Recommended Streamflow Schedules To Meet the AFRP Doubling Goal in the San Joaquin River Basin

27 September 2005

Introduction

The goal of the Anadromous Fish Restoration Program (AFRP) is to make all reasonable efforts to at least double natural production of anadromous fish in California's Central Valley streams on a long-term, sustainable basis. However, production of fall-run Chinook salmon (Chinook Prod) between 1992 and 2004 has declined by 28% in the Stanislaus River, 46% in the Tuolumne River, and increased by only 4% in the Merced River, which is a hatchery supported stream, compared to the 1967-1991 baseline period. Evidence is provided here that the declines in salmon production primarily resulted from a reduction in the frequency and magnitude of spring flooding in the San Joaquin River Basin during the 1992-2004 period compared to the baseline period. Additional evidence is provided that the most likely means of increasing adult production would be to increase flows during February and March to substantially increase the survival of juveniles in the lower half of the tributaries and the San Joaquin River and thereby increase the production of smolts, and then to increase flows between April and mid-June to increase smolt survival. It is also likely that production can be further increased by (1) providing fall pulse flows that help minimize the number of adult salmon that stray to the Sacramento Basin when Delta export rates are high and minimize delays of adults in the Delta that may impair gamete viability; (2) gradually ramping down spring flows during June to facilitate riparian vegetation recruitment and thereby increase the input of allochthonous organic matter and food into the aquatic habitat; and (3) increasing summer flows to increase the survival of juvenile Central Valley steelhead and Chinook yearlings.

The population models described below suggest that the physical habitat in the Stanislaus, Tuolumne, and Merced rivers can support the progeny of no more than 2,000 spawners. If true, restoring the spawning, rearing, and/or floodplain habitats should substantially increase salmonid production in all three tributaries. However, it is likely that habitat restoration by itself will not increase juvenile production, unless flows are increased to increase the amount of rearing habitat, the frequency of floodplain inundation, and thereby increase juvenile survival.

There is also a slight possibility that increasing flows during spawning in early November to increase the amount of habitat with suitable water temperatures would reduce redd superimposition and thereby increase juvenile production; however, screw trap data from the Stanislaus River, which are presented below, do not support this hypothesis.

Ten analyses that were used to justify and determine the flow schedules needed to help achieve the AFRP doubling goal are summarized below:

1. Relationships between salmon recruitment and flow in the Stanislaus and Tuolumne rivers;
2. Relationships between juvenile survival and flow in the Stanislaus River;
3. Salmon production models for the San Joaquin River Basin;
4. Spring flows required to double fall-run Chinook salmon populations;
5. Fall pulse flows required for adult passage through the Delta;
6. Fall flows required for spawning and incubation habitat;
7. Ramping down spring flows to promote riparian vegetation;
8. Summer flows required to increase habitat for yearling steelhead and salmon;
9. The effect of Delta Exports rate reductions on Chinook salmon production; and
10. Comparison of Flow Schedules for a 53% increase in production and doubling.

1. Relationships Between Salmon Recruitment And Flow In The Stanislaus And Tuolumne Rivers

Fall-run Chinook salmon production in the San Joaquin River Basin is well correlated with flow, particularly in the San Joaquin River at Vernalis, during the spring when the juveniles are migrating from the tributaries (Mesick 2005). Mesick's analysis converts production, which consists of several different cohorts of fish that all return to spawn in the tributaries during the same year, into recruitment, which consists of same-aged adults that all migrated through the Basin as juveniles during the same year. This conversion requires age data to segregate escapement into cohorts, which was not collected on the Merced River until 1988; therefore, these analyses that compare the baseline and post-baseline periods could only be done for the Tuolumne and Stanislaus rivers.
Comparing the regressions of average flow in the San Joaquin River at Vernalis for the March through May period and salmon recruitment suggests that the slope of the regressions has declined by about 10% for the Stanislaus River (Figure 1) and 20% for the Tuolumne River (Figure 2); however, statistical tests cannot be conducted to determine the significance of the declines because the tests can only be conducted if the variances of the two regressions are not significantly different (Snedecor and Cochran 1989) and F-tests indicate that the variances of the baseline and 1992-2002 regressions were significantly different ($p \leq 0.01$). Therefore, most if not all of the declines in production observed in the Stanislaus and Tuolumne rivers since 1992 are a result of a lower frequency of wet years during the 1992-2004 period compared to the baseline period. For example, the average March through May flows at Vernalis during the slightly wet years (San Joaquin River Index of 4.0 to 5.0 million acre feet) ranged between 5,000 and 10,000 cfs during the 1992-2004 period and between 15,000 and 20,000 cfs during the baseline period (Figure 3). The lower flood magnitudes observed after 1992 are primarily due to differences in climate because the large San Joaquin reservoirs that capture all or most of flood flows were all completed prior to 1992: New Melones was completed in 1980, New Don Pedro was completed in 1971, and New Exchequer was completed in 1966.

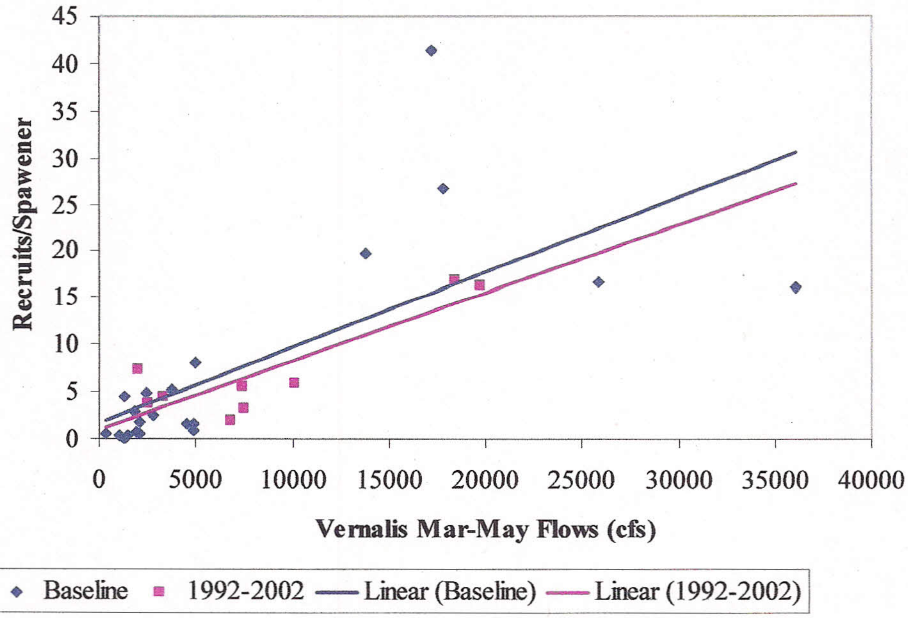

Figure 1. The relationship between the number of fall-run Chinook salmon recruits/spawner to the lower Stanislaus River and the average flow in the San Joaquin River at Vernalis between 1 March and 31 May during the 1967-1991 baseline period and the 1992-2002 AFRP period. The lines labeled as "linear" show the linear regression models for each period. The adjusted R-Squared for the linear regression model is 0.50 for the 1967 to 2002 dataset.

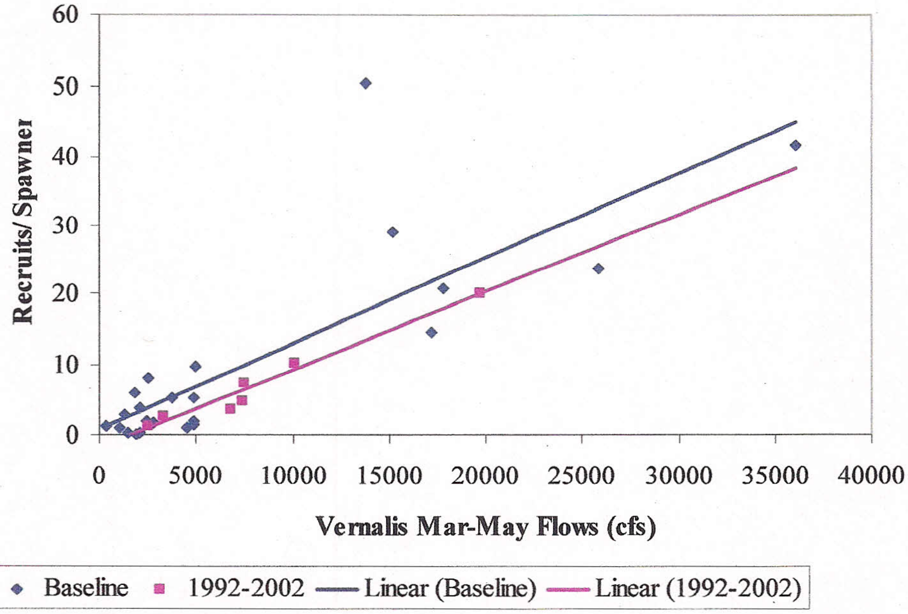

Figure 2. The relationship between the number of fall-run Chinook salmon recruits/spawner to the lower Tuolumne River and the average flow in the San Joaquin River at Vernalis between 1 March and 31 May during the 1967-1991 baseline period and the 1992-2002 AFRP period. The lines labeled as "linear" show the linear regression models for each period. The adjusted R-Squared for the linear regression model is 0.59 for the 1967 to 2002 dataset.

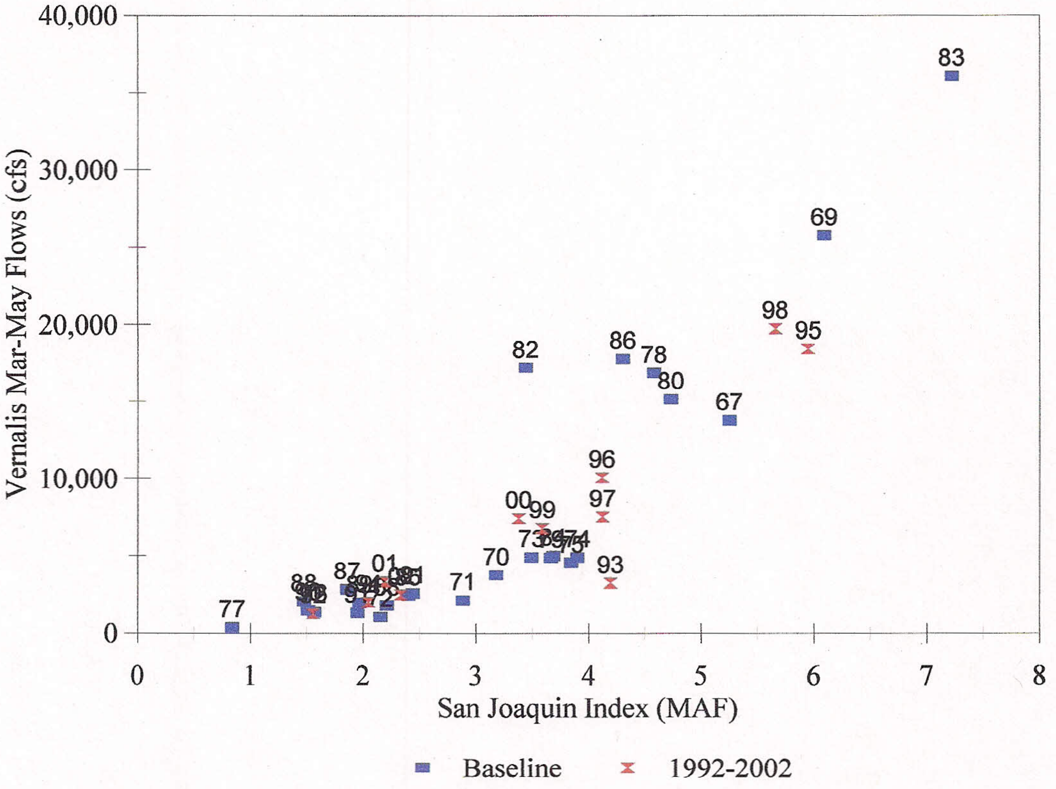

Figure 3. The relationship between the mean March through May flow in the San Joaquin River at Vernalis and the San Joaquin Index in millions of acre-feet (MAF) for the baseline and 1992-2002 periods.

2. Relationships between juvenile survival and flow in the Stanislaus River

The survival of fry and parr migrating and rearing in the Stanislaus River between Oakdale and Caswell State Park is highly dependent on flow between March and early June and presumably the same is true for the Tuolumne and Merced rivers. Many more fry, parr, and smolts were captured in the Stanislaus River at the Caswell traps when the flow at Ripon in February and March ranged between 1,000 and 5,000 cfs during above normal and wet years (1998-2000) than when it was typically less than 600 cfs during dry and normal years (2001-2004; Appendix 1). The fact that more juveniles passed the downstream Caswell trap (RM 5) than the upstream Oakdale trap (RM 40) in April and May during the above normal and wet years strongly suggests that high February and March flows may be needed for fry and parr to rear in the lower river. It is also likely that the extended periods of high flows in April, May and early June during the above normal and wet years were responsible for the high survival rates of migrating smolts. Supporting evidence is provided by the strong correlations between adult recruitment and Vernalis flows in March, April, May, and June (Mesick 2005). The relatively weak correlations between recruitment and Vernalis flows in February suggest that February flows may be as important as those between March and mid June. It is assumed that high flows in February through mid June would also be important for juvenile salmonids in the Tuolumne and Merced rivers as well.

3. Salmon production models for the San Joaquin River Basin

Regression equations were computed for the number of Chinook salmon recruits per spawner in each of the San Joaquin River tributaries (Mesick 2005) and the average flow at Vernalis during April and May for the purpose of estimating the amount of flow required to double populations. It was assumed that the magnitude of flow during April and May was more directly related to juvenile salmon survival because this is the period when most of the smolt-sized fish are migrating[1] and water temperatures are in the range that may affect smolt survival[2]. Vernalis flows were used in the model instead of tributary reservoir releases for two reasons. First, juvenile survival in the Stanislaus River is much more highly correlated with flow at Vernalis (adjusted-$R^2 = 0.53$) than with flow at Goodwin Dam in the Stanislaus River (adjusted-$R^2 = 0.16$), which suggests that Delta flows are more important than tributary flows (Mesick 2005). Second, there were insufficient flow data at Snelling to estimate reservoir releases in the Merced River during the entire AFRP baseline period, which precludes model development based on tributary flows.

Stanislaus River model: Recruits/Spawner = 0.0008611 * April-May Vernalis Flows + 1.17688. The adjusted-R^2 was 0.53 with a probability level of 0.0000 for the model developed with the estimates for 1983 to 2002. Recruitment was computed by multiplying the model's predicted number of recruits/spawner by the number of spawners. It was assumed that recruitment increased linearly until 2,000 spawners, after which and there was no further change in recruitment as the number of spawners exceeded 2,000 fish. This assumption reflects the relationship between stock and the total estimated number of juveniles passing the Oakdale Screw trap between 1996 and 2004 (Mesick 2005). Figure 4 compares the recruitment estimates based on escapement surveys (Mesick 2005) with the model results. One possible explanation for the unusually large discrepancies between the measured and modeled recruitment estimates for 1980 and 1981 is that escapement in 1979 and 1980 may have been substantially underestimated and the resulting low stock estimate caused the low recruitment estimates in 1980 and 1981. Poor or no escapement estimates occurred in 1977, 1982, 1983, and 1996; however the CDFG Inland Fisheries Administrative Reports have not been located for the 1979 and 1980 surveys to verify the accuracy of the estimates.

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[1] CDFG Mossdale Trawl Data presented to the State Water Resources Control Board in Spring 2005.
[2] Vernalis Adaptive Management Plan technical reports produced by the San Joaquin River Group Authority.

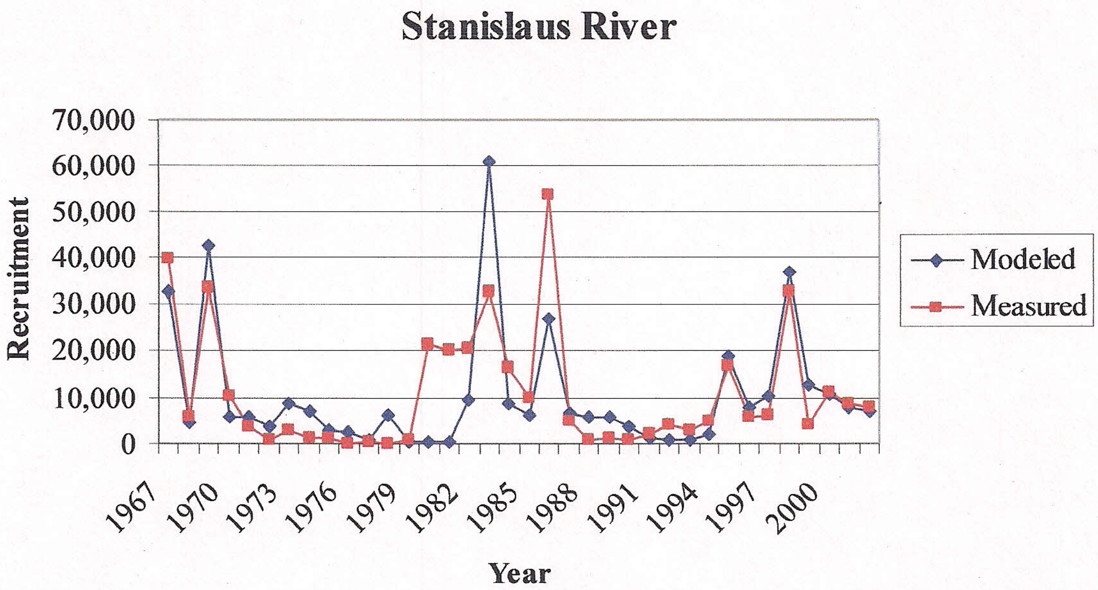

Figure 4. Adult Chinook salmon recruitment to the Stanislaus River from 1967 to 2002 based on escapement surveys (Measured) and regression model predictions (Modeled).

Tuolumne River model: Recruits/Spawner = 0.00140 * April-May Vernalis Flows + 0.18957. The adjusted-R^2 was 0.65 with a probability level of 0.0000 for the model developed with the estimates for 1980 to 2002. Recruitment was computed by multiplying the estimated number of recruits/spawner by the estimated number of spawners. It was assumed that recruitment increased linearly until 2,000 spawners, after which there was no further change in recruitment aas the number of spawners exceeded 2,000 fish. This assumption was made because the model's adjusted-R^2 declined to 0.44 and then to 0.32 as the spawner-recruit inflection point was increased to 3,000 and 4,000 spawners respectively. Figure 5 compares the recruitment estimates based on escapement surveys (Mesick 2005) with the model results.

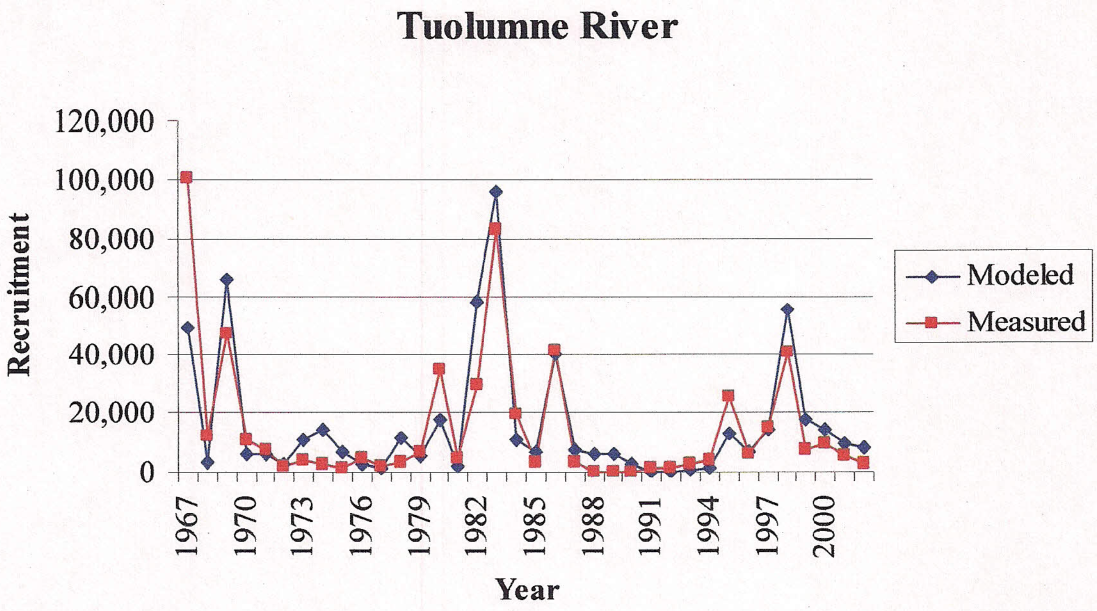

Figure 5. Adult Chinook salmon recruitment to the Tuolumne River from 1967 to 2002 based on escapement surveys (Measured) and regression model predictions (Modeled).

Merced River model: Recruits/Spawner = 0.000554 * April-May Vernalis Flows + 0.07938. The adjusted-R^2 was 0.61 with a probability level of 0.0000 for the model developed with the estimates for 1980 to 2002. The recruitment estimates between 1980 and 1986 were based on Age 2 estimates from the Tuolumne River whereas the later estimates were based on length-frequency derived Age 2 estimates from the Merced River (Mesick 2005). Recruitment was computed by multiplying the estimated number of recruits/spawner by the estimated number of spawners. It was assumed that each fish collected in the Merced River Fish Hatchery, up to the approximate hatchery's capacity of 1,000 spawners, contributed twice the in-river production compared to naturally spawning adults. It was also assumed that recruitment increased linearly until 2,000 in-river spawners, after which there was no further change in recruitment after the number of spawners exceeded 2,000 fish. This assumption was made because the physical condition of the spawning and rearing habitat in the Merced River is more degraded than those habitats in the Stanislaus and Tuolumne rivers[3]. In addition, the number of recruits produced per spawner in the Merced River is substantially lower than in the Tuolumne and Stanislaus rivers, and so it is highly unlikely that the habitat in the Merced River can support the progeny of more than 2,000 spawners. Figure 6 compares the recruitment estimates based on escapement surveys (Mesick 2005) with the model results.

[3] The physical condition of the Merced, Tuolumne, and Stanislaus rivers was visually assessed by Carl Mesick, USFWS, during boat surveys in 2005, 2004, and 2002 respectively.

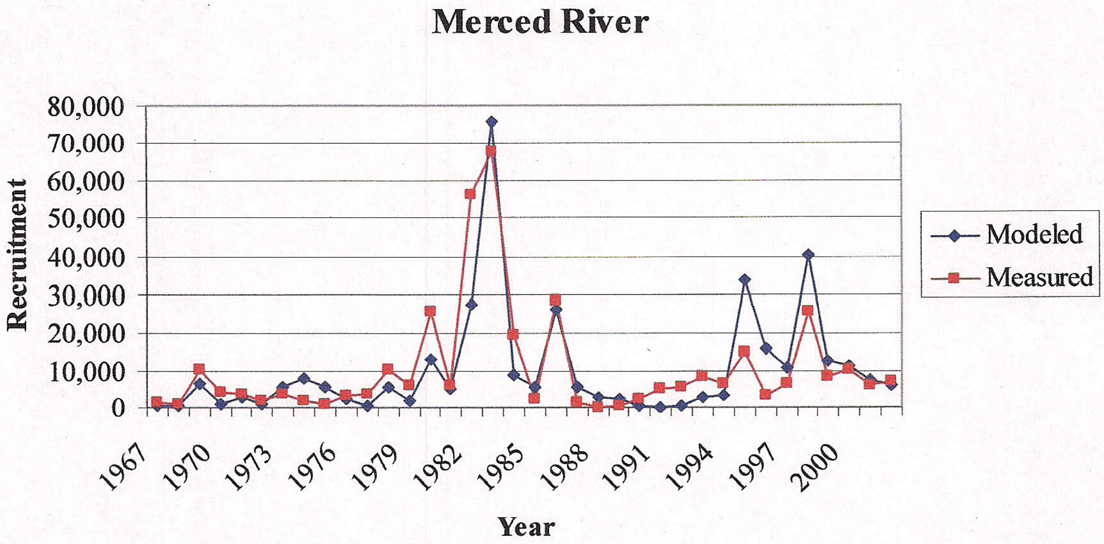

Figure 6. Adult Chinook salmon recruitment to the Merced River from 1967 to 2002 based on escapement surveys (Measured) and regression model predictions (Modeled).

4. Spring flows required to double fall-run Chinook salmon populations

To use the above recruitment models to estimate the amount of flow at Vernalis that would be needed to double salmon production in the San Joaquin Basin, it is necessary to maintain the historical conditions that formed the basis of the model. This means that each of the three San Joaquin River tributaries must maintain the similar contributions to Vernalis flows as well as maintain a similar hydrograph. Based on the estimated annual unimpaired flows, the Stanislaus River contributes 28%, the Tuolumne River contributes 49%, and the Merced River contributes 23% of Vernalis flows historically. To convert the modeled flows into monthly averages for March, April, and May in a functional flow schedule, a constant percentage of the average unimpaired historical flow (1901 to 2004) was used for each month. For example, the Merced River Model indicates that an average flow of 3,480 cfs would be needed for the months of April and May during wet years to double production. The flow schedule was determined by multiplying the average unimpaired flow during wet years by 76.86%, which computes to a March flow of 2,279 cfs, an April flow of 2,559 cfs, and a May flow of 4,402 cfs. Suitable February flows were assumed to be either half of March flows or a minimum of 350-500 cfs, which was slightly lower than the recommended March flow.

Two sets of recommended flows were developed. The first set of flows simply extended the Vernalis flow standards in the State Water Resources Control Board's 1995 Water Quality Control Plan from April 15 to May 15 to April 1 to May 30, and then proportioned the flow during each month between March and May to match the natural hydrograph. Based on all three recruitment models, the total modeled population for the San Joaquin River Basin would increase by 53% from 36,494 fish during the AFRP baseline period to 55,945 fish, if the flows in Table 1 were implemented. The increase in recruitment varies between the three tributaries: 59% for the Stanislaus River, 42% for the Tuolumne River, and 57% for the Merced River, because the populations respond differently in terms of the effects of flow on juvenile survival and increases in spawner abundance. Historically, spawner abundance limited recruitment more frequently on the Stanislaus and Merced rivers than in the Tuolumne River and so an increase in flow would improve both spawner abundance as well as smolt survival in the Stanislaus and Merced rivers to a greater degree than for the Tuolumne River, and thereby, produce the largest increases in recruitment in the Stanislaus and Merced rivers. The rate that recruitment increases with flow would be expected to decline after spawner abundance consistently reaches the habitat's capacity of 2,000 fish.

Table 1. The average flow (cfs) for February, March, April, and May for the Stanislaus, Tuolumne, and Merced rivers that would be expected to achieve a 53% increase in total predicted Chinook salmon production for the basin.

	WET	ABOVE NORMAL	BELOW NORMAL	DRY	CRITICAL
Stanislaus					
February	674	500	500	500	450
March	1,348	814	571	545	462
April	1,641	1,364	1,109	1,065	814
May	2,541	1,902	1,520	1,146	845
Tuolumne					
February	1,060	638	500	500	500
March	2,119	1,276	883	922	874
April	2,532	1,881	1,792	1,586	1,420
May	4,284	3,605	2,646	2,395	1,702
Merced					
February	600	500	450	350	300
March	1,200	613	480	383	329
April	1,347	1,022	832	808	654
May	2,317	1,687	1,339	1,038	783
Total					
February	2,333	1,638	1,450	1,350	1,250
March	4,667	2,703	1,933	1,850	1,665
April	5,520	4,266	3,733	3,459	2,888
May	9,142	7,194	5,505	4,579	3,331

The second set of flows would be expected to double the total predicted San Joaquin Basin recruitment from 36,494 fish during the AFRP baseline period to 72,916 fish. The increase in recruitment varies considerably between the three tributaries: 114% for the

Stanislaus River, 86% for the Tuolumne River, and 112% for the Merced River. The following table indicates the average flow for February, March, April, and May in the Stanislaus, Tuolumne, and Merced rivers that would be expected to double salmon production for the basin.

Table 2. The average flow (cfs) for February, March, April, and May in the Stanislaus, Tuolumne, and Merced rivers that would be expected to double the total predicted Chinook salmon production for the basin.

	WET	ABOVE NORMAL	BELOW NORMAL	DRY	CRITICAL
			Stanislaus		
February	1,280	787	514	500	500
March	2,560	1,573	1,028	927	785
April	3,117	2,636	1,998	1,811	1,385
May	4,827	3,676	2,738	1,950	1,438
			Tuolumne		
February	2,013	1,212	794	784	744
March	4,027	2,424	1,589	1,568	1,487
April	4,811	3,574	3,225	2,696	2,415
May	8,139	6,850	4,763	4,072	2,895
			Merced		
February	1,140	582	500	500	500
March	2,279	1,165	864	651	559
April	2,559	1,941	1,498	1,375	1,112
May	4,402	3,205	2,410	1,766	1,332
			Total		
February	4,433	2,581	1,809	1,784	1,744
March	8,866	5,162	3,481	3,146	2,832
April	10,487	8,151	6,721	5,883	4,912
May	17,369	13,732	9,912	7,787	5,665

5. Fall pulse flows required for adult passage through the Delta

Poor water quality in the deep-water ship channel near Stockton and excessive exports at the State Water Project and Central Valley Project at Tracy in October can either delay the upstream migration of adults or cause them to stray to the Sacramento River basin.

Delayed Adult Migration

Hallock and others (1970) showed that radio-tagged adult Chinook salmon delayed their migration at Stockton whenever dissolved oxygen (DO) concentrations were less than 5 mg/l and/or water temperatures exceeded about 65 °F in October. DO concentrations near Stockton in October were greater than 5 mg/l from 1983, when DWR began monitoring, to 1990, but were lower than 5 mg/l for most of October in 1991 and 1992. The Head of the Old River Barrier was installed in fall 1992 to maximize flows in the deep water ship channel, but it did not correct the problem until late October (Figure 7). In 1993, DO levels were low until about 10 October and it is likely that pulse flows that raised Vernalis flows to about 4,000 cfs on 7 October were responsible for increasing DO levels at Stockton (Figure 7). Similarly in 1994, DO levels were low until 15 October when pulse flows raised Vernalis flows to about 2,000 cfs (Figure 7). In 1995, DO levels were at least 6 mg/l in October when Vernalis flows ranged about 3,000 cfs to 6,000 cfs through mid October. DO levels were low or greatly fluctuated in 1996 until 13 October when pulse flow releases increased Vernalis flows from 2,000 to about 3,000 cfs (Figure 7).

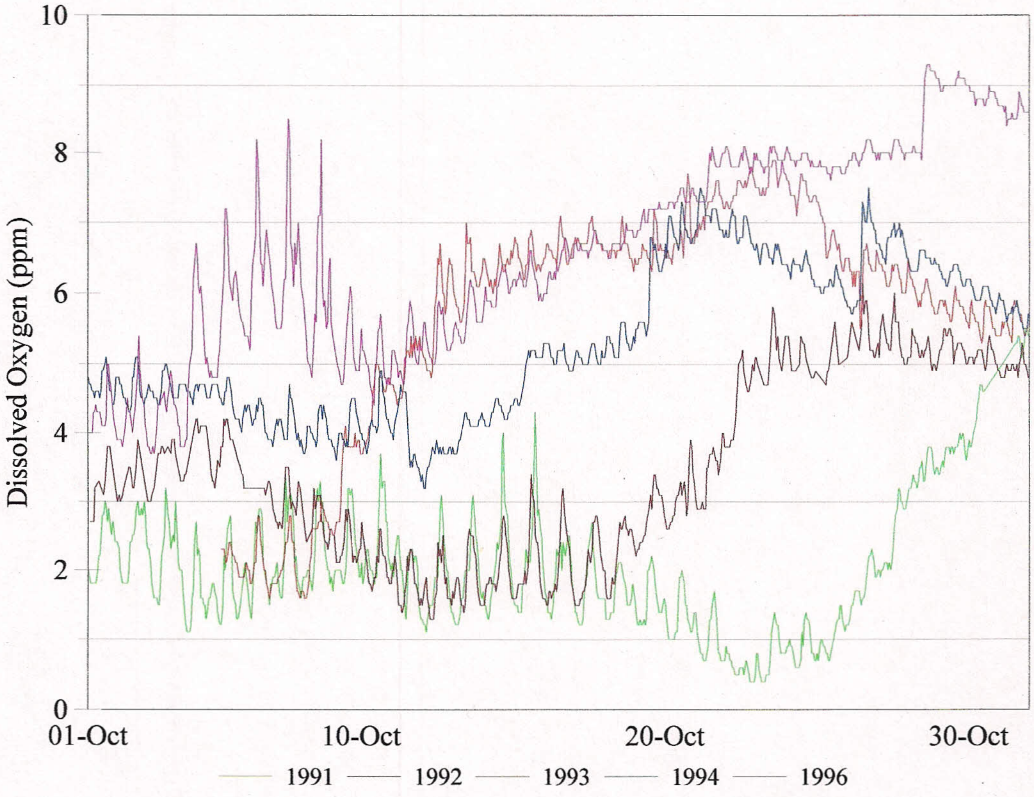

Figure 7. Hourly dissolved oxygen measurements at the Department of Water Resources' Burns Cut Off Road monitoring station during October in 1991 through 1994 and in 1996.

There are concerns that delaying the migration of adult salmon in the deep-water ship channel near Stockton may reduce gamete viability if the fish are exposed to high temperatures for prolonged periods. Egg survival at the Merced River Hatchery increased from a mean of 46% from 1990 to 1992 during the peak of the drought to a mean of 77% from 1993 to 1999 after fall pulse flows were made[4]. A more in-depth analysis should be conducted to determine whether the mid-October pulse flows help maintain gamete viability in Chinook salmon migrating in the Delta.

Adult Straying

Delta export rates at the State Water Project and Central Valley Project were increased to near maximum (about 9,600 cfs) in fall 1996 and in subsequent years to "make-up" for reduced pumping rates during the spring outmigration period to improve salmon smolt survival (Mesick 2001). The adult fall-run salmon are migrating upstream through the Delta primarily in October typically when San Joaquin River flows at Vernalis are low (Mesick 2001). It is likely that when exports are high relative to San Joaquin River flows, little if any San Joaquin River water reaches the San Francisco Bay where it may be needed to help guide the salmon back to their natal stream. An analysis by Mesick (2001) of the recovered adult salmon with coded-wire-tags (CWT) that had been reared at the Merced River Fish Facility and released in one of the San Joaquin tributaries suggests straying occurred when more than 400% of Vernalis flows were exported at the CVP and SWP Delta pumping facilities. The analysis indicates that during mid October from 1987 through 1989 when export rates exceeded 400% of Vernalis flows, straying rates ranged between 11% and 17% (Figure 8). In contrast, straying rates were estimated to be less than 3% when Delta export rates were less than about 300% of San Joaquin River flow at Vernalis during mid-October. Between 1993 and 2002, pulse flow releases from the San Joaquin tributaries and/or reductions in Delta exports for 10 days in mid-October have kept Delta export rates to less than 300% of the San Joaquin River flow at Vernalis (Figure 8).

To maintain high levels of gamete viability in migrating salmon and minimize straying during periods of high exports (i.e., export no more than 300% of Vernalis flows), it is recommended that a 1,000-cfs pulse flow should be released for 10 days in mid-October from each of the three San Joaquin River tributaries.

6. Fall flows required for spawning and incubation habitat

Adult Chinook salmon typically crowd into the uppermost six miles of habitat in the Tuolumne and Merced rivers, and to a lesser extent the Stanislaus River, in early November. Crowding of spawning is thought to be detrimental because the rate of redd superimposition, where females either destroy or bury the eggs in pre-existing redds, would be abnormally high and thereby reduce the production of juvenile fish. Crowding may be a result of inadequate fall spawning flows that result in excessively warm temperatures in the downstream areas. Although the percentage of spawners that use the downstream areas increases as water temperatures decline with declining air temperatures, there is no evidence that increased fall flows reduces spawner crowding or improves juvenile production (Figure 9).

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[4] Merced River Hatchery Production Reports by CDFG

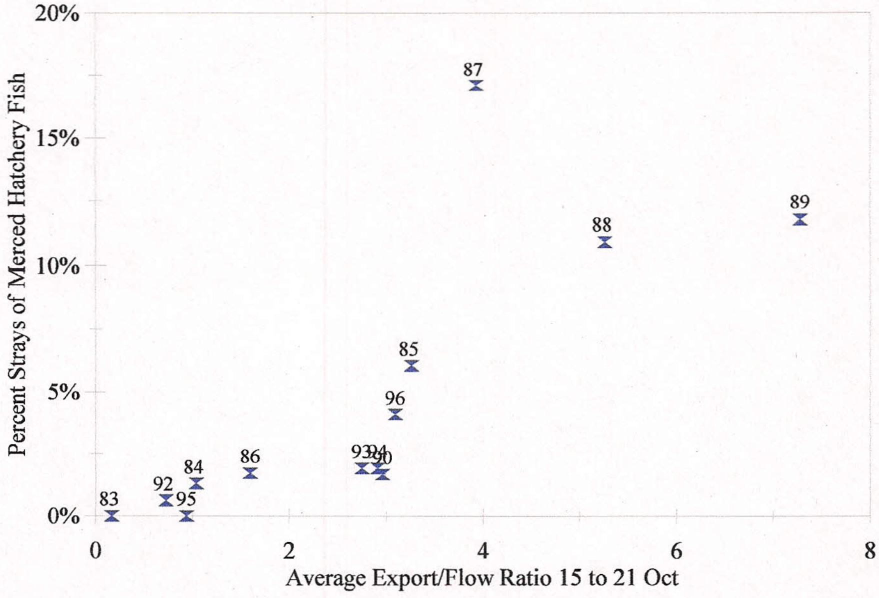


Figure 8. Estimated percent of adult CWT Chinook salmon that were reared at the Merced River Hatchery, released in the San Joaquin basin as juvenile salmon, and subsequently strayed to the Sacramento River and eastside tributary basins to spawn relative to the average ratio of the export rate at the CVP and SWP pumping facilities in the Delta to the flow rate in the San Joaquin River at Vernalis between 15 and 21 October from 1983 to 1996.

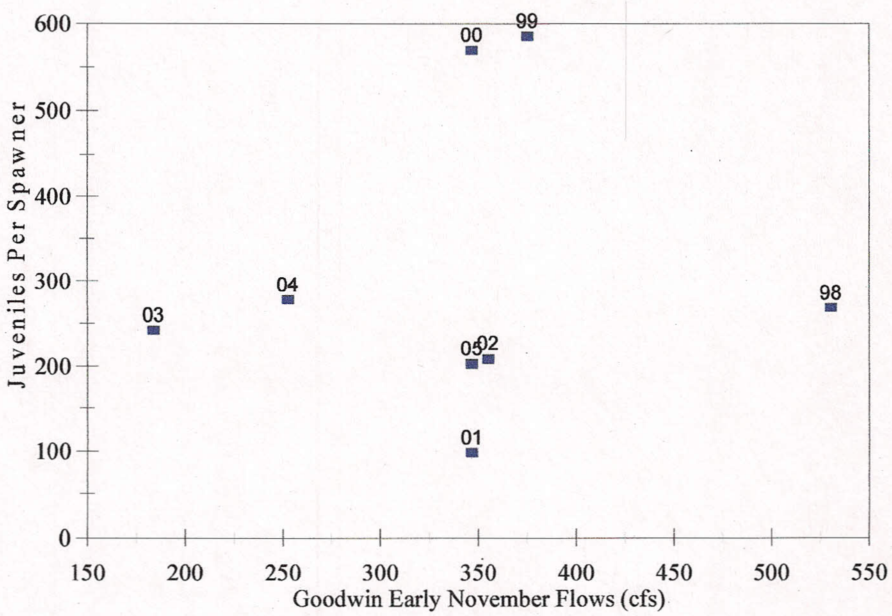


Figure 9. Relationship between the estimated number of juvenile salmon passing Oakdale per spawner and the Goodwin Dam flow release in early November in the Stanislaus River from 1998 to 2004.

It is recommended that studies should be conducted to determine the relationship between the magnitude of fall spawning flows and juvenile production in the Tuolumne and Merced rivers where spawner crowding is high. In the meantime, it is recommended that fall flows should be based on the optimum amount of physical habitat as determined by the PHABSIM model: 300 cfs for the Stanislaus River, 175-300 cfs for the Tuolumne River, and 200-250 cfs for the Merced River. These flows should be implemented from late October following the pulse flows until the end of January when flows begin to increase for juvenile rearing.

7. Ramping down spring flows to promote riparian vegetation

A likely benefit of spring flooding is the flushing of food and organic matter that produces food from the floodplains into the rivers where it can benefit juvenile salmonids. A healthy riparian forest is an integral component of the food chain.

A key factor for successful riparian recruitment is ensuring that the general rate of stage decline during the recession limb of flood control releases is gradual enough to support riparian seedling establishment. Another important issue is the timing of the recession limb. Recruitment flows should be targeted from mid-April to late-May to improve cottonwood recruitment and mid-May to late June to benefit black willow.

Research on a variety of cottonwood and willow species suggests that 1 to 1.5 inches/day is the maximum rate of water table decline for seedling survival (McBride et al. 1989; Segelquist et al. 1993; Mahoney and Rood 1992, 1998; Amlin and Rood 2002). However, a recent manipulation experiment of Fremont cottonwood, black willow, and narrow leaf willow seedlings found that water table declines of one inch or more resulted in 80% mortality within 60 days, even when the water table was maintained near the soil surface for several weeks before drawdown (Stillwater Sciences, unpublished data). Therefore more conservative rates may be appropriate. Flow recession rates of 100 to 300 cfs/day in the San Joaquin Basin are thought to prevent seedling desiccation under the assumed 1 inch/day maximum root growth rate.

A secondary benefit of a gradual ramp down of flows during June would be to increase juvenile salmon survival. Juvenile salmon migrate from the tributaries through early June and it is likely that they require 10 to 14 days to complete their migration through the Delta.

To promote the riparian vegetation recruitment and enhance the survival of juvenile salmon through the Delta, it is recommended that flows should be gradually ramped down at a constant rate between May 31 and June 30.

8. Summer flows required to increase habitat for yearling steelhead and salmon

Naturally produced juvenile steelhead typically rear in fresh water for two years before smolting and it is likely that successful rearing must occur in the tributaries because of the unsuitable conditions that occur in the Delta during the summer. The physical habitat is most suitable for rearing steelhead in the 12-mile reach below the lowermost dams in the Stanislaus, Tuolumne, and Merced rivers. Although it would be preferable to provide water that is cooler than 65°F throughout the entire 12-mile reach during all water year types, doing so would require an unreasonable volume of water and could possibly exhaust the cold water pool in the primary reservoirs. A more reasonable alternative would be to maintain suitable water temperatures in at least a 5-mile reach, which presumably would be sufficient to sustain a population.

It is recommended that a block of water should be allocated in each of the tributaries to manage flows on a daily basis so that water temperatures do not exceed 65 °F in the uppermost 5-mile reach between July 1 and mid October when the pulse flows begin. Flow management should be based on the new water temperature model for the Stanislaus River and on empirical flow-water temperature data for the Tuolumne (Figure 10) and Merced rivers until new models can be developed. It is anticipated that summer flows will range between 150 and 325 cfs depending on air temperatures and the desired length of river with suitable water temperatures.

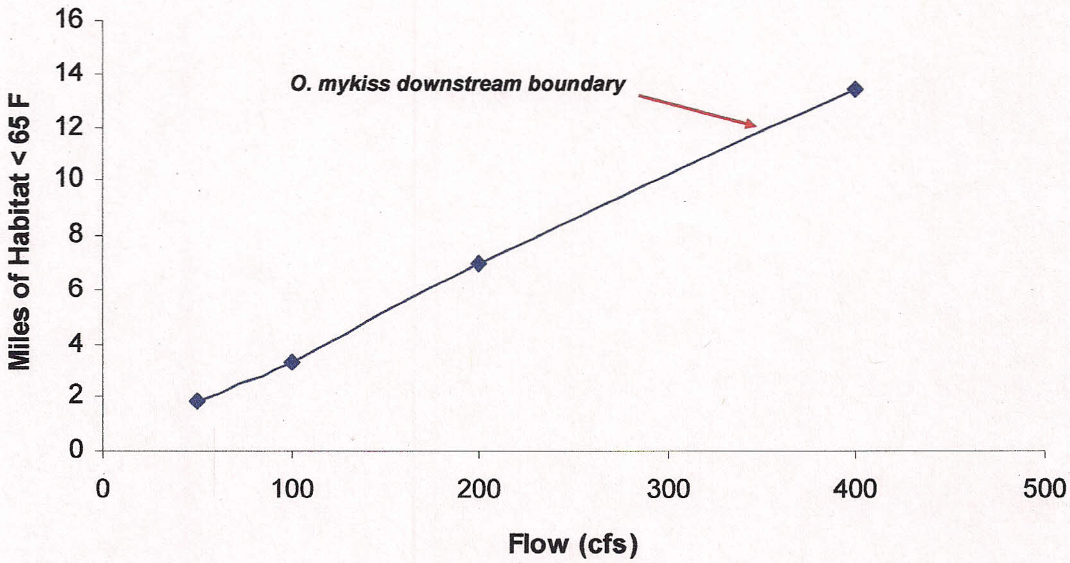


Figure 10. Relationship between the flow from La Grange Dam and the amount of habitat with water temperatures less than 65°F in the Tuolumne River based on a simple water temperature model (EA Engineering, Science, and Technology 1991).

9. The effect of Delta Exports rate reductions on Chinook salmon production

Export rates at the State's Harvey O. Banks pumping facilities (SWP) and the Federal pumping facilities at Tracy (CVP) have been substantially reduced during the VAMP period (typically April 15 to May 15) since 1996 to improve the survival of outmigrating smolts. However, the numbers of recruits-per-spawners in the Stanislaus and Tuolumne rivers are similar since the export reductions began in 1996 compared to the years when exports were high prior to 1996 (Figures 11 and 12). This suggests that reducing exports below 400% of Vernalis flows for 31 days has had no detectable affect on adult recruitment. If true, experimental water transfers that increase flows in the San Joaquin Basin tributaries as prescribed above could be captured at the SWP and CVP pumping facilities without affecting the expected increase in salmonid recruitment.

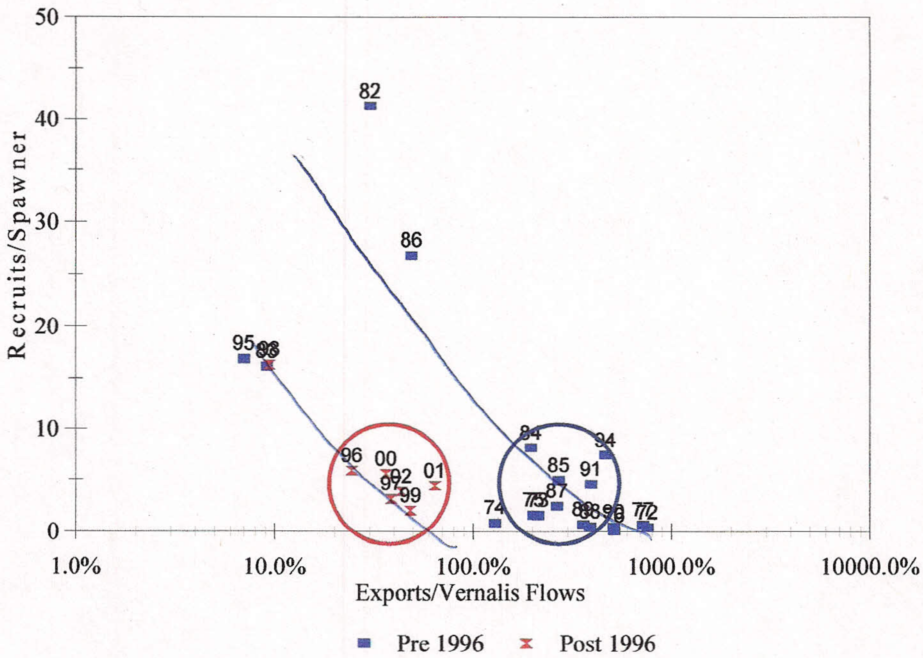


Figure 11. The relationship between the number of fall-run Chinook salmon recruits/spawner to the lower Stanislaus River and the average ratio of combined CVP and SWP exports to the flow in the San Joaquin River at Vernalis between 15 April and 15 May from 1972 to 2002. Exports were reduced during this period since 1996 (Blue Symbols) to improve the survival of outmigrating smolts.

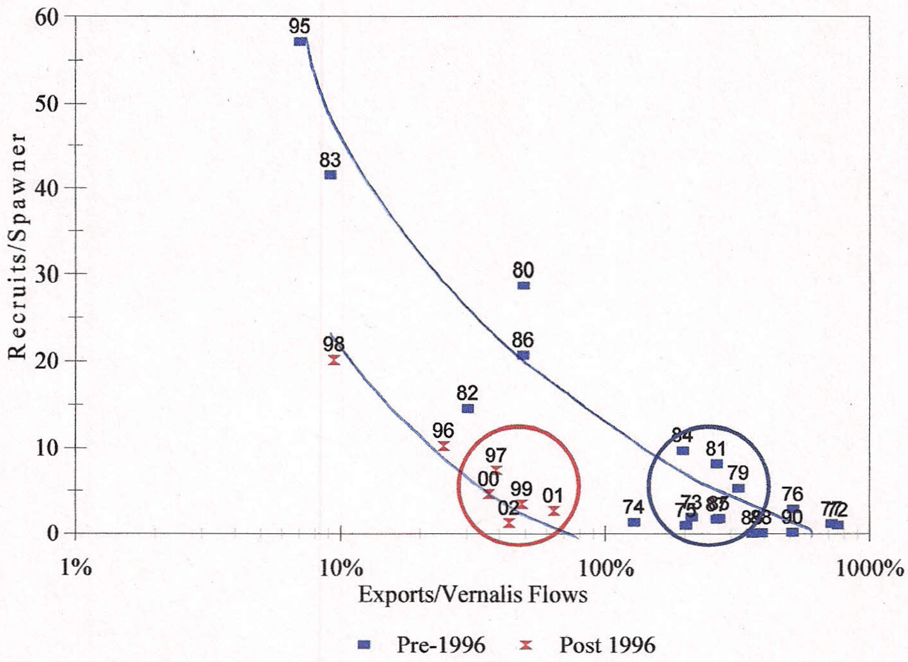
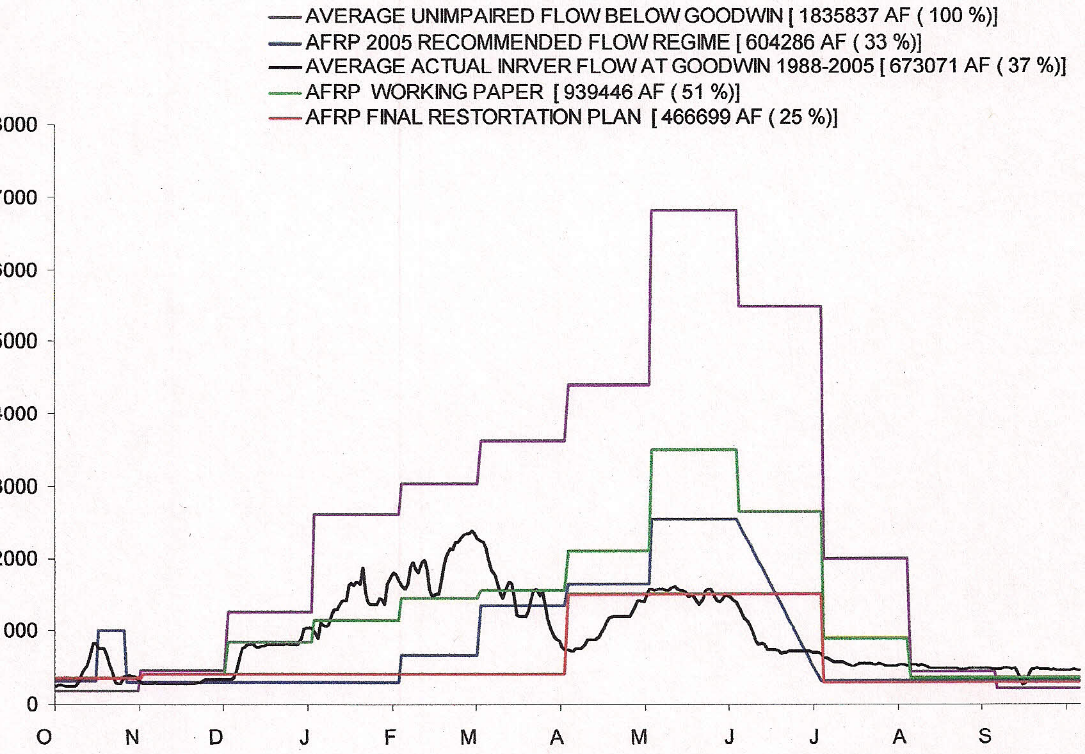


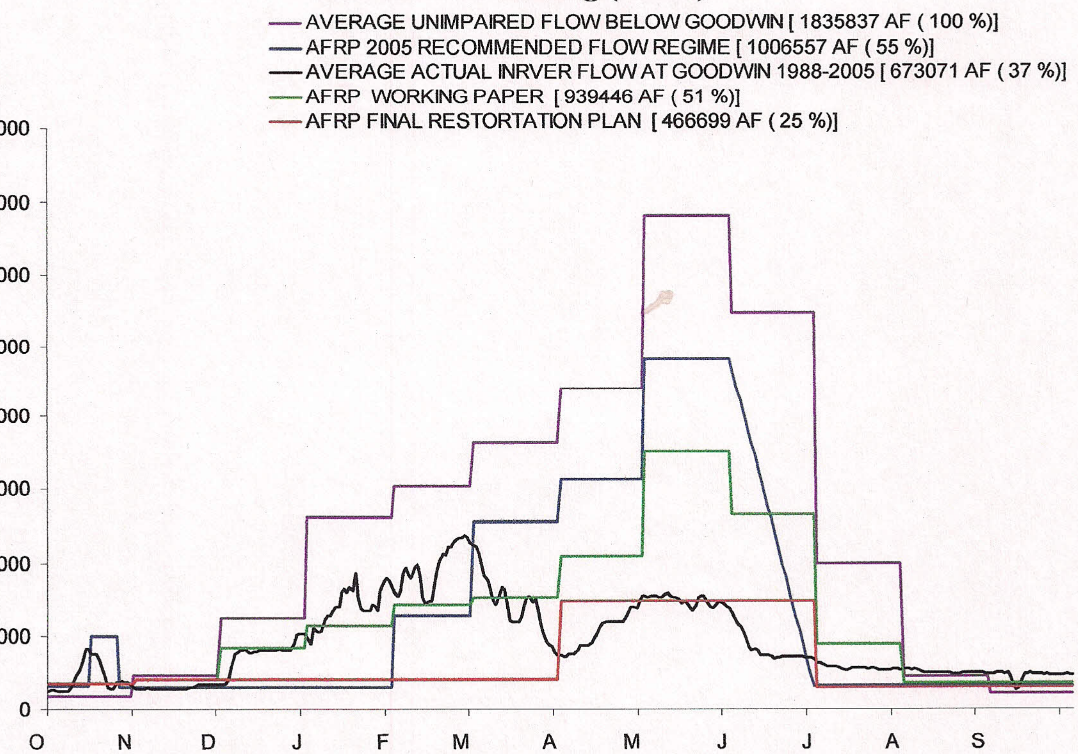
Figure 12. The relationship between the number of fall-run Chinook salmon recruits/spawner to the lower Tuolumne River and the average ratio of combined CVP and SWP exports to the flow in the San Joaquin River at Vernalis between 15 April and 15 May from 1972 to 2002. Exports were reduced during this period since 1996 (Blue Symbols) to improve the survival of outmigrating smolts.

10. Comparison of Flow Schedules: Stanislaus River

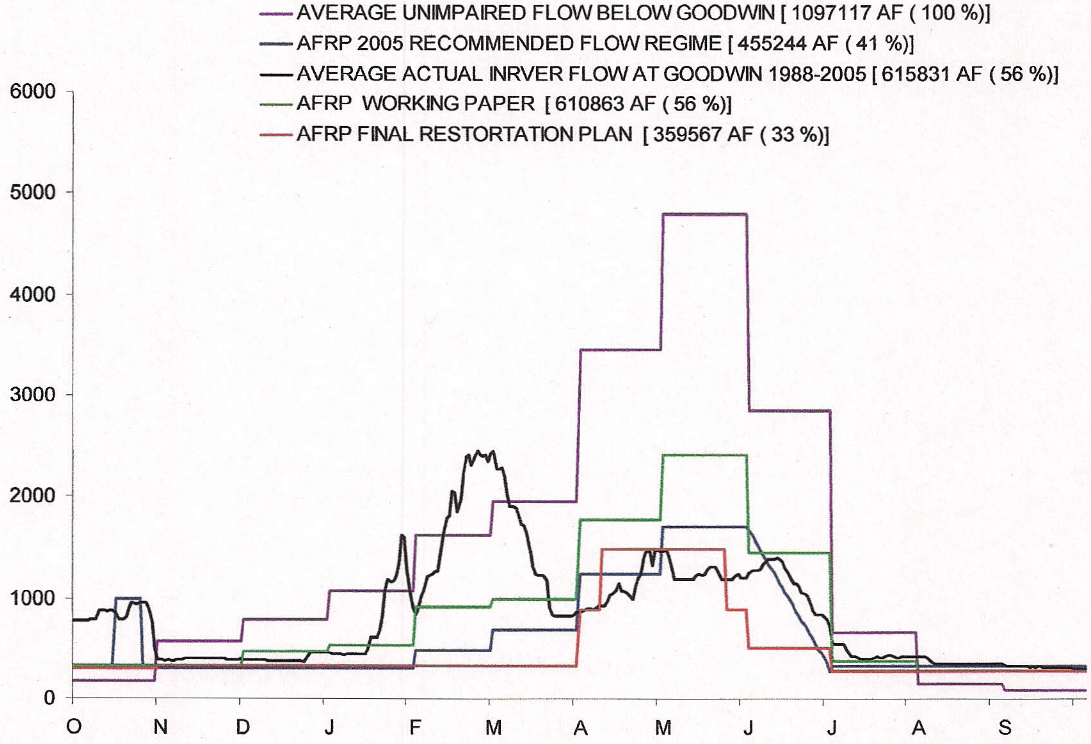
Wet Year – 69% Increase



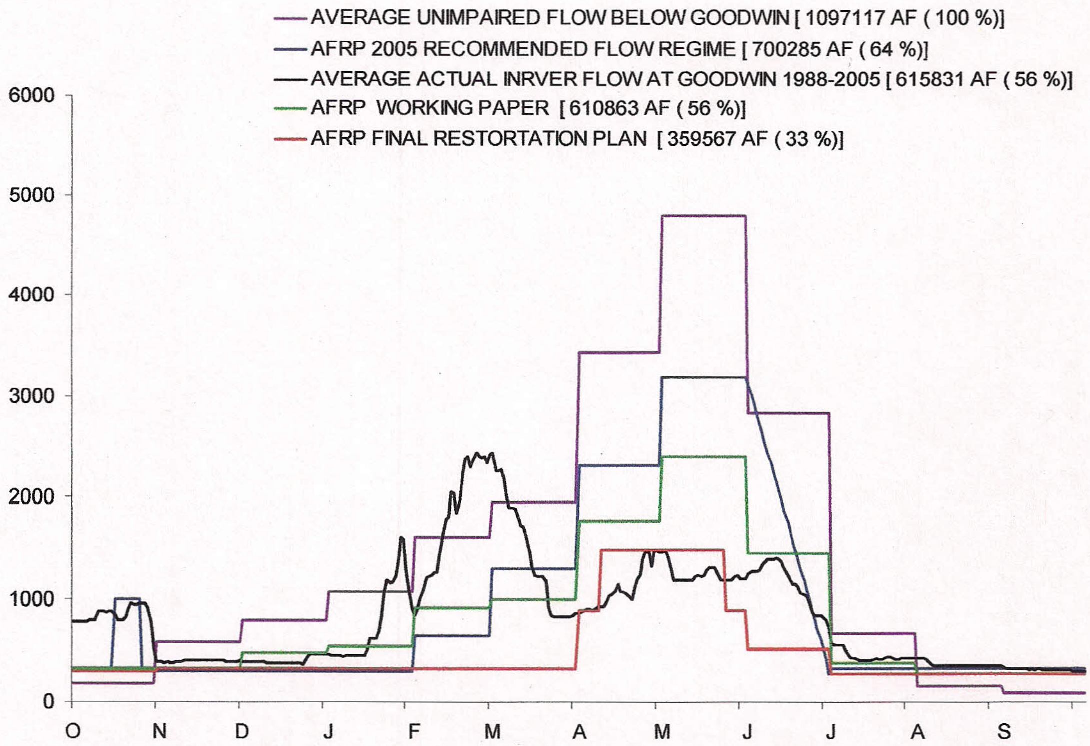
Wet Year – Doubling (114%)



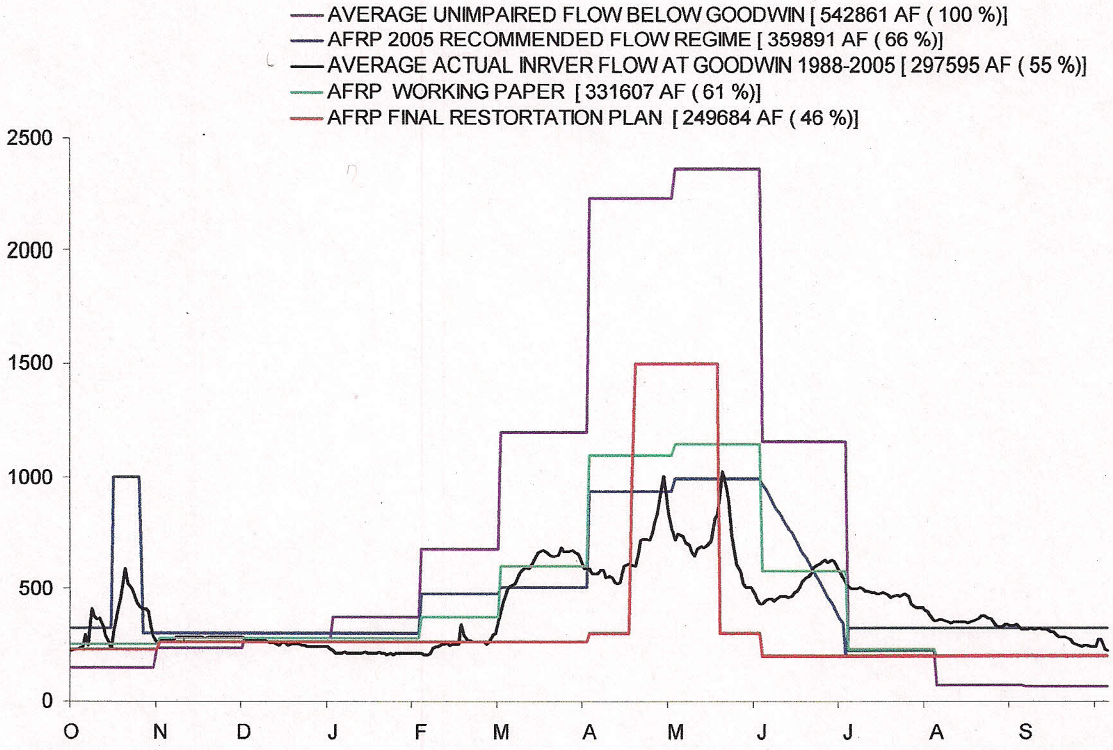
Stanislaus River: Normal Year – 69% Increase



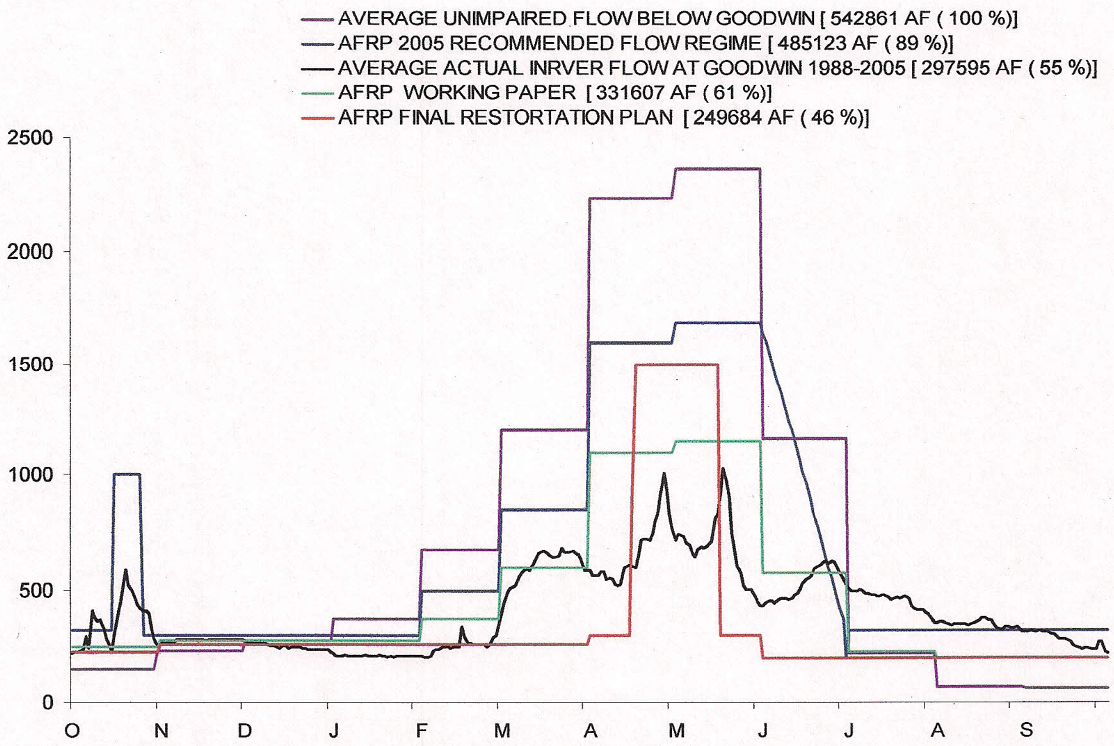
Normal Year – Doubling (114%)



Stanislaus River: Dry Year – 69% Increase

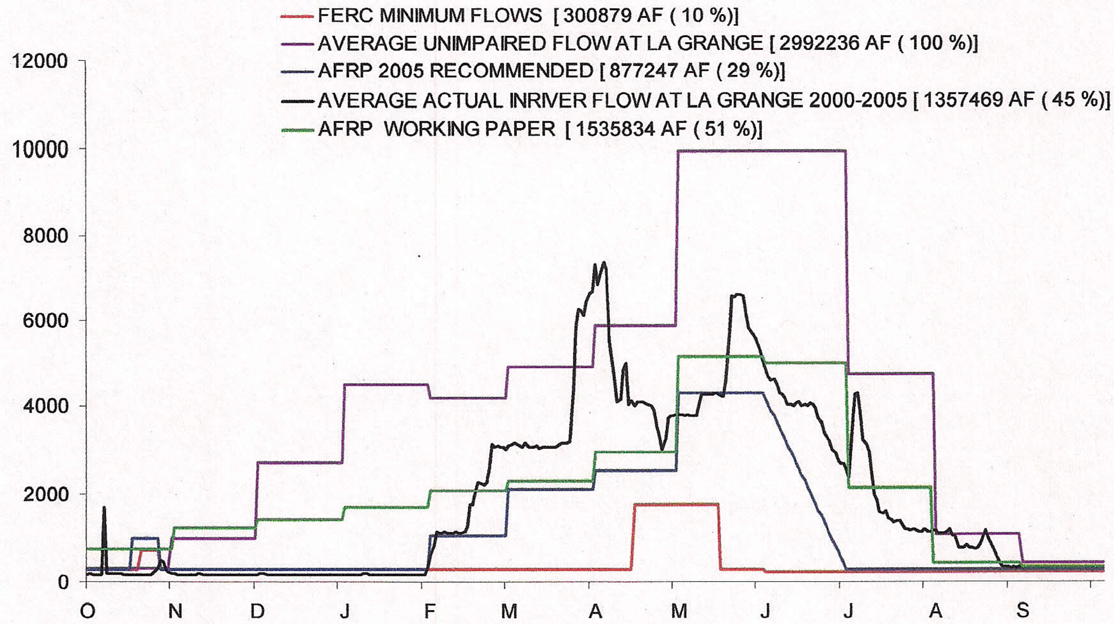


Dry Year – Doubling (114%)

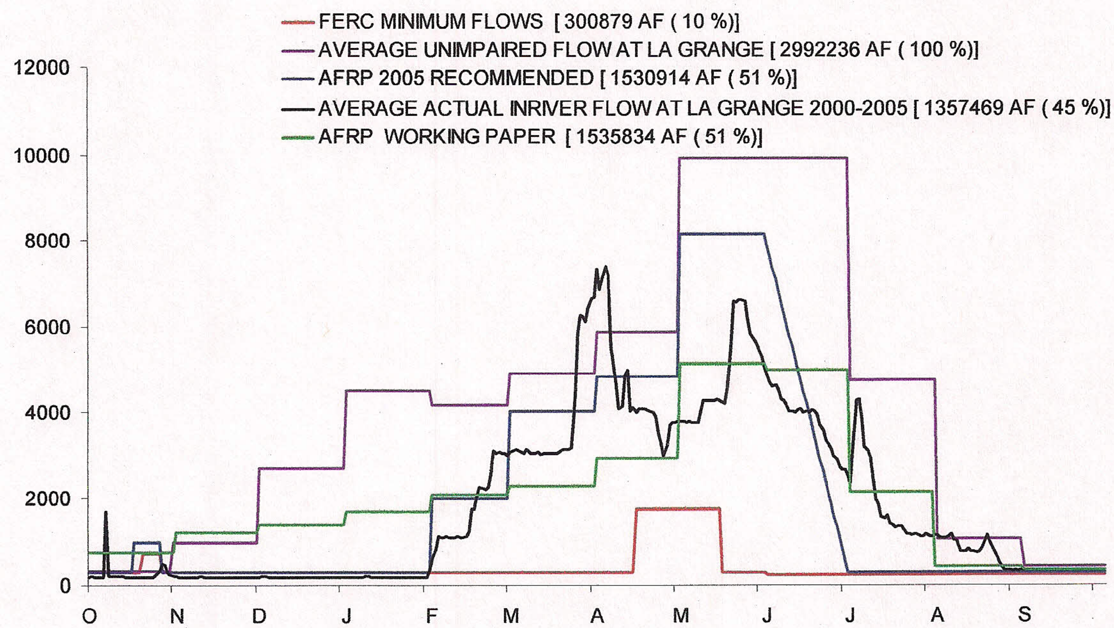


11. Comparison of Flow Schedules: Tuolumne River

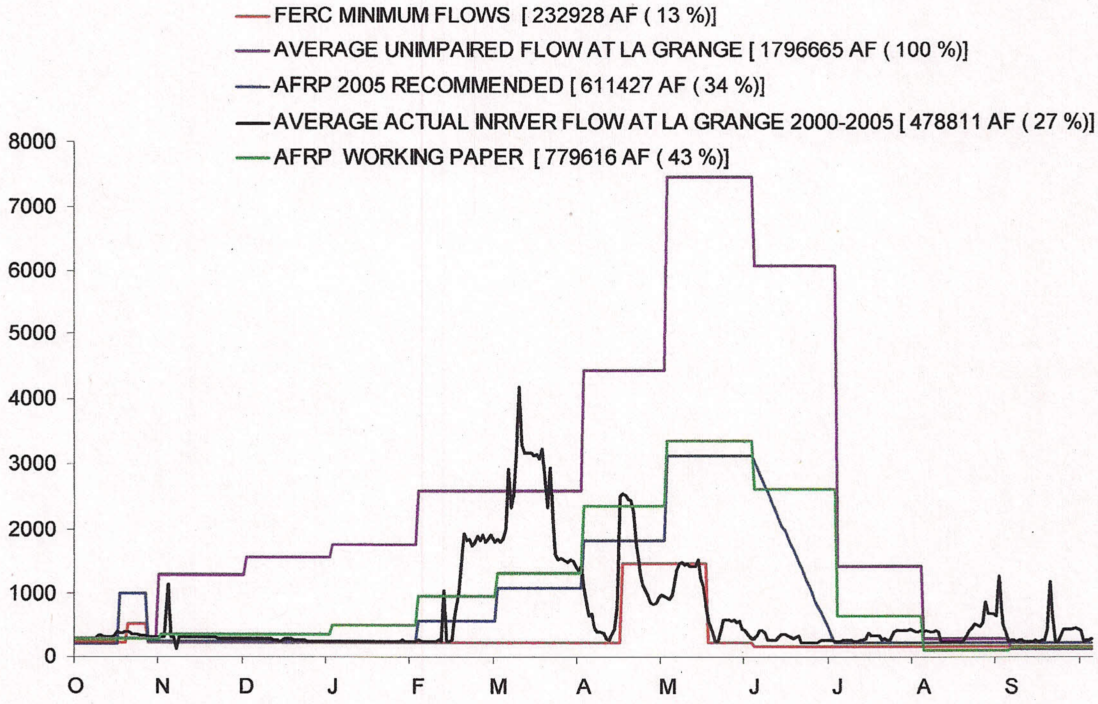
Wet Year – 42% Increase



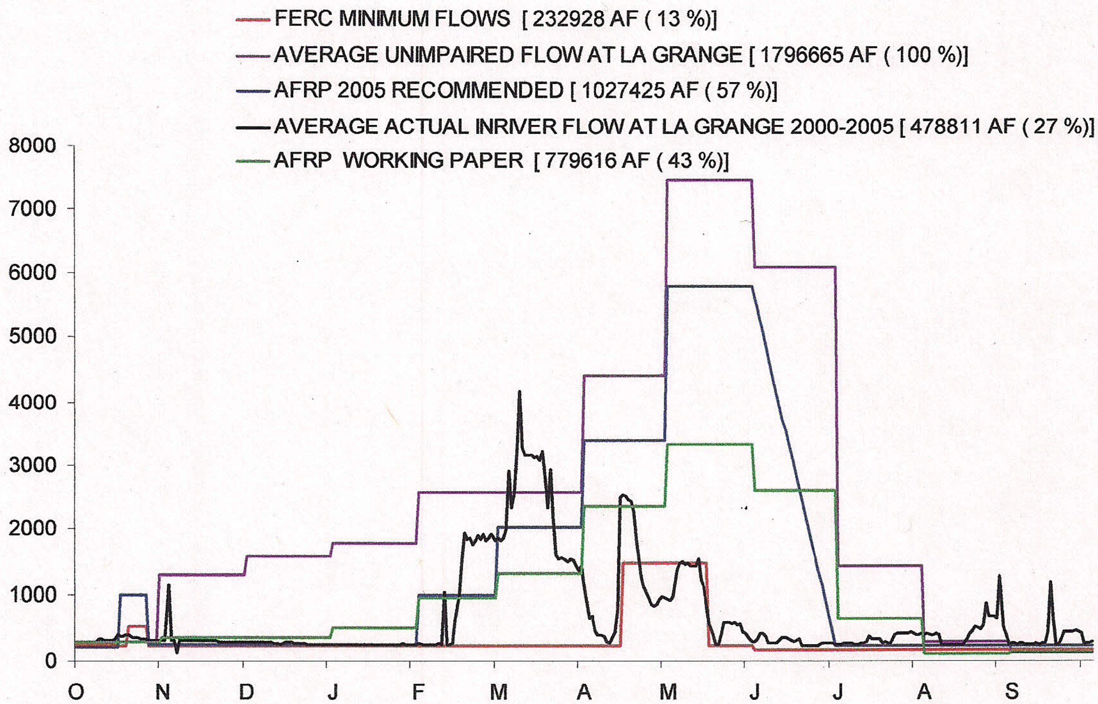
Wet Year – Doubling (86%)



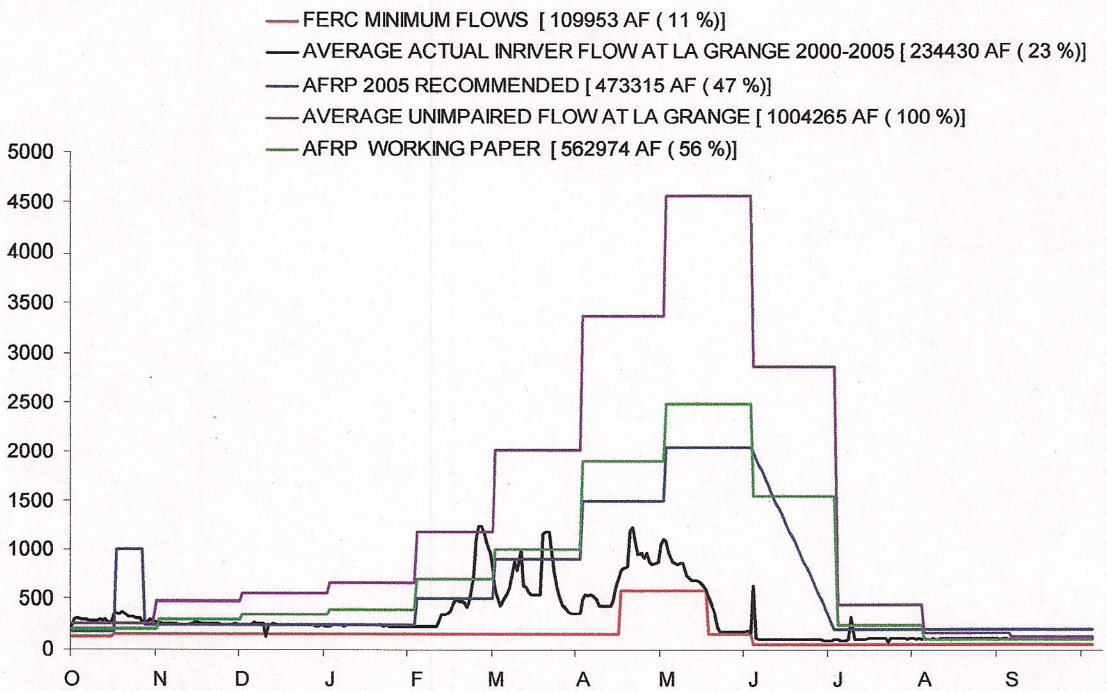
Tuolumne River: Normal Year – 42% Increase



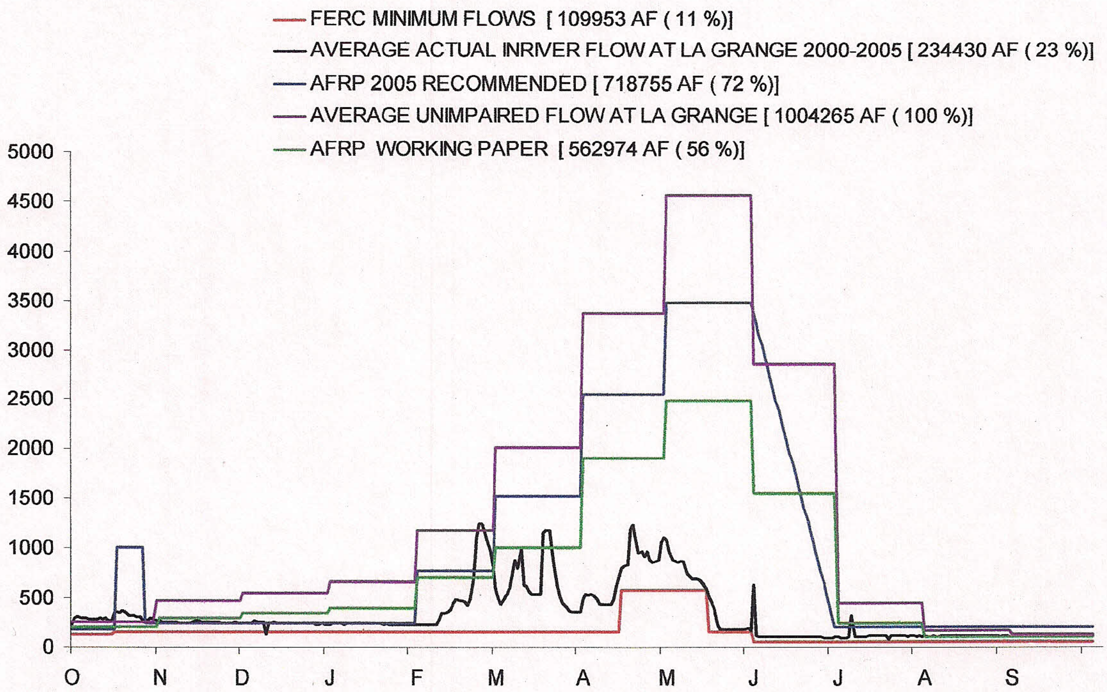
Normal Year – Doubling (86%)



Tuolumne River: Dry Year – 42% Increase

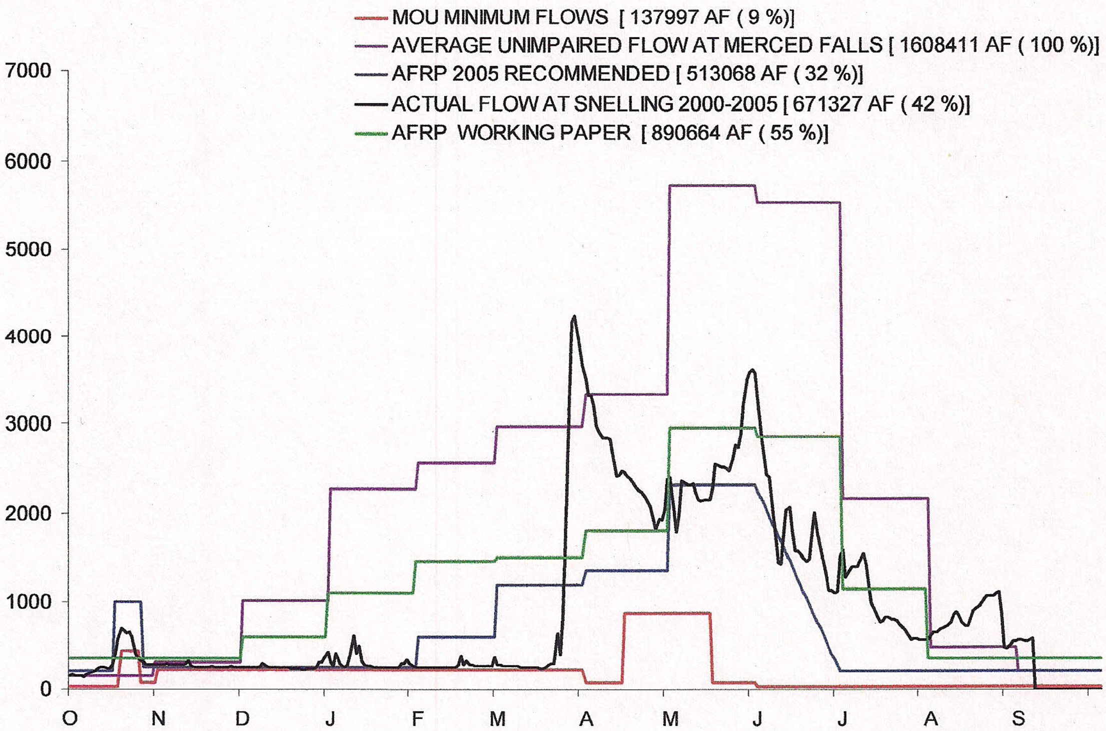


Dry Year – Doubling (86%)

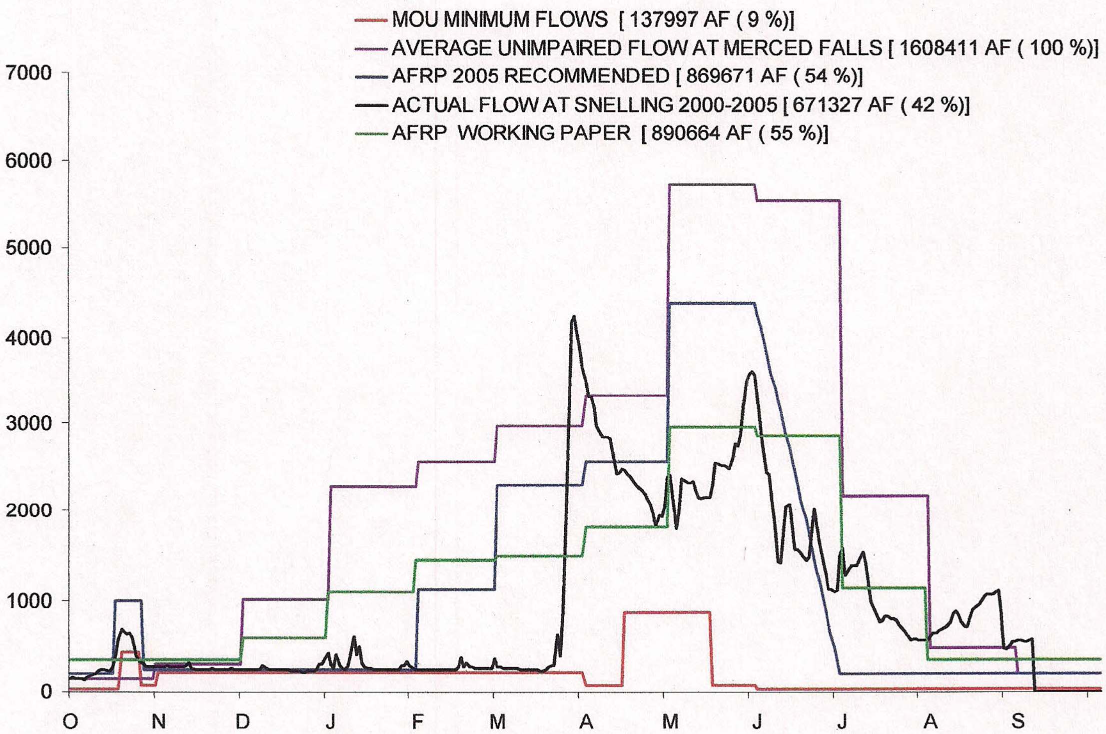


12. Comparison of Flow Schedules: Merced River

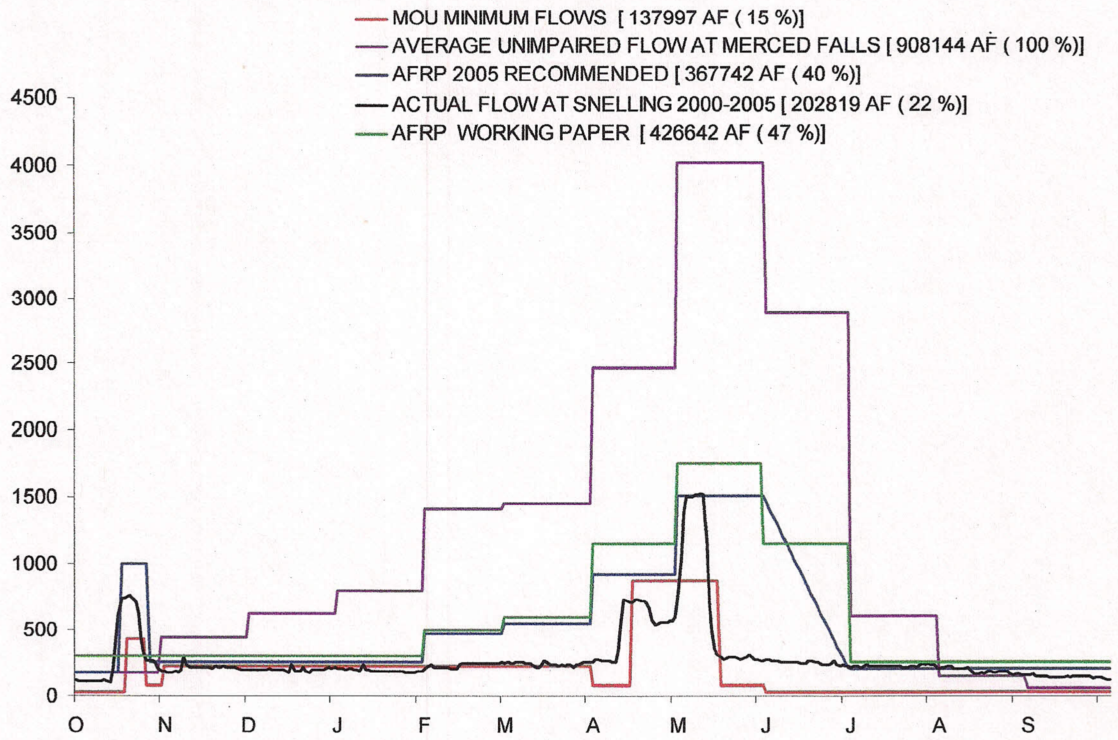
Wet Year – 85% Increase



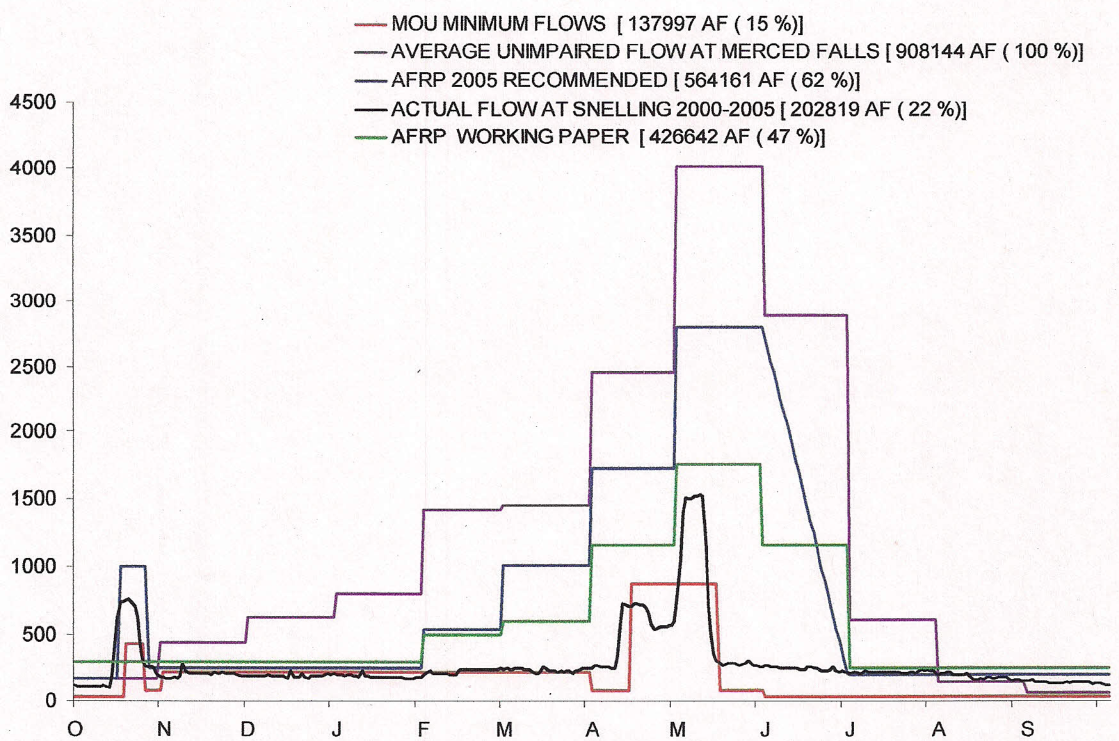
Wet Year – Doubling (134%)



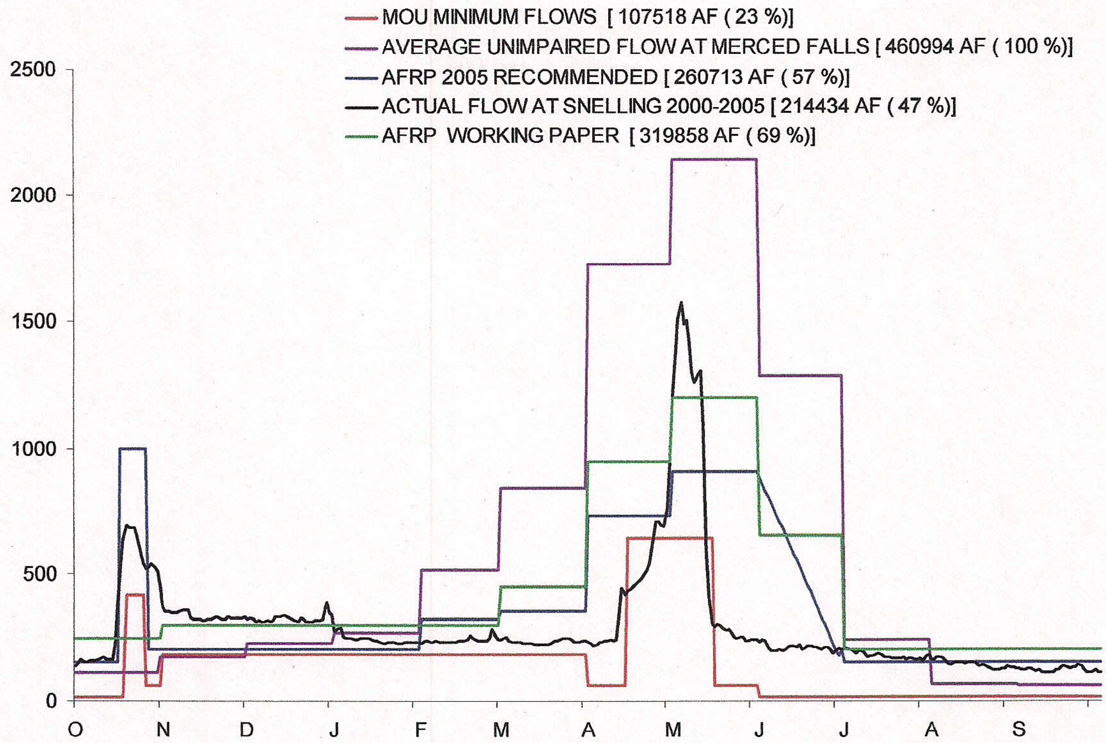
Merced River: Normal Year – 85% Increase



Normal Year – Doubling (134%)



Merced River: Dry Year – 85% Increase



Dry Year – Doubling (134%)

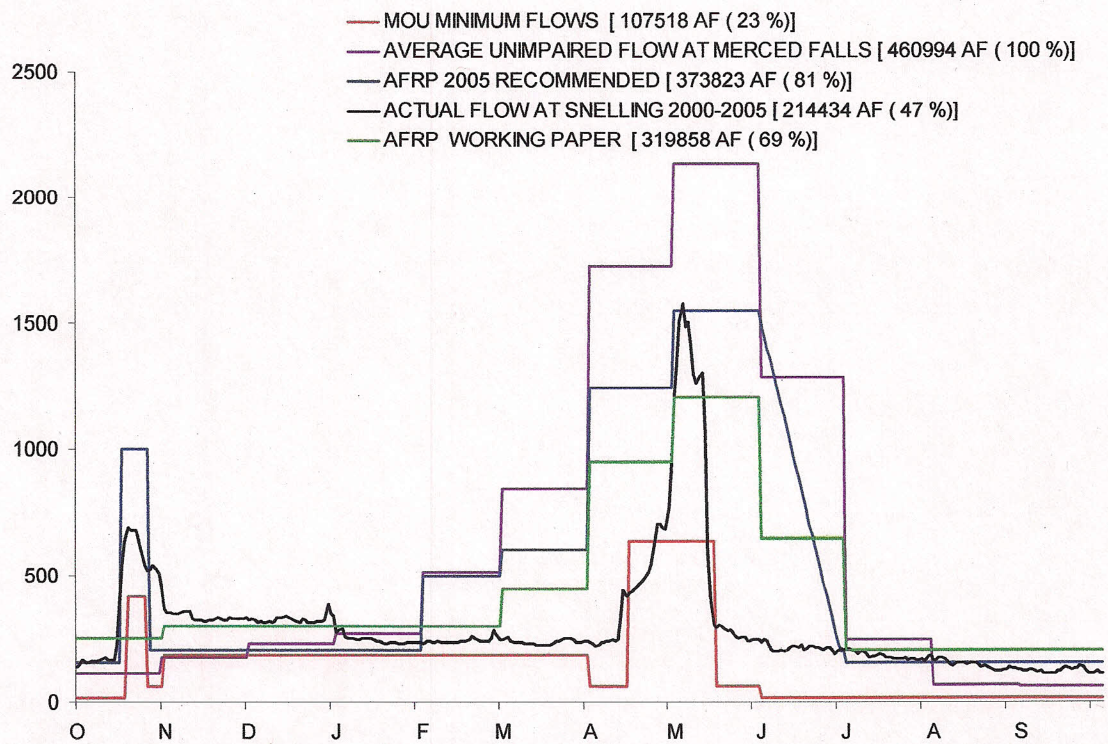


Table 3. The total annual volume of water (acre-feet) and percentage of unimpaired flows required to increase Chinook production by an average of 53% and 100% in the Stanislaus, Tuolumne, and Merced rivers.

	WET	ABOVE NORMAL	BELOW NORMAL	DRY	CRITICAL
53% Increase					
Stanislaus	604,286	487,578	422,911	384,882	334,899
	33%	*38%*	*48%*	*60%*	*73%*
Tuolumne	877,247	673,275	549,579	510,996	435,634
	29%	*32%*	*37%*	*44%*	*50%*
Merced	513,068	394,518	340,966	279,861	241,566
	32%	*38%*	*47%*	*52%*	*61%*
Doubling					
Stanislaus	1,006,557	785,985	614,584	525,231	445,016
	55%	*62%*	*70%*	*82%*	*97%*
Tuolumne	1,530,914	1,169,192	885,659	783,854	653,656
	51%	*55%*	*59%*	*68%*	*76%*
Merced	869,671	624,749	503,572	404,055	343,591
	54%	*59%*	*69%*	*75%*	*86%*

Appendix 1

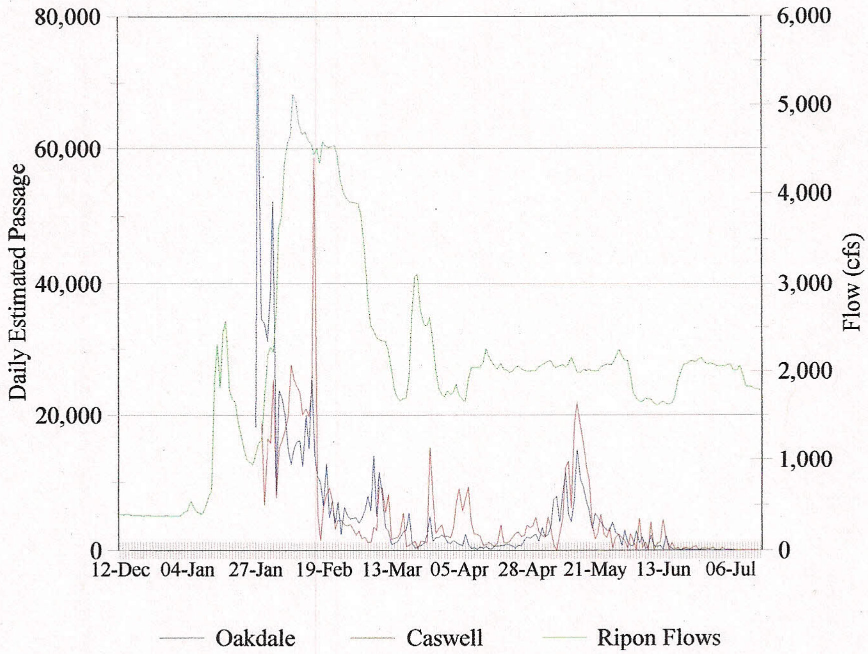


Figure 1. The relationship between the estimated daily passage at the Oakdale and Caswell Park screw traps and the mean daily flow at Ripon in the Stanislaus River between 12/12/97 and 7/1598, a wet year. Overall juvenile survival between the Oakdale and Caswell traps was 95% in 1998.

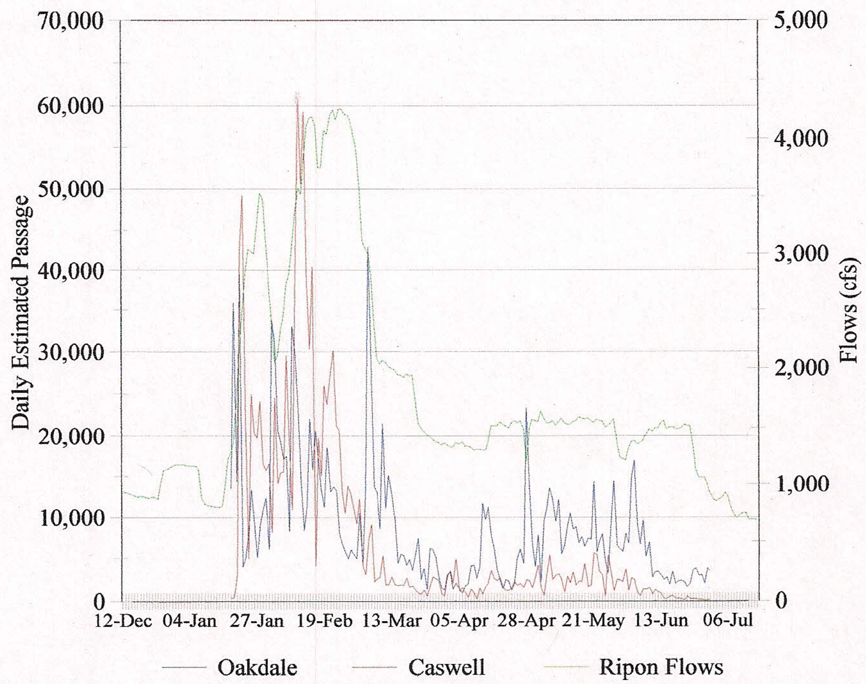


Figure 2. The relationship between the estimated daily passage at the Oakdale and Caswell Park screw traps and the mean daily flow at Ripon in the Stanislaus River between 12/12/98 and 7/15/99, an above normal year. Overall juvenile survival between the Oakdale and Caswell traps was 83% in 1999.

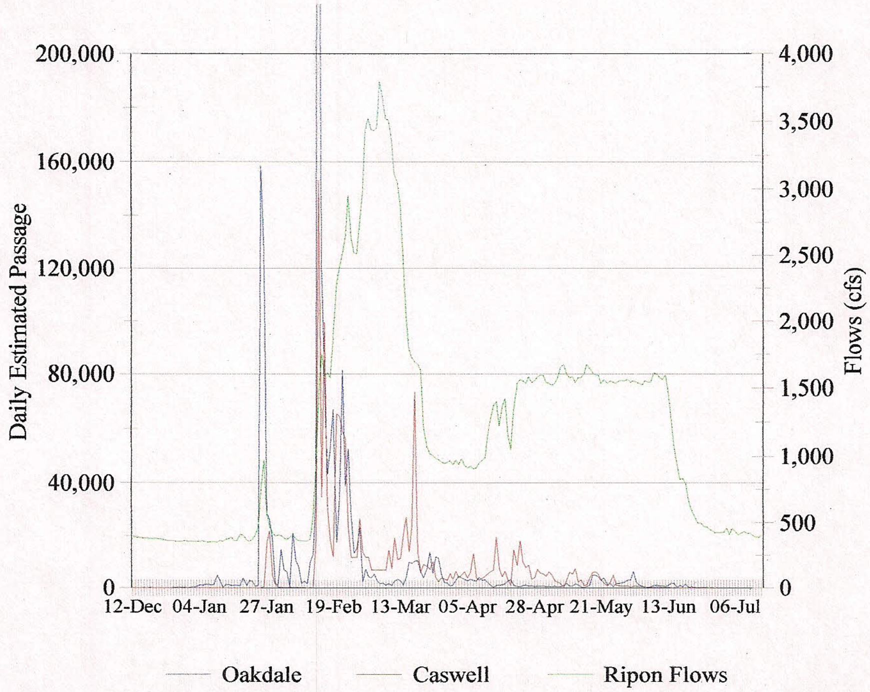


Figure 3. The relationship between the estimated daily passage at the Oakdale and Caswell Park screw traps and the mean daily flow at Ripon in the Stanislaus River between 12/12/99 and 7/15/00, an above normal year. Overall juvenile survival between the Oakdale and Caswell traps was 74% in 2000.

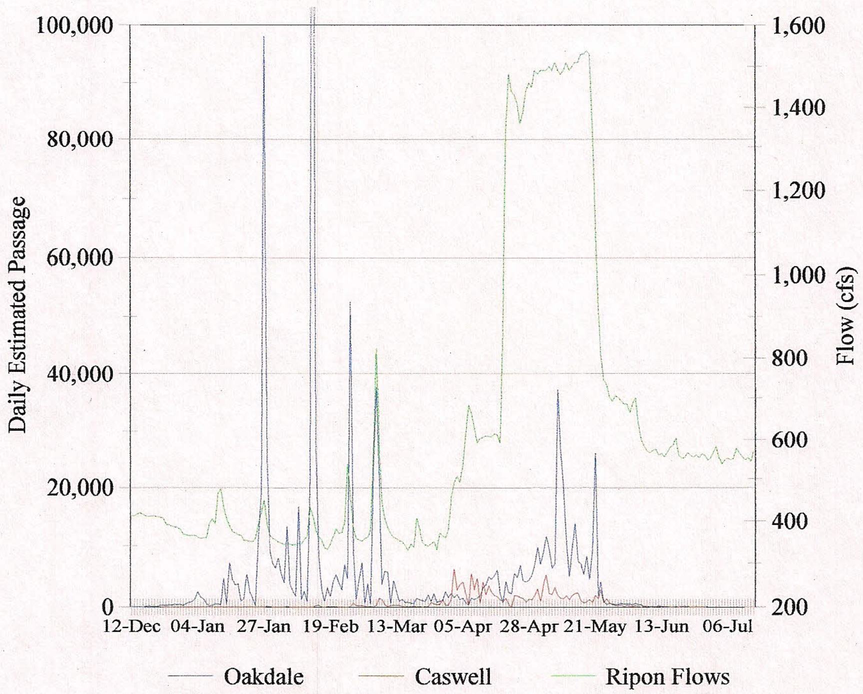


Figure 4. The relationship between the estimated daily passage at the Oakdale and Caswell Park screw traps and the mean daily flow at Ripon in the Stanislaus River between 12/12/00 and 7/15/01, a dry year. Overall juvenile survival between the Oakdale and Caswell traps was 11% in 2001.

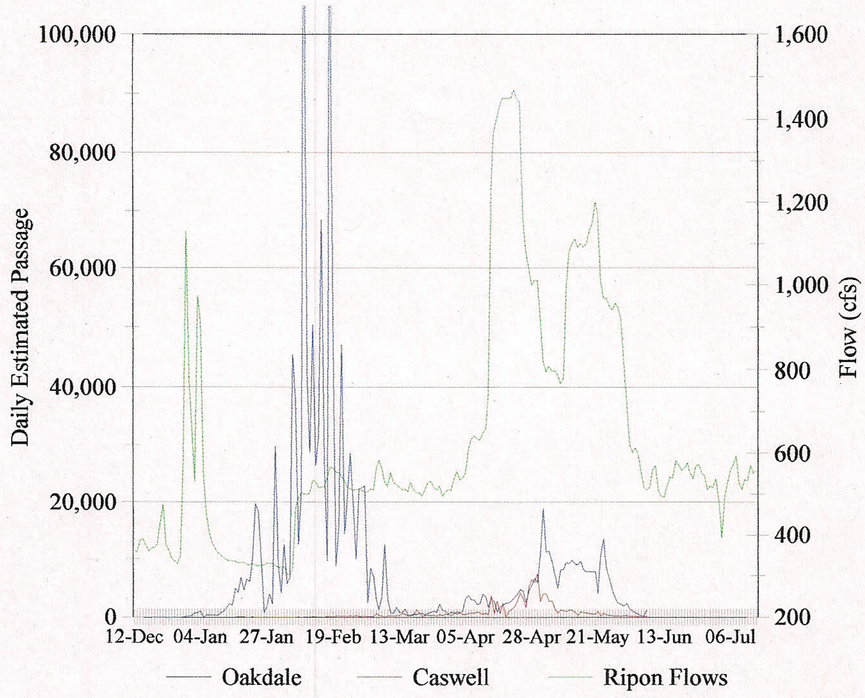


Figure 5. The relationship between the estimated daily passage at the Oakdale and Caswell Park screw traps and the mean daily flow at Ripon in the Stanislaus River between 12/12/01 and 7/15/02, a dry year. Overall juvenile survival between the Oakdale and Caswell traps was 7% in 2002.

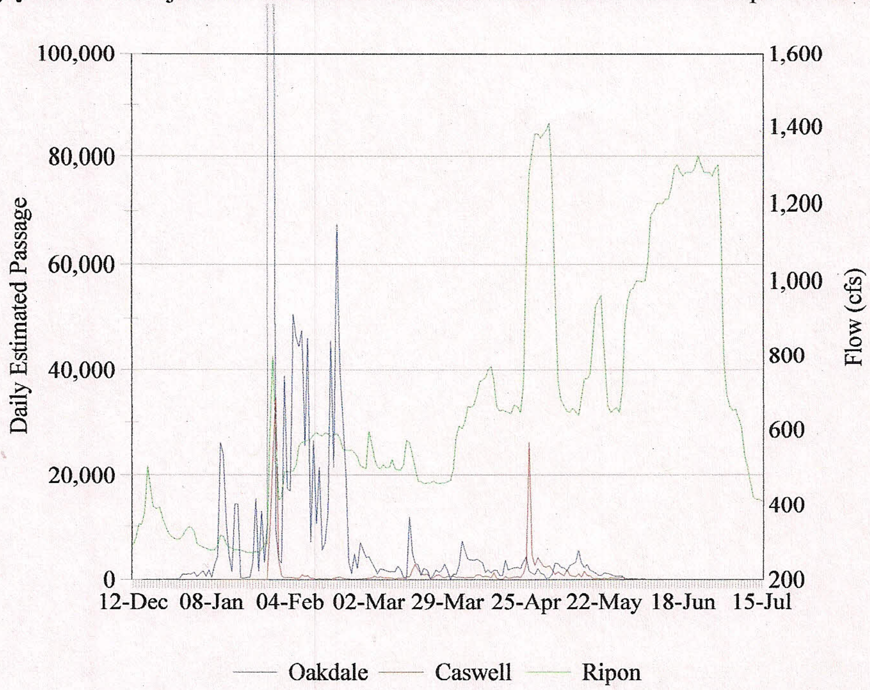


Figure 6. The relationship between the estimated daily passage at the Oakdale and Caswell Park screw traps and the mean daily flow at Ripon in the Stanislaus River between 12/12/02 and 7/15/03, a below normal year. Overall juvenile survival between the Oakdale and Caswell traps was 11% in 2003.

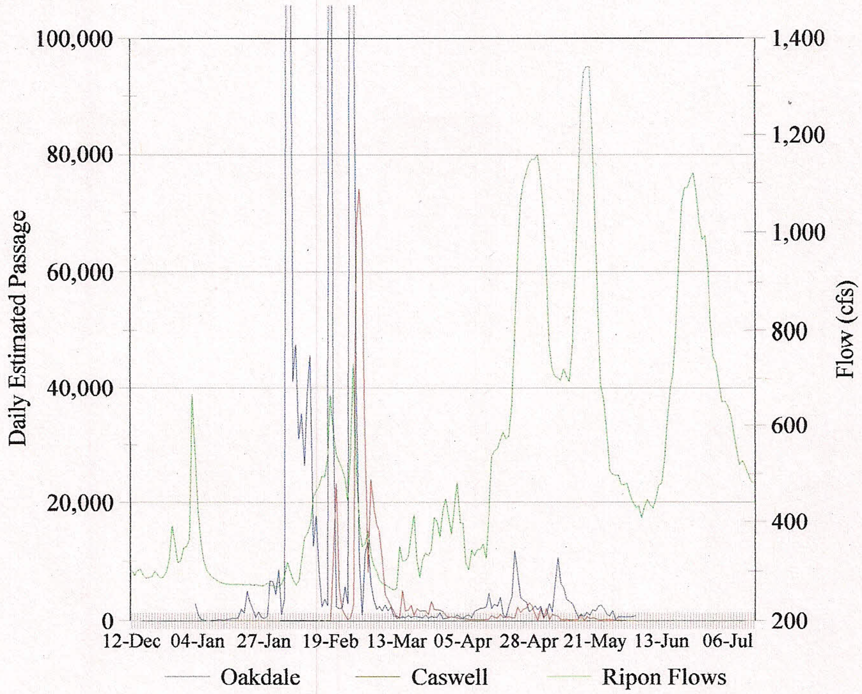


Figure 7. The relationship between the estimated daily passage at the Oakdale and Caswell Park screw traps and the mean daily flow at Ripon in the Stanislaus River between 12/12/03 and 7/15/04, a dry year. Overall juvenile survival between the Oakdale and Caswell traps was 30% in 2004.