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STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME

FISH BULLETIN 151

MIGRATIONS OF ADULT KING SALMON *Oncorhynchus tshawytscha* IN THE SAN JOAQUIN DELTA

As Demonstrated by the Use of Sonic Tags

by

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ABSTRACT

Each fall, king salmon, *Oncorhynchus tshawytscha*, bound for the Sacramento and San Joaquin River systems, pass through the Sacramento-San Joaquin Delta. Starting in 1961, salmon runs of the San Joaquin, but not of the Sacramento, suffered a disastrous collapse, probably due to water conditions in the San Joaquin part of the Delta. A partial recovery started in 1964. An annually recurring oxygen block caused by pollution in the south-eastern part of the Delta, plus reversal of direction of flow in all three major north-south channels of the San Joaquin (southern) part of the Delta, were believed responsible for the collapse. In the eastern channel, flow reversal which lasts into the salmon migration period occurs only in exceptionally dry falls such as 1961; in the other channels it occurs annually. Reversal is caused by operation of a 4,600 cfs capacity pumping plant which pulls Sacramento River water south through channels that normally carry San Joaquin water north. From 1964 through 1967, salmon tagged with sonic tags were released in the central part of the Delta to determine their reaction to low oxygen levels and reversed flows. Electronic equipment enabled us to follow tags by boat and to record their movement past fixed points. Salmon avoided water with less than 5 ppm dissolved oxygen by staying farther downstream until the oxygen block cleared. Temperatures over 66° F. had a similar but less sharply defined effect. In 1964, pumped water and partial closure of one major west-flowing channel were used to force extra water through the polluted area and break up the oxygen block. At present pumping rates, this method is practical in dry years, but is not needed in normal or wet years. Relatively few fish used either of two western channels which had reversed flows but would have led them to their destination. The pattern of salmon movement is complicated by a large flow of Sacramento River water which diverts through the Delta Cross Channel and Georgiana Slough and flows successively through the Mokelumne and San Joaquin Rivers and back into the Sacramento. Some Sacramento salmon go upstream by this route. A second large pumping plant (10,000 cfs capacity) has recently been completed, and will greatly increase flow reversal problems until a closed canal system (such as the proposed Peripheral Canal) is used to conduct Sacramento River water to the two large pumping plants.

ACKNOWLEDGMENTS

This project could not have been completed without help from many people, both Department and non-Department of Fish and Game employees.

We are particularly grateful to the Fish Passage Research Program, U.S. Fish and Wildlife Service, for the loan of sonic tag signal detecting equipment in 1964, and for guiding us in its use and operation throughout much of the study period. Our special thanks are due Gerald B. Collins, director of this program and James H. Johnson, Fisheries Biologist. David Smith and Lee Root of Smith-Root, Inc. (formerly Smith-Root Electronics) of Seattle, Washington developed the electronic tape recorder tag signal monitor which we used after 1964, and assisted us in preparing the sections on sonic tags and tag signal detecting equipment.

We wish to express our appreciation to the U.S. Bureau of Sport Fisheries and Wildlife for supplying adult salmon and for providing facilities at Coleman National Fish Hatchery to carry out sonic tag attachment studies in early 1966. We especially thank John Pelnar, then Superintendent of Coleman Hatchery.

We are grateful to: The U.S. Geological Survey staff in Sacramento for furnishing stream flow figures well in advance of normal publication times; the California Department of Water Resources (DWR) for supplying stream flow figures at numerous points throughout the Delta, and especially to Gerald C. Cox of DWR's Delta Studies Section for valuable information and advice on water behavior in the Delta Channels.

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We wish to offer further gratitude to all Department of Fish and Game employees who participated in the field work including: Vincent Catania, Robert Iselin, Paul Jensen, Donald Manzer, Robert Menchen, Ratzi Mercurio, John Riggs, John Rowell, John Shaver, William F. Van Woert, Phil Swartzell, and Linn Wixom.

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MIGRATIONS OF ADULT KING SALMON, *ONCORHYNCHUS TSHAWYTSCHA*, IN THE SAN JOAQUIN RIVER DELTA AS DEMONSTRATED BY THE USE OF SONIC TAGS

INTRODUCTION

California's salmon have provided an important fishery for as long as California has been a state. Commercial catches since 1916 have averaged over 7,600,000 pounds, with peaks over 13 million pounds in 1918, 1919, 1945, and 1946. More recently, ocean sportfishing for salmon has become important, not only to those indulging in it, but to commercial partyboat operators who take these sportsmen to and from the fishing grounds and supply them with tackle, bait, and fishing instructions. In several years, ocean sport catches have exceeded 150,000 salmon.

Prior to 1963, more than 90% of the salmon caught in California were king (chinook), *Oncorhynchus tshawytscha*; most of the remainder were silver (coho) salmon, *Oncorhynchus kisutch*. Most California kings originate in the Sacramento-San Joaquin River System. Salmon other than kings are a rarity in the Sacramento River System and are absent from the San Joaquin and Mokelumne systems. In the San Joaquin Valley salmon are for practical purposes all fall-run. Spring-run kings have been unable to survive below the storage dams in the San Joaquin Valley and the last good spring-run died out in the late 1940's after the construction of Friant Dam. Spring-run kings still persist in the Sacramento River and some of its tributaries, but in the river system as a whole, they are outnumbered by both fall- and winter-run kings.

Silver salmon occur in many of California's coastal streams, but most ocean caught silvers, taken off California, originate in Oregon or Washington. Larger than usual influxes of northern silvers started in 1963 and peaked in 1966 and 1967. In the latter year ocean catches of king salmon were low and were exceeded slightly in numbers, but not in weight, by the silver salmon catch. This was the only known year when silver salmon outnumbered kings in the California catches. The catch of silver salmon decreased in 1968 and again in 1969, though it was still above its pre-1963 level. If silver salmon off California are returning to their relatively unimportant status, it means the Sacramento-San Joaquin River System will again be the primary source of salmon for all commercial and sport salmon fishermen operating in the ocean waters off California.

In the Sacramento-San Joaquin River System, the Sacramento and its tributaries have always been the more important, although in many years the San Joaquin has had excellent runs of fish. The largest runs of the San Joaquin have exceeded the poorest of the Sacramento.

In 1961, an unprecedented disaster hit all the runs of the San Joaquin River System. In 1960, the total escapement had been over

53,000 fish; a good run. In 1961, it dropped to 2,550. The next two years were far worse; 560 and 320 fish, respectively.

The Sacramento runs had suffered no corresponding disaster. The escapement there had shown some drop, but it was well within normal limits. In 1960, the Sacramento runs were well above the 1953–1967 average, were a little below average in 1961, and had returned to slightly better than average by 1963.

This disaster in one river system, but not the other could not be explained by anything which had happened to the parents of the 1961 spawners. Most Sacramento and San Joaquin salmon mature at either three or four years. Presumably most males and almost all females maturing in 1961 were from the 1957 or 1958 year class. In 1957, spawning escapement was poor in both river systems (15,000 in the San Joaquin and 102,000 in the Sacramento). In 1958 it was well above average in the San Joaquin (46,000) and a little below average in the Sacramento (237,000). Survival conditions for the two groups of fish were so different that the 1961 escapement in the San Joaquin was 2,500 (a then record low), and in the Sacramento it was 247,000 (above that of the parent years). Presumably, the oceanic experience of the two groups had been quite similar and the only obvious difference between the two was that fish from the San Joaquin tributaries traveled through the southern part of the Delta and into the lower San Joaquin River, immediately south of the Delta. Sacramento fish had done neither.

In the lower San Joaquin River and southern Delta, there are continuous or frequently reoccurring conditions (i.e. pollution, low flows, and flow reversals) which could have a serious depressing effect on the salmon population.

For decades there has been a serious pollution problem originating at Stockton, on the main channel at the San Joaquin River. Most of this pollution is due to wastes from fruit and vegetable canneries. It causes an oxygen block which lasts into the fall, but eventually breaks up as the canning season nears its end and the river flow increases. Salmon cannot ascend the San Joaquin River past Stockton until this oxygen block dissipates.

Low flows have affected the fish even longer than pollution. We can be sure that they were sometimes a problem even before men started altering the flow regime with storage dams, irrigation and power diversions, return irrigation water, and power releases. Upstream from the Delta, low flows can inhibit movement and spawning of salmon. In the Delta proper the most detrimental effect on the adults is undoubtedly the worsening of the already bad pollution problem, and in increasing the frequency and duration of flow reversal.

Flow reversal became a problem after the activation of the U.S. Bureau of Reclamation's Tracy Pumping Plant in 1951. This plant has a rated capacity of 4,600 cfs, and during much of the year, takes in so much water that the major Delta channels reverse their direction of flow and carry Sacramento River water south across the San Joaquin River and on to the pumping plant. Under extreme conditions, this flow reversal includes the main channel of the San Joaquin, on the eastern side of the Delta. At these times all the San Joaquin water, together with a larger amount of Sacramento water, is inhaled by the Tracy pumps; without any of the San Joaquin water ever reaching the central part of the Delta. San Joaquin salmon entering the Delta, in these periods, and looking for water from their home stream, would be unable to find anything except Sacramento River water and would quite possibly never succeed in finding the San Joaquin River. The migration of these salmon might be blocked also if the main San Joaquin channel was the only one in the southern part of the Delta flowing in a normal direction, and it was so badly polluted that the salmon could not use it. This latter combination of circumstances occurs each summer, but usually clears up during the fall. It can be expected to get progressively worse and to last longer as the demand for water for export increases. Much of the increase in "off season" demand has come about as the result of the construction and operation of San Luis Reservoir. This 2,100,000 acre-foot reservoir is filled by pumping water from the Delta-Mendota Canal during parts of the year when the Tracy Pumping Plant would otherwise be inoperative or operating at a small fraction of its capacity. During some years this can be expected to affect the salmon runs.

As of October 1969, the State's Italian Slough Pumping Plant was in operation, but at far below capacity. Its capacity, 10,000 cfs, is more than double that of the nearby Tracy plant, but presumably it will not operate at above 6,500 cfs until the Peripheral Canal is built. By the time the State plant is operating at near 6,500 cfs, there will be a complete flow reversal every year unless preventive steps are taken.

The proposed Peripheral Canal would bring Sacramento water around the Delta to the pumping plants and prevent all reversal, but at best this facility is many years away and some of the problems it will create have not yet been solved. Prior to the completion of this canal it will be possible to prevent flow reversal in the San Joaquin past Stockton by partially blocking Old River at its upstream end (thus keeping San Joaquin water from being drawn to the pumps), and by releasing pumped water into the San Joaquin. The procedure was largely successful in 1964 and the agencies involved have formally agreed to repeat it when necessary.

Salmon pass through the Delta twice, once as fingerlings on their seaward migration and again as adults returning to spawn. If these salmon are suffering serious losses in the Delta, it could be as young, as adults, or both. The experiments described in this paper were confined to adults. The work was done in an effort to determine just what does happen when adult salmon encounter various unnatural but not uncommon conditions, such as those outlined above. With these studies we hoped to answer, at least in part, the following questions:

1. What do San Joaquin salmon do if:
   a. All flows are in the normal direction and no oxygen or temperature block exists?
   b. All flows are in the normal direction and there is an oxygen or temperature block in the San Joaquin River?
   c. The San Joaquin River is flowing in the normal direction but has an oxygen or temperature block and the flows in Old and Middle rivers are reversed?
   d. All flows are reversed?

2. What oxygen concentrations and what temperatures constitute a block in the Delta?
3. Are any number of Sacramento salmon entering the lower part of the San Joaquin River and then returning to the Sacramento?
4. What will be the effect on salmon from the vastly increased pumping in the southwest corner of the Delta as the new Italian Slough Pumping Plant approaches its full operating schedule?
5. Will installation of a barrier at the head of Old River plus supplemental releases into the San Joaquin River make conditions below Stockton suitable for salmon migration?

SOME OF THE BASIC REACTIONS THAT GOVERN THE UPSTREAM MIGRATION OF SALMON IN THE DELTA[1]

Some of the movements of salmon are well understood and others are not. The reactions that govern these movements are less understood than the movements themselves. The following have a bearing on the upstream migration of king salmon in the San Joaquin Delta:

1. Salmon which hatch in a stream and migrate from it to the ocean will return to that stream to spawn if given the opportunity.
2. Salmon recognize the water of their home stream. Although the evidence on this basic point is now very convincing, it is not yet known how much this home stream water can be diluted and still be recognized.
3. If salmon from stream A are forced to spawn in stream B, or if their eggs are hatched in stream B, the resulting descendents will return to stream B.
4. There is a small amount of "straying" to different river systems; considerably more to different tributaries.
5. If salmon are prevented from entering their home tributary, sooner or later many will move away and spawn, or attempt to spawn, elsewhere (see page 62).
6. Presumably salmon use a series of clues to find their way. If this is true, a Merced River salmon might not detect Merced River water in the ocean, but might first detect Sacramento-San Joaquin water, move upstream, recognize and enter San Joaquin water, move further upstream, recognize and finally enter Merced River water.
7. Salmon from a certain tributary often go past the mouth of that tributary and then drop back to it.
8. Reactions of salmon to reversing tidal currents are not understood.
9. Reactions of salmon to oxygen and temperature blocks are discussed in this paper.

[1] Hasler (1966) and Harden-Jones (1968) discuss salmon migrations in detail and each book contains a lengthy reference list.

WATERS OF THE SACRAMENTO-SAN JOAQUIN RIVER SYSTEM AND ITS DELTA

All salmon streams of the Sacramento-San Joaquin Valley converge into three major rivers which in turn enter a large and complex Delta. The two main Delta channels join at the extreme western part of this complex and continue towards the ocean through Suisun, San Pablo, and San Francisco bays. All salmon of the valley have to pass through the Delta on their way to the spawning grounds (Figure 1).

The Delta includes over 700,000 acres of land, 39,000 acres of water, 700 miles of navigable channels from 1,500 yards to less than 100 feet wide, 30 large below-sea-level islands surrounded by levees, and hundreds of small unleveed islands in the tortuous channels. Tidal action creates strong reversing currents throughout the Delta. These reversing flows are often many times the net flow in a channel and greatly increase the difficulty of measuring that net flow (Table 1).

By far the largest of the rivers entering the Delta is the Sacramento, which comes in from the north. The major part of the salmon of the valley spawn in the main stem of the Sacramento or in its tributaries.

The next largest stream in flow and in numbers of salmon using it is the San Joaquin River, which flows in a general northward direction and enters the southeast corner of the Delta. Salmon of the San Joaquin Valley move up the San Joaquin River but spawn in the Stanislaus, Tuolumne, and Merced rivers.

The third major river is the Mokelumne which flows in a general westerly direction, then swings northwest and enters the northeastern corner of the Delta. It almost joins the Sacramento at this point but turns south, stays east of the Sacramento, and eventually joins the San Joaquin in the midst of the maze of islands and channels. The Mokelumne can be regarded as a tributary of the San Joaquin or a tributary of the Delta. In this paper, it is treated as tributary to the Delta because its salmon problems are distinct from those of either the San Joaquin or the Sacramento. The Mokelumne River has one salmon-producing tributary, the Cosumnes, which joins it just outside of the Delta.

The greatest part of the valley's water comes from its eastern slopes and from the north. The San Joaquin and its tributaries, the Mokel-

TABLE 1

Examples of Tidal Flows * in Sacramento-San Joaquin Delta

	Flows in C.F.S.		
	Net	Maximum	Minimum
San Joaquin River at Brandt Bridge (Above Stockton) Aug. 26-27, 1954	−220	1,700	−2,300
San Joaquin River below Stockton Aug. 28-29, 1951	92	10,225	−10,800
San Joaquin River at Antioch Bridge Sept. 14-17, 1953	--	152,000	−124,000
Old River above Rock Slough July 9-10, 1953	−256	12,800	−13,100

* From Department of Water Resources (1962).

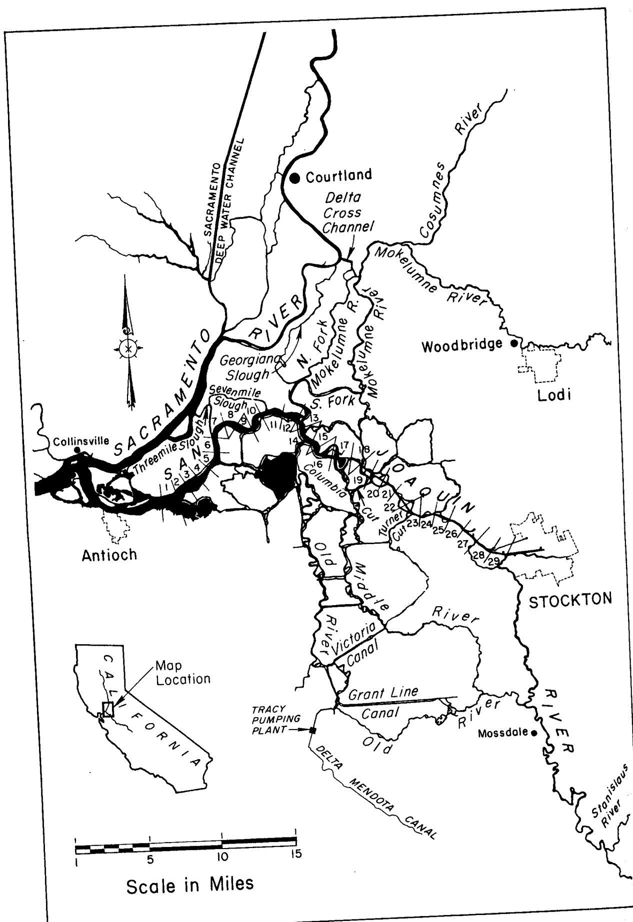

FIGURE 1. Sacramento-San Joaquin Delta and tributary streams. For easy reference, tag tracking crews divided the San Joaquin River into 29 sections between the Antioch Bridge and Stockton. Some minor and blind sloughs have been omitted.

umne and the southern Sacramento tributaries, all originate in the Sierra Nevada. The Sacramento and the tributaries that join it above Shasta Dam come from north, northeast and east of Shasta Lake (north of the Sierra Nevada).

Most of the runoff is from winter and spring rains which fall on the lower elevations or from spring and early summer melting of snows which fall on the higher elevations. The greatest part of the snow pack is on the higher elevations of the Sierra Nevada where there is a larger area at high elevations than anywhere else in the State.

Water from the Trinity River flows through tunnels into the Sacramento River, a short distance downstream from Shasta Dam.

Stream flows are largely controlled by storage dams on the Sacramento, San Joaquin, Mokelumne, and the larger tributaries. There are irrigation diversion dams on the lower part of most of the salmon streams. Most of the diversion dams have fishways; the storage dams do not.

The Sacramento River System carries more water than is used locally and sends a good flow into the Delta twelve months out of the year. Migrating salmon which stay in the Sacramento are able to move up the main stem whenever they choose. Salmon using either the Mokelumne or the San Joaquin are not always so fortunate.

There are two major storage dams on the Mokelumne, but most of the flow below the lower one is not diverted for irrigation until the stream has reached Woodbridge diversion dam, within a few miles of the Delta. Summer and early fall releases below Woodbridge Dam are so low that salmon have difficulty negotiating the channels up to the base of the dam. As the irrigation season comes to a close, there is usually enough increase in the spill over Woodbridge Dam to permit fish to get there with no difficulty. There is a good fishway over this dam. Usually the irrigation season ends entirely and the splashboards are taken out of the dam during the course of the salmon run. There have been serious localized pollution problems in the Mokelumne, but presumably the Mokelumne salmon are not affected by the pollution in the Stockton area which affects the San Joaquin portion of the Delta, or by flow reversals in the southern part of the Delta.

The Cosumnes River joins the Mokelumne between Woodbridge Dam and the Delta. As yet there is no storage dam on the Cosumnes. This stream originates at relatively low elevations and its summer flows drop to zero below the foothills. Sometimes there is insufficient flow to permit a salmon migration before December.

In the San Joaquin System, the three salmon spawning streams are blocked by storage dams. Releases from storage are picked up by diversion dams farther downstream and used for irrigation. During summer and early fall, most of the water below these diversion dams is return irrigation water and is too warm for salmonids. During this period, main stem water of the San Joaquin is also nearly 100% return water. By fall the weather cools and the irrigation season comes to a close; then the stored water is used for power generation and released into the streams. When this happens, the three San Joaquin tributaries again become suitable for spawning salmon.

During summer and early fall the San Joaquin near Stockton has an oxygen block bad enough to stop migrating salmon. In general, the lower the flows the longer this block lasts. Major contributors to the block include partially treated wastes from fruit and vegetable canneries and return irrigation water which carries enough fertilizer to trigger a bloom of algae. The problem worsens as the algae die.

Tracy Pumping Plant and Flow Reversal

Prior to 1951, San Joaquin salmon entering the Delta and encountering an oxygen block below Stockton theoretically had an alternate route available. At the southeast corner of the Delta, about 60% of the flow of the San Joaquin diverted from the main channel, flowed west in Old River and other channels for about 12.5 miles (air line), then turned north and went by way of Old and Middle Rivers until it rejoined the main channel of the San Joaquin. We know that some salmon went upstream by this route but do not know how many nor whether they were largely those which had gone downstream by that route as fingerlings (Figure 2).

In 1951, the U.S. Bureau of Reclamation activated its Tracy Pumping Plant to send Sacramento River and San Joaquin River water south in the San Joaquin Valley to the Mendota and Los Banos areas. The canal heading is at the southwest corner of the Delta where Old River stops flowing west and starts north. The pumps have a rated capacity of about 4,600 cfs, and in a normal summer or fall they withdraw far more water than the San Joaquin is carrying. The combined flows of Grant Line Canal and the east-west part of Old River carry San Joaquin water west to the pumps. That part of Middle River which is north of Victoria Canal and the north-south part of Old River reverse their direction of flow and carry Sacramento River water south to the pumps. The route is still there for any salmon, but presumably fish in this area are looking for San Joaquin water and relatively few get far enough south to find enough San Joaquin water to guide them.

Most of the Sacramento water which reaches the Tracy pumps leaves that river near Walnut Grove, goes through the short Delta Cross Channel and Snodgrass Slough into the north and south forks of the Mokelumne River. These two forks rejoin and are then joined in turn by Georgiana Slough which also carries Sacramento water from the vicinity of Walnut Grove. These combined flows then enter the San Joaquin near the mouths of Old and Middle Rivers. Part of this water enters these channels and flows to the pumps. During periods of complete flow reversal, a relatively small amount of water flows up the San Joaquin channel past Stockton. Whether there is complete flow reversal or not, the remaining water, from the mouth of the Mokelumne, goes down the San Joaquin channel and rejoins the Sacramento River near Antioch.

The Tracy Pumping plant takes nothing but San Joaquin water as long as the flow down Old River and Grant Line Canal is great enough to supply it. When the pumps are taking more than is available from the San Joaquin, the flows in the northern part of Old and Middle Rivers reverse and carry Sacramento River water southward to the pumps.

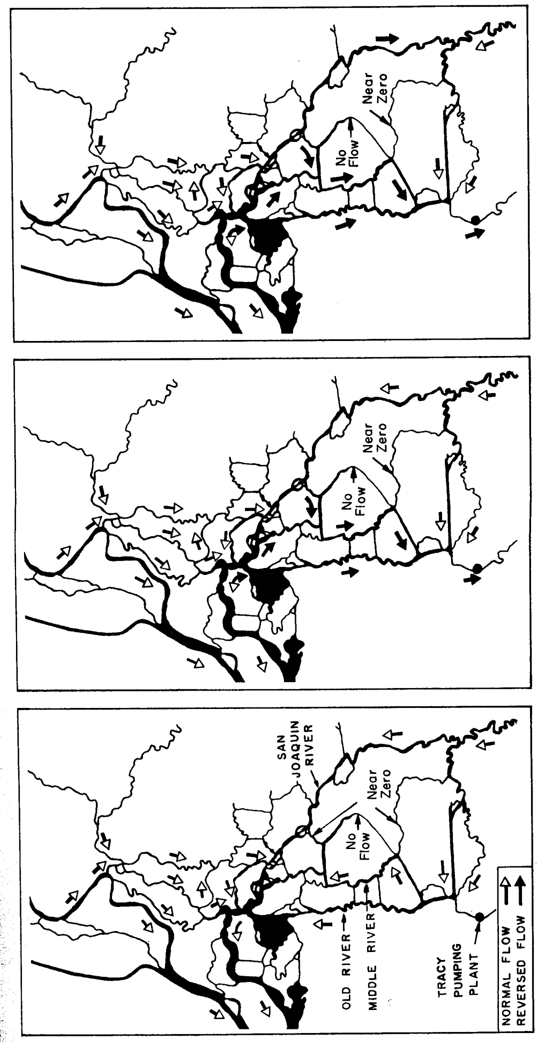

FIGURE 2. Direction of currents in the Sacramento-San Joaquin Delta. Tidal reversals not shown.
LEFT: Normal flows. Tracy Pumping Plant not taking water.
CENTER: With pumping. Old and Middle rivers have reversed, but San Joaquin River still flows normally.
RIGHT: San Joaquin River has reversed.

As the flow to the pumps increases, the proportion of the San Joaquin water which diverts into Old River increases. This results in a reduction in the flow past Stockton. After going past Stockton, part of the San Joaquin water diverts into Turner Cut, and a similar diversion takes place at Columbia Cut a few miles farther on. The remainder of the San Joaquin water reaches the mouth of Middle River, which has reversed and is flowing toward the pumps.

As long as the flow past Stockton exceeds the net southward (reversed) flow in the other channels of the southern Delta, there is no question about enough San Joaquin water reaching the mouth of the San Joaquin to guide migrating salmon. Even when the net flow towards the pumps is somewhat greater than the flow past Stockton, the tide sweeps some San Joaquin water past the mouths of Middle and Old Rivers, but as the flow towards the pumps increases or the flow past Stockton decreases, an increased proportion of San Joaquin water diverts into Turner and Columbia cuts, and decreases the amount which the tides may flush through to the confluence of the San Joaquin and Sacramento Rivers.

Flow reversal in all main channels of the southern Delta occur whenever the draft of the pumps is more than five times the flow of the San Joaquin above Old River heading. The entire flow of the San Joaquin then enters Old River, and some Sacramento water flows up the main San Joaquin channel and joins it. While this is happening, there would seem to be no chance of any San Joaquin water reaching the Sacramento River or the ocean. The tidal sweep might take some San Joaquin water a few miles toward Stockton, but it is extremely doubtful if a detectable amount would reach that city, let alone go past it, and reach the Sacramento River. In most years there has been either no flow reversal past Stockton, or none after mid-September. The State's 10,000 cfs Italian Slough Pumping Plant near the Tracy plant is now taking a relatively small amount of water. Long before it reaches full operating schedule there will be flow reversal every year and, in most years, it will continue late in the season. Under these conditions, an even more extreme form of flow reversal could occur during the salmon migration period. When the Sacramento River flow is low and the pumps are taking more Sacramento water than will flow through the Delta Cross Channel and Georgiana Slough, the balance must come through Threemile Slough and by Sacramento water flowing upstream from the mouth of the San Joaquin, thus resulting in a reversal of all flows in the San Joaquin from its mouth upstream to Old River heading. This has happened, but the condition has not lasted late enough to interfere with upstream salmon migration. We do not believe that the San Joaquin salmon could be saved if this condition were allowed to last late each fall. The fish would find no trace of San Joaquin water to guide them upstream. Such a reversal can also result in serious downgrading of water quality due to salt water intrusion, hence we can assume that everything possible will be done to prevent it. This condition goes far beyond any we have studied and we will not discuss it further.

An added complicating factor is consumptive use and other loss of water in the Delta itself. The Department of Water Resources uses the term "channel depletion" to include all such losses. The amounts involved cannot be disregarded. Between the Tracy pumps and the main channel of the San Joaquin, channel depletion in Old and Middle rivers exceeds 1,200 cfs in late July and early August, is about 650 cfs in mid-October, and reaches a low of about 150 cfs in mid-February. When determining the amount of water that gets from one point to another in the Delta, the channel depletion between the two points must always be taken into account. Available data on channel depletion give the average loss at each time of year, but it should be kept in mind that depletion at any specific time can differ quite markedly from the average. For example, during a hot, dry spell in the fall, water loss plus water usage would be considerably higher than average, whereas during a rain, the channel depletion might be negative in that the Delta islands would be adding water to the various channels. Calculated flows in the Delta are approximations for this and other reasons.

TABLE 3

Key Flows Affecting the Sacramento-San Joaquin Delta
September 15–December 15, 1964–1967

Date	Sacramento R. at Sacramento	San Joaquin R. near Vernalis	San Joaquin R. past Stockton	Mokelumne R. at Woodbridge	Cosumnes R. at McConnell	Tracy Pump. Plant
1964						
Sept.						
15	13,500	740	17	42	0	1,820
20	12,300	722	510	42	0	2,121
25	11,900	1,220	982	35	0	2,991
30	12,900	1,300	1,053	32	0	2,790
Oct.						
5	11,100	1,410	1,180	73	0	2,519
10	8,940	1,430	1,009	42	0	2,415
15	8,860	1,520	1,081	51	0	2,046
20	8,810	1,180	809	56	0	1,990
25	9,030	1,160	793	69	0	1,834
31	11,000	2,050	1,505	117	0	1,723
Nov.						
5	11,600	1,820	1,364	75	39	643
10	11,100	1,790	627	91	45	536
15	21,200	2,460	889	81	171	715
20	12,400	3,190	1,165	102	48	558
25	11,400	2,750	1,002	134	36	775
30	13,300	2,150	789	109	70	499
Dec.						
5	17,500	2,170	864	108	156	0
10	12,000	2,020	800	325	78	0
15	13,500	1,840	722	313	238	0
1965						
Sept.						
15	16,200	1,360	269	335	0	1,728
20	16,700	1,760	432	426	0	1,811
25	16,300	1,950	509	414	0	1,779
30	15,400	2,560	754	484	0	2,017
Oct.						
5	14,200	2,970	967	1,680	0	1,882
10	13,900	3,030	989	1,750	0	1,919
15	12,900	3,610	1,233	1,750	0	1,847
20	14,400	3,340	1,133	1,760	0	1,635
25	13,900	2,060	620	1,750	0	1,465
31	14,200	3,040	1,052	1,740	0	1,213
Nov.						
5	14,300	2,640	933	1,790	0	929
10	14,000	2,510	908	1,800	0	646
15	17,100	3,130	1,181	2,030	68	611
20	31,300	3,710	1,486	1,950	401	395
25	23,800	5,190	2,107	898	378	358
30	25,400	5,730	2,391	762	134	0
Dec.						
5	20,600	9,270	3,917	745	96	0
10	22,600	7,220	3,036	478	90	0
15	23,600	5,390	2,249	458	118	0
1966						
Sept.						
15	10,900	695	8	26	0	1,952
20	10,500	780	24	32	0	1,916
25	9,950	780	24	27	0	1,917
30	9,680	785	18	27	0	2,074
Oct.						
5	9,570	940	107	56	0	1,881
10	9,300	1,000	119	102	0	2,022
15	9,100	1,220	211	68	0	1,905
20	9,080	1,260	233	68	0	1,912
25	8,720	1,190	248	53	0	1,426
31	9,290	1,130	252	97	0	1,191

TABLE 3—Continued

Key Flows Affecting the Sacramento-San Joaquin Delta
September 15–December 15, 1964–1967

Date	Sacramento R. at Sacramento	San Joaquin R. near Vernalis	San Joaquin R. past Stockton	Mokelumne R. at Woodbridge	Cosumnes R. at McConnell	Tracy Pump. Plant
1966—Continued						
Nov.						
5	10,700	1,340	400	186	0	963
10	12,600	1,450	453	86	0	865
15	12,700	1,390	405	76	0	1,044
20	18,900	1,410	425	116	110	964
25	29,800	1,460	456	64	132	862
30	32,300	1,220	381	65	212	573
Dec.						
5	59,400	1,730	625	78	992	358
10	68,800	7,510	3,161	66	709	213
15	54,500	5,170	2,103	56	343	357
1967						
Sept.						
15	20,700	1,830	366	1,300	0	2,833
20	18,800	2,040	538	1,290	0	1,940
25	17,700	2,230	599	1,460	0	2,210
30	16,500	2,470	628	1,450	0	2,812
Oct.						
5	17,800	2,570	773	1,090	91	2,132
10	17,200	2,450	709	1,120	24	2,066
15	15,800	2,200	647	1,200	9.4	1,724
20	15,800	2,570	873	1,240	6.6	1,095
25	15,700	3,030	1,107	1,210	8.4	717
31	15,400	3,660	1,359	1,660	5.8	864
Nov.						
5	16,000	3,350	1,236	477	9.8	869
10	13,600	3,430	1,267	358	7.2	1,058
15	14,100	3,440	1,271	237	17	1,094
20	14,900	3,470	1,282	106	135	900
25	14,000	3,350	1,269	93	34	571
30	14,600	3,780	1,441	92	49	574
Dec.						
5	18,300	3,620	1,381	103	127	576
10	20,900	3,870	1,595	95	122	140
15	16,900	3,740	1,392	83	49	997

1964 Flow of Sacramento River Water to the Central and Southern Delta

During September, October, and November 1964, monthly net flows of 5,000 to 6,000 cfs left the Sacramento River through the Delta Cross Channel and Georgiana Slough. When this water reached the main San Joaquin channel, over half continued down the San Joaquin and rejoined the Sacramento River near Antioch. Most of the remainder was drawn up Old and Middle Rivers to the Tracy pumps.

During late September and all of October, the Tracy Pumping Plant took considerably more water than it would have in the absence of closure and supplemental pumping. It was receiving much less San Joaquin water than normal because of the closure in Old River, and more Sacramento water had to flow south to make up the difference. The result was a stronger than normal reversed flow in Old and Middle Rivers in September and October. The average November flow was weakly positive. The strong reversed flows may have reduced the likelihood of salmon migrating to the San Joaquin tributaries via the Old and Middle River routes, but this was more than compensated for by the vastly improved water conditions past Stockton.

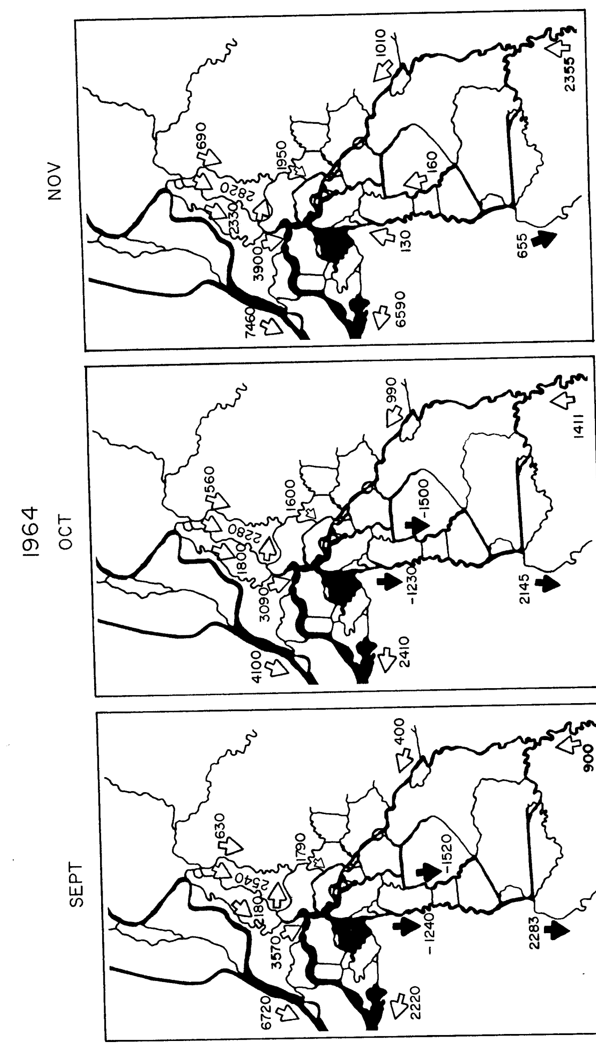

FIGURE 3. Rate (cfs) and direction of mean monthly net flows in the Sacramento-San Joaquin Delta. Fall of 1964. Open arrows indicate flows in normal direction, solid arrows indicate reversed flows.

It has been generally assumed that adult salmon require water with at least 5 ppm of dissolved oxygen if they are to function properly and move normally through an area. The present work strengthens that assumption. In 1964, the mid-depth dissolved oxygen level was dangerously low in early September, but as soon as the supplementary releases of water passed Stockton, the DO climbed above 5 ppm and remained there except for one lone reading of 4.8 ppm.

Salmon are known to avoid high temperatures, and although water releases from the Delta-Mendota Canal had a highly beneficial effect on dissolved oxygen levels, they do not appear to have cooled the water. The highest temperatures encountered below Stockton were generally above 70° F. until after October 15. On October 23 the temperature was 66° F., but it dropped to 64° F. on the 27th; later than in any of the other three years (Appendix 1).

1965 Flows of the San Joaquin River

Fall water conditions in 1965 were better than average, and there was no need for a barrier or for pumping for flow augmentation; neither was used during 1965 or in the following two years.

The early part of 1965 was relatively moist, and during the fall months, the flows of the San Joaquin River were higher than average. On September 1, the San Joaquin near Vernalis was discharging 1,180 cfs; this flow gradually increased to 2,560 by the end of the month. Mean flows in September and October were roughly twice those of 1964, even though the 1964 flows included pumped water. September flows were 1.47 times the average September (1953–1967); October and November were 1.79 and 1.80 times their respective averages.

Flows past Stockton in 1965 were lower than in 1964. Because there was no barrier, the major part of the 1965 flow went down Old River towards the Tracy pumps. On September 1, the flow past Stockton was only 132 cfs, but by the end of the month it had increased to 754 cfs. During October, it averaged 915 cfs.

1965 Flows of Sacramento River Water Into the Central and Southern Delta

At flows below 25,000 cfs, the amount of water which diverts from the Sacramento River into the Delta Cross Channel and Georgiana Slough [2] increases when the flow of the Sacramento River increases. In 1965 the Sacramento River flows were higher than in 1964, and its flows into the central Delta were greater. Early September pumping demands at Tracy were somewhat more than in 1964 but were less in late September and in October because there was no supplemental pumping. The net reversed flow in Old and Middle Rivers was much less in 1965, partly because there was no barrier and no supplemental pumping. In October, the net flow reversal in Old and Middle Rivers was only about one-fifth of that of the previous year. The average November flow in Old River was positive (Figure 4).

[2] There are gates on the Delta Cross Channel which are closed when the flows of the Sacramento River, at Sacramento, reaches 25,000 cfs. Georgiana Slough has no gates and flows there continue to increase with the river flows.

FALL WATER CONDITIONS IN THE DELTA, 1964–1967

1964 Flows in the San Joaquin River

As the fall of 1964 approached, it had been considered probable that if no preventive steps were taken, the flow of the San Joaquin River near Stockton would stay reversed into the time of the salmon migration, or the positive flows would be so low that the effects of pollution would be far worse than normal. It was further presumed that either eventuality might result in a serious block to migrating salmon.

In 1963, it had been demonstrated that pumping additional water at the Tracy plant and releasing the excess into the San Joaquin River would not sufficiently increase the positive flow past Stockton, but that such an increase could be obtained by partly closing Old River at its head in addition to releasing water. The partial closure had been effected by sinking a large barge in Old River just below its heading (Calif. Dept. Fish and Game, Dept. Water Res. and Central Valley Reg. Water Poll. Control Bd., 1964).

In 1964, a barrier of loose rock was installed across the head of Old River on September 16, and flows in the San Joaquin above Vernalis were augmented by releases into the San Joaquin River from the Delta-Mendota Canal via the Westley and Newman wasteways. The first releases were made on September 23 and the last on November 1. It was hoped that this manipulation and augmentation of flows would eliminate the possibility of flow reversal during the salmon run, create an adequate positive flow past Stockton, and improve the water quality in the San Joaquin River below Stockton. It had most of the desired effects, but did not lower the temperature. The fish delayed their migration longer than we liked, but in all probability, not nearly as long as if closure and pumping had not been conducted (Calif. Dept. Fish and Game, Dept. Water Res. and Central Valley Reg. Water Poll. Control Bd., 1965).

After the barrier was in place, flow measurements indicated that 94% of the water was continuing down the San Joaquin towards Stockton, and only 6% was entering Old River. This was a little too effective, and local users had trouble obtaining the water they needed. The structure was modified on October 6 to allow about 20% of the San Joaquin flow to enter Old River. The barrier was removed November 5 and 6, when there was no further need for it.

The barrier affected flows at Stockton, and the water releases affected flows at both Vernalis and Stockton (Table 2.). The gaging station "near Vernalis" gives the best measure of the amount of San Joaquin water entering the Delta. From 1953–1967, the average September flow of the San Joaquin at this station was 1,138 cfs. During the first 23 days of September 1964, it varied from 700 to 930 cfs. Supplementary water was released on September 23 and presumably its full flow was reaching the gaging station by the 25th. From that date until releases were stopped on November 1, the flow varied from 1,140 to 2,120 cfs, but most of the time it was between 1,290 and 1,530 cfs. Even with the supplementary water, the actual flow "near Vernalis"

TABLE 2

San Joaquin River Flows Near Vernalis and Past Stockton Changes in Flows Resulting From Releases of Pumped Water and from Partial Closure of Old River September 15–November 15, 1964

Date		Flows near Vernalis		Flows past Stockton				
		Actual	Without pumping	Actual	Without closure or water releases	With closure but no water releases	With water releases but no closure	Pumped water released into San Joaquin R.
September	15	740	740	17	17	17	17	0
	20	722	722	510	−5	510	−5	0
	25	1,220	451	982	−40	255	87	769
	30	1,300	661	1,053	−7	453	156	639
October	5	1,410	912	1,180	92	712	245	498
	10	1,430	936	1,009	114	614	264	494
	15	1,520	1,029	1,081	192	688	330	491
	20	1,180	678	809	106	407	201	502
	25	1,160	654	793	99	388	196	506
	31	2,050	1,340	1,505	330	937	577	710
November	5	1,820	1,820	1,364	621	1,364	621	0
	10	1,790	1,790	627	627	627	627	0
	15	2,460	889	889	889	889	889	0

for all of September was only 0.79 times the 15-year average for September; October (with releases all month) was 0.86 times the average October; November (with very little supplementary water) was up to 1.16 times the average, thanks to increased natural runoff. (Table 3 and Figure 3).

At Stockton, conditions were much better than they would have been without the combination of supplemental releases and the Old River closure. Together, these two assists resulted in flows which were calculated to range from about 780 to 1,620 cfs; several times the flow which would otherwise have occurred.

The water which passed Stockton during the period of supplemental pumping included a fairly high proportion of Sacramento River water because most of the water picked up at the Tracy Pumping Plant was from that source. It had been argued that this might confuse the salmon, but apparently it did not. Salmon were moving upstream while Sacramento water was being released and continued at about the same rate after it was turned off.

Neither closure nor pumping were needed during the next three years but the agencies involved have since agreed to repeat the procedure whenever necessary. The California Department of Water Resources will install the Old River closure, the U.S. Bureau of Reclamation will pump the extra water. The California Department of Fish and Game is already hatching and rearing salmon from the San Joaquin River System and will continue this program as long as desirable.

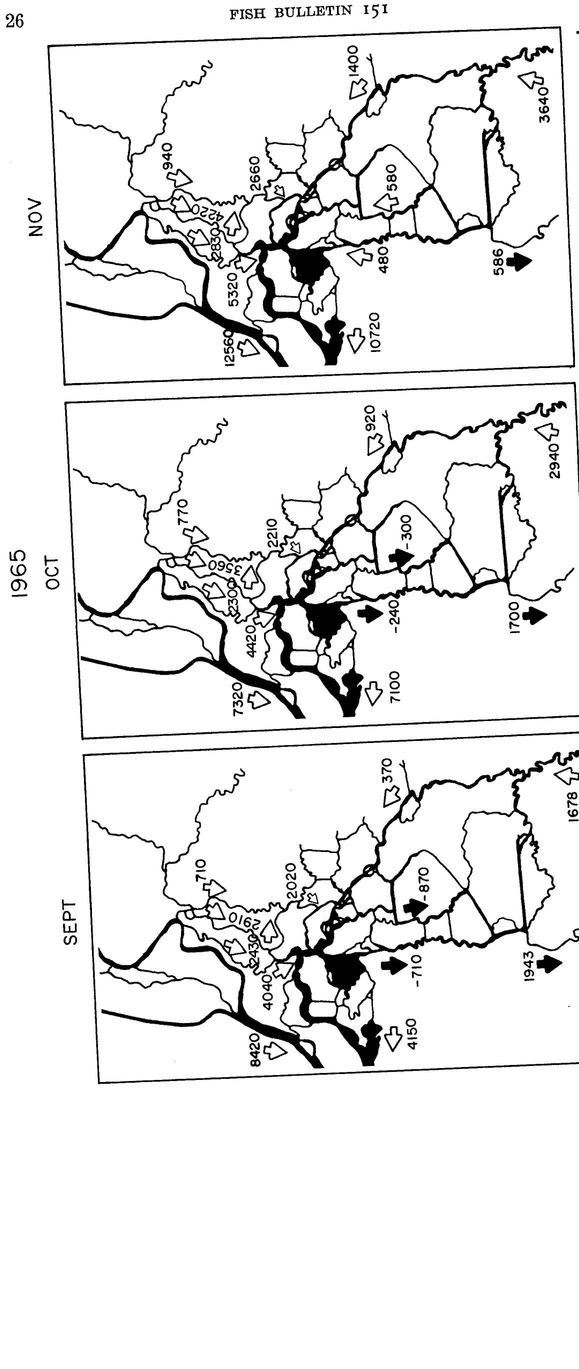

FIGURE 4. Rate (cfs) and direction of mean monthly net flows in the Sacramento-San Joaquin Delta. Fall of 1965. Open arrows indicate flows in normal direction, solid arrows indicate reversed flows.

The lowest dissolved oxygen levels encountered below Stockton were 3.3 ppm on September 22, they were above 4 ppm by September 30, and above 5 ppm on and after October 8. In 1965, the oxygen levels reached 5 ppm, 11 days later than in 1964, but about two weeks earlier than in 1967 and over three weeks earlier than in 1966.

Water temperatures in late September and early October (1965) averaged about 2° F. lower than during a corresponding period in the other three years; but as the season advanced the water cooled more slowly and temperatures were about average during the middle and late parts of the season.

1966 Flows of the San Joaquin River

Early 1966 was dry, and the fall flows of the San Joaquin River were lower and salmon were delayed longer than in any other year of this four year study. For the season as a whole, dissolved oxygen levels in 1966 probably approached the minimum under which San Joaquin salmon could be expected to make their way through the Delta, to their home streams, without excessive mortality or without large numbers abandoning the wait and ascending a relatively clean stream such as the Sacramento. It is quite possible that in 1966 some San Joaquin salmon did ascend the Sacramento (see page 61). Before 1961, salmon had made their way upstream in years when the flows of the San Joaquin were lower than in 1966, but in those earlier years the Tracy pumps had taken considerably less water in October and November.

On September 1, 1966, the flow of the San Joaquin River near Vernalis was 597 cfs and increased to 785 cfs by the end of the month. Flows in October and November averaged 1,101 and 1,330 cfs respectively. September discharges were 0.64 times those of the average September; October and November flows were 0.67 and 0.66 times their respective 1953–1967 averages.

In 1966, there were very small reversed flows past Stockton for the first half of September, followed by very small positive flows for the second half of the month. The mean September flow past Stockton was calculated to be a minus 9 cfs which is not significantly different from zero in either a statistical or a practical sense. By the end of October, the flow had increased to a positive 252 cfs and was up to 400 by November 5. It stayed close to this latter figure for the remainder of the month.

1966 Flows of Sacramento River Water Into the Central and Southern Delta

September and October flows from the Sacramento River into the central Delta via the Delta Cross Channel and Georgiana Slough were 5,100 and 4,500 cfs respectively; these were the lowest September and October flows during the four-year experiment. The mean November flow had increased to 6,850 cfs which was above average (Figure 5).

The water taken by the Tracy Pumping Plant was about average for the four years. The average flow in Old and Middle Rivers was strongly reversed in September and October, and weakly reversed in November. In the other three years, the average November flow was positive.

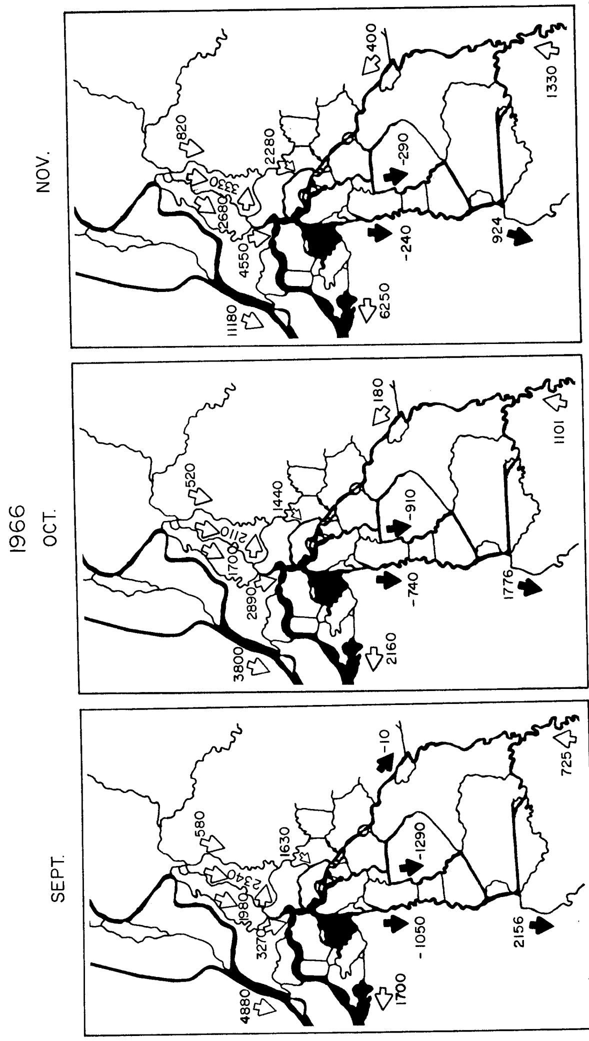

FIGURE 5. Rate (cfs) and direction of mean monthly net flows in the Sacramento-San Joaquin Delta. **Fall of 1966. Open arrows indicate flows in normal direction, solid arrows indicate reversed flows.**

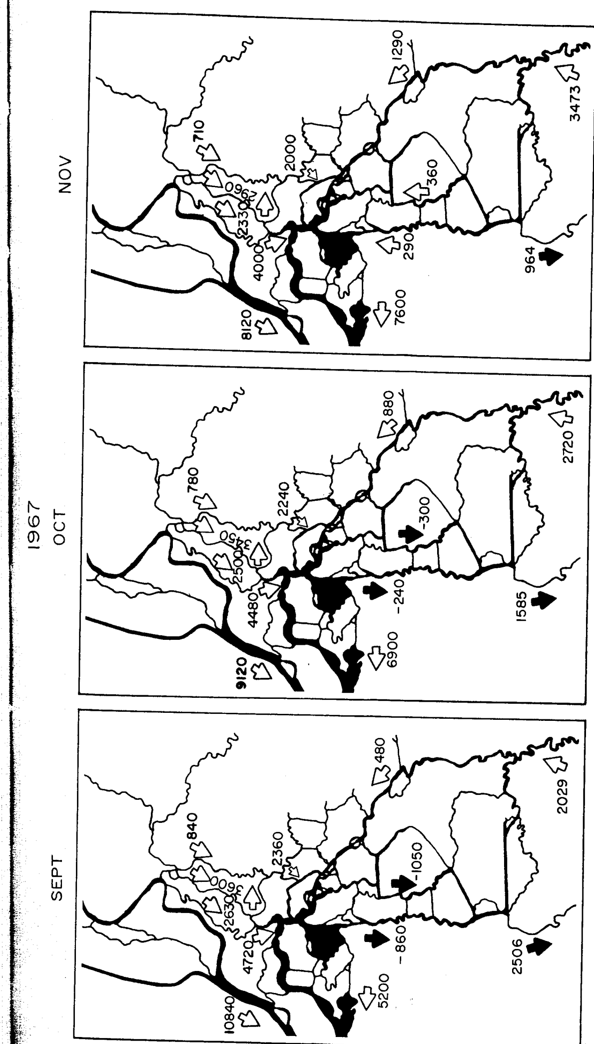

FIGURE 6. Rate (cfs) and direction of mean monthly net flows in the Sacramento-San Joaquin Delta. **Fall of 1967. Open arrows indicate flows in normal direction, solid arrows indicate reversed flows.**

As might be expected, dissolved oxygen levels in 1966 in the San Joaquin River below Stockton stayed below 5 ppm later than in any of the four years under discussion. The oxygen level was not up to 5.0 ppm until October 31. It reached 5.5 on November 2 and remained above that figure for the remainder of the season.

The fall of 1966 started out with a relatively warm water temperature of 73° F. but the water cooled to 70° F. by October 11 and was down to 65° F. by October 19. Temperature conditions during 1966 were as good as in any of the four years.

1967 Flows of the San Joaquin River

Early 1967 was moist, and fall water conditions were roughly similar to those in 1965.

Flows near Vernalis were 1,910 on September 1 and increased to 2,470 cfs by the end of the month. The mean September flow was 1.78 times the average September; October and November were 1.66 and 1.72 times their average, respectively.

Flows past Stockton were good. September, October, and November averages were 479 cfs, 884 cfs, and 1,290 cfs respectively. Overall, the 1967 average was very slightly below that of 1965 (Figure 6).

1967 Flows of Sacramento River Water Into the Central and Southern Delta

Mean flows from the Sacramento to the central Delta were 6,800 cfs in September, 6,200 cfs in October, and 5,900 cfs in November. The September and October flows were the highest of the four years; the November flow, one of the lowest.

The Tracy Pumping Plant took a little more water in 1967 than in any of the other three years, reflecting the trend toward an increase in fall pumping.

Average flows in Old and Middle Rivers were strongly reversed in September, weakly reversed in October, and weakly positive in November.

In spite of the relatively high water flows, the lowest dissolved oxygen levels encountered below Stockton remained less than 5 ppm until sometime between October 20 and 23; later than any year studied except 1966.

Water temperatures were a little higher in late September than in the other years, but dropped to 65° F. by October 25, only two days later than the 1964–67 average.

STUDY METHOD

To study the migrations of adult San Joaquin River salmon through the Delta, fish were captured with a trammel net in the lower Delta and tagged with sonic transmitter fish tags. Tagging was done through the principal period of migration—September through November. The tags produced vibrations in the ultrasonic range (130,000 or 160,000 cycles per second). Tag tracking crews traveled by boat and used portable tag signal detecting equipment to determine the daytime distribution and movement of tagged fish. Primary emphasis was in the San Joaquin River, but other channels were checked as time permitted.

Stationary tag signal detectors (shore monitors) were placed at carefully selected locations along principal waterways. These instruments recorded passing tags and the time of passage. In theory, all or almost all tagged fish migrating up the Sacramento and all those going up the San Joaquin River would pass a monitor. No monitors were placed on the Mokelumne River System, but part of the fish going there to spawn would be counted through the Woodbridge Dam fish ladder.

To determine water conditions which the fish encountered, the tag tracking crews took mid-depth water samples and determined the dissolved oxygen content at key locations several times a week, particularly in the main San Joaquin channel below Stockton where pollution was at its worst.

Information on stream flows was obtained from published and unpublished reports of the California Department of Water Resources and the U.S. Geological Survey. Supplementary information on temperature and dissolved oxygen was obtained from the Department of Water Resources, the U.S. Bureau of Reclamation, and the Corps of Engineers.

SONIC TAGS: THEIR DETECTION AND RECOVERY

For our 1964 experiment, signal detecting and recording equipment was borrowed and sonic tags purchased from the U.S. Fish and Wildlife Service's Fish Passage Research Program. This organization had developed tags and equipment to study movement of salmon through reservoirs in the Columbia River System (Trefethen 1956; Trefethen, Dudley, and Smith, 1957; and Johnson 1960). The tags had been manufactured to Fish and Wildlife specifications by DeVoe and Malm, Inc., of Kirkland, Washington.

For our 1965 and later experiments, the California Department of Fish and Game purchased tags and equipment from Smith Root Electronics of Seattle, Washington. These tags were similar to the earlier ones, but there were important differences in the tag recording equipment (see below).

Sonic Transmitter Fish Tags

The sonic tags sent high frequency (ultrasonic) vibrations into the water, were battery-powered, and used a crystal transducer to change electrical oscillatory signals into mechanical motion (vibrations). Each tag was enclosed in a polystyrene case about $3\frac{9}{16}$ inches (90 mm) long by $\frac{3}{4}$-inch (19 mm) diameter with rounded ends, designed to be watertight down to a depth of 150 feet (46 meters) (Figure 7). The sound waves were sent out in short pulses to conserve battery life and to permit the identification of more than one tag group within the same frequency range. During our 1964 study, four tag groups were used: A long- and short-pulse rate vibrating at 130 kilocycles per second and a long- and short-pulse rate vibrating at 160 kilocycles. From 1965 through 1967, all our tags were in the 127–130 kilocycle range. All 1965 tags had the same pulse rate; in 1966 and 1967 two groups of tags with supposedly different pulse rates were used each year (Table 4).

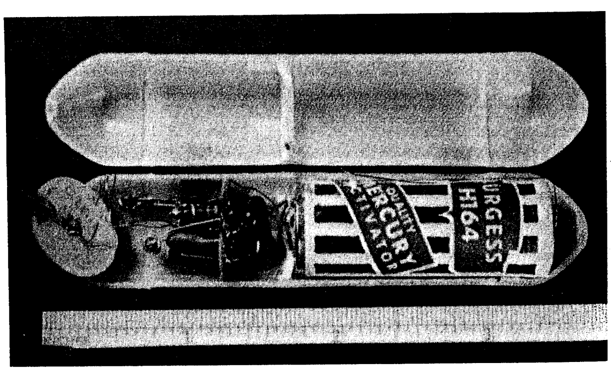

FIGURE 7. Cut-away view of sonic tag. *Photograph by John E. Riggs.*

TABLE 4

Signal Specifications of Sonic Tags

Year	Group number	Cycles per second	Time between pulses	Length of pulses
1964	130S	130,000	0.3 second	0.03 second
1964	130L	130,000	10 seconds	1 second
1964	160S	160,000	0.3 second	0.03 second
1964	160L	160,000	10 seconds	1 second
1965	2	127,000–130,000	1.2 seconds	0.06 second
1966 & '67	2	127,000–130,000	1.2 seconds	0.06 second
1966 & '67	3	127,000–130,000	2.2 seconds	0.11 second

The field life expectancy of the tags depended on the life of the enclosed batteries; about 6 weeks in 1964 and 12 weeks in later years. There was variation in length of life among tag groups because of the different pulse lengths and pulse rates. Tags were received with the circuit "turned off", each tag was activated just before use by closing a magnetic reed switch inside the capsule. This was accomplished by attaching a small alnico magnet to the tag capsule directly over the switch. The magnet was placed in a groove cut into a piece of polystyrene about $\frac{9}{16}$ x $\frac{5}{16}$ x $\frac{1}{8}$ inches (14 x 8 x 3 mm) and the plastic cemented to the capsule. A smaller piece of plastic or a drop of cement at each end of the groove kept the magnet from sliding out. The magnets used from 1965 through 1967 were about $\frac{1}{2}$ x $\frac{1}{8}$ x $\frac{1}{16}$ inches (13 x 3 x $1\frac{1}{2}$ mm). Those used in 1964 were slightly smaller. The smaller magnets would not activate the tags used during the last three years of the project.

To insure that the tags were transmitting satisfactorily, a day's quota of tags was activated and tested at dockside or enroute to the tagging area. Since the acrylic cement required at least an hour to harden after the magnet was attached, a second test was given each tag shortly before it was applied to a fish. In 1964, the limited life of the tag (6 weeks) was conserved by activating them the morning they were to be used and deactivating any that were left over in the evening. The longer life (12 weeks) of the later tags made it practical to activate them the day before use and unnecessary to deactivate any that were left over at the end of the day.

The vibrations sent out by a tag could be detected by either a portable receiver or a fixed recording monitor. Both devices change the vibrations into electrical oscillatory signals.

Portable Receivers and Tag Tracking

The portable receivers consisted of a unidirectional crystal transducer or portable hydrophone which was lowered into the water, and a battery-powered receiver which was kept on deck. The hydrophone, or probe, was on the end of a tubular metal handle about 61 inches (155 cm) long. Wires passing up this tube led to the receiver. Receivers were permanently tuned to the tag frequency; different receivers were used to detect 130 kc and 160 kc tags. Since the tags sent out signals at a far higher frequency than the human ear could detect, the receiver converted and amplified these to audible sounds which the oper-

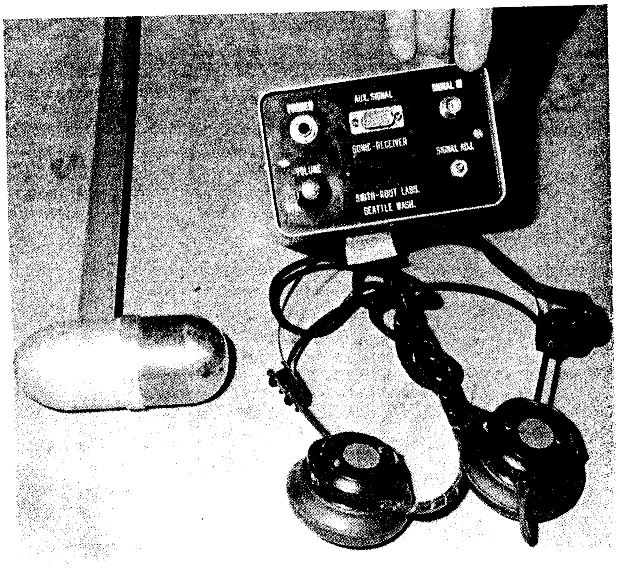

FIGURE 8. Portable probe (or hydrophone) and receiver for tracking sonic tags. *Photograph by John A. Shaver.*

ator could hear as "beeps" either through earphones or on a loudspeaker. The strongest reception was about 2 degrees at 1,000 feet although tags could be detected over a considerably wider angle. This narrow beam made it possible to locate and follow an individual tag. Signals were detected at distances up to three-quarters of a mile (1.2 km) (Figure 8).

The equipment purchased in 1965 and used from 1965 through 1967 was quite similar to that borrowed in 1964, but it did not include a receiver for 160 kc signals since all the tags were in the 130 kc range.

We usually used 16- to 18-foot (4.9 to 5.5 m) boats, both outboard and inboard-outboard drive powered, to carry our portable equipment and follow the tagged fish.

At first two-man crews were regularly assigned this task. One man operated the boat, took dissolved oxygen samples, and recorded water temperatures while the other operated the tag-tracking gear. Later in the study, one man could perform all these duties satisfactorily but somewhat more slowly than a two-man crew. When relatively few tagged fish were in the main San Joaquin channel, one two-man crew could locate all fish between Mossdale and the Antioch Bridge in one day. However, with a large number of fish or when the water was rough, it required two days or two crews to cover this section.

Highest priority was always given to monitoring the daily movements of fish in the main San Joaquin River between Antioch Bridge and Stockton, or Mossdale. To facilitate tag location on daily tracking records, each crew carried a map of the Delta on which the San Joaquin River between Antioch Bridge and Stockton had been marked in 29 sections (Figure 1).

In addition to covering the main San Joaquin River, tracking crews also explored its many tributary rivers and sloughs between Mossdale and Collinsville, plus the main Sacramento between Collinsville and Courtland. The Mokelumne River, its two forks, and Georgiana Slough were also explored from time to time. Occasionally, when a spare boat and crew were available, tag tracking gear was operated near the release point of newly-tagged fish to observe their movements.

Tags detected in the San Joaquin River were recorded by appropriate river section and sometimes by landmark as well. In other areas tagged fish were recorded by their position relative to a landmark.

In 1965, 1966, and 1967, whenever a fish was located, a count of the pulses emitted by the tag in a 30-second period was taken and noted on the daily tracking record. The majority of tags used in all of the last three years were supposed to have a pulse duration of 0.06 second followed by a time-off period of 1.2 seconds (23–24 pulses/30 seconds). In practice, we found that the number of pulses in a 30-second period varied between 17 and 28, but was constant for each tag. An additional help in separating tags when two or more were being heard at the same time was the tone of the individual beep which was usually distinct enough to make a separation possible. Unfortunately, it was found that the pulse rate of these Type 2 tags sometimes overlapped that of the Type 3 used for a short time at the end of the 1966 and 1967 seasons. Type 3 was supposed to have a pulse of 0.11 second on, followed by an off period of 2.2 seconds.

In 1964, the men using the portable receivers did not count pulses, but there was no possibility whatever of mistaking a fast-pulse tag (0.3 second between beeps) and a slow-pulse tag (10 seconds between beeps). In contrast, a weak tag signal sometimes did leave room for doubt on the monitor strip-chart recordings used in 1964.

Reporting the two signal lengths separately seemed to add nothing to the information obtained in any of the four years, so we have combined the long- and short-pulse rate tags. The two signal frequencies (130 and 160 kc) used in 1964 have been kept separate.

In searching for tags, the standard procedure was to stop the boat every half mile or less, lower the hydrophone over the side until it was below the bottom of the boat and rotate it very slowly. Tags could be detected by a portable receiver from at least three-quarters of a mile. When a tag was detected, its direction was determined and the boat was usually moved directly over it, or at least close enough to obtain a count of the beeps in a 30-second period. When a tag was found in exactly the same place day after day, it was assumed that it had either become detached from the fish or that the fish was lying dead on the bottom.

Stationary Receivers (Shore Monitors)

The monitors borrowed in 1964 were quite different from those used in later seasons. Primary components were a receiver for each of the two tag signal frequencies, a battery-pack power supply, and a paper strip-chart recorder. Tag signals were picked up by two stationary hydrophones placed on the river bottom near each recorder and sent through coaxial cables to the proper receiver for amplification. The reception beam was approximately 30 degrees at 1,000 feet (305 m). Tag signals appeared as a tracing of characteristic shape on paper strip-charts. Chart movement, regulated by an eight-day clock mechanism, was 6 inches (152 mm) per hour.

From 1965 through 1967, fish tag signals were picked up by a single stationary underwater microphone, or hydrophone, and amplified approximately three million times by a fixed-tuned receiver tuned to the tag signal frequency, much as they were with the 1964 monitors. However, with the monitors used after 1964, when the tag signal was received, a second signal was sent within the instrument to a control circuit which activated a magnetic tape recorder. The control circuit would then hold the recorder on five seconds and then shut it off. If another signal was received within five seconds, the recorder would reset and continue to function another five seconds. Without some form of restraining device, a tagged fish remaining close to the monitor could keep it running continuously; therefore, to conserve recorder tape, a "lockout" circuit was built into the monitor. When a tag signal was received the recorder would operate only 30 seconds before being shut off by the lockout circuit, even though the receiver might still be getting a tag signal. From this point on, the behavior of the lockout circuit depended on the position of the lockout switch. If the switch was in the "auto" position the circuit would reset automatically when the fish tag signal was lost for a period of five seconds or longer. If the switch was set in the "5-minute lockout" position, the lockout circuit was reset by a clock timer which made a switch closure every five minutes. If a tag signal was still being received at the end of any "5-minute lockout" period, the recorder would operate another 30 seconds.

The tape recorder had two channels: one for recording tag signals and another for recording time. A "time tone" was automatically recorded at $\frac{1}{4}$-, $\frac{1}{2}$-, or 1-hour intervals, depending upon the position of the "time" switch. This time tone was completely independent of fish tag signals and made it possible to tell when a tag signal had been recorded.

Installation of Shore Monitors

In 1964 we used 13 monitors—11 in the Delta and one each on the lower Stanislaus and Tuolumne Rivers. In each of the other three years of our experiment, there were only four monitors used, all in the Delta.

The way in which monitors were installed depended on terrain and opportunity. One was placed inside the U.S. Bureau of Reclamation's gaging station at Courtland. The remainder were housed outdoors in weatherproof boxes in a variety of ways. Some were on stream gaging station platforms, on navigation light platforms, on horizontal timbers beneath wharves (Figure 9), or on pipe legs which were driven into the bank. Some were merely rested on the bank and chained to a tree.

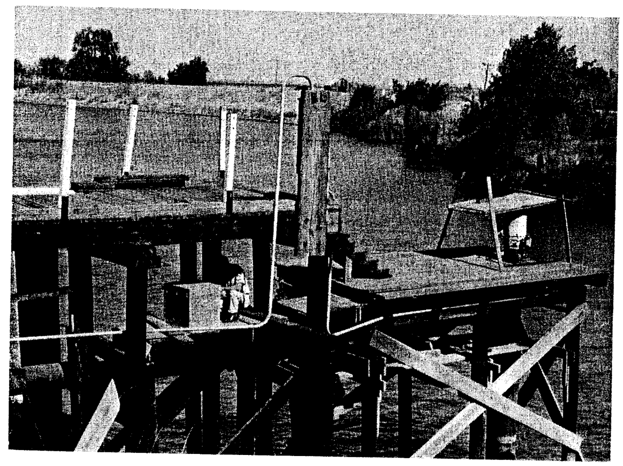

FIGURE 9. Monitor housed on an irrigation pump platform, San Joaquin River near Bowman Road, fall 1965. *Photograph by John A. Shaver.*

The older strip-chart recorders needed to be kept cool, so each box was placed in a shady spot, or shade was created with a piece of plywood. The later type recording monitors were housed in boxes originally constructed for shipping blood plasma. These boxes were insulated with about four inches (100 mm) of styrofoam, about half of which we cut away to make room for the instrument. No shade was needed (Figure 10).

Each hydrophone, or transducer, was mounted on a weighted iron stand so it would be about one foot (30 cm) off the river bottom when in place, and so it would monitor the entire stream width (Figure 11). To be sure the hydrophone would detect all tagged fish passing by, an activated sonic tag was submerged in the river and manipulated from a boat at different distances, angles, and depths from the installation. To aid in placing and recovering the hydrophone and stand, a $\frac{1}{4}$-inch diameter rope was attached to the stand and was also lashed to the hydrophone lead-in cable in several places.

Servicing Shore Monitors

During 1964, the shore monitors were routinely serviced every five days. A check list attached to the inside of the box listed the various duties necessary. These included: replacing the roll of strip-chart; winding the clock mechanism; and placing an activated sonic tag in the water at various locations near the hydrophone to ensure that tags were being recorded.

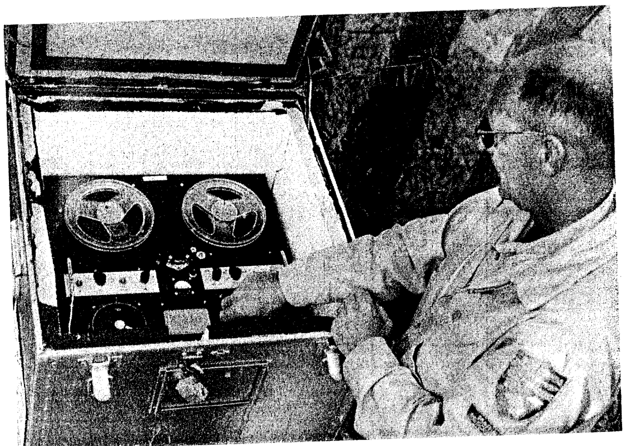

FIGURE 10. Tape recorder type of stationary sonic tag monitor used in 1965–1967; note insulated housing box. *Photograph by Wm. F. Van Woert.*

During 1965–67, one man maintained and serviced the four shore monitors. On Mondays, recorder tapes were changed or used sections removed. On Mondays and Thursdays, the timer clocks were wound, batteries were tested, and an activated sonic tag was placed in the water to make sure the receiver and recorder were functioning properly. Finally, the time channel tones were tested. In addition, for those occasions when more than a field check was needed, the Department had a service agreement with Arnold's Marine Electronics, Concord, California, to handle any necessary repair work on sonic tag equipment. This was a workable arrangement but not as satisfactory as in 1964 when an electronics technician was available at all time.

Replacing Shore Monitor Recorder Tapes

The recorder tape used was quarter mil (0.006 mm) mylar on 7-inch (180 mm) reels. Tapes were threaded on the recorders with the glossy side away from the recording head. As each tape was started, it was marked for later identification with a black marking pen by drawing a line across the tape and writing the words "Start Tape". Next, a test tag was placed in the water near the hydrophone and the tag signal recorded. Another line was then drawn across the tape and marked "End Tag Test". The date, hour, and tag type were written between these two lines. A "Time Channel Tone" was then recorded, following which a third line was drawn across the tape. The words "Time Signal" were written between the second and third lines. The timer clock was then reset to the correct time.

FIGURE 11. Hydrophone, iron stand used to hold it above the river bottom and lead-in cable. *Photograph by Wm. F. Van Woert.*

A full reel of tape lasted two weeks or more at all monitor locations, depending upon the amount of interference or non-tag signals recorded. Each Monday, the amount of tape used during the previous week was removed from the recorder for reading. If there was a week's supply of tape still unrecorded, this portion was left on the reel but the used portion was cut off and rolled on an empty reel. The cut end of the used section was marked by a line drawn across the tape and the words "End Tape", followed by the date and time of day. The cut end of the tap section left on the recorder was marked in the same manner as a new tape.

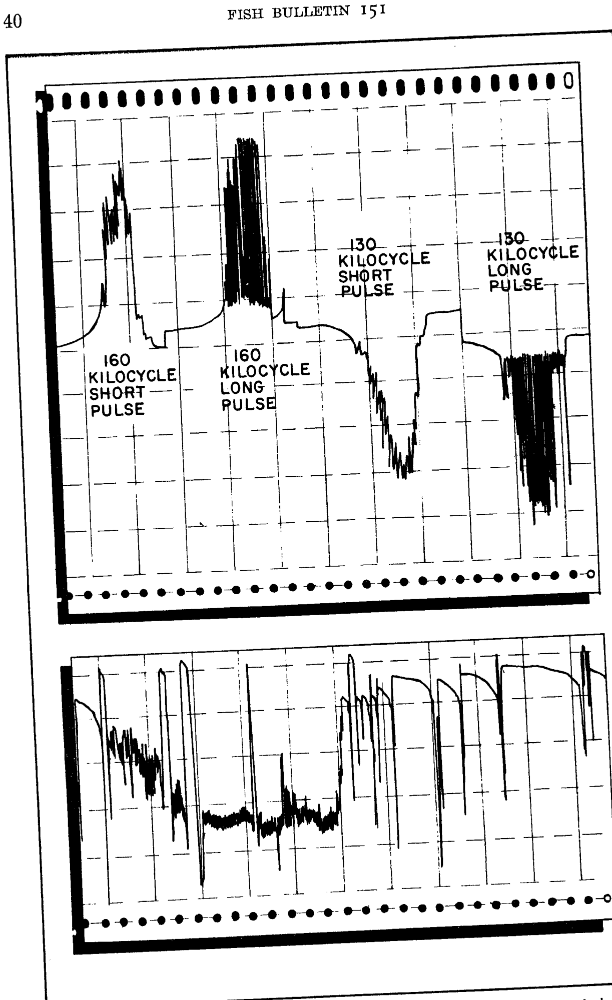

FIGURE 12. Facsimile of sonic tag recordings on strip-chart as used in 1964. Typical recordings at top. Bottom recordings show a slow-moving salmon (left) and numerous boats.

Reading Shore Monitor Strip-Charts

In 1964, all recordings were in the form of 6-inch-wide (150mm) paper strip-charts. The 160 kc tags were recorded on one-half of the chart and the 130 kc tags on the other half (Figure 12).

Since the chart moved in the monitor at a rate of 6 inches (152 mm) per hour, each section of used chart covering five days of continuous operation was 60 feet long (18.3 m). Tag detection data were limited primarily to the time a tag signal was being recorded on the chart at one of the fixed locations. Where two recorders were installed fairly close together, some indication of the direction a tagged salmon was moving was demonstrated. Where a single recording unit was installed, only the actual time a tagged fish was passing a monitor was obtainable.

Underwater sounds of many types were recorded on these charts, and it was necessary to spend many hours watching the recorder and the river to note what caused the different types of marks. A tag close to the recorder produced a mark that typically jumped away from the base line about 1½ or 2 inches (4 or 5 cm) and then oscillated with the tag pulses. Long-pulse tags showed marks that would drop back almost to the base line between pulses. Short-pulse tags were "off" such a short time between pulses that the recording point would not have time to swing back more than ¼ to ⅜ of an inch (6-10 mm) before the next pulse caused it to move away again. After the tagged fish had passed, the mark would typically drop back almost to the base line and then have a smooth "toe" as it spent about 3 minutes dropping the rest of the way. The 130 kc tag signals caused the marker to swing down and the 160 kc signals caused it to swing up, otherwise the marks were similar. Salmon moved at a rate which usually kept the recorder activated for a period of 3 to 6 or 7 minutes (not including the toe of the curve). Occasionally, a recording would be over a much longer period.

Some boats caused interference marks that were very much like long-pulse or short-pulse tag signals. Fortunately, this type of noise was usually of short duration—about one minute. If such a boat had circled close to a monitor for five minutes, we might have misinterpreted the resulting signal as a sonic tag.

Combinations of noise and tag signals were bothersome on occasion, but the usual tag signal was clear and distinct.

Reading Shore Monitor Recorder Tapes

From 1965 through 1967, all monitor records were on magnetic sound recording tape. These were read each week on a tape recorder rented for this purpose. The tapes were played back at a recorder speed of 3¾ inches (95 mm) per second.

Time tones and tag signals heard were noted on record sheets, labeled to include the 24 hours in a day.

As with the recording charts, used in 1964, the tapes contained various amounts of interference noise or non-tag signals, necessitating a prolonged study of the different sounds and their origins. With experience, it was possible to recognize most of the common non-tag signals. Tugboats and high-speed outboard motor boats caused the greatest amount of interference. These sounds were more of a nuisance than a real handicap to accurate tape reading as the human ear is very effective at separating tag signals from all other sounds.

Usually two men read the tapes together. Two days each week were required to read and double check the tapes from the four monitors. The time required to read each tape generally varied directly with the amount of interference recorded. We consider that the tape recorders were a definite improvement over the older chart recorders.

Location of Monitors

In 1964, we had 14 borrowed monitors on hand and set up 13 of them in and around the Delta in an effort to get as good coverage as possible (Figure 13). The 14th was kept available as a replacement. Some monitors were set up in pairs to determine which way the fish were moving. Monitor locations in the Delta were:

Area 2 (Blind Point Monitors): A pair of monitors; one near Blind Point on Jersey Island, the other across the channel on Sherman Island about ½ mile (0.8 km) upstream. Data from this pair of monitors and the pair in Areas 17 and 18 (below) proved useless and are not included in the report. Both pairs of monitors were too close to the tagging areas, and tagged fish moved in and out of the range of the recorders in such numbers and with such frequency that it was impossible to keep track of individuals.

Areas 17 and 18 (Venice Island Monitors): A pair of monitors, one at the downstream mouth of Middle River and the other about 1½ miles (2.4 km) farther upstream.

Areas 25 and 26 (Light 35 Monitors): A pair of monitors, one at the mouth of Fourteenmile Slough, the other about 1 mile (1.6 km) farther upstream. These two monitors were about 4 and 5 miles downstream from the point where the Stockton ship channel joins the San Joaquin River. Oxygen depletion was usually at its worst in this general area.

Mossdale Monitor: One monitor a short distance upstream from the Highway 50 bridge over the San Joaquin River. This monitor was upstream from the point where Old River diverts from the San Joaquin and in theory, any salmon bound for one of the San Joaquin tributaries would have to pass this point.

Middle River Monitor: One monitor about 2 miles (3.2 km) from the south end of that channel. Very little water flows through this part of Middle River and we did not expect any salmon to use this route. No tags were recorded.

Old River Monitor: One monitor just north of the point where Grant Line Canal joins Old River and close to the entrance of the Delta-Mendota Canal. Fish coming south in Old River could pass this point and go up either Grant Line Canal or Old River and proceed to the point where these two channels rejoin and then continue up Old River to the San Joaquin.

Stanislaus River Monitor: One monitor about 2 miles (3.2 km) upstream from the mouth.

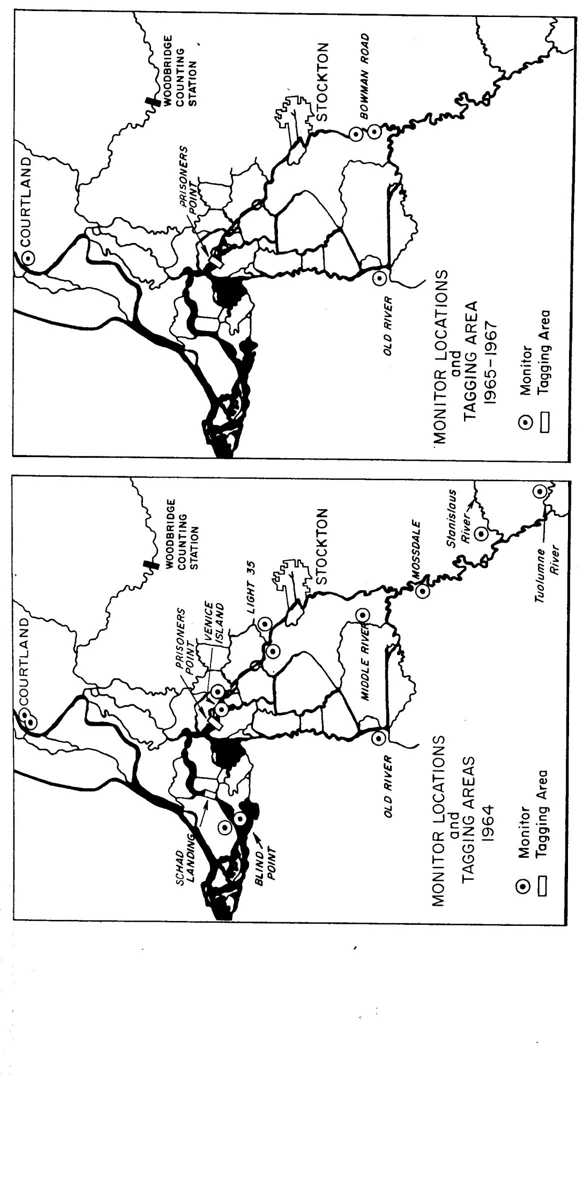

FIGURE 13. Location of shore monitors for recording the passage of sonic tags.

Tuolumne River Monitor: One monitor about 3 miles (4.8 km) upstream from the mouth.

Sacramento River (Courtland Monitors): A pair of monitors. One just upstream from the head of Sutter Slough; the other about ¾ of a mile (1.2 km) farther upstream; both near Courtland.

In 1965, the Department of Fish and Game purchased six monitors of the newer design described above. These were the only ones used from 1965 through 1967 (Figure 13). Two were held as replacements and four were operated at the following locations:

San Joaquin River, Main Channel (Bowman Road Monitors): A pair of monitors, one at the Bowman Road crossing (often referred to as Brandt Bridge) and the second at Todd's River Club, about 1¾ miles (2.8 km) farther upstream. Both of these monitors are downstream from the heading of Old River. In 1964, a fish which had gone south through Old River and then up the San Joaquin River would be recorded on both the Old River and Mossdale monitors, whereas a fish doing the same thing in any of the latter three years would be recorded only at the Old River monitor. It would enter the San Joaquin River upstream from the monitors at Bowman Road and Todd's River Club.

Old River Monitor: One monitor north of the end of the Grant Line Canal—the same location as in 1964.

Sacramento River: One monitor near Courtland.

Tag Recoveries

Tag recoveries and tag sightings, as distinguished from tag signal detection, were relatively few and gave us a limited amount of information. The recoveries were made by a variety of methods.

There was no monitor on the Mokelumne River but each year a count is made of salmon going over Woodbridge Dam. The counters recovered or observed five tags in the four years. There was a complete count of the fish only in 1966. Another five tagged fish were recorded by fish counters at Red Bluff Dam on the Sacramento River, but these fish had presumably passed a monitor.

Every year a spawning stock survey is made on the Cosumnes River which was the only salmon stream the fish could reach without passing either a monitor or a counting station. About one-sixth of the spawned-out carcasses were examined during the 1964–1967 period; one tag was recovered in the four years. Spawning stock surveys were made on other streams but the eight tagged fish recovered had presumably passed a monitor.

Tracking crews recovered four tags from fish that had died, and also recovered one detached tag. These fish and the tag were all below at least one monitor. One live tagged fish was netted during an exploratory net drift in the Sacramento River. It died while being untangled.

Anglers reported catching 12 tagged salmon, six below the monitors in the Delta, and six farther upstream and above all monitors.

Eight tags were recovered at salmon hatcheries. All were upstream from the monitors.

Egg-taking crews trapped two tagged salmon. These also were upstream from all monitors.

CATCHING THE SALMON

In 1964, 1965, and 1966, tagging was usually done by a three-man crew on the California Department of Fish and Game's 26-foot research vessel, *M.V. Striper*. Basically, this boat was a river gill netter with a net reel (Figure 14).

FIGURE 14. Trammel net being wound onto powered net reel on the *M.V. Striper*, San Joaquin River at Prisoners Point; fall, 1965. *Photograph by Richard J. Hallock.*

In 1967, the *Striper* was replaced by a new boat, the *M.V. Alosa*. The net was fished from the *Alosa* but tagging was done from a skiff.

All salmon were captured with a trammel net similar to those used for commercial salmon fishing in and below the Delta prior to the closing of this fishery in 1957. The net consisted of a wall of 7½ inch, 8 inch, or 8½ inch (19, 20, or 22 cm) 7-ply nylon gill netting hung in 50% (100 fathoms of netting hung on 50 fathoms of cork line). On each side was a wall of cotton trammel netting of 30– to 34–inch mesh (76 to 86 cm) hung with one mesh of trammel to four meshes of gill net. The net was 4 fathoms (7 m) deep. In 1964, it was 300 fathoms long; in the later years, a 230 fathom net was fished (550 and 420 m).

Fishing was done in the manner of the commercial gill netters who formerly fished the Delta. The net was never anchored or tied to the bank, but was allowed to drift with the current and was preferably fished at or near slack tide.

Although the best salmon catches are made at night, all our netting was done during daylight hours so crew members could keep a better watch on the cork line and be sure of detecting the first struggles of a netted fish. When the water was so choppy the boat crew could not be sure of detecting activity at the far end of the net, an additional two men in a skiff watched half the net.

The problem of where to do our tagging was important. San Joaquin salmon runs were very low, and Sacramento runs were many times as great. For financial reasons, our supply of sonic tags was quite limited and it was essential to tag a high proportion of San Joaquin fish. If we fished below the junction of the two rivers, we could expect to catch dozens to hundreds of Sacramento salmon for every one of San Joaquin origin. In contrast, if the fishing site was too far upstream we would learn very little about the movement of San Joaquin salmon through the lower part of the Delta.

In 1964, tagging operations were started at Schad Landing on the lower part of the main San Joaquin channel. The area had been known to commercial netters as a very good fish producer, but that part of the river carries a great deal of Sacramento water, and within two weeks it became quite clear that it was being used by entirely too many Sacramento salmon for our purposes.

Our second choice of fishing spots was Prisoners Point, about 11 miles farther upstream and 2½ miles (4 km) above the mouth of the Mokelumne River. This area proved satisfactory and was used for most of the 1964 season and all of the 1965, 1966, and 1967 fishing seasons.

The catch per hour of fishing at Prisoners Point was calculated for 1964, 1966, and 1967. Through an oversight, the man in charge of the 1965 tagging was not alerted to the desirability of keeping a record of the time the net was in the water.

The average catch during the three-year period was just over one fish per hour (244 fish in 231 hours). This includes many dreary hours at the ends of the seasons when the catch was far lower. Catches during the peak week of each season averaged considerably better: 5.36 fish per hour in 1964, followed by 2.09 in 1966, and 4.64 in 1967. Fishing was best in 1964, the year with the smallest San Joaquin run, and second best in 1967, the year with the best run (Figure 15 and Appendix Table 2).

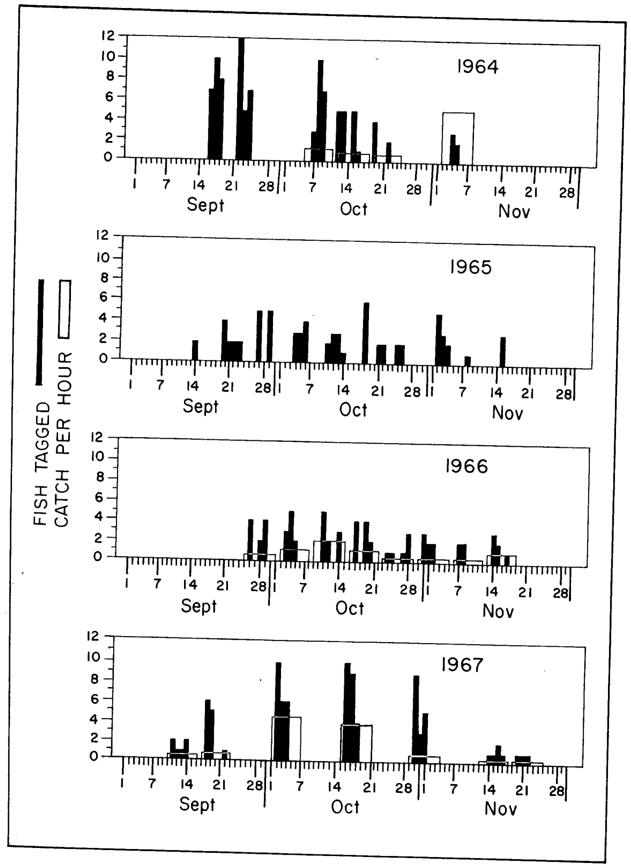

FIGURE 15. Catch per net hour and number of salmon tagged, 1964–1967.

TAGGING THE SALMON

During our four-year study period, 316 salmon were released with sonic tags; ranging from 63 in 1966 to 96 in 1964 (Table 5).

TABLE 5

Summary of Sonic Tags Released, 1964–1967

Year	Place	Number of tagged salmon released: September	October	November	Total
1964	Schad Landing	49	0	0	49
1964	Prisoners Point	0	41	5	46
1964	Mouth of Sevenmile Slough*	0	1	0	1
1965	Prisoners Point	22	31	14	67
1965	Mouth of Sevenmile Slough*	0	2	0	2
1966	Prisoners Point	10	39	14	63
1967	Prisoners Point	18	57	13	88
	Total tagged salmon released				316

* Included with tags released at Prisoners Point in most parts of this report.

As soon as a fish was caught, that part of the net containing the fish was lifted aboard the boat, the fish untangled and removed (Figure 16) and the net dropped back in the water. The boat was then immediately taken out into the channel, clear of the net. Meanwhile, the tagger had placed the fish in a wooden V-shaped cradle and tagged it (Figure 17). The fish were out of water about two minutes although the tagging took only about 30 seconds. After being tagged, any fish that was active and struggling was immediately released. Others were given artificial respiration; the fish was grasped by the caudal peduncle, its head submerged beside the boat and moved up and down to pass water over the gills (Figure 18). After about 10 seconds (6 or 7 strokes) most fish started to struggle and were released. The tag was removed from any fish that was particularly slow to revive and seemed unlikely to survive.

Initially, fish were held in an anesthetic (MS-222) for a short time prior to tagging. This was soon discontinued because the placid behavior of gill net-caught fish did not warrant it. Early in the tagging operation, there were three known tagging mortalities, and all were fish that had been anesthetized.

The tags were fastened to the fish just above the back, just forward of the dorsal fin, and with their axis parallel to that of the fish. At first, the crystal (transmitting) end of the tag was pointed towards the rear, on the assumption that it would be easier to follow a fish so tagged. It later became apparent that fish could be followed easily, whether the crystal faced fore or aft. In the last three years of our experiment the crew standardized on pointing the crystal forward.

Two plastic straps and two plastic pins were used to fasten the tag to each fish. Each pin went through one end of a strap, the back of the fish, and the other end of the strap. The tags were encased in smooth

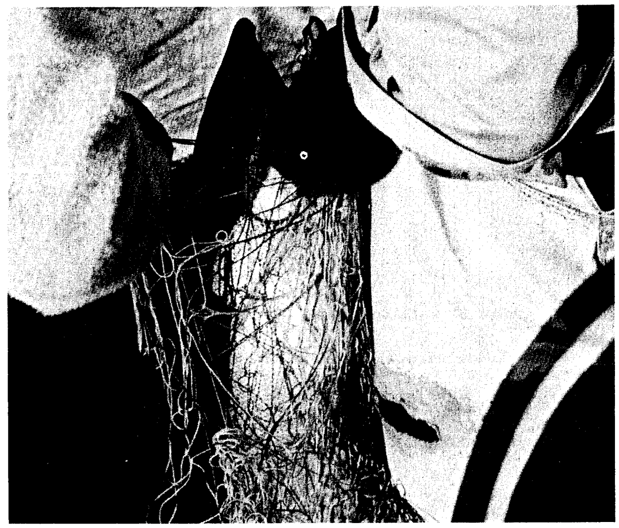

FIGURE 16. A salmon thoroughly enmeshed in the trammel net. Former commercial fishermen routinely removed such tangled fish uninjured and in relatively few seconds. *Photograph by John E. Riggs.*

FIGURE 17. Attaching a sonic tag to a salmon on board the *M.V. Striper*. *Photograph by Richard J. Hallock.*

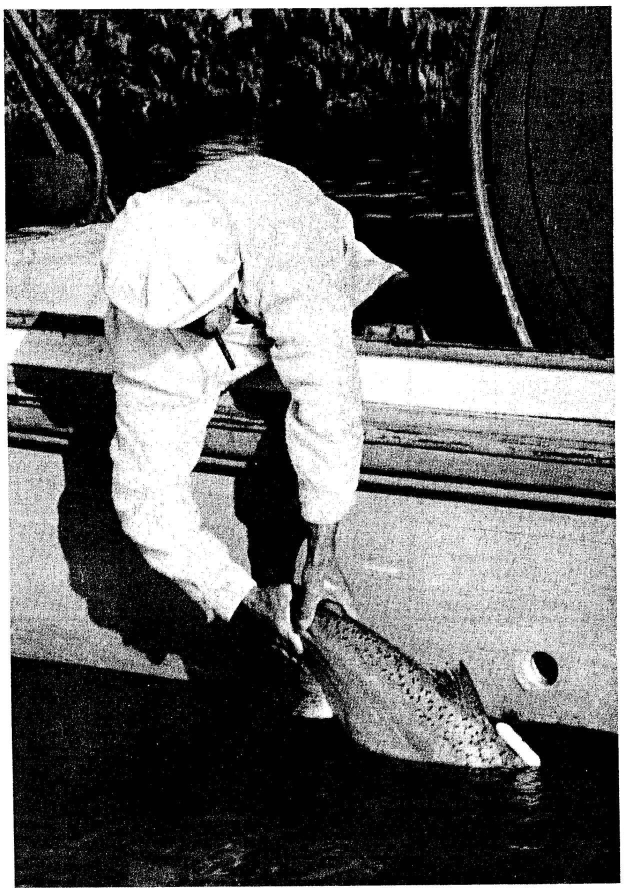

FIGURE 18. Giving artificial respiration to a tagged salmon by "pumping" it up and down to pass water over the gills. Most fish started to struggle in about ten seconds and were immediately released: San Joaquin River at Prisoners Point; fall, 1965. *Photograph by Richard J. Hallock.*

polystyrene tubes with rounded caps at each end. No available cement would bond the straps to the tubes so the equivalent of belt loops were cemented to the tags (two loops for each strap). Each "loop" consisted of a $1\frac{1}{16}$ inch (27 mm) length of half-round polystyrene rod of $\frac{5}{32}$ inch (4 mm) diameter, each end of which was cemented to a rectangular polystyrene spacer which held the rod just over $\frac{1}{32}$ inch (0.8 mm) from the tube and allowed the straps to be slipped between the tag and the rod. The manufacturers supplied these belt loops but we attached them. In three of the four years, the straps were simply slipped through the loops and attached to the fish. An innovation tried in 1965, and later abandoned, was to trisect the central parts of the strap with lengthwise slits. These were just long enough to permit the tag to be slipped over the center-third and under the two outer-thirds of the strap. Thus the straps encircled the tags. They were then fastened to the tag by cementing the polystyrene belt loops over them. The method worked but did not seem superior to the original and considerably simpler procedure.

The straps were plastic. Those used in 1964 were of soft vinyl, about $\frac{1}{32}$ inch (0.8 mm) thick and were supplied with the tags. Those used in 1965 were of nylon, 0.010 inch (0.25 mm) thick. After some experiments in the winter of 1965 and 1966 (see below) we changed to mylar, 0.014 inch (0.36 mm) thick which was used in 1966 and 1967. The dimensions of the straps were not held to close limits but were about 6 x $\frac{5}{8}$ inches (150 x 16 mm). Each strap had three holes in each end to adapt it to different sizes of fish. All three materials were reasonably satisfactory, but the soft vinyl did show a tendency to be cut by the edges of the belt loops. This did not happen to the nylon or mylar, both of which were quite hard.

The pins were plastic, $\frac{3}{32}$ inch (2.4 mm) in diameter. Surgical tubing "pins" were used in 1964. The tubing pins were received with one end enlarged to form a head. Much harder and stiffer nylon rods of the same diameter were used from 1965 to 1967. The rod was cut into five-inch (127 mm) lengths, and heads made by crimping an electrical solderless connector on one end, and sliding on a $\frac{9}{16}$ x $\frac{1}{32}$ inch (14 x 0.8 mm) plastic washer. Washers were made by enlarging the hole in some surplus Petersen Disk fish tags that were on hand. Both the rods and the tubes worked satisfactorily, but we suspect the thin, hard, strap material used from 1965 through 1967 could saw its way through a soft tube.

The tagging procedure was to put a salmon in the V-shaped tagging trough or cradle. The tag was placed lengthwise on the fish's back, just in front of the dorsal fin. The straps which encircled the tag each lay pointing downward with one end on each side of the fish. A pin, held in a hollow needle, was then pushed through one hole in a strap through the fish's back and out through a hole in the other end of the strap. A washer and an electrical solderless connector were then pushed onto the pin until the washers were snugly against both sides of the fish. The connector was then crimped and the excess rod or tube cut off. The operation was then repeated, putting the second pin through the second strap (Figure 19).

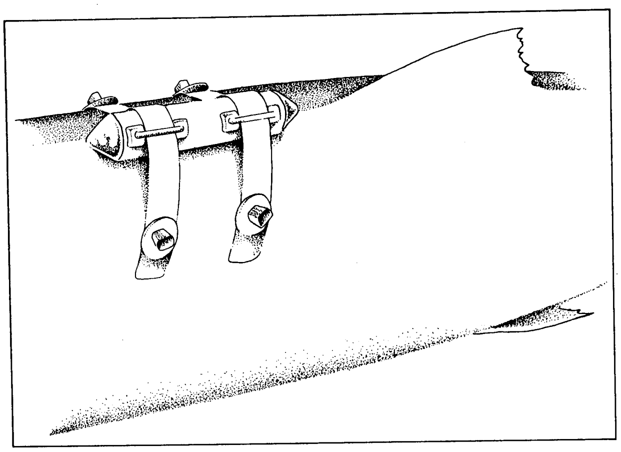

FIGURE 19. Sonic transmitter tag in place on the back of a salmon.

At the conclusion of 1965 tagging we tried a variety of tagging methods, using January and February spawning king salmon at Coleman National Fish Hatchery, in hopes of finding more satisfactory materials and better methods of tag attachment. Twelve tagged fish were placed in a holding pond and observed daily; most of them until they matured and died. The first fish was recovered for examination 18 days after tagging, the last after 65 days. Ten fish died, but two were still alive at recovery. Of the 12 salmon tagged, six had the tags attached anterior to the dorsal fin, as previously described, using the same strap design but different materials for the strap or pins. The other six fish had the tag placed posteriorly to the dorsal fin, using four separate strap designs and several combinations of materials for the straps and pins (Figure 20). The straps were of either 0.010-inch (0.25 mm) nylon, or 0.014-inch (0.36 mm) mylar, and the pins were solid nylon rod, $\frac{1}{16}$-inch, $\frac{3}{32}$-inch, $\frac{1}{8}$-inch or $\frac{3}{16}$-inch (1.6 mm, 2.4 mm, 3.2 mm, or 4.8 mm) in diameter. All straps were trisected to encircle the tag in the manner used in the Delta in 1965.

Test results showed that all straps and tags mounted anterior to the dorsal fin remained in place. The posteriorly-mounted tags also stayed in place, but the rear straps pulled out. Tag pin holes in the mylar straps were only slightly enlarged, while those in the nylon straps elongated considerably; however, the more flexible nylon caused less abrasion on the fish. The $\frac{3}{32}$-inch diameter pins were less damaging to the flesh of fish than the larger pins in that the hole was initially smaller and remained smaller.

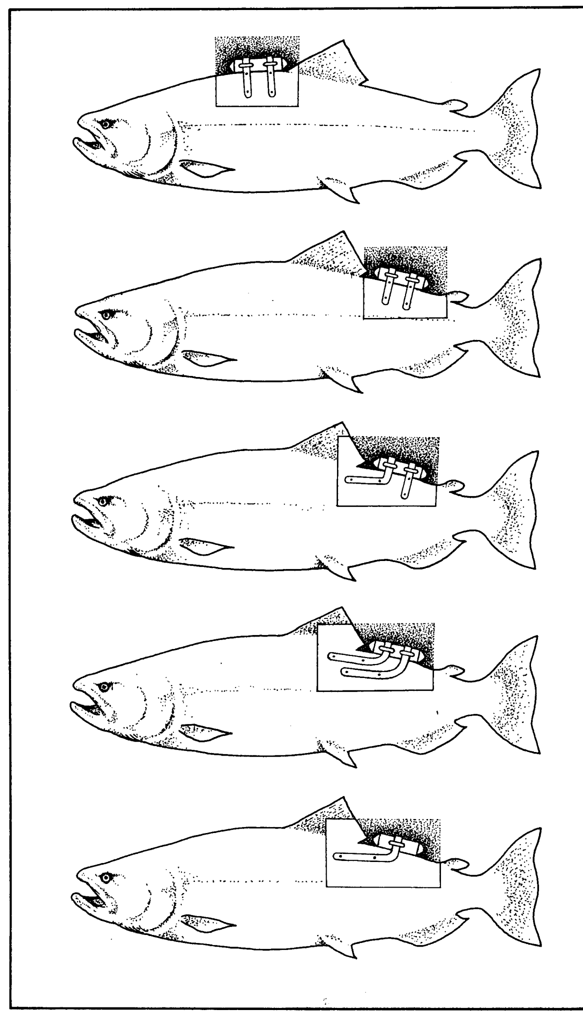

FIGURE 20. Five different methods of mounting sonic tags tested at the end of 1965. The original method (top) proved best.

An entirely different approach tried at this time was to insert a tag inside the stomach of a salmon. Because they do not feed actively after migrating into fresh water to spawn, we presumed the tags would be retained. Problems of tag retention became academic when we determined that the thickness of a fish's body wall so deadened the sound waves and limited reception distance that this method could not be considered. At that time, it was suggested that a sonic tag be constructed with the crystal separated by a wire from the remainder of the tag capsule. The tag capsule could then be placed in the fish's stomach and the crystal allowed to dangle freely outside the gill cover.

We concluded that none of these methods was entirely satisfactory, but that fastening the tag forward of the dorsal fin with $\frac{3}{32}$-inch (2.4 mm) pins (as we had done in 1964 and 1965) was the best. Therefore this method was continued during the 1966 and 1967 seasons.

THE SONIC TAGGING EXPERIMENT

Tagging in 1964 was conducted in two areas. Operations began at Schad Landing, but were later moved farther upstream after it developed that the majority of the fish being captured were from the Sacramento River. In the other three years, all tagging was at Prisoners Point except for three fish released at the confluence of Sevenmile Slough and the San Joaquin River; one in 1964, and two in 1965. This spot is roughly half way between Prisoners Point and Schad Landing. Monitor recordings of these three tags would be inseparable from those of tags released at Prisoners Point.

San Joaquin salmon had been so scarce in 1963 that there seemed to be a strong possibility that it would prove very difficult to catch a meaningful number in 1964. The tagging policy that year was "get them while you can." Tagging operations were started at Schad Landing on September 16. The crew fished for nine consecutive days and tagged 49 fish. No tagging was done during the next 12 days while we followed tagged fish, checked monitors, and assessed results. Tagging was resumed farther upstream at Prisoners Point on October 7, and 36 fish were tagged by October 16. An additional (and final) 11 were tagged by November 5.

In 1965 and 1966, we attempted to tag throughout the season at the rate of 10 fish per week; no more than five in one day. Some weeks (particularly at the beginning or end of a season) it proved impossible to catch 10 fish. In 1967, we scheduled 20 in each two-week period, with no more than 10 in any one day (Appendix 3).

Salmon tagged in 1965, 1966, and 1967 were measured to the nearest half inch (fork length) and their sex was determined by external examination. Of the 220 salmon tagged, 158 were females (72%). This sex ratio was approximately constant in all three years (71, 72, and 73% females). The trammel nets used were selective against jacks but among larger salmon such nets are less size selective than gill nets. Eighty percent of the fish tagged were from 30 to 38 inches long (76 to 97 cm) (Figure 21).

Reaction of Tagged Salmon to Currents

In the course of tagging and tracking operations, we did not detect any obvious tendency of tagged salmon to travel with or against the tidal currents in getting from place to place. Immediately after being tagged and released, the fish did show a preference for swimming away from the boat into the current, but after this first "getaway" reaction, we were unable to detect consistency. During both flood and ebb tides, some fish were roughly stationary, some were moving against the tide, and some with it. During slack tides, salmon might be moving in any direction or not at all.

Movements of Salmon Tagged at Schad Landing

The first 49 tags used were the only 130 kc short and long pulse tags used in 1964 and all were attached to salmon released at Schad Landing during the nine-day period September 16 through 24. No other tagging was done at this location.

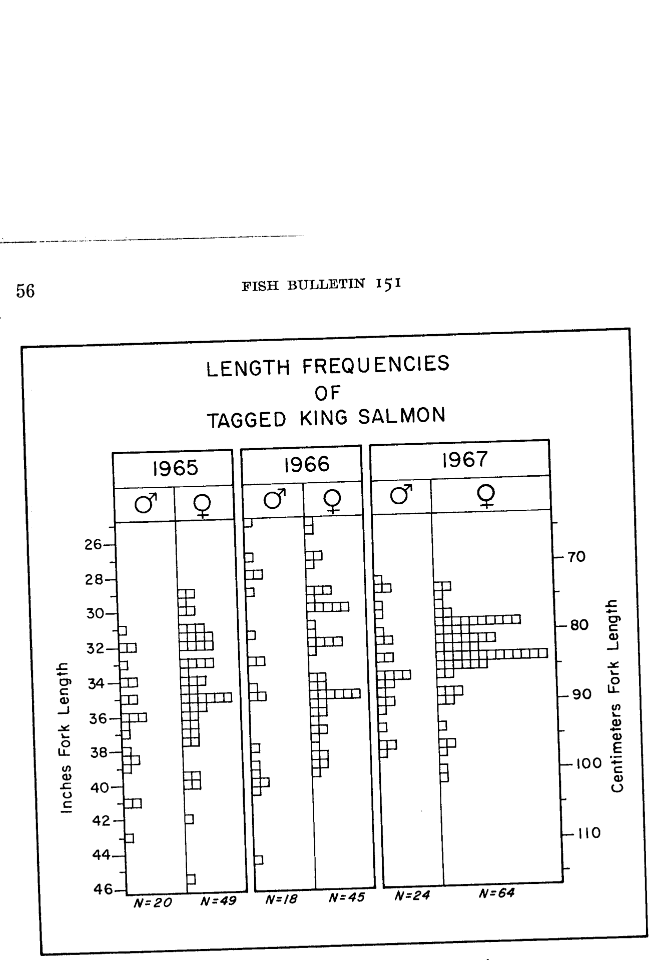

FIGURE 21. Length frequencies of tagged king salmon.

Tracking crews with portable electronic probes determined that tagged fish did not accumulate in or near the tagging area. Between areas 1 and 14, the largest number encountered by the trackers was 15 on September 23 (at which time 42 fish had been tagged, including five on that day). On no other day did we encounter more than nine, and after the last fish had been tagged, the number encountered per day dropped rapidly. None was found this far downstream after October 9 (Table 6 and Appendix 4).

Many fish dropped downstream after tagging and some were found all the way to the junction of the San Joaquin and Sacramento Rivers, and in the Sacramento River at various distances above the junction.

The majority of the fish tagged at Schad Landing (33 of the 49 tagged) went past the Courtland monitor on the Sacramento River; the first on September 25, the last on November 9. Only one passed Courtland after October 17. These fish could have reached the Sacramento River by at least seven different routes.

TABLE 6

Monitor Recordings of Tagged Salmon Released at Schad Landing in 1964, Showing the Maximum and Minimum Numbers and Proportions of Sonic Tags Recorded in Each River System *

	Maximum San Joaquin count†	Minimum San Joaquin count†
San Joaquin River System		
Via Main Channel‡	7 (15.9%)	3 (7.5%)
Via Old River§	2 (4.5%)	2 (5.0%)
San Joaquin Total	9 (20.5%)	5 (12.5%)
Sacramento River	33 (75.0%)	33 (82.5%)
Mokelumne River System	2 (4.5%)	2 (5.0%)
Total	44 (99.9%)	40 (100.0%)

* Monitor recordings only, except in the Mokelumne River System where fish were recovered at Woodbridge salmon counting station. These counts were not complete.
† All San Joaquin fish had to pass the Mossdale monitor to reach their spawning streams, but the Stanislaus plus Tuolumne counts exceeded that of Mossdale. Maximum and minimum counts are those of the Stanislaus plus the Tuolumne monitors and those of Mossdale, respectively. The maximum count seems the more probable.
‡ Main channel counts are the counts at Mossdale (or Stanislaus plus Tuolumne) minus the counts at Old River. One fish lost its tag between Old River and Mossdale monitors. This individual is included in the San Joaquin total.
§ Three very similar atypical recordings within four hours indicated that one, two, or three salmon lingered near the monitor for three prolonged periods of up to a half hour. We have listed these as being from a single fish. The other fish listed here gave an entirely typical recording.

A few tagged fish moved rapidly up the San Joaquin as far as the Mokelumne River. At least two salmon were located by tracking crews in the Mokelumne approximately one mile above its mouth on September 22, 23, and 24. These fish could have gone up the Mokelumne (two did pass the counting station at Woodbridge Dam; one on November 18, the other on November 22), or they could have gone from the Mokelumne to the Sacramento via Georgiana Slough or the Delta Cross Channel.

Two tagged fish passed the Old River monitor, one on September 19, the other on the following day. To reach this monitor, they must have gone with the reversed net flow towards the Tracy pumps. Near the monitor, there should have been a detectable quantity of San Joaquin water arriving via the Grant Line Canal. One fish with a 130 kc tag did get as far as the downstream side of the barrier at the head of Old River, then lost its tag. The tracking crew precisely located this tag by using two portable receivers, and then picked it up with a magnet.

No live fish with a 130 kc tag was found in the San Joaquin above the mouth of Old River until October 6 (one carcass was found on September 25). The first tagged salmon passed the Light 35 monitor (below Stockton) on October 12 and the Mossdale monitor on October 14.

Some Salmon in the Delta Almost Two Months

Of interest is the length of time that some of the 130 kc tagged fish stayed in or near the Delta. These fish were tagged from September 16 through September 24, 1964. Two were recovered at Woodbridge Dam on the Mokelumne River on November 18 and 22. Somewhat earlier in November monitors showed five tag recordings in the Stanislaus River, one at Courtland and two below Stockton. Apparently some fish reach the Delta well in advance of their spawning time and wait there while ripening, even when nothing blocks their migration. The above-mentioned Sacramento fish could have moved upstream at any time and the two from the Mokelumne River could have passed Woodbridge Dam at least as early as October 7. (Fishway counts were started on that date and salmon were already moving past the dam.) Tagging with 160 kc tags in 1964 and tagging in the other three years was not done in a way which would demonstrate a long delay by a tagged fish.

Movements of Salmon Tagged at Prisoners Point

After it had been determined that the salmon passing Schad Landing included too few bound for the San Joaquin, the tagging site was moved above the mouth of the Mokelumne River in the hope that the majority of the Sacramento fish moving up the San Joaquin would have turned into the Mokelumne on their way back to the Sacramento. A suitable gill net drift existed in the vicinity of Prisoners Point, in the San Joaquin about 2½ miles (4 km) upstream from the mouth of the Mokelumne. The move proved to be a good choice. In 1964, the proportion of proven San Joaquin fish jumped from 20% at Schad Landing to 46% at Prisoners Point.

In all four years, the behavior of fish immediately after their release at Prisoners Point was similar to that of fish released at Schad Landing in 1964; i.e., they dropped rapidly downstream below the tagging area. Some apparently went past Antioch and entered the Sacramento River (they were found in the lower part of the San Joaquin and the lower part of the Sacramento, but not actually at the junction of the two streams). Some of those that dropped downstream moved back into the immediate tagging area within a few hours and upstream as far as the mouth of Middle River within a few days. The time of movement above Middle River varied from season to season. In contrast to the mass exodus of fish from the Schad Landing area, more of those released at Prisoners Point remained in the San Joaquin between Antioch Bridge and the mouth of Middle River until well into October or early November. This would lead one to surmise that there was more tendency for San Joaquin fish to stay in this area during the early part of the season and more tendency for the Sacramento fish to leave quickly. The presence of an oxygen block farther upstream on the San Joaquin could certainly delay the fish. There was no such block on the Sacramento. Some fish are known to have dropped back from the tagging area and gone up the Mokelumne (a logical route for both Sacramento and Mokelumne River spawners). Threemile Slough connects the San Joaquin and Sacramento rivers not far upstream from Schad Landing. This channel was not searched often, but tagged fish were found there. Old River, the northern part of Middle River, and the various connecting channels were occasionally explored by the tracking crews and occasionally a tag was found. There are many islands in these channels, and a fish on the far side of an island would not have been detected. A regularly checked monitor was placed near the south end of Middle River in 1964 (only); it recorded no fish whatever. The lack of fish in this part of Middle River is not surprising as the channel is quite small.

In none of the four seasons of this experiment was it ever possible for the tracking crew to find more than half the salmon that had been tagged on any one trip through the Delta. Had the fish remained in the main channel of the San Joaquin, there is little doubt that the tracking crew would have located most of them. Presumably, part of the missing individuals were in various side sloughs when the trackers went past. Most of the fish tagged (68%) did eventually go past a monitor. Of the remainder, some were taken by anglers, a few were known mortalities, and less than 10% remained unaccounted for.

There is doubt about the number of salmon tagged at Schad Landing which went up the San Joaquin River in 1964, although we do know it was low. Only four 130 kc tags were recorded by the Mossdale monitor. To reach their spawning tributaries, all San Joaquin fish had to pass this monitor, but the combined counts of the Stanislaus and Tuolumne River monitors exceeded that of Mossdale. The Stanislaus monitor recorded six 130 kc tags from October 16 to November 11, and the Tuolumne monitor recorded two, both on October 26. Under the flow conditions which existed at that time, we know of no way a salmon could have reached the Stanislaus or Tuolumne River without passing Mossdale. In theory, it is possible for a fish to make more than one recording by entering the range of a monitor more than once, but it hardly seems likely that four fish would register nine times. Neither does it seem likely that five fish would pass a properly functioning monitor undetected in a relatively narrow channel. A third improbable possibility is that of having two or more tagged fish pass the monitor at the same time and register as one. We compared the counts and times of passage at Light 35 and Old River monitors (both below Mossdale) with those of the Stanislaus and Tuolumne rivers (both above Mossdale), and concluded the most probable answer was that the Mossdale counts were low[3]. In calculating the percent distribution by river systems, the sum of Stanislaus plus Tuolumne counts was used as the San Joaquin count. One fish shed its tag above the Old River monitor, but below Mossdale, and was added to this total.

Of the fish tagged at Schad Landing in 1964, only 20% went up the San Joaquin; two fish which went past the Old River monitor are included in this figure (Table 6).

During the four years of tagging at Prisoners Point, the proportion which went up the San Joaquin was lowest in 1966 (29%). This was a dry year and the fish were delayed longer than in any other year. The next lowest proportion of San Joaquin fish (among those tagged at Prisoners Point) was in 1964 (46%). This also was a dry year, but the flow past Stockton had been increased to somewhat above normal levels by the release of pumped water and the use of the barrier across the head of Old River. Both 1965 and 1967 were wetter than normal in the fall, and the proportion of tagged salmon ascending the San Joaquin was 85 and 86%, respectively. In each wet year the proportion of San Joaquin fish is significantly higher than in either dry year at the 1% level (Chi-square tests with one degree of freedom). The two dry years were not significantly different from each other at the 5% level.

There was one important difference between the two wet years: In 1967, 35% of the fish went past Old River monitor, while in 1965 only

[3] The Merced River had no monitor, but it seems unlikely that any additional tagged fish went up that stream which had an estimated total escapement of only 35 salmon in 1964.

11% did so. Statistically this difference is significant, at the 1% level. Most of the tagged fish which went past the Old River monitor did so at a time when there was a relatively strong net flow toward the Tracy pumps (i.e., a reversed flow). The flows down the San Joaquin and those toward the Tracy pumps were quite similar in 1965 and 1967. We do not know why so many more fish went past the Old River monitor in 1967 (Table 7 and Appendix 5).

TABLE 7

Monitor Recordings of Salmon Released at Prisoners Point, 1964–1967 Number and Proportion of Sonic Tags Recorded * in Each River System

	1964	1965	1966	1967
San Joaquin River System				
Via Main Channel	15 (42.9%)	35 (74.5%)	14 (26.9%)	39 (50.6%)
Via Old River	1 (2.8%)	5 (10.6%)	1 (1.9%)	27 (35.1%)
San Joaquin Total	16 (45.7%)	40 (85.1%)	15 (28.8%)	66 (85.7%)
Sacramento River	18 (51.4%)	7 (14.9%)	34 (65.4%)	11 (14.3%)
Mokelumne River System	1 (2.8%)	0 ----	3 (5.8%)	0 ----
Total	35 (99.9%)	47 (100.0%)	52 (100.0%)	77 (100.0%)

* Monitor recording only except in Mokelumne River System where fish were reported at Woodbridge salmon counting station (incomplete) or by Cosumnes River spawning survey crew.

There were no monitors in the Mokelumne River System, but each year the salmon of that stream were counted or estimated as they passed Woodbridge Dam. Each year a spawning stock survey was made on the Cosumnes River.

Woodbridge Dam is a demountable structure with splashboards that are normally removed at the end of the irrigation season. In some years, virtually the entire run is counted through the fishway and any tagged fish would be seen. In other years, the splashboards are removed from the dam and part or even all of the fish swim through the openings in the dam, thus making it necessary to estimate the total run from such fish as can be seen. Visibility is poor and tags would probably be overlooked even on the fish that passed moderately close to the counter. The hours of darkness further complicate the problem.

The Cosumnes River enters the Mokelumne below Woodbridge. Of the streams involved in this experiment, the Cosumnes was the only one which a tagged salmon could have ascended without first passing either a monitor or a counting station. The Cosumnes fish run late because the lower part of that river is dry until the first heavy rains.

In the four annual spawning stock surveys (1964 through 1967), a total of 649 carcasses was examined. In 1966, the survey crew took the only sonic tag recovered in this stream. About 4,100 fish were estimated to have spawned in the Cosumnes during the four-year period.

The proportion of tagged salmon found in the Mokelumne River System was highest in 1966 (5.8%) and zero in 1965 and 1967.

The salmon run in the Mokelumne System is such a small fraction of the total entering the Sacramento-San Joaquin System that there was little reason to expect many of our tagged fish were of Mokelumne origin.

Salmon tagged and released at Schad Landing were below all entrances to the Mokelumne System. Our tagging area at Prisoners Point was about 2½ miles upstream from the mouth of the Mokelumne.

The proportion of fish tagged at Prisoners Point, which went past the Sacramento River monitor at Courtland, varied from lows of 14% in 1967 and 15% in 1965, up to 65% in 1966. It is not surprising that numbers of Sacramento salmon are found near Prisoners Point. Seaward migrant salmon move with the current and many divert from the Sacramento River into the Delta Cross Channel or Georgiana Slough. Most of them reach the San Joaquin River via the mouth of the Mokelumne River. Presumably many migrating adults roughly retrace these same routes. At the mouth of the Mokelumne River they would be within 2½ miles of Prisoners Point and in an area of relatively strong tidal currents. Even in areas where there is no tide many salmon are known to go past the mouth of a tributary and then return and enter it.

Although the proportion of Sacramento salmon in the catch at Prisoners Point was substantial, it is evident that only a small fraction of the Sacramento run was involved.

In 1964, the spawning escapement of the Sacramento System was estimated to be 304,000 salmon, while that of the San Joaquin was estimated to be 6,000. Of the fish tagged at Prisoners Point, 18 went up the Sacramento River past the Courtland monitor and 16 went up the San Joaquin. The 18 Sacramento fish represent 1/16,900 of the entire Sacramento run, or 59 fish per million in the run. The 16 San Joaquin fish are 1/378 of that run, or 2,670 per million. Each San Joaquin fish had 2670/59, or 45 times as great a chance of being caught at Prisoners Point as its Sacramento River counterpart.

In 1965, 1966, and 1967, each San Joaquin salmon had respectively 216 times, 10 times, and 47 times as great a chance of being captured as an individual Sacramento fish (Table 8). The fact that in 1967 (for example) a San Joaquin salmon had 47 times as great a chance of being caught, does not mean that it had 47 times as great a chance of being at Prisoners Point. Unlike their Sacramento counterparts the San Joaquin fish were delayed by an oxygen block. By staying longer, they would presumably increase their chance of being caught. The length of this delay varied from year to year.

Various possible reasons have been suggested for the relatively high proportion of Sacramento fish in the catch at Prisoners Point in 1966. Two of these will be discussed. San Joaquin flows that fall were the lowest in the four years of this experiment, and the oxygen block below Stockton lasted so late that many salmon may have been getting desperate. Is it possible that some of the fish entering the Sacramento were actually San Joaquin fish which gave up the long wait, took advantage of the strong flow of relatively unpolluted water in the Mokelumne and eventually followed it through the Delta Cross Channel or Georgiana Slough to the Sacramento? Salmon of the Sacramento-San Joaquin Valley have been known to do this. An example

TABLE 8

Fraction of the Salmon in the San Joaquin and Sacramento Runs Captured at Prisoners Point

	1964	1965	1966	1967
Sacramento River System				
(a) Estimated spawning escapement	304,000	189,000	187,000	158,000
(b) Sonic tagged salmon recorded at Courtland	18	7	34	11
(c) Fraction of run recorded (b/a)	59.2×10^{-6}	37.0×10^{-6}	182×10^{-6}	69.6×10^{-6}
San Joaquin River System				
(d) Estimated spawning escapement	6,000	5,000	8,000	20,000
(e) Sonic tagged salmon recorded at a San Joaquin monitor	16	40	15	66
(f) Fraction of run recorded (e/d)	2670×10^{-6}	8000×10^{-6}	1880×10^{-6}	3300×10^{-6}
Relative availability to capture of individual fish in the run				
San Joaquin Salmon / Sacramento Salmon (f/c)	45	216	10	47

occurred in 1949. Flows below Friant Dam were such that it would have been impossible for spring-run salmon to have reached the spawning grounds in the San Joaquin. The (then) Division of Fish and Game deflected the spring run into the Merced River by placing a fish-tight net across the San Joaquin immediately above the mouth of the Merced. The flow of the San Joaquin was low, warm, and somewhat polluted. That of the Merced was high, cold and clean. The fish cooperated perfectly. Occasionally a salmon would nose the net, turn away and disappear. The men tending the installation saw few fish fight the net. Most, if not all of the run went up the Merced.

Besides this possible effect on San Joaquin salmon, it also seems possible that the low flows in the San Joaquin in the fall of 1966, could have had a direct effect on Sacramento salmon. Little San Joaquin water passed Stockton, part of that was diverted into Turner Cut, Columbia Cut, and Middle River, and little if any, got as far as the mouth of the Mokelumne River. Essentially all of the water in the lower Mokelumne and the adjoining part of the San Joaquin was of Sacramento plus Mokelumne origin.

It seems possible that in 1966 about the usual proportion of Sacramento salmon was starting up the San Joaquin River, but that more than the usual fraction reached Prisoners Point simply because there was not enough change in the water to alert them to the fact that they had passed the turnoff into the Mokelumne River.

Monitor recordings in 1964 and 1967 indicate that about the same proportion of the Sacramento run reached Prisoners Point in these two years. The fall of 1964 was much drier than that of 1967, but because of the Old River closure, the flow of San Joaquin water past Stockton was not greatly different. On the other hand, the flow of San Joaquin water past Stockton in 1965 was not far different from that of 1964 or 1967, but the portion of the 1965 Sacramento run reaching Prisoners Point appears to have been less than a quarter as great. We have no reasonable explanation for this.

WATER TEMPERATURE, DISSOLVED OXYGEN AND SALMON MOVEMENTS

In 1965, 1966, and 1967, dissolved oxygen concentration seems to have been the factor that controlled the movement of the first salmon past Stockton. In each year, no tagged fish appeared above Stockton until the lowest dissolved oxygen reading below Stockton had risen above 4.2 ppm, and in none of these three years did the first fish fail to appear by the time the dissolved oxygen had increased to 5.0 ppm. In 1965, the first three fish appeared on October 3, 4, and 5; the dissolved oxygen readings were 4.2 ppm on October 1 and 4.6 ppm on October 5. In the following two years, the first salmon appeared on the day the dissolved oxygen rose to 5.0 and 4.5 ppm, respectively. In 1964, the dissolved oxygen level does not appear to have been the controlling factor; the first fish appeared on a day when the dissolved oxygen reading was 4.9 ppm, but had been well above 5 ppm for the previous two weeks (Figure 22).

In each of the four years, there was a five to ten day delay after the first one, two or three tagged fish appeared. After this fishless period, there was a relatively steady passage of tagged fish past the monitor with tags being recorded on most days and with no gaps longer than three days. At the start of the steady run of fish, the dissolved oxygen was betwen 5.5 and 6.1 ppm in 1965, between 5.7 and 6.0 ppm in 1966, and between 4.5 and 5.3 ppm in 1967. Although the number of observations is relatively small, it would appear that a few fish will go through water containing a little less than 5.0 ppm dissolved oxygen, but the bulk of the salmon will not migrate until the oxygen concentration is 5.0 ppm, or preferably more.

The dissolved oxygen measurements listed are the lowest found on the dates given. This seems to be the best measure of the fish blocking capacity of the pollution. Readings at any one station do not give a satisfactory picture of the problem because the low point of the "oxygen sag" is moved away from the point of effluent discharge by the net flow of the river and is also moved up and downstream by the tide. The lowest reading was usually in areas 22, 23, or 26, but was occasionally in areas 19 or 29 (Figures 1 and 22). In 1966 the net river flows were lowest, and the lowest oxygen readings averaged farthest upstream. We had no water sampling stations between areas 19 and 29 other than those just listed.

In addition to avoiding an oxygen block, salmon try to avoid high temperatures. Apparently temperature became the controlling factor in 1964, after the Old River barrier and the release of pumped water had removed the oxygen block. Except for one reading of 4.8 ppm, the dissolved oxygen had been above 5 ppm for two weeks before the first tagged fish appeared above Stockton. During those two weeks, the salmon would have had to traverse waters of 70° F., or above, most of the time. The first three tagged salmon appeared when the temperature was 70° to 71° F., but there were no more for another ten days, by which time the water had cooled to 66° F. Apparently in 1964, most of the fish in the San Joaquin River refused to move upstream and into 70° F. water even though there was adequate dissolved oxygen. To us

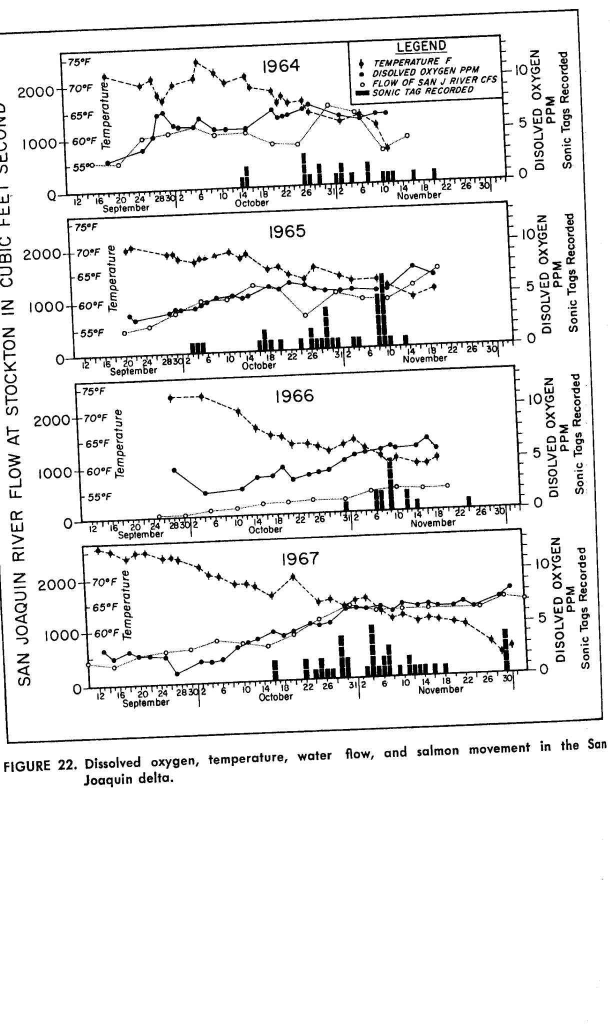

FIGURE 22. Dissolved oxygen, temperature, water flow, and salmon movement in the San Joaquin delta.

this seems understandable; they had been staying in water that was mostly of Sacramento origin and was two or three degrees cooler (Table 9 and Appendix 6). In 1966 the temperature had dropped to 63° F. by the time the first fish appeared above Stockton. Clearly the oxygen block was the controlling factor that year. In 1967 the temperature was 66° F. and it was between 67° F. and 68° F. in 1965 when the first fish were recorded above Stockton. In all four years, the bulk of the tagged salmon moved up the San Joaquin at temperatures of 65° F. or less.

TABLE 9

Summary of Water Temperature, Dissolved Oxygen, and Salmon Movement Past Stockton *

Year	Date		Highest temperature		Lowest dissolved oxygen	
	First fish	Start of Steady run†	First fish	Start of Steady run*	First fish	Start of Steady run*
1964	Oct. 14	Oct. 26	70–71	66	4.8–5.6	7.4
1965	Oct. 3	Oct. 16	67–68‡	63.5–65.5‡	4.2–4.6‡	5.5–6.1‡
1966	Oct. 31	Nov. 6	63	62.5–61‡	5.0	5.7–6.0‡
1967	Oct. 16	Oct. 22	66	69–66‡	4.5	4.5–5.3‡

* 1964 fish were monitored at Mossdale, 1965–67 fish were monitored at Bowman Road.
† When no more than two full days passed without a tag being recorded.
‡ The readings given were taken before and after the date listed; no observations made on the exact date.

The pumped water released into the San Joaquin River in 1964 appears to have had little if any cooling effect after its long and circuitous trip through the San Joaquin Valley. Certainly it did not lower temperatures enough to start the salmon moving upstream. This was probably just as well. There would have been no advantage in having salmon move upstream and out of the Delta while the tributary streams were still too warm for them.

We considered the possibility that tagged salmon might be reaching the San Joaquin River above Stockton earlier or later than untagged individuals. A partial check on this was made by comparing the time when tagged fish had passed the San Joaquin or Old River monitors with the time untagged salmon had entered a temporary trap installed each fall on the Stanislaus River to take salmon for artificial reproduction. In the event that any number of salmon were trapped before the first tagged salmon reached the Bowman Road or Old River monitors it might indicate that the tagged fish were not moving upstream as soon as untagged ones. What did happen was that in no year were any fish trapped before at least one monitor had recorded a tag. However the data obtained were not conclusive primarily because the trapping operation had not been related to our tagging experiment, and only in 1966 was the trap in place before the first tagged fish passed one of the monitors. In that year one tag had been recorded at Old River monitor before any salmon were taken in the trap (Table 10).

TABLE 10

Comparison of Times When Tagged Salmon Passed Monitors with Dates When Salmon Entered Stanislaus River Trap

Date	1965			1966			1967		
	Tagged salmon recorded		Salmon captured	Tagged salmon recorded		Salmon captured	Tagged salmon recorded		Salmon captured
	Old River monitor	Bowman Road monitor	Stanislaus River trap	Old River monitor	Bowman Road monitor	Stanislaus River trap	Old River monitor	Bowman Road monitor	Stanislaus River trap
Oct.									
2- 3	--	1	--	--	--	--	--	--	--
4- 5	--	2	--	--	--	--	6	--	--
6- 7	1	--	--	--	--	--	2	--	--
8- 9									
10-11	1	--	--	--	--	--	11	--	--
12-13	--	--	*	--	--	--	--	--	1*
14-15	--	--	1	--	--	--	1		
16-17	--	3	5	--	--	--	--	2	8
18-19	--	1	4	--	--	*	--	--	5
20-21	--	1	14	1	--	--	--	--	27
22-23	--	--	4	--	--	1	1	2	14
24-25	--	1	4	--	--	--	--	3	1
26-27	3	3	9	--	--	--	--	2	2
28-29	--	5	9	--	--	1	--	4	3
30-31	--	2	12	--	--	3	--	2	2
Nov.									
1- 2	--	--	13	--	1	1	1	--	25
3- 4	--	2	17	--	--	3	--	6	27
5- 6	--	--	18	--	2	5	--	3	63
7- 8	--	5	19†	--	2	15	--	3	58
9-10	--	8	--	--	5	27	3	1	48
11-12	--	--	--	--	2	19	1	3	37
13-14	--	1	--	--	1	20	--	2	58
15-16	--	--	--	--	--	89	--	1	5†
17-18	--	--	--	--	--	24	--	1	
19-20	--	--	--	--	--	30	--	--	--
21-22	--	--	--	--	--	20	1	--	--
23-24	--	--	--	--	1	17	--	--	--
25-26	--	--	--	--	--	16	--	--	--
27-28	--	--	--	--	--	21	--	--	--
29-30	--	--	--	--	--	15	--	4	--
Dec.									
1- 2	--	--	--	--	--	22	--	--	--
3- 4	--	--	--	--	--	10†	--	--	--
Total	5	35	129	1	14	359	27	39	384

* Trapping started.
† Trapping ended.

FLOW REQUIREMENTS OF MIGRATING SALMON

The flow required to get migrating salmon past Stockton must be enough to dilute the sources of pollution, in that area, and raise the oxygen concentration to 5.0 ppm or above. If oxygen was not the problem (i.e., if pollution in the Stockton area were eliminated or greatly reduced) there would still need to be enough San Joaquin water flowing past Stockton so that the salmon could detect it. Further, this water temperature would have to be suitable (less than 66° F.).

In all four years of our sonic tagging experiment, salmon did make their way upstream through the Delta, most of them by way of the main San Joaquin channel. The lowest flow was in 1966; in that year the first tagged fish passed Bowman Road on October 31 and the second on November 6. The flow past Stockton on those two days was 252 and 391 cfs. The start of the 1966 run was the latest in any of the four years and, as mentioned above, its delay appears to have been due to lack of dissolved oxygen. When temperature is no problem and pollution is controlled it might be presumed that about 250 cfs would be enough to get some salmon through and that about 400 cfs of San Joaquin water would keep the run moving. This assumption would be safe only if the fall pumping schedule were no heavier than in 1966. The amount of water being taken by the Tracy and Italian Slough pumping plants may turn out to be a highly complicating factor. As the strength of flow reversal increases in Old and Middle Rivers, there comes a point when the flow in the San Joaquin above the mouth of the Mokelumne River reverses and water flows upstream as far as Turner Cut, then enters Turner Cut and goes by that route to Middle River. When this happens, any San Joaquin water going downstream past Stockton also goes into Turner Cut. If the flows were steady (non-tidal), no San Joaquin water would get past Turner Cut under these conditions; however, tidal flows in the San Joaquin channel are strong enough to carry some San Joaquin water past Turner Cut on an outgoing tide. The question is, "Under what conditions would the tide carry enough water past Turner Cut, Columbia Cut, and the mouth of Middle River to alert salmon further downstream and start them moving past Stockton?" A model study taking tidal flows into account would help answer this question.

In 1966, the steady movement of salmon past the Bowman Road monitor began on November 6, when the stream flow past Stockton was calculated to be 391 cfs and the draft of the Tracy Pumping Plant was 1,030 cfs. The flow of the San Joaquin River just above Old River heading was about 1,300 cfs, of which about 860 cfs entered Old River and took the more direct route to the pumps. About 615 cfs was starting south from the central part of the Delta in Old River, Middle River, Turner Cut, etc. Roughly 135 cfs or about 22% of this total was going via Turner Cut. Since 391 cfs was coming down the San Joaquin via Stockton, it appears that about 256 cfs was going past the entrance to Turner Cut. Some of it appears to have gotten far enough to attract the salmon. If a similar flow of 391 cfs were to be going past Stockton at a time when the Tracy and Italian Slough pumps were pulling an additional 1,000 cfs south through the Delta, the flow into Turner Cut would increase by 22%

of that figure, or by another 220 cfs. Under these conditions only about 36 cfs of the flow past Stockton would get past Turner Cut. It would not be safe to assume that this would be enough to alert the salmon waiting below Columbia Cut. Because of the lack of adequate data in this area, all the above flow calculations can only be crude approximations, but the principal involved should be very carefully considered when deciding in some future dry year whether or not a barrier should be installed in Old River.

The fall of 1966 was the driest in the four years of this investigation. The first salmon did not move past Stockton until the last day of October, and a steady run did not start until November 6. At that time there was still a reversed flow in Old and Middle Rivers north of the Tracy pumps and salmon were not using that route. In spite of this long delay, the run was about 8,000 fish; the best escapement since the San Joaquin runs had collapsed in 1961.

Pumping at Tracy started in 1951, and by 1960 there had been dry falls in four years—1954, 1955, 1959, and 1960, but fair to good runs of salmon had gone up the San Joaquin in each.[4] Were water conditions in any of those years any worse than in 1966? If so, it might give some indication of the minimum flow conditions under which salmon might be expected to migrate satisfactorily through the Delta. Although 1964 was also a dry year, it is not being considered here because the closure at the head of Old River and the supplementary water added resulted in flows below Stockton which were much larger than in any of the other dry years listed above.

The fall of 1961 was also dry, and in that year the escapement was catastrophic: it dropped to about 1/20 that of the previous year. We have assumed that fall water conditions in the San Joaquin part of the Delta in 1961 must have affected the adults before they reached the rivers, or that water conditions three and four years previously had affected the young before or during their seaward migration because experiences downstream from the Delta were shared between San Joaquin and Sacramento salmon, and the latter suffered no corresponding decline.

A comparison of flows at several key places during the dry years since 1951 shows that water conditions for salmon were far worse in the fall of 1961 than in any other year. For example, on November 5, 1961, San Joaquin River flows past Stockton were calculated to have been only 103 cfs. In the other dry years, the flows at Stockton on that date ranged from 285 to 436 cfs.[5] Below Turner Cut, our calculations give a reversed flow of 56 cfs on November 5 of 1961, and positive flows of 204 to 433 cfs in the other dry years. Flows in Old and Middle Rivers were reversed in all the dry years, but the reversal was strongest in 1961. These calculated flows are subject to quite large error (at least 100 cfs) because water in the Delta seldom behaves exactly as calculated. However, we believe the comparison between 1961 and the other years is basically valid and that there was no chance that salmon could have

[4] The escapement in 1955 was 27,000; in the other three years, it was 50,000 to 62,000.

[5] In 1955 (the second driest year), flows before and after November 5 were about 230 cfs, but a brief rise resulted in a flow calculated to be 401 cfs on November 5. It is conceivable that good numbers of salmon went upstream during this rise.

used the San Joaquin near Stockton as early as November 5, 1961, and little chance that any could have used it during the following three weeks. It seems probable then that the only salmon reaching the San Joaquin tributaries in 1961 were late spawners or fish which found their way through Old and Middle Rivers despite flow reversal in those channels. The reversal there lasted through November (Table 11).

TABLE 11

San Joaquin River Flows in Six Dry Falls
One Approximately Median Year (1962) Included for Comparison

	San Joaquin R. near Vernalis	San Joaquin R. past Stockton	San Joaquin R. below Turner Cut	Old River plus Middle R.	Withdrawn by Tracy Pumping Plant
1954 Nov. 5	1,300	436	433	−13	333
1955 Nov. 5	1,210	401	374	−126	391
* Nov. 10	834	231	137	−439	498
1959 Nov. 5	985	285	204	−379	535
1960 Nov. 5	1,010	294	208	−400	572
1961 Nov. 5	584	103	−56	−741	678
1966 Nov. 5	1,340	400	278	−567	963
1962† Nov. 5	1,550	504	443	−284	786

* The flow of the San Joaquin River near Vernalis on Nov. 10, 1955 is typical of the flows from Oct. 25 to Nov. 15 of that year; flows on Nov. 5 were up to 1,210 cfs. There is a possibility that this brief rise could have induced some fish to move past Stockton.

† 1962 is the latest year having approximately the median San Joaquin River flow near Vernalis on Nov. 5. The Tracy pumping rate at this time of year has been increasing; in 1962 it was above median, but below that of 1965, 1966 and 1967.

In 1966, the flow past Stockton and below Turner Cut was greater than in most of the dry years, but the reversed flow in Old and Middle Rivers was stronger than in any dry year except 1961. On November 5, the flow past Stockton was calculated to have been 400 cfs as compared with 294 cfs in 1960 and 285 cfs in 1959. Below Turner Cut the flows in these same three years were calculated to have been 278 cfs, 208 cfs, and 204 cfs. Good runs got upstream in 1960 and 1959 on these lesser flows, suggesting that such flows would be adequate if the dissolved oxygen concentration were also adequate. A lack of oxygen occurred in 1966 despite the larger flows. It would not be safe to assume that flows as small as those of 1966 could get salmon upstream in the future unless there is a great improvement in the water quality at and below Stockton.

The three worst spawning escapements on record for the San Joaquin River System were in 1961, 1962, and 1963. Water conditions in the fall of 1962 and 1963 were sufficient to preclude the fish being blocked on their upstream migration. However, salmon can also be seriously affected by poor water conditions when on their seaward migration. Downstream migrants make their seaward journey when only a few months old and a strong relationship exists between the spring water flows of the San Joaquin and the numbers of those downstream migrants returning to spawn (Calif. Dept. Fish and Game, Dept. Water Res. and Central Valley Reg. Water Poll. Control Bd., 1965).

Could the 1961 drop in escapement have been due to poor water conditions in the spring rather than in the fall? Could poor water conditions account for the low escapement in 1962 and 1963? Most San Joaquin salmon spawn at either three or four years of age. There were excellent flows in the spring of 1958, but very poor ones in the following three years. Thus, in 1961, the four-year-old salmon (1957 brood year) were salmon that had experienced very good conditions on their seaward migration, whereas the three-year-olds (1958 brood year) spawning with them had experienced very poor conditions. Therefore, spring water conditions may have been responsible for some, but not all, of the decline in salmon escapement in 1961. In contrast, it is probable that low spring flows may have been the major reason for the failure of the 1962 and 1963 runs. In these two years, the three- and four-year-old salmon ascending the San Joaquin would have made their downstream migrations in either 1959, 1960, or 1961, three successive dry springs.

SUMMARY

From 1960 to 1961, the spawning escapement of king salmon in the San Joaquin River System dropped from 53,000 to 2,550 fish. The following two years were worse, but there has been some recovery since then. All three spawning streams in the San Joaquin Valley suffered similar declines in their salmon populations, but there was no corresponding decline in the Sacramento River or its tributaries. The one experience shared by all salmon from the San Joaquin tributaries and by none of the Sacramento fish was passage through the San Joaquin just south of the Sacramento-San Joaquin Delta, and passage through the southern part of the Delta itself.

The Tracy Pumping Plant near the southwest corner of the Delta has a rated capacity of 4,600 cfs and has greatly altered hydrographic conditions within the Delta since it started operating in 1951. Every summer and early fall, flows in Old and Middle Rivers have been reversed; i.e., these channels are carrying Sacramento River water toward the pumps instead of carrying San Joaquin water toward the ocean. Under these conditions, the pumps are taking from 60 to 100% of the flow of the San Joaquin River. As fall water demands have increased, the reverse flows have become stronger and last later in the season. When the water taken by the Tracy pumps exceeds five times the flow of the San Joaquin River above Mossdale, the flow in the main San Joaquin channel also reverses and Sacramento River water then flows upstream past Stockton and into the upstream end of Old River. This degree of reversal has occurred in most summers since 1960, but it usually dies away by fall. In 1961, it lasted until mid-October.

The new State pumping plant at Italian Slough has a capacity of 10,000 cfs, but is not scheduled to take more than 6,500 cfs before completion of the Peripheral Canal. This operation added to that of the Tracy plant will result in flow reversals which will be much stronger and will last later in the season.

By reducing or reversing the flows in the San Joaquin River past Stockton, heavy pumping has worsened an already bad pollution problem in the Stockton area. A major part of this pollution is from fruit and vegetable canning wastes and creates a serious oxygen block which lasts well into the fall.

To determine the reactions of salmon to reversed flows and pollution, 316 salmon were tagged with sonic tags and released in the Delta during the period 1964 through 1967. The tags used gave off pulsed ultrasonic signals of 130,000 or 160,000 cycles per second. The signals could be detected at distances up to three-quarters of a mile by portable or stationary receivers.

The portable receivers, which amplified the signals and converted them to an audible frequency, were used to search an area for tagged fish. The stationary receivers were designed to record any sonic tags coming within their range. Unfortunately, they also recorded "interference noise" from passing boats and other sources. Although an annoyance, this did not appear to be a significant source of inaccuracy.

In 1964, 13 borrowed, stationary receivers were mounted in the Delta, on the Sacramento River, and on the Stanislaus and Tuolumne Rivers.

Eight of these were mounted in pairs in an attempt to determine the direction the fish were moving. The other five were mounted singly. Four receivers (two pair) were mounted near areas where tagged fish were released. So many of these fish remained nearby that at times the resulting confusion of signals made it impossible to keep track of individual tags.

From 1965 through 1967, four, purchased, stationary receivers were used. They were of different design and proved to be superior. Two were mounted on the San Joaquin River above Stockton and one each on the Sacramento and Old River.

Boat crews with portable receivers kept track of tagged fish in the main channel of the San Joaquin between the Antioch Bridge and Mossdale, and searched for tags in other channels of the Delta as time permitted. These boat crews routinely measured temperatures and oxygen levels at many points in the San Joaquin River as part of their tag detection work.

Salmon for tagging were captured with a trammel net and the sonic tag was attached externally in the vicinity of the dorsal fin. The first 49 fish were tagged in September 1964 and released near Schad Landing on the main channel of the San Joaquin, well below the mouth of the Mokelumne River. These fish turned out to be primarily of Sacramento River origin, so our base of tagging operations was moved to Prisoners Point, upstream from the mouth of the Mokelumne. This location was used for the remainder of 1964 and all of 1965, 1966 and 1967.

The fall of 1964 was quite dry, and to remove the threat of a flow reversal in the main channel of the San Joaquin, the Resources Agency of California installed a partial barrier across the head of Old River so that most of the San Joaquin flow would go down the main channel past Stockton; and the U. S. Bureau of Reclamation pumped additional water at the Tracy Pumping Plant and released it into the San Joaquin River above Mossdale. This procedure was effective in that it maintained a good positive flow past Stockton and cleared up the oxygen block, but for some time the water temperatures were high and the salmon did not move upstream. Neither pumping nor a barrier was used in any of the other three years, but there is now an agreement to do so if, and when, necessary.

The falls of 1965 and 1967 were both wetter than normal. The dissolved oxygen level rose above 5 ppm about October 7 in 1965, but not until October 22 in 1967. The fall of 1966 was dry—almost disastrously so. Flows past Stockton were very low, and the dissolved oxygen did not rise above 5 ppm until October 31.

Monitor recordings demonstrate that the proportion of the tagged salmon going up the San Joaquin River system varied greatly from year to year, in 1964, about 20% of the fish tagged at Schad Landing and 46% of those tagged at Prisoners Point were of San Joaquin origin. At Prisoners Point in 1965 and 1967, the San Joaquin fish were 85 and 86% of the total. In 1966 (with very poor water conditions), only 29% went up the San Joaquin. There would seem to be a possibility that in 1966 some San Joaquin fish gave up after the long

delay below Stockton and spawned elsewhere. It is also possible that Sacramento salmon going upstream via the lower part of the San Joaquin River went farther than usual up that channel because in the fall of 1966 the water there was of almost 100% Sacramento plus Mokelumne River origin. Monitor counts on the Sacramento River show that of the fish tagged the proportion going up that stream ranged from 75% of the total (Schad Landing releases in 1964) down to 14% (Prisoners Point releases in 1967). Mokelumne River System counts were not made by a monitor and were not complete. They ranged from 0–6% of the total. Although the proportion of Sacramento salmon among those taken at Prisoners Point was quite substantial, the numbers tagged were a very small fraction of the total Sacramento spawning escapement. The San Joaquin run was much smaller, the number recaptured somewhat larger, and the percentage of the San Joaquin run captured was from 10 to 216 times as great as the captured percentage of the Sacramento run.

In all four years of this investigation, after varying periods of delay, the major part of the San Joaquin salmon run moved up river past Stockton. While waiting, they ranged rather widely in the area below Columbia Cut in water that was mostly of Sacramento River origin and was both cleaner and cooler than that farther up the San Joaquin. In general, no salmon moved past Stockton until the dissolved oxygen had risen to about 4.5 ppm, and the run did not become steady until oxygen levels were above 5 ppm. Three tagged fish did move up the San Joaquin when the temperature was 72°F.; anything over 66°F. appears to be a partial block, in that the runs did not become steady until the temperature was 66°F. or less.

In all four years of the experiment, flows were reversed in Old and Middle Rivers during the earlier part of the salmon migration. During 1964, 1965, and 1966, the proportion of the San Joaquin salmon which left the Delta via Old or Middle Rivers was under 15%. In 1967, the proportion which did so was 41%. We can determine no reason for this difference.

When there is relatively little water flowing down the San Joaquin past Stockton and the reversed flow in Old River and Middle River is strong enough, the result is a reverse flow in the San Joaquin River from the mouth of the Mokelumne River upstream to Turner Cut. The reversed flow in Old and Middle Rivers appears to keep most salmon from using that route. It further appears that a reversed flow between Turner Cut and the mouth of the Mokelumne River would have a similar effect in the San Joaquin channel. Under present conditions, such a flow reversal in the fall is accompanied by an oxygen block below Stockton. Under greatly increased fall pumping, this could occur even when there was adequate dissolved oxygen.

ANSWERS TO QUESTIONS POSED IN THE INTRODUCTION

1. What do San Joaquin salmon do if:

(a) All flows are in the normal direction and no oxygen or temperature block exists?

These conditions occurred only in the late part of the season and only in 1964, 1965, and 1967. Most tagged fish used the main San Joaquin channel in 1967; all of them used it in 1964 and 1965.

(b) All flows are in the normal direction and there is an oxygen or temperature block in the San Joaquin River?

This condition did not occur during our investigation.

(c) The San Joaquin River is flowing in the normal direction, but has an oxygen or temperature block and the flows in Old and Middle Rivers are reversed?

Most salmon will remain below the block until it clears. A few salmon will use the Old or Middle River route; usually they will do so early in the season. It is quite possible that after too long a delay salmon will enter another stream to spawn. To prove or disprove this in the Delta would require a marking experiment lasting several years. There was no indication that numbers of salmon entered the polluted water and were being killed by it. Too long a delay is known to affect the viability of salmon eggs, but evidently this did not happen to the salmon involved in this study; eggs taken at the Stanislaus River trap were normal.

(d) All flows are reversed?

This did not happen during the salmon migration in 1964–1967. We assume that if it did happen, few, if any, salmon would find their way to the San Joaquin tributaries. The San Joaquin below Stockton would not be carrying any San Joaquin water and we cannot presume that salmon would use Old or Middle River because the north end of these channels would have no San Joaquin water. (Under condition (c) above, some San Joaquin water does enter the north end of these channels after passing Stockton.)

2. What oxygen concentrations and what temperatures constitute a block in the Delta?

Less than 4.5 ppm of oxygen should be regarded as a total or near total block and less than 5 ppm as a partial block.

The effect of the water temperatures encountered is less clear, but anything over 66° F. appears to be a partial block.

3. Are any number of Sacramento salmon entering the lower part of the San Joaquin River and then returning to the Sacramento?

Yes. Most of the salmon tagged at Schad Landing and many of those tagged at Prisoners Point reentered the Sacramento

River. A great deal of Sacramento River water flows into the San Joaquin River by way of the Delta Cross Channel or Georgiana Slough and the lower Mokelumne River. This appears to be a regular migration route.

4. What will be the effect on salmon from the vastly increased pumping in the southwest corner of the Delta as the new Italian Slough Pumping Plant approaches its full operating schedule?

Disaster, unless the Peripheral Canal or some similar facility is constructed. Even with the Peripheral Canal there will be important problems to solve.

5. Will installation of a barrier at the head of Old River plus supplemental releases into the San Joaquin River make conditions below Stockton suitable for salmon migration?

We cannot predict with confidence until we learn more about the effect on temperature of pumping, transporting, and releasing Sacramento River water. In 1964, the barrier plus pumping immediately created a good positive flow past Stockton and increased the dissolved oxygen to suitable levels, but the water temperatures remained high. Most of the salmon stayed below Stockton until the temperature dropped to 65° F. In 1964, this happened soon enough to produce a satisfactory final result. We do not know if it would always do so.

CONCLUSIONS

1. Few adult salmon will migrate past Stockton when the San Joaquin River contains less than 5 ppm of dissolved oxygen or the water is warmer than 66° F.
2. Most salmon will not migrate to the tributaries via Old and Middle Rivers when the flows there are reversed, or when conditions in the San Joaquin are suitable.
3. The minimum positive river flow past Stockton, required for adult salmon migration, was not established, but it can be as low as 400 cfs if the water is of San Joaquin origin, if the dissolved oxygen level and temperature are suitable, and if an adequate amount of this water remains in the San Joaquin River past Turner and Columbia Cuts.
4. Installing a barrier across the head of Old River and releasing supplemental water from the Delta-Mendota Canal into the San Joaquin River above Mossdale will insure a positive flow in the San Joaquin River past Stockton and will increase the dissolved oxygen levels, at and below Stockton, but will not necessarily insure a decrease in water temperatures to levels that will induce salmon migration. This lack is probably just as well since we can see no advantage in inducing salmon to migrate past Mossdale before their tributary streams are cool enough.
5. The combination of low flows, flow reversal and presumably the low amounts of dissolved oxygen during the fall of 1961 appear responsible for the collapse of San Joaquin salmon runs in that year.
6. Fall water conditions do not appear responsible for the small salmon runs in 1962 and 1963. Instead the low spring flows in 1959, 1960, and 1961 could have greatly reduced the survival of downstream migrants and thereby reduce the upstream, or adult, migrations in 1962 and 1963.
7. The Peripheral Canal or some similar closed-circuit system seems to be the best solution to salmon problems in the Sacramento-San Joaquin Delta. However, large releases of Sacramento River water from this canal into the southern Delta may attract numbers of adult Sacramento River salmon to the spill sites.
8. There are at least two major routes by which adult Sacramento River salmon migrate through the Delta, one is directly into the Sacramento River; the other is via the lower San Joaquin, from its mouth to its confluence with the Mokelumne, then up the Mokelumne and back through Georgiana Slough or the Delta Cross Channel into the Sacramento River. There are many minor variations of these routes.

RECOMMENDATIONS

To insure adequate upstream passage for San Joaquin salmon, the following should be provided:

a. A minimum positive flow past Stockton of 400 cfs of San Joaquin water, or enough to raise the dissolved oxygen level to 5 ppm, after October 1, whichever is greater, and
b. A minimum positive flow in the San Joaquin River past Turner Cut (consider 200 cfs as a first approximation).
c. A barrier at the head of Old River whenever it appears to be needed, but that barrier should never be a total block to salmon migrating up Old River.
d. Release of water from the Delta-Mendota Canal into the San Joaquin River above Mossdale when necessary,. but only when the Old River barrier is in place.

The above flows past Stockton and Turner Cut are considered to be minimal, and should be exceeded whenever San Joaquin run-off permits.

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APPENDIX 1

The Association of Stream Flow, Dissolved Oxygen and Water Temperature with the Migration of Tagged Salmon in the San Joaquin River 1964, 1965, 1966, 1967

Date	1964					1965					1966					1967				
	Salmon tagged	Flow at Stockton cfs	Min. D.O. ppm	Max. Temp. °F.	Tagged salmon past Mossdale Monitor	Salmon tagged	Flow at Stockton cfs	Min. D.O. ppm	Max. Temp. °F.	Tagged salmon past Bowman Rd. Monitor	Salmon tagged	Flow at Stockton cfs	Min. D.O. ppm	Max. Temp. °F.	Tagged salmon past Bowman Rd. Monitor	Salmon tagged	Flow at Stockton cfs	Min. D.O. ppm	Max. Temp. °F.	Tagged salmon past Bowman Rd. Monitor
Sept.																				
1	--	45	--	--	--	--	132	--	--	--	--	−82	--	--	--	--	405	--	--	--
2	--	56	--	--	--	--	166	--	--	--	--	−72	--	--	--	--	462	--	--	--
3	--	59	--	--	--	--	216	--	--	--	--	−47	--	--	--	--	485	--	--	--
4	--	56	--	--	--	--	233	--	--	--	--	−17	--	--	--	--	517	--	--	--
5	--	47	--	--	--	--	273	--	--	--	--	−5	--	--	--	--	471	--	--	--
6	--	38	--	--	--	--	320	--	--	--	--	−16	--	--	--	--	423	--	--	--
7	--	52	--	--	--	--	274	--	--	--	--	−57	--	--	--	--	415	--	--	--
8	--	38	--	--	--	--	291	--	--	--	--	−76	--	--	--	--	412	--	--	--
9	--	24	--	--	--	--	255	--	--	--	--	−70	--	--	--	--	393	--	--	--
10	--	−5	--	--	--	--	245	--	--	--	--	−70	--	--	--	--	454	--	--	--
11	--	−13	4.2	70.0	--	--	250	--	--	--	--	−49	--	--	--	2	484	--	--	--
12	--	−6	--	--	--	--	284	--	--	--	--	−35	--	--	--	1	427	--	--	--
13	--	5	--	--	--	--	309	--	--	--	--	−21	--	--	--	1	382	3.3	76.0	--
14	--	535	--	--	--	2	283	--	--	--	--	−26	--	--	--	2	377	--	--	--
15	--	527	--	--	--	--	257	--	--	--	--	−8	--	--	--	--	366	2.5	75.4	--
16	--	493	--	--	--	--	257	--	--	--	--	10	--	--	--	--	387	--	--	--
17	--	489	--	--	--	--	311	--	--	--	--	−6	--	--	--	--	447	--	--	--
18	--	489	2.9	72.0	--	--	378	--	--	--	--	−4	--	--	--	6	518	3.1	74.0	--
19	--	493	--	--	--	--	394	--	--	--	--	23	--	--	--	--	557	--	--	--
20	--	510	--	--	--	4	432	--	--	--	--	24	--	--	--	--	538	2.7	75.0	--
21	--	561	--	--	--	2	358	3.8	70.0	--	--	39	--	--	--	--	497	--	--	--
22	--	574	--	--	--	2	416	3.3	70.5			58	--	--	--	1	515	2.7	75.0	--
23	--	598	--	--	--	2	459	--	--	--	--	47	--	--	--	--	537	--	--	--
24	--	809	--	--	--	--	480	--	--	--	--	42	--	--	--	--	556	--	--	--
25	--	978	3.8	70.0	--	--	509	--	--	--	--	24	--	--	--	--	599	2.6	74.0	--
26	--	875	--	--	--	--	604	--	--	--	4	35	--	--	--	--	553	--	--	--
27	--	955	5.0	71.0	--	5	640	--	--	--	--	35	--	--	--	--	523	1.1	74.0	--
28	--	1,035	7.2	68.0	--	--	633	--	--	--	2	23	4.7	73.0	--	--	488	--	--	--
29	--	875	7.4	67.0	--	5	676	3.8	69.0	--	4	10	--	--	--	--	552	--	--	--
30	--	883	--	--	--	--	754	4.1	69.0	--	--	18	--	--	--	--	628	--	--	--
Oct.																				
1	--	993	5.7	70.0	--	--	797	4.1	68.0	--	--	38	--	--	--	--	640	--	--	--
2	--	1,049	5.9	--	--	--	832	--	--	--	--	39	--	--	--	10	643	2.0	72.0	--
3	--	1,001	--	--	--	--	887	--	--	1	3	66	--	--	--	6	677	--	--	--
4	--	977	--	--	--	3	930	4.3	67.5	1	5	108	2.4	73.0	--	6	711	2.0	70.5	--
5	--	993	5.9	72.0	--	3	880	4.7	68.0	1	2	107	--	--	--	--	773	--	--	--
6	--	1,009	6.7	74.0	--	4	867	4.9	68.0	--	--	101	--	--	--	--	784	2.2	70.0	--
7	3	1,025	--	--	--	--	923	--	--	--	--	118	--	--	--	--	804	--	--	--
8	10	985	--	--	--	--	909	5.1	68.5	--	--	101	--	--	--	--	817	--	--	--
9	7	993	5.6	72.0	--	--	971	--	--	--	--	119	--	--	--	--	824	3.3	68.5	--
10	--	1,009	--	--	--	--	930	--	--	--	--	119	--	--	--	--	709	--	--	--
11	--	1,041	5.6	70.0	--	2	930	5.3	69.0	--	5	108	2.6	70.0	--	--	624	3.7	68.5	--
12	5	1,017	--	--	--	3	964	--	--	--	2	161	--	--	--	--	641	--	--	--
13	5	1,017	--	--	--	3	1,050	5.1	68.0	--	--	194	--	--	--	--	581	4.0	68.0	--
14	--	1,065	--	--	*1	1	1,096	5.3	68.5	--	3	201	3.7	67.0	--	--	620	--	--	--
15	5	1,081	4.8	71.0	*2	--	1,198	--	--	--	--	211	--	--	--	--	647	--	--	--
16	1	1,089	5.8	68.0–70.0	--	--	1,322	--	--	1	--	233	--	--	--	10	732	4.6	66.0	2
17	--	1,033	--	--	--	--	1,296	--	--	2	4	243	3.9	65.5	--	9	767	--	--	--
18	--	953	--	--	--	6	1,176	6.1	65.5	1	--	233	--	--	--	4	770	4.2	67.5	--
19	4	897	--	--	--	--	1,144	--	--	--	4	211	4.5	65.0	--	--	793	--	--	--
20	--	809	7.4	68.0	--	--	1,100	5.9	66.0	1	2	233	--	--	--	--	873	4.6	69.5	--
21	--	777	6.5	66.0	--	2	1,036	--	--	--	--	238	3.4	63.5	--	--	945	--	--	--
22	2	785	6.6	67.0	--	2	798	6.5	64.5	--	--	250	--	--	--	--	1,033	--	--	2
23	--	777	6.7	66.0	--	--	671	--	--	--	--	261	--	--	--	--	1,093	5.3	66.5	--
24	--	777	--	--	--	--	631	--	--	1	1	274	3.8	63.5	--	--	1,042	--	--	1
25	--	793	--	--	--	2	580	6.1	63.5	--	1	339	--	--	--	--	1,107	5.1	64.5	2
26	--	825	7.4	66.0	*1,2	2	563	--	--	2	--	233	4.0	63.0	--	--	1,223	--	--	1
27	--	841	6.6	64.0	1	--	600	5.8	65.5	1	1	233	--	--	--	--	1,331	5.3	65.0	1
28	--	993	--	--	--	--	557	--	--	1	3	239	4.2	62.0	--	--	1,359	--	--	--
29	--	1,289	--	--	2	--	767	5.6	65.0	4	--	245	--	--	--	--	1,263	--	--	4
30	--	1,417	--	--	--	--	964	--	--	1	--	239	--	--	--	9	1,215	6.7	63.5	2
31	--	1,505	--	--	--	--	992	--	--	1	3	252	5.0	63.0	1	3	1,359	--	--	--
Nov.																				
1	--	1,604	--	--	1	--	1,044	5.5	64.0	--	2	265	--	--	--	5	1,425	6.6	64.5	--
2	--	1,620	6.5	62.0	2	5	1,069	--	--	--	2	246	5.5	64.0	--	--	1,393	--	--	--
3	--	1,548	--	--	--	3	993	5.7	63.0	1	--	328	--	--	--	--	1,294	6.5	65.0	1
4	3	1,396	--	--	1	2	989	--	--	1	--	387	5.7	62.5	--	--	1,301	--	--	5
5	2	1,364	--	--	--	--	985	--	--	--	--	400	--	--	--	--	1,236	--	--	1
6	--	1,340	6.2	63.0	--	--	989	--	--	--	--	391	--	--	2	--	1,204	6.7	62.5	2
7	--	619	--	--	2	--	969	--	--	--	2	414	6.0	61.0	2	--	1,173	--	--	3

APPENDIX 1—Continued

The Association of Stream Flow, Dissolved Oxygen and Water Temperature with the Migration of Tagged Salmon in the San Joaquin River 1964, 1965, 1966, 1967

	1964					1965					1966					1967				
Date	Salmon tagged	Flow at Stockton cfs	Min. D.O. ppm	Max. Temp. °F.	Tagged salmon past Mossdale Monitor	Salmon tagged	Flow at Stockton cfs	Min. D.O. ppm	Max. Temp. °F.	Tagged salmon past Bowman Rd. Monitor	Salmon tagged	Flow at Stockton cfs	Min. D.O. ppm	Max. Temp. °F.	Tagged salmon past Bowman Rd. Monitor	Salmon tagged	Flow at Stockton cfs	Min. D.O. ppm	Max. Temp. °F.	Tagged salmon past Bowman Rd. Monitor
8	--	627	--	--	--	1	937	5.5	63.0	5	2	449	--	--	--	--	1,257	6.2	61.0	--
9	--	623	6.3	61.0	--	--	901	--	--	7	--	449	6.3	59.0	5	--	1,239	--	--	1
10	--	627	--	--	1	--	933	5.7	61.5	1	--	453	6.1	60.0	--	--	1,267	6.8	61.5	--
11	--	670	6.6	55.0–58.0	1	--	993	--	--	--	--	453	--	--	--	--	1,087	--	--	2
12	--	729	--	--	1	--	1,073	--	--	--	--	445	--	--	2		1,097	--	--	1
13	--	740	--	--	--	--	1,129	--	--	1	--	449	--	--	--	--	1,279	6.6	60.5	1
14	--	768	--	--	--	--	1,177	--	--	--	3	428	6.2	59.0	1	1	1,335	--	--	1
15	--	889	--	--	--	3	1,181	7.6	59.5	--	2	404	--	--	--	1	1,271	6.7	61.0	--
16	--	1,133	--	--	1	--	1,157	--	--	--	--	428	6.9	59.0	--	2	1,282	--	--	1
17	--	1,109	--	--	--	--	1,189	--	--	--	1	442	--	--	--	1	1,263	6.5	60.5	--
18	--	973	--	--	--	--	1,328	--	--	--	--	467	5.9	60.0	--	--	1,236	--	--	1
19	--	993	--	--	--	--	1,377	6.8	61.0	--	--	460	--	--	--	--	1,275	--	--	--
20	--	1,205	--	--	1	--	1,413	--	--	--	--	425	--	--	--	1	1,282	6.5	60.0	--
21	--	1,241	--	--	--	--	1,537	--	--	--	--	340	--	--	--	1	1,325	--	--	--
22	--	1,225	--	--	--	--	1,653	--	--	--	--	306	--	--	--	1	1,409	6.8	59.5	--
23	--	1,177	--	--		--	1,709	--	--	--	--	358	--	--	1	--	1,377	--	--	--
24	--	1,129	--	--	--	--	1,837	--	--	--	--	445	--	--	--	--	1,317	6.3	58.0	--
25	--	1,002	--	--	--	--	2,005	--	--	--	--	456	--	--	--	--	1,269	--	--	--
26	--	912	--	--	--	--	2,242	--	--	--	--	365	--	--	--	--	1,333	--	--	--
27	--	826	--	--	--	--	2,292	--	--	--	--	340	--	--	--	--	1,297	6.9	56.0	--
28	--	779	--	--	--	--	2,321	--	--	--	--	336	--	--	--	--	1,301	--	--	--
29	--	768	--	--	--	--	2,309	--	--	--	--	330	--	--	--	--	1,421	7.2	54.0	--
30	--	789	--	--	--	--	2,334	--	--	--	--	393	--	--	--	--	1,441	--	--	4

* Tagged at Schad Landing (130 kc) (all others tageed at Prisoners Point).

APPENDIX 2

Salmon Catch Per Hour, San Joaquin River at Prisoners Point

	1964			1965	1966			1967		
	Fishing hours	Salmon caught	Catch per hour	*	Fishing hours	Salmon caught	Catch per hour	Fishing hours	Salmon caught	Catch per hour
Sept. 10–Sept. 16	--	--	--	--	--	--	--	17.42	6	0.34
Sept. 17–Sept. 23	--	--	--	--	--	--	--	18.20	16	0.88
Sept. 25–Oct. 1	--	--	--	--	15.56	12	0.77	--	--	--
Oct. 1–Oct. 7	--	--	--	--	--	--	--	6.90	32	4.64
Oct. 2–Oct. 8	--	--	--	--	9.53	12	1.26	--	--	--
Oct. 5–Oct. 11	16.00	20	1.25	--	--	--	--	--	--	--
Oct. 9–Oct. 15	--	--	--	--	5.74	12	2.09	--	--	--
Oct. 12–Oct. 18	15.17	15	0.99	--	--	--	--	--	--	--
Oct. 15–Oct. 21	--	--	--	--	--	--	--	5.87	23	3.92
Oct. 16–Oct. 22	--	--	--	--	7.32	10	1.36	--	--	--
Oct. 19–Oct. 25	9.58	6	0.63	--	--	--	--	--	--	--
Oct. 23–Oct. 29	--	--	--	--	15.56	8	0.51	--	--	--
Oct. 29–Nov. 4	--	--	--	--	--	--	--	15.33	17	1.11
Oct. 30–Nov. 5	--	--	--	--	15.85	8	0.50	--	--	--
Nov. 2–Nov. 8	4.66	25	5.36	--	--	--	--	--	--	--
Nov. 6–Nov. 12	--	--	--	--	11.65	5	0.43	--	--	--
Nov. 9–Nov. 15	1.58	none	--	--	--	--	--	--	--	--
Nov. 12–Nov. 18	--	--	--	--	--	--	--	18.92	5	0.26
Nov. 13–Nov. 19	--	--	--	--	9.30	9	0.96	--	--	--
Nov. 19–Nov. 25	--	--	--	--	--	--	--	11.33	3	0.26
Totals	46.99	66	1.40	--	90.51	76	0.84	93.97	102	1.09

* No available information on time the nets were in the water in 1965.

APPENDIX 3

Salmon Tagged with Sonic Tags

1964

Salmon Tagged at Schad Landing

Date	Number released
September 16	7
17	10
18	8
22	12
23	5
24	7
Total at Schad Landing	49

Salmon Tagged at Prisoners Point

Date	Number released
October 7	3
8	10
9	7
12	5
13	5
15	5
16	1
19	3
19	1*
22	2
November 4	3
5	2
Total at Prisoners Point	47

* Tagged at mouth of Sevenmile Slough. Included in total.

1965

Salmon Tagged at Prisoners Point

Date	Number released	Male	Female	Date	Number released	Male	Female
September 14	2	1	1	October 14	1	--	1
20	4	2	2	18	6	2	4
21	2	1	1	21	2	--	2
22	2	1	1	22	2	1	1
23	2	--	2	25	2	--	2
27	5	2	3	26	2*	1	1
29	5	--	5	November 2	5	1	4
October 4	3	--	3	3	3	2	1
5	3	1	2	4	2	2	--
6	4	--	4	8	1	--	1
11	2	--	2	15	3	2	1
12	3	1	2	Total	69	20	49
13	3	--	3				

* Tagged at mouth of Sevenmile Slough and included in total.

APPENDIX 3—Continued

Salmon Tagged with Sonic Tags

1966

Salmon Tagged at Prisoners Point

Date	Number released	Male	Female	Date	Number released	Male	Female
September 26	4	1	3	October 25	1	--	1
28	2	--	2	27	1	1	--
29	4	1	3	28	3	1	2
October 3	3	--	3	31	3	2	1
4	5	1	4	November 1	2	1	1
5	2	--	2	2	2	--	2
11	5	3	2	7	2	1	1
12	2	--	2	8	2	2	--
14	3	1	2	14	3	--	3
17	4	2	2	15	2	--	2
19	4	--	4	17	1	--	1
20	2	1	1				
24	1	--	1	Total	63	18	45

1967

Salmon Tagged at Prisoners Point

Date	Number released	Male	Female	Date	Number released	Male	Female
September 11	2	--	2	October 18	4	1	3
12	1	--	1	30	9	4	5
13	1	--	1	31	3	1	2
14	2	1	1	November 1	5	1	4
18	6	1	5	14	1	--	1
19	5	2	3	15	1	--	1
22	1	--	1	16	2	--	2
October 2	10	3	7	17	1	--	1
3	6	--	6	20	1	--	1
4	6	1	5	21	1	--	1
16	10	5	5	22	1	--	1
17	9	4	5				
				Total	88	24	64

APPENDIX 4

Location and Movement of Tagged Salmon Detected by Portable Receivers or Recorded by Shore Monitors

Dates	September							October										November										December			Total
	11-13	14-16	17-19	20-22	23-25	26-28	29-1	2-4	5-7	8-10	11-13	14-16	17-19	20-22	23-25	26-28	29-31	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	1-3	4-6	7-9	
1964	Sonic tags detected or recorded							Sonic tags detected or recorded										Sonic													
Fish tagged at Schad Landing																															
Sacramento River							7		0					0																	
Courtland Monitor					2	3	3	4	3	5	7	3	2							1											33
Below Antioch Bridge					1	1	1		0								0						0								
Areas 1- 4		1	4	0	13		0	1	0			0	0	0	0	0	0	0	0	0	0		0	0							
5- 9		8	7	6	10		0	0	0		0	0	0	0	0	0	0	0	0	0	0		0	0							
10-14			1	2	3	2	4	2	2	2	0	0	0	0		0	0	0	0	0	0		0	0							
15-19			1	0	0	0	0	0	0	0	1	2	0	0		0	0	0	0	0	0		0	0							
20-24			0	0	0	0	0	0	0	0	1	0	0	0		0	0	0	0	0	0		0	0							
Light 35 Monitor (in area 26)											2			2			1														5
Areas 25-29			0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0		0	0							
Above Stockton						0	0		1	0	0	0	0	0	0		0	0	0		0		0	0							
Mossdale Monitor												3				1															4
Old River Monitor			1	1																											2
Middle River Monitor																															0
Stanislaus River Monitor												1						2		2	1										6
Tuolumne River Monitor																2															2
1964																															
Fish tagged at Prisoners Point																															
Sacramento River														0																	
Courtland Monitor											1					4	4	1	3	2	1	1	1								18
Below Antioch Bridge																	1							0							
Areas 1- 4											2	5	1	7	0	0	1	0	3	1	0		0	2							
5- 9											1	6	5	4	5	0	5	2	2	0	0		1	0							
10-14									1	8	6	5	3	12		3	1	6	10	2	1		1	0							
15-19									3	7	6	15	5	8		8	0	1	9	0	0		0	0							
20-24										0	0	0	0	1		3	1	1	1	1	0		1	0							
Light 35 Monitor (in area 26)													1			3	4	3	2	3	5										21
Areas 25-29										0	0	0	0	0		1	0	0	1	0	0		0	0							
Above Stockton										0	0	0	1	0	1		1	1	0		1		0	0							
Mossdale Monitor																3	2	3	1	2	3		1	1							16
Old River Monitor															1																1
Middle River Monitor																															0
Stanislaus River Monitor																1	1	3	2	2	2	1									12
Tuolumne River Monitor																				1											1
1965*																															
Sacramento River							0																								
Courtland Monitor			1	1							1	2			1								1								7
Below Antioch Bridge							0																								
Areas 1- 4				2	0	0	1	0	2		3	0	0	1	1	0	0	0	0	1	0	0	0	0							
5- 9				3	2	1	4	2	6		6	1	2	6	2	3	3	5	4	2	4	2	2	2							
10-14				1	1	1	2	1	4		5	4	4	10	7	6	4	6	0	1	5	0	0	0	0						
15-19		3		8	3	6	6	2	10	1	13	6	8	8	5	6	3	11	5	2	0	3		0	0						
20-24				0	0	0	0	1	1	0	3	0	0	1	2	2	2	3	1	0	0	0		0	0						
25-29				0	0	0	0	1	0	0	0	0	0	1	1	0	1	2	0	1	1	0		0	0						
Above Stockton				0			0		1	0	0		0	1	1	1	0	0	0	3		0	0	0							
Bowman Road Monitor								2	1			1	3	1	1	4	6	1	1	12	1	1									35
Old River Monitor									1		1					3															5
1966*																															
Sacramento River																		2													
Courtland Monitor													3	1		2	6	6		7	6			3							34
Below Antioch Bridge																															
Areas 1- 4						0	0			0	0	0	0	0	2	1	1	2	0	1	1	0	2								
5- 9						0	3			0	1	0	2	4	6	5	1	1	2	1	1	0	4								
10-14						0	2	0		0	0	1	8	3	0	5	5	4	2	3	1	1	1								
15-19						6	4	2		1	7	3	8	5	4	9	7	8	2	3	0	3	1								
20-24						0		0		0	0	0	0	0	0	0	0	1	0	2	1	0	0								
25-29						0		0		0	0	0	0	0	0	0	0	0	0	1	1	0	0								
Above Stockton											0	0	0			0	0	0		4	0	1	0								
Bowman Road Monitor																	1		2	7	2	1			1						14
Old River Monitor														1																	1
1967*																															
Sacramento River											1																				
Courtland Monitor									1			1		1						1	3				2		1			1	11
Below Antioch Bridge											1			0	0	0								1							
Areas 1- 4			1	0	0	0		0		1	1	0	0	0	0	0	1		1			0	0	0	0		0	0			
5- 9			1	3	1	1		4	2	4	8	1	2	1	3	1	1	5	6	4		2	3	0	17	0	2	0			
10-14	1	0	1	4	0	1	0	5	7	8	9	2	13	7	14	10	1	3	6	2	3	4	9	2	8	2	2	2			
15-19	2	3	5	9	4	5	3	27	6	3	15	9	9	11	6	3	9	15	5	4	7	11	8	2	4	2	1	0			
20-24	0	0		0	0	0	0	0	0	0	0	0	1	10	2	1	1	0	1	0	0	1	1	1	0	1	0	0			
25-29	0	0		0	0	0	0	0	0	0	0	0	0	2	3	0	1	1	0	0	1	1	0	0	0	0	0	0			
Above Stockton										0				0	1	0	2	0	1	0	0	0	0	0	0			0			
Bowman Road Monitor												2		2	3	2	6	1	8	4	3	2	2				4				39
Old River Monitor									8	5	6	1		1				1			4				1						27

* Fish tagged at Prisoners Point.

APPENDIX 5

Sonic Tag Recoveries and Recordings, 1964–1967

(Routine recordings by tracking crews not included)

Where tagged:	1964 Schad Landing	1964 Prisoners Point	1965 Prisoners Point	1966 Prisoners Point	1967 Prisoners Point
Where recovered or recorded					
San Joaquin River					
Light 35 Monitor	5	21	--	--	--
Mossdale Monitor	4	16	--	--	--
Bowman Road Monitor	--	--	35	14	39
Angler recovery	0	1	0	1	0
Mortality	1	1	0	0	0
F & G staff recovery	0	0	0	0	1
Old River					
Monitor	2	1	5	1	27
Barrier (staff recovered shed tag)	1	0	--	--	--
F & G staff recovery	0	0	0	0	1
Angler recovery	0	0	0	1	0
Middle River					
Monitor	0	0	--	--	--
Stanislaus River					
Monitor*	6	12	--	--	--
F & G staff recovery*	1	2	3	1	1
Angler recovery*	0	0	1	0	0
Tuolumne River					
Monitor*	2	1	--	--	--
F & G staff recovery*	0	0	0	1	0
Mokelumne River					
Woodbridge Counting Station	2	1	0	2	0
Angler recovery (in Delta)†	0	2	0	0	0
Cosumnes River					
F & G staff recovery	0	0	0	1	0
Sacramento River					
Courtland Monitor	33	18	7	34	11
Gill net recovery (Below Courtland)‡	0	1	0	0	0
Angler recovery (Below Courtland)	1	0	0	0	0
Angler recovery (Above Courtland)*	2	0	0	0	2
Counting station Red Bluff Dam*	--	--	--	2	3
American River					
Nimbus Hatchery*	0	1	1	3	2
F & G staff recovery*	0	1	0	0	0
Angler recovery*	0	1	0	0	0
Battle Creek					
Coleman Hatchery*	0	1	0	0	0
Located by tracking crew in Delta at end of experiment	0	2	8	0	9

* These fish had to pass at least one monitor to get where they were taken or recorded.
† Could have been Sacramento River fish.
‡ Taken by Fish & Game staff. Died in net.

APPENDIX 6

Temperature and Dissolved Oxygen Readings in the San Joaquin River

1964	Area 13				Area 19				Area 23				Area 26				Area 29			
	Time	Depth (Ft.)	Temp.	D.O.	Time	Depth (Ft.)	Temp.	D.O.	Time	Depth (Ft.)	Temp.	D.O.	Time	Depth (Ft.)	Temp.	D.O.	Time	Depth (Ft.)	Temp.	D.O.
9-11	----	----	----	----	----	----	----	----	----	----	----	----	0600–	1-3′	70.0	4.2	----	----	----	----
-11	----	----	----	----	----	----	----	----	----	----	----	----	0800	*	----	----	----	----	----	----
9-18	----	----	----	----	----	----	----	----	----	----	----	----	1350	20	72.0	2.9†	----	----	----	----
9-25	----	----	----	----	----	----	----	----	1400	20	70.0	4.8	1150	20	70.0	3.8	1110	20	70.0	5.9
9-27	----	----	----	----	----	----	----	----	----	----	----	----	0625–	1-3′	71.0	5.0	----	----	----	----
-27	----	----	----	----	----	----	----	----	----	----	----	----	0830	*	----	----	----	----	----	----
9-28	0700	----	67.0	8.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
-28	1600	15	68.0	7.2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
9-29	----	----	----	----	1445	20	67.0	7.4	----	----	----	----	----	----	----	----	1210	20	----	7.8
10- 1	----	----	----	----	----	----	----	----	1115	35	70.0	5.7	1130	10	70.0	6.1‡	----	----	----	----
10- 2	----	----	----	----	----	----	----	----	----	----	----	----	1445	10	----	5.9	----	----	----	----
10- 5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1130	15	72.0	6.3
- 5	----	----	----	----	----	----	----	----	1315	12	72.0	5.9	1215	10	72.0	6.2	1150	15	71.0	5.9
10- 6	----	----	----	----	----	----	----	----	1600	15	73.0	6.7	----	----	----	----	1500	15	74.0	6.7
10- 9	----	----	----	----	1440	16	71.0	6.7	----	----	----	----	1230	16	71.0	5.6‡	1215	15	72.0	6.7
10-11	----	----	----	----	----	----	----	----	----	----	----	----	0625–	1-3′	70.0	5.6	----	----	----	----
-11	----	----	----	----	----	----	----	----	----	----	----	----	0915	*	----	----	----	----	----	----
10-15	----	----	----	----	----	----	----	----	1405	17	71.0	4.8	1445	18	71.0	5.5	1500	18	71.0	6.5
10-16	----	----	----	----	----	----	----	----	----	----	----	----	0900–	1-3′	68.0–	5.8	----	----	----	----
-16	----	----	----	----	----	----	----	----	----	----	----	----	1200	*	70.0	----	----	----	----	----
10-20	----	----	----	----	1530	16	68.0	7.4	----	----	----	----	----	----	----	----	1415	16	67.0	7.4
10-21	----	----	----	----	0945	15	66.0	6.5	----	----	----	----	----	----	----	----	1015	15	66.0	7.2
10-22	----	----	----	----	1030	16	67.0	6.6	----	----	----	----	----	----	----	----	1115	15	66.0	7.5
10-23	----	----	----	----	1130	15	66.0	6.7	----	----	----	----	----	----	----	----	1100	20	65.0	7.7
-23	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1230	15	66.0	7.5
10-26	----	----	----	----	1145	16	64.0	8.0	----	----	----	----	----	----	----	----	1130	20	63.0	7.5
-26	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1300	15	66.0	7.4
10-27	----	----	----	----	1500	20	64.0	7.3	----	----	----	----	0600–	1-3′	63.0	6.6	1350	20	63.0	8.4
-17	----	----	----	----	----	----	----	----	----	----	----	----	1000	*	----	----	1615	20	63.0	8.0
11- 2	----	----	----	----	1030	15	62.0	6.9	----	----	----	----	----	----	----	----	1000	20	61.0	8.0
- 2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1100	15	62.0	6.5
11- 6	----	----	----	----	1045	15	61.0	6.8	----	----	----	----	----	----	----	----	1015	20	60.0	7.7
- 6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1115	15	63.0	6.2
11- 9	----	----	----	----	1030	15	60.0	7.2	1045	15	60.0	6.3	----	----	----	----	1000	20	59.0	8.4
- 9	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1130	15	61.0	6.6
11-11	----	----	----	----	----	----	----	----	----	----	----	----	0900–	1-3′	55.0–	6.6	----	----	----	----
-11	----	----	----	----	----	----	----	----	----	----	----	----	1400	*	58.0	----	----	----	----	----

* These samples were taken 1–3 feet above the bottom. † = taken from area 27. ‡ = taken from area 25.

APPENDIX 6—Continued

Temperature and Dissolved Oxygen Readings in the San Joaquin River

1965*	Area 13			Area 19			Area 22			Area 26			Area 29			Hwy. #4		
	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.
9-21	----	65.5	8.0	----	67.5	7.4	----	----	----	----	----	----	----	70.0	3.8	----	----	----
9-22	----	65.5	8.0	----	67.5	7.7	----	----	----	----	70.5	3.3	----	----	----	----	----	----
9-29	----	64.5	7.7	----	66.0	7.6	----	68.0	6.2	----	69.0	3.8	----	69.0	7.2	----	----	----
9-30	----	----	----	1800	66.0	7.4	1745	68.0	5.4	1730	69.0	4.1	1630	69.0	7.7	1700	68.5	8.9
10- 1	0900	63.5	7.5	0930	65.0	7.0	0945	67.0	5.4	1015	68.0	4.1	1030	66.5	6.9	----	----	----
10- 4	0915	64.5	7.6	1050	67.0	6.3	1110	67.0	4.3	1130	67.5	4.9	1200	67.5	6.8	1225	67.0	7.5
10- 5	1000	64.0	7.7	1020	66.5	5.8	1100	67.0	4.7	1120	67.5	5.2	1135	68.0	6.3	----	----	----
10- 6	0930	65.0	7.8	0950	67.0	6.1	1020	67.5	4.9	1035	68.0	5.2	1100	68.0	5.9	1115	67.0	7.7
10- 8	0900	64.5	7.8	0945	66.0	6.9	1010	67.0	5.1	1030	68.0	5.2	1055	68.0	6.2	1115	68.5	7.5
10-11	0950	64.5	9.0	1050	67.0	7.0	1115	67.5	5.3	1140	68.5	5.5	1150	69.0	6.7	1215	68.0	7.9
10-13	1000	65.0	7.8	1030	66.5	7.1	1055	67.5	5.4	1115	68.0	5.1	1135	68.0	7.0	1200	68.0	8.2
10-14	0930	65.0	7.9	1000	65.9	7.3	1015	67.0	5.8	1030	68.0	5.3	1120	68.5	7.0	----	----	----
10-18	0930	61.0	8.0	1000	63.5	6.7	1015	65.5	6.1	1030	63.5	6.6	1100	63.0	7.3	1115	62.5	8.2
10-20	0900	61.0	8.0	0930	62.0	6.2	1345	66.0	5.9	1000	62.0	7.0	1020	62.5	7.1	1040	62.0	7.7
10-22	0915	62.0	7.9	1020	64.5	6.5	1046	64.0	8.4	1110	64.5	7.2	1140	64.5	7.0	----	----	----
10-25	----	----	----	----	----	----	0945	63.5	6.1	----	----	----	----	----	----	----	----	----
10-27	0900	62.0	7.8	0930	63.5	7.0	0950	64.0	6.0	1010	64.0	5.8	1030	65.0	7.2	1120	65.5	8.0
10-29	0930	62.0	7.9	1000	64.0	6.9	1030	64.0	5.8	1055	64.5	5.6	1110	65.0	7.2	1120	65.0	8.6
11- 1	0900	61.0	7.8	0945	63.0	6.9	1005	64.0	5.5	1030	64.0	6.1	1100	63.0	7.1	1130	62.5	7.9
11- 3	0900	61.0	7.8	0930	62.0	6.5	0950	63.0	5.7	1015	63.0	6.7	1045	62.0	7.0	1105	61.0	8.1
11- 8	0950	61.0	7.8	1020	63.0	6.2	1045	63.0	5.5	1115	63.0	6.4	1130	62.5	6.9	1145	62.0	7.4
11-10	0930	59.0	8.0	0945	61.0	6.9	1010	61.5	5.7	1030	61.0	6.1	1100	61.0	6.7	1115	61.5	7.7
11-15	0945	58.5	9.6	1000	59.0	8.6	1030	59.0	7.8	1045	59.5	7.6	1100	59.0	7.9	1115	58.0	7.8
11-19	1000	58.0	8.6	1115	59.0	8.1	1130	59.0	7.3	1300	60.0	6.8	1315	60.0	7.1	1330	61.0	7.1

* 1965 readings taken at 17 ft. depth in areas 13, 19, 22, 26 and 29. Hwy. #4 readings taken at 5 to 7 feet.

APPENDIX 6—Continued

Temperature and Dissolved Oxygen Readings in the San Joaquin River

1966†	Area 13			Area 19			Area 22			Area 26			Area 29			Hwy. #4		
	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.
9-28	1020	68.5	8.2	1045	70.0	7.5	1110	71.0	7.7	1135	72.0	4.7	1215	73.0	4.7	1230	72.5	8.9
10- 4	1300	68.5	7.9	1335	70.0	8.1	1420	71.0	7.3	1440	71.5	3.9	1510	73.0	2.4	1530	72.0	11.4
10-11	0930	66.5	8.1	1010	67.5	7.9	1035	68.0	6.4	1100	70.0	2.6	1200	70.0	3.8	1405	70.0	9.6
10-14	0830	61.0	9.0	0900	62.0	9.0	0925	64.0	7.7	0950	64.0	4.8	1020	67.0	3.7	1040	63.0	10.7
10-17	0855	60.5	9.1	0930	61.0	9.1	0955	62.5	8.4	1020	64.5	6.1	1105	65.5	3.9	1130	63.5	7.4
10-19	0845	59.5	8.6	0920	61.0	8.6	1010	63.0	7.8	1035	64.0	4.7	1110	65.0	4.5	1135	61.0	12.3
10-21	0840	60.0	8.8	0905	61.0	8.7	0930	62.0	7.4	0950	63.5	3.4	1020	63.0	6.1	1040	60.0	12.3
10-24	0850	59.5	8.7	0920	61.5	8.1	0945	62.5	7.1	1015	63.5	3.8	1050	62.5	8.3	1110	62.0	11.2
10-26	0835	60.0	8.7	0910	61.0	8.5	0930	62.5	7.4	0955	63.0	4.0	1040	63.0	7.8	1100	62.0	11.3
10-28	0840	59.0	9.2	0910	60.0	8.5	0930	61.0	7.5	1000	62.0	4.2	1022	62.0	7.8	1045	62.0	11.5
10-31	0830	60.0	8.8	0900	60.5	8.6	0925	62.0	7.6	0950	63.0	5.0	1020	63.0	8.6	1040	63.0	12.2
11- 2	0850	60.0	8.6	0915	61.0	8.5	0935	62.0	7.5	1000	63.5	5.5	1030	64.0	7.5	1055	63.0	11.6
11- 4	0835	60.0	9.0	0900	60.5	8.4	0940	61.5	7.4	1005	62.5	5.7	1030	62.5	8.0	1050	62.5	13.2
11- 7	1135	58.5	9.0	1200	59.0	8.6	1220	60.0	7.5	1240	61.0	6.0	1310	61.0	7.6	1325	60.0	10.4
11- 9	0825	56.0	9.1	0855	57.5	8.2	0920	58.0	7.3	0940	59.0	6.3	1000	58.0	7.7	1020	56.0	9.6
11-10	1325	57.0	9.0	1240	58.5	8.8	1220	59.0	7.4	1200	60.0	6.1	1130	59.5	9.3	1100	56.5	9.6
11-14	0845	56.5	8.7	0910	57.0	8.4	0930	58.0	7.6	0950	59.0	6.2	1020	58.0	7.8	1045	57.5	9.5
11-16	0900	57.0	8.9	0920	58.0	8.5	0945	58.0	8.0	1010	59.0	6.9	1030	59.0	6.9	1050	59.0	8.3
11-18	0845	57.5	8.7	0915	58.0	8.4	0945	59.0	7.3	1010	59.0	5.9	1045	60.0	7.4	1115	60.0	8.7

† 1966 readings taken at 17 ft. depth in areas 13, 19, 22, 26, and 29. Hwy. #4 readings taken at 7 feet.

APPENDIX 6—Continued

Temperature and Dissolved Oxygen Readings in the San Joaquin River

1967‡	Area 13			Area 19			Area 22			Area 26			Area 29			Hwy. #4		
	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.	Time	Temp.	D.O.
9-13	1030	72.0	8.2	1300	75.0	7.6	1345	75.5	5.8	1430	76.0	3.3	----	----	----	1535	76.0	6.1
9-15	1020	70.0	7.8	1100	73.0	7.3	1125	75.0	5.1	1145	75.5	2.5	----	----	----	1215	75.5	6.2
9-18	0900	69.0	8.2	0945	71.0	8.2	1005	73.5	6.2	1035	74.0	3.1	----	----	----	1105	73.0	6.1
9-20	0915	70.0	8.1	0945	71.0	8.1	1005	74.0	6.6	1025	74.5	2.7	1045	75.0	3.1	1100	75.0	5.7
9-22	1145	71.0	8.3	1215	72.5	8.1	1230	74.5	5.6	1245	75.0	2.7	1300	75.0	3.1	1310	74.5	5.9
9-25	0850	69.0	8.0	0915	71.0	7.6	0935	72.5	5.5	1037	74.0	2.6	1050	74.0	2.7	1105	73.0	5.6
9-27	0845	69.5	7.6	0915	71.5	6.8	1010	74.0	4.5	1020	74.0	1.1	1030	74.0	3.7	1050	73.0	6.3
10- 2	0942	68.0	7.8	1000	69.5	7.3	1015	72.0	4.5	1030	72.0	2.0	1040	71.5	3.9	1055	69.5	5.9
10- 4	0855	66.0	7.7	0910	68.0	7.1	0927	69.5	4.7	0945	70.5	2.0	0957	69.0	3.5	1015	67.5	6.8
10- 6	0915	65.5	7.9	0930	66.5	7.3	0945	67.5	5.7	1430	70.0	2.2	1454	68.0	3.7	1525	67.0	6.9
10- 9	0830	64.0	7.8	0847	66.5	6.6	0915	68.5	4.0	0935	67.0	3.3	0950	66.0	6.9	1010	66.0	8.3
10-11	0935	66.0	7.7	0950	67.0	6.1	1010	68.0	3.7	1020	68.5	4.5	1040	68.0	7.4	1050	68.0	8.6
10-13	0900	65.0	7.8	0920	66.5	6.7	0935	68.0	4.0	0950	68.0	4.7	1005	67.5	7.1	1015	67.5	7.9
10-16	0935	62.5	8.1	0955	64.5	7.3	1005	65.5	5.3	1015	65.5	4.6	1027	66.0	6.4	1040	63.0	8.0
10-18	0935	62.5	7.9	1040	65.5	7.2	1055	67.5	4.7	1110	67.5	4.2	1125	66.0	7.0	1135	66.0	8.3
10-20	1252	63.0	8.1	1323	67.0	6.7	1335	68.0	4.6	1425	69.5	6.7	1440	68.5	7.7	1552	67.0	9.0
10-23	1018	63.0	8.5	1135	65.5	7.6	1146	66.0	5.9	1204	66.5	5.3	1217	66.0	7.5	1235	65.5	8.5
10-25	0825	62.5	8.0	0842	63.0	6.5	0903	64.5	5.1	0938	64.0	6.2	0953	64.0	7.0	1002	64.0	7.7
10-27	0855	62.0	8.1	0950	64.0	6.0	1020	65.0	5.3	1040	64.5	6.1	1107	64.0	7.1	1130	63.5	7.6
10-30	0835	61.0	8.2	0955	63.0	6.7	1040	63.5	6.8	1057	63.0	7.2	1110	62.5	7.5	1125	62.0	7.8
11- 1	1040	62.0	8.1	1100	64.5	6.6	1117	64.0	6.6	1132	63.0	7.1	1145	62.5	7.7	1200	61.5	8.0
11- 3	0900	61.0	8.1	1055	64.0	6.8	1107	65.0	6.5	1125	63.0	7.3	1145	62.0	7.7	1158	61.5	8.0
11- 6	0945	60.0	8.4	1055	62.0	7.3	1110	62.5	6.7	1125	62.0	7.2	1142	61.5	7.5	1157	61.5	7.8
11- 8	0840	60.0	8.0	0855	61.0	7.1	0907	61.0	6.2	0920	61.0	7.1	0930	61.0	7.4	0947	61.0	7.6
11-10	0830	60.0	7.8	0855	61.0	6.8	0910	61.5	6.9	0930	61.5	7.3	0950	61.0	7.7	1012	61.0	7.8
11-13	0850	60.0	7.7	0918	60.5	6.6	0930	60.5	7.0	0947	60.0	7.1	1002	59.5	7.6	1015	59.0	8.0
11-15	0922	60.0	7.5	1024	61.0	6.7	1035	61.0	6.7	1053	60.0	7.0	1108	60.0	7.5	1118	59.5	7.9
11-17	0820	59.0	7.6	0840	60.5	6.7	0900	60.5	6.5	0910	60.0	6.7	0920	60.0	7.3	0935	60.5	7.6
11-20	0830	58.5	7.8	0955	60.0	6.8	1007	60.0	6.5	1020	60.0	6.7	1033	60.0	7.2	1045	60.0	7.4
11-22	0910	57.0	8.1	0942	59.5	7.2	1003	58.0	6.8	1018	59.0	7.1	1037	58.0	7.6	1048	57.5	7.8
11-24	1000	57.0	8.1	1020	57.5	7.0	1040	58.0	6.3	1100	57.5	7.0	1120	57.0	7.6	1138	55.5	8.2
11-27	1137	54.5	8.7	1150	55.0	7.4	1205	56.0	6.9	1255	56.0	7.5	1310	54.5	8.4	1325	54.0	8.8
11-29	0835	53.0	8.6	0900	54.0	7.5	0920	54.0	7.2	0935	53.5	8.0	0950	52.5	9.0	1010	52.0	9.0
12- 1	0810	51.0	9.0	0950	55.0	8.1	1005	53.5	8.1	1019	54.0	8.4	1035	54.0	9.0	1049	52.5	9.1

‡ 1967 readings taken at 17 ft. depth in areas 13, 19, 22, 26, and 29. Hwy. #4 readings taken at 7 feet.

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