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CALIFORNIA DEPARTMENT OF FISH AND GAME
HABITAT CONSERVATION DIVISION
Native Anadromous Fish and Watershed Branch
Stream Evaluation Program

Evaluation of Effects of Flow Fluctuations on the Anadromous Fish Populations in the Lower American River

Prepared for
U.S. Bureau of Reclamation

Stream Evaluation Program
Technical Report No. 01-2
November 2001

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INTRODUCTION

In 1996, the Bureau of Reclamation (BOR) entered an agreement with the California Department of Fish and Game (DFG) to generate information pertinent to development of flow fluctuation standards for operation of the Folsom Project. The goal was to improve protection of salmon and steelhead using the lower American River. Recent occurrences of substantial flow fluctuations and attendant losses of salmon and steelhead pointed to the need to determine the effects of flow fluctuations on anadromous salmonids in the LAR and identify opportunities to modify operations and implement other management actions that would mitigate flow fluctuation impacts. This report provides a summary of the results of that investigation.

Definitions and Terms

The terms describing components of flow fluctuation were based upon definitions provided by Hunter (1992).

Flow Fluctuation - Unnatural rapid changes in stream flow or stage over short periods resulting form operational activities of dams and diversions. Flow fluctuations can be immediately lethal or have an indirect or delayed biological effect. The effect of flow fluctuations are evaluated by studying the direct effects such as stranding mortality and redd dewatering, and behavioral aspects such as migration.

Flow Alteration - Changes in flow over long periods of time. The net changes in flow usually affect habitat availability.

Isolation - Isolation is the trapping of fish in side channels, potholes, depressions, etc., within and outside the active channel, with no access to the free flowing surface water of the stream. Isolation in the lower American River occurs in two general areas, side channels and scour holes. Side channels are areas seasonably or intermittently reconnected to the free flowing water in the main channel. As used here, side channels include secondary channels, sloughs and backwater areas. Scour holes are formed by water scour of gravel substrate around boulders, large woody debris, and where opposing flows meet around man-made objects, such as bridge pilings. Isolation typically results when flows increase above a certain stage, inundating adjacent areas, then receding to a lower stage eliminating access to the free-flowing, continuous portion of the stream channel river.

Stranding - Stranding is the beaching of fish on or in the gravel substrate by the separation of fish from flowing water as flow recedes; stranding is associated with areas that have been dewatered.

Ramping Rate - The rate of change in stage.

Bar type - Classification of gravel bars based upon profile: Low profile bars are relatively flat with slopes less than 2%; medium profile bars have slopes between 2 and 5%.

Background

Flow fluctuations, as defined herein, are unnaturally rapid changes in flow as compared to flow alterations that are changes in flow over long periods of time. Flow fluctuations rarely occur in unregulated streams except during or immediately after floods. Since natural flow fluctuation are rare, it is highly unlikely that aquatic animals have developed learned behavioral or evolutionary responses that would accommodate unnatural, rapid changes in flow commonly associated with regulated streams.

Historically, the American River supported an expansive population of anadromous fish (U.S. Fish and Wildlife Service, 1953). Adult chinook salmon and steelhead were known to migrate to distal reaches of the watershed to spawn. Spawning migrations were nearly year-around. Young salmonids could rear year-around throughout most of the drainage. Juvenile emigration was typically associated with the increasing hydrograph, occurring from late fall through early summer.

The life cycle of these anadromous fish was well suited to the habitat conditions provided throughout the drainage. Spring-run chinook salmon and steelhead used the upper reaches of the watershed where perennial supplies of cool water supported the typical one-plus years of juvenile rearing exhibited by these fish. Smaller, more confined and complex channel profiles typical of these upstream reaches allowed effective use of the reduced summer flows in sustaining rearing habitats and mitigated the effects of high flood flows. Migration typically occurred during the high flow period when up and downstream transport was optimum. Fall run chinook salmon typically spend less than one year in freshwater. They arrive early and ripe, ready to spawn when temperature declined in the fall, and their young leave the system before summer. As a result, they spawned and reared in lower portions of the drainage where high winter and spring flows have a more ephemeral affect on habitat availability. Fall run juvenile appeared to have survived the high flow periods by using the more persistent, high flow habitats present historically (e.g., flood plains).

As the extent of the watershed available for salmonid spawning and rearing progressively decreased with the increase in water development, as dams blocked migration and diversions altered habitats, the flexibility of the salmonid population to use the American River plummeted . Eventually, construction of the Folsom Complex restricted anadromous fish to the lowermost 23 miles of the American River, that heretofore, had been rarely used for spawning and rearing by anadromous salmonids. This reach provided some spawning and early juvenile rearing for only one (fall run) of the at least two races of chinook salmon that historically inhabited the American River . Spring run chinook salmon and steelhead primarily used this reach as a migratory route to and from the ocean, and it is likely that some juvenile salmon and steelhead produced in the upper drainage used this reach for short term rearing during the high flow periods when persistent flood plane associated habitats were available. As a result, spring run were extirpated from the American River, steelhead numbers drastically declined and the remaining populations of fall-run chinook salmon and steelhead became totally dependent upon regulated flows.

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The Folsom Complex has substantially modified the unregulated flow regime of the lower American River. Flow fluctuations have become routine, and in combination with changes in the stream channel resulting from both flood management and the affects of the Folsom Project on the hydrograph and sediment flow, flow fluctuations have become a serious threat to the remnant populations of salmon and steelhead.

Study Objectives

1. Determine the relationships between flow fluctuation, both magnitude and rate, and isolation of fishes.

2. Determine the significance of fish losses relative to timing, magnitude and rate of flow fluctuation.

3. Determine the relationships between flow fluctuation and viability of salmon and steelhead spawning.

4. Establish criteria for flow releases from the Folsom Project that would eliminate/minimize inundation of areas that become occupied by fish as flows increase, but become isolated from the main channel when flow recedes, trapping fish and eventually causing fish losses due to dessication of prolonged isolation.

5. Establish criteria for ramping flow releases from the Folsom Project that would eliminate/minimize stranding of fish in areas contiguous to the main channel.

6. Establish spawning flow criteria that would eliminate/minimize reduction in redd/spawning site viability due to stranding of spawning sites caused by decreasing flow during critical spawning periods and reducing spawning habitat availability resulting in loss of redds due to superimposition.

7. Establish criteria to eliminate/minimize effects of short-cycle flow changes on the anadromous fish population.

Problems

Several problems and associated questions were identified relative to flow fluctuations that were to be addressed in order to accomplish the objectives listed above

1. Fish Isolation - Increasing and decreasing flow beyond a specific critical, threshold flow level causing isolation of fishes in backwaters, side channel, mid channel and flood plane locales.

Question 1. Where are the potential isolation areas?

Question 2. Where are the points controlling these isolation areas?

Question 3. What are the threshold flows that allow inundation of the isolation areas?

Question 4. What is the relative significance to the fish population of losses due to isolation?

Question 5. What is the critical timing of use by species/life stages?

2. Fish Stranding - Increasing or decreasing flow too quickly to allow fish to relocate to suitable, continuously flowing areas of the channel.

   Question 1. What areas of the main channel are vulnerable to rapid decreases in flow?

   Question 2. What are the different flow ranges at which these areas are vulnerable to rapid flow changes?

   Question 3. What rate of flow ramping minimizes of eliminates stranding within these vulnerable areas?

   Question 4. What species/life stages would be affected by ramping within the vulnerable areas and when?

3. Redd Stranding/ superimposition - Decreasing flow causing desiccation or decreasing viability of spawning sites/redds.

   Question 1. What is the relationship between flow and spawning habitat viability for anadromous salmonids?

   Question 2. Are there threshold spawning flows that control use of potential spawning habitats; what are the threshold spawning flows?

4. Short-term flow changes - Frequent changes in flow magnitude causing cyclic inundation and desiccation of main channel habitats.

   Question 1. What is the relationship between the periodicity of flow change and salmon and steelhead?

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Approach

In order to accomplish the objectives and address the questions listed above, the study was defined in terms of six basic tasks. Each task has a specific objective(s) and approach(s) as described below. In general, the tasks were defined to focus on anadromous salmonids specifically to accommodate needs of the Central Valley Project Improvement Act (CVPIA). Emphasis of these tasks is to investigate several potentially significant results of fluctuating flows upon salmonids: isolation and stranding of rearing fishes; influences of flow fluctuation on spawning success; and dewatering of redds. Information from studies done elsewhere and information concerning timing and distribution of spawning, temporal and spatial distributions of other chinook salmon and steelhead life stages and implications of influences of flow fluctuations on anadromous salmonids has and will be used to define and implement the tasks and ultimately assess the results.

Tasks

Task 1. Aerial and Ground Surveys

Objective: The objective of this task is to identify potential stranding and isolation areas and bracket threshold flows on a site specific basis.

Approach: Aerial photographs were opportunistically taken of the entire 23 mile-long study reach (Sacramento River to Nimbus Dam) at various flows ranging between 1,500 cubic feet per second (cfs) and 11,000 cfs between 1996 and 2000. Surveys were conducted at ground level concurrent with the aerial photographs to validate the occurrence and distribution of isolated areas. The extent of the isolated areas resultant from the prevailing flow condition associated with each of the photographed/surveyed flow events was then depicted on the aerial photographs. A tabular relationship was then developed identifying the distribution and topographical areal extent of isolation sites as a function of flow conditions.

Task 2. Topographic Survey

Objective: The objectives of Task 2 are: 1) to determine the threshold or critical flow associated with site specific isolation areas; and 2) to assess the potential for stranding fish, specifically on gravel bars.

Approach: Aerial photographs taken per Task 1 were used to identify the occurrence of isolation areas as a function of flow. The potential range of threshold flows was determined by associating the first occurrence of inundation of a potential isolation area (obtained from aerial photographs) with the precedent flow conditions. The topographic distribution of flow depicted on the photographs was used to identify the general location of the point potentially controlling inundation of the isolation areas. Ground surveys were then conducted to confirm the extent of the isolation. Flow associated with the isolation for that locale was determined from the series of photographs representing inundation of the locales relative to flow change.

Stranding potential was assessed relative to gravel bar type (based upon profile). Bars were classified based upon percent slope as having a low(< 2%), medium (2–5%) or high (> 5%) profile. Aerial photographs were used to initially determine the bar type. Ground surveys were conducted to measure the actual profile of representative bars.

Task 3. Significance of Isolation to Salmon and Steelhead Populations

Objectives: The objectives of Task ~~4~~ 3 are: 1) to determine the vulnerability of salmon and steelhead to isolation relative to temporal and spatial distribution of life stages; 2) to determine the extent of loss of the various life stages of salmon and steelhead as a function of critical flows; and, 3) to determine the significance of the potential losses of fish to the American River salmon and steelhead populations relative to the magnitude and frequency of critical flows.

Approach: The vulnerability of salmon and steelhead to isolation events was determined 1) by reviewing information collected on rearing and emigration of the various salmon and steelhead life stages. This information included results of fish community surveys conducted from 1991 through 2000 and emigration monitoring conducted between 1994 and 2000; and 2) by directly surveying occupancy of salmon and steelhead in isolation areas following flow fluctuation events between 1995 and 1999. The potential vulnerability of the various life stages was defined as the presence/absence of those life stages in the river on a monthly basis. A liberal determination of vulnerability was identified by cumulatively assessing presence/absence from the 10 years of data described above. The relative magnitude of monthly life stage occurrence was also identified cumulatively and on an annual basis, to describe variability, using the 10-year data set. Composition of the juvenile populations (species and life stage abundance, etc.) occupying isolated areas was compared with the composition of juvenile populations occupying the river (both concurrently and comprehensively) to identify relationships between life stage occurrence and relative vulnerability to isolation.

The relative magnitude of loss of the various salmon and steelhead life stages associated with critical flows was assessed by estimating the number of isolated fish per unit area and applying the density (fish/unit area of isolation) to the total isolation area associated with increments of critical flow.

The relative significance associated with the potential loss of fish to isolation was determined 1) by estimating the potential contribution of the lost portion of the population to recruitment, and 2) by associating annual survival from egg to emigrant (for salmon) with the magnitude, frequency and temporal occurrence of isolation events.

Task 4. Spawning Habitat Relationships

Objective: Determine the relationship between flow change and changes in spawning habitat availability, redd stranding and superimposition.

Approach: Summarize information of temporal and spatial distribution of salmon and steelhead spawning. Delineate spawning habitats on aerial photographs and measure the amount of spawning habitat inundated at each survey flow. A general characterization of potential change in the area of spawning habitat as a function of flow change is represented by the difference in habitat areas measured at various flow increments (typically 1,000–2,000 cfs increments).

Secondly, summarize data relating redd superimposition (i.e., spawning over existing redds considered to indicate a shortage of spawning habitat) as a function of flow and spawner population density. Use these data to develop a relationship between superimposition and flow for varying spawner population sizes. This relationship can then be used to define the change in the amount of viable spawning habitat as flow changes for a given population size. Relative to the approach described above, this approach does not assume that all spawning habitat is equally useable at all flows (i.e., inundation/dessication of potential spawning habitat does not necessarily mean the habitat is viable).

METHODS AND RESULTS

Task 1. Aerial Surveys

Methods

Aerial photographs were taken of the 23 miles of the American River between the Sacramento River confluence and Nimbus Dam, the upstream limit to anadromous fish migration. Our goal was to take aerial photographs to represent conditions in the river at a range of flows between 1,000 cfs and 14,000 cfs, preferably at 1,000 cfs increments. Photographs were taken between 1996 and 2000 (Table 1). In addition, similar photographs taken between 1993 and 1996 as part of a spawning habitat evaluation conducted by the DFG were used, as needed, to provide information on flow conditions that were not available to photograph during the study period. The photographs were used to identify potential stranding and isolation areas, the flow or stage at which these events occur, and to delineate the features controlling these events. Aerial photograph surveys were also conducted each fall (1996–2000) to document the spatial and temporal distribution of fall-run chinook salmon spawning. Information was obtained from these photographs and those obtained between 1993 and 1996 to define the potential impacts of flow fluctuations on spawning habitat including area of inundation and redd dewatering associated with flow changes during the spawning period.

Table 1. Flow and date when aerial photographs were taken for use in the lower American River flow fluctuation study.

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Flow (cfs)	Date
1,034	6 Sep 1997
1,800	1 Dec 1997
2,000	10 Jan 1996
2,500	18 Dec 1997
2,800	8 Nov 1996
3,000	23 Dec 1998
4,086	Dec 1993
4,500	26 Nov 1996
8,000	19 Mar 1999
10,000	29 Jun 1995
11,000	4 Mar 1999

The aerial photographs and concurrent ground surveys were used to define isolation areas and potential stranding areas (based upon gravel bar profiles). Isolation and stranding areas were delineated on each photograph set, as appropriate. The relationship between flow change and isolation was identified by comparing the location and magnitude of isolated areas among the photographs representing conditions at the targeted flows. Flows incurring isolation at specific locations were bracketed using the photographs exhibiting the site when it first became inundated and the next lowest flow represented by aerial photographs, assuming that inundation occurred between the flows represented in the two photograph sets.

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The areal extent of isolation locals and spawning habitat at each flow represented by aerial photographs was determined using a planimeter. The area of inundation incurred from changing from flow *A* to flow *B* was estimated as the absolute difference between the area of isolation at each flow. This approach was used to account for the area of isolation that would become dry as flows receded.

The river was divided in to three study reaches[1] based upon the geometry of the channel (Table 2). Effects of flow fluctuation (i.e., isolation, stranding, etc.) were stratified by reach enabling a more direct association with biological impacts. For example, essentially no salmonid spawning occurs within reach 1; most fry rearing occurs within reaches 2 and 3, etc.

Table 2. Location of study reaches established during the lower American River flow fluctuation evaluation, 1996–2000.

Reach	Description
Reach 1	Sacramento River–Paradise Beach
Reach 2	Paradise Beach–Gristmill
Reach 3	Gristmill–Nimbus Dam

Results

Isolation occurred between each flow change evaluated (e.g., 3,000–2,000 cfs, 2,000-1,000 cfs, etc.) (Table 3). The greatest change in areas of isolation occurs when flow changes from 4,000 cfs to 8,000 cfs then back to 4,000 cfs when area of isolation increases nearly 24 fold (Tables 3 and 4)[2]. The extent of isolation increased 5% between 1,000 and 2,000 cfs and 9% between 2,000 and 3,000 cfs. The amount of isolated area decreased 4 fold when flow increased from 3,000 to 4,000 cfs. Among the evaluated flow ranges, the least amount of isolation occurred at 4,000 cfs, indicating that once flow reaches 4,000 cfs, isolation problems increase with any change in flow. ?

The majority of acreage prone to isolation events at or above flows of 8,000 cfs is in reaches 1 and 2 (Figures 1–3, Appendix 2). Similarly, the majority of acreage prone to isolation events between flows of 1,000 and 4,000 cfs is in reach 2 (Figures 1 and 3). The greatest amount of isolation occurs when flow exceeds 4,000 cfs in all reaches (Figures 1–4). Isolation is relatively absent in reach 1 until flow exceeds 4,000 cfs (Figure 2). Isolation occurs between all evaluated flows in reach 2 where substantial amounts of isolation were identified with each flow, except 4,000 cfs (Figure 3). Isolation within reach 3 is minimal until flows exceeds 2,000 cfs (Figure 4).

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[1] A fourth "reach" was established upstream of the Nimbus Hatchery weir for descriptive purposes. This reach was not included in all of the summaries presented below.

[2] Photographs of flow conditions between 4,000 and 8,000 cfs were not analyzed for this preliminary report.

Isolation events have routinely occurred during the past 10 water years (1991–2000) (Figures 5 and 6). During this 10-year period, isolation events (i.e., when flow surpassed then receded to the identified flow) occurred on the average of 3.2 times per year at 3,000 and 8,000 cfs, 2.5 times per year at 11,000 cfs, and 2.3 times per year at 4,000 cfs (Figure 5). Isolation events associated with high flows (e.g., > 4,000 cfs) occurred from December through August (Figure 6). On the average, high flow isolation events occurred at least once in January, February, March and May. Low flow isolation events, when flow changes were between 1,000 and 4,000 cfs, occurred in each month at least once during the 10-year period (Figure 6). The low flow events were typically associated with the low flow period in the river occurring on the average of at least once per year during the July through October period (Figure 6).

Task 2. Topographic Surveys

Methods

Aerial photographs obtained per Task 1 were used to identify river locations that represented isolation and stranding areas. These areas included gravel bars of all three profile types that were suspected to be potential stranding sites and probable isolation sites including backwater areas, ponds and side and off channel areas. Each location was surveyed to determine the slope/profile of selected gravel bars and control points associated with isolation locations.

Gravel bar gradients were determined by measuring the change in elevation along longitudinal and cross sectional bar profiles using a Lietz automatic level (Lietz model C-40). Between 3 and 20 elevations were measured across each gravel bar. Each gravel bar was classified as a high, medium or low gradient bar based upon the results of the surveys. A review of salmon stranding studies conducted in the west indicate that stranding on bars tends to occur on medium profile bars (slope 2–5%) and that salmon fry are most vulnerable to stranding on low profile bars (slope < 2%).

Results of PHABSIM modeling on the lower American River were used to identify typical stage discharge relationships associated with gravel bars. The results were used to determine the rate of change in stage for the various bar types. Literature review of stranding conditions observed in other western US streams suggest a general consensus that elevation changes of 2 inches or greater per hour results in stranding young fish. The gravel bar profile data was combined with the stage discharge relationship data for the various bar types to determine the ramping rate that would result in a decrease in associated stage of 2 inches per hour.

Seining surveys conducted from 1991 through 2000 were stratified to habitat zone (e.g., bar complexes) and habitat type (e.g., riffles) (Snider and Titus, 1996). Results of seining within the margin areas of bar complexes were used to determine the composition of juvenile salmonids occupying bar complexes vulnerable to stranding.

Table 3. The areal extent of isolation associated with flows measured during the lower American River flow fluctuation study, 1996–2000.

Reach	Flow	Area of isolation (acres)			
		North bank	South bank	Island	Total
Reach 1	1,000	0.0	0.0	0.0	0.0
	2,000	0.0	0.0	0.0	0.0
	3,000	3.3	0.0	0.0	3.3
	4,000	0.0	0.0	0.0	0.0
	8,000	31.5	3.3	2.8	37.6
	11,000	48.8	16.9	0.0	65.7
Reach 2	1,000	6.0	6.4	0.0	12.4
	2,000	0.1	7.3	2.3	9.7
	3,000	1.4	3.3	0.7	5.4
	4,000	0.0	0.6	0.5	1.1
	8,000	2.8	20.1	0.7	23.6
	11,000	10.9	61.0	2.7	76.6
Reach 3	1,000	0.1	0.2	0.0	0.3
	2,000	0.5	3.1	0.0	3.6
	3,000	1.2	4.2	0.4	5.8
	4,000	0.0	2.5	0.0	2.5
	8,000	9.9	10.4	3.9	24.2
	11,000	17.5	19.6	3.6	40.7
Above weir	1,000	0.0	0.0	0.0	0.0
	2,000	0.0	0.0	0.0	0.0
	3,000	0.0	0.0	0.0	0.0
	4,000	0.0	0.0	0.0	0.0
	8,000	1.4	0.0	0.0	1.4
	11,000	1.7	0.0	0.0	1.7
Total	1,000	6.1	6.6	0.0	12.7
	2,000	0.6	10.4	2.3	13.3
	3,000	5.9	7.5	1.1	14.5
	4,000	0.0	3.1	0.5	3.6
	8,000	45.6	33.8	7.4	86.8
	11,000	78.9	97.5	6.3	184.7

Table 4. Net change in area of isolation resulting from flow events that increase to the higher flow then decrease to the lower flow observed during the lower American River flow fluctuation study, 1996–2000.

Reach	Flow change event (cfs)	Net change in area of isolation (acres)			
		North bank	South bank	Island	Total
Reach 1	2,000–1,000	0	0	0	0
	3,000–2,000	3.3	0	0	3.3
	4,000–3,000	3.3	0	0	3.3
	8,000–4,000	31.5	3.3	2.8	37.6
	11,000–8,000	17.3	13.6	2.8	33.7
Reach 2	2,000–1,000	5.9	0.9	2.3	9.1
	3,000–2,000	1.3	4	1.6	6.9
	4,000–3,000	1.4	2.7	0.2	4.3
	8,000–4,000	2.8	19.5	0.2	22.5
	11,000–8,000	8.1	40.9	2	51
Reach 3	2,000–1,000	0.4	2.9	0	3.3
	3,000–2,000	0.7	1.1	0.4	2.2
	4,000–3,000	1.2	1.7	0.4	3.3
	8,000–4,000	9.9	7.9	3.9	21.7
	11,000–8,000	7.6	9.2	0.3	17.1
Above weir	2,000–1,000	0	0	0	0
	3,000–2,000	0	0	0	0
	4,000–3,000	0	0	0	0
	8,000–4,000	1.4	0	0	1.4
	11,000–8,000	0.3	0	0	0.3
Total	2,000–1,000	6.3	3.8	2.3	12.4
	3,000–2,000	5.3	5.1	2.0	12.4
	4,000–3,000	5.9	4.4	0.6	10.9
	8,000–4,000	45.6	30.7	6.9	83.2
	11,000–8,000	33.3	63.7	5.1	102.1

Results

Seining surveys associated with bar complexes from 1991 through 2000 show that all juvenile life stages of both salmon and steelhead can be found in areas vulnerable to stranding (Snider and Titus, 1996).

Evaluation of PHABSIM results suggest that a flow change of 300 to 500 cfs, within the range of 1,000 to 4,000 cfs, results in a 6 inch change in stage. Without evaluating bar-specific stage-discharge relationships, a stage reduction rate of less than 2 inches per hour could be achieved by limiting the ramping rate to less than 100 cfs per hour (when flows are between 1,000 cfs and 4,000 cfs).

Task 3. Biological Implications Associated with Isolation

Methods

The temporal and spatial distributions of salmon and steelhead was acquired from information collected on the lower American River between 1991 and 1996 to describe their potential vulnerability to flow fluctuation events. Determination of the vulnerability to isolation of the salmon and steelhead rearing in the lower American River was enhanced by directly surveying isolated areas and connected areas concurrently when the opportunities arose from 1997 through 2000. The occurrence of isolation was monitored during this period by surveying the river following expected isolation events, focusing on areas identified per Task 1 as probable isolation sites. Isolated sites and adjacent connected sites were surveyed in reaches 2 and 3 using seines and electrofishers, as appropriate. Collected fish were counted by species and measured (fork length [FL] in mm and weight in gm). The areal extent sampled was also measured at each isolated sample site. Relative vulnerability was assessed by comparing the size and species compositions of the salmon steelhead collected in the isolated areas with the compositions measured in the connected areas.

Estimates of losses associated with isolation events were developed by expanding the measured fish densities of the isolated areas to account for the total area of isolation incurred by the event. Not all sites could be sampled. Some sites were too deep to use either seine or electrofishers. Other sites were too overgrown with vegetation and were unaccessible to sampling.

The overall impact associated with isolation events was evaluated by comparing the survival of salmon to emigrant as a function of flow isolation events. Rotary screw traps located near river mile 9, at Watt Avenue, were used to collect downstream migrants and estimate emigrant abundance for each year migration data were available. The estimated number of migrants was compared with the number of female spawners estimated to have successfully spawned to obtain a survival index. The survival index was compared with the magnitude, duration and frequency of isolation events to identify any influences of isolation on survival. Results of the isolation site surveys were also integrated into the evaluation of the significance of the isolation events. Life stage composition (e.g., salmon fry versus juvenile versus smolt and steelhead young of the year versus yearlings, etc.) observed in the traps versus the isolated sites were compared. (For example, losses of older, larger salmon and steelhead was considered more significant than comparable losses of fry).

Results

Juvenile rearing distribution

Recently emerged chinook salmon are typically present in the lower American River from early January through March (Table 5, Figures 7–9). Some recently emerged sized salmon have been observed as early as December and as late as late April, depending primarily on temperature conditions in the fall through spring period. Older, larger chinook salmon juveniles (> 100 mm FL) and an occasional yearling typically occur in the lower American River between February and July. Juvenile chinook salmon have also been routinely found in the river in December. These early appearing juveniles are both winter-run and spring-run sized salmon that likely use the American River for non-natal stream rearing.

Steelhead fry generally first appear in the river during early to mid March (Figures 10 and 11). Recently emerged sized steelhead have been observed in the American River as early as December and as late as July. Steelhead rear in the American River for about one year. Yearling-sized steelhead have been trapped while emigrating as early as December and as late as April (Figure 12).

Isolation event monitoring

During the four year study period (1997–2000) a total of 22 isolation events were monitored (Table 6, Figures 13–16). At least one flood control release (>20,000 cfs) was made each year resulting in creation of substantial areas of isolation and potentially abundant fish losses. As a result, this component of the study characterizes the vulnerability of salmon and steelhead to isolation events, identifies densities of isolated fish and magnitude of isolation and potential losses associated with major, typically unavoidable flow fluctuations. The temporal distribution and duration of the high flows associated with most observed isolation events generally masked the opportunity to directly evaluate the response of fish to isolation events that might occur under managed flow conditions (defined as up to 11,000 cfs for purposes of this study) during the more critical rearing periods for salmon (January–May) and steelhead. The results, do however, encompass some events that were due to operational changes of the Folsom Project that were not strictly for purposes of passing high, flood flows. The characterization of the response of fish to the high flow releases compared with the observed response of fish during the few, lower flow, managed isolation events should allow prediction of salmon and steelhead responses to isolation events as a function of fish availability (e.g., time and location).

Table 5. Percent monthly distribution of salmon and steelhead life stages collected by seining in the lower American River from 1992–1995.

Species - life stage	Year	Jan	Feb	Mar	Apr	May	Jun	Jul
Chinook salmon - fry	1992	ns	49	43	8	<0.1	<0.1	0
	1993	<0.1	1	26	66	6	1	0
	1994	2	30	55	12	1	<0.1	0
	1995	1	36	26	37	<0.5	<0.1	ns
Chinook salmon - juvenile	1992	ns	5	27	54	14	<0.5	<0.5
	1993	<0.1	1	2	76	13	6	<0.5
	1994	0	<0.1	36	41	20	3	<0.1
	1995	<0.5	1	2	21	58	17	ns
Chinook salmon-yearling	1992	None caught						
	1993	None caught						
	1994	100	0	0	0	0	0	0
	1995	100	0	0	0	0	0	0
Steelhead - fry	1992		<0.1	4	64	31	1	0
	1993	0	0	3	42	40	14	ns
	1994	0	<0.1	3	43	47	6	<0.1
	1995	0	0	2	31	35	32	ns
Steelhead - juvenile	1992		0	0	8	34	41	17
	1993	0	0	0	<0.5	<0.5	29	71
	1994	0	0	<0.1	3	39	55	3
	1995	0	0	0	0	30	70	ns
Steelhead - yearling	1992		15	80	5	0	0	0
	1993	75	25	0	0	0	0	0
	1994	None caught						
	1995	100	0	0	0	0	0	0

Results of concurrent sampling of isolated sites and connected main channel sites between 1997 and 2000 indicates that all life stages of salmon and steelhead rearing in the lower American River are quite vulnerable to isolation events (Table 7). We found that at the beginning of an isolation event, isolated areas contained species and life stage compositions that were comparable to those found concurrently in the adjacent connected areas. Occasionally, there were life stages ✓ found in the isolated areas that were not found in the connected areas. Fish density was always higher in the isolated areas, likely due to sampling conditions that were more favorable to the survey methods. The isolated areas were typically shallower and with no velocity compared to the much swifter areas in the main channel, especially when the flows were high which was generally the case when high-flow isolation events were being investigated. ✓

1997 results - In 1997, a total of 5,532 chinook salmon and 1,219 steelhead were collected between 14 January and 22 May 1997 from 22 individual isolated sites (Table 7, Figures 17 and 18). Similarly, a total of 2,020 chinook salmon and 1,068 steelhead were collected form 85 adjacent, connected sites between 14 January and 27 June 1997. The surveys encompassed 6 isolation events (Table 6). During the first event, following an unusually high flood flow of 106,000 cfs (1 January 1997), sampling occurred during weeks 3 and 4 (14–21 January 1997). Chinook salmon life stage composition was comparable in both the isolated and connected sites; the salmon catch rate was slightly higher in the connected sites (Figures 19 and 20). Salmon catch rates increased in the isolated sites, relative to the connected sites, during the next event (weeks 4–8, 22 January–21 February 1997). This event was characterized by a high flow of 32,000 cfs followed by a decrease in flow to near 4,000 cfs (Table 6, Figure 13). The higher catch rate in the isolated areas appeared associated with increased numbers of shallower, easier to sample sites. The catch rate declined toward the end of the event suggesting that salmon were progressively lost over the 4 week-long period. Life stage composition was again comparable. Fry dominated catches in both areas with a few spring-run and winter-run sized fish occurring in both catches (Figures 17 and 18). During the next event, flows declined from 7,000 cfs to 2,400 cfs between weeks 9 and 21 (24 February–22 May 1997). Salmon catch rates increased substantially in the isolated (25 fish/seine haul early and up to over 45 fish/haul late in the event) and connected sites (15 fish/seine haul early to a high of over 20 fish/haul during the middle of the event) as fry numbers increased in the river. Only fry were collected in both areas early; juveniles were represented in the catches of both areas. Mostly smolt sized salmon (> 70 mm FL) were collected in both areas toward the end of the event.

Steelhead catches during the first isolation event of 1997 were very high in the isolated areas (Figures 19 and 20). The steelhead catch in both areas comprised both in-river produced steelhead yearlings and hatchery produced steelhead[3] (Figure 21); the numbers were substantially higher in the isolated areas. Catches remained nearly consistent through the next event with slight decreases in catch rates, primarily in the connected sites (Figure 22). Steelhead fry began to

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[3] The entire 1996 brood year production of steelhead at Nimbus Hatchery were released into the river during the early part of the first isolation event due to poor water quality in the hatchery caused by gas compression associated with the high flood releases.

appear in the connected site catches early beginning in week 9 (24–27 February 1997) but did not occur in the isolated site catches until week 18 (sampling was not conducted in the isolated areas between weeks 15 and 18 when flow was essentially constant at 2,500 cfs). Since so few steelhead fry were collected in the isolated sites in 1997, it is highly likely that the steelhead that were caught in the isolated areas during week 18 were present but not caught in week 15 (due to size and the small numbers). As such, the last isolation event to entrap steelhead likely occurred in week 14 when flow decreased from 3,500 to 2,500 cfs.

1998 results - During 1998 we monitored species life stage distributions associated with nine isolation events (Table 6). A total of 9,058 chinook salmon and 89 steelhead were collected from 21 distinct isolation sites between weeks 10 and 27 of 1998 (4 March–24 July 1998) (Figures 23 and 24). Similarly, 559 salmon and 261 steelhead were collected from 46 connected sites, including 12 off-channel locations (Figures 23 and 24).

As in 1997, the first isolation event was associated with a flood flow (34,000 cfs) on 4 February 1998 (Table 6, Figure 14). Sampling during this event (4–6 March 1998, flow range 4,500–29,500 cfs) yielded relatively high catch rates of salmon fry in both the isolated and connected sites (Figures 25 and 26). A few juvenile-sized salmon were collected in each site type; one winter-run sized salmon in the isolated areas and one spring-run sized salmon in the connected areas (Figure 25, Appendix 1). Average size for all collected salmon was essentially equal for both areas. Flows fluctuated between about 7,500 and 12,000 cfs from week 10 through 20 (19 March–15 May 1998) creating four isolation events (Figure 14). Salmon catch rates were high in the isolated areas early in this period (week 12); catch comprised mostly fry. Two spring-run sized salmon were caught along with 20 juvenile fall-run salmon (~6% juveniles). Catch rate was also high in the connected areas; all captured salmon were fry (Figures 25 and 26, Appendix 1). Catch rates declined during the remainder of this period in the isolated and connected "in-channel" areas; rates were higher in the connected "off-channel" areas (Figure 26). Average salmon size increased between weeks 10 and 20 in all three area types as fewer fry entered the catch. The reduced catch rates in the isolated sites and comparable size compositions among the three area types suggests that few fish entered the isolated sites as flows fluctuated late in the salmon rearing period (after May 1st). However, increased steelhead catches during this period, in both the isolated and connected areas, indicate that available fish continued to enter the isolated areas as flow fluctuated (Figures 27 and 28). As flows receded slightly, but continued to fluctuate (3,500 to 10,000 cfs) through week 30 (24 July 1998)~~, steelhead catches in~~ STET the isolated areas also fluctuated relative to catches in the connected areas. Isolation area catches reflected an increase in isolation as flows fluctuated between lows of 3,500 and 4,000 cfs and highs of 9,000 and 10,000 cfs, respectively. The size composition of steelhead in all three area types was comparable during this latter part of the 1998 survey period (Appendix 1).

1999 results - Four isolation events were surveyed during the 1999 survey period between 13 December 1998 and 22 March 1999 (Table 6, Figure 15). The first event occurred late in 1998 when flow decreased form 3,000 cfs to 2,500 cfs. Unfortunately, no isolated sites were surveyed

Table 6. Summary of isolation event sampling during the lower American River flow fluctuation study, 1996–2000.

Isolation Event/ Date	Maximum Flow Immediately Preceding	Sample Weeks, Date	Flow Range During Sample	Flow Change
1 Jan 1997	106,000	3–4, 14–21 Jan	6,000–17,000	100,000
23 Jan 1997	32,000	4–8, 22 Jan–21 Feb	4,000–32,000	28,000
23 Feb 1997	7,000	9, 24–25 Feb	4,000–5,000	3,000
27 Feb 1997	7,000	9–13, 27 Feb–27 Mar	3,500–7,000	3,500
Continuous	4,000	15, 7–11 Apr	2,500–3,000	1,000
Continuous	2,500	18–19, 28 Apr–5 May	2,500	0
Continuous	2,900	21, 20–22 May	2,400-2,900	500
17 Jun 1997	3,400	26, 23–27 Jun	1,800–3,000	1,600
4 Feb 1998	34,000	10, 4–6 Mar	4,500	29,500
19 Mar 1998	8,000	12, 19 Mar	8,000	0
26 Mar 1998	12,000	15–17, 8–23 Mar	7,500	4,500
30 Apr 1998	10,000	17–18, 24–30 Apr	7,500–10,000	2,500
4 May 1998	11,000	19–20, 4–15 May	9,000–11,000	2,000
15 May 1998	11,000	21–22, 18–28 May	6,000–11,000	5,000
1 Jun 1998	9,000	23–24, 2–14 Jun	5,300–8,500	3,700
17 Jun 1998	10,000	25, 15–19 Jun	9,000–10,000	1,000
25 Jun 1998	9,000	26, 22 Jun–24 Jul	3,500–9,000	5,500
Continuous	8,000	27–30, 7–24 Jul	4,000–8,000	4,000
13 Dec 1998	3,000	52–1, 13 Dec–2 Jan	2,500–3,000	500
21 Jan 1999	20,000	5–6, 26 Jan–2 Feb	4,500–10,000	15,500
18 Feb 1999	26,000	9, 23 Feb	16,000	10,000
2 Mar 1999	11,000	10–13, 4–22 Mar	4,000–11,000	7,000
11 May 2000	4,200	25 May	2,400–4,200	1,800

Flow was 6,000 cfs on 4/29/00.
5,750 on 5/8/00
5000 on 5/9/00

Table 7. Summary annual catch of chinook salmon and steelhead collected from isolated and connected sample sites during the lower American River flow fluctuation study, 1997–2000.

Chinook Salmon

	Isolated					Connected				
Year	Fall	Spring	Winter	Late fall	Total	Fall	Spring	Winter	Late fall	Total
1997	5,440	99	1	0	5,540	2,010	7	3	0	2,020
1998	9,027	2	1	28	9,058	472	1	0	86	559
1999	15,926	0	0	0	15,926	2,268	18	267	68	2,638
2000	14	0	0	4	18	18	0	0	0	18

Steelhead

	Isolated			Connected		
Year	YOY	Yearling	Total	YOY	Yearling	Total
1997	336	856	1,219	1,047	21	1,068
1998	31	0	31	261	0	261
1999	3	0	3	116	0	116
2000	21	0	21	30	0	30

during this event. Surveys of the connected sites during this event yielded a relatively large number of winter-run-sized (267 salmon, 93% of the catch), a few spring and fall-run-sized juvenile salmon (Appendix 1). Isolated sites were first sampled during the 1999 survey following another flood flow event (20,000 cfs on 21 January 1999). A total of 23 distinct isolated sites were surveyed between 26 January and 26 March 1999 (Figure 29) yielding a total catch of 15,926 chinook salmon and 3 steelhead (Table 7, Figure 30). Only very small, recently emerged steelhead were collected during the last survey period within the connected sites. The latest isolation event had occurred over one week earlier, apparently just as steelhead emergence started. A total of 53 connected sites (47 in-channel and 6 off-channel) were surveyed yielding a total 2,638 salmon and 116 steelhead (Table 7, Figures 29 and 30).

Results of the isolation surveys in 1999 were comparable to those conducted in 1997 and 1998. Catches in the isolation areas reflected the distribution of salmonids at the time, i.e., they were comparable to concurrent catches in the connected sites (Figures 31–34, Appendix 1). Catch densities increased as the numbers of the available life stages increased and isolation events continued to occur. As expected per the results described above, isolation events encompassing flow changes between 4,000 and 7,000 to 10,000 cfs resulted in large numbers of available life stages in isolated sites.

2000 results - In 2000, one isolation event was opportunistically evaluated when a managed flow fluctuation occurred in mid May (Table 6, Figure 16). Flow was increased from 4,500 cfs to 6,000 cfs, dropped to 2,500 cfs, increased to 4,200 cfs then eventually reduced to 2,300 cfs within a 2-week period 27 April–11 May 2000). A survey of an isolated site on 25 May 2000 showed that the species/life stage composition and densities were comparable in both the isolated and adjacent, connected sites (Table 7).

Task 4. Spawning Habitat Evaluation

Methods

Spawning distribution

The temporal and spatial distributions of salmon and steelhead life stages describing their potential vulnerability to flow fluctuation events was acquired from information collected on the lower American River between 1991 and 1996. Chinook salmon spawning distributions were obtained directly from spawning habitat evaluations conducted between 1992 and 1996. Steelhead spawning distributions were obtained indirectly by relating the temporal and spatial distributions of recently emerged salmon to an estimated timing and distribution of spawning. Temporal and spatial distributions of rearing were obtained directly for both species from the results of seining data collected between 1991 and 1996.

Effects of flow fluctuation

The influence of flow fluctuation on spawning was evaluated using data obtained from aerial photograph surveys conducted between 1991 and 1996. Two approaches were used to relate flow change to change in spawning habitat. The first approach involved direct measurements of potential spawning habitat pictured on aerial photographs at various flows between 1,000 and 4,000 cfs. The net change in inundated spawning habitat accounted in 1,000 cfs increments provided a rough determination of the change in spawning habitat availability relative to a specific change in flow. This approach also allowed determination of the relative area that would be desiccated, and result in redd loss as flow decreased from one level to another.

The second approach used data collected on the occurrence of redd superimposition determined from aerial redd surveys conducted between 1991 and 1995 (Snider and Vyverberg, 1996). Snider and Vyverberg (1996) reported the percentage of redds that were superimposed each survey year, the estimated spawner population and flow conditions during spawning (Table 8). These data were analyzed using both linear and polynomial regression analyses to determine the significance of the relationships between spawning population, flow and the rate of superimposition. These analyses indicated that the only statistically significant relationship was between flow and rate of superimposition ($r^2 = 68$, $p < 0.10$). These data were then used to determine relative spawning habitat availability, or an index of viable spawning habitat as a function of flow. The effective spawner population for each year was multiplied by the 1 - the superimposition rate to determine the relative numbers of spawners that were accommodated with available spawning habitat. The number of accommodated spawners was then normalized to the number incurring the lowest superimposition rate, assuming the conditions during the year with the lowest rate of superimposition (1995) expressed the optimum relationship between spawner population and flow (habitat availability). The results, termed herein percent of optimum spawning habitat availability (S_o) were analyzed using a polynomial regression model to determine the relationship between flow and percent optimum spawning habitat. The relationship[4] was determined to be statistically significant ($r^2 = 95.9$, $p < 0.01$). S_o was then calculated using the regression model for flows ranging from 500 cfs to 2,500 cfs in 250 cfs increments.

Results

Chinook salmon spawning

Distribution - Temporal distribution of salmon spawning in the lower American River during the redd surveys conducted between 1991 and 1995 ranged from as early as 18 October to as late as 28 December (Figure 35). Aerial redd surveys were generally terminated in the end of December, except in 1991, when flow typically increased and water visibility decreased rendering aerial surveys less informative. During the 1991–1992 spawning period, aerial surveys

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[4] $S_o = 0.00971797 + 0.0000070819 * \text{flow} + 1.37122E\text{-}7 * \text{flow2};$

Table 8. Summary of redd superimposition rates, flow and spawner populations used to analyze the relationship between flow change and spawner habitat viability in the lower American River flow fluctuation survey, 1997–2000.

Year	Superimposition rate(%)	Spawner population	Flow
1991	8	18145	1200
1992	42	4472	500
1993	19	26786	1750
1994	17	31333	1500
1995	1.3	70096	2625

were continued through mid March 1992 to monitor late salmon spawning and steelhead spawning. Nineteen salmon redds were observed during January and 8 during February. No new redds were observed after the February flight (2 February 1992).

Occurrence of recently emerged salmon fry in seine and emigration surveys was used to estimate the extent of early and late salmon spawning. Emigration survey data revealed that recently emerged salmon were present in the river as early as 26 November (1995) 15 December (1996) and 18 December (1994) (Table 9). Seine survey results revealed that recently emerged salmon fry were present in the river as late as June in all years (1992–1996) (Table 10). The latest catch of a recently emerged salmon occurred on 23 June 1993. These results indicate that successful spawning in the lower American River occurred as early as September and as late as May.

The distribution of salmon spawning was directly measured using the aerial survey results from 1991–1995 (Figure 36). Salmon spawning occurred as far downstream as river mile 6, but was concentrated in the upper 3 miles. Seine survey results from 1991 through 1993 (the only years that seine surveys included the entire 3 reaches of the river) showed that recently emerged salmon were distributed throughout the river. Since some salmon begin to emigrate immediately following emergence, the seine distribution results do not necessarily reflect spawning habitat distribution.(A schematic delineation of chinook salmon spawning habitat is presented in Appendix 2).

Table shows 350 acres

Effects of flow fluctuation - Measurements made using aerial photographs showed that approximately 280 acres of potential spawning habitat were inundated at 4,000 cfs (Table 11). The amount of habitat inundated at 3,000, 2,000 and 1,000 cfs was 340, 325 and 275 respectively. These results indicate that the area of spawning habitat is reduced 3 % when flows drop from 4,000 cfs to 3,000 cfs, 5 % when flows drop from 3,000 cfs to 2,000 cfs and 12 % when flows drop from 2,000 cfs to 1,000 cfs. As such, flow fluctuations during the spawning period, when flow is typically between 1,000 cfs and 3,000 cfs, could reduce inundated spawning habitat by as much as 17%. The data also suggest that potentially 17% of the redds constructed at around 3,000 cfs would be desiccated if flows fluctuated to near 1,000 cfs.

Based upon the above analysis, optimum spawning conditions were available for a population of about 70,000 chinook salmon spawners at a flow of 2,625 cfs. In order to identify relative optimum conditions for different spawner populations at different flows, the population in question was divided by 70,000 and then the result of that calculation was divided into the percent optimum conditions calculated for 70,000 spawners at various flows derived from the regression model[5].

Steelhead spawning

Distribution - The only year steelhead spawning was directly monitored (aerial and ground surveys) was in the 1991–1992 spawning period. Results of this survey showed that steelhead spawning occurred from January into March (when the survey ended) and was distributed throughout most of the river situated upstream of Paradise Beach. Spawning was concentrated in the uppermost reach, similar to salmon spawning distribution.

Occurrence of recently emerged steelhead fry in the seine surveys was used to further develop information on steelhead spawning distribution (Table 12). Recently emerged fry were found as early as February (1992 and 1994) and March (1993 and 1995). They were found as late as June (1992 and 1995) and as late as July in 1993 and 1994. Seine survey results showed that recently emerged fry occurred from near Paradise Beach upstream to near Nimbus Dam. Since young steelhead are much less likely to migrate early in life, the distribution of recently emerged steelhead identified in the seine surveys likely reflects steelhead spawning distributions. The above results suggest that steelhead spawning can occur as early as December and as late as June, from Paradise Beach upstream to at least Sailor Bar. (A schematic delineation of steelhead spawning habitat is presented in Appendix 2).

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[5]

$$S_{on} = S_{oq}/(N_s/56{,}000)$$

where:

S_{on} = percent of optimum habitat for population Ns at flow Q
N_s = Target spawner population
S_{oq} = % of optimum habitat available for 56,000 salmon at a flow of Q cfs

Table 9. First occurrence of recently emerged sized chinook salmon in the trap catches during emigration monitoring on the lower American River, 1994–1997.

Year	First Occurrence
1994	9 Jan 1994
1995	18 Dec 1994
1996	26 Nov 1995
1997	15 Dec 1996

Table 10. First and last occurrence of recently emerged sized chinook salmon caught during seine surveys conducted in the lower American River from 1992–1995.

Year	Sample period	First occurrence	Last Occurrence
1992	Feb–Jul	Feb	May
1993	Jan–Aug	Jan	Jun (23rd)
1994	Jan–Jul	Jan	Jun
1995	Jan–Jun	Jan	May

Table 11. Potential spawning habitat availability and net change in habitat availability resulting from a flow change of 1,000 cfs in the lower American River.

Flow (cfs)	Potential Spawning Habitat Available* (acres)	Net change in area w/ 1,000 cfs decrease (acres/percent)
1,000	275	na
2,000	325	40 (12%)
3,000	340	15 (5%)
4,000	350	10 (3%)

* Rough measurements of potential spawning habitat obtained from planimetric measurements of aerial photographs (Scale: 1:24,000).

Table 12. First and last occurrence of recently emerged sized steelhead caught during seine surveys conducted in the lower American River from 1992–1995.

Year	Sample period	First occurrence	Last Occurrence	Distribution
1992	Feb–Jul	Feb	Jun	H St–Sunrise
1993	Jan–Aug	Mar	Jul	H St–Sunrise
1994	Jan–Jul	Feb	Jul	Gristmill–Sunrise*
1995	Jan–Jun	Mar	Jun	Gristmill–Sunrise*

* Only Gristmill to Sunrise was sampled.

Effects of flow fluctuation - Since steelhead spawning occurs later than chinook salmon spawning when flow is typically much greater, the threat of spawning losses to flow fluctuation would primarily be restricted to low flow year types (i.e., when flows in the January though April period are generally less than 4,000 cfs. Applying the results of the planimetric analysis of chinook salmon spawning habitat to steelhead spawning suggests that the effects described above relating losses of spawning habitat as flow fluctuates between 1,000 cfs and 4,000 cfs during the steelhead spawning period would apply to steelhead spawning.

DISCUSSION

Several problems and associated questions relative to flow fluctuations were identified above as the focus of this investigation. Results of the investigation are discussed below relative to those questions.

Fish Isolation

Question 1. Where are the potential isolation areas?

Areas of potential isolation are distributed throughout the entire reach of the lower American River. These areas have been delineated on aerial photographs of the river and are presented in Appendix 2.

Question 2. Where are the points controlling these isolation areas?

The resolution of the topographical surveys conducted during this survey was insufficient to identify exact locations of sites controlling inundation of isolation areas. The general location of isolation areas relative to flow, as presented in Appendix 2, provides a schematic that can be used to identify potential control points. This information can be used to focus further, more elaborate topographical surveys to more closely locate the control points. Methods involving digital photography and geographic positioning satellite technology have been used on other rivers in the Central Valley to develop rather precise relationships between areas of inundation versus flow stage. This technology could be used on the lower American River to provide a more exact location of the control points relative to discharge.

Question 3. What are the threshold flows that allow inundation of the isolation areas?

Prior to initiation of this investigation the relationship between flow and isolation was considered to be discrete. The results of the investigation suggest a continuous relationship exists between flow change and area of inundation resulting from the flow change between 1,000 cfs and 11,000 cfs (i.e., the range of study flows).

The rigor of the relationship between flow change and resultant area of isolation as flow incrementally changed from 11,000 to 1,000 cfs was evaluated by conducting both linear and polynomial regression analyses. The analyses showed that the a polynomial model expressed the relationship slightly better than a linear model. The results of the polynomial regression analysis indicates that there is a significant relationship between area of isolation and flow change ($r^2 = 99.26$, $p < 0.01$) using the following expression:

$$A_i = 2.81124 + 0.222217 \text{ x } Q_c - 8.85713\text{E-}7 \text{ x } Q_c^{\,2}$$

where: A_i = area of isolation
Q_c = flow change from 11,000 cfs

The model was used to construct a matrix containing the area of isolation associated with flow changes from 11,000 cfs in 1,000 cfs increments (Table 13). The matrix was used to calculate the resultant area of isolation associated with each flow change by subtracting the isolation area associated with starting flow from the area associated with the ending flow. For example, the area of isolation associated with a starting flow of 8,000 cfs was determined by using the model to calculate the area of isolation associated with a change of 3,000 cfs from the originating flow of 11,000 cfs. The net change in isolation area resulting from a change from 8,000 cfs to 5,000 was then determined by calculating the area of isolation associated with a flow change of 6,000 cfs from 11,000 cfs (equals 5,000 cfs) and then subtracting the isolation value associated with 8,000 cfs from that associated with 5,000 cfs. A second matrix was generated using the process described above to list the net change in isolation area associated with an incremental (1,000 cfs) change in flow from starting flows of 1,000 cfs, 2,000 cfs, etc.

The results of the second matrix were used to develop a set of curves depicting the change in area of isolation relative to flow for starting flows ranging from 1,000 cfs to

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9,000 cfs in1,000 cfs increments (Figure 37). These charts can be used to estimate the amount of isolation area created when fluctuating from a specific flow.

Question 4. What is the relative significance to the fish population of losses due to isolation?

The question of the significance of losses due to isolation to salmon and steelhead was addressed in two ways: 1). The proportion of the potential production lost to isolation was determined by estimating the numbers of fish lost to isolation relative to the estimated numbers of fish produced based upon the effective spawner population (the number of female spawners that successfully spawn); and, 2). The predicted loss of adult spawners based upon an expected survival rate of 0.067% for chinook salmon, based upon 2 adults surviving from every spawning female with an estimated average fecundity of 3,000 (Lietritz, 1963) , and similarly 0.047% for steelhead fry (average fecundity of 4,300 per Lietritz, 1963). A survival rate to adult of 2% for older (larger) juvenile steelhead (FL > 100 mm) was estimated based on Shapovalov and Taft (1954).

The potential losses of salmon and steelhead to isolation events was evaluated by multiplying the estimated densities of fish within the isolated areas by the estimated isolation area associated with the magnitude of the isolation event (maximum flow).

Chinook salmon - The density of salmon and steelhead measured within isolated areas from 1997 through 1999 varied substantially. Densities of juvenile salmon was highest in 1998 and lowest in 1997 (Tables 14–16, Figures 38–40). The estimated[6] number of juvenile salmon within potential isolation areas ranged from 1.5 million in 1997 to 13.6 million in 1998 (Tables 14–16). The potential impact that would have occurred if all fish estimated to occupy the isolation areas in 1997 would have been 1.5% of total production and 1,005 potential returning adults. In 1998 the result would have been the loss of 19% of potential production and 9,112 returning adults and in 1999, 8.3% of potential production and 3,618 returning adults (Table 17)

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[6] The area of potential isolation was calculated using the maximum area measured during the survey (i.e., measured at 11,000 cfs). The actual area of potential isolation was likely much greater than the value used in the calculation. This figure was used, however, to demonstrate the magnitude of impact associated with flow fluctuations within the range of manageable flows.

Table 13. Area of potential isolation resulting from changing flow from the starting flow the among indicated in the flow change column then returning to the starting flow.

	Starting Flow/ area isolated (acres)									
Flow Change	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
1,000	12.1	9.1	7.6	10.7	12.5	14.3	16.0	17.8	19.6	24.147227
2,000	21.2	16.7	18.3	23.2	26.7	30.3	33.8	37.4	43.7	
3,000	28.8	27.4	30.8	37.4	42.8	48.1	53.4	61.5		
4,000	39.5	39.9	45.0	53.5	60.5	67.6	77.5			
5,000	52.0	54.1	61.1	71.3	80.1	91.8				
6,000	66.2	70.2	78.9	90.8	104.3					
7,000	82.3	88.0	98.4	115.0						
8,000	100.1	107.5	122.6							
9,000	119.6	131.7								
10,000	143.8									

The actual effect of the isolation events appeared to be directly related to the timing and duration of the potential isolation flow (i.e., when and if isolation occurred) and the overall abundance of juveniles (i.e., spawning success). Production potential (i.e., spawner population) during the three survey years (1997–1999) was highest in 1997 and lowest in 1998, inversely related to salmon densities (Table17). Numbers of emigrating salmon however was lowest in 1997 and highest in 1998, directly related to observed salmon densities. The primary isolation event in 1997 was earlier than those observed in 1998 and 1999, occurring in early January before salmon typically emerge from the gravel. However, even later in the season, after emergence typically peaks, after week 8 when densities were very high during 1998 and 1999, densities were extremely low in 1997. The reason for low densities throughout 1997 was apparently due to low spawning success. The extremely high flows in early January apparently killed many redds resulting in relatively few fish being available to isolation and an overall, very low number of salmon emigrating from the river.

In 1998, survival to emigration was very high even though isolation loss potential was great based upon the densities of fish and large area of potential isolation. Isolation loss potential was not realized since flows were sustained at a relatively high level throughout most of the rearing/emigration period (> 10,000 cfs through April).

In 1999, flow fluctuated from 11,000 cfs to 4,000 cfs twice, once in mid February and once in mid March. The potential loss of chinook salmon was estimated using the average densities observed during those periods times the net acreage of isolation occurring between 11,000 and 4,000 cfs. An estimated total of 1.1 million salmon were lost in 1999 to isolation. The loss was equal to 2% of the potential production resulting in the projected loss of 740 returning adults.

Steelhead - Annual trends in steelhead densities was the opposite from that observed for chinook salmon. The highest densities in steelhead within potential isolation areas occurred in 1997. During the first isolation event in January 1997, densities of yearling steelhead averaged over 500 fish/acre (Tables 18–20). Based upon the potential survival to adult discussed above, the number of steelhead within the isolation area equated to over 1,600 returning adults. The densities of young-of-the-year steelhead that began to occur in the samples in early February, were also much higher than observed in 1998 and 1999. The higher densities may have been due to the earliness of the initial high flow event in 1997.

The yearling fish had not emigrated yet and the flows were already high when YOY began to emerge. In contrast, the initial high flows in 1998 and 1999 potentially occurred after most yearling steelhead had migrated and after emergence had started. Occurrence of high flows while during the emergence period could adversely affect survival of young steelhead.

Table 14. Summary of isolation area surveys and expansion of salmon catch data for surveys conducted in 1997 on the lower American River.

Week	Area sampled	Salmon collected	Salmon/ acre	Potential isolation area (acres)	Critical flow (cfs)	Flow during sample (cfs)	Potential N of isolated salmon
3	12,904	10	34	185	106,000	16,874	6,248
4	42,179	650	672	185	106,000	31,647	124,244
5	10,085	38	164	185	36,000	31,804	30,379
6	13,749	364	1,154	185	36,000	12,448	213,447
7	43,838	1,574	1,565	185	36,000	7,029	289,476
8	41,176	1,017	1,076	185	36,000	4,073	199,130
9	13,616	130	416	70	7,000	6,912	29,126
13	1,219	215	7,686	70	7,000	3,552	538,047
15	19,157	1,134	2,580	4	4,000	2,535	10,319
18	9,315	362	1,694	13	2,500	2,500	22,017
19	6,601	10	66	15	2,900	2,553	990
21	6,007	36	261	15	3,400	2,521	3,918
Total							1,467,339

Table 15. Summary of isolation area surveys and expansion of salmon catch data for surveys conducted in 1998 on the lower American River.

Week	Area sampled	Salmon collected	Salmon/ acre	Potential isolation area (acres)	Critical flow (cfs)	Flow during sample (cfs)	Potential N of isolated salmon
10	6,214	3,004	21,068	185	34,000	4,500	3,897,514
12	2,238	4013	78,144	87	8,000	8,000	6,798,538
15	1,577	0	0	185	12,000	7,500	0
16	2061	113	2,389	185	12,000	7,500	442,038
17	9,448	1259	5,807	185	12,000	8,300	1,074,348
18	26,922	0	0	185	10,000	10,000	0
19	4,483	36	350	185	11,000	11,000	64,743
20	2,023	164	3,533	185	11,000	9,000	653,592
21	3,022	127	1,831	185	11,000	7,600	338,819
23	7,140	337	2,057	185	11,000	8,400	380,532
24	8,666	0	0	87	9,000	6,000	0
25	12,155	0	0	185	10,000	9,800	0
26	12,195	0	0	185	10,000	9,000	0
27	7,190	0	0	87	8000	7600	0
28	9,049	5	24	87	8000	4000	2,095
Total							13,652,218

Table 16. Summary of isolation area surveys and expansion of salmon catch data for surveys conducted in 1999 on the lower American River.

Week	Area sampled	Salmon collected	Salmon/ acre	Potential isolation area (acres)	Critical flow (cfs)	Flow during sample (cfs)	Potential N of isolated salmon
5	16,974	335	860	185	20,000	10,000	159,118
6	12,276	245	870	185	20,000	4,500	160,904
9	3,189	208	2,842	185	26,000	16,000	525,857
10	915	78	3,715	185	11,000	11,000	687,278
11	29,576	3,553	5,235	185	11,000	6,000	968,534
12	56,054	10,770	8,373	185	11,000	4,000	1,549,059
13	10,328	616	2,599	185	11,000	4,000	480,865
16	3,250	35	469	185	11,000	4,000	86,825
17	864	86	4,338	185	11,000	4,000	802,497
Total							5,420,938

Table 17. Summary of parameters used to estimate chinook salmon production potential and possible losses relative to flow fluctuation events monitored from 1997–2000 on the lower American River.

Parameter	1997	1998	1999	2000
N emigration	4.3	19	10	11
N isolation areas	1.5	13.6	5.4	na
N female spawners	33,500	23,500	21,500	24,000
N production	100.5	71	65	72
Production loss to emigration %	95.7	73	84.6	84.7
Maximum potential loss to isolation %	1.5	19.0	8.3	na
Adult equivalent loss	1,005	9,112	3,618	na

Table 18. Summary of isolation area surveys and expansion of steelhead catch data for surveys conducted in 1997 on the lower American River.

Week	Area sampled	Steelhead collected	Steelhead/ acre	Potential isolation area (acres)	Critical flow (cfs)	Flow during sample (cfs)	Potential N of isolated steelhead
3	12,904	107	361	185	106,000	16,874	66,853
4	42,179	636	657	185	106,000	31,647	121,568
5	10,085	0	0	185	36,000	31,804	0
6	13,749	0	0	185	36,000	12,448	0
7	43,838	4	4	185	36,000	7,029	736
8	41,176	321	340	185	36,000	4,073	62,852
9	13,616	135	432	70	7,000	6,912	30,246
13	1,219	0	0	70	7,000	3,552	0
15	19,157	3	7	4	4,000	2,535	27
18	9,315	13	61	13	2,500	2,500	791
19	6,601	0	0	15	2,900	2,553	0
21	6,007	0	0	15	3,400	2,521	0
Total							283,073

Table 19. Summary of isolation area surveys and expansion of steelhead catch data for surveys conducted in 1998 on the lower American River.

Week	Area sampled	Steelhead collected	Steelhead/ acre	Potential isolation area (acres)	Critical flow (cfs)	Flow during sample (cfs)	Potential N of isolated steelhead
10	6214	0	0	185	34000	4500	0
12	2,238	0	0	87	8,000	8,000	0
15	1,577	0	0	185	12,000	7,500	0
16	2,061	0	0	185	12,000	7,500	0
17	9,448	2	9	185	12,000	8,300	1,707
18	26,922	0	0	185	10,000	10,000	0
19	4,483	15	146	185	11,000	11,000	26,976
20	2,023	1	22	185	11,000	9,000	3,985
21	3,022	1	14	185	11,000	7,600	2,668
23	7,140	3	18	185	11,000	8,400	3,388
24	8,666	0	0	87	9,000	6,000	0
25	12,155	0	0	185	10,000	9,800	0
26	12,195	2	7	185	10,000	9,000	1,322
27	7,190	0	0	87	8,000	7,600	0
28	9,049	7	34	87	8,000	4,000	2,933
Total							42,979

Table 20. Summary of isolation area surveys and expansion of steelhead catch data for surveys conducted in 1999 on the lower American River.

Week	Area sampled	Steelhead collected	Steelhead/ acre	Potential isolation area (acres)	Critical flow (cfs)	Flow during sample (cfs)	Potential N of isolated steelhead
5	16,974	0	0	185	20,000	10,000	0
6	12,276	0	0	185	20,000	4,500	0
9	3,189	0	0	185	26,000	16,000	0
10	915	0	0	185	11,000	11,000	0
11	29,576	0	0	185	11,000	6,000	0
12	56,054	0	0	185	11,000	4,000	0
13	10,328	2	8	185	11,000	4,000	1,561
16	3,250	0	0	185	11,000	4,000	0
17	864	1	50	185	11,000	4,000	9,331
Total							10,893

As discussed above, flow fluctuated from 11,000 cfs to 4,000 cfs twice in 1999, once in mid February and once in mid March. The potential loss of YOY and yearling steelhead was low due to the timing (i.e., after most yearling would have left the river and before many YOY had emerged.

Question 5. What is the critical timing of use by species/life stages?

The results of this investigation show that the vulnerability of juvenile salmon and steelhead to isolation is directly related to their presence in the river. All life stages of salmon and steelhead were found in isolation prone areas concurrent with their presence in the main channel. This finding is not surprising since juvenile salmonids are commonly associated with the shallower, slower moving bank associated habitats and that isolation prone areas generally increase the amount of such habitat. As such, the potential risk of losing large numbers of young salmon and steelhead is directly related to the timing of their occurrence in the river.

Fall-run chinook salmon fry are typically present in increasing abundance from late January into April. And, although the number of salmon in the river begins to decrease following the peak of emergence, the proportion of larger salmon found rearing and emigrating from April through June increases. The significance of the older, larger salmon increases, as the potential to survive to adults increases with size. Non-natal rearing winter-run chinook salmon also inhabit the lower American River from late fall into early winter. Their presence in the isolation prone areas during the survey confirms their vulnerability to isolation.

Juvenile steelhead are found in the river year around. Their numbers are greatest typically from March through June during emergence through the fry stage. Abundance decreases following the fry stage while the significance of the remaining, typically rapid growing juveniles increases with time. Vulnerability of the larger juvenile to isolation appears to decrease between mid summer into early fall before these fish begin to congregate in small groups often in areas linked with bank associated habitats. It is during this late fall through late winter period when these fish are readying to migrate to the ocean that their vulnerability to isolation increases along with their significance to the river's steelhead population.

Fish losses due to isolation were apparently relatively low during 1997 and 1998. High flows were sustained throughout most of the critical periods in 1998 and most of the salmon production in 1997 was lost prior to periods of isolation. In 1999, significant isolation events occurred during February and March when flow decreased from 11,000 cfs to 4,000 cfs for at least 2 weeks. The losses could explain the substantially lower survival index calculated for 1999 versus 1998 (Table 21).

The lowest critical flow during the survey was 26,000 cfs in 1999 and flows subsequent to the critical flows in 1998 and 1999 were at or above 10,000 cfs during most of the critical periods. Critical flow, the flow that inundates the greatest area of potential isolation, was at least 26,000 cfs during each survey year. Subsequent flow decreases were protracted, especially in 1998, ameliorating the impact of isolation, as discussed above. However, much lower critical flows would have jeopardized fish numbering as high as those estimated for the critical flows observed during the survey. Lower critical flows typically means less water is coming into the system and thus decreases the opportunity to sustain the higher flows for extended periods following the critical flow event. As such, the probability of loss due to isolation would increase as the critical flow level falls within the range of manageable flows (i.e. ≤ ~11,000 cfs). Flow fluctuations that reduce flow from 11,000 cfs occurred on the average at least once per year during January, February, March and May between 1991 and 2000. Decreases from 11,000 cfs to 8,000 cfs during these critical months could result in losses of 5 to 10% of the total potential productions (based on results observed in 1998 and 1999). Similarly, losses of 8 to 15% of the potential production could be lost if flow receded from 11,000 to 4,000 cfs.

Flow fluctuation in late fall and early winter ranging from 4,000 cfs down to 1,000 cfs occurred at least once every two years between 1991 and 2000. Prolonged reductions within this range of flow during this time of year could result in the loss of thousands of winter-run juveniles and tens of thousands of yearling steelhead given the salmon and steelhead population attributes identified during the three survey years.

The results of surveys of isolated areas in 2000 were not included in the preceding discussion since only one isolation event was monitored. This event involved an increase in flow from 3,600 cfs to 6,000 cfs in late April followed by a reduction to 2,400 cfs in late May. Similar to the results of the three other survey years, the species/life stage composition sampled in the isolated areas was comparable to that observed in the mainstem (Table 7). The unique feature of this event was that it occurred under controlled flow releases and late in the critical spring period when steelhead and larger chinook salmon were vulnerable to isolation. The results corroborate their vulnerability. The estimated effect of the event was a loss of over 7,000 juvenile salmon and steelhead each.

Results of emigration monitoring and spawner escapement surveys conducted between 1994 and 2000 were used to estimate a survival index for fall-run chinook salmon. The index was calculated as the estimated number of emigrants divided by the estimated number of female spawners for each year. A regression analysis was conducted comparing the survival indices with attributes of flow that were intended to characterize isolation events (e.g., minimum, maximum, mean monthly flows and the monthly coefficient of variation of flow [sd/mean flow]).

The survival index was not significantly related to flow conditions in December, February, March or April (Table 22). The survival index was significantly related to the coefficient of variation of flow in November and to maximum and mean flow in January (p=0.05) (Figures 41 and 42). These results indicate that: 1) flow fluctuations in November significantly affect survival of salmon to emigration since November is the primary spawning period for chinook salmon and spawning is essentially the only natal salmon life stage occurring in the lower American River during November; and 2) salmon survival decreases as maximum January flow increases. High January flows can cause scouring of redds during a period when most young salmon are still in the redd. Isolation can also incur losses of salmon in January especially if the higher flows force early emergence. In 1997 following an exceptionally high flow event, most of the salmon collected in the emigration survey were yolk-sac fry indicating that the high flow flushed young fry from the redds at a very vulnerable life stage. Salmon survival likely decreased due to physical trauma while in the redd, exposing more young, vulnerable fish to the open water than would otherwise occur and potentially isolating large numbers of fish.

Table 22. Results of regression analysis of survival index as a function of monthly flow conditions characterizing flow fluctuation in the lower American River, 1994–2000.

Dependent variable					
Month	Flow Condition	*r*	r^2	Function	Significance
Nov	Mean	-0.41	0.17	exponential	ns
	Minimum	0.04	0.002	linear	ns
	maximum	-0.46	0.22	exponential	ns
	CV	-0.82	0.68	exponential	p=0.02
Dec	Mean	-0.64	0.40	exponential	ns
	Minimum	-0.32	0.10	linear	ns
	maximum	-0.61	0.37	exponential	ns
	CV	-0.06	0.004	linear	ns
Jan	Mean	-0.82	0.67	power	p=0.02
	Minimum	-0.68	0.47	exponential	ns
	maximum	-0.84	0.70	power	p=0.02
	CV	-0.71	0.50	linear	ns
Feb	Mean	-0.25	0.06	power	ns
	Minimum	-0.50	0.25	power	ns
	maximum	-0.22	0.05	power	ns
	CV	-0.47	0.22	power	ns
Mar	Mean	-0.50	0.25	linear	ns
	Minimum	-0.47	0.22	linear	ns
	maximum	-0.52	0.27	power	ns
	CV	-0.43	0.19	power	ns
Apr	Mean	-0.20	0.04	power	ns
	Minimum	-0.15	0.02	power	ns
	maximum	-0.29	0.08	linear	ns
	CV	-0.24	0.06	linear	ns
Total escapement		-0.37	0.14	linear	ns

Conclusions Regarding Isolation

- Isolation under controlled flow conditions (i.e., when maximum flow is 11,000 cfs or less) can incur significant losses of salmon and steelhead.

- The vulnerability of salmon and steelhead to isolation is directly related to their abundance in the river at the time of the isolation event for all species, races and life stages inhabiting the river.

- The longer the isolation event flow occurs, the less severe the loss of salmon and steelhead to potential isolation; the shorter the isolation event flow is sustained, the greater the loss of fish to isolation.

- Isolation of salmon and steelhead is possible year around. The least critical period of potential loss to isolation is from July through September (Table 5)

- Isolation can occur throughout the entire lower American River within the managed flow range.

- Isolation events occurring during February through May within the managed flow range can incur as much as a 2 to 18% loss in salmon production per event, assuming a reduction in flow from 11,000 cfs to 2,000 cfs and chinook salmon juvenile densities of isolation prone areas observed in during the surveys.

- Isolation events occurring during April through June within the managed flow range can result in losses of from 4 to 32 potential returning adults with a flow change from 11,000 cfs to 2,000 cfs and steelhead YOY densities of isolation prone areas observed in the surveys.

- Isolation events occurring during October through March can result in loss in potential production of more than 2000 adult steelhead with a flow change form 11.000 cfs to 2,000 cfs and steelhead yearling densities in isolation prone areas observed during the surveys.

- Isolation events occurring during October through March can result in loss of non-natal rearing winter-run chinook salmon.

- Flow fluctuation events that occurred during the 1994 through 2000 water years did not appear to significantly influence survival of chinook salmon to emigration based upon analysis of survival index as a function of minimum, maximum and mean flow during the months of November through April.

- The potential for flow fluctuation related losses due to isolation increase when overall water availability in the drainage decreases. The results of this investigation represent conditions during average and above average water years. The potential to induce flow fluctuation events within the flow management range would likely increase during drier years.

Fish Stranding

Question 1. What areas of the main channel are vulnerable to rapid decreases in flow?

Stranding investigations conducted on salmon and steelhead streams throughout the West Coast determined that stranding can occur on medium gradient gravel bars (slope 2–5%) and has the greatest probability of occurring on low gradient bars (slope < 2%). Both medium and low gradient gravel bars occur within the lower American River, predominantly within the upper two reaches of the river (upstream of Paradise Beach).

Question 2. What are the different flow ranges at which these areas are vulnerable to rapid flow changes?

The majority of medium and low gradient gravel bars in the lower American River are inundated at about 4,000 cfs. The greatest threat of stranding, therefore, would occur at flows ≤ 4,000 cfs.

Question 3. What rate of flow ramping would minimize or eliminate stranding within these vulnerable areas?

Research conducted on the effects of ramping rates on stranding of juvenile salmon and steelhead showed that rates of flow change that result in a decrease in water surface elevations of 2 inches or more per hour will cause stranding. Information on the rate of water surface elevation change relative to flow indicate that stage can decrease more than 1 inch per 100 cfs change in flow within the critical range (≤ 4,000 cfs).

To accommodate the requirement that flow decreases occur at a rate of less than 2 inches per hour, the maximum flow rate change should be no greater than 100 cfs per hour when flow is ≤ 4,000 cfs.

Folsom Project operation typically results in all flow passing through the power generation facilities when releases are ≤ 8,000 cfs. The rate flow through these facilities is automated; the rate of change in flow can be incrementally changed automatically. For example, the facilities can be set to gradually decrease flow at a rate of 50,cfs, 100 cfs, etc. per hour. The availability of this level of flow control within the critical flow range should facilitate meeting a ramping rate of ≤ 100 cfs per hour (2,400 cfs/day).

Question 4. What species/life stages would be affected by ramping within the vulnerable areas and when?

> All life stages of juvenile salmon and steelhead are associated with medium and low gradient gravel bars during their rearing period. Smaller juveniles typically occupy the margin areas of these bars indicating that the most susceptible life stage occurs in the areas most vulnerable to stranding. Stranding potential therefore, is greatest from January through July when small, fry-sized salmon or steelhead are present in the river.

Conclusions Regarding Fish Stranding

- Low and medium gradient gravel bars, identified as probable areas of stranding, are situated throughout the salmon and steelhead rearing areas of the lower American River.
- Changes in water surface elevations of 2 or more inches per hour will result in stranding juvenile salmon and steelhead.
- Stranding in the lower American River is most likely to occur on gravel bars when flows are ≤ 4,000 cfs.
- Ramping rates of ≤ 100cfs/h when flows are ≤ 4,000 cfs will prevent stranding in the lower American River.

Redd Stranding and Superimposition

Question 1. What is the relationship between flow and spawning habitat viability for anadromous salmonids?

> *Chinook salmon* - Chinook spawning generally occurs from late October through December. Flow during this period is usually between 1,000 and 4,000 cfs. The results of the planimetric analysis of spawning habitat availability versus flow showed that % of potential spawning habitat could be lost to dewatering as flow range from 4,000 to 1,000 cfs (Table 11). The greatest utility of these findings addresses the question of dewatering redds as flow fluctuates within this range. A simple, direct relationship between flow fluctuation and dewatering assumes that redds are evenly distributed throughout all potential spawning habitat and that the percentage of redds desiccated as flows fluctuates is equal to the percentage of desiccated potential habitat.
>
> Spawning distribution is not evenly distributed over all potential spawning habitats. Distribution is related to flow, as demonstrated by the relationship between flow and hyperuse or superimposition. The relationships developed above between flow and superimposition and ultimately flow and percentage of optimum viable habitat for

varying sizes of spawner populations should be used to characterize the relationship between flow fluctuation and chinook salmon spawning. The information presented in Table 13 and Figure 43 provide guidance as to the potential impacts of changing flow during spawning. For example, the amount of spawning habitat added/deleted as flow ? changes between 1,000 cfs and 2,000 cfs for a population size of 40,000 spawners would be . This information can also be used to identify optimum salmon spawning flow conditions.

Question 2. Are there threshold spawning flows that control use of potential spawning habitats; what are the threshold spawning flows?

The relationship between spawning habitat viability and flow shows a continuous increase in viability as flow increases. This suggests that there is no threshold flow controlling spawning habitat viability within the flow range modeled (500 to 2,500 cfs). The rate of change in viability ($dS_o = 2.3^{-7}$ flow) indicates that viability increases more per unit change as flow increases. A third order polynomial regression analysis indicated that there was no change in the slope that might indicate a threshold in the flow-viability relationship and that the second order model we used best represents the relationship.

Results of the planimetric analysis of spawning habitat indicates that the greatest net change in potential spawning habitat availability occurs when flow decreases from 2,000 cfs. Decreases in flow from around 2,000 cfs could result in a 12% loss of wetted habitat. As such, a threshold flow could be generally defined as 2,000 cfs.

Steelhead - The answers to questions 1 and 2 regarding effects of flow fluctuation on steelhead were not as clearly defined as they were for chinook salmon. Steelhead spawn when flows are typically higher and turbidity is greater. Their redds are smaller and are therefore difficult to interpret using aerial photography at the scale used during the study (1:24,000). A more focused evaluation of steelhead spawning would be required to provide the resolution necessary to develop the same detail used to analyze salmon spawning.

Steelhead spawn within the same general locations as salmon (Appendix 2), although at a substantially density and in areas containing different microhabitat conditions (e.g., smaller gravel). The results of the salmon spawning evaluation can therefore be applied macroscopically for flows below 4,000 cfs. Under such conditions, the same general conclusions for salmon stated above would apply. For example, the percentage change in habitat availability identified above for salmon would apply to steelhead. Similarly, the change in spawning habitat viability relative to change in flow could also be applied.

Conclusions Regarding Redd Stranding and Superimposition

- Potential redd stranding can occur when flow fluctuates between < 1,000 and 4,000 cfs.
- The greatest potential for redd stranding occurs when flows are reduced from near 2.000 cfs (up to 12%).
- Spawning habitat viability, analyzed as a rate of superimposition of redds, can vary significantly as flow fluctuates between 500 and 2,500 cfs during the spawning periods.
- Information relating spawning habitat viability to flow should be used to determine the potential impacts of flow fluctuations during spawning periods.
- Flow fluctuations in November have a negative influence on redd survival.

Short-term Flow Changes

Question 1. What is the relationship between the periodicity of flow change and salmon and steelhead?

Cyclic, short term changes in flow were not directly observed during the investigation. Extrapolation of the investigation results were therefore used to discuss the probable implications of cyclic flow fluctuations.

Juvenile salmon and steelhead responded to increased flow immediately. Once flows increase, the potential isolation areas become occupied as described above. Depending upon the duration of the isolation event (i.e., how long the higher flow is sustained) determines the potential impact. Thus the net effect of cyclic changes would depend upon the high flow incurred and the duration of the intervening lower flow. If, for example, the cycle simply involved a short term increase then decrease, the net result would be the isolation of fish corresponding to the net change in flow. If such a cycle was repeated routinely, the net effect would be a cumulative loss to isolation that would depend upon the amount of flow change and the resultant creation of isolation areas that would routinely dry within the cycle versus those that would pond and support fish between events. Ponded fish would be lost to predation and potentially thermal stress depending upon the time of year (water temperatures in the ponded areas sampled in May 2000 were 74 °F versus 64 °F in the mainstem). Repetitive sampling of ponded sites in 1997 revealed that salmon and steelhead were progressively lost over a four week period.

The interval between changes would likely determine the impact of the flow fluctuation and would depend upon whether the event involved increasing then decreasing flow or the opposite. A one day cycle of increasing flow would have relatively minor impacts (again depending upon the high flow during the event); progressively longer cycles would incur progressive increases in lost fish unless the time extended to the end of the rearing period. A decreasing flow event would incur immediate losses of fish (magnitude depending upon the net flow change). Prolonged maintenance of lower flows would equate to loss of all fish in the isolated area.

Conclusions Regarding Short Term Flow Fluctuation

- Short term flow fluctuations can have the same effect as isolation events when flow increases then decreases. The longer the intervening time, the greater the losses of salmon and steelhead.

- Short term flow fluctuations will result in an immediate loss of fish to isolation and can have the same long-term effects as isolation events when flow decreases then increases if the period between change is prolonged. The longer the intervening time, the greater the losses of fish.

- Duration of the intervening flow period and the magnitude of change dictate the potential loss of salmon and steelhead to flow fluctuations.

CONCLUSIONS

- Flow fluctuations have the potential to incur significant losses of salmon and steelhead.

- Flow fluctuations are a regular occurrence in the lower American River.

- Flow fluctuations within the defined management range of flows (≤ 11,000 cfs) routinely occur in the lower American River throughout the year (at least once per month during nine months per year).

- Flow fluctuation within the defined management range routinely occur during the more critical periods (October through June).

- Flow fluctuation within the defined management range can incur significant losses of salmon (as much as 18% of potential production) and steelhead (as much as 2,000 potential adult spawners) per event. *

- Flow fluctuation within the defined management range can incur losses of winter-run chinook and steelhead listed as endangered and threatened, respectively.

- Flow fluctuation within the defined management range can significantly change spawning habitat viability. Reductions from 2,500 cfs to 1,500 cfs would result in loss of over 60% of viable spawning and dewater up to 40 acres (12%) of potential spawning habitat.

- The severity of flow fluctuations is a function of the magnitude of the flow change and the duration of the critical flow.

- The potential severity of the magnitude of flow change on rearing salmon and steelhead can be determined using the information presented relating potential isolation area to flow change.

- The potential severity of the magnitude of flow change on spawning can be determined using the information presented relating change in spawning habitat viability to flow.

- The potential severity of the magnitude of flow change on redd dewatering can be determined using the information presented relating change in potential spawning habitat availability to flow.

- Flow fluctuations in November were found to be related to survival to emigration indicating that such fluctuations reduce spawning success.

- The critical period for juvenile fall-run chinook salmon rearing extends from February through June.

- The critical period for fall-run chinook salmon spawning extends from mid October through December.

- The critical period for steelhead spawning extends from December through May.

- The critical period for steelhead rearing extends year around and is greatest from March through June for young-of-the year and October through March for yearlings.

- The critical periods for non-natal, winter-run chinook salmon rearing extends from October through January.

- Stranding of juvenile salmon and steelhead has the greatest potential of occurrence on steep-sloped bar complexes when rate of flow change exceeds 100 cfs per hour and when initial flow is less than 4,000 cfs.

- Potential isolation areas occur throughout the lower American River.

- More detailed topographic surveys of the channel morphology is needed to pinpoint sites controlling inundation of potential isolation areas.

- More detailed information is needed to more precisely define the relationships between flow fluctuation and steelhead spawning and rearing.

RECOMMENDATIONS

- The results of this investigation should be used as a basis for a Functional analysis workshop on flow fluctuations in the lower American River.

- An adaptive management approach, including monitoring salmon and steelhead status and responses to flow fluctuations if they occur, should be established to implement the findings of this investigation when addressing operations of the Folsom Project that would result in flow fluctuations

- A high resolution survey of the morphology of the lower American River should be conducted and integrated with hydrology to enable specific siting of locations controlling inundation of potential isolation areas as a function of flow. Results of this activity should be used to identify physical modifications of the channel that would reduce opportunities for isolation.

- Flow fluctuations should be avoided whenever possible.

- Operation of the Folsom Project should work to integrate the findings of this investigation such that:

    1. Ramping rates should not exceed 100 cfs per hour when flows are $\leq$ 4,000 cfs;

    2. Flow increases to 4,000 cfs or more should be avoided during critical rearing periods (January–July for YOY salmon and steelhead and October–March for yearling steelhead and non-natal rearing winter-run chinook salmon) unless they can be maintained throughout the entire period; and,

    3. Flow fluctuations that decrease flow below 2,500 cfs during critical spawning periods should be precluded: October–December for chinook salmon and December–May for steelhead .

ACKNOWLEDGMENTS

This investigation was partially funded by the U. S. Bureau of Reclamation and was conducted under the general guidance of the American River Operations Group. The report was prepared by Bill Snider, Robert Titus and Kris Vyverberg of the California Department of Fish and Game's Stream Evaluation Program STEP). Field investigations were overseen by the STEP staff and conducted by Michael Demme, James Galos, Jennifer Ikemoto, Tiffany Meyer, Shawn Oliver, Briget Payne, Doug Post, Glenn Sibbald, Mike Stiehr, and Katherine Taylor. Katherine assisted in preparation of the data tables and figures. Paul Bratovich of Surface Water Resources Incorporated assisted in providing detailed planning of the investigation.

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FIGURES

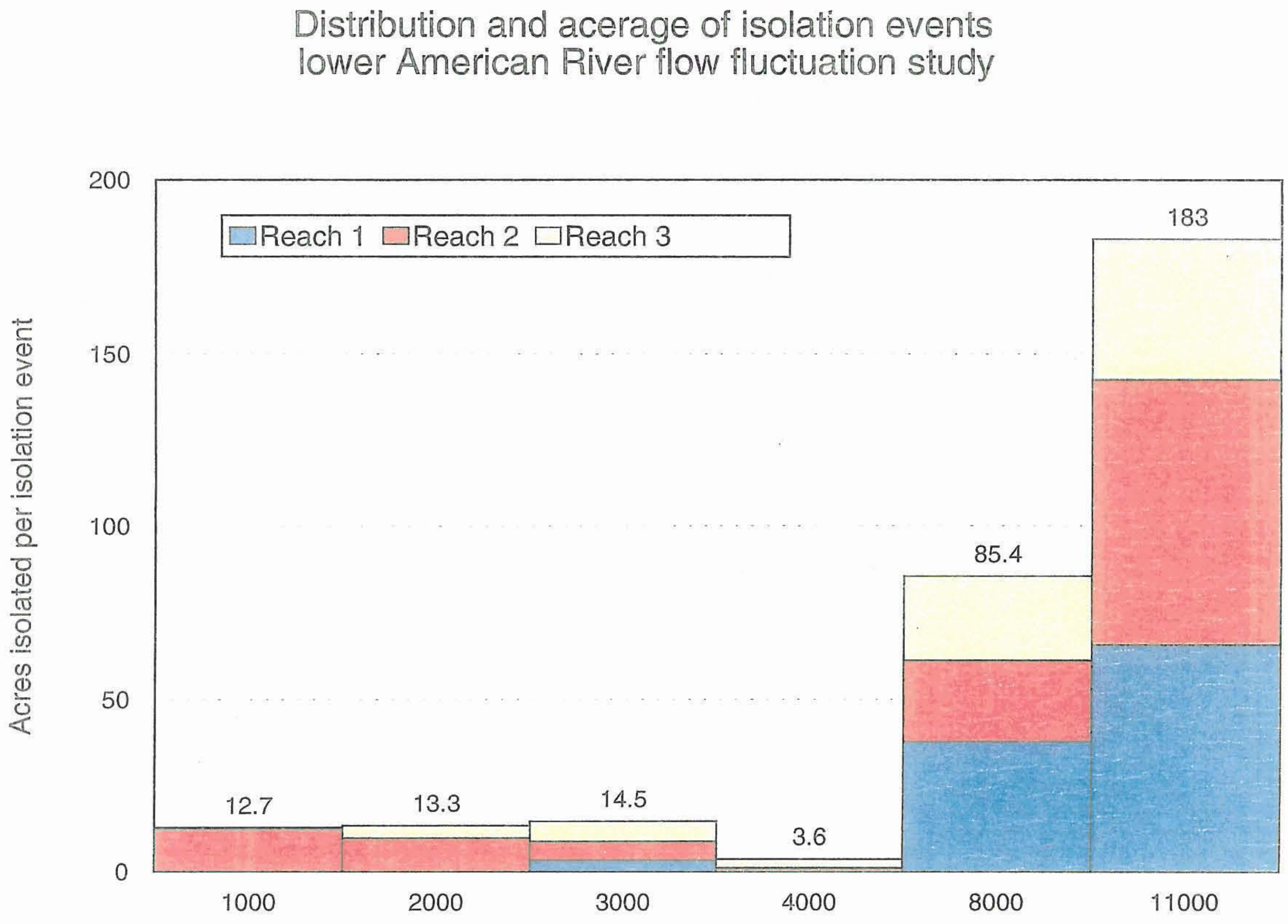


Figure 1. Total acerage of isolated areas relative to flow associated with isolation event measured during the lower American River flow fluctuation study, 1997 - 2000.

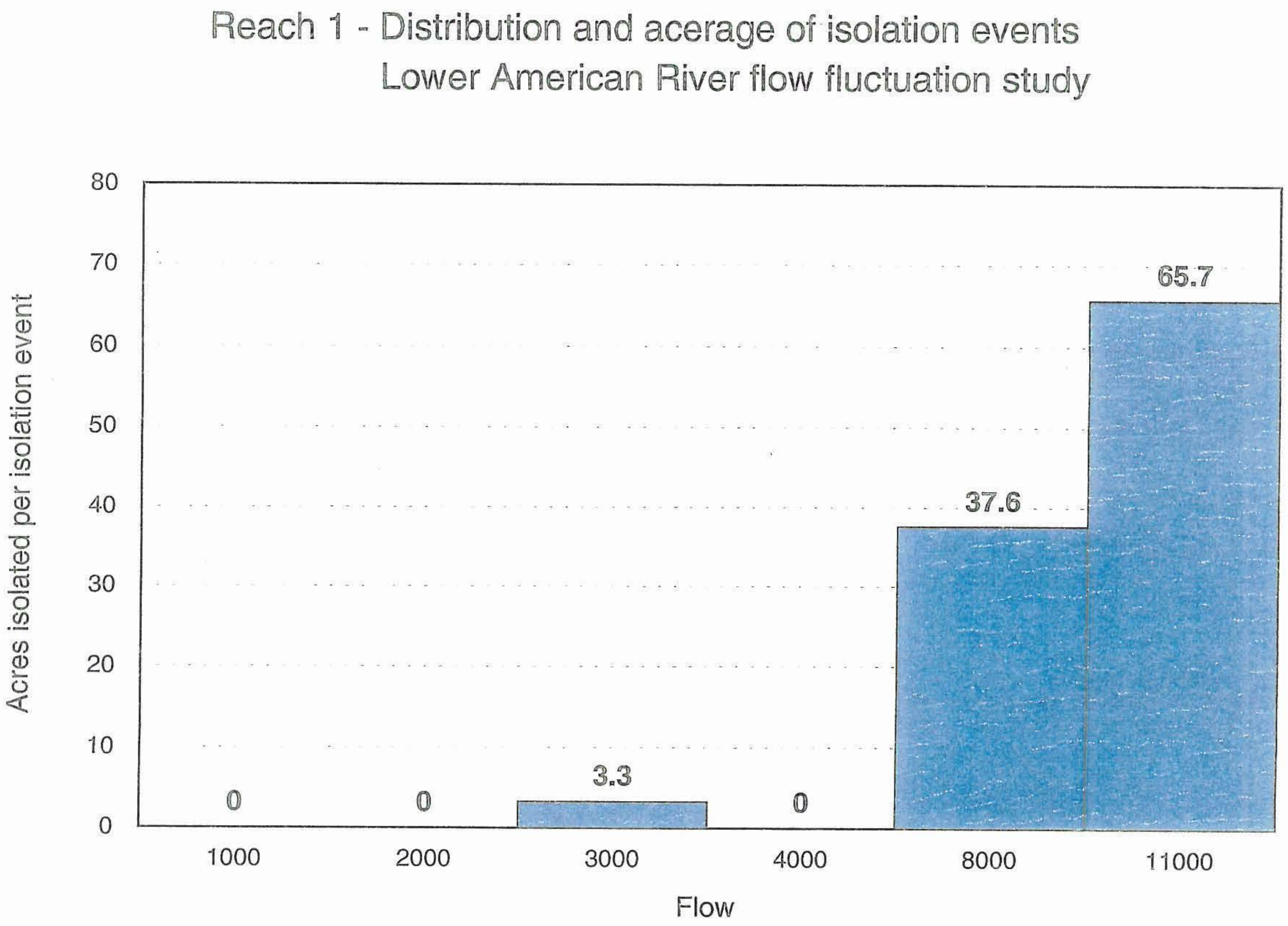


Figure 2. Total acerage of isolated areas in Reach 1 (river mouth to Paradise Beach) relative to flow associated with isolation event measured during the lower American River flow fluctuation study, 1997 - 2000.

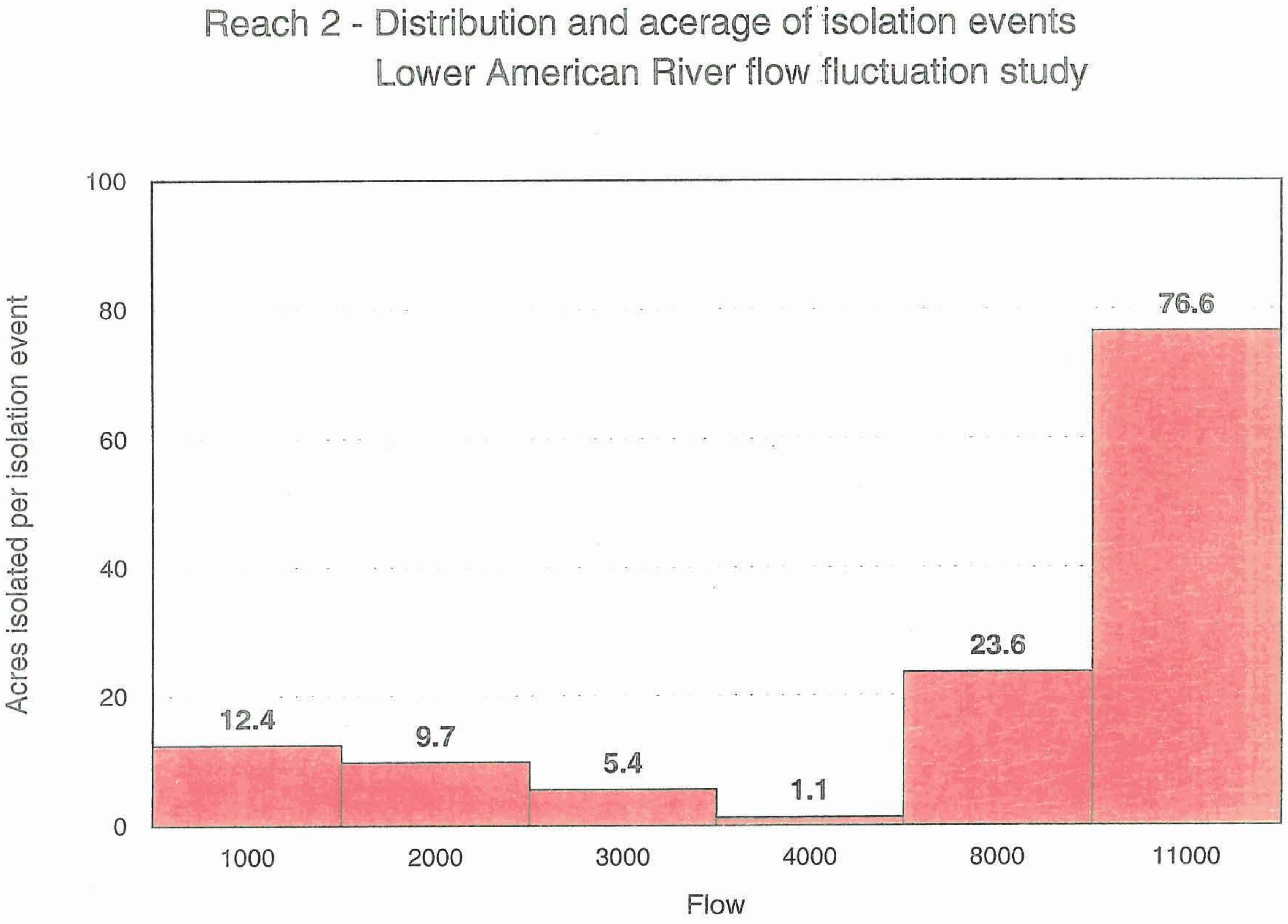


Figure 3. Total acerage of isolated areas in Reach 2 (Paradise Beach to Ancil Hoffman Park) relative to flow associated with isolation event measured during the lower American River flow fluctuation study, 1997 - 2000.

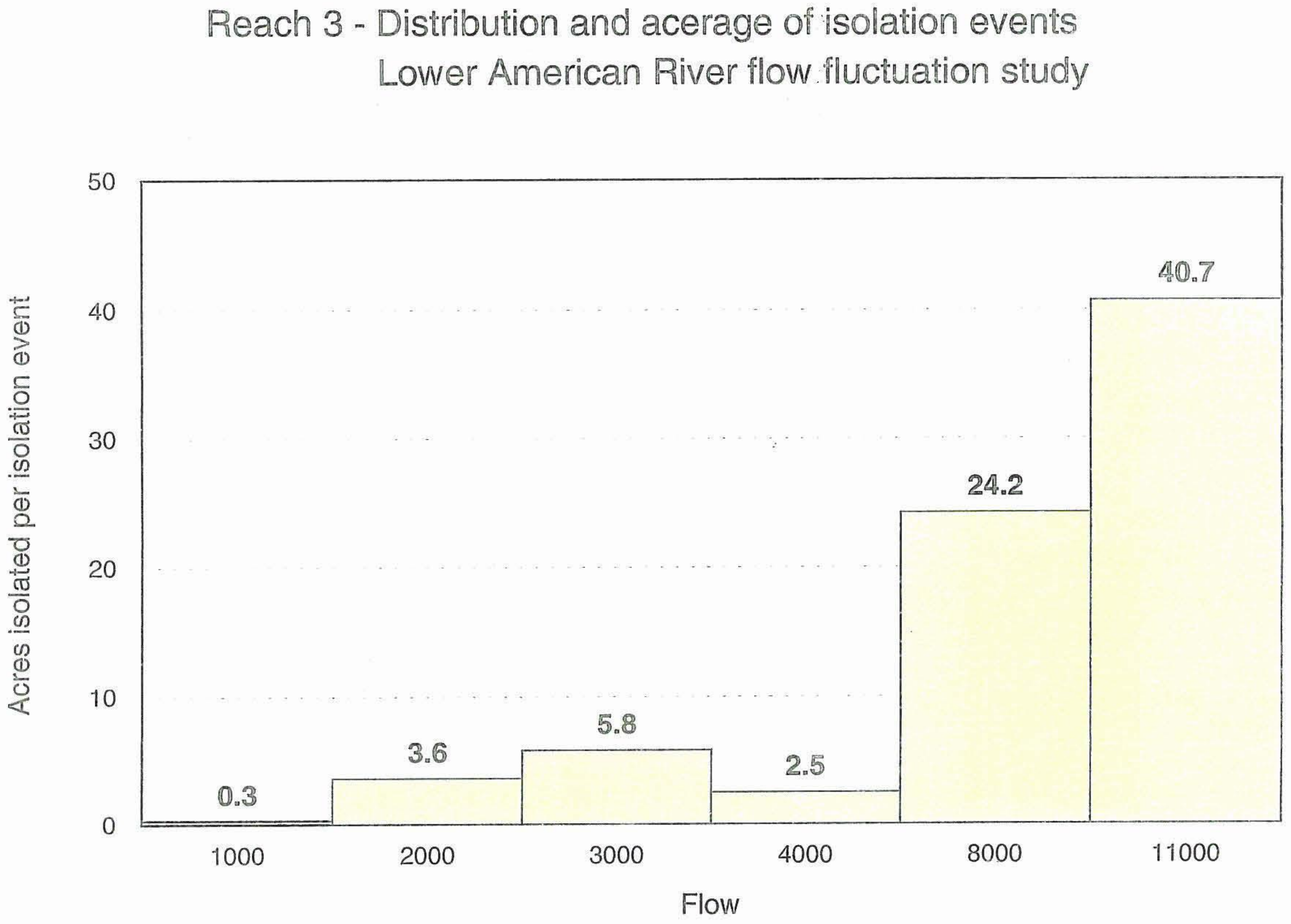


Figure 4. Total acerage of isolated areas in Reach 3 (Ancil Hoffman Park to Nimbus Hatchery) relative to flow associated with isolation event measured during the lower American River flow fluctuation study, 1997 - 2000.

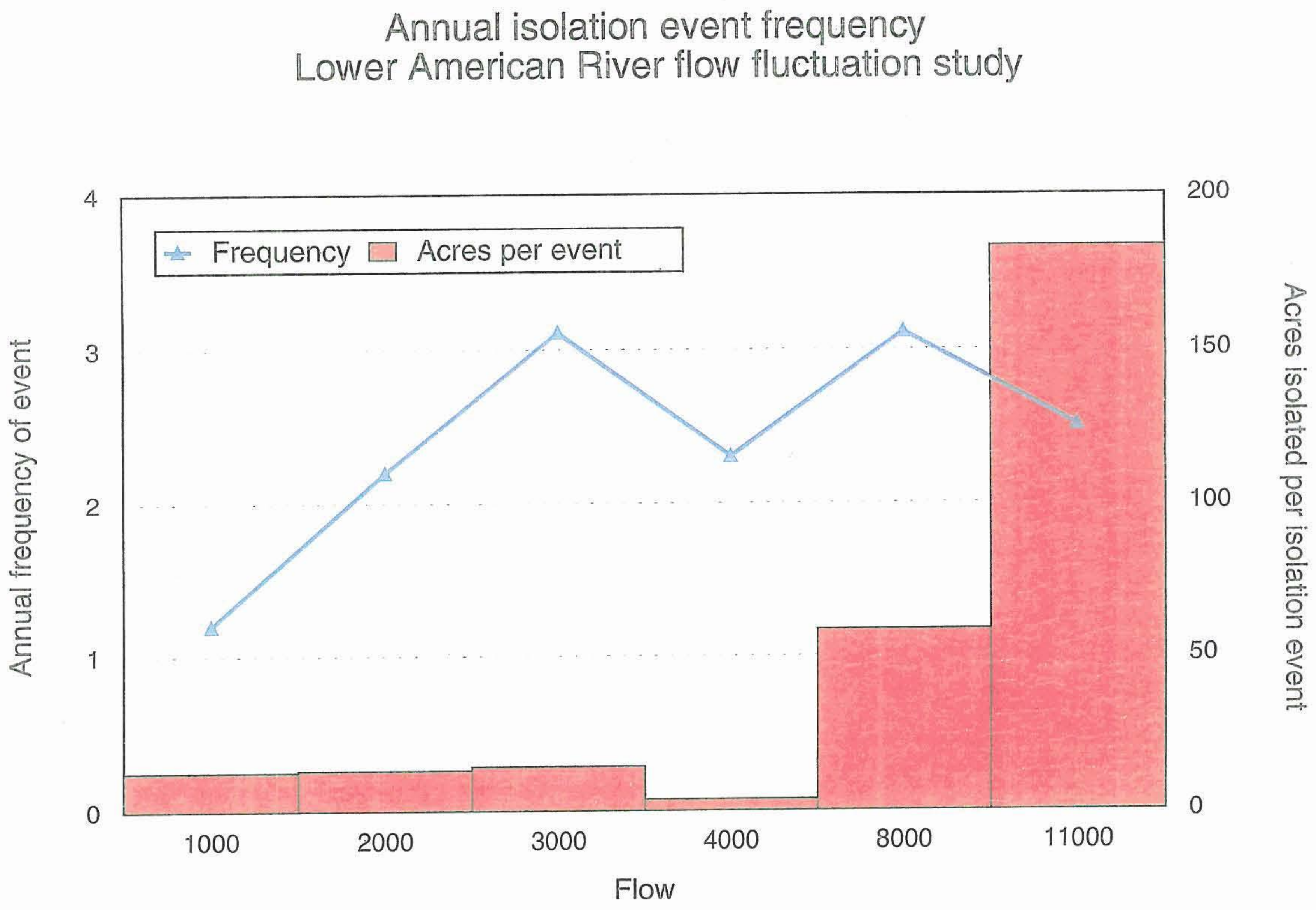


Figure 5. Annual frequency of flow incurred isolation events (1991- 2000).

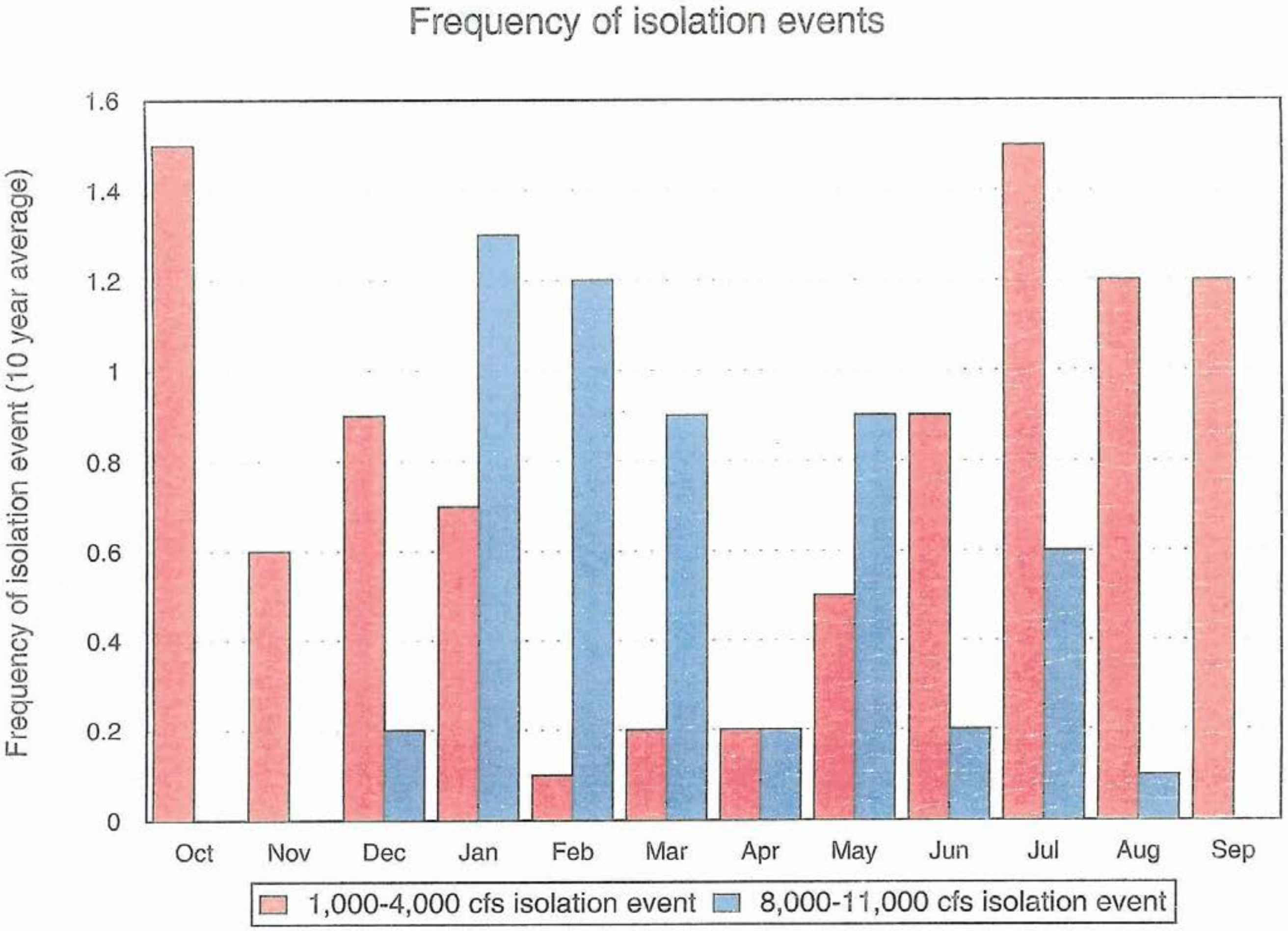


Figure 6. Frequency of isolation events in the lower American River during the 1991 - 2000 period.

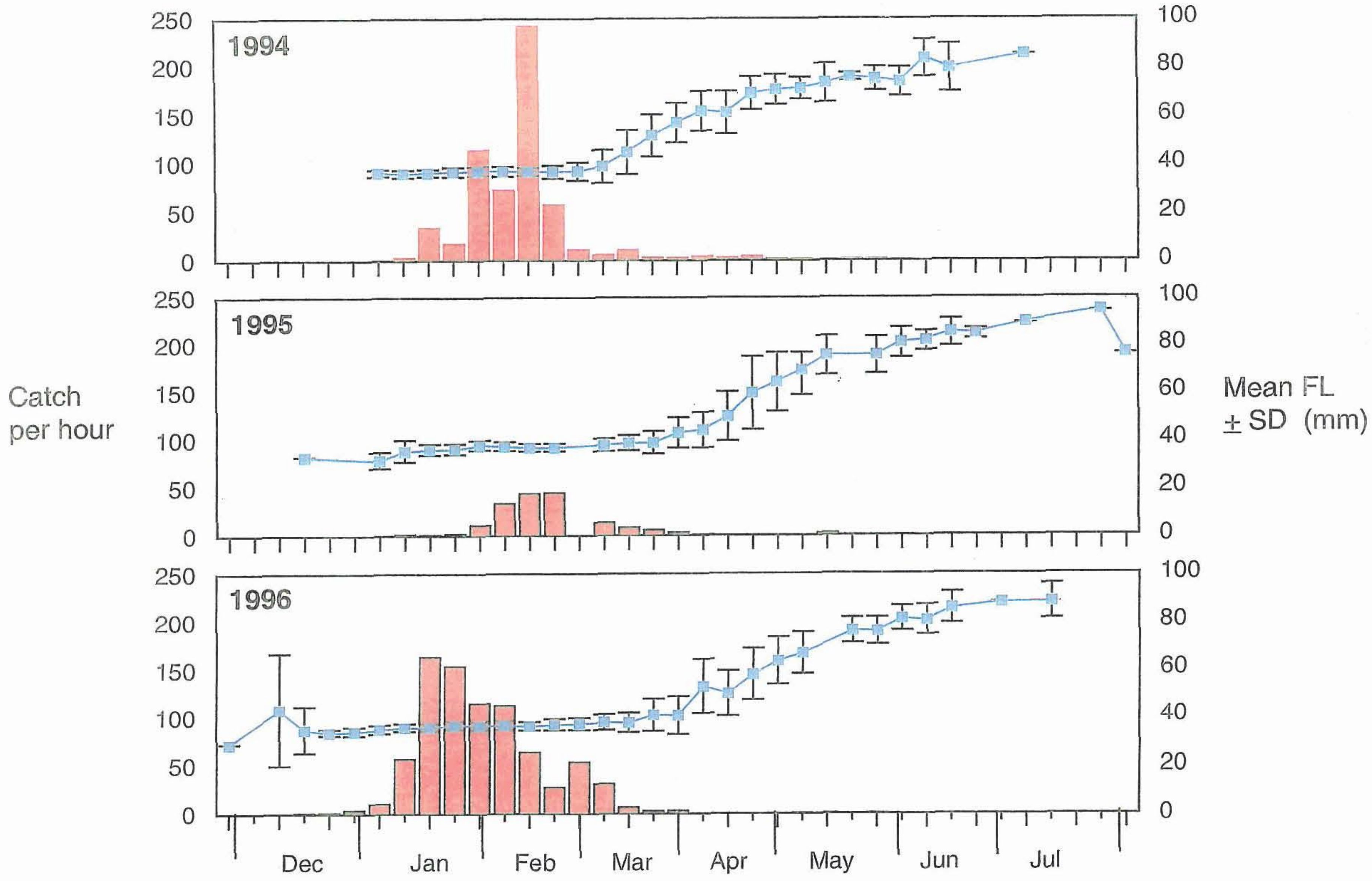


Figure 7. Temporal distribution of chinook salmon life stages represented by timing of emigration observed during the lower American River emigration surveys, 1994 - 1996.

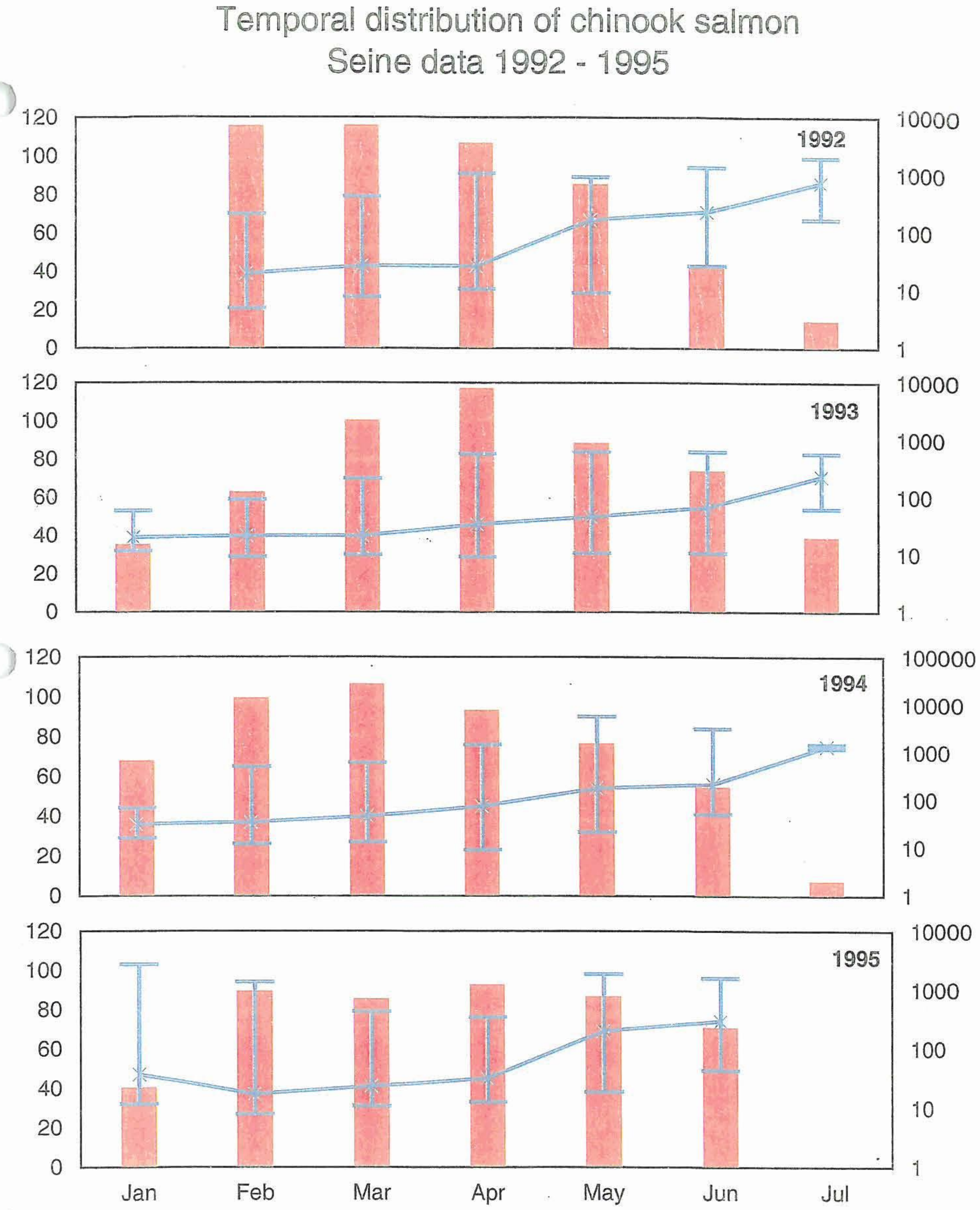

Temporal distribution of chinook salmon
Seine data 1992 - 1995

Figure 8. Temporal distribution of chinook salmon rearing in the lower American RIver based upon results of seining surveys conducted form 1992 through 1995.

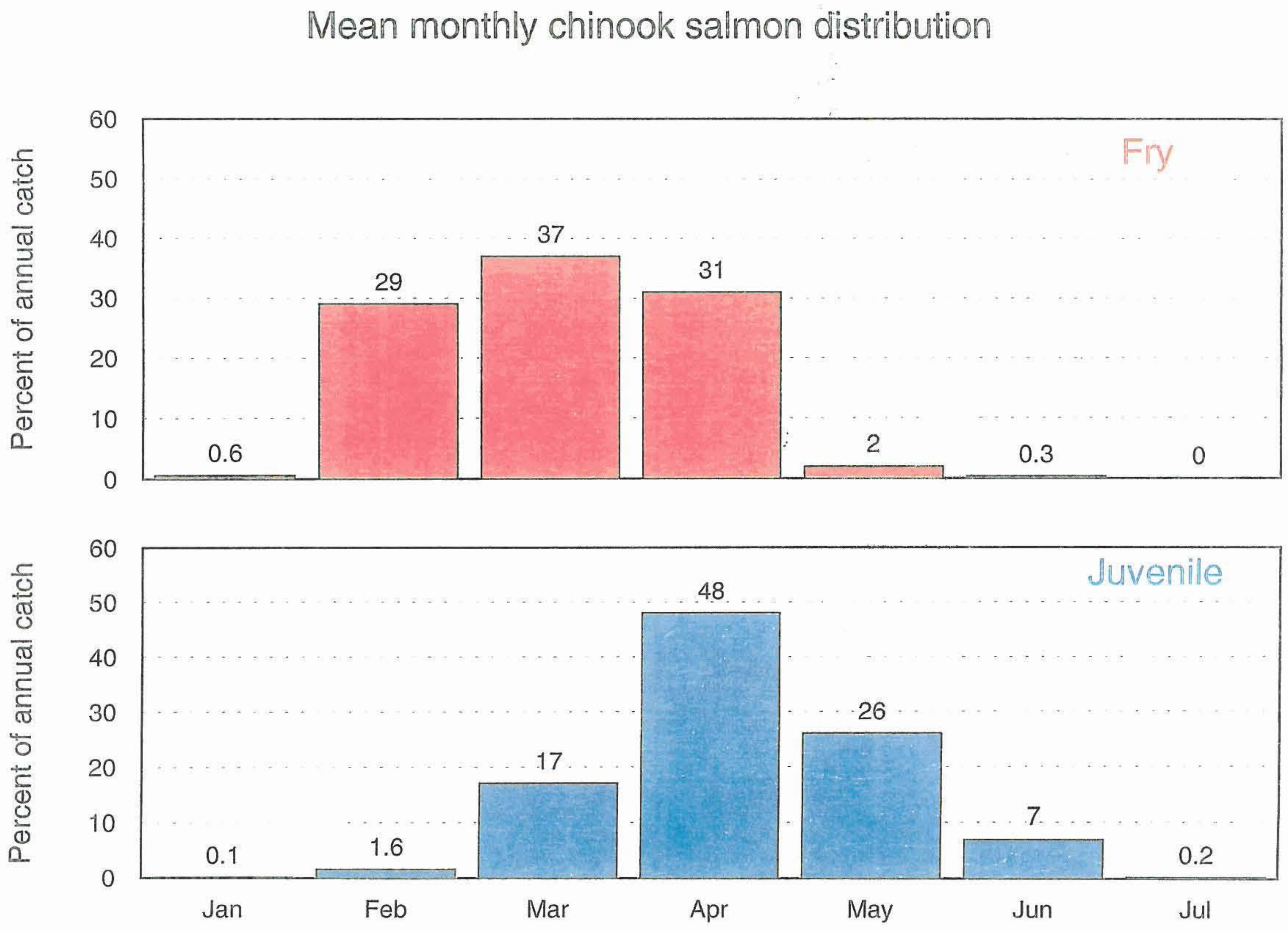


Figure 9. Mean monthly distribution of chinooksalmon life stages observed during seining surveys on the lower American River, 1992 - 1995.

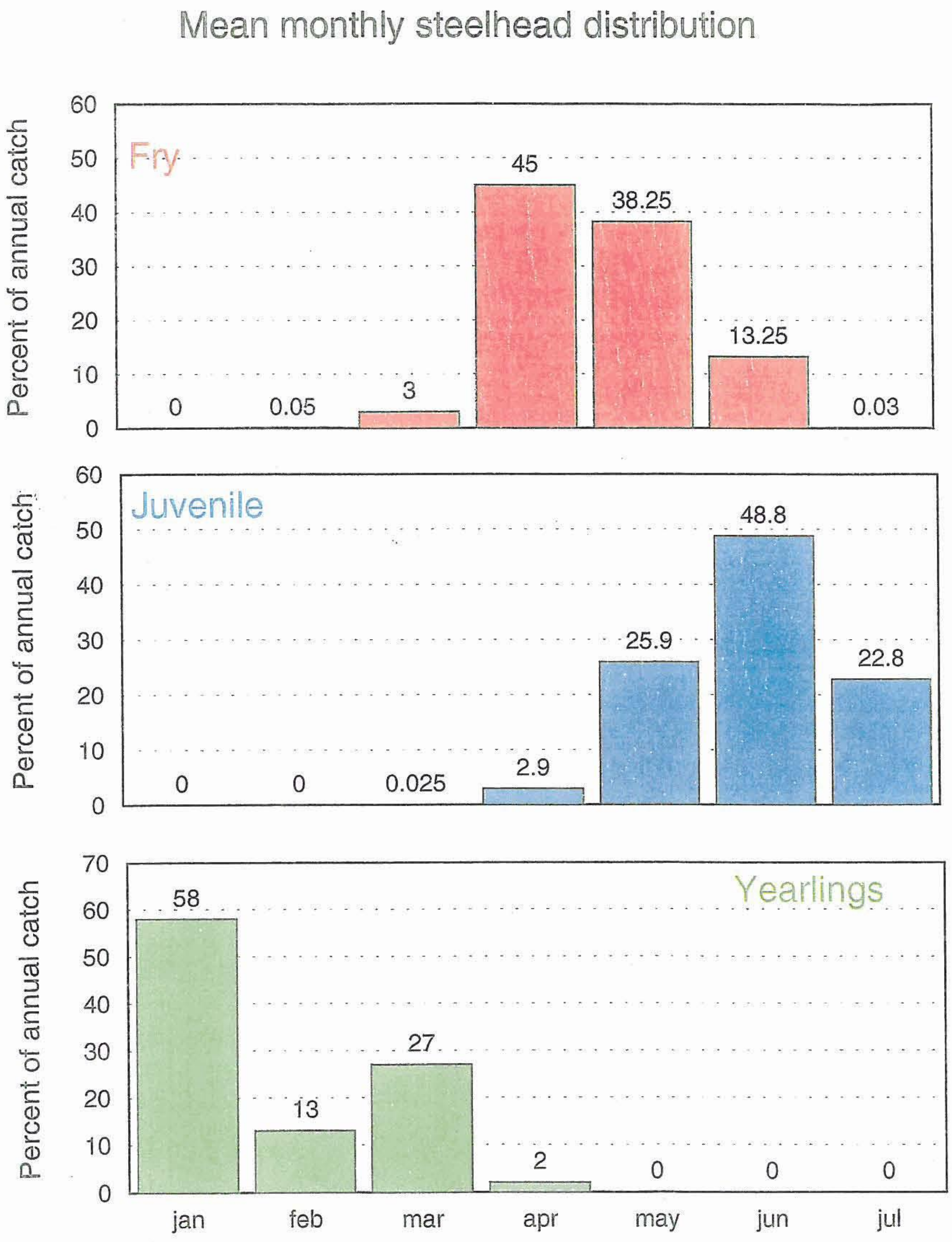


Figure 10. Mean monthly distribution of steelhead life stages observed during seining surveys on the lower American River, 1992 - 1995.

Temporal distribution of steelhead
Seine data 1992 - 1995

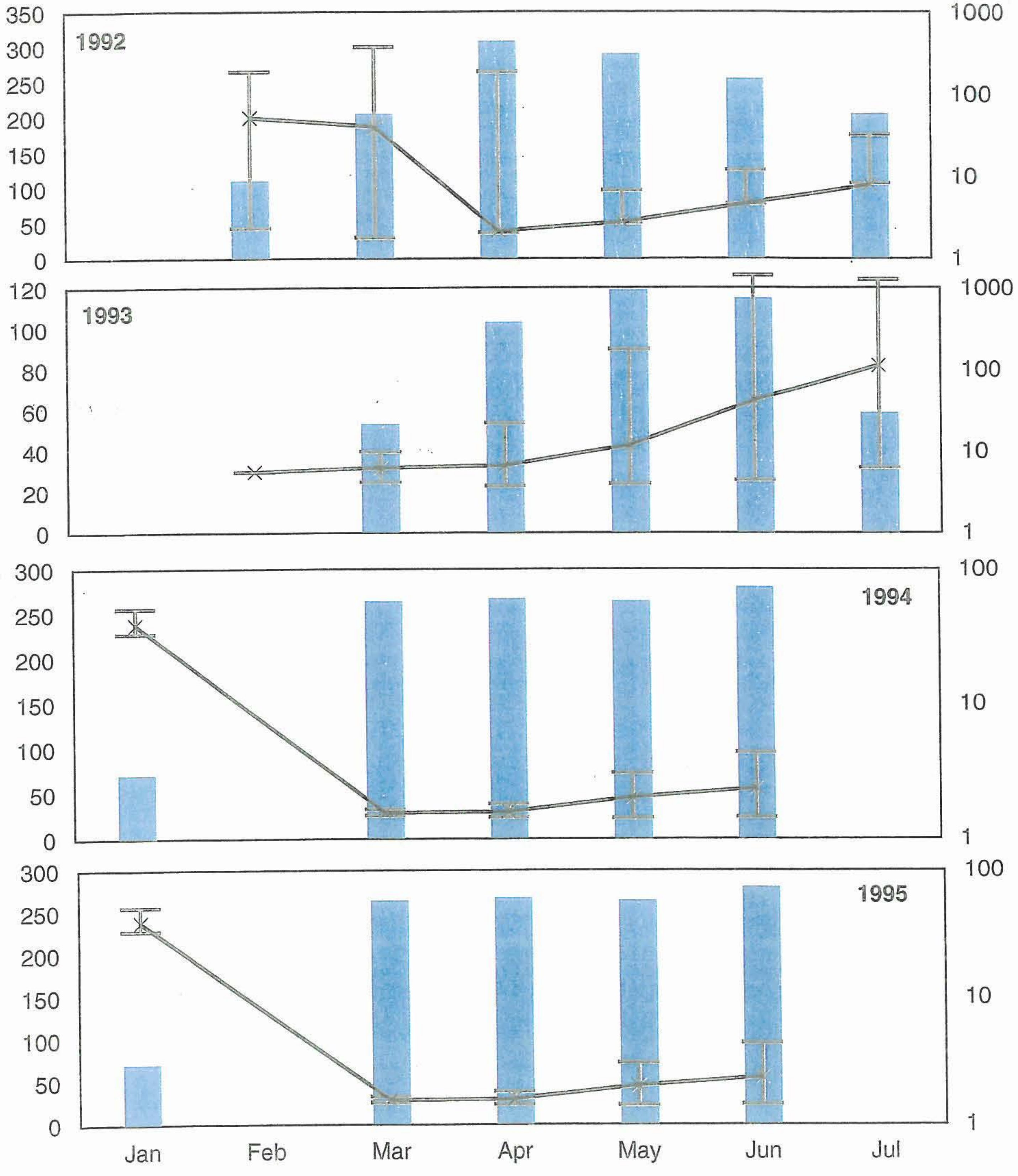


Figure 11. Temporal distribution of steelhead rearing in the lower American River based upon results of seining surveys conducted form 1992 through 1995.

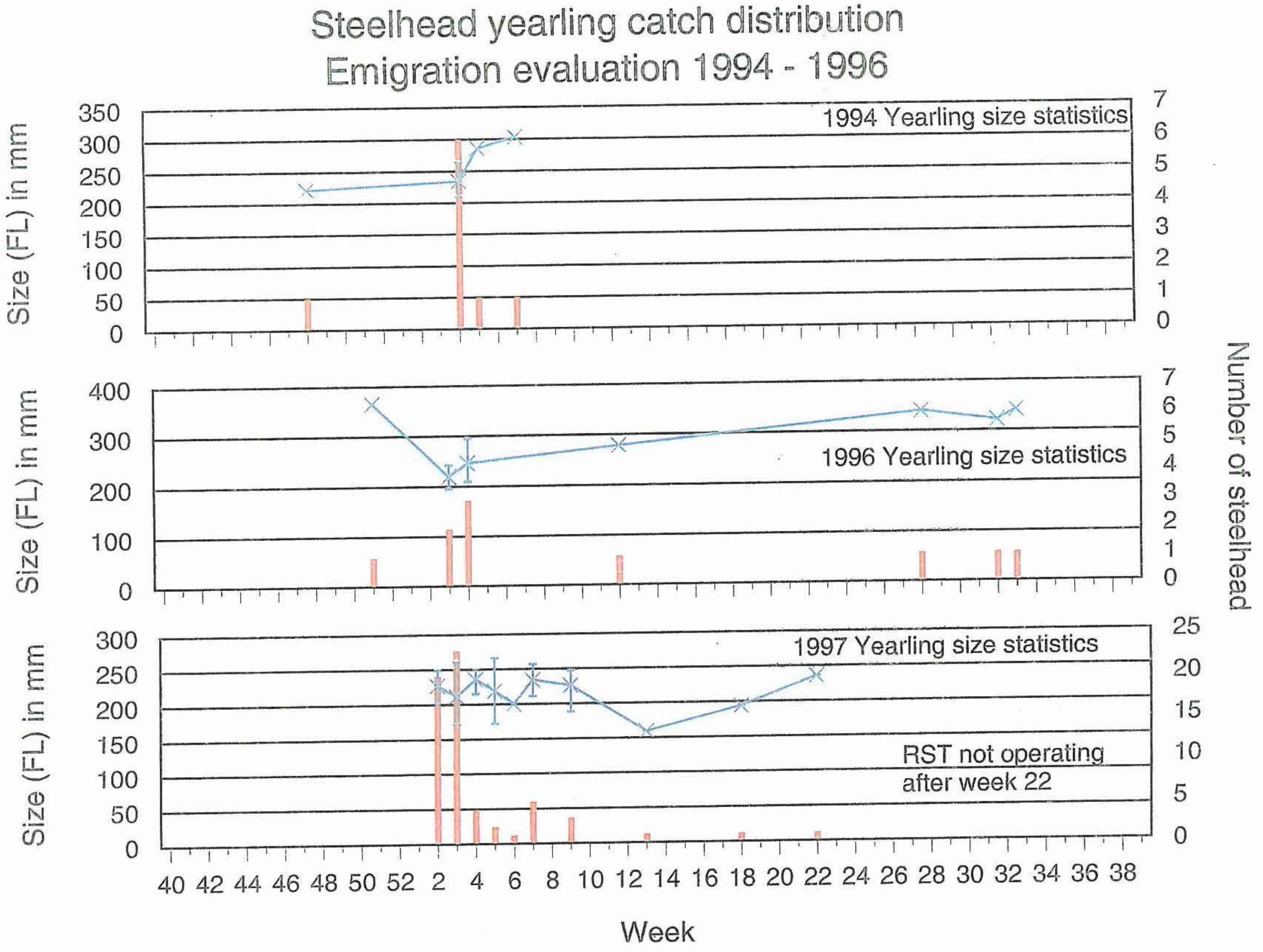


Figure 12. Mean fork length and size range of yearling steelhead caught by screw traps during lower American River emigration surveys (1994 - 1997). No yearling-sized steelhead were caught during 1995.

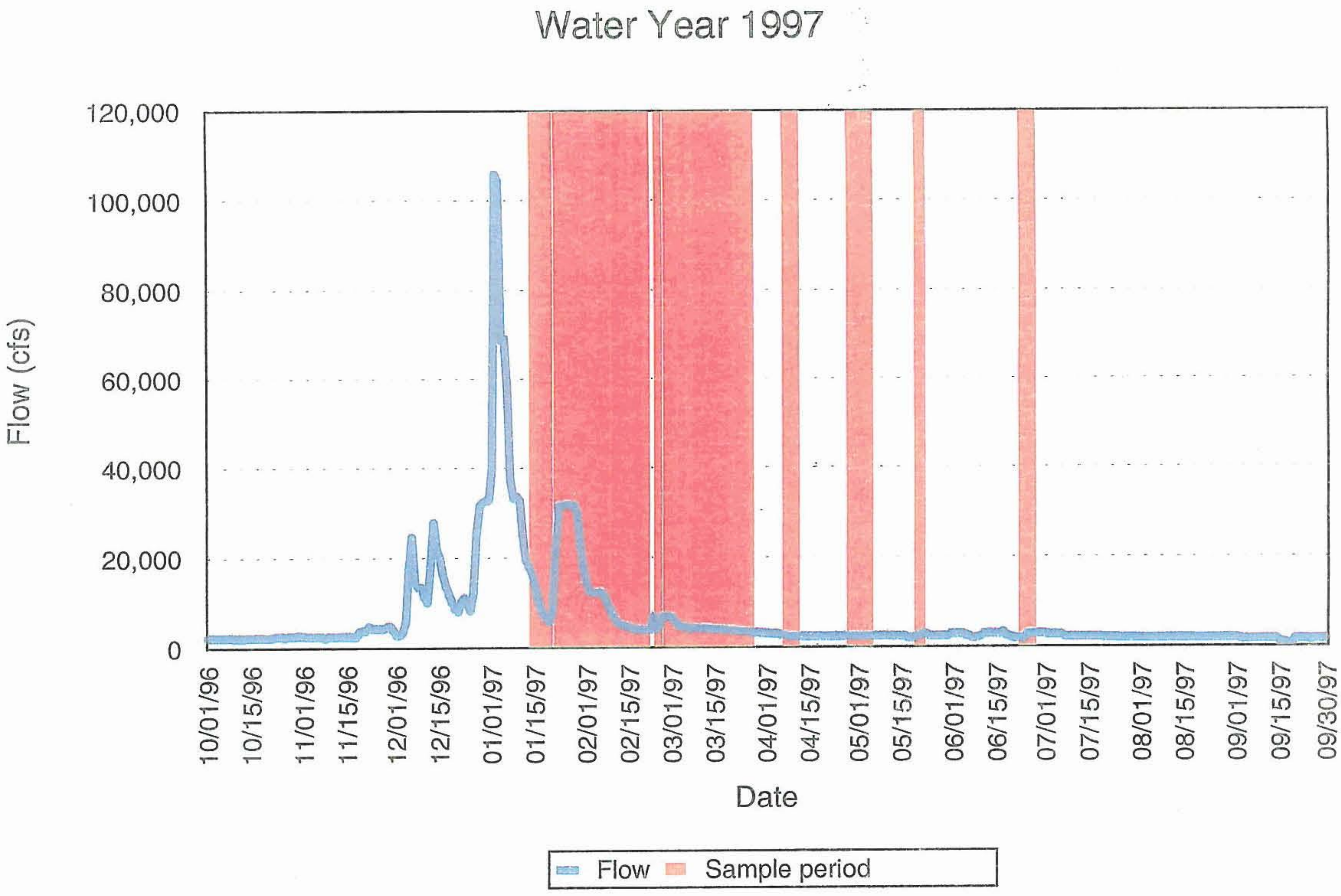


Figure 13. Flow and isolation sample period distribution during water year 1997, lower American RIver flow fluctuation investigation.

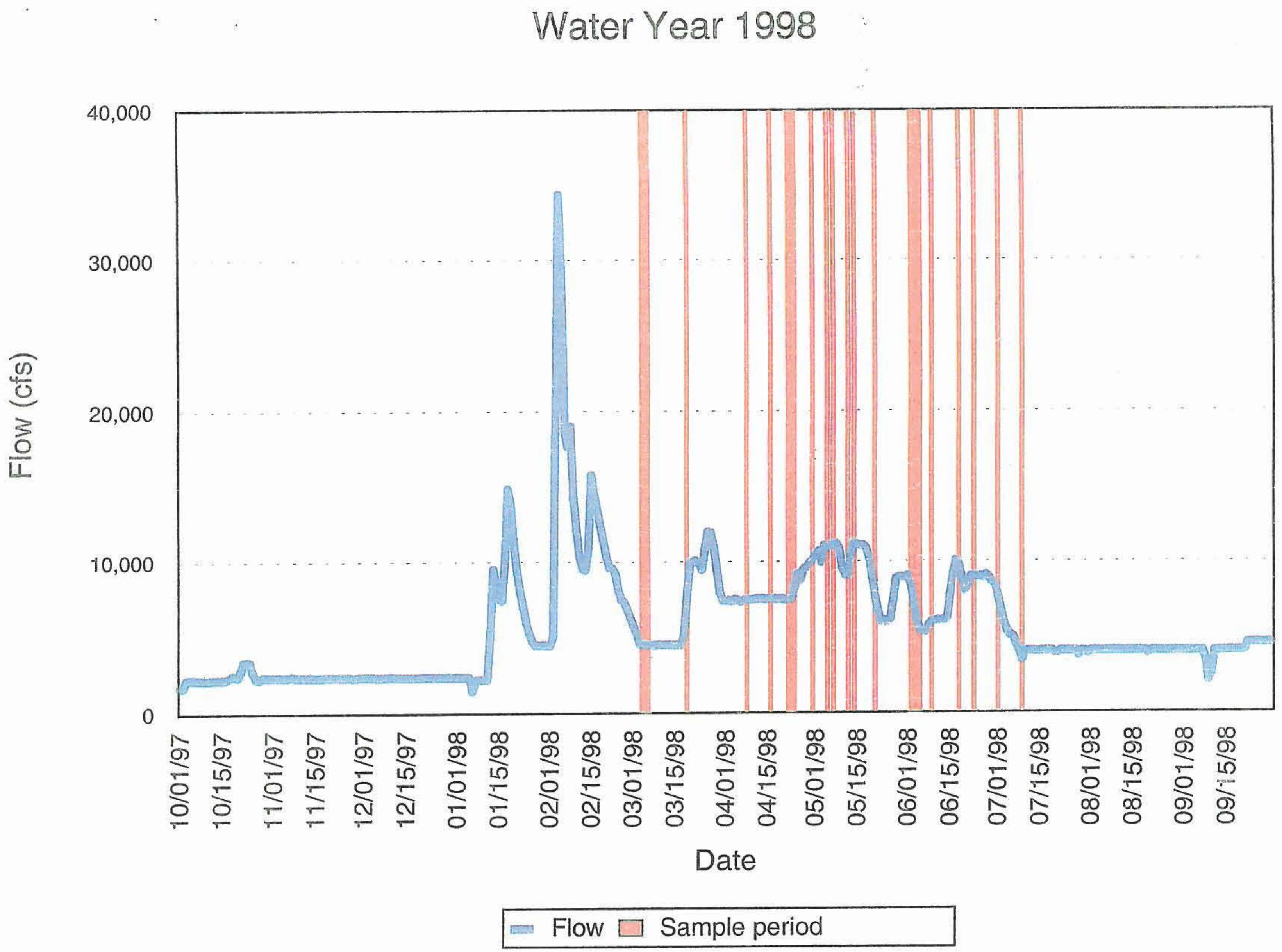


Figure 14. Flow and isolation sample period distribution during water year 1998, lower American River flow fluctuation investigation.

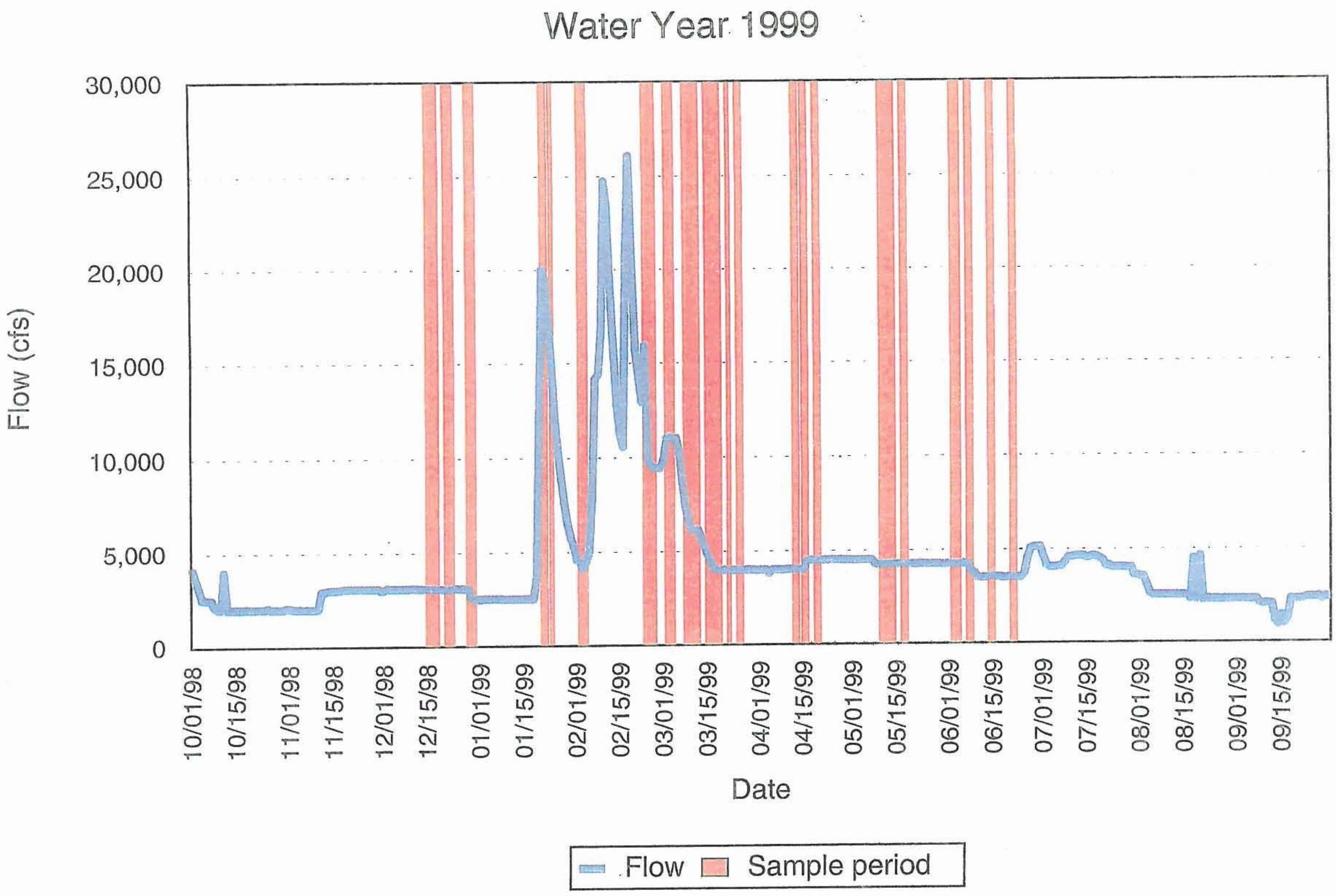


Figure 15. Flow and isolation sample period distribution during water year 1999, lower American River flow fluctuation investigation.

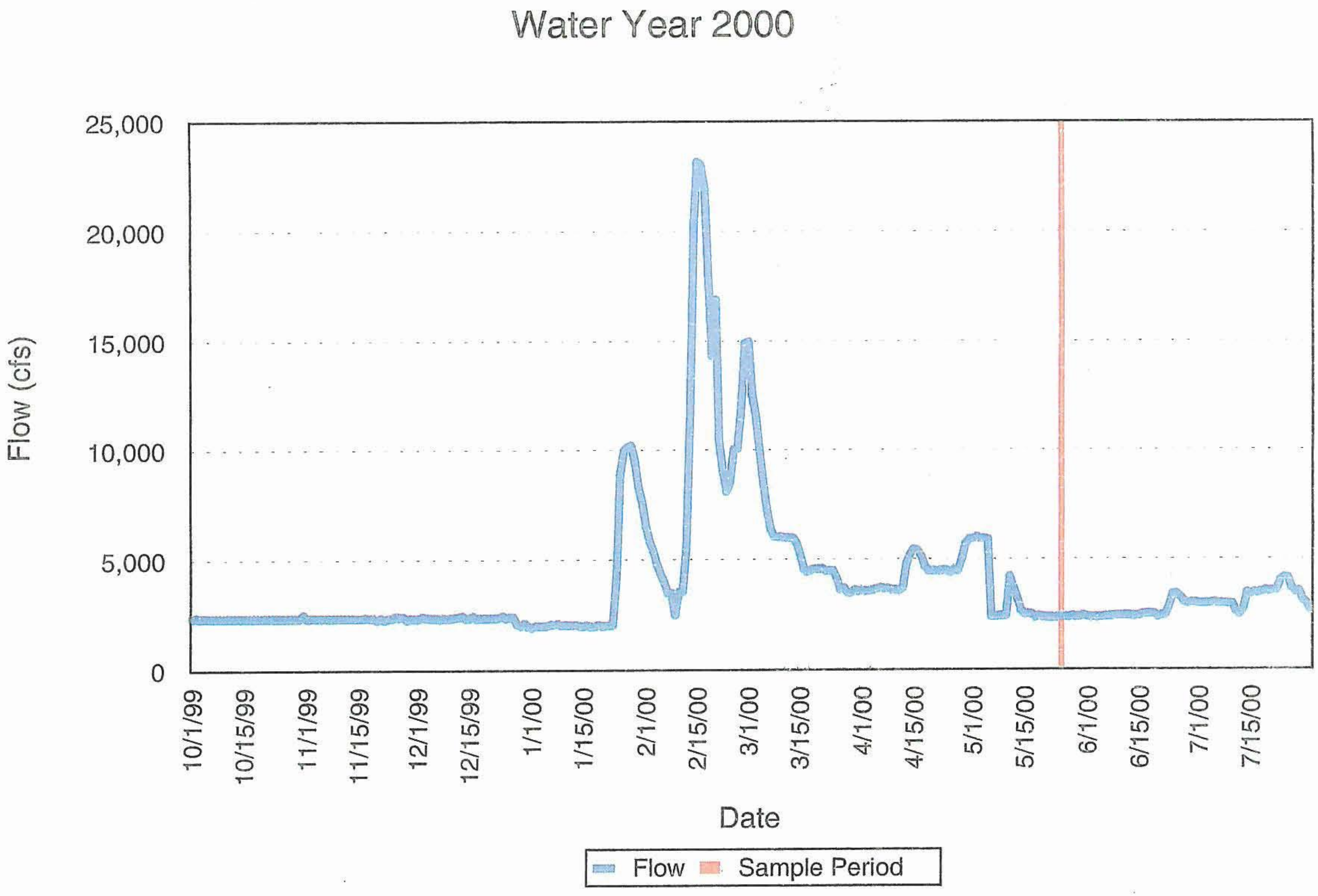


Figure 16. Flow and isolation sample period distribution during water year 2000, lower American River flow fluctuation investigation.

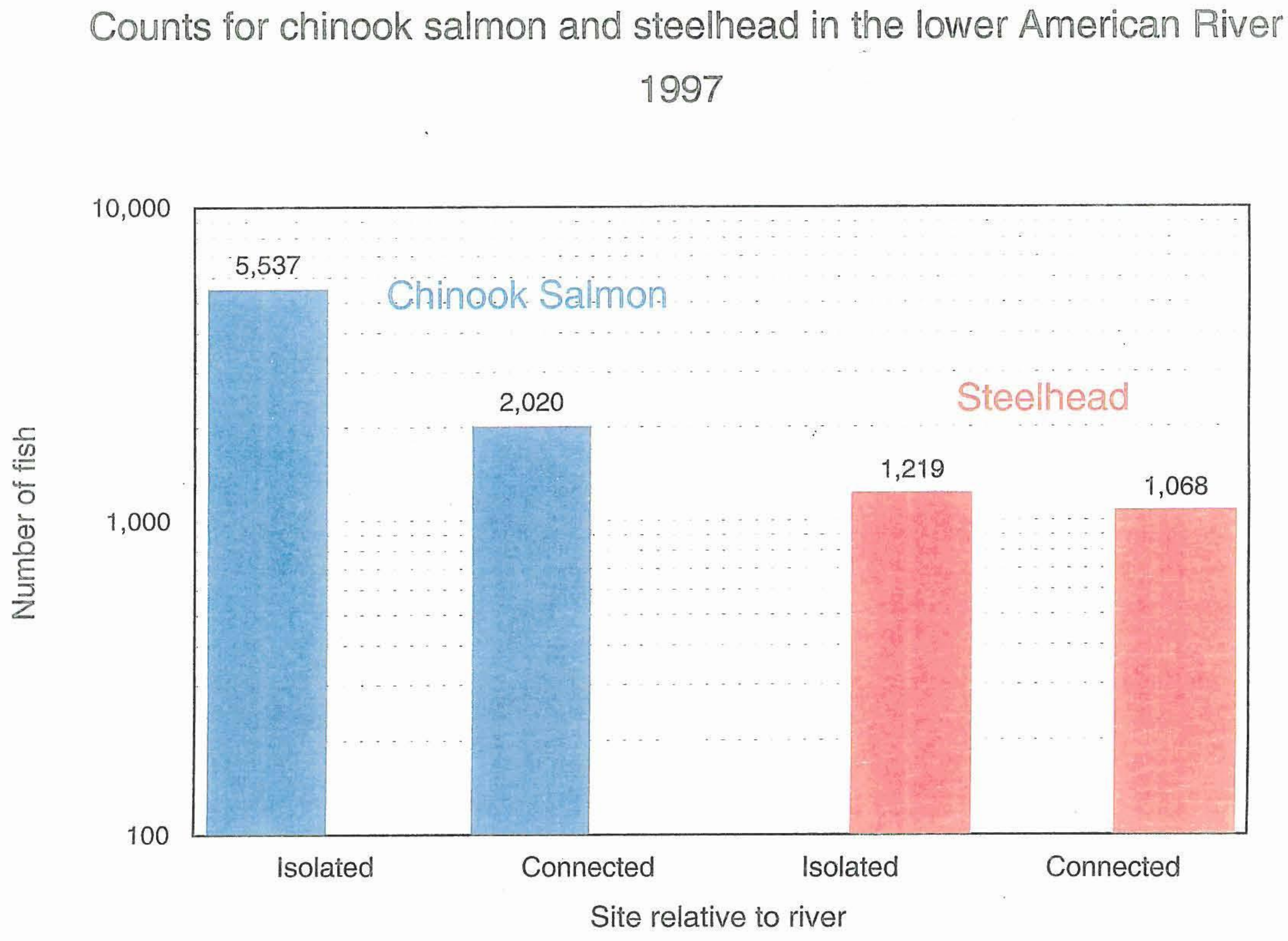
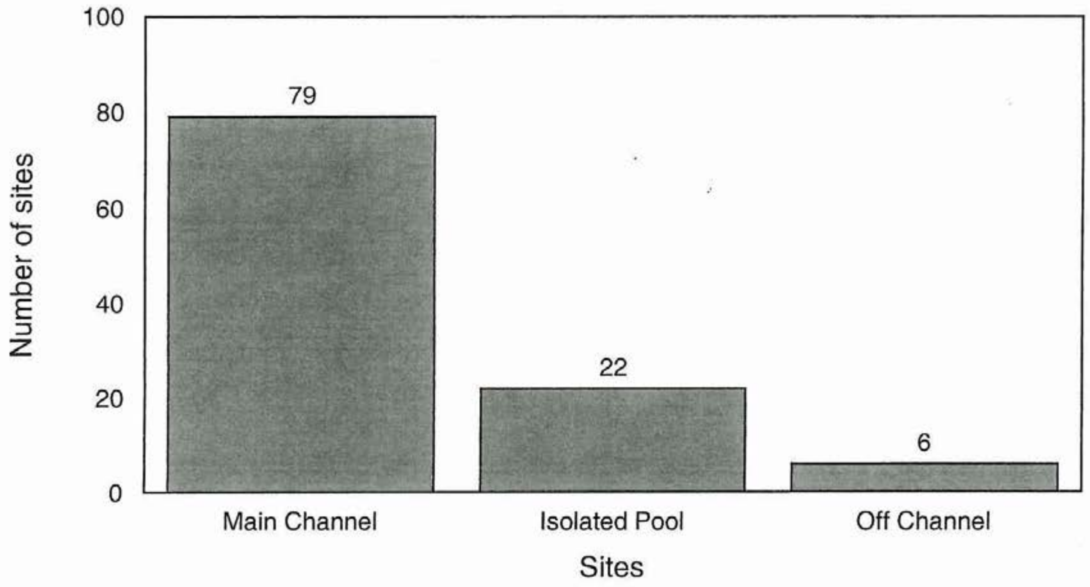


Figure 17. Total catch distribution of chinook salmon and steelhead collected in 1997during the lower American River flow fluctuation study, 1997 - 2000.



Total number of survey sites connected to or isolated from the lower American River

1997

Figure 18. Total number of individual sample sites connected to or isolated from the main channel of the lower American River surveyed in 1997 during the lower American River flow fluctuation study, 1997- 2000.

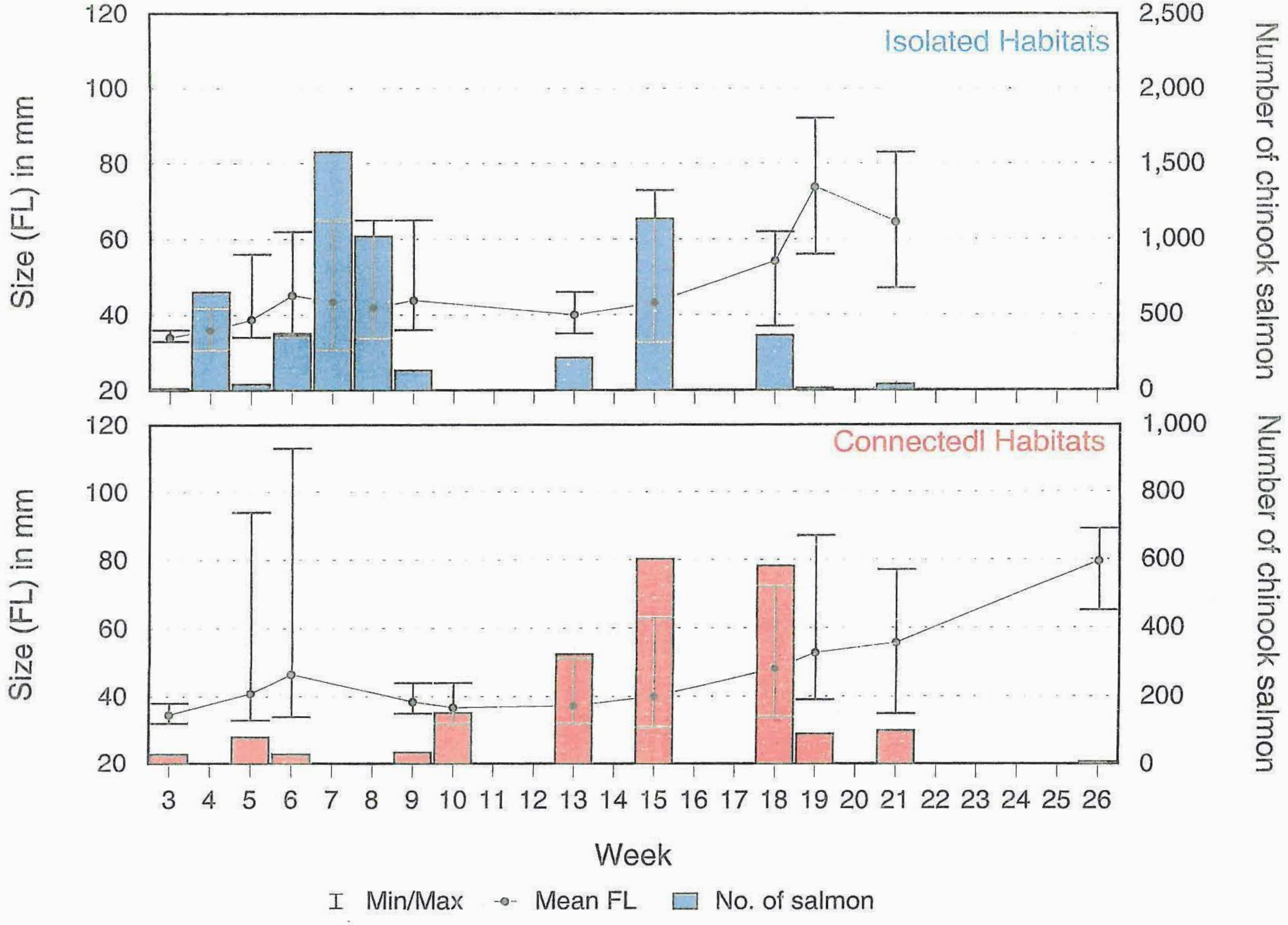

Size statistics and weekly catch for chinook salmon
1997 lower American River flow fluctuation study

Figure 19. Total chinook salmon caught and the mean fork length (minimum and maximum) collected during the lower American River flow fluctuation study,1 January - 27 June 1997.

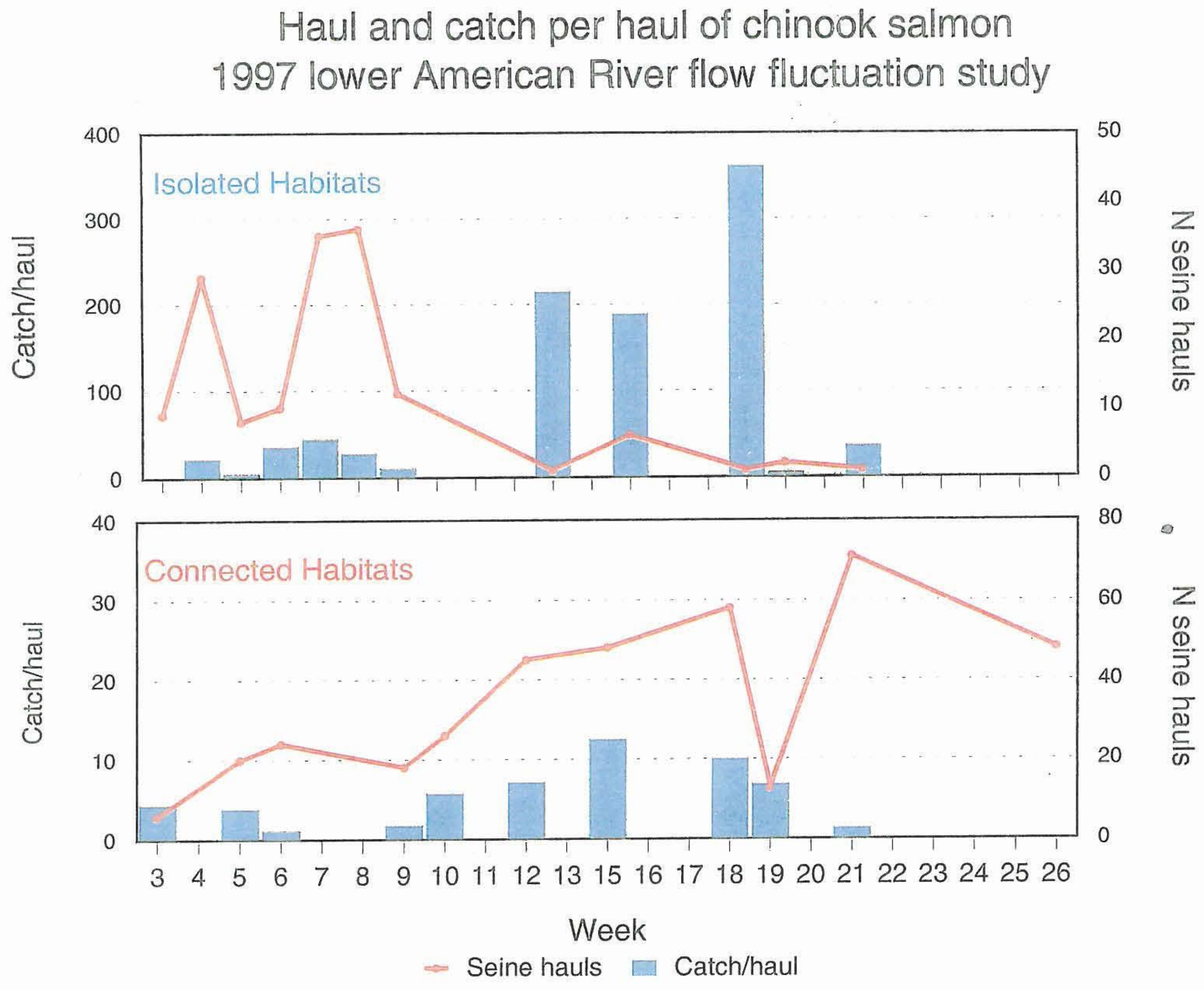
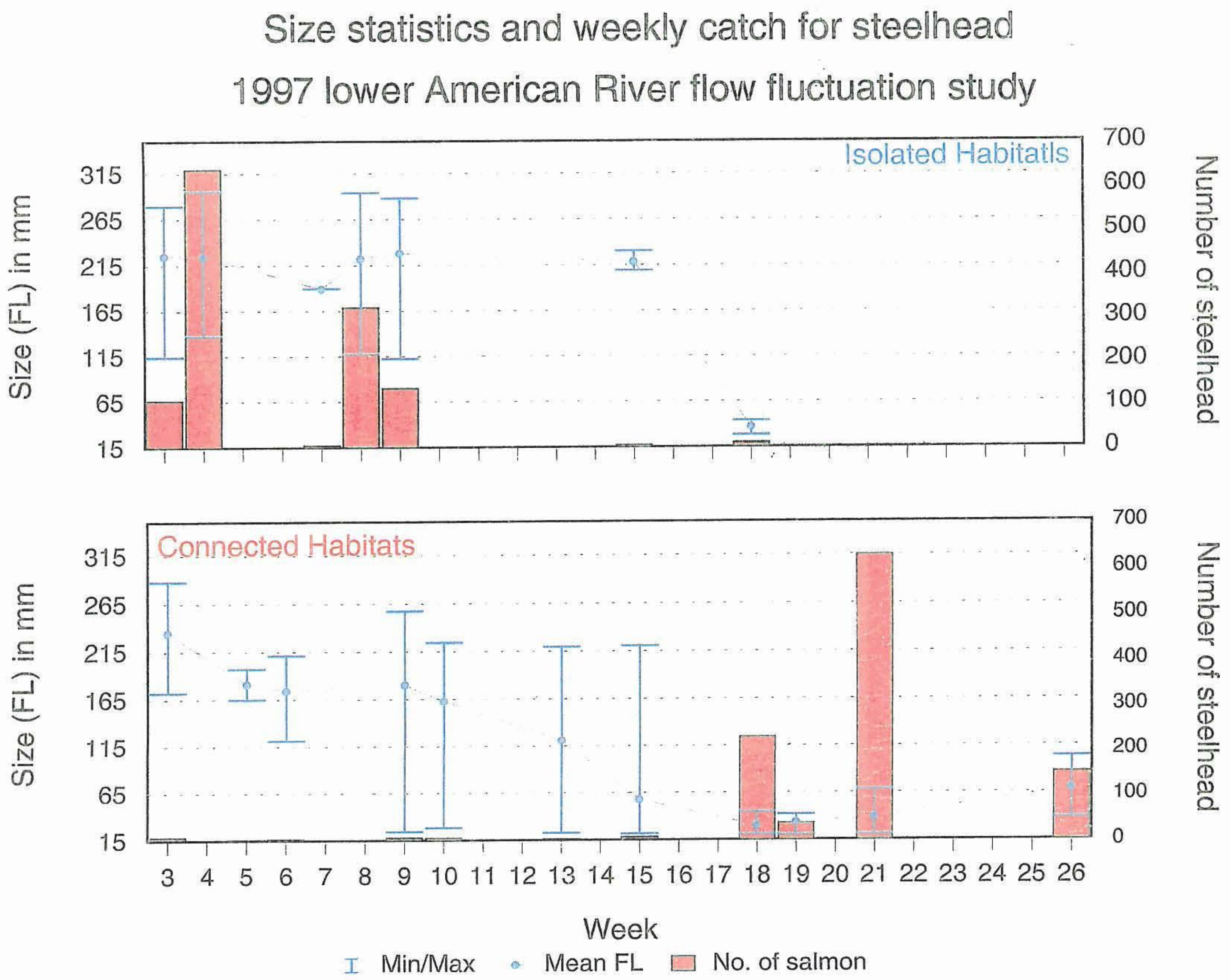

Haul and catch per haul of chinook salmon
1997 lower American River flow fluctuation study

Figure 20. Effort (seine hauls) and catch-per-haul for chinook salmon collected during the lower American River flow fluctuation study, 1 January - 27 June 1997.


Size statistics and weekly catch for steelhead

1997 lower American River flow fluctuation study

Figure 21. Total number and size (mean and range) of steelhead caught during the lower American River flow fluctuation study, 1 January - 27 June 1997.

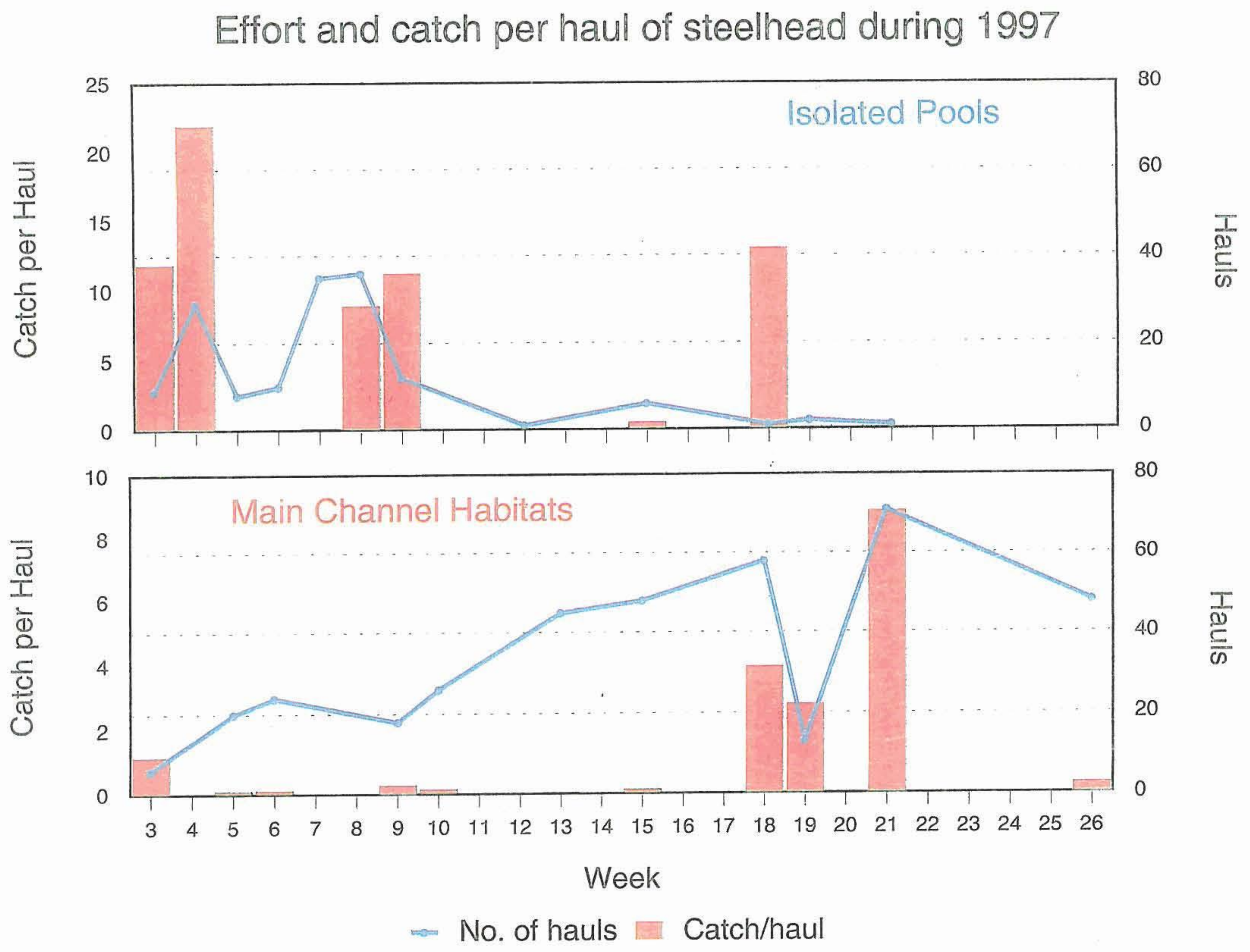


Figure 22. Effort (seine hauls) and catch/haul for steelhead collected during the lower Ameircan RIver flow fluctuation investigations, 1 January to 27 June 1997.

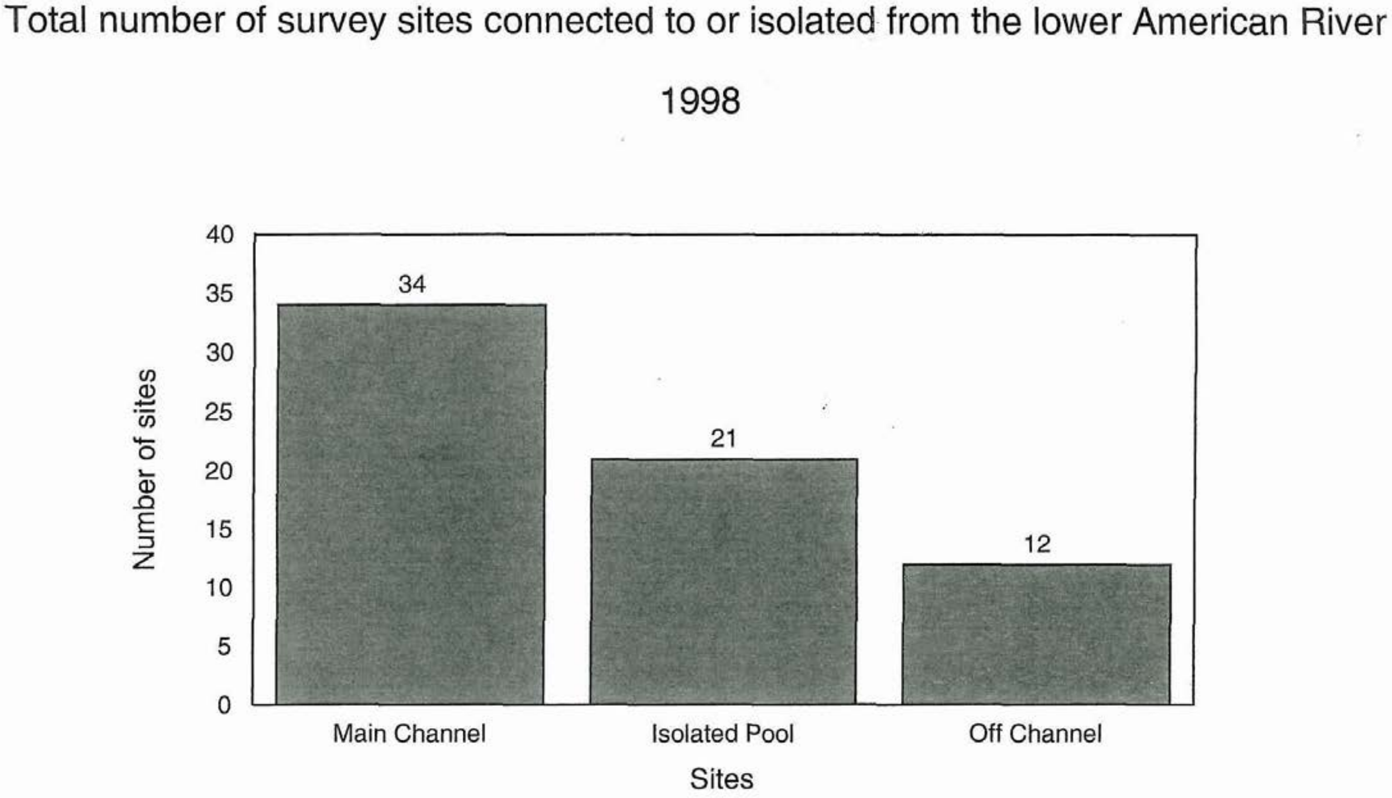


Figure 23. Total number of individual sample sites connected to or isolated from the main channel of the lower American River surveyed in 1998 during the lower American River flow fluctuation study, 1997- 2000.

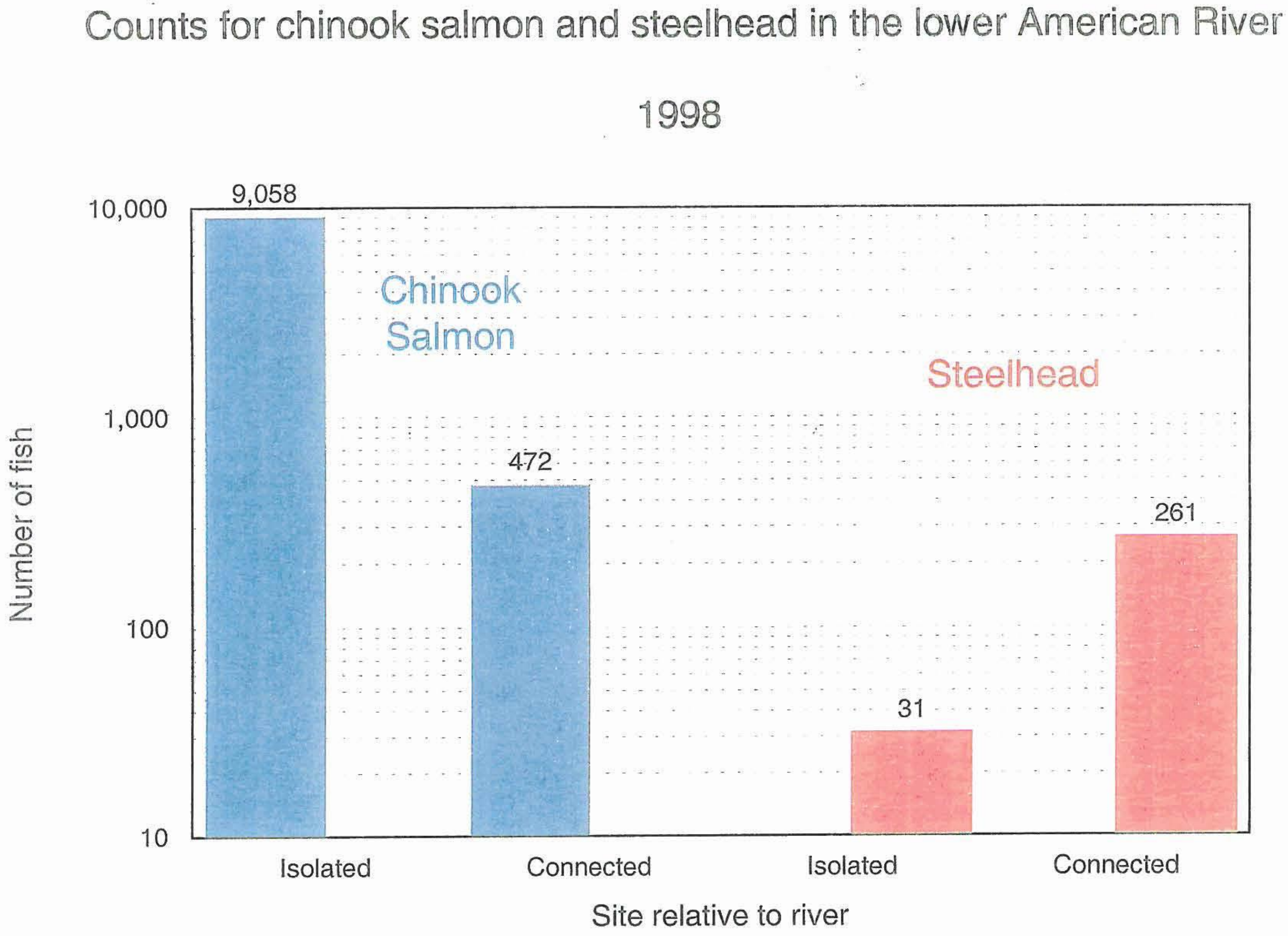
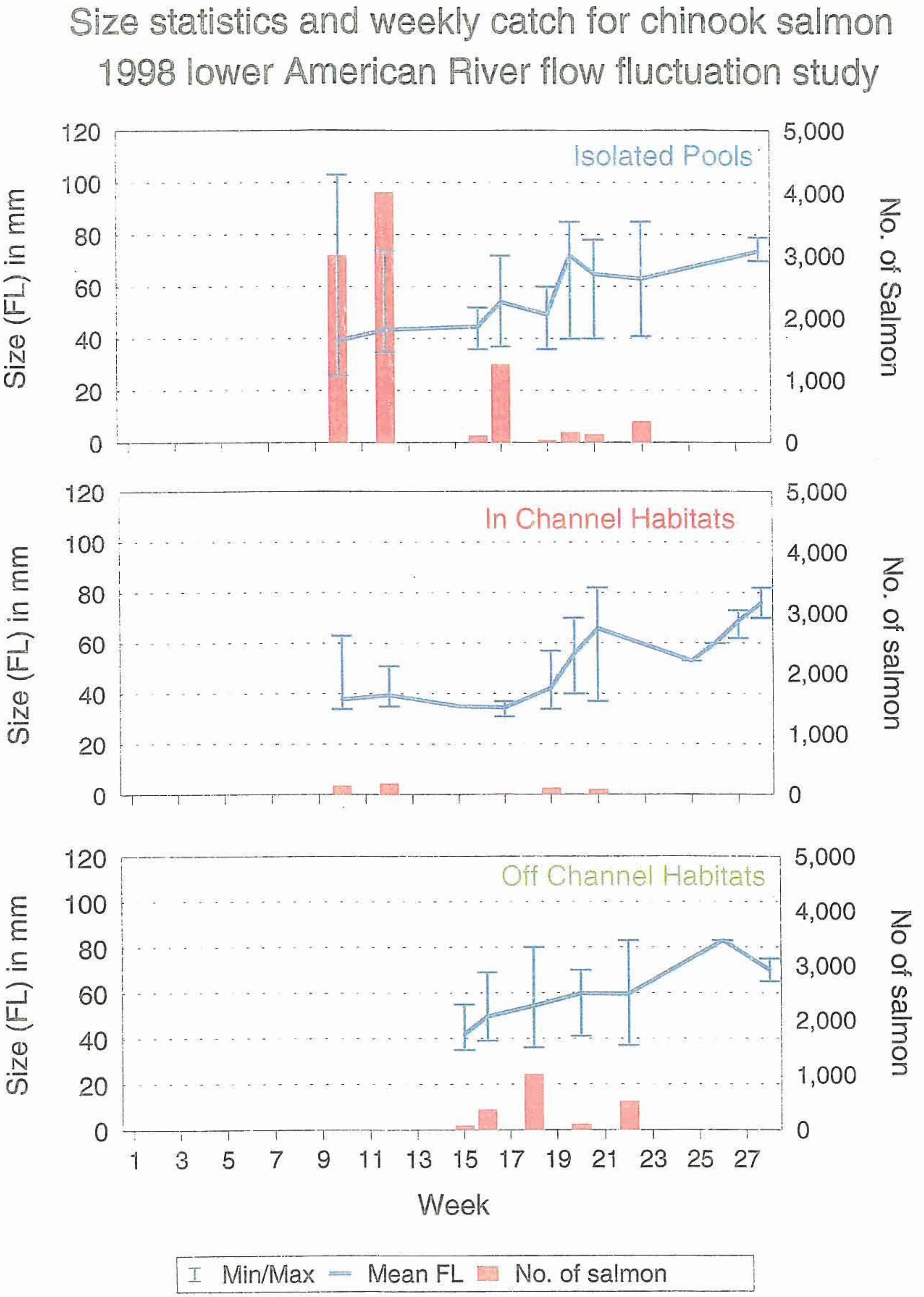


Figure 24. Total catch distribution of chinook salmon and steelhead collected in 1998 during the lower American River flow fluctuation study, 1997 - 2000.



Size statistics and weekly catch for chinook salmon
1998 lower American River flow fluctuation study

Figure 25. Total number and size (mean and range) of chinook salmon caught during the lower American River flow fluctuation study, 4 March - 10 July 1998.

Effort and average catch per haul of chinook salmon 1998 lower American River flow fluctuation study

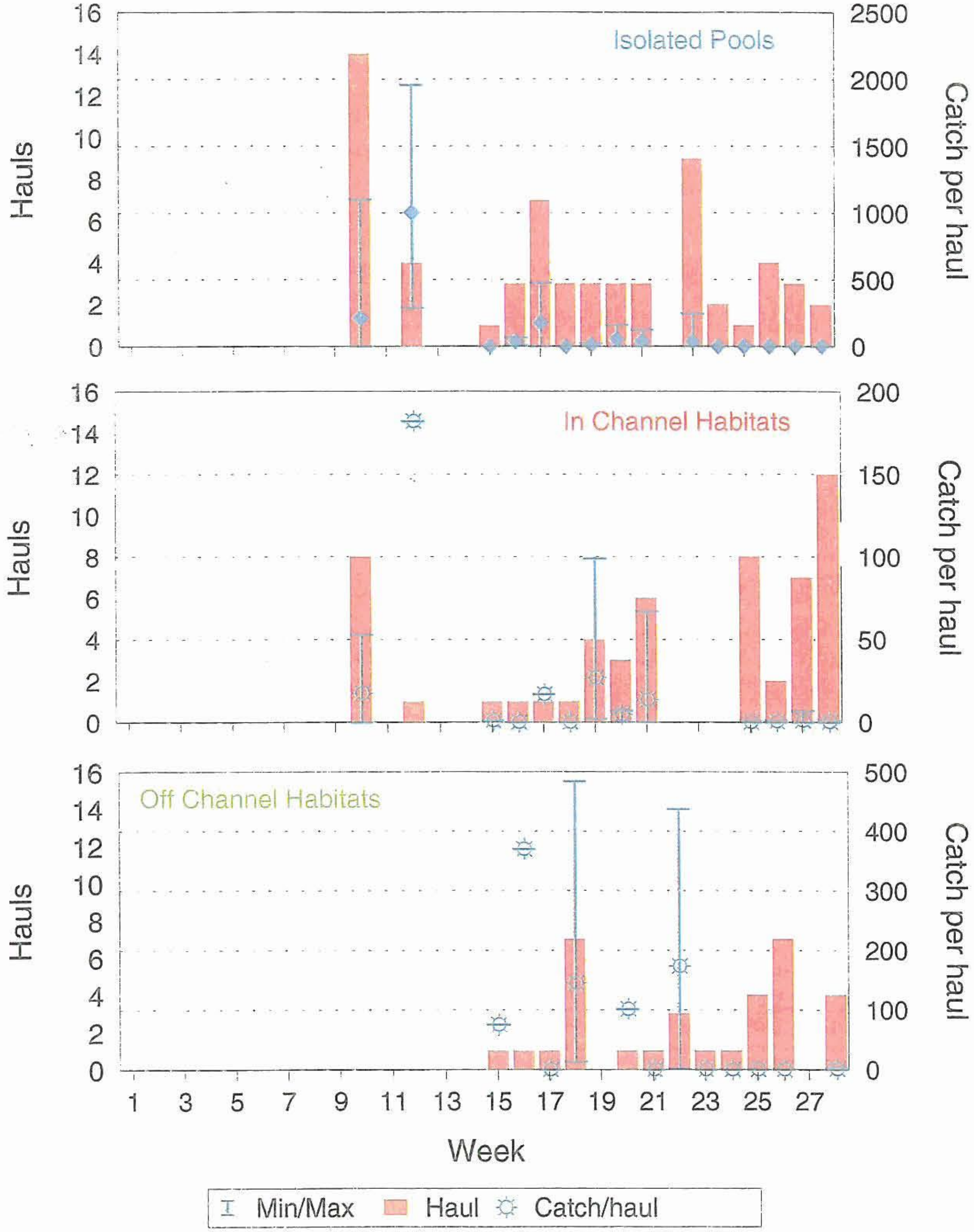


Figure 26. Effort (seine hauls) and catch per haul of chinook salmon collected during the lower American River flow fluctuation study, 4 March - 10 July 1998.

Size statistics and weekly catch for steelhead in 1998 - lower American River flow fluctuation investigation

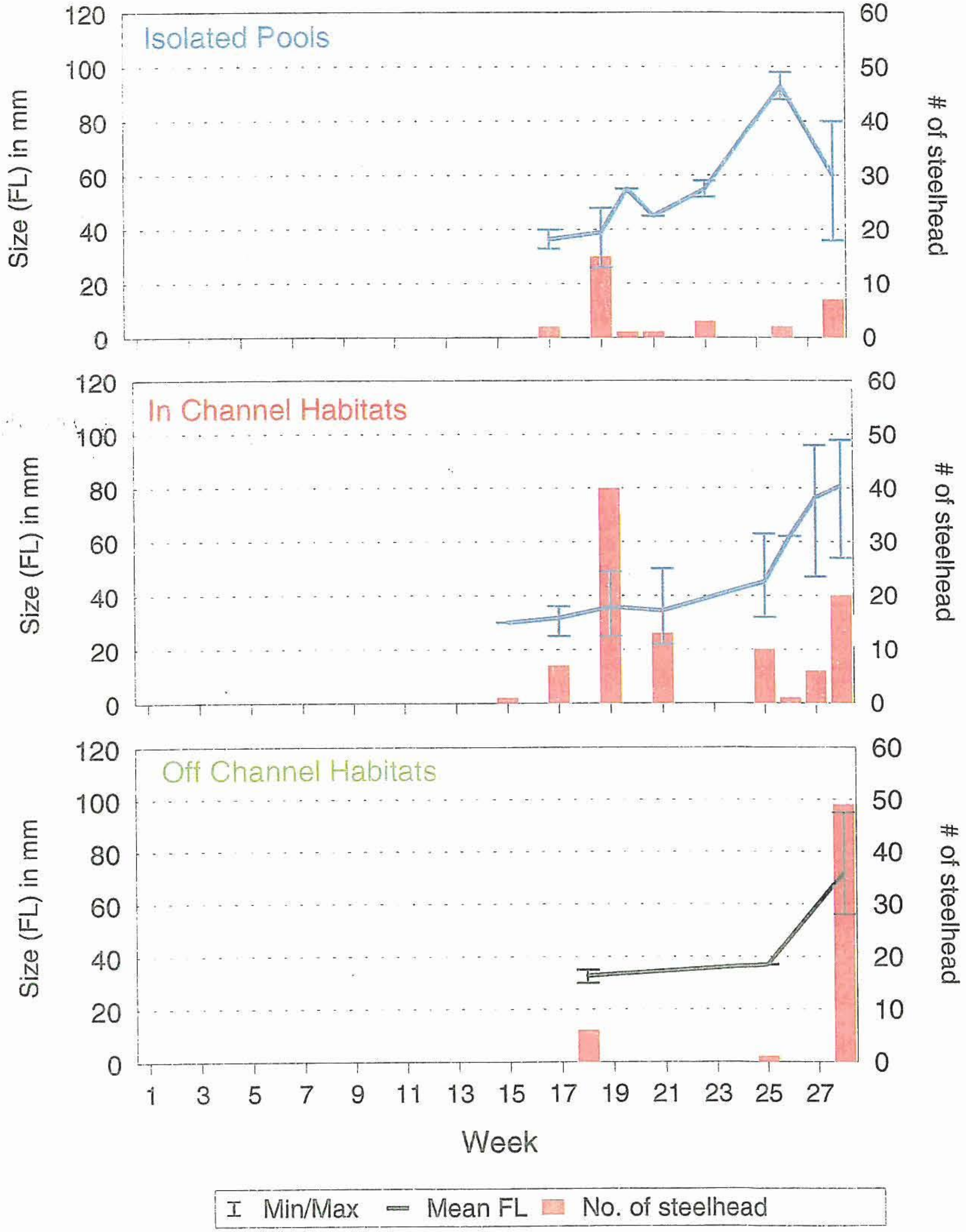


Figure 27. Total steelhead caught and mean fork length (range) collected during the lower American River flow fluctuation investigation, 4 March--10 July 1998.

Effort and average catch/seine haul of steelhead in 1998 - lower American River flow fluctuation investigation

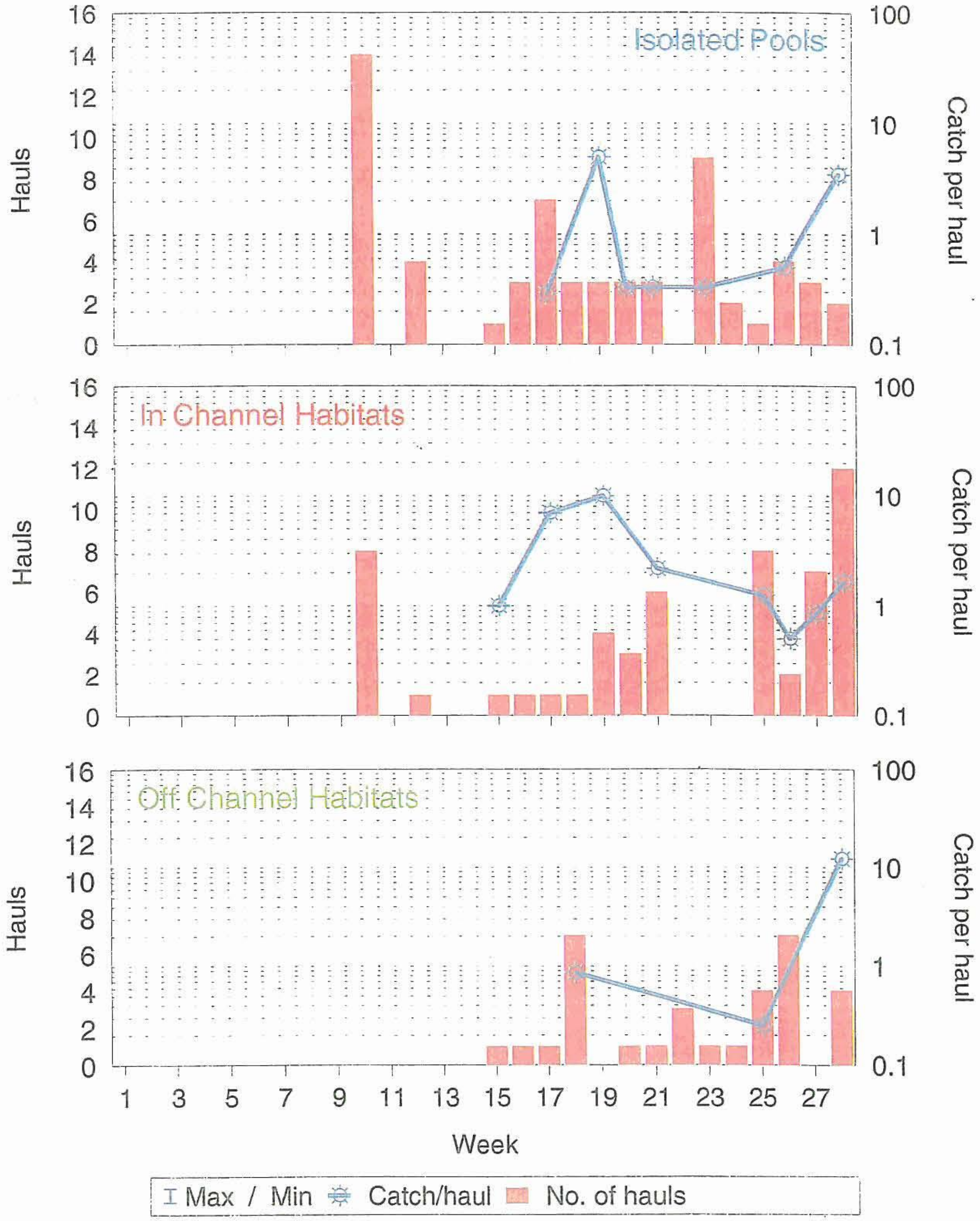


Figure 28. Effort (seine hauls) and catch/haul of steelhead collected during the lower American River flow fluctuation investigation, 4 March - 10 July 1998.

Total number of survey sites connected to or isolated from the lower American River

1999

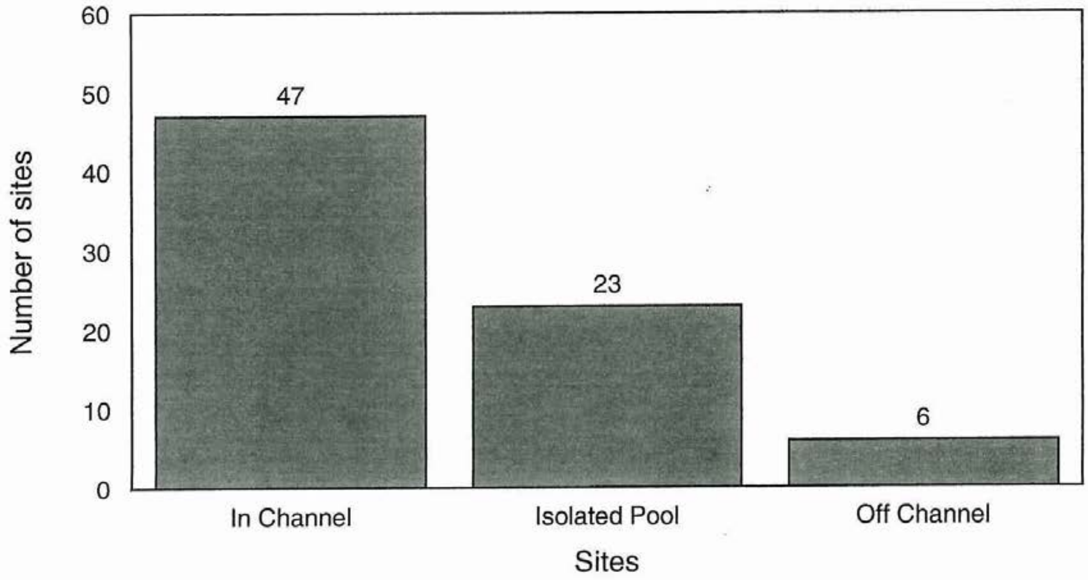
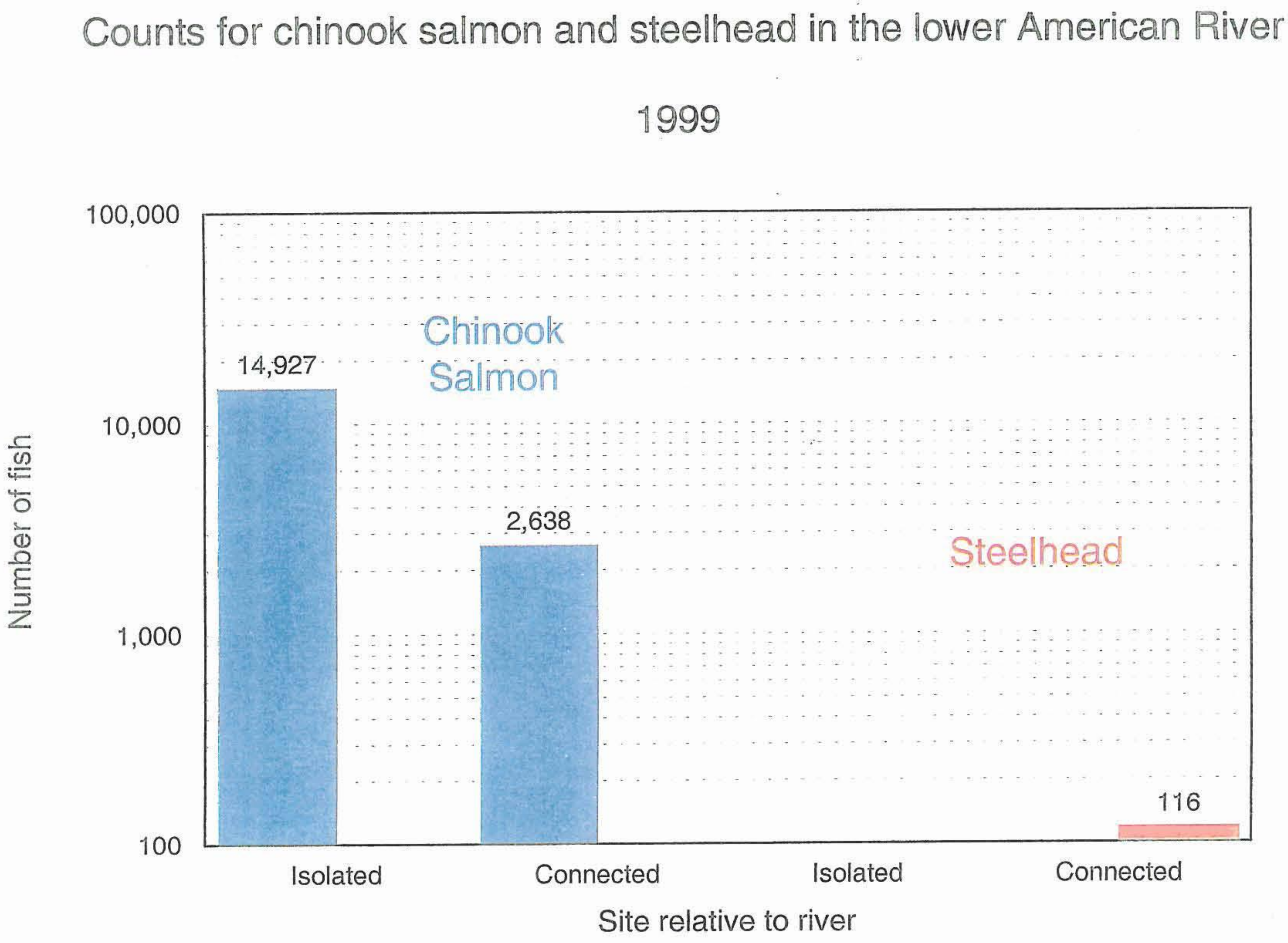


Figure 29. Total number of individual sample sites connected to or isolated from the main channel of the lower American River surveyed in 1999 during the lower American River flow fluctuation study, 1997- 2000.



Counts for chinook salmon and steelhead in the lower American River

1999

Figure 30. Total catch distribution of chinook salmon and steelhead collected in 1999 during the lower American River flow fluctuation study, 1997 - 2000.

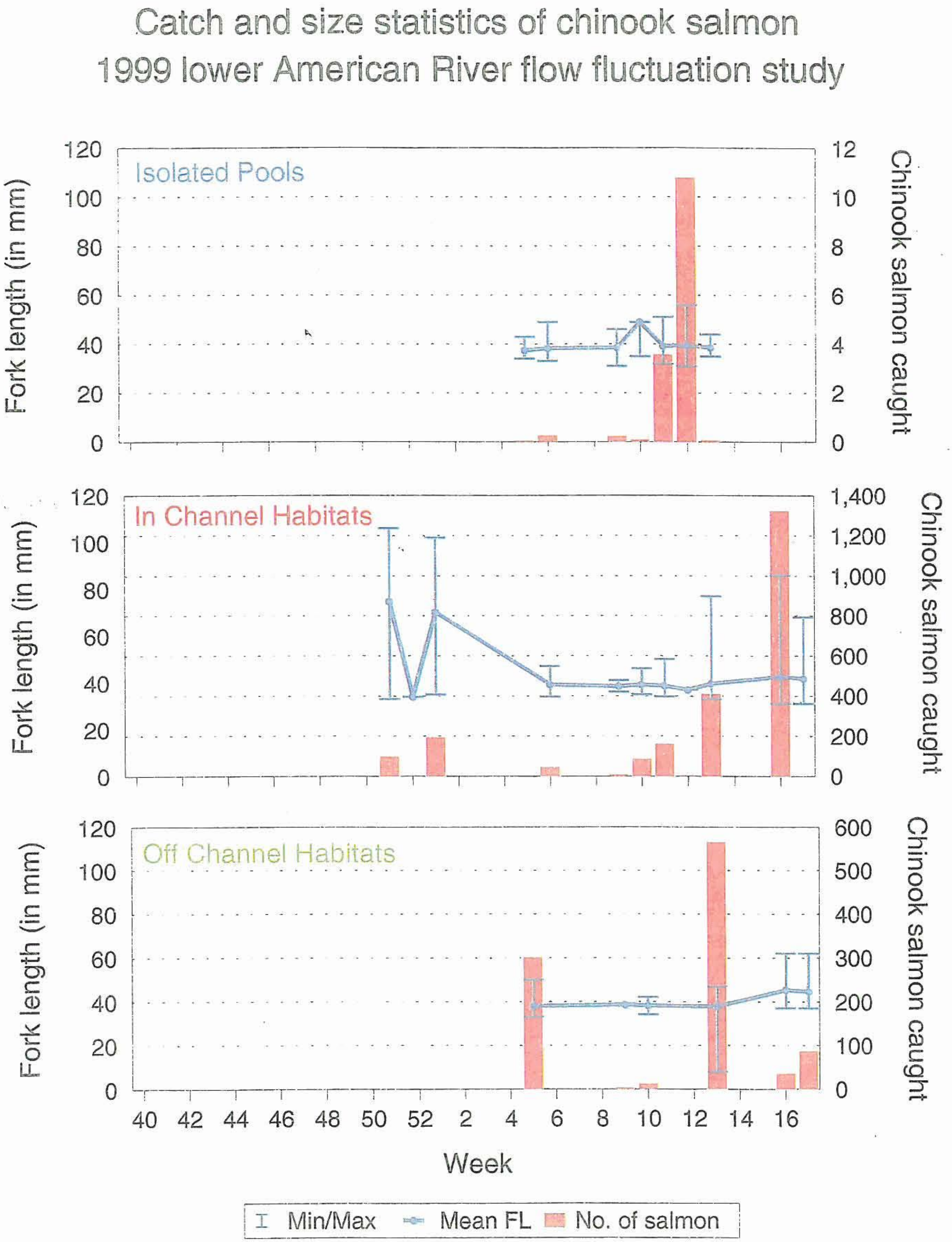


Figure 31. Total number and size (mean and range) of chinook salmon caught during the lower American River flow fluctuation study, 13 December 1998 - 22 March 1999.

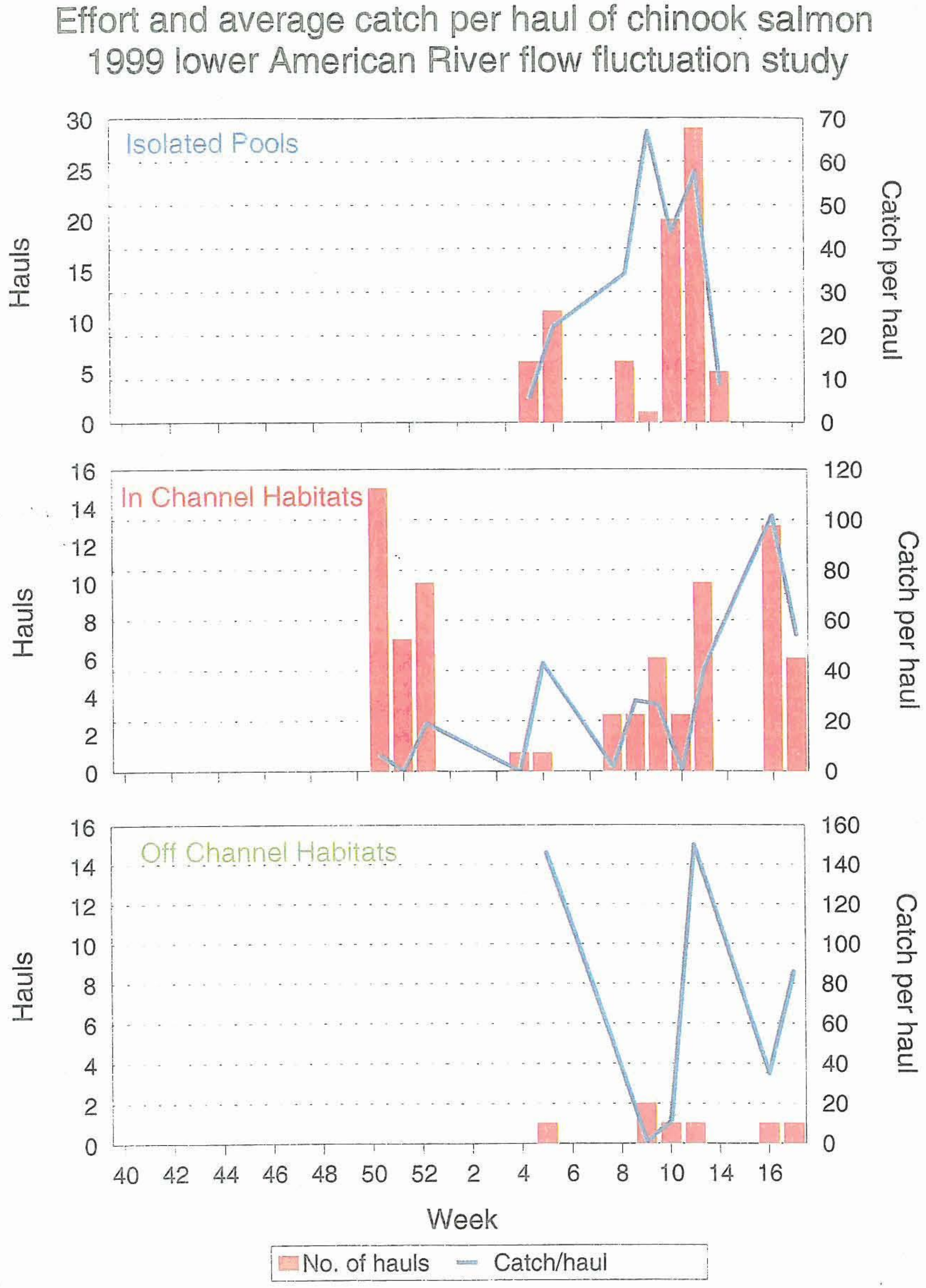


Figure 32. Effort (seine hauls) and catch per haul of chinook salmon collected during the lower American River flow fluctuation study, 13 December 1998 - 22 March 1999.

Catch and size statistics of steelhead
1999 lower American River flow fluctuation study

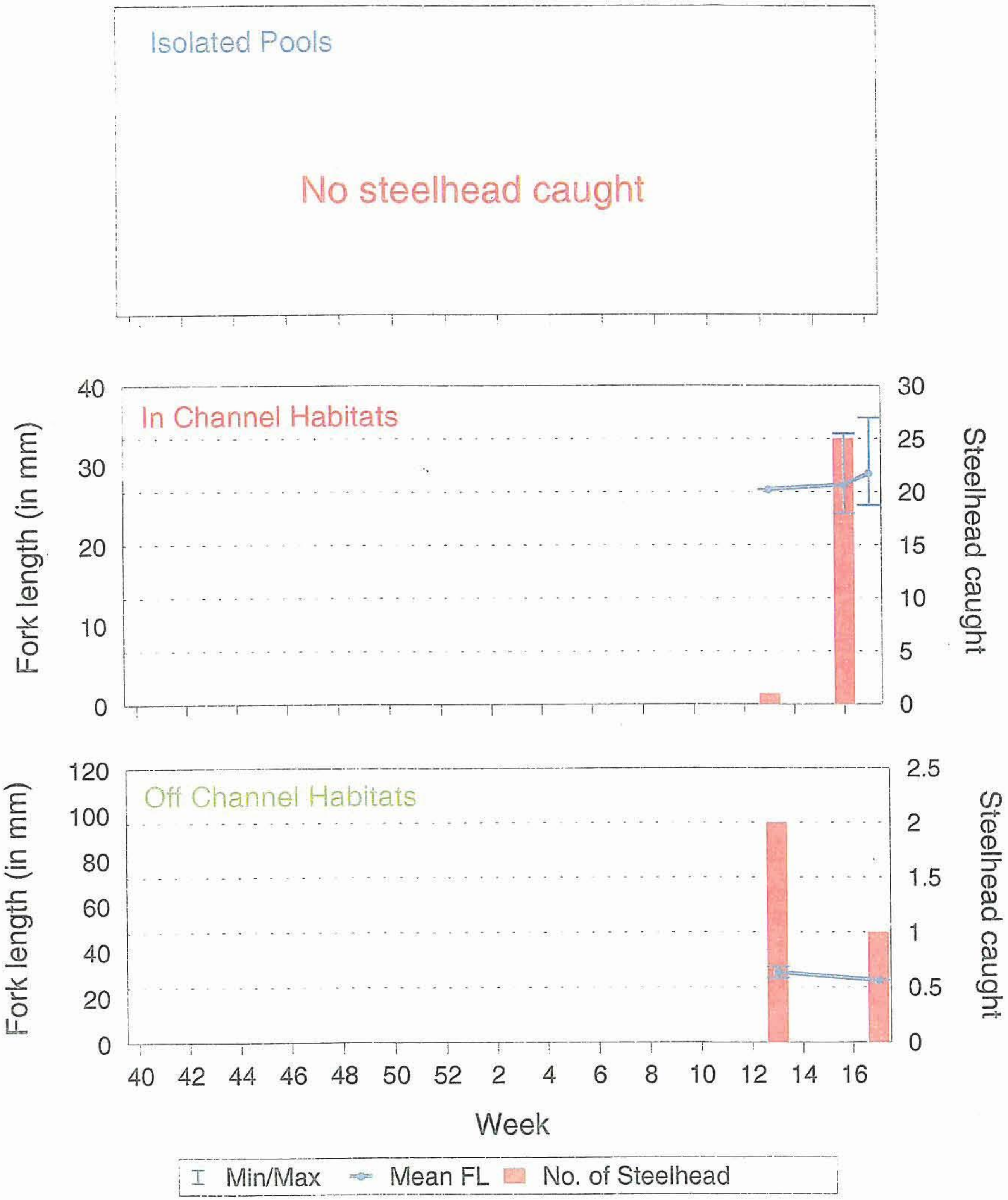
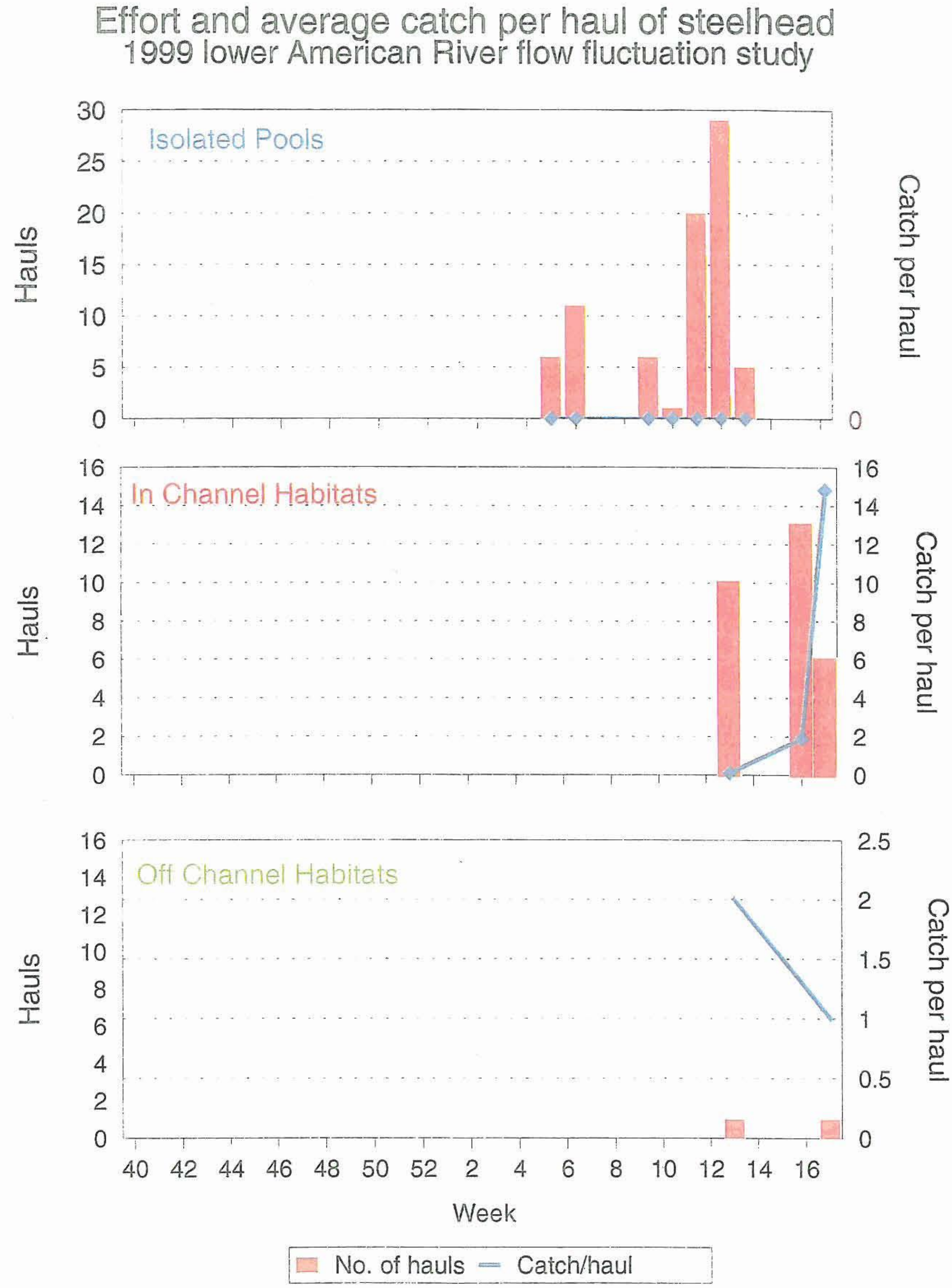


Figure 33. Total number and size (mean and range) of steelhead caught during the lower American River flow fluctuation study, 13December 1998 - 22 March 1999.



Effort and average catch per haul of steelhead
1999 lower American River flow fluctuation study

Figure 34. Effort (seine hauls) and catch per haul of steelhead collected during the lower American River flow fluctuation study, 13 December 1998 - 22 March 1999.

Temporal distribution of chinook salmon spawning, 1991 - 1995

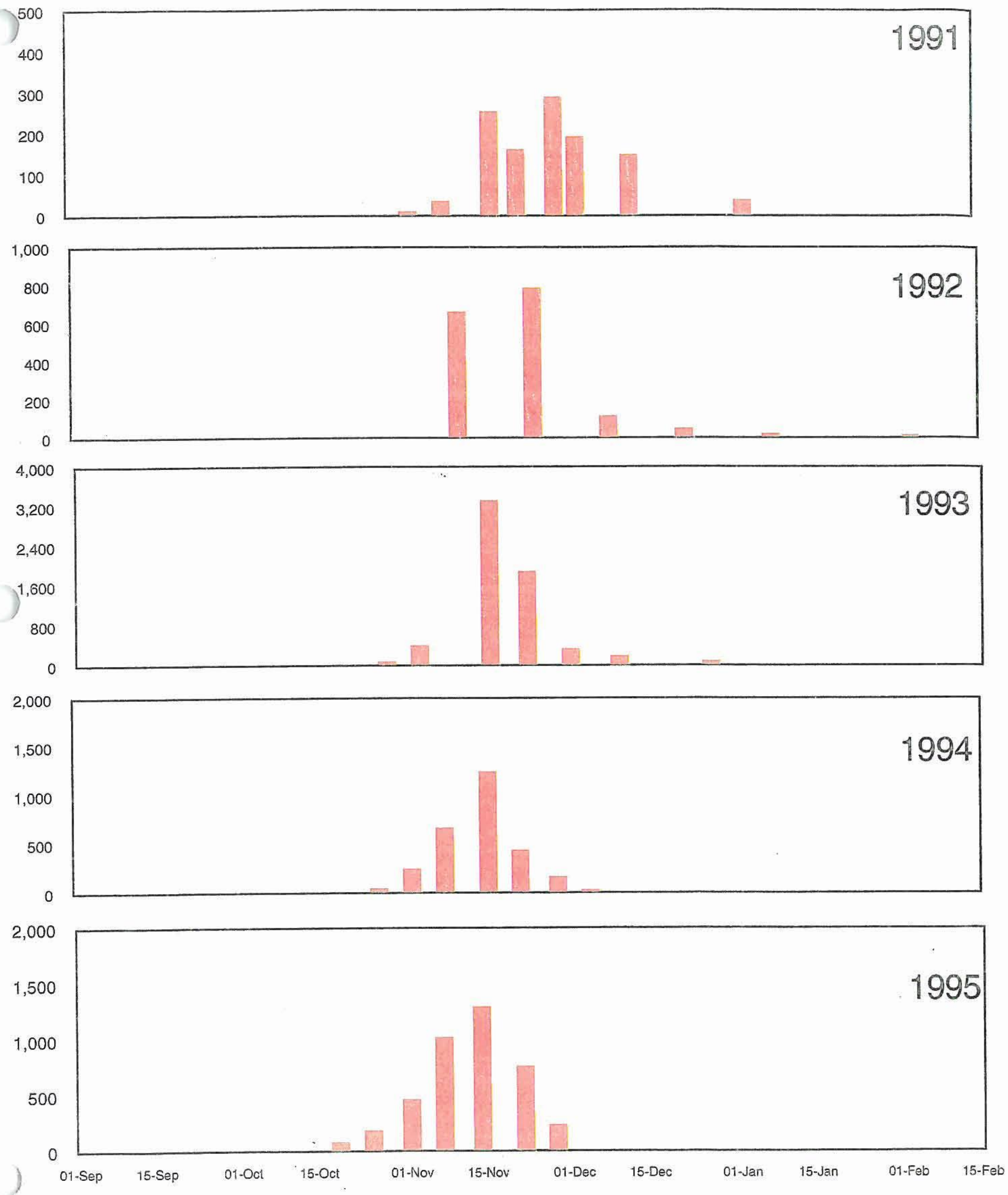


Figure 35. Temporal distribution of fall-run chinook salmon spawning observed on the lower American River from 1991 to 1995.

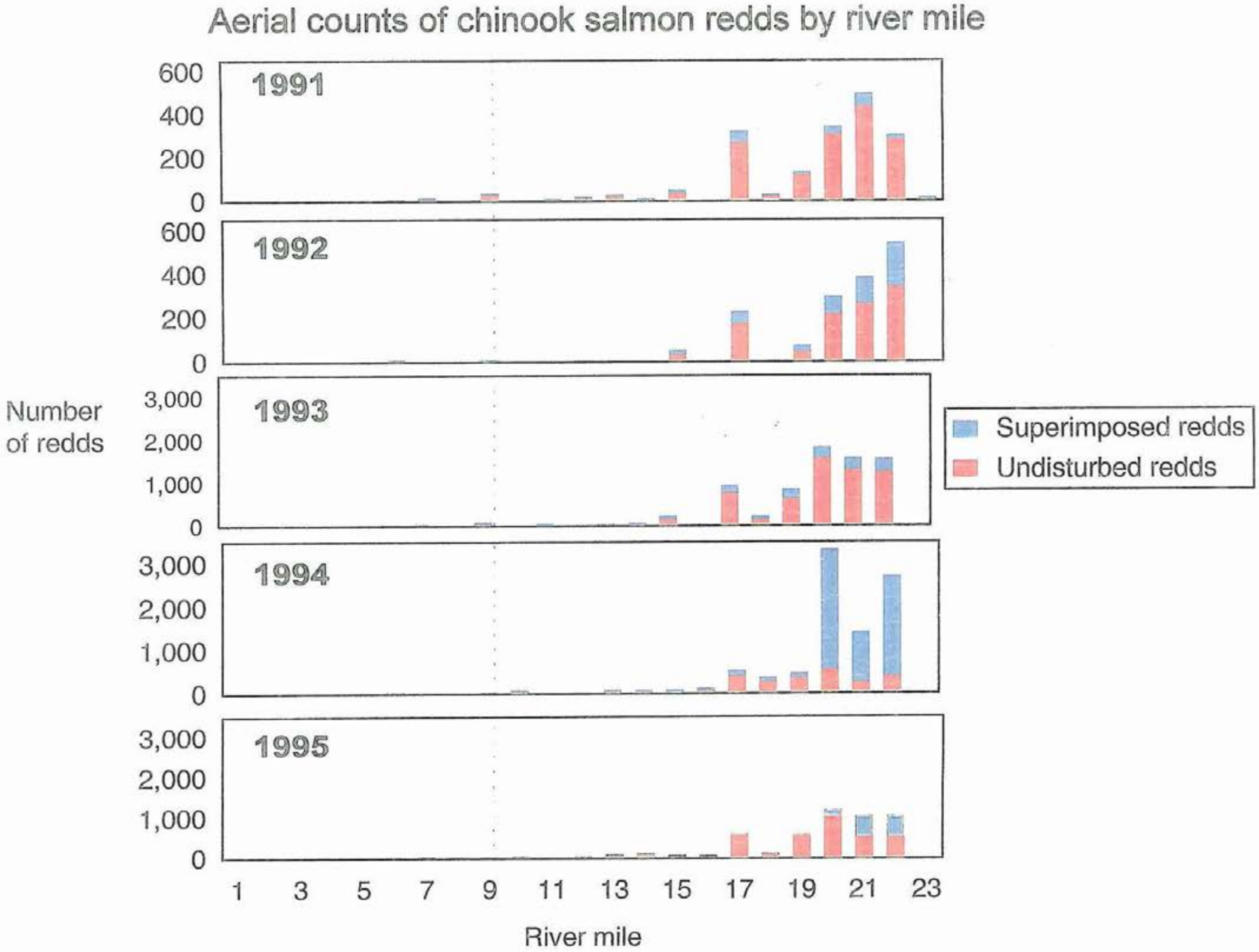


Figure 36. Spatial distribution of chinook salmon spawning observed in the lower American River during aerial redd photographic surveys conducted from 1991 through 1995.

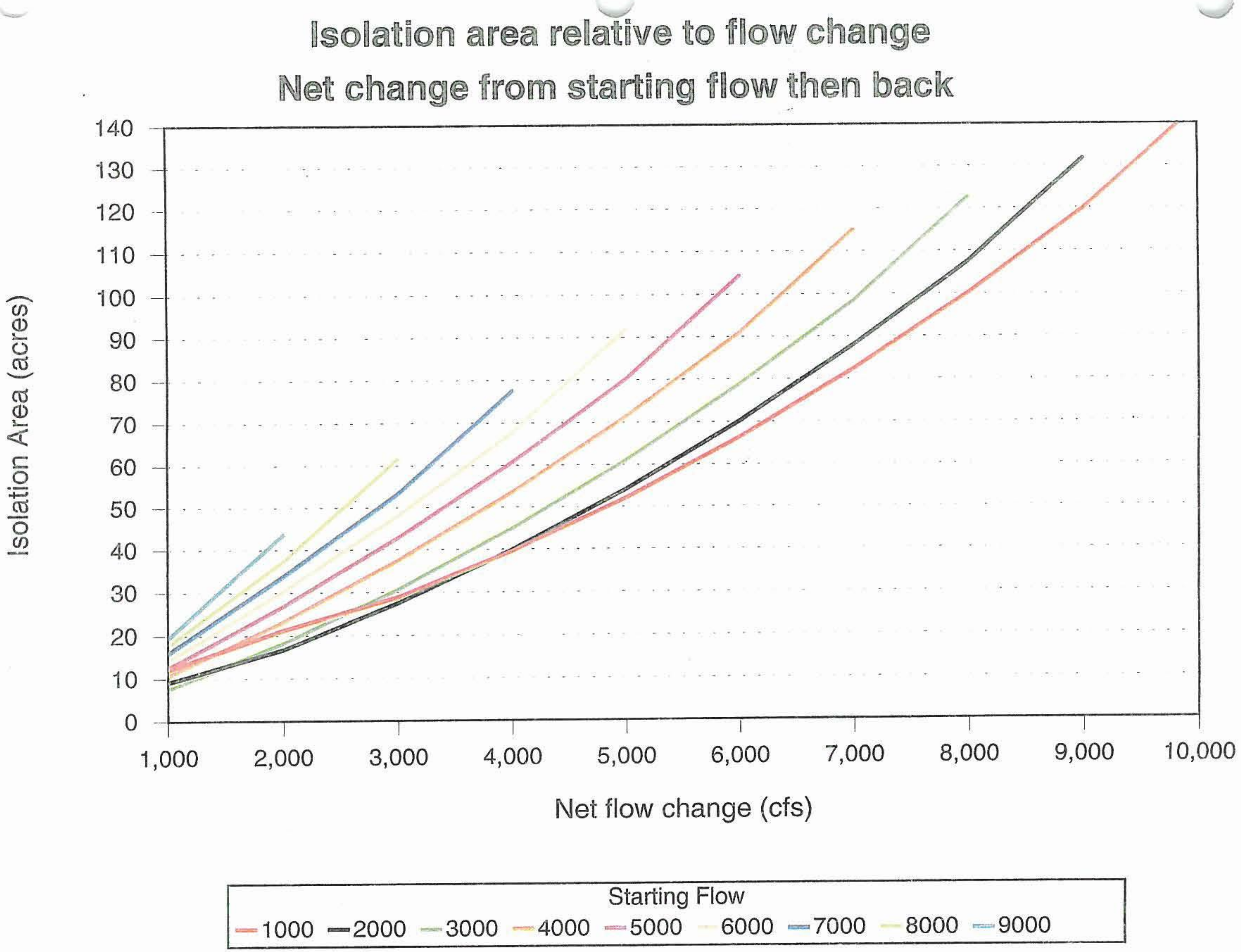


Figure 37. Incremental change in area of isolation associated with net change in flow for flows ranging from 1,000 to 10,000 cfs in the lower American River.

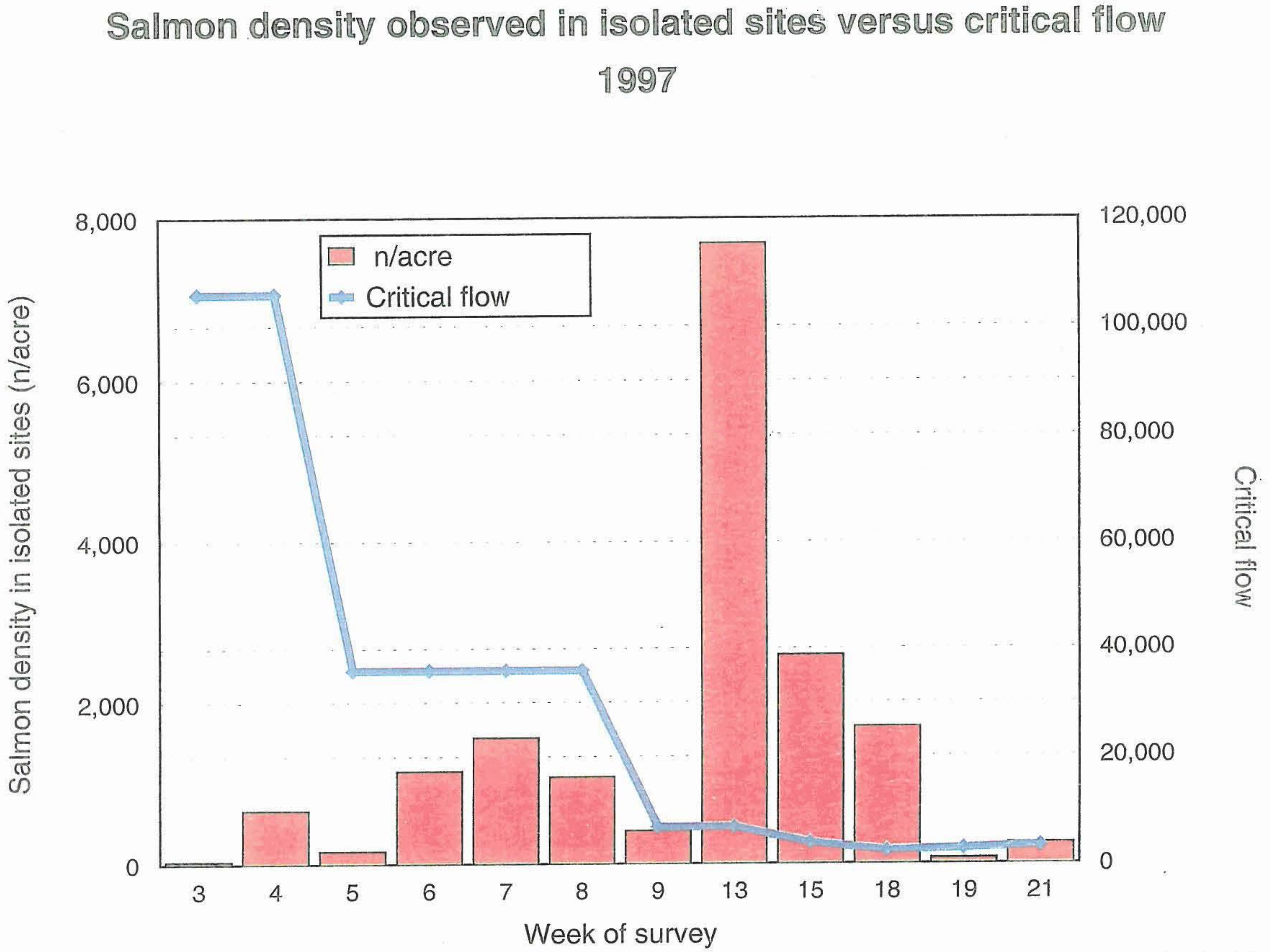


Figure 38. Salmon densities (n/acre) observed in isolated sites and critical flow preceding survey conducted in 1998 during the lower American River flow fluctuation investigation.

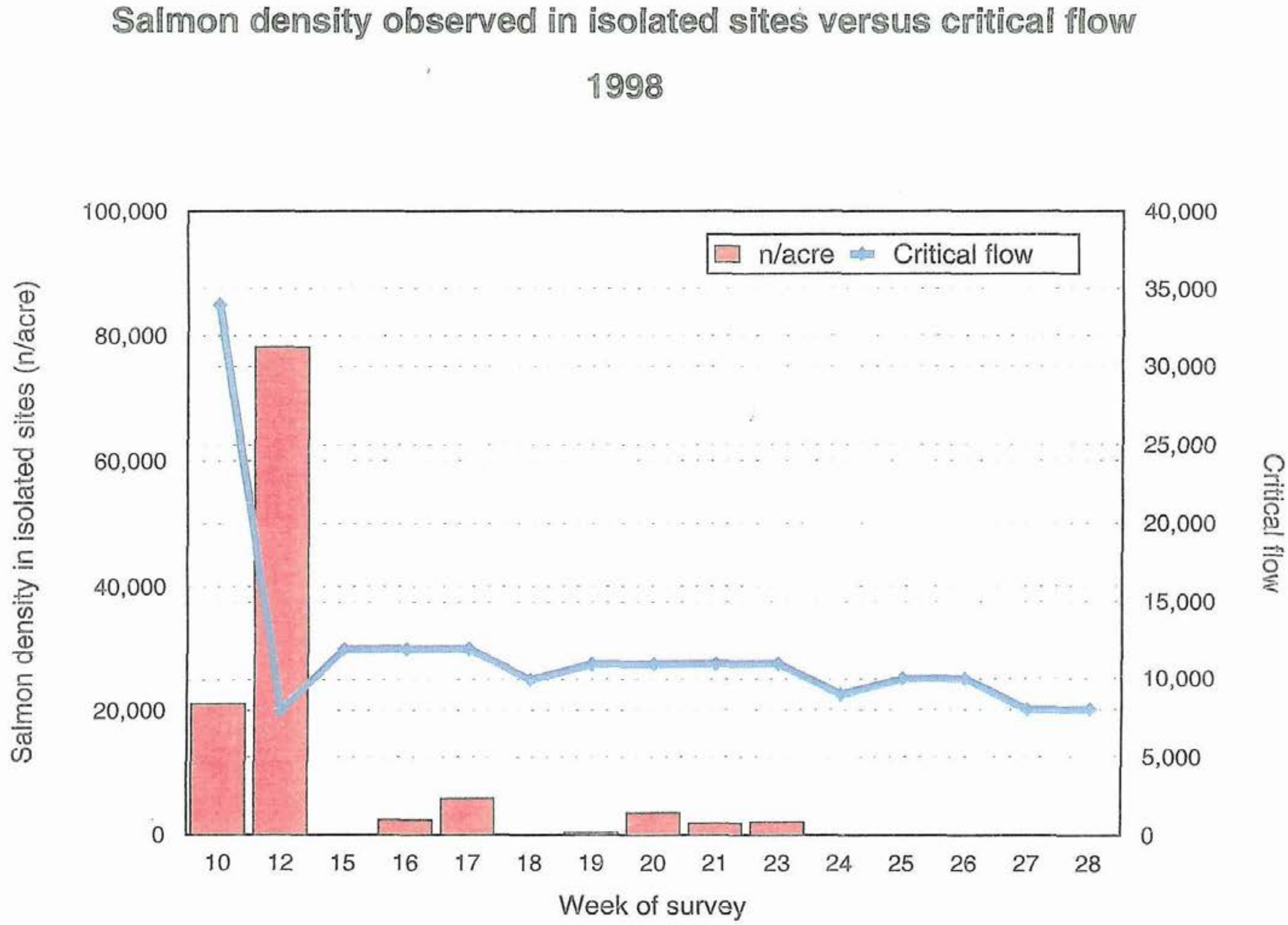


Figure 39. Salmon densities (n/acre) observed in isolated sites and critical flow preceding survey conducted in 1998 during the lower American River flow fluctuation investigation.

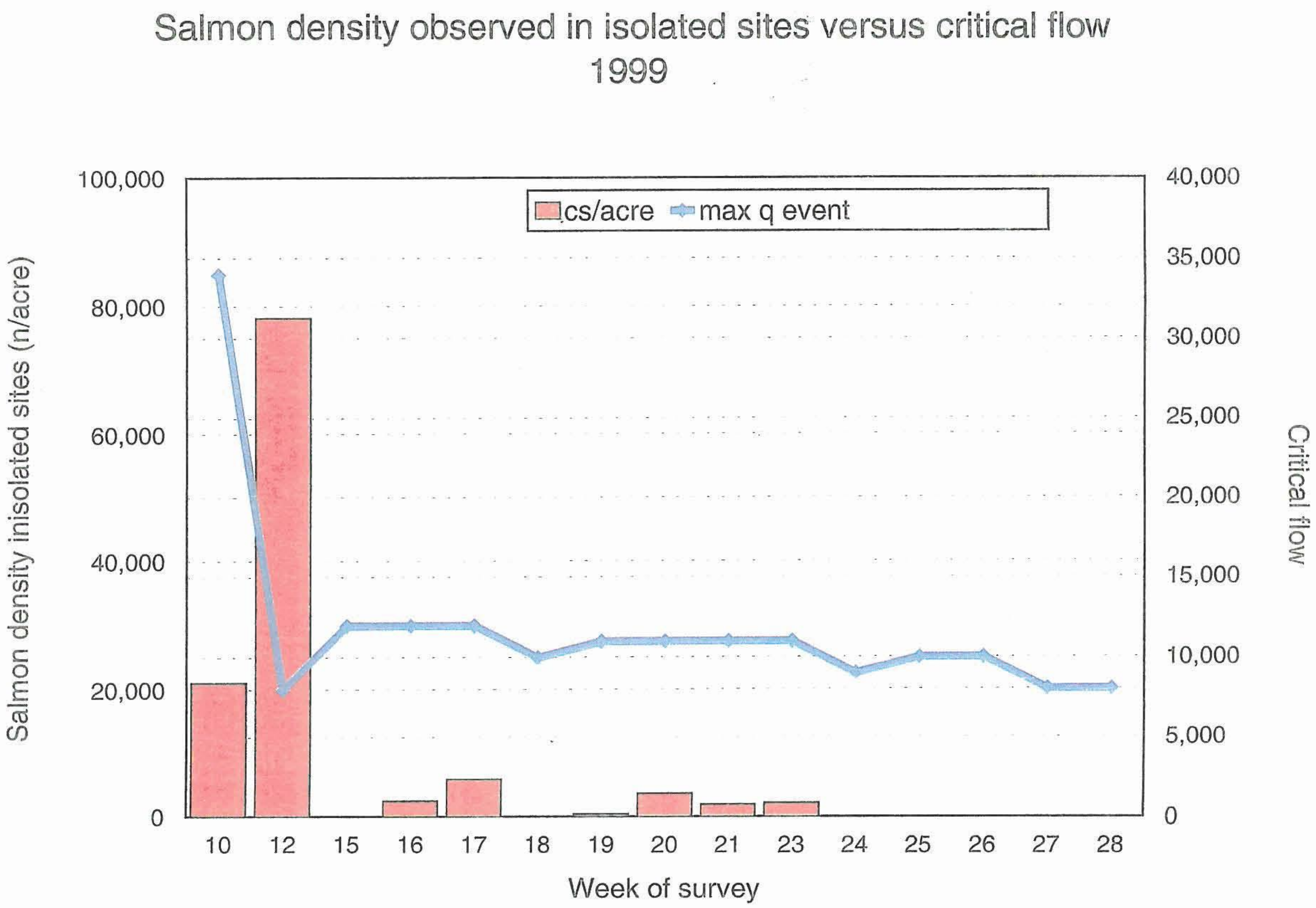


Figure 40. Salmon densities (n/acre) observed in isolated sites and critical flow preceding survey conducted in 1999 during the lower American River flow fluctuation investigation.

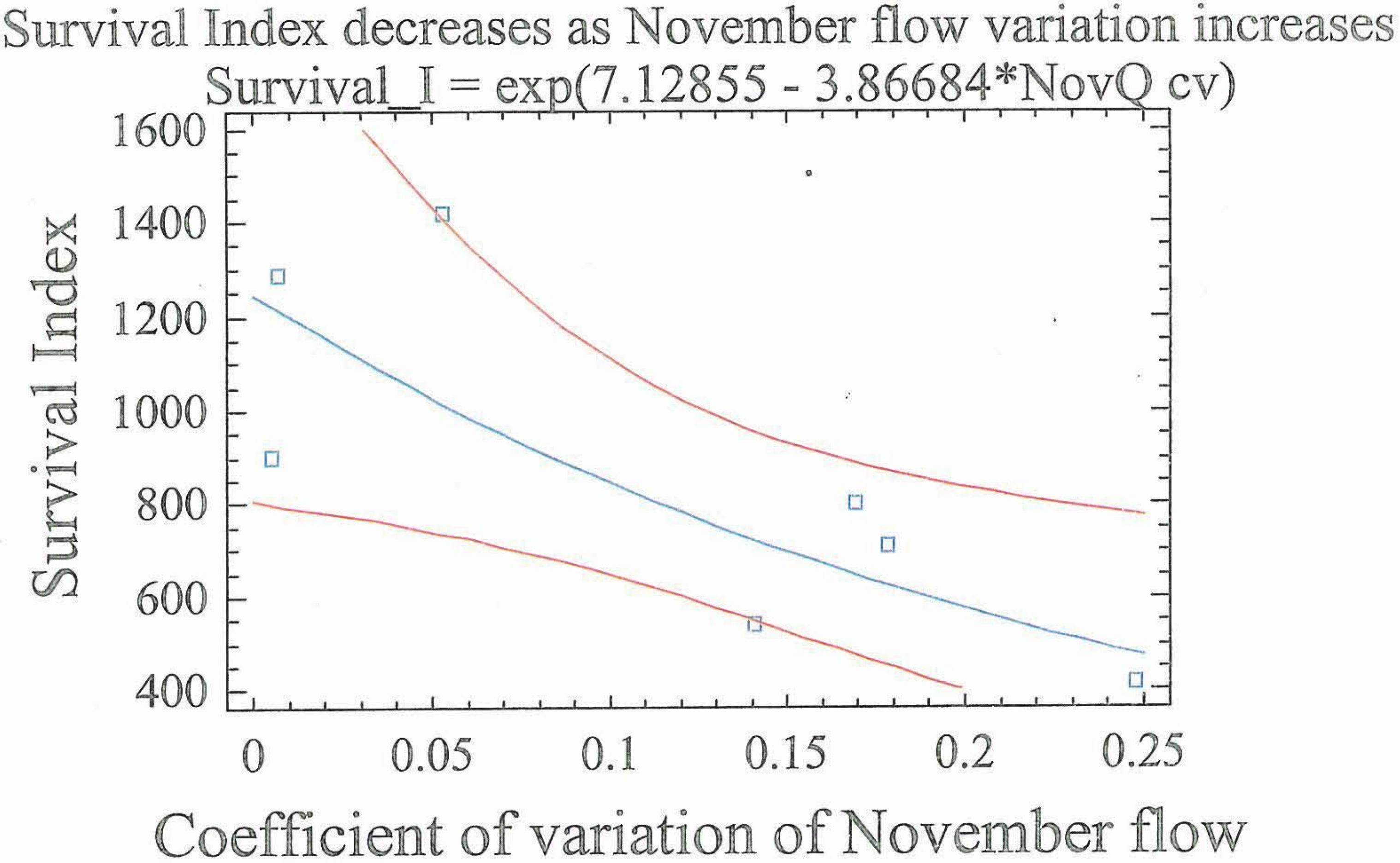


Figure 41. Relationship between chinook salmon survival index and coefficient of variation of November flows in the lower American River, 1994–2000.

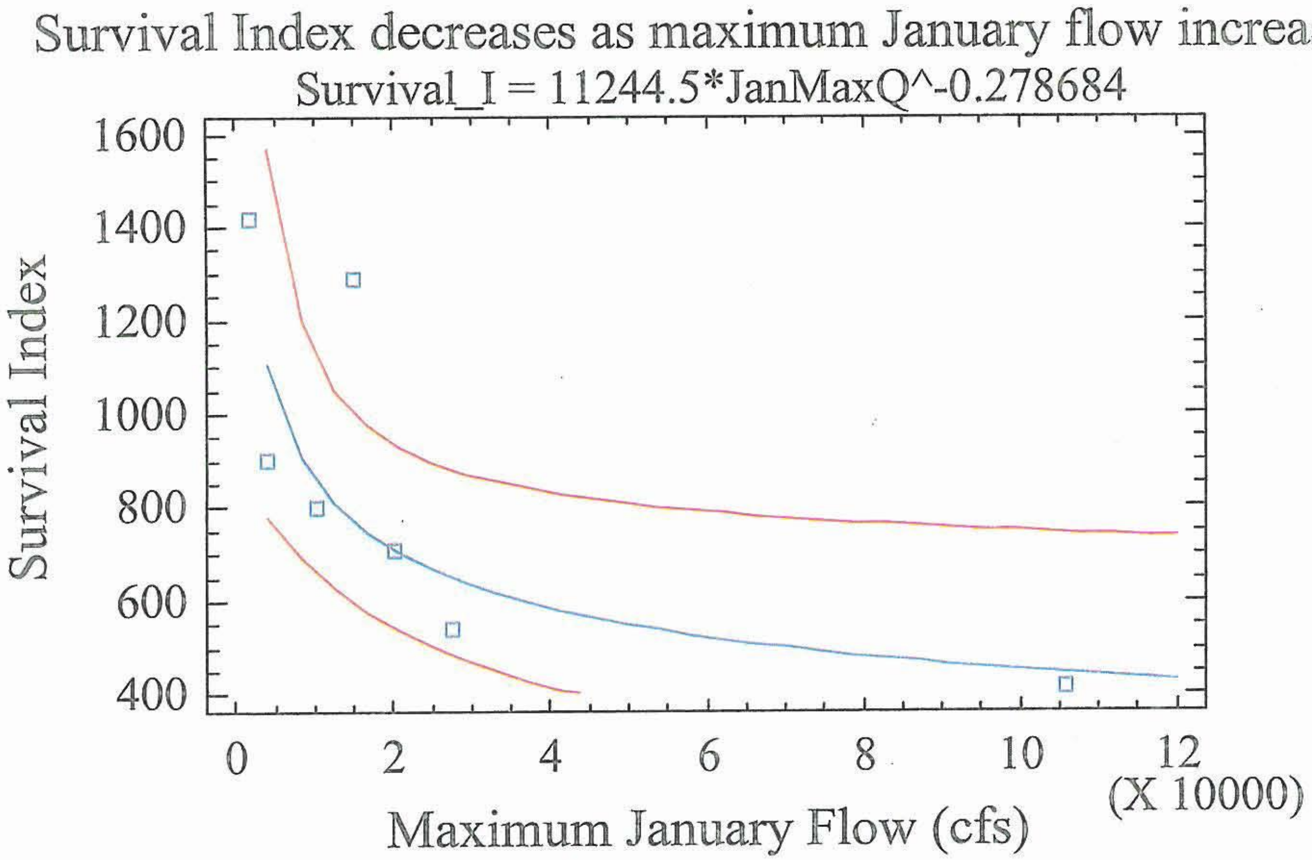


Figure 42. Relationship between chinook salmon survival index and maximum January flows in the lower American River, 1994–2000.

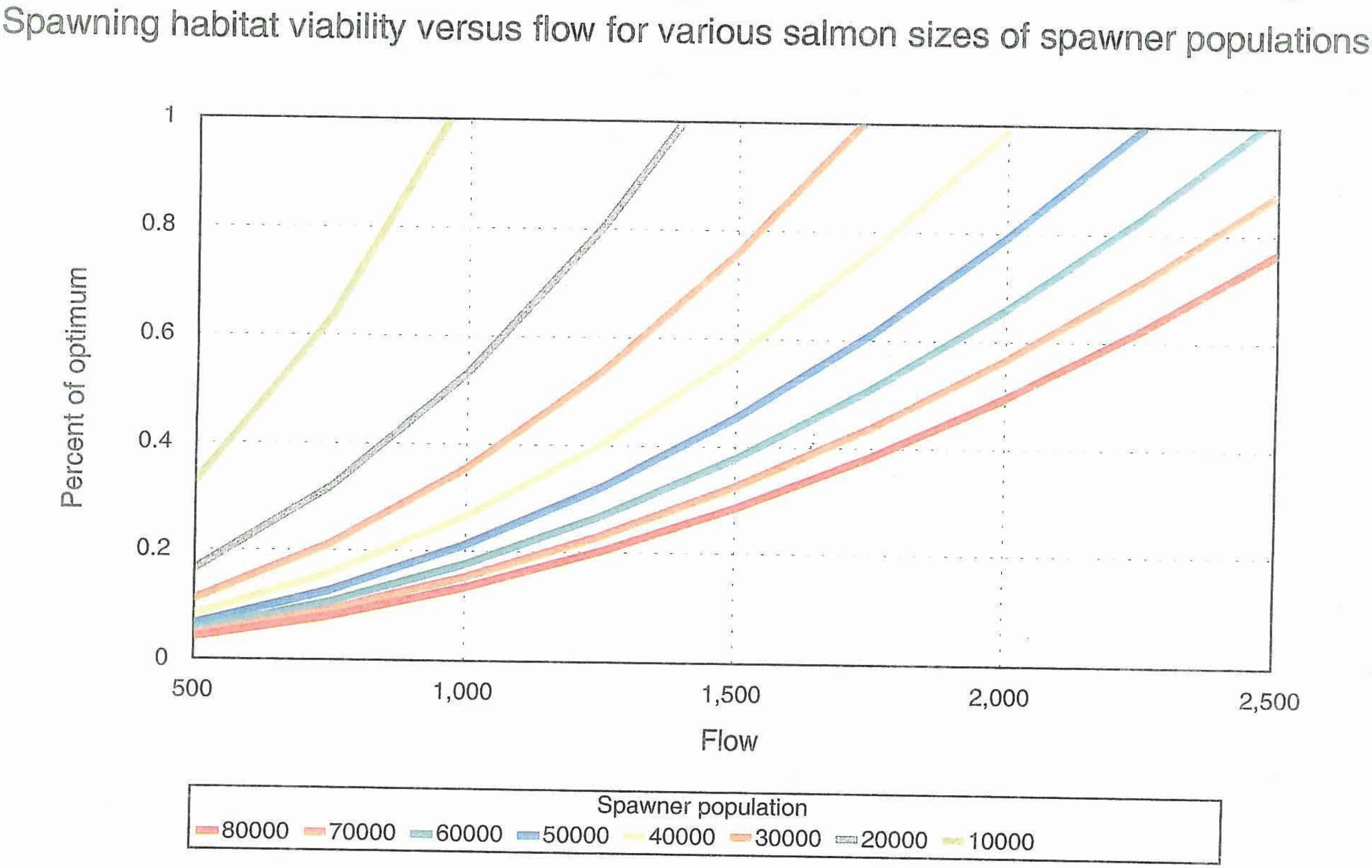
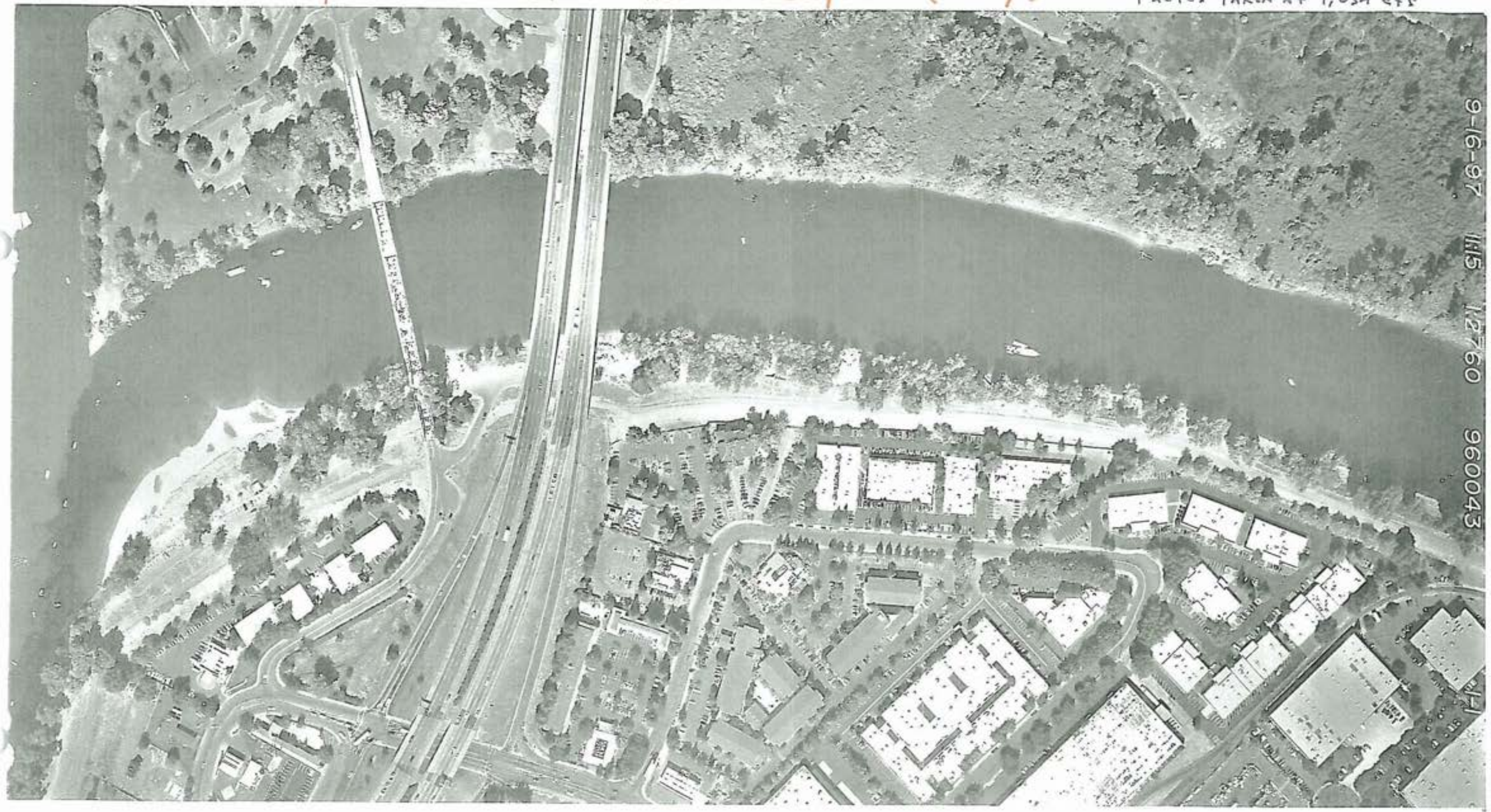
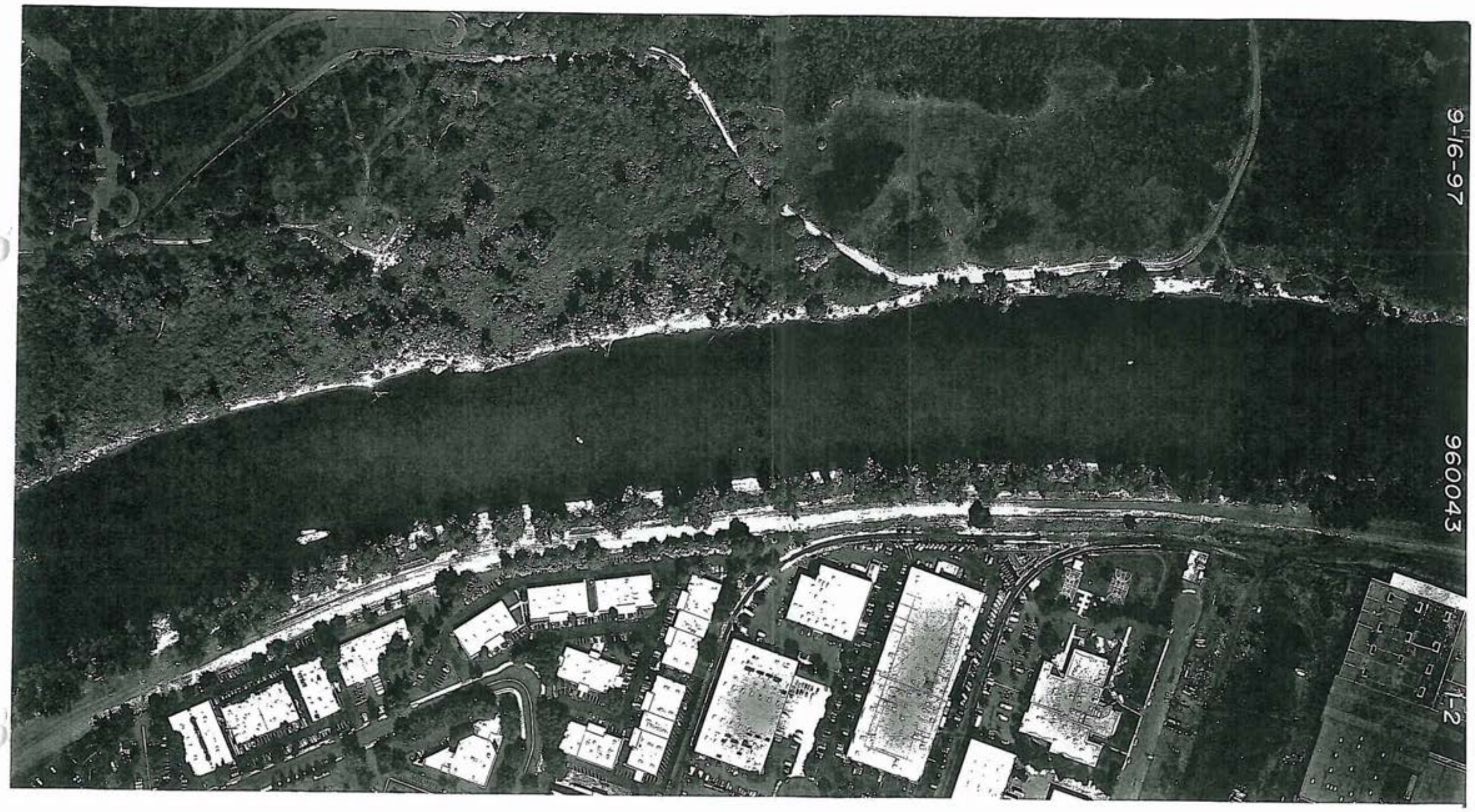


Figure 43. Relationship between percent of viable spawning habitat and flow relative to population size.

Chinook salmon spawning areas (purple)
steelhead spawning areas (green)
Isolation areas for rearing salmon and steelhead (red)
Redd stranding areas (orange)
Photos taken at 1,034 cfs

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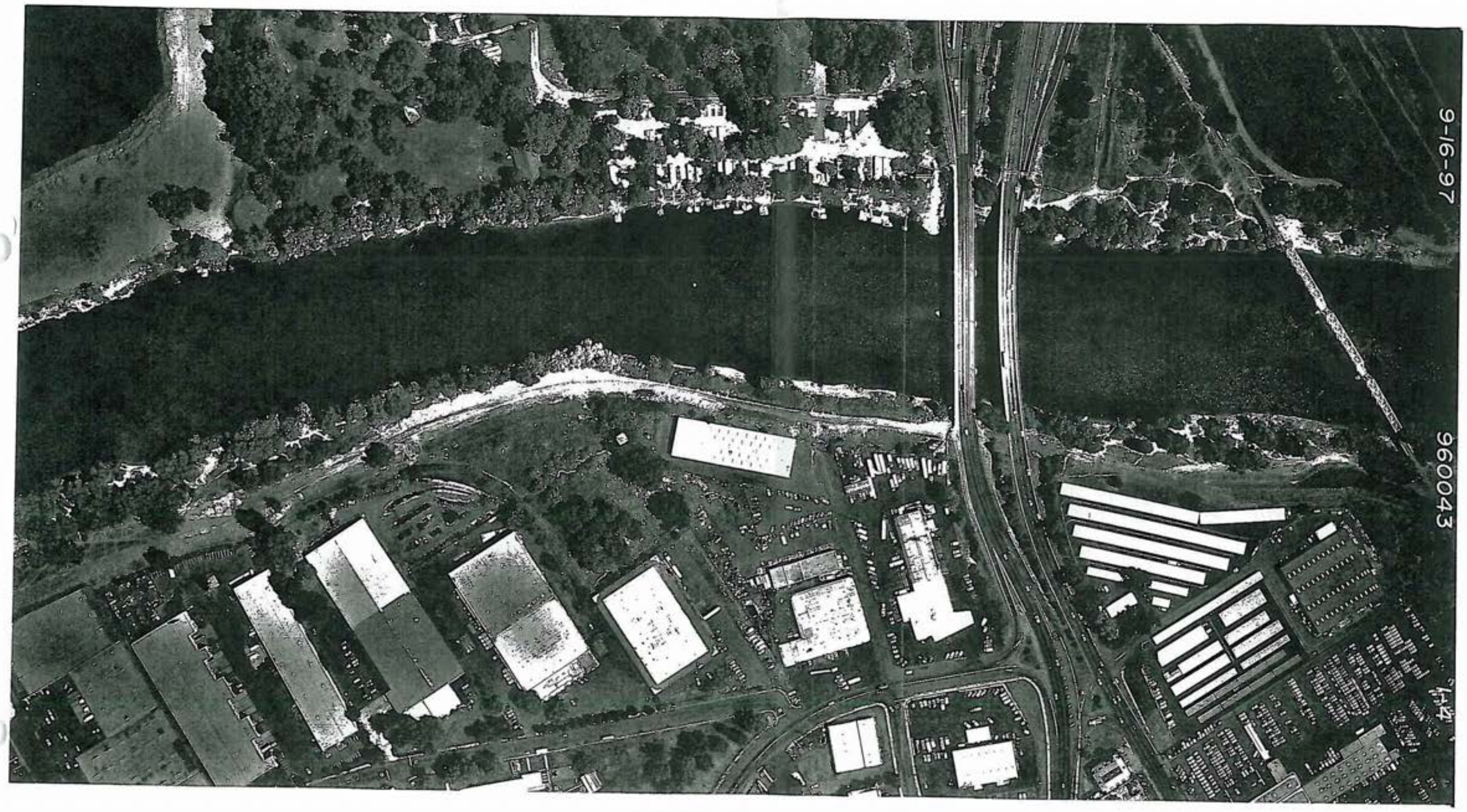
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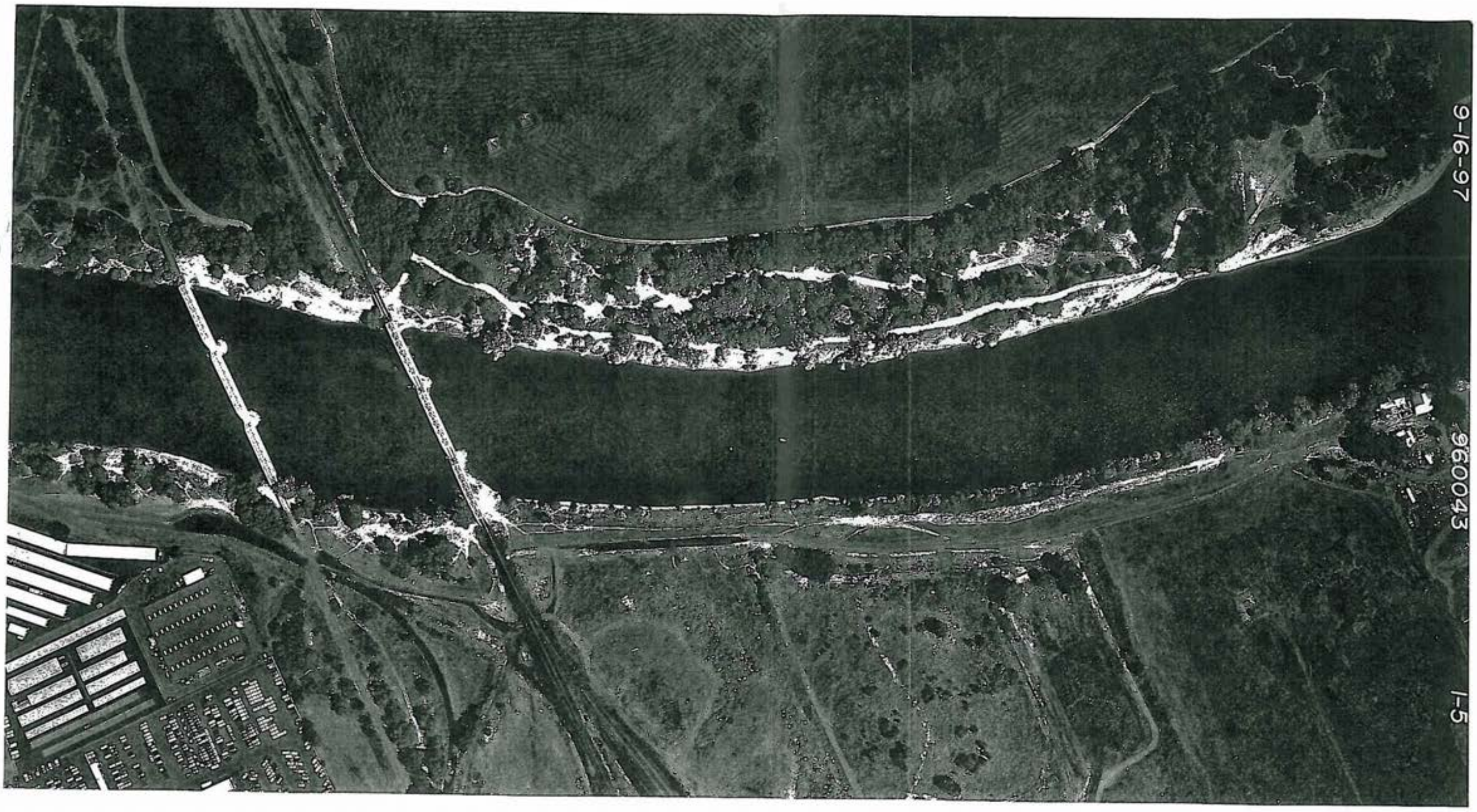
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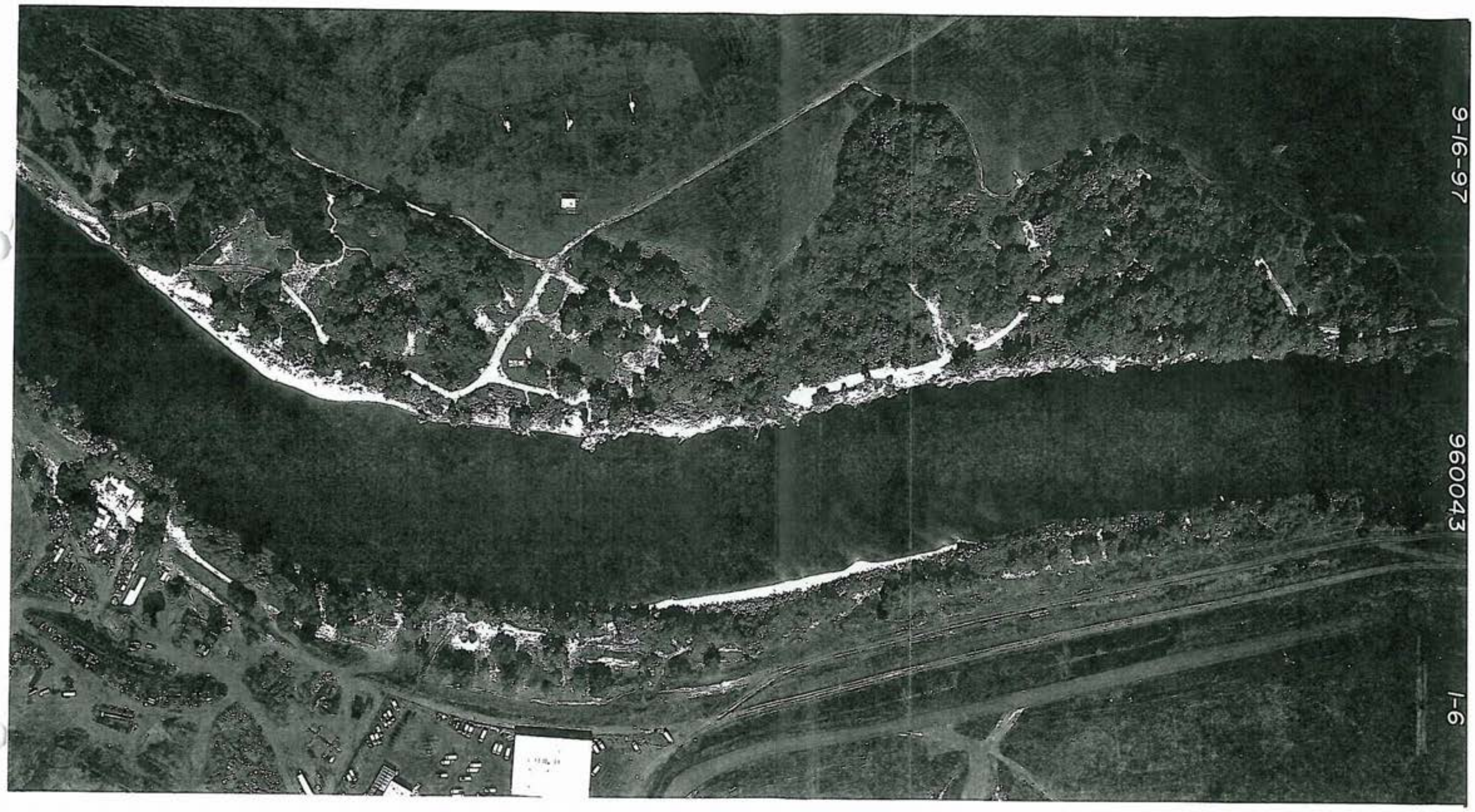
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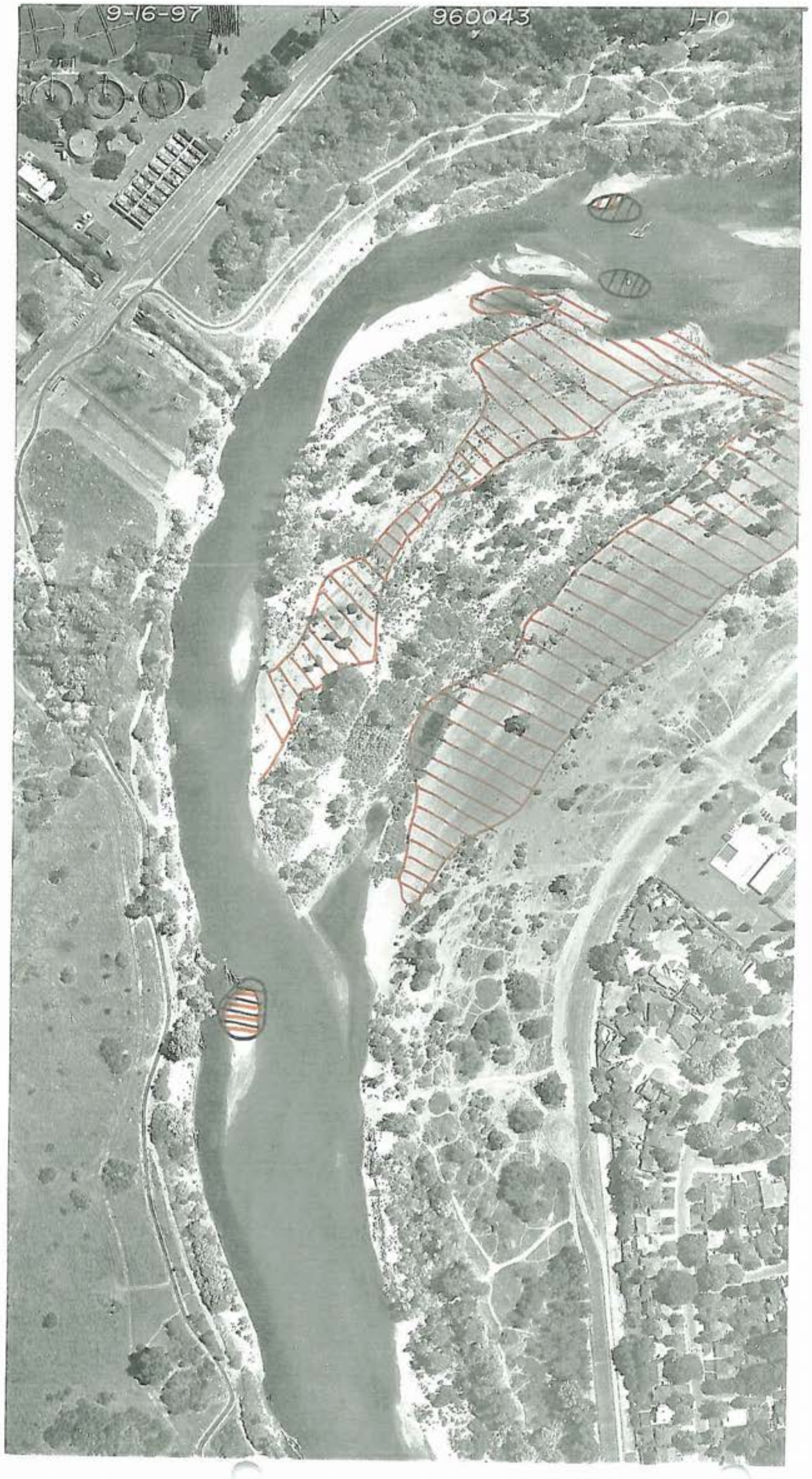
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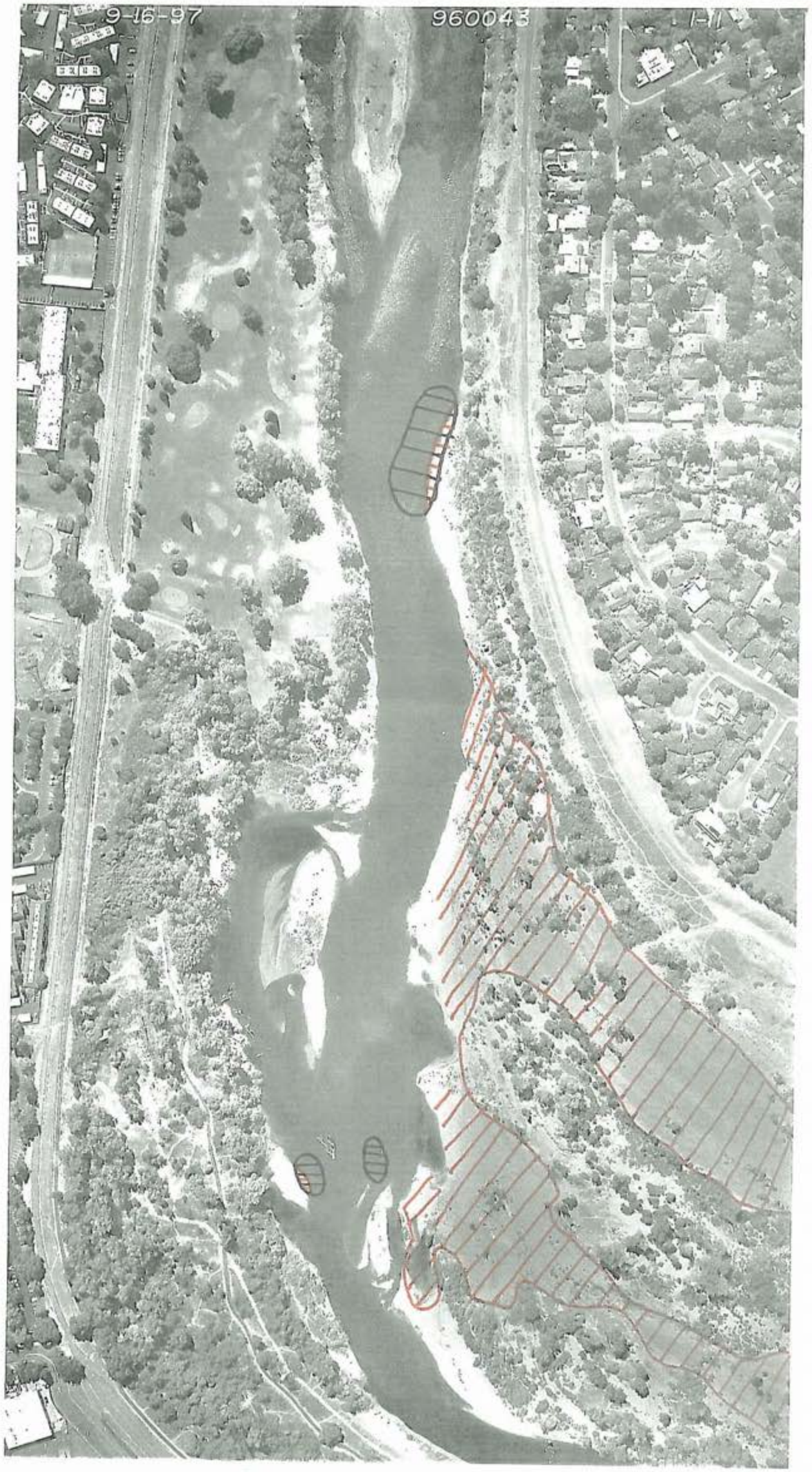
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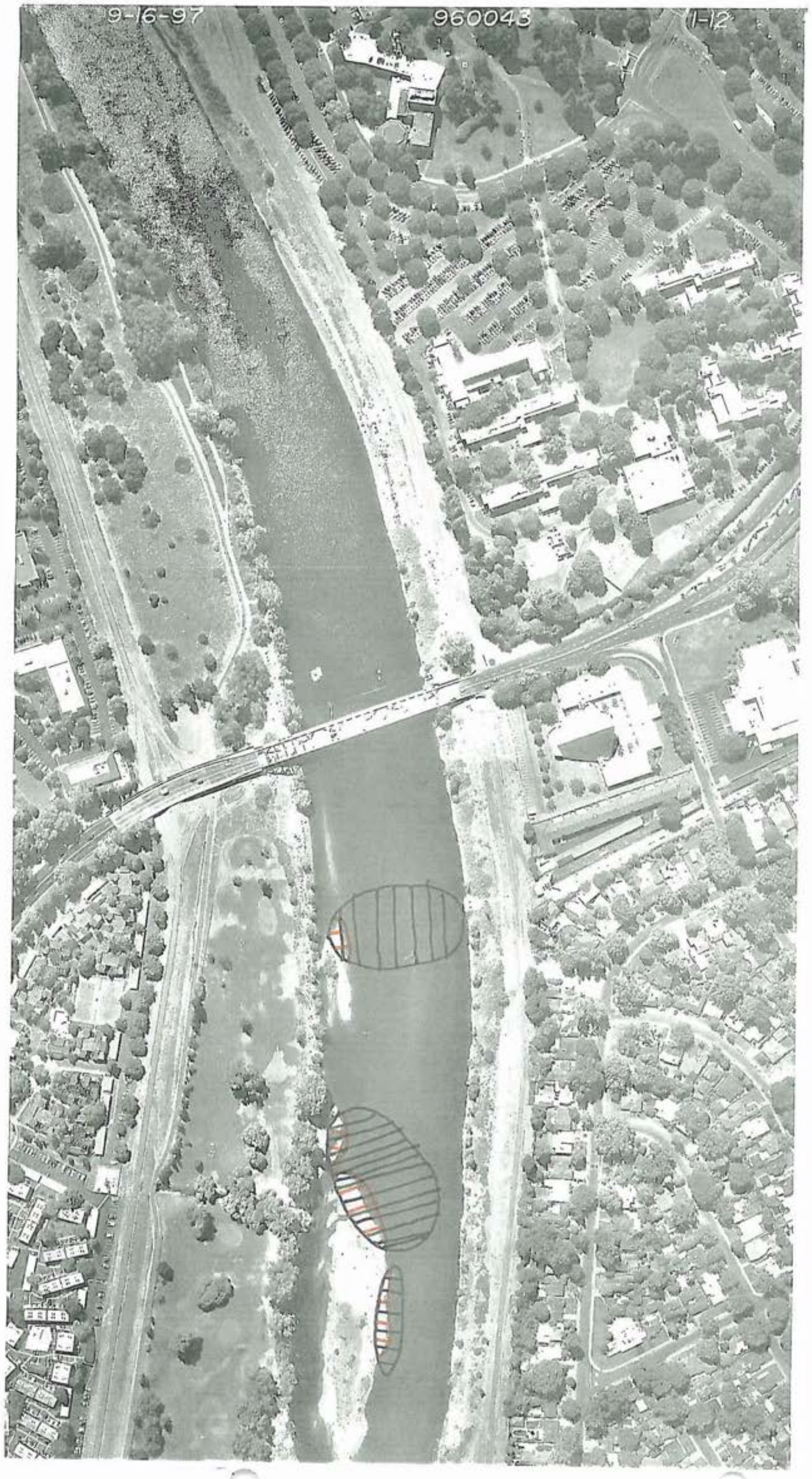
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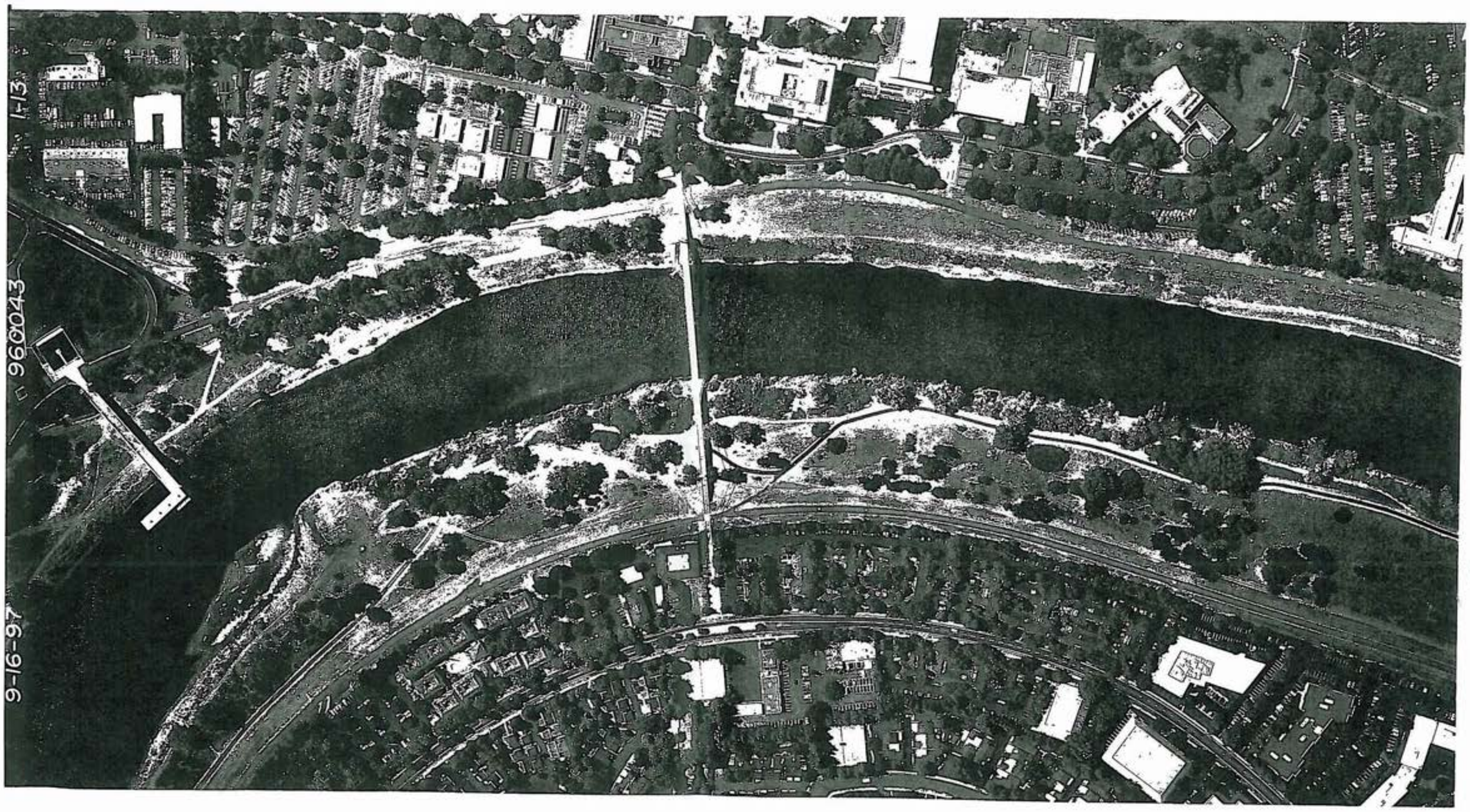
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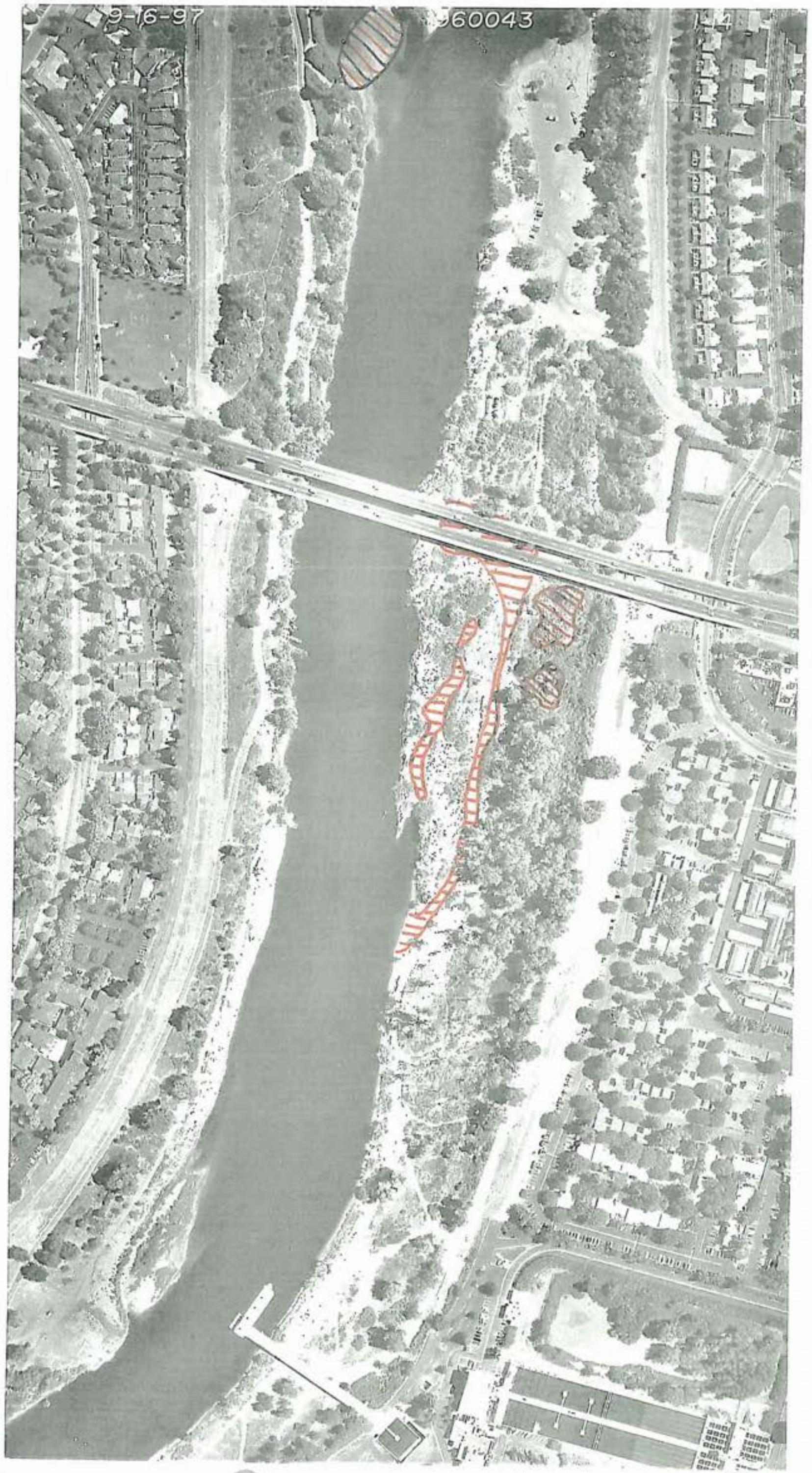
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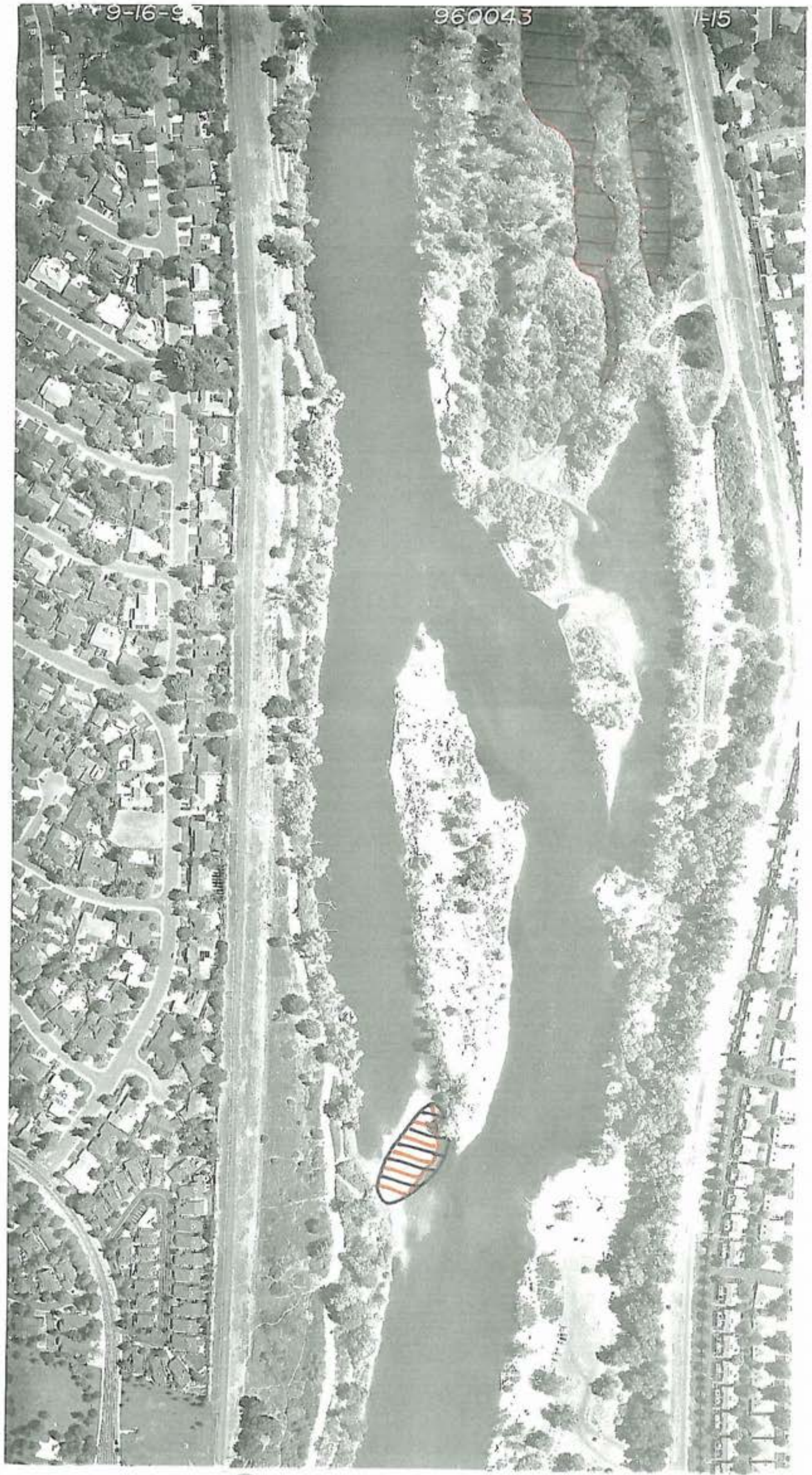
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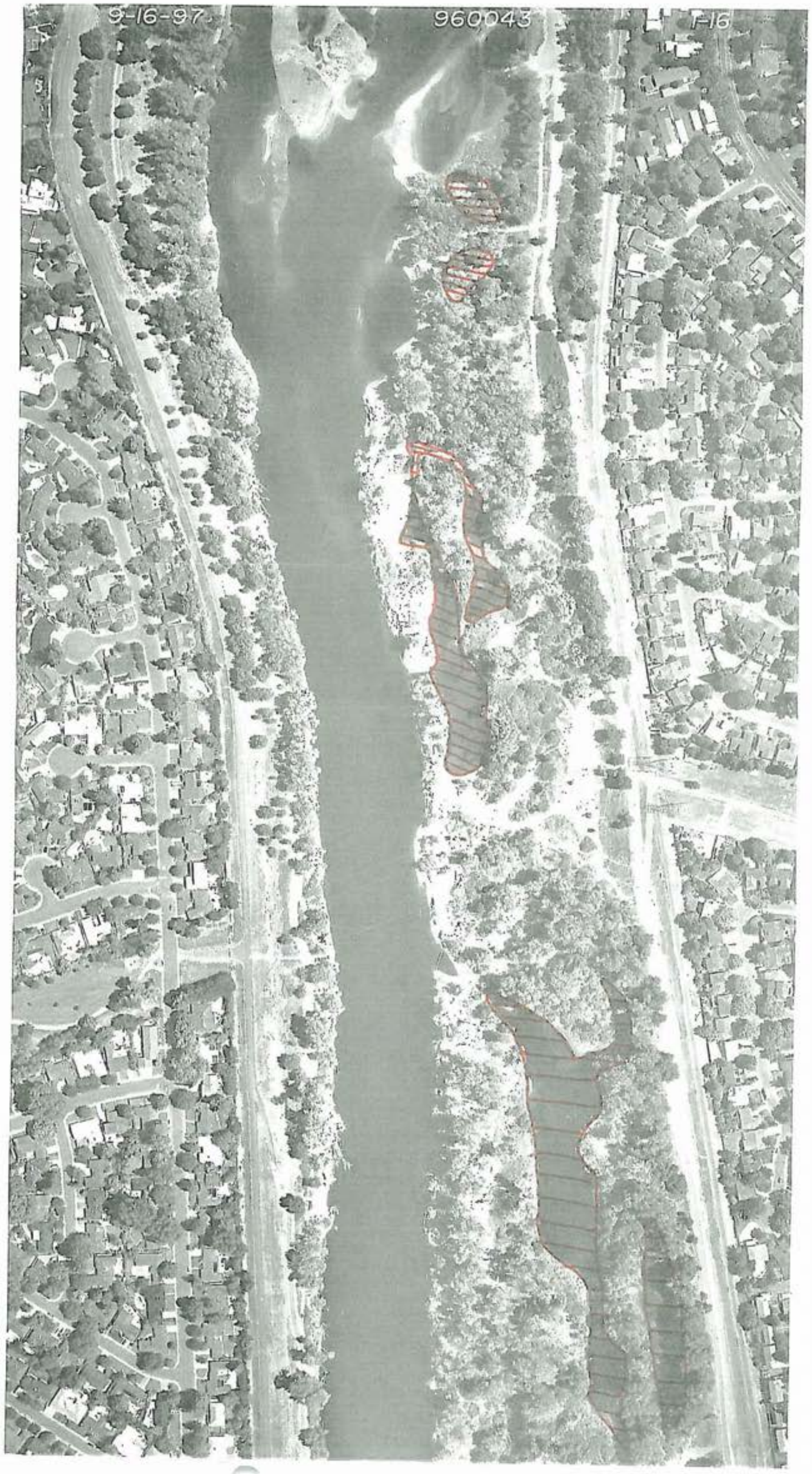
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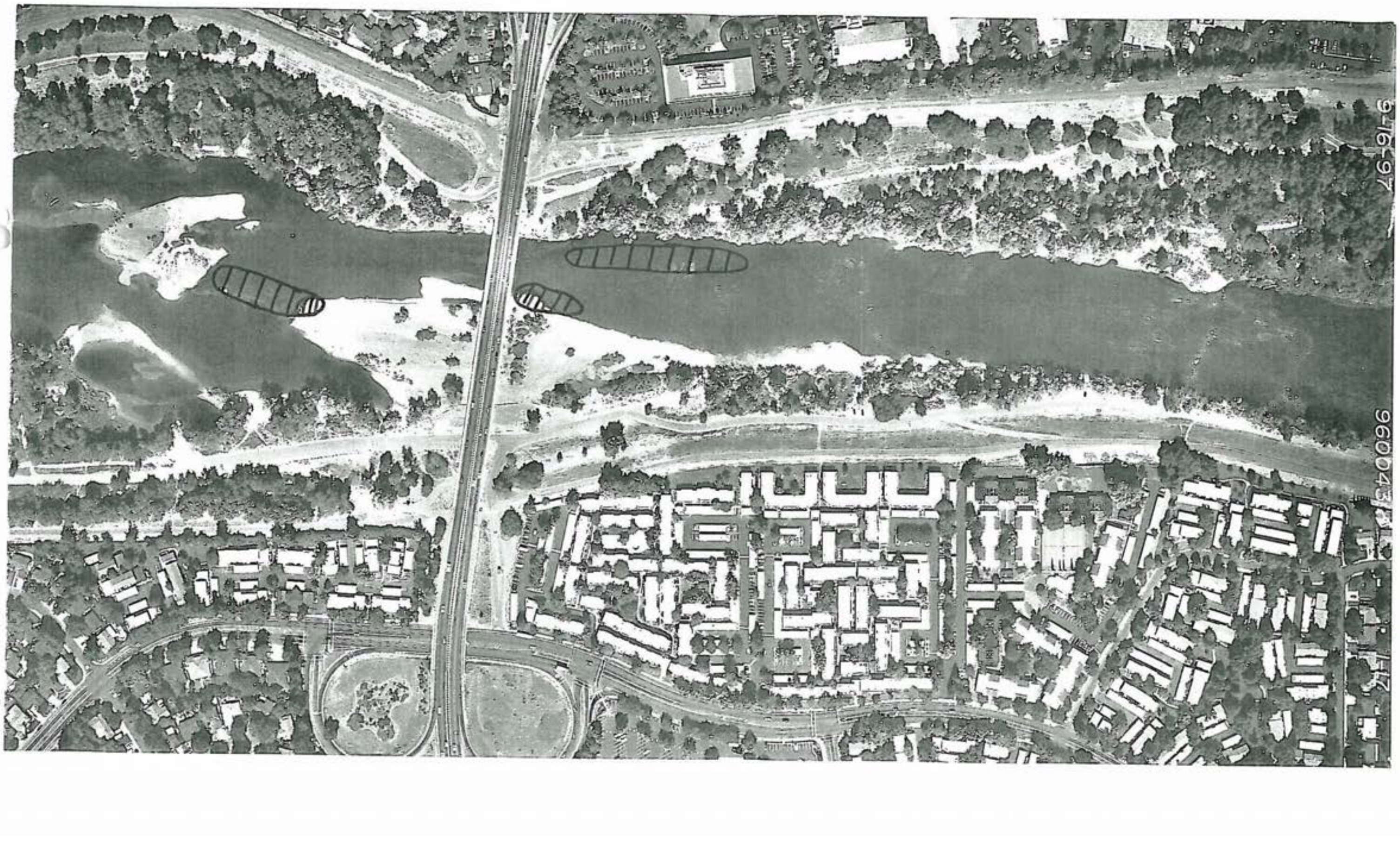
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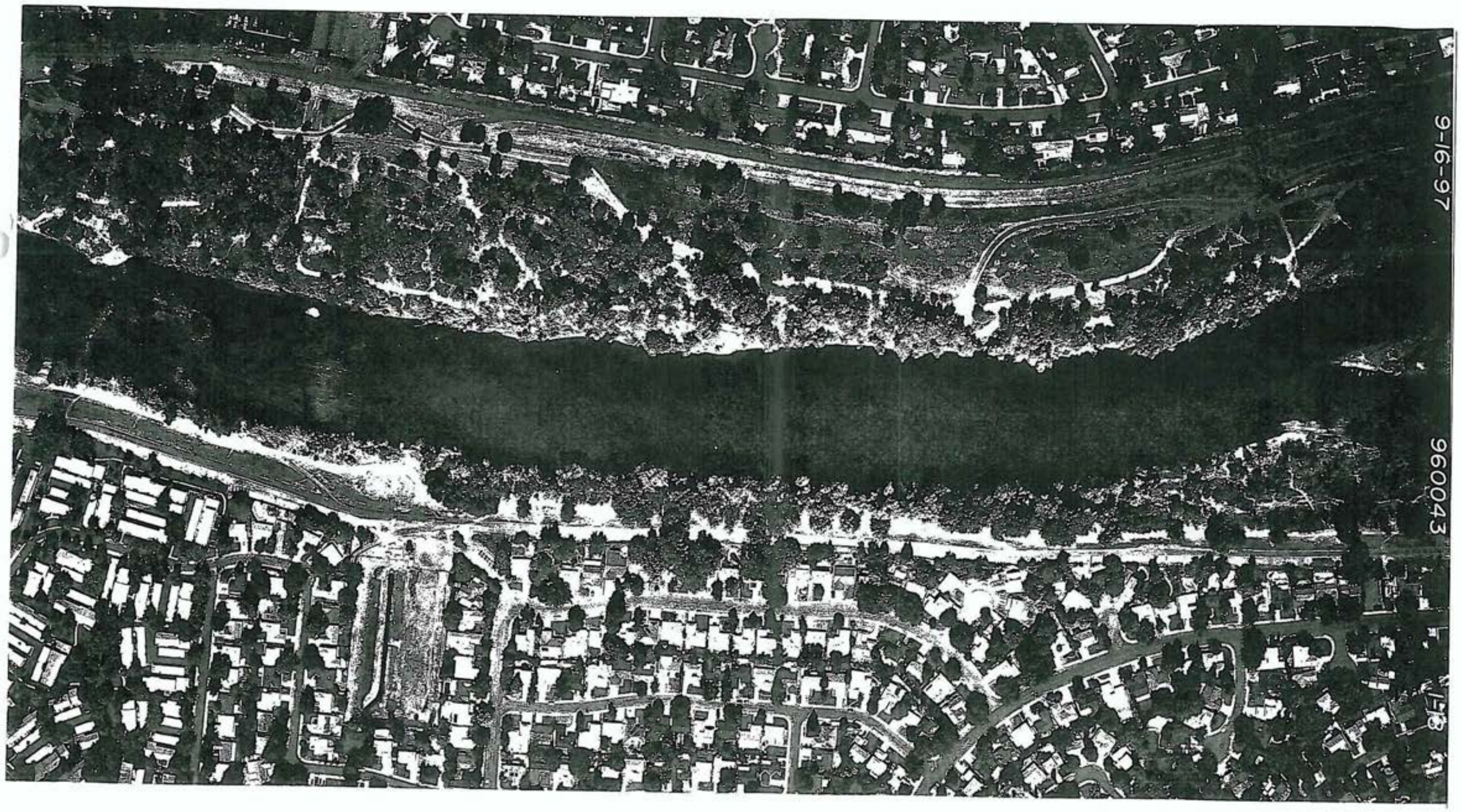
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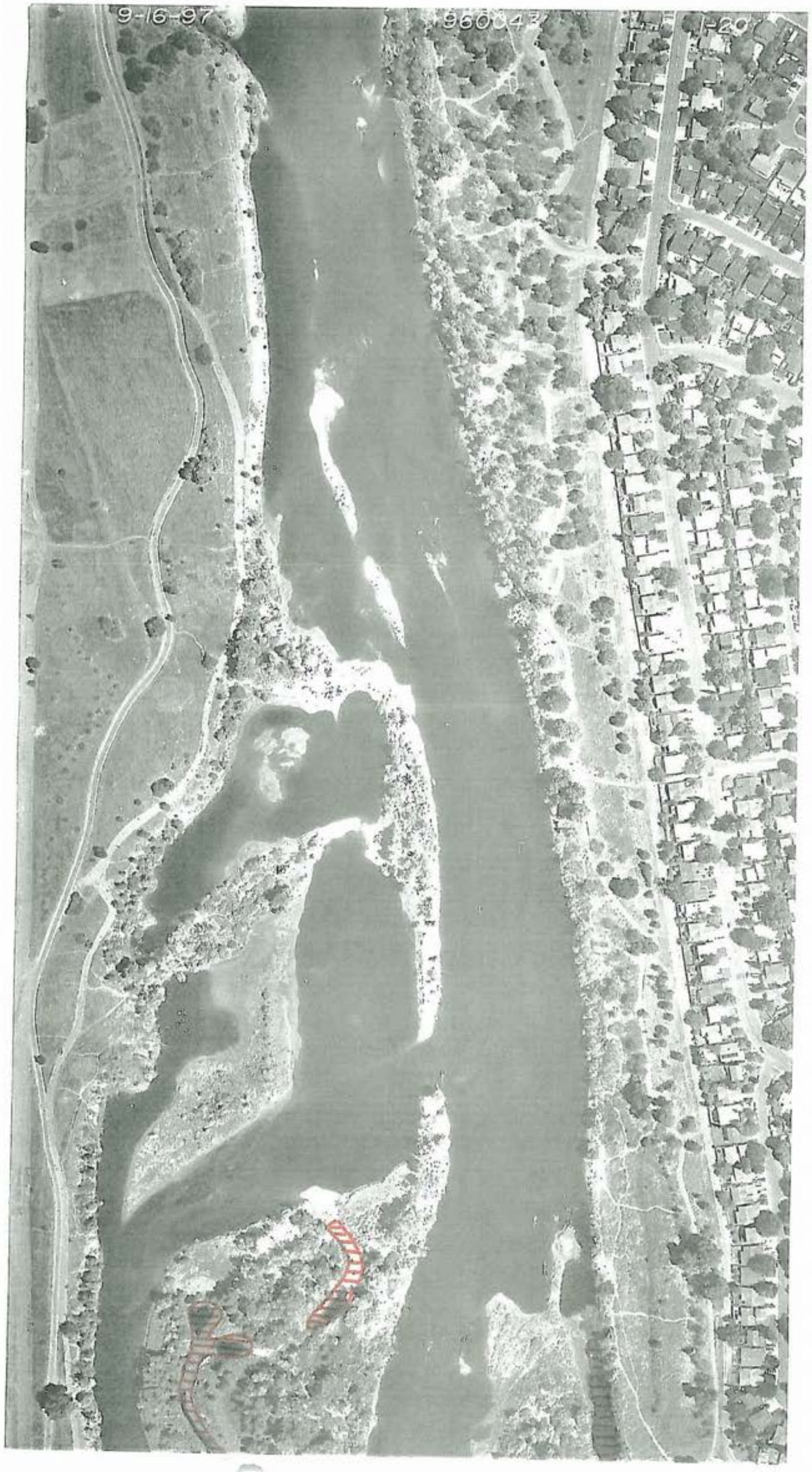
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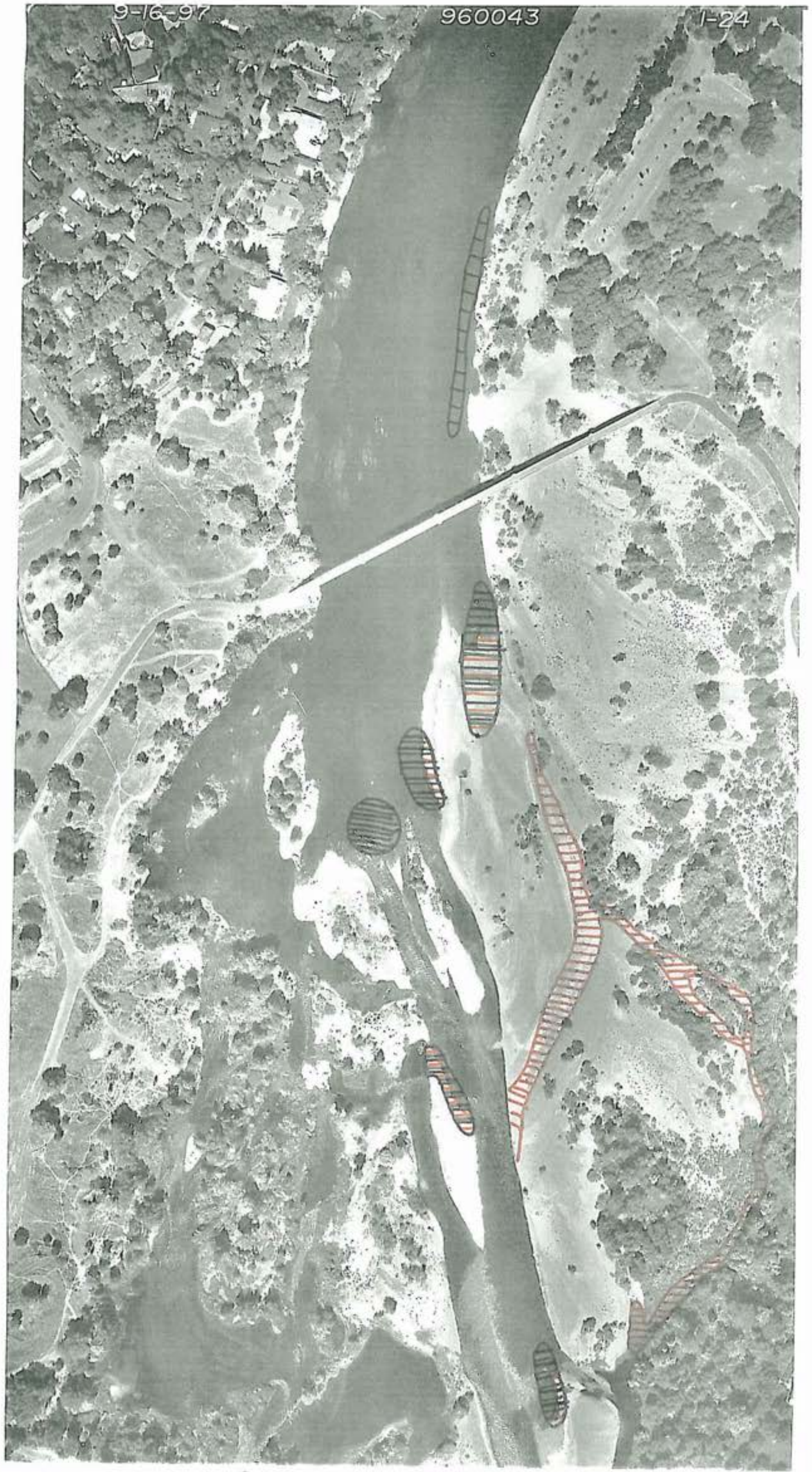
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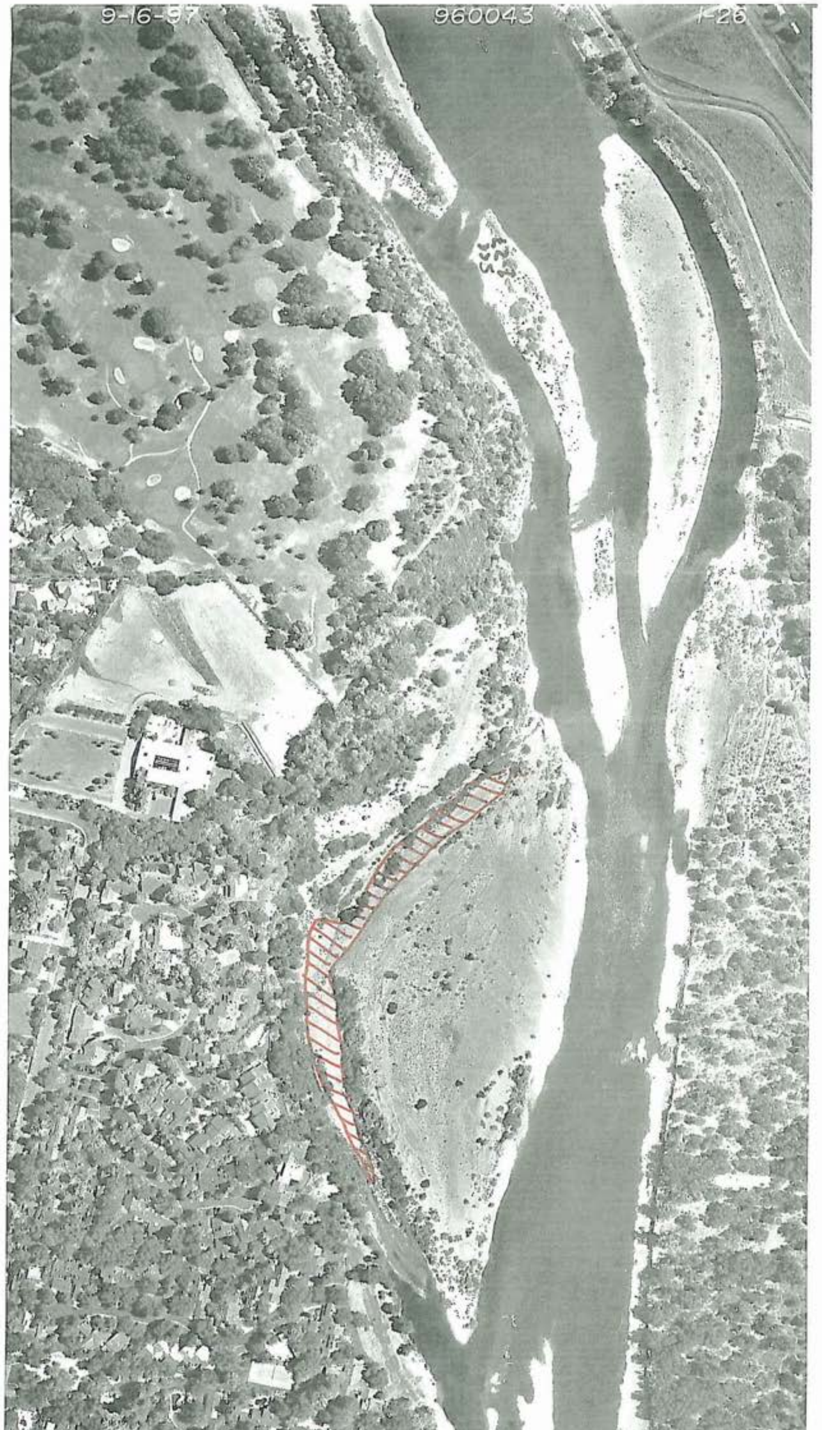
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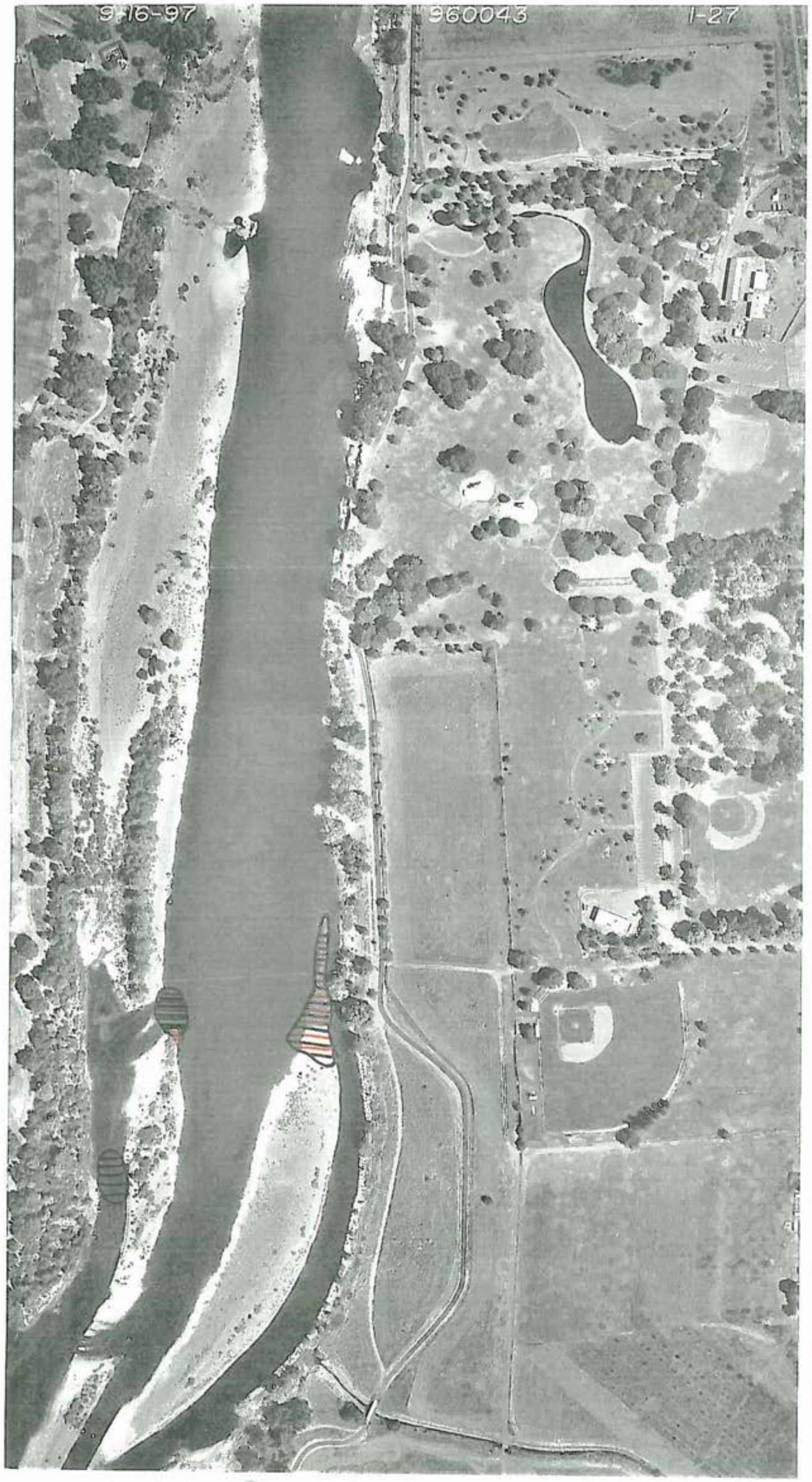
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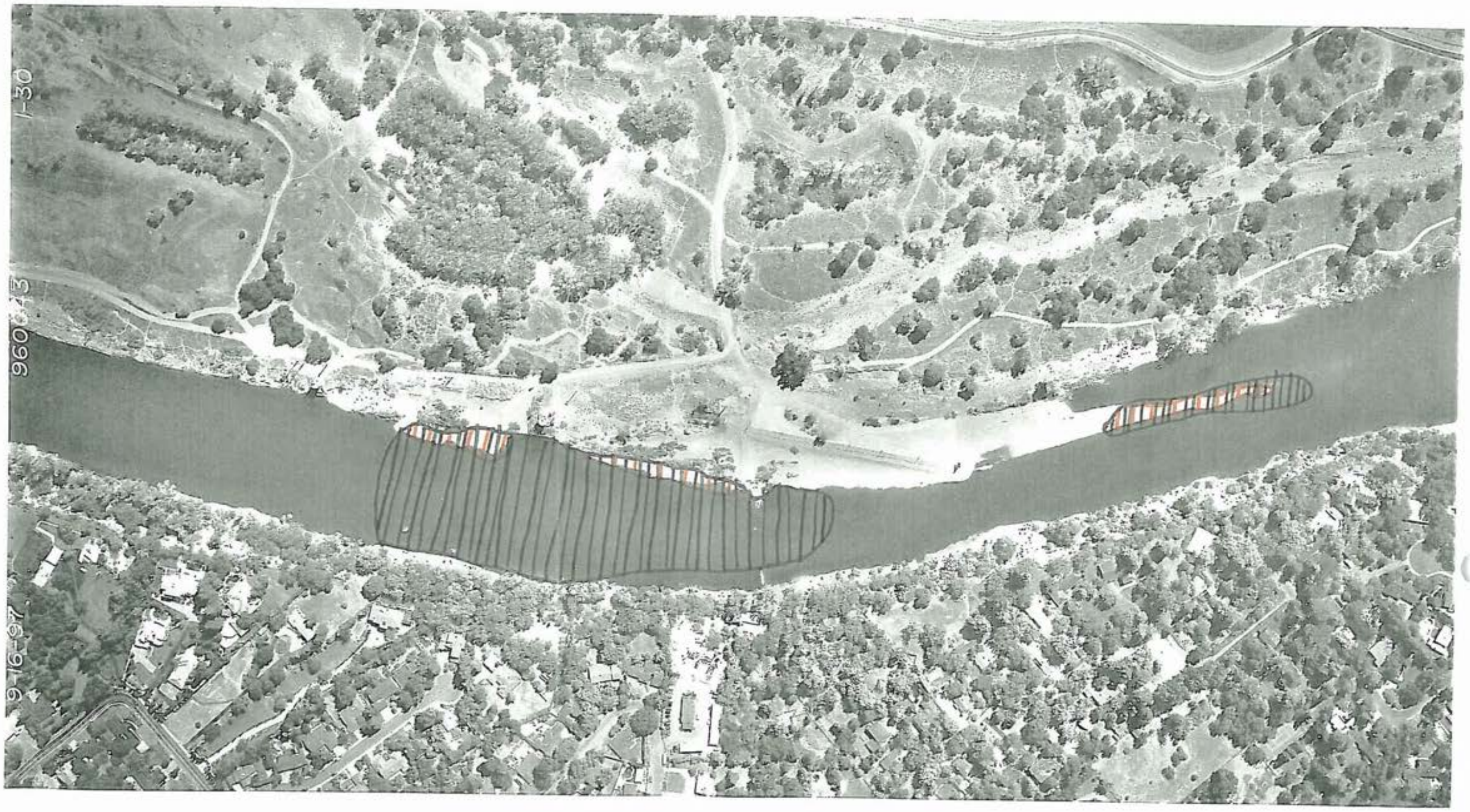
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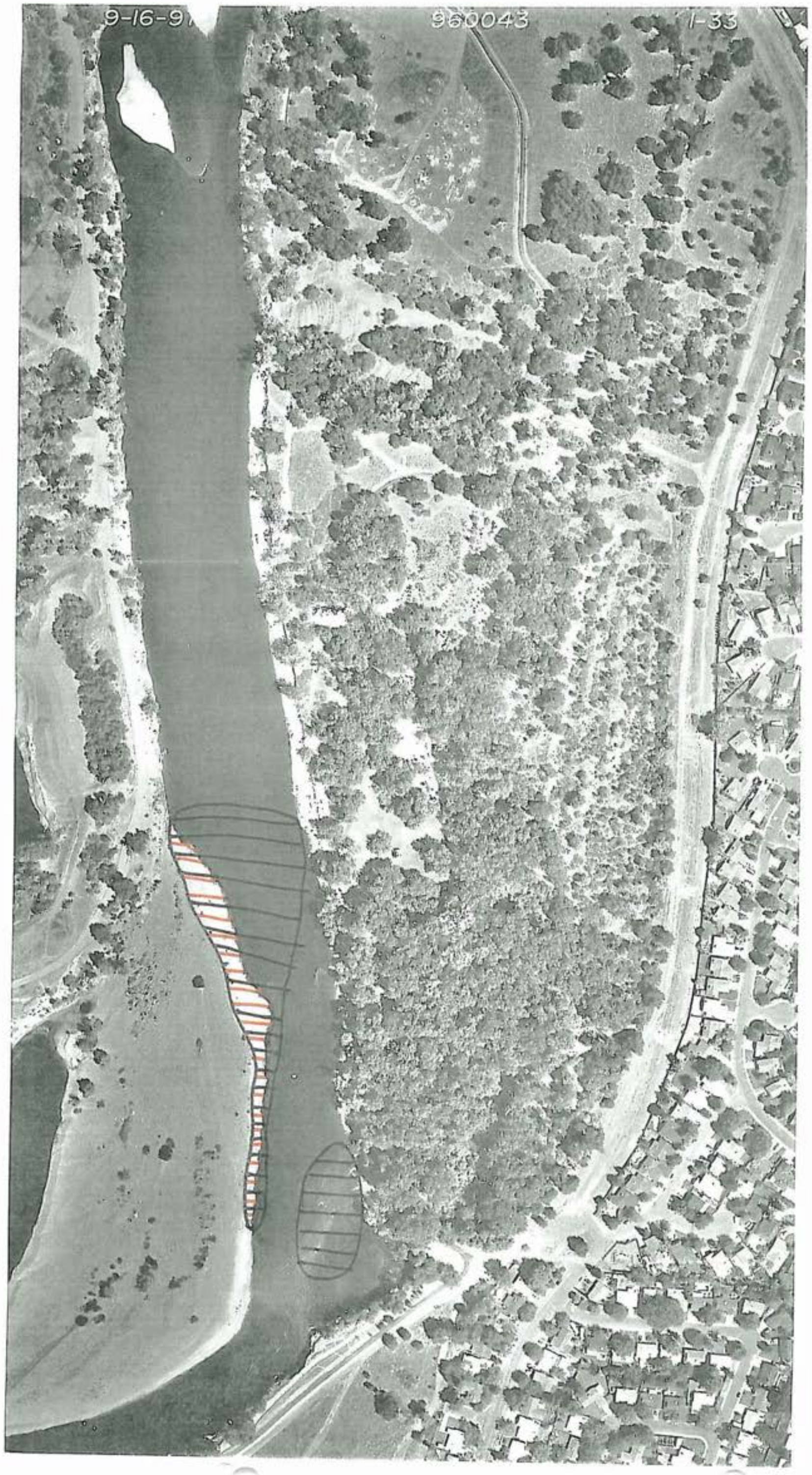
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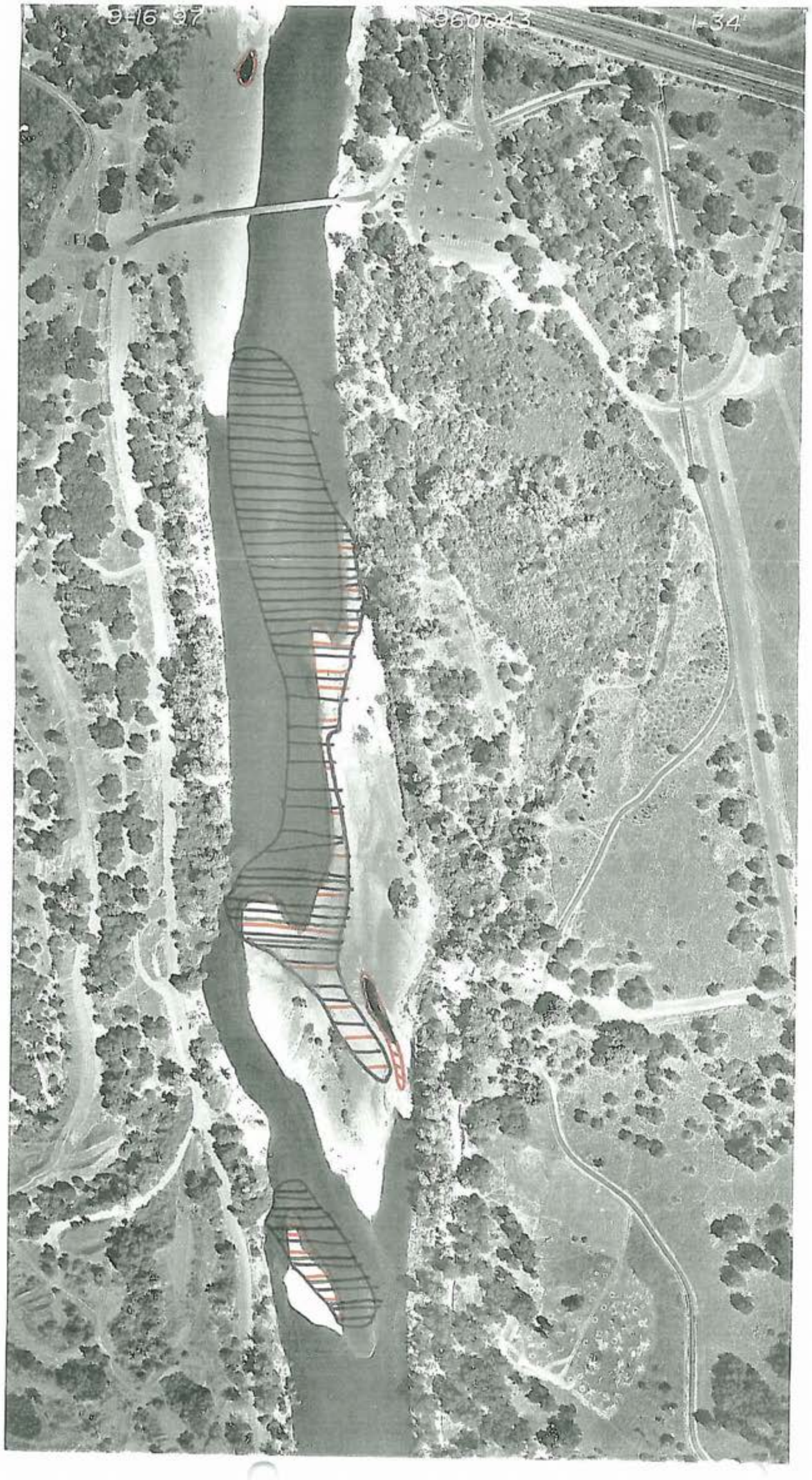
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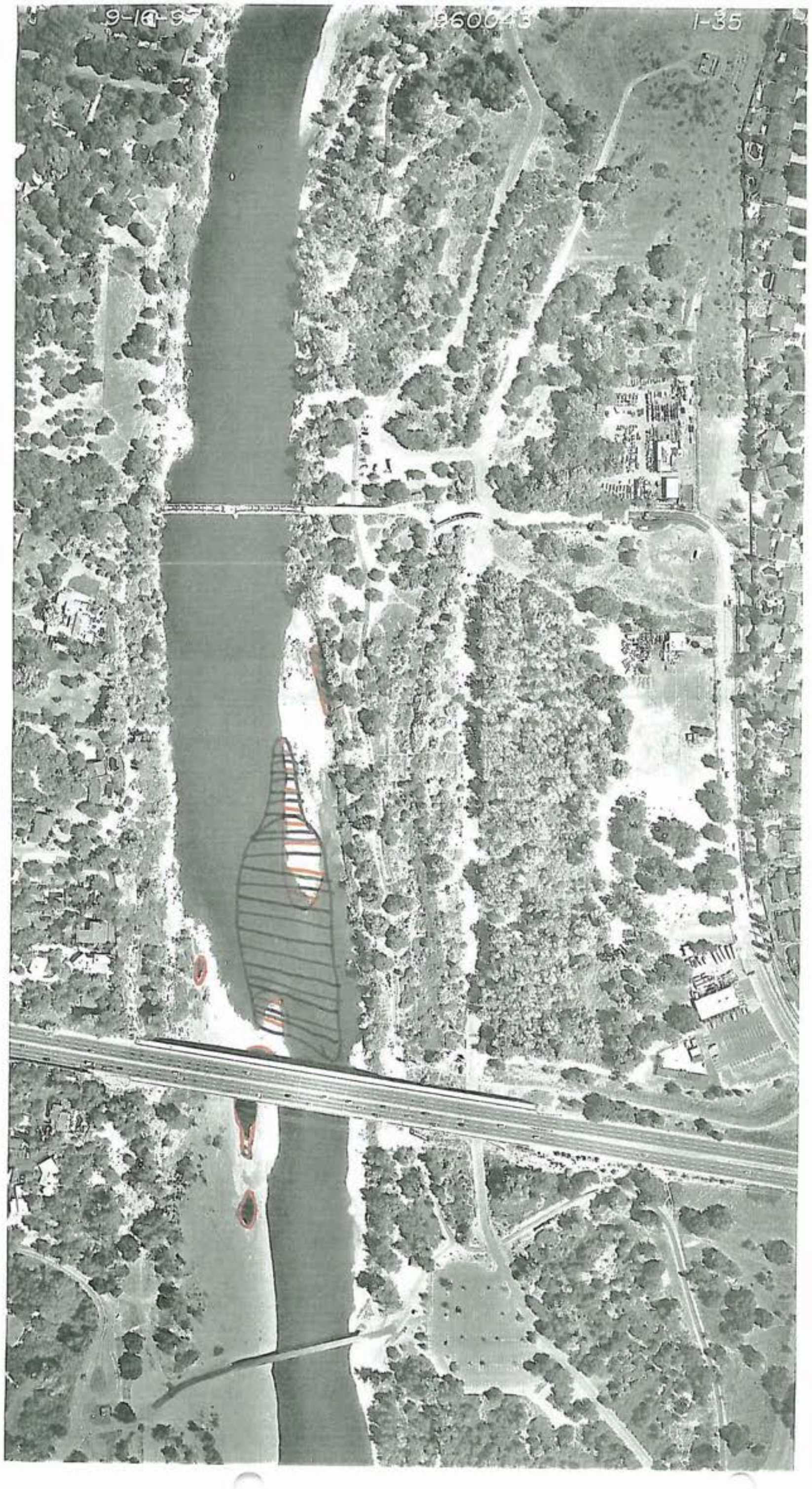
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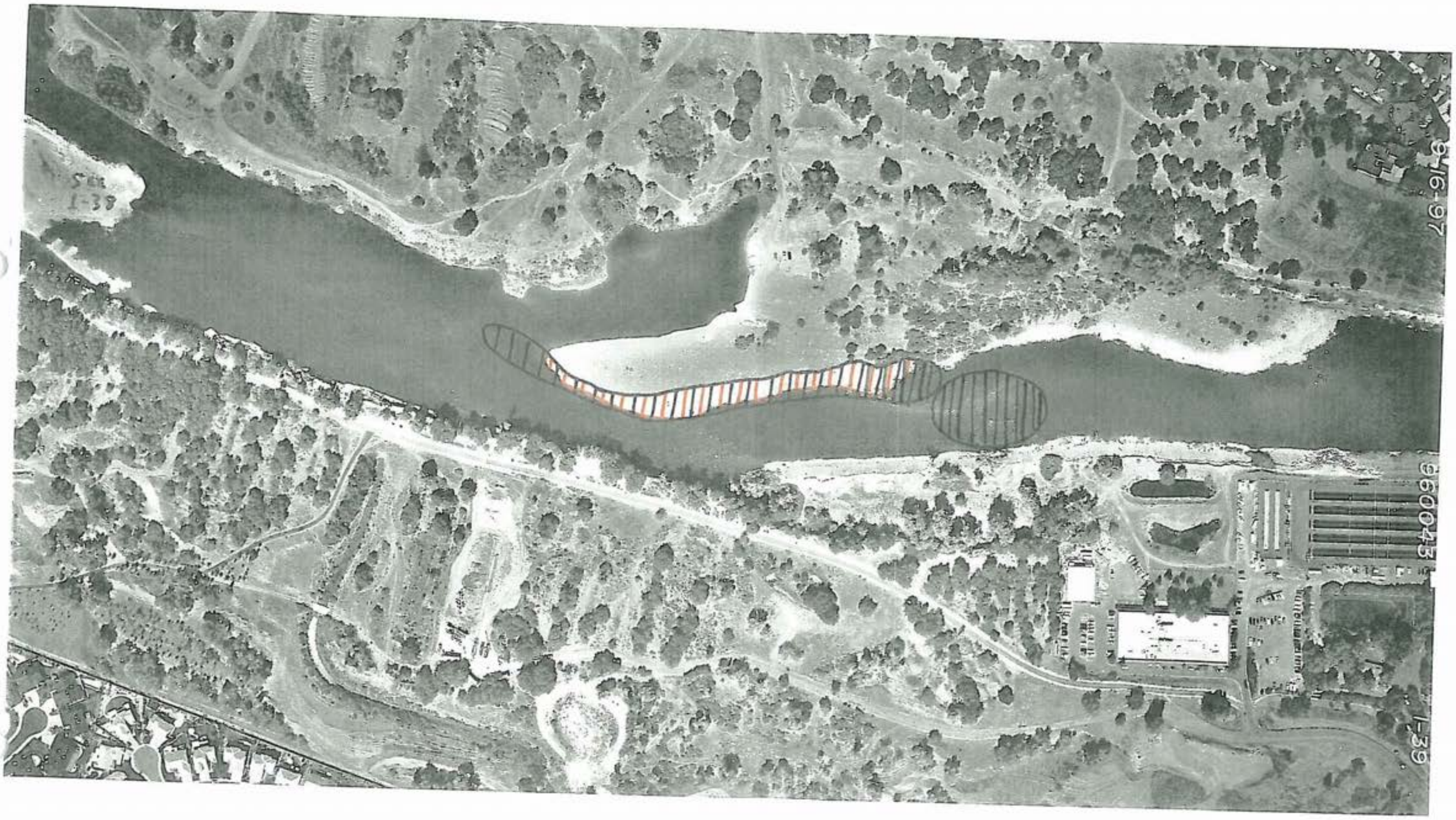
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