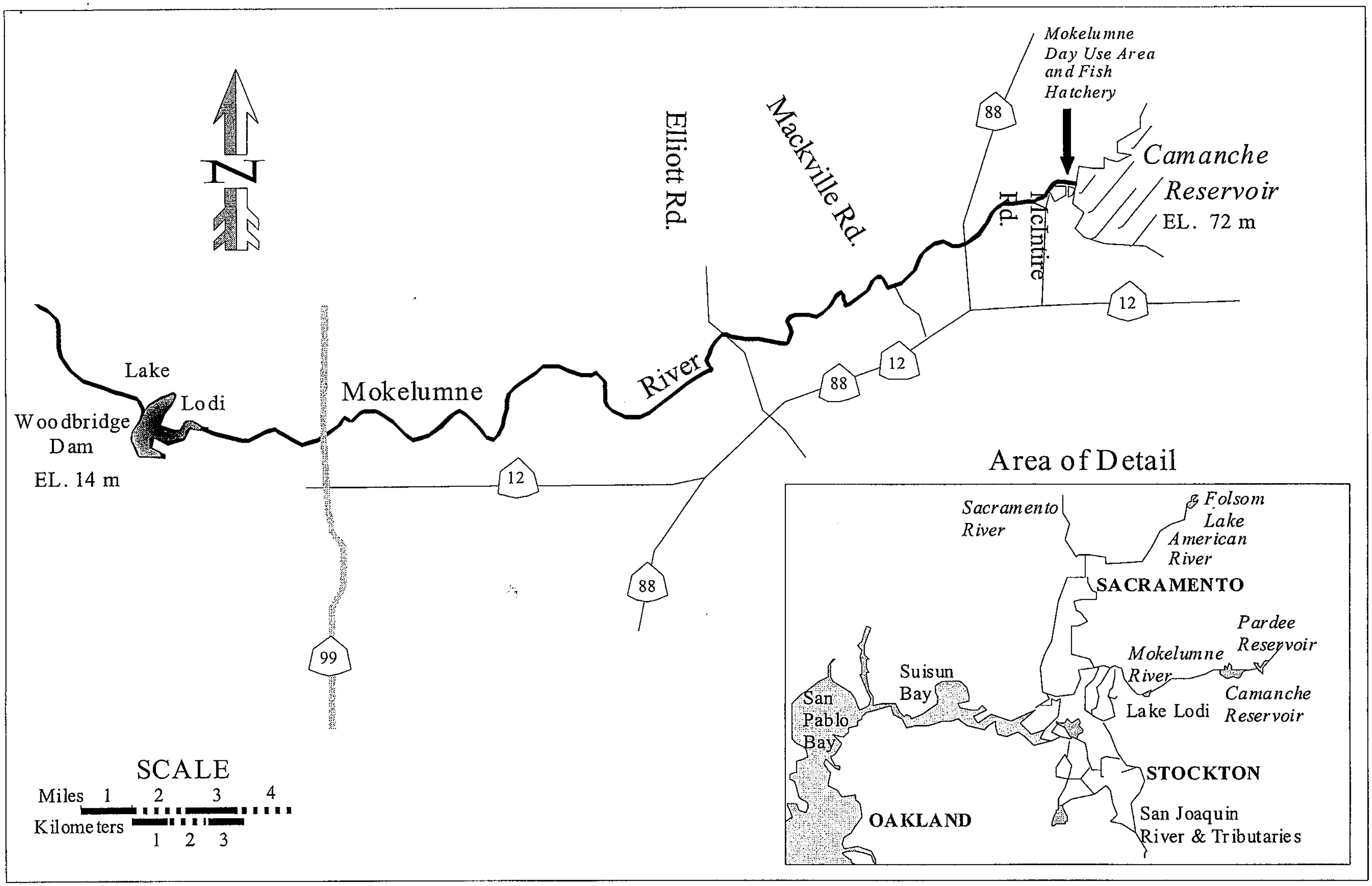


Figure 1. The lower Mokelumne River between Camanche and Woodbridge dams. San Joaquin County, California.

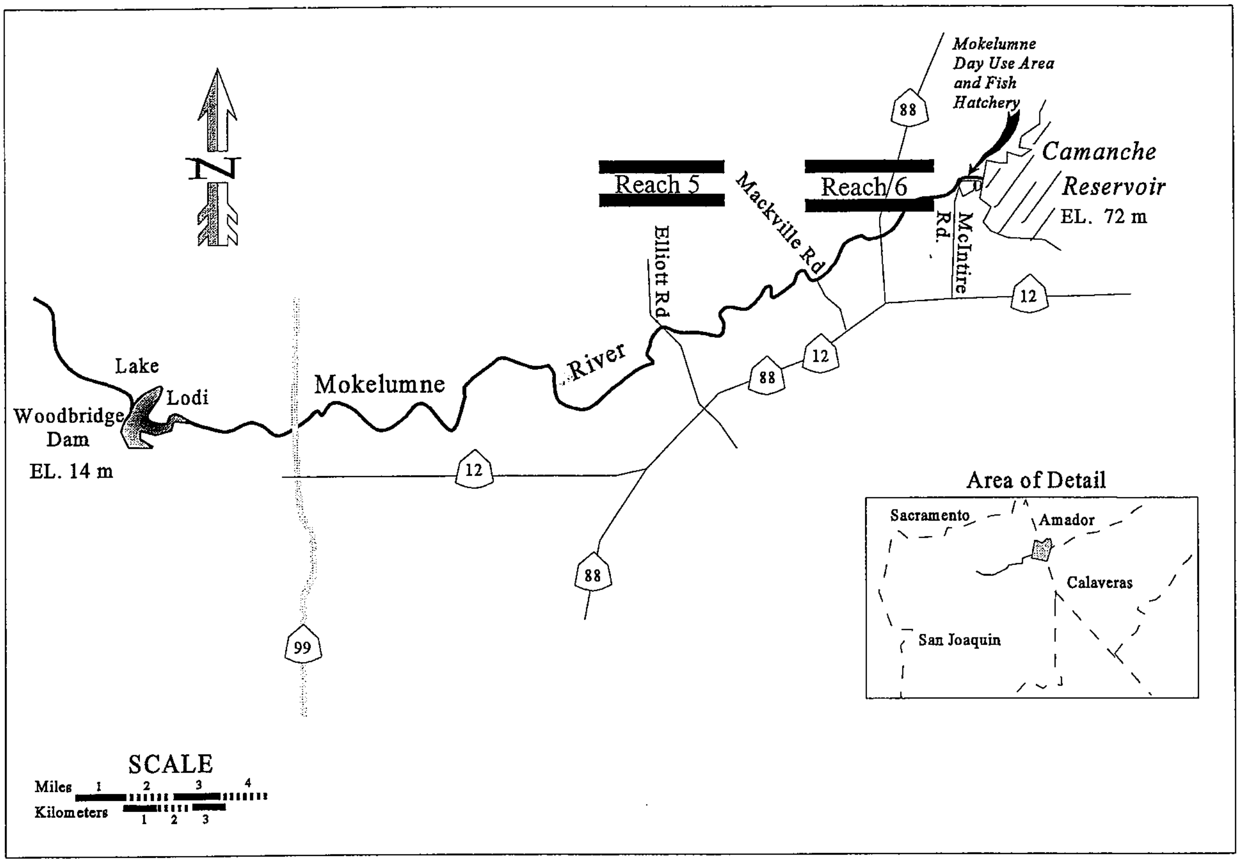


Figure 2. The lower Mokelumne River between Camanche Dam and Woodbridge Dam. Spawning Reaches 5 & 6 are depicted. San Joaquin County, California.

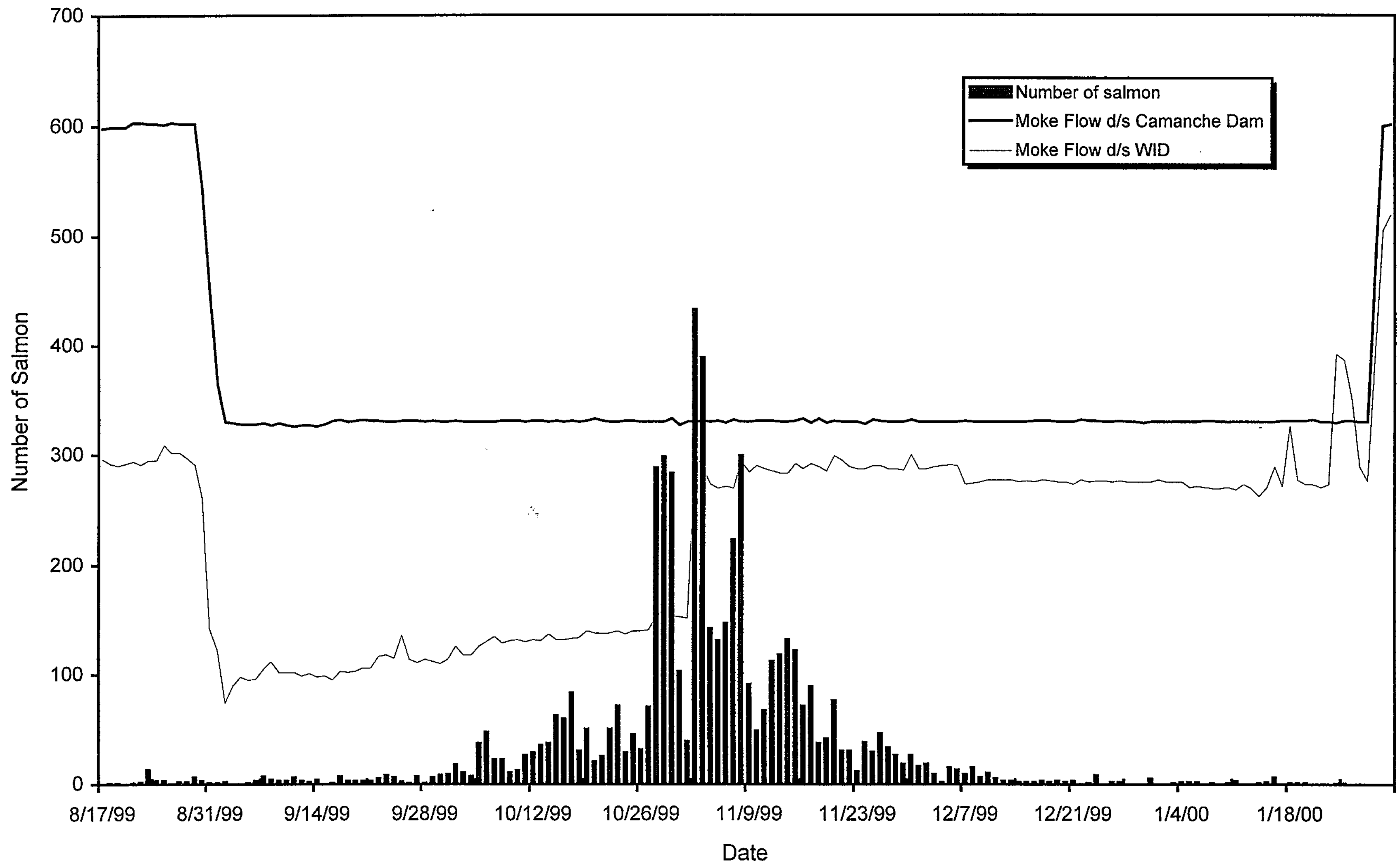


Figure 3. Daily fall-run salmon escapement recorded at Woodbridge Dam during 1999 spawning season in the lower Mokelumne River, CA.

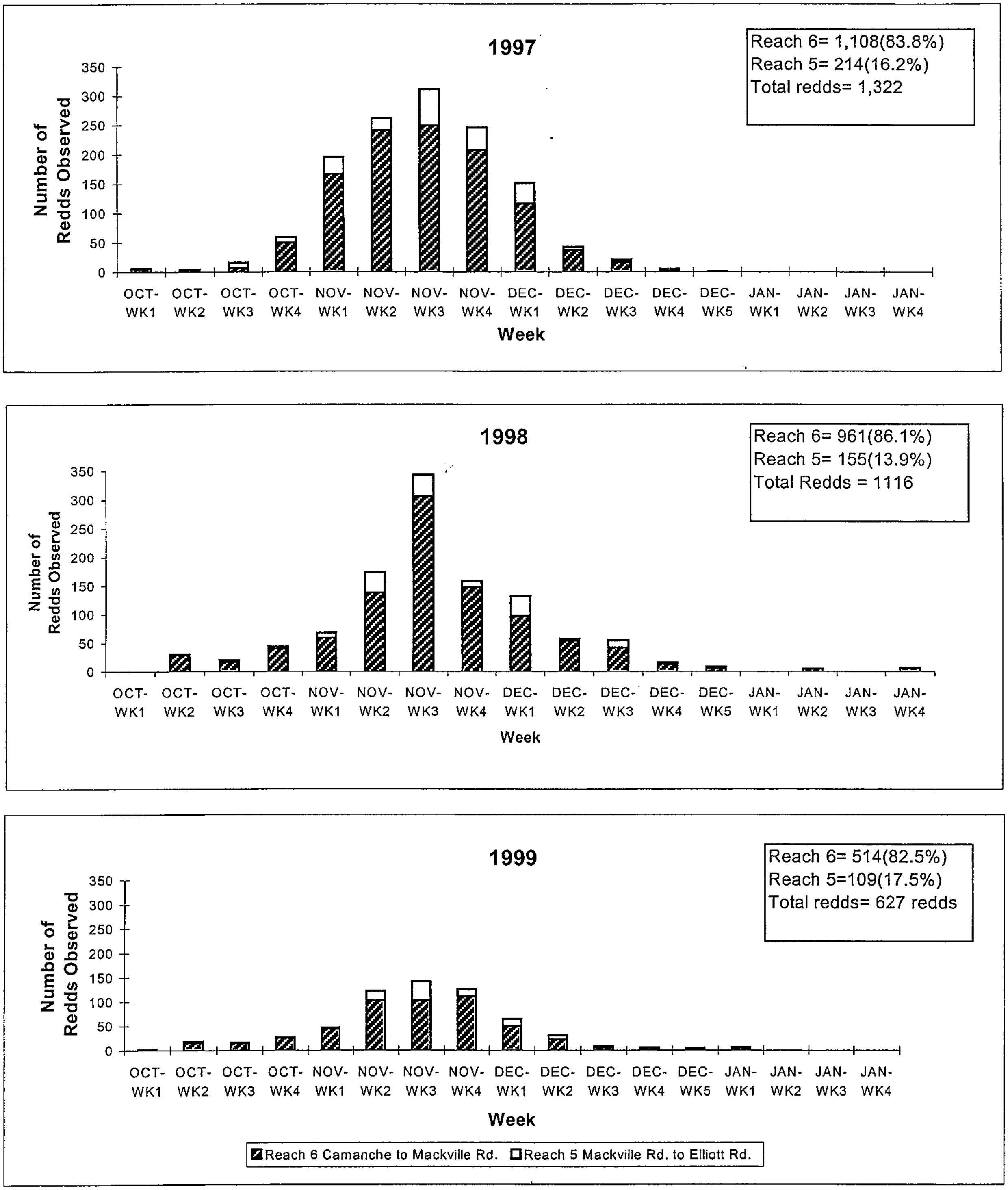


Figure 4. Weekly fall-run chinook salmon redd construction observed by reach in 1997, 1998 and 1999 in the lower Mokelumne River, CA.

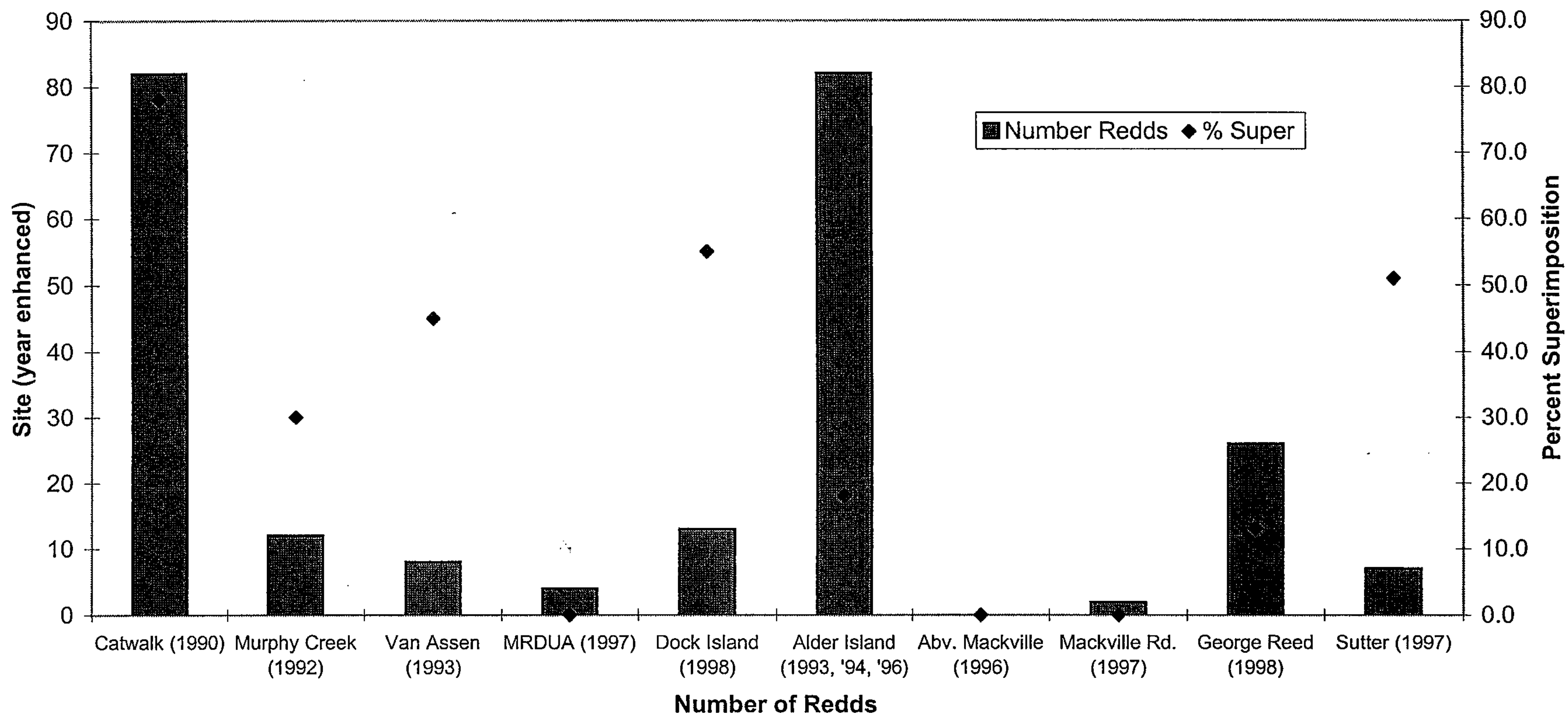
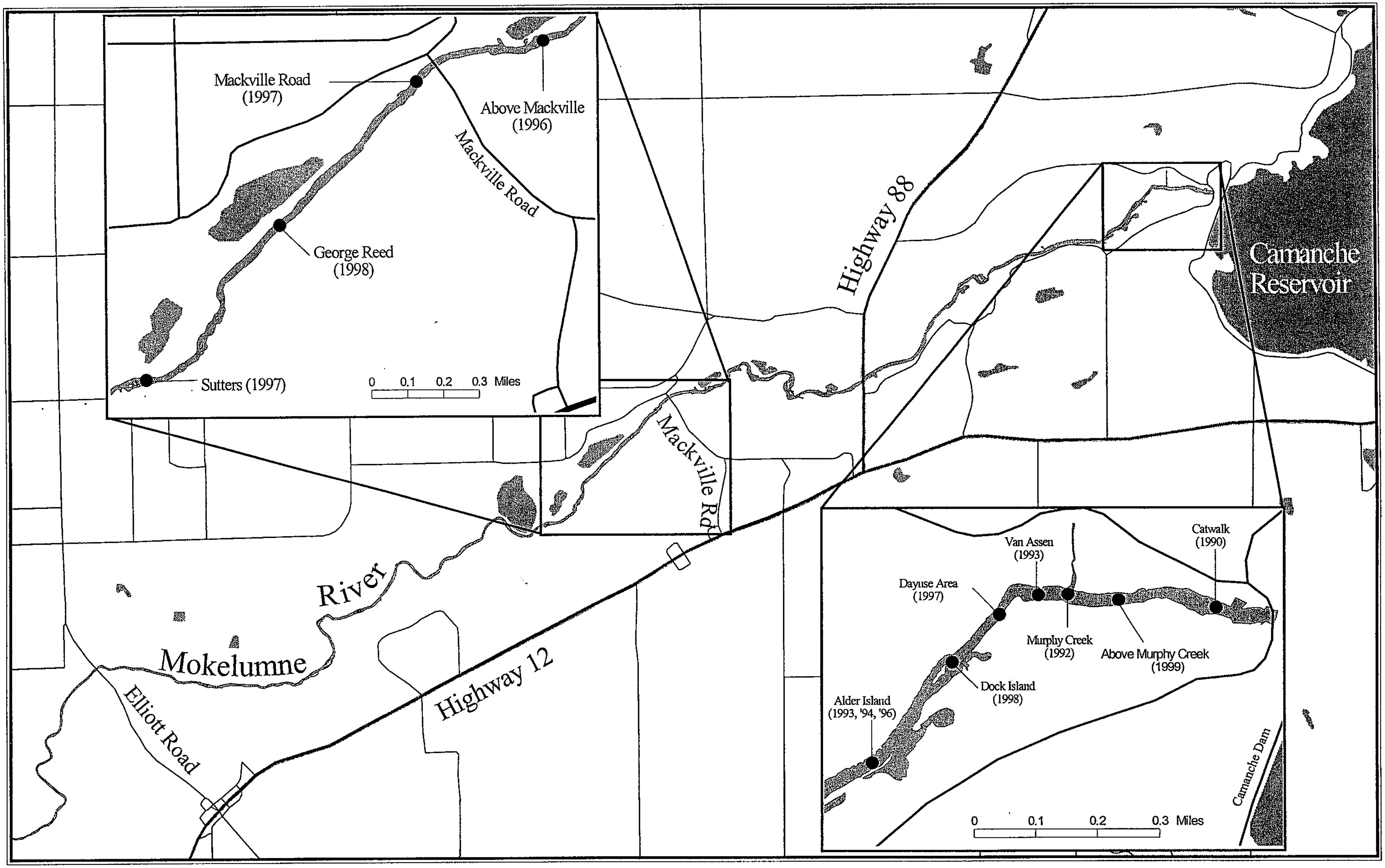


Figure 5. Usage and superimposition of enhancement areas in the Mokleumne River by chinook salmon during the 1999 spawning season (see Figure 6 for map of locations).



Sources: 1/4800 Photogrammetry and 1/24000 USGS Quadrangles

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Figure 6. Spawning Gravel Enhancement Areas - Lower Mokelumne River

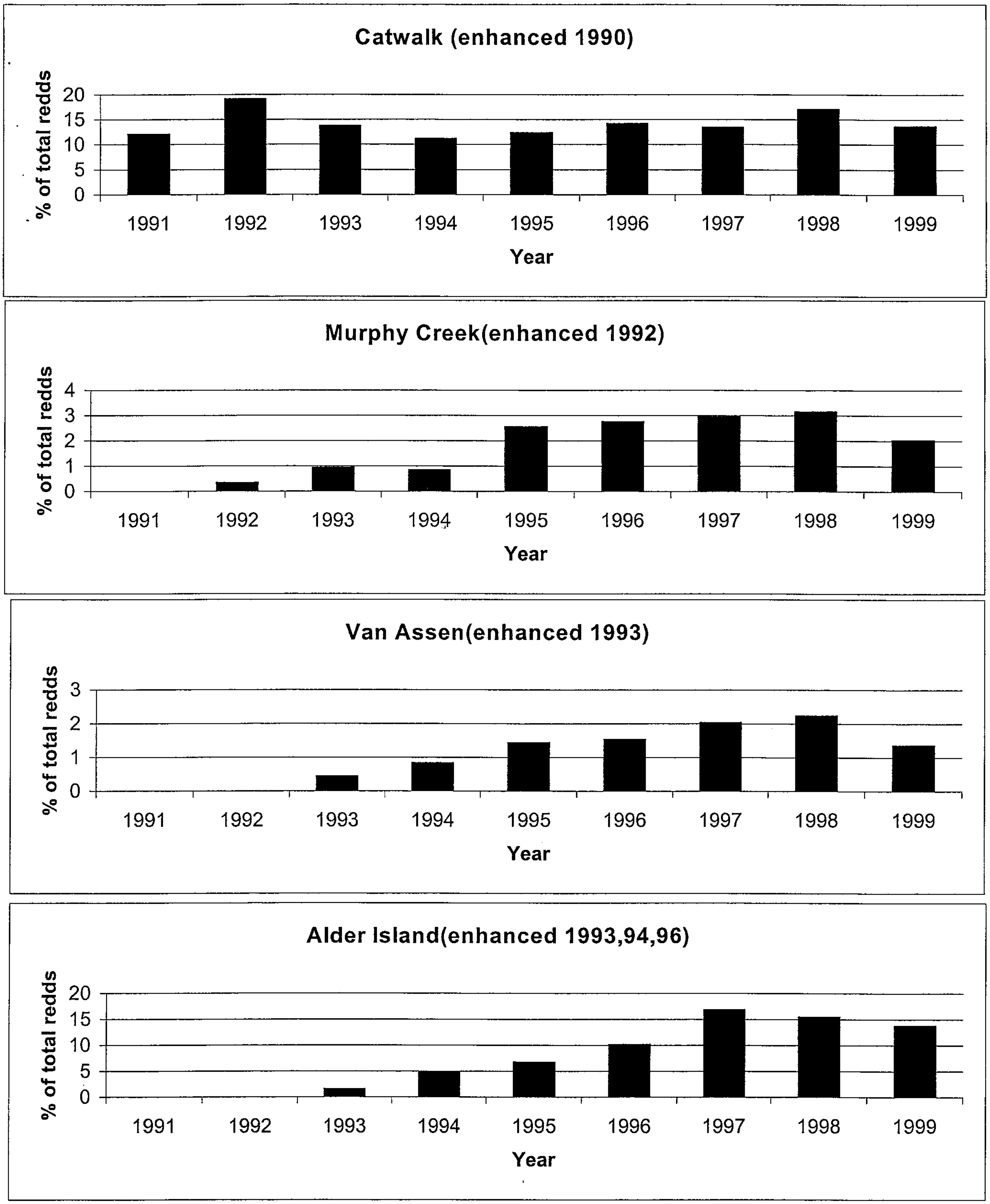

Figure 7. Percentage of total redds built in pre-1995 gravel enhancement areas within the lower Mokelumne River from 1991-1999.

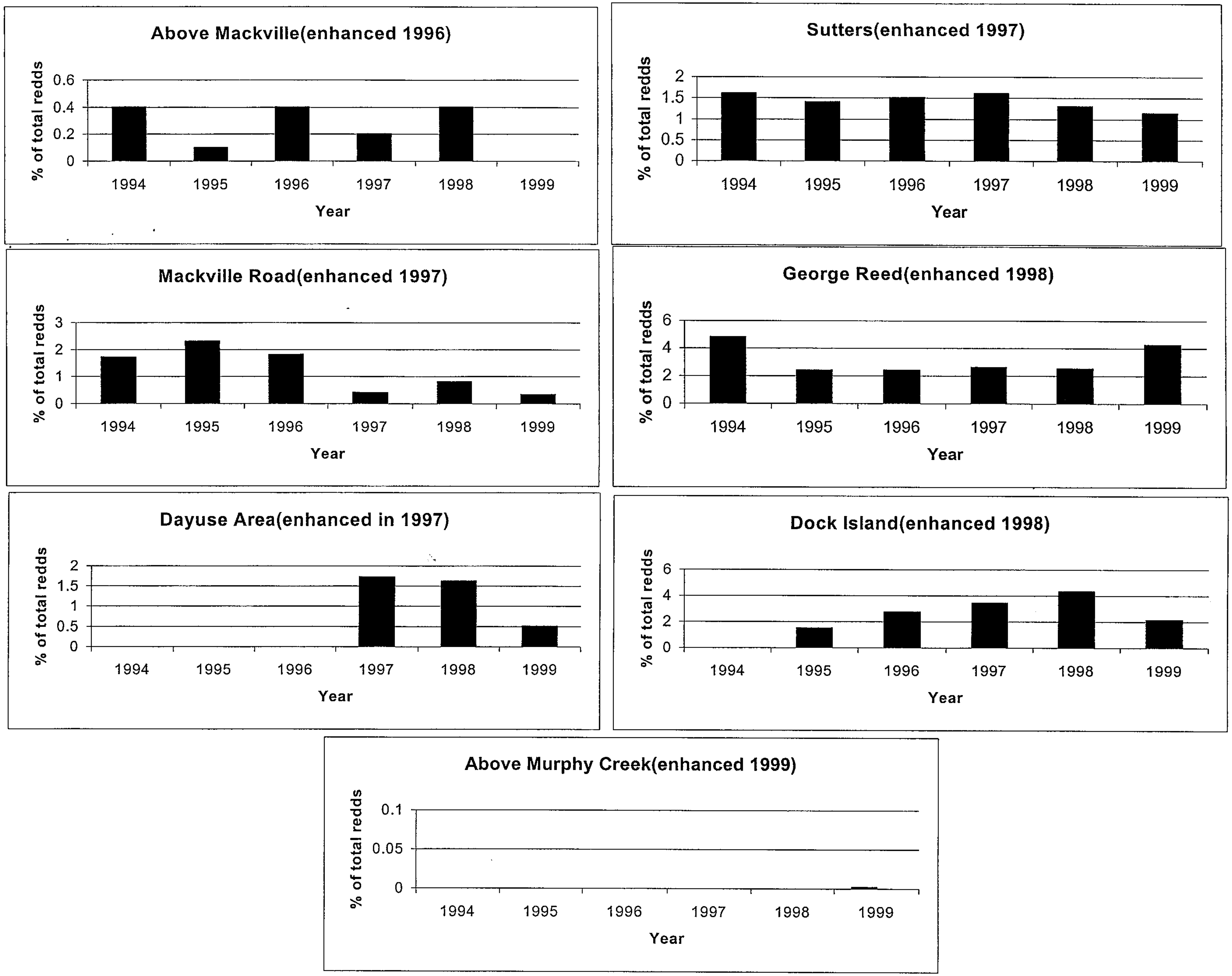

Figure 8. Percentage of total redds built in post-1995 gravel enhancement areas within the lower Mokelumne River from 1994-1999.

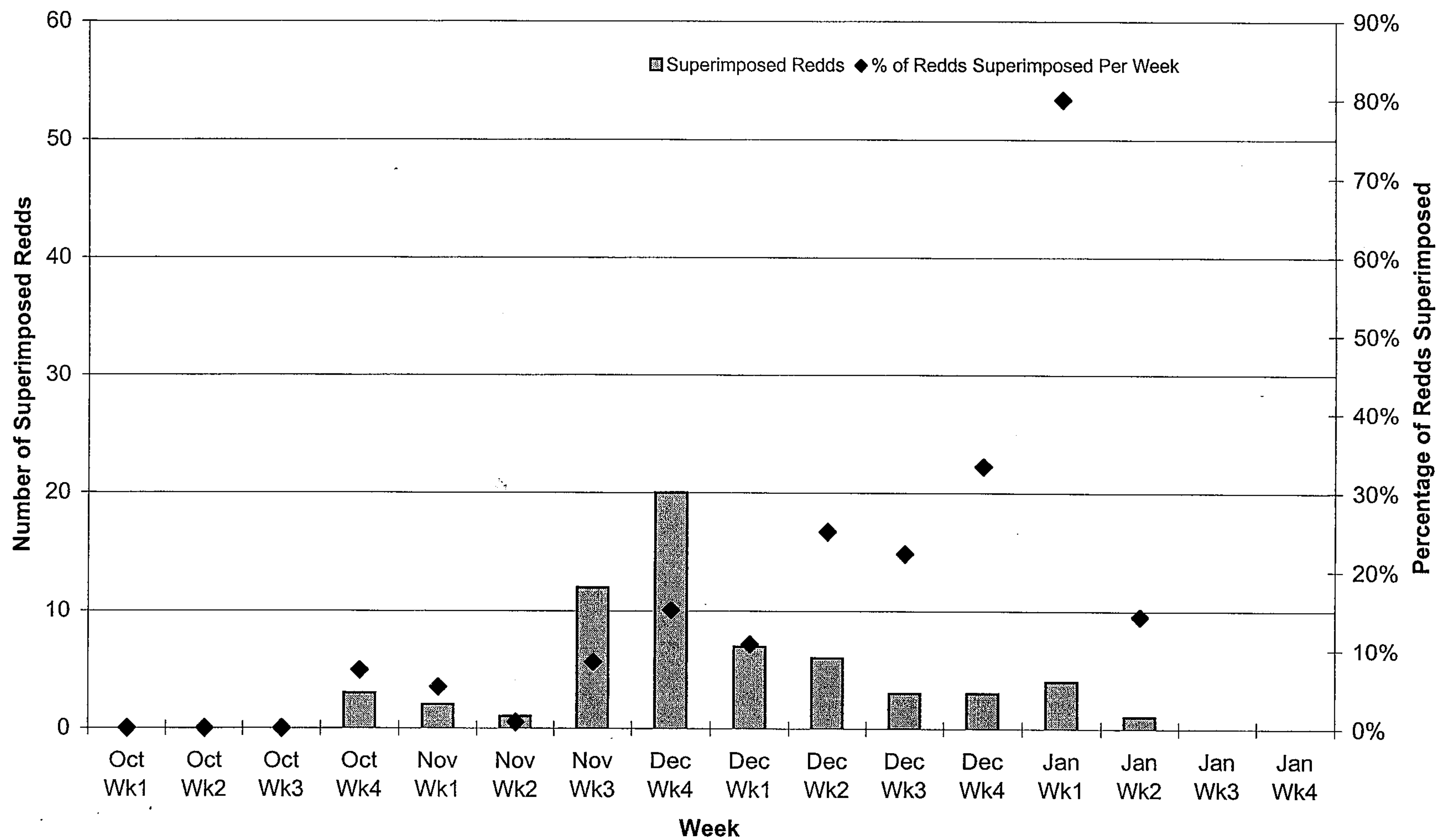

Figure 9. Number and percentage of redds superimposed during 1999/00 chinook salmon spawning run Mokelumne River, CA.

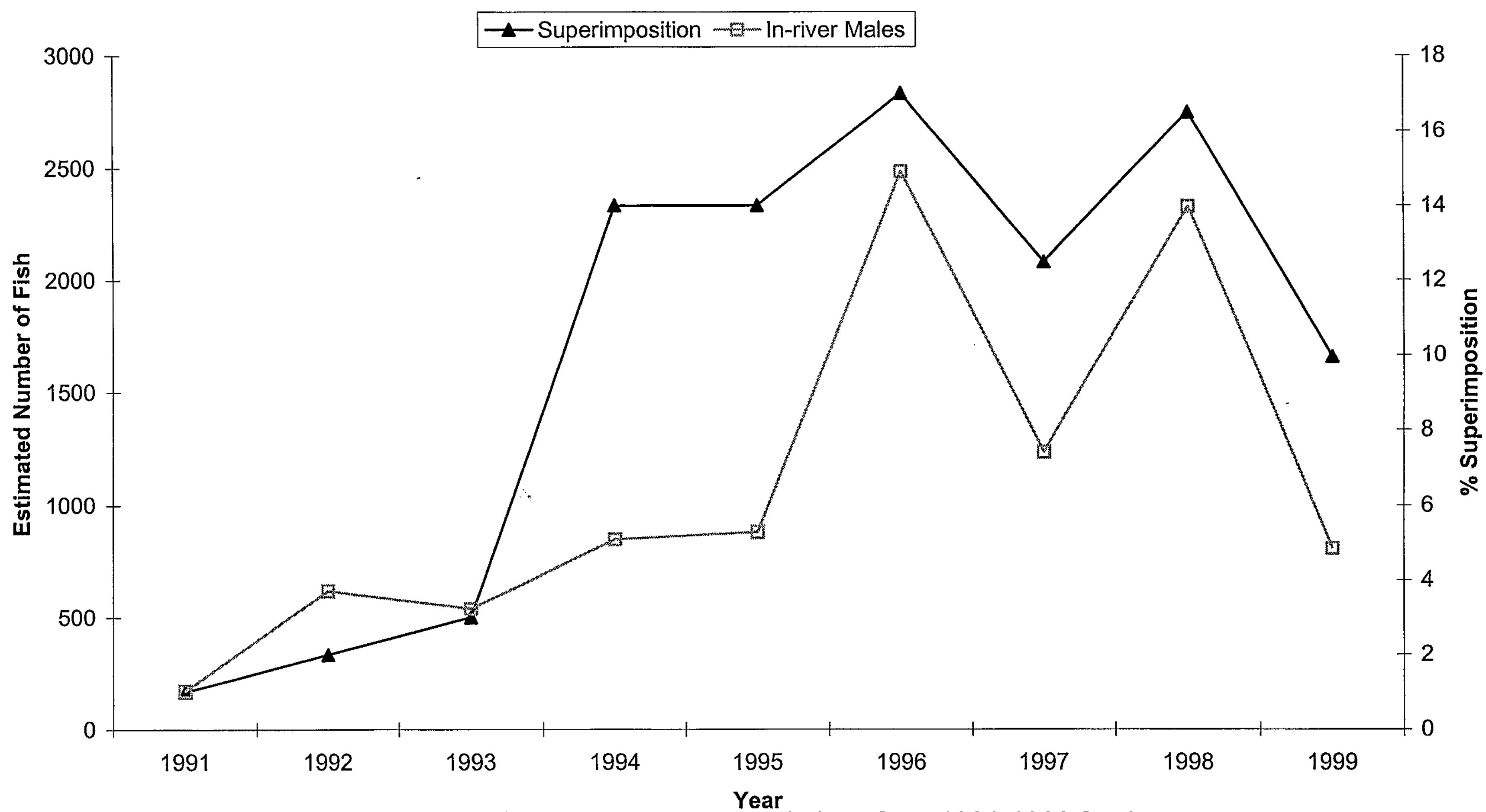

Figure 10. Superimposition level(percentage) vs. male in-river populations from 1991-1999 for the lower Mokelumne River, CA.

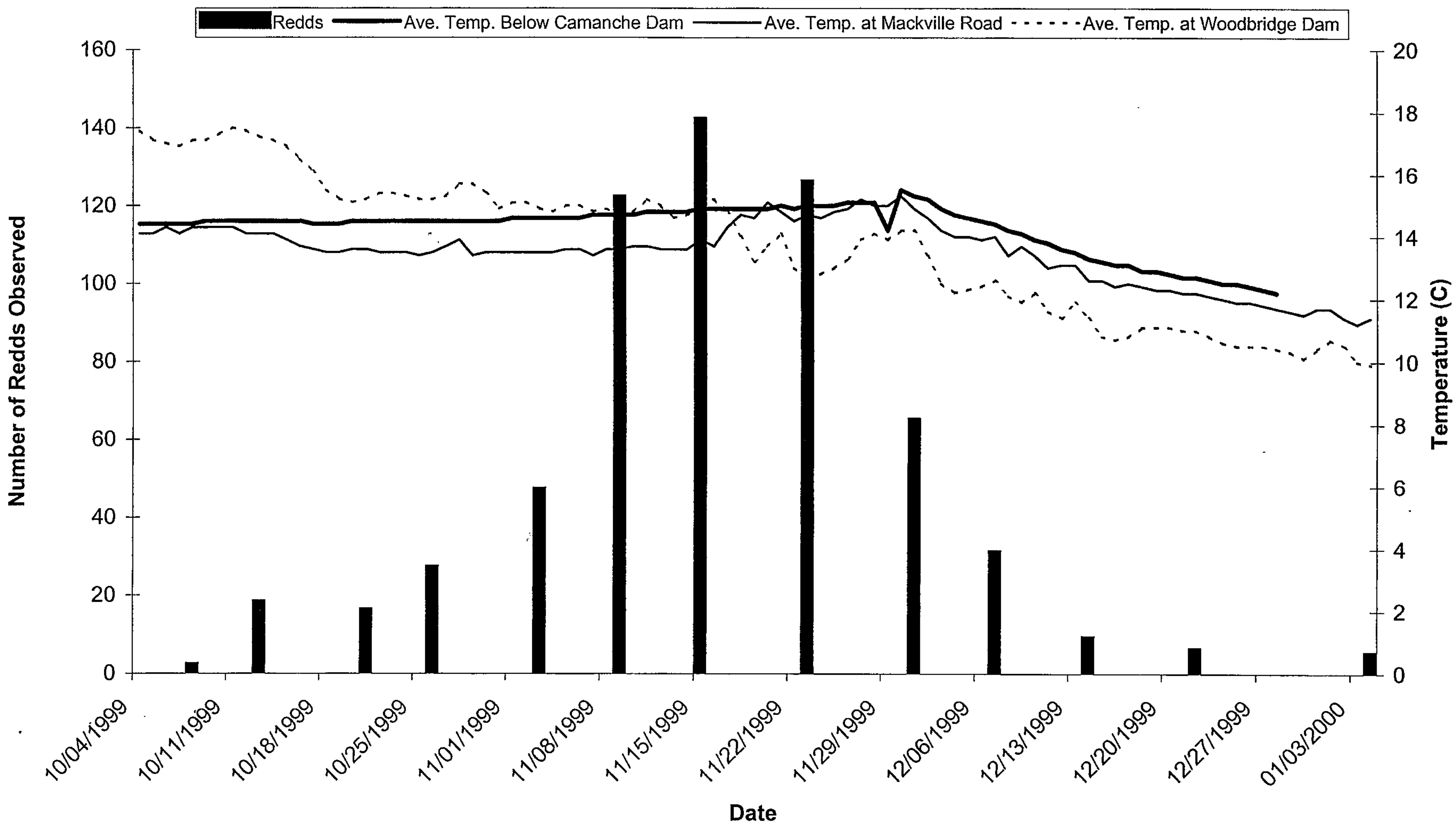

Figure 11. Water temperatures and weekly redd counts during 1999/00 chinook salmon spawning run Mokelumne River, CA.

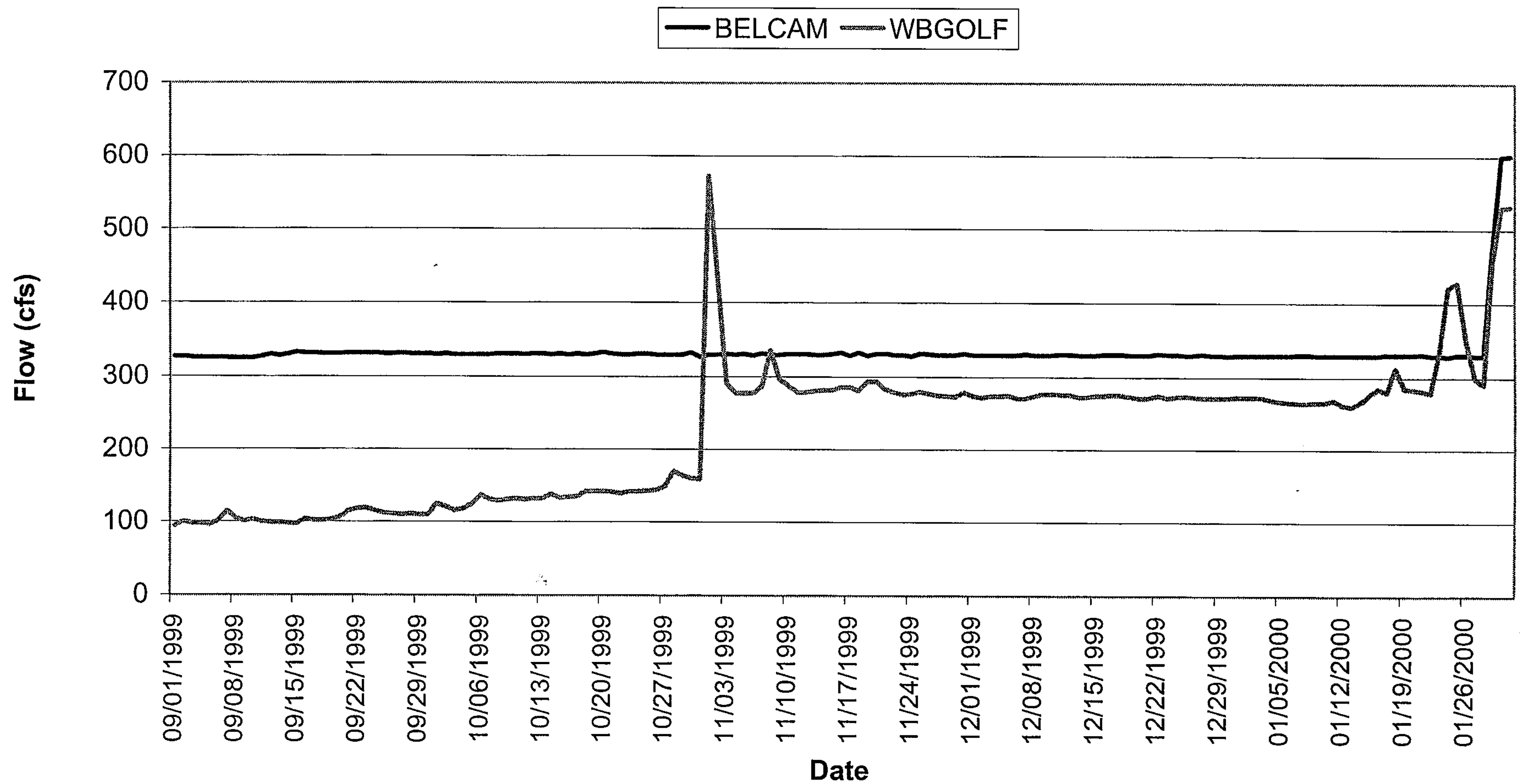

Figure 12. Mokelumne River flows (Camanche release and flow past Woodbridge Dam) from September 199 through January 2000.