THE POSSIBILITY OF RESTORING SALMON AND STEELHEAD RUNS IN WALKER CREEK, MARIN COUNTY

Prepared for The Marin Municipal Water District

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April 1, 1976

Mr. J. Dietrich Stroeh, General Manager Marin
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Dear Mr. Stroeh;

Here is our report on the possibility of using your proposed Soulajule Project to restore salmon and steelhead in Walker Creek.

My conclusion is that if designed and operated as planned, the project will restore spawning runs averaging 600 silver salmon and 500 to 600 adult steelhead per year. This will contribute approximately 10,000 pounds of salmon annually to the ocean commercial fishery. About 700 additional adult salmon would be caught by anglers primarily in or near Tomales Bay. The steelhead fishery which was once popular at the lower end of Walker Creek would also be reestablished and in the average year about 400 steelhead could be caught there.

Predictions of environmental change should always be viewed with suspicion. We have therefore made a careful, conservative, and objective analysis of all factors that argue for and against success and recorded our logic, data, and assumptions in what we hope is an understandable fashion.

Sincerely,

Don W. Kelley

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ACKNOWLEDGEMENTS

During this study we have sought and received help from many persons.

D. Stroeh, R. Rogers, C. Zumwalt and the Directors of the Marin Municipal Water District constantly encouraged and supported the idea that the Soulajule Project be used for environmental enhancement. We received additional encouragement and help to accomplish this from J. Fraser, E. Vestal, T. Wooster, A. Giddings, K. Anderson, and L. B. Boydstun of the California Department of Fish and Game.

J. Holman of that Department and R. Thompson of MMWD measured streamflows during the experimental summer release. E. LaCornu of the US Geological Survey provided us with useful information about streamflows and their measurements. N. Dennis of Madrone Associates helped us understand the factors influencing riparian vegetation. W. Haible of the University of California, Berkeley, Geology Department helped us understand the stream's geology and bank erosion.

E. Smith and others at the Pacific Marine Station permitted me to work out of there during the spring and summer of 1975, and graduate students R. Crittenden, W. Evans, and J. Rae all helped with the measurements of environmental conditions and fish populations. W. Fields, B. Green, and S. Sorenson of Hydrozoology collected, identified and analysed the benthic animals and prepared a reference collection of them for the UOP Pacific Marine Station.

Professor Luna Leopold of the UC Berkeley Geology Department questioned our original concepts of erosion and substrate changes in Walker Creek and was thereby instrumental in reversing our original conclusion that the Walker Creek salmon and steelhead runs were a lost cause.

J. Peckham and C. Von Bargen of MMWD designed and completed the difficult model operation studies to determine how the available water supply could be used to meet the District's need and biolog ical criteria for restoring salmon and steelhead.

My assistant, W. Tippets, did much of the literature search and prepared the graphs in this report.

Finally we are grateful to all the owners along Walker Creek who allowed us to work on their land and who told us of previous conditions in the stream.

D. W. Kelley
Sacramento, California
March 10, 1976

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INTRODUCTION AND SUMMARY

Walker Creek is a small stream originating in the rolling hills of Marin County, California, and meandering northwest 18 miles to enter the north end of Tomales Bay (Figure 1). Long ago, large numbers of silver salmon (Oncorhynchus kisutch) and steelhead (Salmo gairdneri) migrated into Walker Creek each year to spawn, but for the past several decades only a few have done so. In the last 15 years their numbers have not been enough to sustain any significant fishing.

Walker Creek and its tributaries have undergone many environmental changes over the years, but I believe the principal root cause for the loss of salmon and steelhead is overgrazing on the watershed. Overgrazing has accelerated runoff and reduced percolation rates into the soil. It has caused streambed and bank erosion, reduced the storage of water in streambanks, and finally, eliminated the summer flow. Since both silver salmon and steelhead must spend their first year in freshwater, recovery of their populations in Walker Creek cannot be expected unless that flow is restored. The possibility of this happening through reduced grazing or other changes in land use seems very remote.

In 1975, the Marin Municipal Water District, serving domestic water to southern Marin County, evaluated several alternative sites from which to capture and store water to augment their net safe yield by 5,000 acre-feet. One proposal was to enlarge the small existing Soula Jule Reservoir on Arroyo Sausal, an upstream tributary of Walker Creek. Winter storm flows would be captured in this reservoir and later diverted to the District's existing storage reservoirs in the Lagunitas Creek watershed.

Because the need for such water would arise only following dry years, it appeared that much of the time, a part of the stored winter runoff could be released to maintain a summer flow in Walker Creek, and that this might restore the salmon and steelhead runs. This is a report on our further investigation of that possibility.

Since beginning the study in April 1975, we have measured the existing small remnant salmon and steelhead stocks and the environmental factors that keep them so low. Based on these studies I believe there are three major constraints to their restoration.

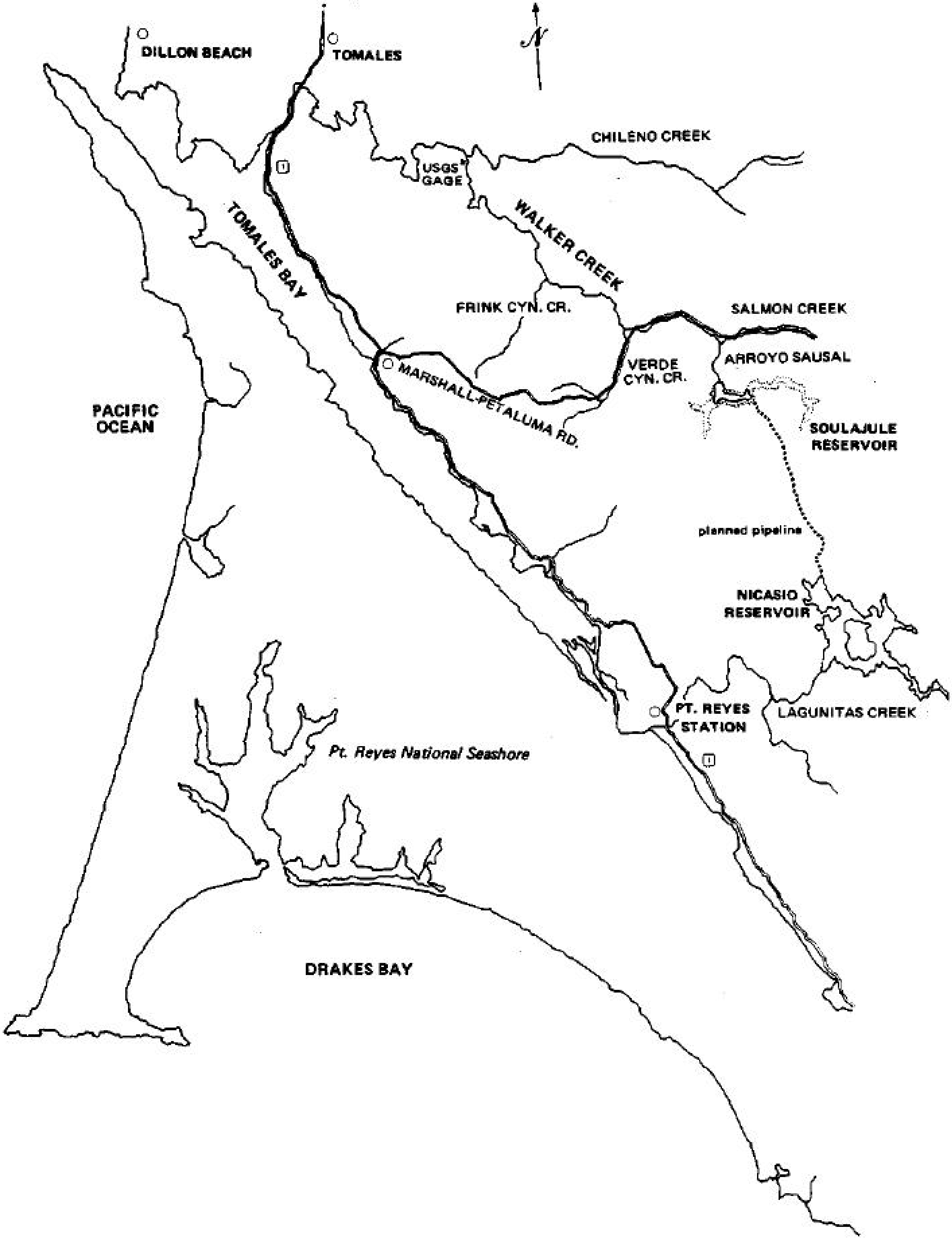


FIGURE 1. Location of Walker Creek and the proposed Soulajule Project.

1. Zero summer and fall flows annually reduce rearing habitat to a few small standing pools.

2. Winter flows often drop to low levels between storms, leaving many salmon and steelhead eggs to die.

3. Streambank erosion washes away riparian vegetation needed for shade and fills the pools with sand.

Several ways of using the proposed project to solve these problems were tested. Model operation studies provide evidence that summer and fall streamflows can be maintained at 5 cfs in 63 percent of the years. In 11 percent of the years, those minimum flows will have to be reduced to 2 cfs, and in 26 percent of the years to 0.5 cfs.

These frequencies assume an annual water consumption by the District of 36,760 acre-feet predicted as the need in 1995. Prior to that time, it will not be necessary to reduce the 5 cfs streamflow release so often.

During June 1975, an experimental release of 1.4 to 1.7 cfs from the existing Soula Jule Reservoir provided evidence that such small flows are not lost in the gravel of the bed, but continue on the surface throughout the stream.

In addition to a summer and fall water release to create a permanent stream and provide rearing habitat, the operation studies have demonstrated the project's ability to maintain a floor on winter flows of 20 cfs between storms more than 80 percent of the years and 10 cfs in almost all other years. This will benefit egg survival.

An additional and major effect of the project operation would be to reduce the flash characteristics of floodflows and bank erosion. Substrate conditions and the quality of spawning and rearing habitat can be expected to improve as the sand, now contributed from the eroding banks, is gradually moved out.

All predicted flow changes would encourage reproduction and growth of riparian vegetation to provide the shade and maintain the low water temperatures.

Based upon the measures of juvenile salmon and steelhead habitat during June, I have estimated the number of young salmon and steelhead likely to be produced with the streamflows that could be provided. Using several models that relate those numbers of young to subsequent adult populations, catch, and returning spawners, I estimate that the project would restore spawning runs in Walker Creek that will average about 600 adult silver salmon and 500 to 600 adult steelhead per year. An annual average of 1,100 adult salmon weighing approximately 10,000 pounds would be added to the ocean commercial salmon fishery and about 700 additional adult salmon would be caught by anglers primarily in and near Tomales Bay.

I believe the project will restore the steelhead fishery at the lower end of Walker Creek. On the average about 400 adult steelhead per year could be caught by anglers without jeopardizing the spawning stocks.

Estimates of the annual economic value of the added commercial landings and the recreation provided, range from $30,000 to $70,000 depending upon the assigned value of a day's recreation.

Supplemental stocking of yearling salmon following critical years when summer releases from the reservoir must be reduced to 0.5 cfs will significantly increase these yields and values.

THE HISTORY OF SALMON AND STEELHEAD RUNS IN WALKER CREEK

Many long-term residents of Marin County remember when Walker Creek supported salmon and steelhead runs. They report adult steelhead migrating nearly 25 miles upstream to spawn in the headwaters of a tributary, Arroyo Sausal.

Peter F. Worsely (1972), in a report to the Conservation Foundation, wrote, "Walker Creek itself at one time had a good return of spawning silver salmon and steelhead. It is said that 40 to 50 years ago it was difficult to drive a horse and buggy across the stream at the height of the winter run because of the numbers of fish in the shallow water. Walker Creek is now virtually a dead estuary. Small numbers of steelhead are reported by local fishermen to swim upstream each year, but the salmon seem to have abandoned the creek."

The loss appears to have taken place gradually over several decades. Some useful data are available from the carefully kept diaries of California Department of Fish and Game Warden Lt. A. Giddings. For many years, one of Lt. Giddings' responsibilities was to check anglers on Walker Creek for proper licensing, legal gear, and catch.

His records (Table 1) describe some steelhead angling at the lower end of Walker Creek during the mid-1950s but very little since then. The salmon run was clearly lost before Lt. Giddings began keeping records in 1948.

Residents report that a few steelhead still enter Walker Creek to spawn during the winter, but we found no one who had seen a salmon for many years.

PRESENT STATUS - THE 1975 INVESTIGATION

During the summer of 1975, we made an intensive search for silver salmon and steelhead. The young of both species remain in fresh water for at least 1 year. Their presence or absence, therefore, is sure evidence of successful spawning or lack of it that previous winter or spring.

Reconnaissance of the stream and its tributaries was followed by extensive sampling with a Smith-Root Type VII electrofisher in the mid- and upper reaches of Walker Creek and by seining with a small-mesh seine from Highway 1 upstream to the upper end of tidal influence. We found young-of-the-year steelhead in all reasonably good salmonid habitat along the 14 miles of stream above tidewater (Figure 2, Table 2). Neither species were found anywhere below the upper end of tidewater (about 1.5 miles above Highway 1) or in unshaded reaches of the stream (Figure 3).

In some large permanent pools that remain throughout the summer, we found a few yearling steelhead and in one deep pool above the Marshall-Petaluma Highway we found a large, emaciated adult steelhead that had probably been trapped during the previous winter.

The young-of-the-year steelhead were abundant in the lower mile of the 3-foot-wide Frink Canyon Creek during my first visit there on May 21, but as the stream became smaller and smaller, these young steelhead gradually disappeared. Most probably moved downstream into Walker Creek, but many fell prey to birds and snakes. We found a few small steelhead also in the lower end of Chileno Creek.

We found only a few young-of-the-year silver salmon. They were restricted to the high quality salmonid habitat near the mouth of Chileno Creek.

Other fishes: California roach, *Hesperoleucus symmetricus;* the riffle sculpin, *Cottus gulosus;* the rough sculpin, *Cottus asperrimus*; the three-spined stickleback,

Table 1. Number of anglers, salmon, and steelhead inspected on Walker Creek by California Fish and Game Warden Lt. A. Giddings, 1949-1974

SEASON	ANGLERS CHECKED	STEELHEAD	SALMON
1948-49	6	0	0
1949-50	_	9	0
1950-51	-	steelhead killed by pollution	—
1951-52	-	no entries	—
1952-53	-	no entries	—
1953-54	—	41	0
1954-55	161	67	0
1955-56	125	63	0
1956-57	598	181	2
1957-58	10	8	0
1958-59	10	9	0
1959-60	68	2	0
1960-61	-	4	0
1961-62	0	0	0
1962-63	0	0	0
1963-64	10	0	0
1964-65	4	1	0
1965-66	0	0	0
1966-67	-	off-duty	-
1967-68	45	2	0
1968-69	6	7	0
1969-70	8	0	0
1970-71	14	0	0
1971-72	6	0	0
1972-73	3	0	0
1973-74	0	0	0

FIGURE 2. A well shaded reach of Walker Creek just above Chileno Creek. This photo was taken June 11, 1975 during an experimental release of 1.5 cfs from the existing Soulajule Reservoir. The flow here was 2.8 cfs. Young-of-the-year steelhead from the remnant steelhead population survive in the pools of such reaches when the surface flow ceases each summer.

Table 2. Numbers and size of steelhead and silver salmon captured in Walker Creek with electrofishing gear - July 23 to 25, 1975.

	Area sampled	UPPER WALKER CR. Along Marshall Petaluma Rd. 9000^2 feet		MIDDLE WALKER CR. Upper Synanon Property 4500^2 feet		LOWER MIDDLE WALKER CR. Lower Synanon Property 19000^2 feet		JUST ABOVE CHILENO CR. 13000^2 feet		JUST BELOW CHILENO CR. 7650^2 feet	
TOTAL inches	LENGTH cm	steelhead	salmon	steelhead	salmon	steelhead	salmon	steelhead	salmon	steelhead	salmon
	3										
	4										
2	5					10		10			
	6	1				34		45	1		
3	7	6		1		40		63	4		
	8	7				13		25	2	3	
	9	11				6		3		8	1
4	10	4				4		1		8	
	11	1								1	
5	12									1	
	13					3					
	14										
6	15										
	16					3					
7	17					1		2			
	18	1						1			
8	19	1						4			
	20										
	21	1									
9	22										
	23										
	24										
10	25										
	26							1			
11	27					1					
	28					1					
	Total	33		1		116		155	7	21	1

FIGURE 3. Typical unshaded reach of Walker Creek, June 11, 1975. We found no young steelhead or salmon in such reaches.

Gasterosteus aculeatus, were common in various reaches. The Pacific lamprey, *Entosphenus tridentatus*, spawns in Walker Creek and their young were common in the gravel bottom for several miles above tidewater.

In early June, the surface flow in most of Walker Creek ceased. For experimental purposes, the flow was started again on June 6 with a small, week-long release from the existing Soulajule Reservoir. The release kept the stream alive until late June. After the surface flow ceased for the second time, the pools themselves began to dry up.

As streamflows declined in May and June, the amount of suitable living space for young salmonids and the riffles that were producing abundant aquatic insects used by the young fish for food were gradually reduced. Young salmonids were crowded into standing pools where they foraged on a very limited food supply.

As the summer passed, all pools became smaller and the fish were increasingly preyed upon by snakes and great blue herons. Many pools dried up completely, but weeks before that happened, most of the young salmonids disappeared.

We were unable to find any in the long reach of tidewater at the lower end of Walker Creek. This, and the fact that after mid-July none of the pools above Chileno Creek were connected by running water, led us to conclude that the young steelhead had not migrated downstream.

We were told by local residents and by California Department of Fish and Game biologist Keith Anderson and by Lt. Giddings that what we observed in 1975 happens each year. The records of flows kept by the U.S. Geological Survey on Walker Creek since 1959 show that, except for 1974, Walker Creek has had no surface flow for at least a month every year since measurement began in 1960 (Table 3).

We found a few larger steelhead that were spending their second summer in the stream. It is these few survivors that migrate to Tomales Bay and perhaps the ocean and return to Walker Creek as adults several years later. All the available evidence is that younger fish, even if they could successfully migrate to sea, do not survive well enough to perpetuate a steelhead run, even the remnant run that now exists.

Table 3. Periods of NO FLOW at U.S.G.S. gage in Walker Creek

Period	Total days of no flow	Total previous years runoff in acre feet
June 17, 1960 to Dec 1, 1960	168	12900
June 24, 1961 to Dec 1, 1961	160	13240
June 6, 1962 to Oct 11, 1962	120	23390
Sept 6, 1963 to Nov 2, 1963	57	37970
July 16, 1964 to Nov 1, 1964	108	10150
July 21, 1965 to Nov 12, 1965	114	38030
June 29, 1966 to Nov 8, 1966	132	26830
Sept 10, 1967 to Oct 10, 1967	27	51480
July 17, 1968 to Nov 2, 1968	107	23000
Aug 8, 1969 to Oct 22, 1969	75	60920
Aug 10, 1970 to Nov 11, 1970	71	55640
July 30, 1971 to Dec 2, 1971	123	33620
Aug 7, 1972 to Oct 13, 1972	65	10320
July 7, 1973 to Oct 1, 1973	59	63900
Oct 18, 1974 to Nov 15, 1974	8	61980

Young silver salmon spend only one summer in the stream. Our investigations suggest that not enough young salmon survive even the first summer to maintain a spawning run in Walker Creek. The few young we found could have been the progeny of one pair of adults who strayed during their migration to Lagunitas Creek at the upper end of Tomales Bay.

Certainly neither the salmon nor steelhead run in Walker Creek is now large enough to sustain any fishery.

CAUSES OF THE DECLINE

We have identified three obvious problems: the lack of summer flow, the loss of riparian vegetation which provides shade and keeps the stream cool, and frequent reduction of winter flows between storms.

The Lack of Summer Flow

The most obvious reason for the failure of the salmon and steelhead runs in Walker Creek is the lack of summer streamflow. Long-term residents of the area told us that when they were children (40 to 50 years ago) summer flows normally became very small but rarely ceased completely, and that the pools in the stream were larger than they are now. Such conditions would be necessary to produce the significant runs reported years ago.

But why would summer flows have been larger many years ago? One obvious possibility is less rainfall.

Actual streamflow records collected since 1960 by the USGS on Walker Creek show a rough relationship between the number of days of no flow each summer and fall and the total runoff the previous water year (Figure 4). The higher the runoff in a given water year, the fewer the days of no flow in the succeeding summer and fall. Annual runoff data for the Arroyo Sausal since 1928 (Table 4) demonstrate that years of high runoff were actually less frequent years ago when salmon and steelhead were abundant

We conclude that since 1876 there has been no climatic change large enough to explain the loss of summer and fall flows in Walker Creek.

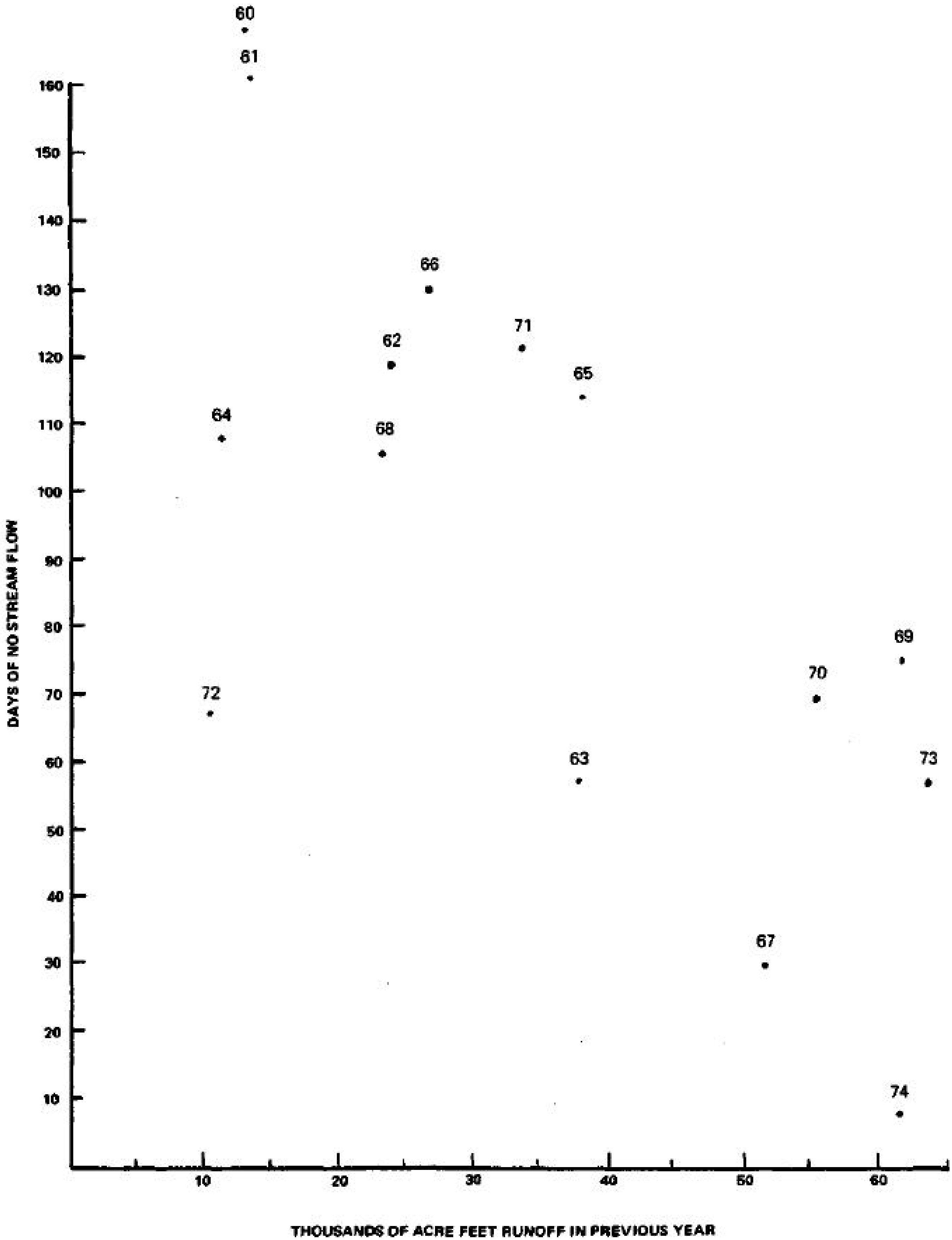


FIGURE 4. Relationship between total runoff and days of no flow in Walker Creek, Marin Co. (data from U.S. Geological Survey).

Table 4. Annual runoff from Arroyo Sausal watershed.
(Source, Marin Municipal Water District)

YEAR	RUNOFF	YEAR	RUNOFF
1928	13,522	1951	20,101
1929	5,247	1952	26,617
1930	13,262	1953	19,660
1931	475	1954	13,798
1932	9,507	1955	3,179
1933	3,365	1956	42,743
1934	3,985	1957	7,089
1935	14,332	1958	34,874
1936	16,805	1959	5,629
1937	11,437	1960	5,917
1938	33,974	1961	5,891
1939	381	1962	11,187
1940	26,674	1963	16,765
1941	38,109	1964	4,572
1942	29,008	1965	17,852
1943	14,343	1966	12,954
1944	6,982	1967	24,679
1945	9,595	1968	9,182
1946	11,521	1969	29,288
1947	4,771	1970	27,325
1948	6,118	1971	15,734
1949	8,406	1972	4,608
1950	10,242	1973	31,027

Streambed Filling with Sand and Gravel

Many people believe that the Walker Creek summer streamflows have ceased because the streambed has been filled with the sand and gravel from either bank erosion and/or soil erosion on the watershed. It is true that there has been extensive erosion of both kinds. Soil erosion from the watershed contributes fine grain material during storms. Streamflows are then high and this material is largely kept in suspension and moved downstream to be deposited in the Walker Creek Delta or in Tomales Bay.

Bank erosion is different. The stream has incised itself deeply into the surrounding land and it is now near or at bedrock in many places. This incision has left high banks which cave into the channel when saturated. These collapsing banks leave large quantities of loose and easily transported material of various sizes within each reach of winter flows (Figure 5). This sand and gravel does tend to fill pools and has reduced the quality of salmonid habitat in several reaches of the stream.

Any subterranean flow, however, is forced to the surface at several places where the stream has cut down to bedrock. The USGS gage where the lack of summer flow has been recorded (Table 3) is at such a point.

We observed surface flows to cease in some of these most-filled reaches where flow over the bedrock ledges (and the USGS gage) was still nearly 0.5 cfs. It is probable that very low flows did maintain more and better salmonid rearing habitat before bank erosion was severe, but the complete cessation of flow for long periods each year at the USGS gage led us to believe that filling of the channel has only contributed to and not been the main cause for the loss of the salmon and steelhead runs.

Loss of Riparian Vegetation and Increased Water Temperature

Loss of shade is detrimental to trout and salmon production. The downward erosion and meandering of Walker Creek has destroyed the riparian vegetation and therefore the shade along about 5 miles or one-third of the stream above tidewater. Most important has been the loss of trees large enough to shade the stream in the reaches just above and for several miles below the Marshall-Petaluma Road crossing, and in two shorter reaches downstream below Chileno Creek (Figure 6). Water temperatures in these reaches last spring before the streamflow ceased often exceeded the desirable 70°F, whereas in reasonably well-shaded reaches, water temperatures rarely exceeded 70°F (Figures 6 and 7). During early June when streamflows ranged

FIGURE 5. Streambank erosion on Walker Creek below the Marshall-Petaluma Road. The photo was taken on June 9 when the flow was 2.98 cfs.

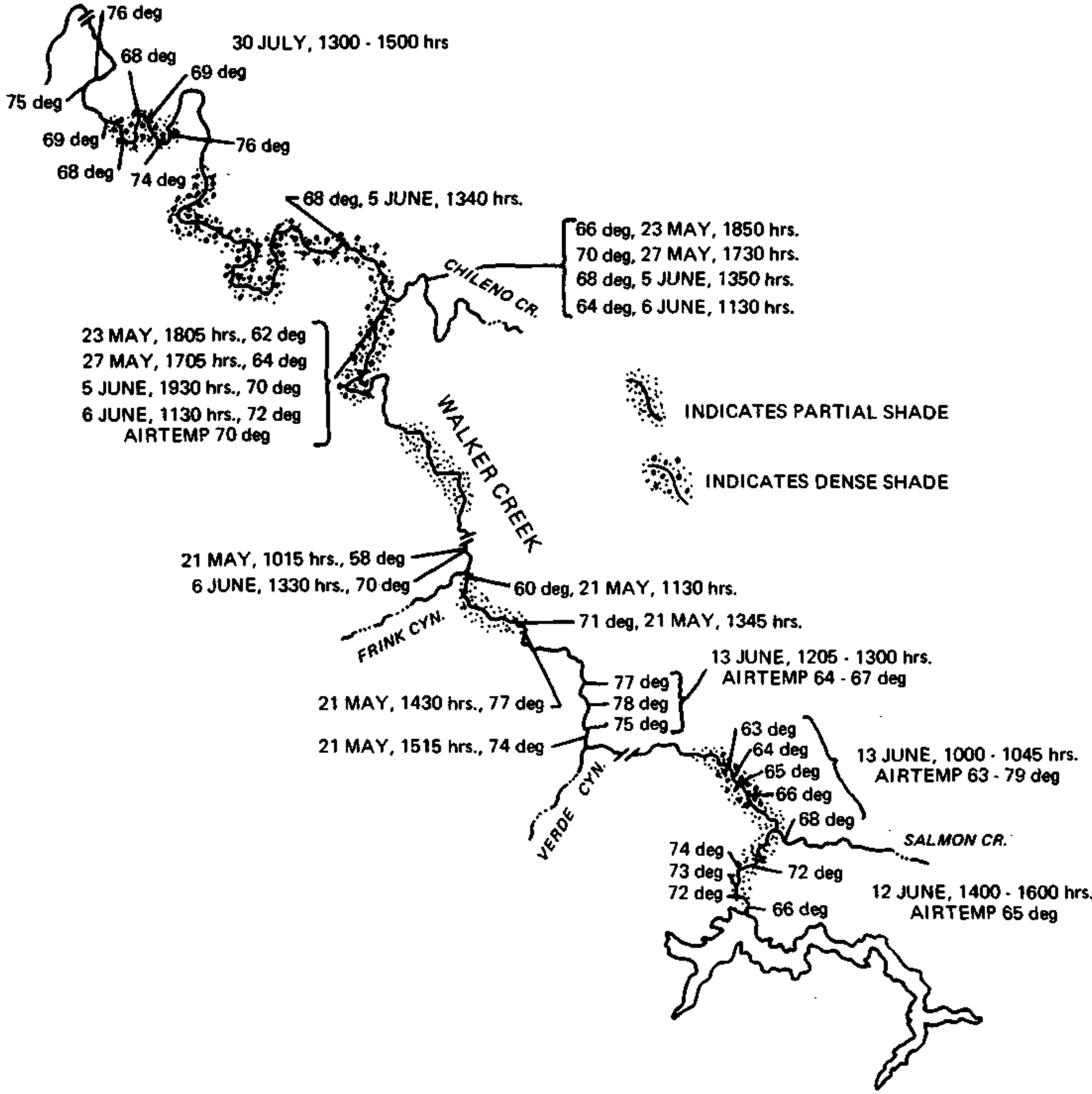


FIGURE 6. Daytime water and air temperatures in shaded and unshaded reaches of Walker Creek and Arroyo Sausal, Marin Co., May to July, 1975.

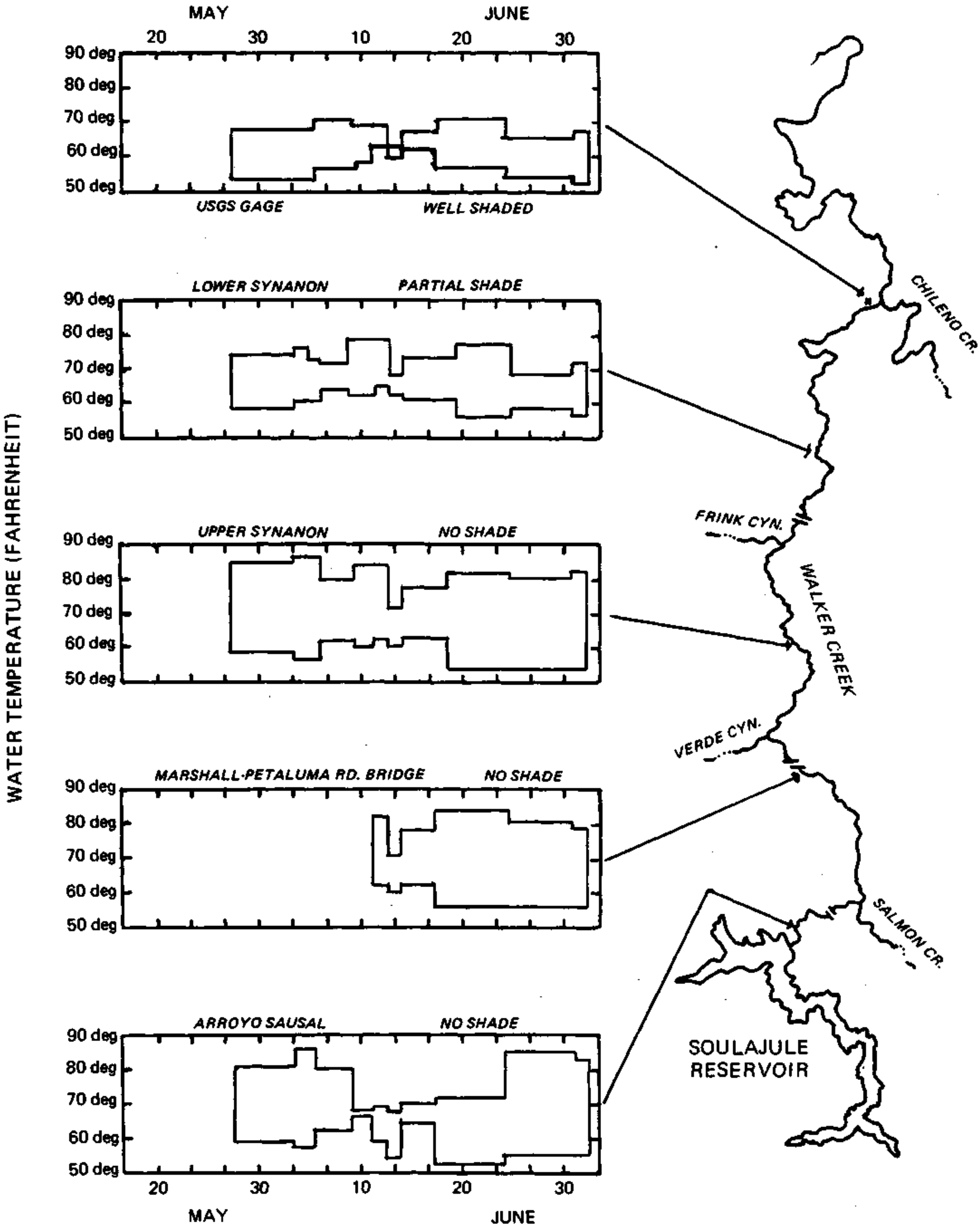


FIGURE 7. Diurnal Range of early summer water temperatures in Upper Walker Creek and Arroyo Sausal (flows at USGS gage varied from 1.7 to 3.0 cfs).

from 1.5 to 3.0 cfs, temperatures remained cool enough for young salmon and steelhead in the shaded 9 miles or about two-thirds of Walker Creek above tidewater.

We do not know if all of Walker Creek was well shaded many years ago, but dense groves of alders on the streambanks are now having their roots exposed by bank erosion and some trees are washing away. In other reaches, primarily below Chileno Creek, willow thickets along the stream edge appear relatively recent.

While loss of shade has caused some loss of salmonid habitat, it seems unlikely to have been a major reason for the demise of the salmon and steelhead runs here. Nearly two-thirds of the stream is still well shaded and water temperatures there remain sufficiently cool.

Low Winter Flows Between Storms

Along the California coast, silver salmon migrate upstream on the first freshet which reaches the sea, usually in December or January. They bury their eggs in gravel over which there is a foot or so of water and a moderately swift current. Buried in this way, the eggs must be continuously bathed in slow currents of freshwater to provide them with dissolved oxygen and carry away carbon dioxide and other waste products of metabolism. Without subsequent rains to maintain at least moderate streamflows during the winter, eggs can be lost as the current velocities through the nests decline. This is often a problem on small watersheds of this kind.

Almost all of the Walker Creek flow comes during and shortly after the three to a half dozen winter storms (Table 5). Between storms, flow drops rapidly, sometimes below 10 cfs. This tendency towards almost flash floods and low intervening flows has probably increased over the years by intensive grazing on the watershed. The significance of these low winter flows would vary greatly from one year to the next, depending upon winter rainfall patterns. Their past role in eliminating salmon and all but token steelhead runs from Walker Creek is impossible to assess but the situation should be improved if those runs are to be restored.

Pollution

Pollution from dairy waste has been a problem in Walker Creek and Warden Giddings' diaries note that steelhead were killed there in 1951. There is no evidence, however, that water quality has been sufficiently bad to eliminate the salmon and steelhead runs.

Table 5. Daily flow *in* Walker Creek, Oct. 1974 through Sept. 1975. Figures are cfs. (Unpublished data of USGS, subject to revision.)

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	.02	.01	.17	4.0	56	30	36	7.0	.58	.15	.02	.02
2	.02	.01	.27	3.0	145	33	32	6.7	.72	.12	.02	.02
3	.02	.01	1.8	2.2	151	28	31	7.0	.72	.12	.02	.02
4	.02	.01	4.7	2.9	427	26	30	6.6	.58	.12	.02	.02
5	.01	0	.88	3.3	141	25	32	6.0	.52	.08	.02	.02
6	.01	0	.57	66	117	24	32	5.7	.58	.08	.02	.03
7	.01	0	.44	40	454	341	28	5.5	1.1	.08	.02	.02
8	.01	.03	.36	93	751	172	29	5.3	2.8	.05	.01	.02
9	.01	.01	.31	35	866	111	28	5.0	2.8	.08	.01	.02
10	.01	.01	.29	24	483	194	25	4.8	2.8	.05	.01	.02
11	.01	.01	.29	17	204	128	23	4.2	2.8	.05	.01	.02
12	.01	0	.30	14	1,010	91	21	3.8	3.0	.05	.01	.02
13	.01	0	.32	11	1,860	104	19	3.3	2.0	.05	.01	.02
14	.01	0	.34	10	444	84	18	3.2	1.6	.03	.01	.02
15	.01	.01	.36	9.0	228	101	16	3.0	.80	.05	.01	.02
16	.01	.01	.35	7.7	140	284	15	2.6	.58	.05	.01	.02
17	.01	.01	.31	6.6	92	158	14	2.4	.47	.05	.02	.02
18	0	.03	.29	5.9	65	157	12	2.0	.38	.05	.02	.02
19	0	.02	.26	5.2	194	171	11	2.2	.34	.05	.02	.02
20	.01	.02	.25	4.5	167	128	10	1.7	.34	.05	.02	.02
21	.01	.05	.25	3.8	103	1,050	9.7	1.5	.34	.05	.01	.02
22	.01	.14	.25	3.3	73	929	8.7	1.5	.34	.03	.01	.02
23	.01	.35	.24	2.8	59	352	8.0	1.3	.34	.03	.01	.02
24	.01	.31	.22	2.6	51	349	17	1.3	.34	.03	.01	.02
25	.01	.24	.23	2.4	42	791	19	1.2	.34	.02	.01	.03
26	.01	.22	.25	2.4	36	322	12	1.1	.30	.02	.01	.03
27	.02	.21	17	2.1	32	182	9.7	.99	.26	.02	.01	.03
28	.04	.19	56	1.9	30	88	8.8	.80	.22	.02	.01	.02
29	.04	.18	17	1.8		56	8.1	.65	.19	.02	.01	.03
30	.04	.17	11	1.6	-----	53	7.3	.52	.19	.02	.01	.03
31	.04	----	7.0	5.0	-----	43	----	.47	-----	.02	.01	----
TOTAL	.46	2.26	122.30	394.0	8,421	6,605	571.3	99.13	28.37	1.69	.43	.66
MFAN	.015	.075	3.95	12.7	301	213	19.0	3.20	.95	.055	.014	.022
MAX	.04	.35	56	93	1,860	1,050	36	7.0	3.0	.15	.02	.03
MIN	0.	0	.17	1.6	30	24	7.3	.47	.19	.02	.01	.02
AC-FT	.9	4.5	243	781	16,700	13,100	1,130	197	56	3.4	.9	1.3

CAL Yr 1974 TOTAL 20,612,93 MEAN 56.5 MAX 2,120 MIN 0 AC-FT 40,890
WTR Yr 1975 TOTAL 16,246,60 MEAN 44.5 MAX 1,860 MIN 0 AC-FT 32,230

Dams

The present reservoir on Arroyo Sausal is known to have blocked some steelhead that otherwise migrated into the headwaters to spawn and it does spill warm water into Arroyo Sausal in the spring. It was, however, built in 1968, years after the steelhead and salmon runs declined to token levels.

Overgrazing

Zumwalt (1972, 1975) described how grazing on the watershed changed the plant cover from native perennials to predominantly introduced annuals, and how the ground cover has been persistently overgrazed and trampled. This has led to accelerated runoff and depletion of the moisture storage capacity of the soil. The accelerated runoff and intensification of the flash characteristics of floods are the most probable causes for what appears to be unnaturally rapid streambed erosion. The vertical incision of Walker Creek into the land has probably caused the ground-water table in high standing terraces to drop and the ground water in the soil on the lower hill slopes to drain more readily and rapidly out through the high steep banks earlier in the spring. This, combined with reduced percolation into the soil for any given amount of rainfall and subsequent reduction in bank storage, would lead to a reduction in summer flow. This is, in our opinion, the most reasonable hypothesis of what has happened on Walker Creek. We believe that overgrazing of the watershed was probably the principal root cause for the elimination of summer streamflow and the salmon and steelhead runs.

THE POSSIBILITY OF RECOVERY

We believe there is little possibility of restoring either salmon or steelhead runs in Walker Creek through land use control. Zumwalt (1975) noted that improvement in surface runoff patterns could be expected in a decade, if all livestock and off-road vehicle use ceased on the watershed, and if erosion control measures were taken on present roads, gullies, and trails. There seems no possibility of this happening. He also noted that with livestock use continued but under strict control, with greatly reduced use of off-road vehicles, and with extensive erosion control work, some effective improvement could be expected in 25 years.

Programs to reduce land erosion are of great importance to the future of this and many other North Coast watersheds. The problem of reduced percolation and bank storage has, however, been compounded by the downcutting of Walker Creek by 20 feet or more in many reaches. This has increased the hydraulic head between water stored in the banks and the stream itself so that, even with greater percolation, springs near the stream and its tributaries will continue to dry up sooner.

The prime impact of grazing and erosion control efforts in the Walker Creek watershed will be to reduce future bank erosion and to preserve riparian vegetation and needed shade. Erosion control will greatly increase the value and usability of any summer flow but, by itself, is not likely to restore the salmon and steelhead runs in Walker Creek.

THE POSSIBILITY OF RESTORATION BY UPSTREAM STORAGE AND RELEASE

Restoration will, we believe, require upstream storage and release of water into the streambed during late summer and fall.

The Marin Municipal Water District proposes to purchase the present Soulajule Reservoir on Arroyo Sausal and raise the dam to impound a maximum 10,560 acre-feet of water. This would provide the District with an additional 5,000 acre-feet of annual net firm yield to carry it over a dry cycle. During other years, Soulajule Reservoir could be used to augment natural flows in Walker Creek.

Maintenance of Minimum Flows

Since the District Directors selected the Soulajule Project as the water supply alternative for further study, we have been working with District engineers to define how much water was available and how it could best be used. During winters of normal or better rainfall, District reservoirs fill and there is sufficient water for domestic use. Much of that captured in Soulajule Reservoir can be used to maintain a minimum flow for fish life. Figure 8 is a graph illustrating proposed releases and minimum streamflows to be maintained.

The proposal for such "normal or better" water years is to maintain at least 5 cfs at the USGS gage located above Chileno Creek during the summer and fall and place a minimum on the winter flows of 20 cfs.

Following dry winters when rainfall is not sufficient to fill the District's reservoirs to 90 percent of capacity, the summer flow would be reduced to 2 cfs and the floor on winter flows would be maintained at 10 cfs.

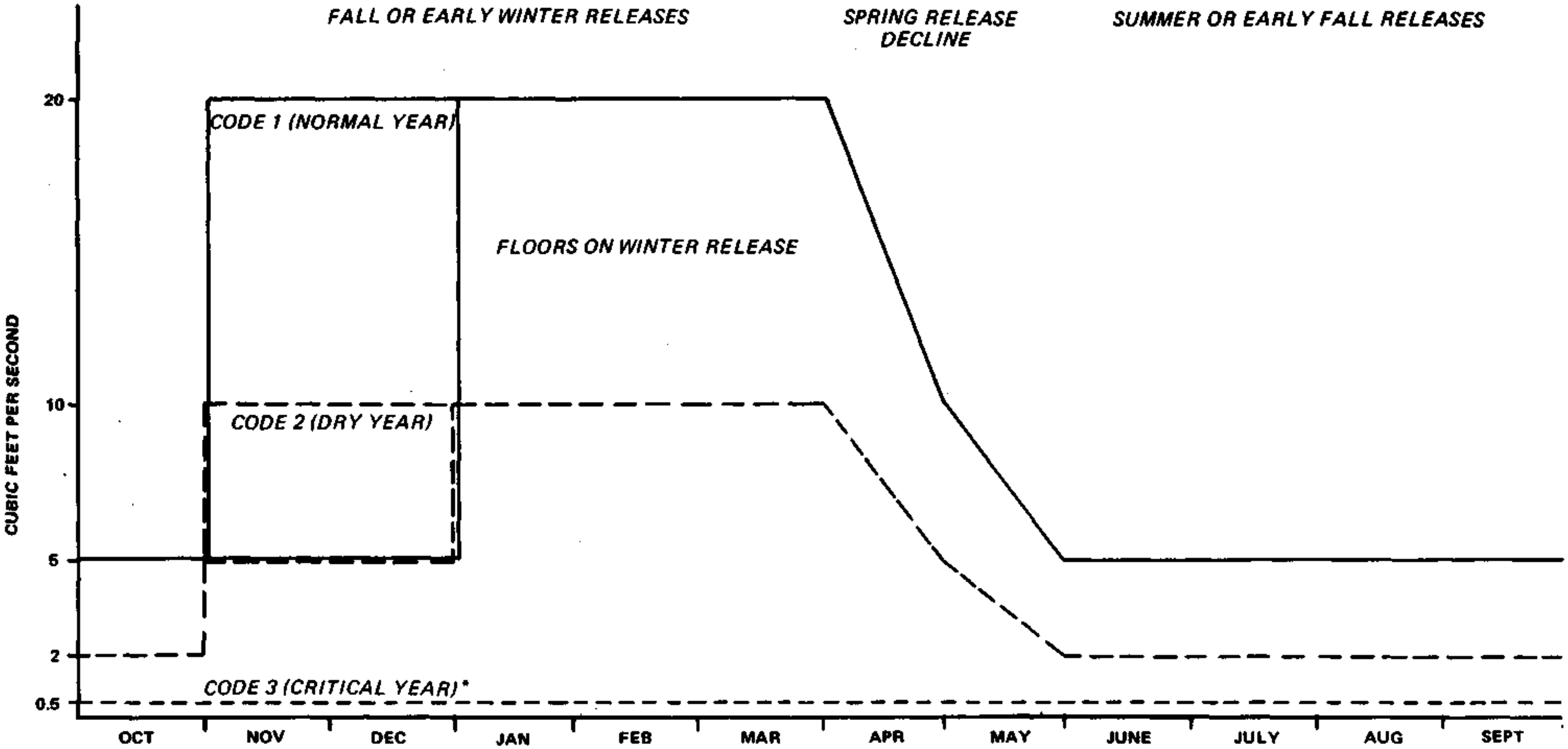


FIGURE 8. Minimum Soulajule Project stream flow releases into Walker Creek measured at USGS gage.

*Measured in Arroyo Sausal below Soulajule Dam.

During a dry cycle--that is, a period of dry years such as occurred in the 1930s, none of these flows could be released without reducing the Water District's net safe yield of 5,000 acre-feet for which the project is to be constructed. During such years, a minimum flow of 0.5 cfs would be released from Soulajule Reservoir in order to keep the pools in Walker Creek from drying up as they do now.

Decisions to adjust the streamflow releases according to the water supply would be made the first of January, February, March, and May. On those dates, the minimum flow schedules would be adjusted to levels described in Figure 8, according to the amount of stored water available in the District's reservoirs (Table 6).

Measurement of these minimum streamflows would be made at the USGS gage above Chileno Creek, some 9 miles downstream from the Soulajule Reservoir. During summer and fall there is no significant accretion between the reservoir site and the gage so that water to maintain these minimum flows would have to be released from Soulajule Reservoir. During, and for some time after winter storms, however, there is significant flow in Salmon Creek and several other tributaries of Walker Creek below Arroyo Sausal and above the USGS gage. When minimum required flows were being met by that downstream accretion, no water, except for a 0.5 cfs flow to keep Arroyo Sausal alive, would be released from the reservoir. When full, the reservoir would spill its total inflow, less evaporation losses, into the stream.

The purpose of this operation, of course, is to maintain the best salmonid habitat possible with the limited amount of water stored in Soulajule Reservoir by saving it for times when downstream augmentations are most needed to enhance the stream environment.

The proposed operation of the Soulajule Reservoir was studied with a model that simulates (i) daily streamflows in Arroyo Sausal and Walker Creek since 1928, (ii) a Soulajule Reservoir of 10,000-acre-foot capacity, and (iii) a predicted annual domestic water demand of 36,760 acre-feet. The model allowed us and District engineers to investigate a series of alternative release schedules and ways of operating the reservoir to meet both the domestic water demand and downstream needs. Table 7 lists the frequency with which each of the three classes of minimum streamflows could have been maintained under the historic rainfall conditions. The operation studies have shown that, during the most critical August through October period, the 5 cfs streamflow (Code 1) could have been maintained at the Walker Creek gage

Table 6. Minimum streamflows to be maintained with the Soulajule Project.

	Code 1 NORMAL OR WET YEAR	Code 2 DRY YEAR	Code 3 CRITICAL YEAR
Storage in Nicasio Reservoir on Jan. 1 in acre-feet	>10580 (>47% full)	10580 to 7392 (47 to 33% full)	<7392 (<33% full)
Minimum January flow in cfs	20 at USGS gage	10 at USGS gage	0.5 in Arroyo Sausal
Storage in Nicasio Reservoir on Feb. 1 in acre-feet	>13800 (>62% full)	13800 to 9400 (62 to 42% full)	<9400 (<42% full)
Minimum February flow in cfs	20 at USGS gage	10 at USGS gage	0.5 at Arroyo Sausal
Storage in Nicasio Reservoir on March 1 in acre-feet	>16800 (>75% full)	16800 to 11300 (75 to 50% full)	<11300 (<50% full)
Minimum March flow in cfs	20 at USGS gage	10 at USGS gage	0.5 at Arroyo Sausal
Minimum streamflow during April	reduce by half no faster than 1 cfs each two days		
Storage in Nicasio Reservoir at end of rainy season (May 1) in acre-feet	>20160 (>90% full)	13440 to 20160 (60 to 90% full)	<60% full
Minimum flow during May	reduce to summer level no faster than 1 cfs each two days		
Minimum streamflow June 1 to first Nov. rise above 25 cfs	10 at USGS gage	5 at USGS gage	0.5 in Arroyo Sausal
Minimum streamflow from first Nov. rise to 25 cfs to Jan 1.	20 cfs at USGS gage	10 cfs at USGS gage	0.5 cfs in Arroyo Sausal

Table 7. Code of minimum streamflows that could have been maintained in Walker Creek under historical rainfall conditions, the expected 1995 demand for domestic water, and with a 10,000 acre-foot Soulajule Reservoir.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1928	1	1	1	1	1	1	1	1	1	1	1	1
1929	1	1	1	1	1	2	1	2	2	2	2	2
1930	3	3	3	1	1	1	1	1	1	1	1	1
1931	1	1	1	2	2	3	2	3	3	3	3	3
1932	3	3	1	1	1	3	3	3	3	3	3	3
1933	3	3	1	1	3	3	3	3	3	3	3	3
1934	3	3	1	1	2	3	3	3	3	3	3	3
1935	3	3	3	1	2	2	1	2	2	2	2	2
1936	2	2	2	1	1	1	1	1	1	1	1	1
1937	1	1	1	2	1	1	1	1	1	1	1	1
1938	1	1	1	1	1	1	1	1	1	1	1	1
1939	1	1	1	2	2	3	2	3	3	3	3	3
1940	3	3	3	1	1	1	1	1	1	1	1	1
1941	1	1	1	1	1	1	1	1	1	1	1	1
1942	1	1	1	1	1	1	1	1	1	1	1	1
1943	1	1	1	1	1	1	1	1	1	1	1	1
1944	1	1	1	2	1	2	2	2	2	2	2	2
1945	2	2	1	1	1	1	1	1	1	1	1	1
1946	1	1	1	1	1	1	1	1	1	1	1	1
1947	1	1	1	2	1	3	2	3	3	3	3	3
1948	3	3	3	3	3	1	1	1	2	1	3	3
1949	3	3	2	1	1	2	2	2	2	2	2	2
1950	2	2	2	1	1	1	1	1	1	1	1	1
1951	1	1	1	1	1	1	1	1	1	1	1	1
1952	1	1	1	1	1	1	1	1	1	1	1	1
1953	1	1	1	1	1	1	1	1	1	1	1	1
1954	1	1	1	1	1	1	1	1	1	1	1	1
1955	1	1	1	1	1	1	1	3	3	3	3	3
1956	3	3	1	1	1	1	1	1	1	1	1	1
1957	1	1	1	2	1	1	2	1	2	2	2	2
1958	2	2	1	1	1	1	1	1	1	1	1	1
1959	1	1	1	1	1	2	2	2	2	2	2	2
1960	3	3	3	2	1	1	1	1	1	1	1	1
1961	1	1	1	1	1	1	2	2	2	3	3	3
1962	3	3	2	1	1	1	2	1	1	1	1	1
1963	1	1	1	1	1	1	1	1	1	1	1	1
1964	1	1	1	1	1	1	1	1	1	2	2	2
1965	3	1	1	1	1	1	1	1	1	1	1	1
1966	1	1	1	1	1	1	1	1	1	1	1	1
1967	1	1	1	1	1	1	1	1	1	1	1	1
1968	1	1	1	1	1	1	2	1	1	1	1	1
1969	1	1	1	1	1	1	1	1	1	1	1	1
1970	1	1	1	1	1	1	1	1	1	1	1	1
1971	1	1	1	1	1	1	1	1	1	1	1	1
1972	1	1	1	1	1	1	1	2	2	2	3	3
1973	2	1	1	1	1	1	1	1	1	1	1	1
Code 1	29	31	37	38	40	35	33	32	30	30	29	29
Code 2	5	4	4	7	4	5	10	7	9	8	7	7
Code 3	12	11	5	1	2	6	3	7	7	8	10	10

in 63 percent of the years. In 11 percent of the years, there would be enough water to maintain a 2 cfs release throughout the summer and fall (Code 2), but in 26 percent of the years, the streamflow release would have to be reduced to 0.5 cfs (Code 3).

During the model operation study we completely ran out of water in late summer or fall of a few years. District engineers and management believe, however, that this can be avoided with careful operation and that the 0.5 cfs release can be a guaranteed year-round minimum from the Soulajule Reservoir.

Thinking that a larger reservoir might provide sufficient storage to reduce the frequency of these very low releases in critical years, the model was changed to include a dam 10 feet higher and with a storage capacity of 12,800 acre-feet. The results show that such a reservoir would do little good (Table 8). In critically dry years, there simply is not enough rain to fill the reservoir, and increasing its capacity by 2,800 acre-feet does not help. A very large reservoir which could accumulate and store large amounts of water captured in wet years for later use during dry cycles, is much more expensive both in dollars and environmental losses due to flooding a satellite tracking station and valuable agricultural land.

THE NEED FOR SUPPLEMENTAL SILVER SALMON STOCKING

Following critically dry years when summer and fall flow releases can do no more than keep the pools in the stream alive (a Code 3 release of 0.5 cfs), young silver salmon will probably have to be stocked in order to maintain the population.

While conditions during such times will be better than they have been for many years, they will be less than desirable for young salmon and relatively few will survive to migrate seaward the following spring. Because silver salmon have such a regular 3-year life cycle (Shapovalov and Taft, 1954), the number of females returning to spawn 2 years later probably would be inadequate to restock the stream.

Critically dry years will therefore influence salmon production that year and every third year afterward for some time in the future. Critical years as frequent as the 26 percent we expect on Walker Creek after 1990 will quickly eliminate viable salmon runs unless these gaps are filled by supplemental planting. Following such years, fish that have grown large enough to migrate to the sea should be

Table 8. Code of minimum streamflows that could have been maintained in Walker Creek under historical rainfall conditions, the expected 1995 demand for domestic water and with a 12,800 acre-foot reservoir.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1928	1	1	1	1	1	1	1	1	1	1	1	1
1929	1	1	1	1	1	1	1	2	2	2	2	2
1930	2	1	1	1	1	1	1	1	1	1	1	1
1931	1	1	1	2	2	2	2	3	3	3	3	3
1932	3	3	1	1	1	2	2	3	3	3	3	3
1933	3	3	1	1	2	2	2	3	3	3	3	3
1934	3	3	1	1	1	2	3	3	3	3	3	3
1935	3	2	2	1	2	1	1	1	2	2	2	2

planted in Walker Creek during the late winter or early spring of the next year when flows are higher. Effective establishment of a significant silver salmon run will also require initial stocking of a suitable genetic strain of silver salmon in the Walker Creek estuary for 3 years following completion of the Soulajule Reservoir. Stocking in Walker Creek following this initial introduction will, except following critically dry years, be unnecessary, and even undesirable.

PROJECT EFFECT ON NATURAL STREAMFLOWS

The flows illustrated in Figure 8 are minimum levels that will be sustained at the USGS gage by releases from the Soulajule Reservoir. They should not be confused with the actual flows of Walker Creek which of course are influenced by rainfall and upon which the Soulajule Reservoir has limited effect. The effect is limited because the tributary of Arroyo Sausal, upon which the Soulajule Reservoir is to be constructed, provides only half of the runoff that accrues to Walker Creek above the USGS gage, and only one-quarter of the total runoff to the stream where it enters Tomales Bay. Half of the watershed above the gaging station and three-quarters of the total watershed cannot be influenced at all by the project.

Table 9 lists the monthly flows in acre-feet at the USGS gage as recorded since the gage was installed in 1959, and as that flow would have been with the Soulajule Project built and in operation. The latter data were provided by the Marin Municipal Water District's model operation study. The data show that zero flows such as always occurred in the summer and fall of past years, would have been avoided. Low flows such as always occurred in the spring and early fall and sometimes in the winter between storms would have been augmented by streamflow releases for fish.

High flows often would have been reduced, sometimes by half. This reduction of high flows would have occurred when the Soulajule Reservoir had empty storage capacity and was filling after the summer drawdown for both domestic use and streamflow maintenance or during the winter when it is drawn down to maintain a floor on the winter streamflows. One of the more interesting aspects of Table 9 is that the total annual flow during the two lowest years of record (1963-64 and 1971-72) would have been higher had the project been in operation.

Table 9. Monthly flows at USGS gage on Walker Creek with and without Soulajule Project (figures are acre-feet, source Marin Municipal Water District)

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1959-60													
WITHOUT	0	0	2	792	8550	2980	454	111	12	0	0	0	12900
WITH	80	77	22	622	4760	1984	990	530	307	307	307	307	10295
1960-61													
WITHOUT	0	0	347	2760	5160	4000	811	142	24	0	0	0	13240
WITH	307	994	346	1446	2943	2312	609	242	123	103	0	0	9424
1961-62													
WITHOUT	0	0	166	842	15740	6070	473	92	4	0	0	0	23380
WITH	30	20	183	507	7944	4068	387	531	307	307	307	307	14896
1962-63													
WITHOUT	5030	183	3850	7250	8520	3360	8700	938	119	14	5	1	37970
WITH	2708	1228	2260	4323	8625	3145	8612	750	307	307	307	307	32880
1963-64													
WITHOUT	0	1220	520	6910	882	405	121	38	49	3	0	0	10150
WITH	307	1013	1228	4234	1346	1228	991	241	134	123	123	30	10997
1964-65													
WITHOUT	0	1060	12560	16400	1300	601	5600	426	75	7	0	0	38020
WITH	30	786	6606	12575	1645	1230	4375	531	307	307	307	307	29004
1965-66													
WITHOUT	0	247	2910	15110	7190	992	290	74	15	0	0	0	26830
WITH	307	1228	1770	12757	7292	1238	992	531	307	307	307	307	27342
1966-67													
WITHOUT	0	2180	10200	23700	2810	4980	6490	737	336	34	5	1	51480
WITH	307	1591	5565	23313	3075	4612	6405	669	354	307	307	307	46811
1967-68													
WITHOUT	6	27	256	5760	8500	5140	567	97	16	2	0	0	20370
WITH	307	1228	1228	3124	6716	4992	633	531	307	307	307	307	19985
1968-69													
WITHOUT	0	66	10730	27530	17030	4410	971	1	0	0	0	0	60920
WITH	307	1228	5707	26964	17121	4282	1018	531	307	307	307	307	58386
1969-70													
WITHOUT	109	59	10280	35030	5380	4450	256	59	6	3	1	0	55640
WITH	337	1228	5335	34958	5487	4416	991	531	307	307	307	307	54508
1970-71													
WITHOUT	0	4120	17700	5820	598	4070	1060	223	34	3	0	0	33620
WITH	307	2378	14090	5807	1240	3326	1134	532	307	307	307	307	30040
1971-72													
WITHOUT	0	0	2640	1760	5010	645	221	41	5	1	0	0	10320
WITH	307	1228	1606	1638	3047	1228	994	241	123	123	55	30	10615
1972-73													
WITHOUT	98	4230	6810	30440	15920	5710	571	105	14	1	0	0	63900
WITH	90	2373	3669	25369	16012	5526	996	531	307	307	307	307	55794

Monthly totals are of course not the complete picture, especially in Walker Creek where flows change rapidly almost overnight. Figures 9, 10, and 11 are graphs illustrating the effect the Soulajule Project would have had on daily flows in the 3 years beginning October 1960. These 3 years were selected because they illustrate three very different but typical hydrological conditions that face the operation of this project; 1961 was the third in a series of dry years. It was followed by a more normal, and then by a wet year. A description of how salmon and steelhead would have responded to the project during these years is also shown on Figures 9, 10, and 11.

It is important to keep in mind that the streamflows at the Walker Creek gage are about half as large as the flow downstream where Walker Creek flows under Highway 1, and enters the north end of Tomales Bay. Most of the downstream accretion comes from the Chileno Creek watershed which joins Walker Creek immediately below the USGS gage.

THE EFFECTS ON THE STREAMBED EROSION AND SUBSTRATE

The reduction of floodflows illustrated in Figures 9, 10, and 11, is expected to reduce bank erosion and cause some changes in substrate conditions. Floodflows will reach caving banks less frequently with the project in operation and, when they do, the water will have less velocity, be less erosive, and have less capacity to pick up loose soil that has fallen into the high flood channel. The contribution of sand and silt to the stream will be reduced.

Winter bedload movement rates will also be reduced. The stream velocities needed to transport silt and sand will be less affected than those required to move gravel and rubble. The net result is that, in time, the substrate of Walker Creek will be composed of more rubble and gravel and less sand and silt. This will be of great benefit to both spawning and young salmon and steelhead.

THE EFFECT ON RIPARIAN VEGETATION AND WATER TEMPERATURES

The establishment of a permanent streamflow in the Walker Creek channel will encourage the invasion of riparian vegetation, particularly willow (_Salax lasiolepis_, _S_. _lasintra_, and _S_. _hindsiana_). These are the first shrubs to invade the wide gravel deposits or recently cut alluvium where the stream has altered its course, and where the shade is now desperately needed. Willow propagation is now inhibited in most reaches by lack of water through the summer and fall. Both the willow and the young alders are invading the stream below Chileno Creek where the streamflow is maintained longer by

Figures 9, 10 and 11 have intentionally been left out of the KRIS edition of this paper due to the amount of memory they require.

summer releases of water from a small reservoir on Chileno Creek. The provision of summer water is also expected to benefit and strengthen established riparian vegetation now threatened by root desiccation as the stream degrades and meanders.

Maintaining riparian vegetation is critical to restoring the salmon and steelhead runs in Walker Creek. Our studies show that water temperature in Walker Creek is a direct function of shade and that, without shade, a 2 cfs release of 55°F water released from the bottom of a large Soulajule Reservoir will, within a mile, become too warm for young salmon or steelhead. The warming comes, not from conduction with air (which is often colder than the water even in summer), but from direct solar radiation.

We found also that heat losses from the stream were greater than heat gains where the stream was about half or more shaded, and that on reaching such points, at flows of 1.5 to 3 cfs, the stream quickly cooled to a maximum daytime temperature of 68 to 70°F (Figures 6 and 7).

The combination of permanent summer flow and reduced bank erosion will encourage willows and alders along the stream. Riparian vegetation that now provides reasonably good shade for two-thirds of the stream's length above tidewater will benefit. We believe that willow growth will shade the now unshaded reaches in about 5 years after the project is completed. In some places it may be necessary to protect young growth from browsing.

GENERAL INSTREAM BIOLOGICAL EFFECTS

At the present time, those parts of Walker Creek which are exposed to sunlight and are warm have very different biological communities than those which are well shaded and cool. In the sunlit reaches of Walker Creek, dominant primary productivity is the result of photosynthesis by sometimes dense populations of several kinds of algae (Evans, 1975). In the well-shaded reaches, organic debris in the form of alder leaves, etc., provides a much larger proportion of the primary productivity. This debris is converted into more useful food by a community of fungi, bacteria, and invertebrate detritus feeders. It is eventually converted into the immature aquatic insects which live in the bottoms of these streams and provide the principal food for young salmon and steelhead so long as the stream flows. At one time, this detritus-aquatic insect food chain was probably dominant in Walker Creek and its tributaries. We expect the encouragement of shade and the provision of permanent summer flow in Walker Creek to return it in that direction.

A permanent flow is likely to encourage some higher aquatic plants in pools along Walker Creek. Flood-flows will be too frequent and too high to expect extensive beds of rooted aquatic vegetation to develop.

ESTIMATE OF EXPECTED SALMON AND STEELHEAD PRODUCTION

Factors Limiting Production

The numerous factors which control the number of salmon and steelhead produced in a spawning stream and that survive to become adults, support a fishery, or escape and return to provide a spawning run have been intensively studied in many streams and rivers. Figure 12 is our conceptual model of the factors we believe are important in Walker Creek.

The principal limitation will probably always be the amount and quality of rearing area.

Estimate of Rearing Area

In June, we measured the amount and quality of juvenile salmonid rearing area at low flows expected during "dry years". A few days after the surface flow throughout nearly all of Walker Creek above Chileno Creek ceased, the gate valve at the present Soulajule Reservoir was opened and left open for one week. Streambed gravels had not dried out and pools were still brim full so that the release caused the stream to begin flowing again within hours. Streamflows, measured below at several points downstream, were always higher than the release from the dam as measured in Arroyo Sausal (Table 10). There was almost no visible accretion and the difference was probably due to water coming into the stream from bank storage.

We measured rearing area at transects 100 feet apart on four sections of the stream, selected because they appeared to represent the range of stream morphology, substrate, and riparian vegetation that existed over the entire stream.

To qualify as usable salmonid rearing area, the stream had to have a minimum depth of 4 inches, over a substrate of large gravel or cobble, or 1 foot over a finer substrate. Current in such shallow water had to be at least 0.5 cfs, but less current velocity was permitted in deeper water.

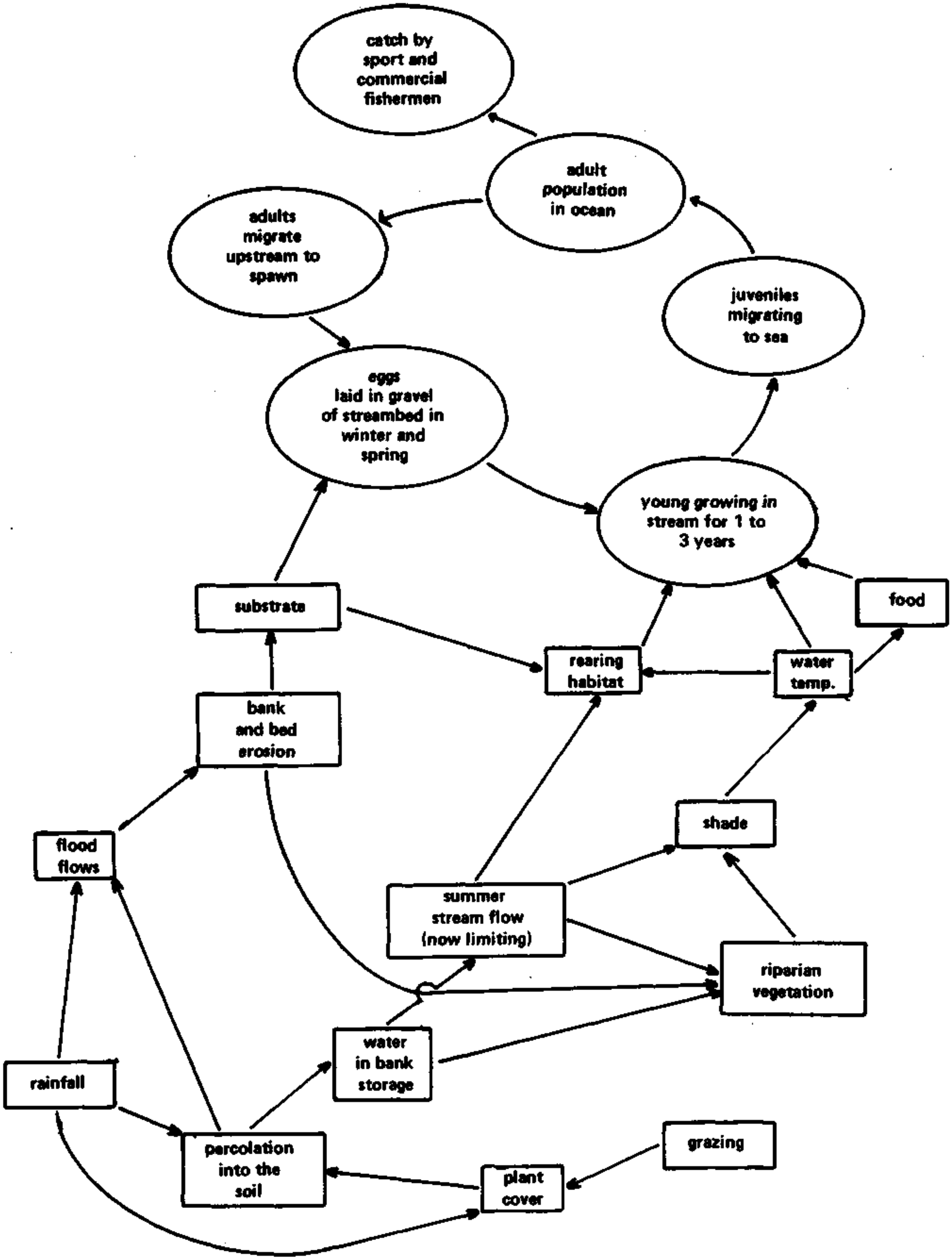


FIGURE 12. Conceptual Model of Factors Influencing Salmon and Steelhead Runs in Walker Creek, Marin Co.

Table 10. Effect of 1975 experimental release from Soulajule Reservoir on Walker Creek streamflow[1] (figures are cubic feet per second)

	Location of measure	Arroyo Sausal just below dam	Below Marshall Petaluma Bridge	Wood bridge below Synanon	USGS gage
Miles below dam		0	4	7	11
Date					
June	5				0.52
	6	trace	0.20	0.28	0.58
Valve on Soulajule Res. open from 1715 June 6 to 1700 June 13	7				1.1
	8				2.8
	9	1.37	2.98[2]	2.59	2.8
	10				2.8
	11				2.8
	12				3.0
	13	1.73	2.49	2.19	2.0
	14				1.6
	15				0.8
	16				0.58
	17				0.47
	18				0.38
	19				0.34

[1] Measurements at gage are from USGS, others were made with a Gurley current meter by Jerry Holeman of the California Department of Fish and Game, and Russell Thompson of the Marin Municipal Water District.

[2] Downstream flows increased more than the amount being released from the dam. This is not a measuring error, but we have found no one who can explain why that occurred.

The quality of usable area was rated from poor to excellent on the basis of the amount of salmonid shelter and food-producing area created. Water temperatures were not considered at this point since they are expected to change in the future.

Following measurements in these four sample sections, we walked over the entire length of Walker Creek gathering similar data. The stream was then divided into nine reaches of relatively homogeneous character and the measurements of quantity and assessments of quality were applied to each reach (Figure 13). Our measurements indicated that at these low flows, Walker Creek and Arroyo Sausal below the Soulajule Dam would provide about 41 surface acres of stream, of which 20 acres would be usable rearing habitat for salmonids, mostly of fair quality (Table 11).

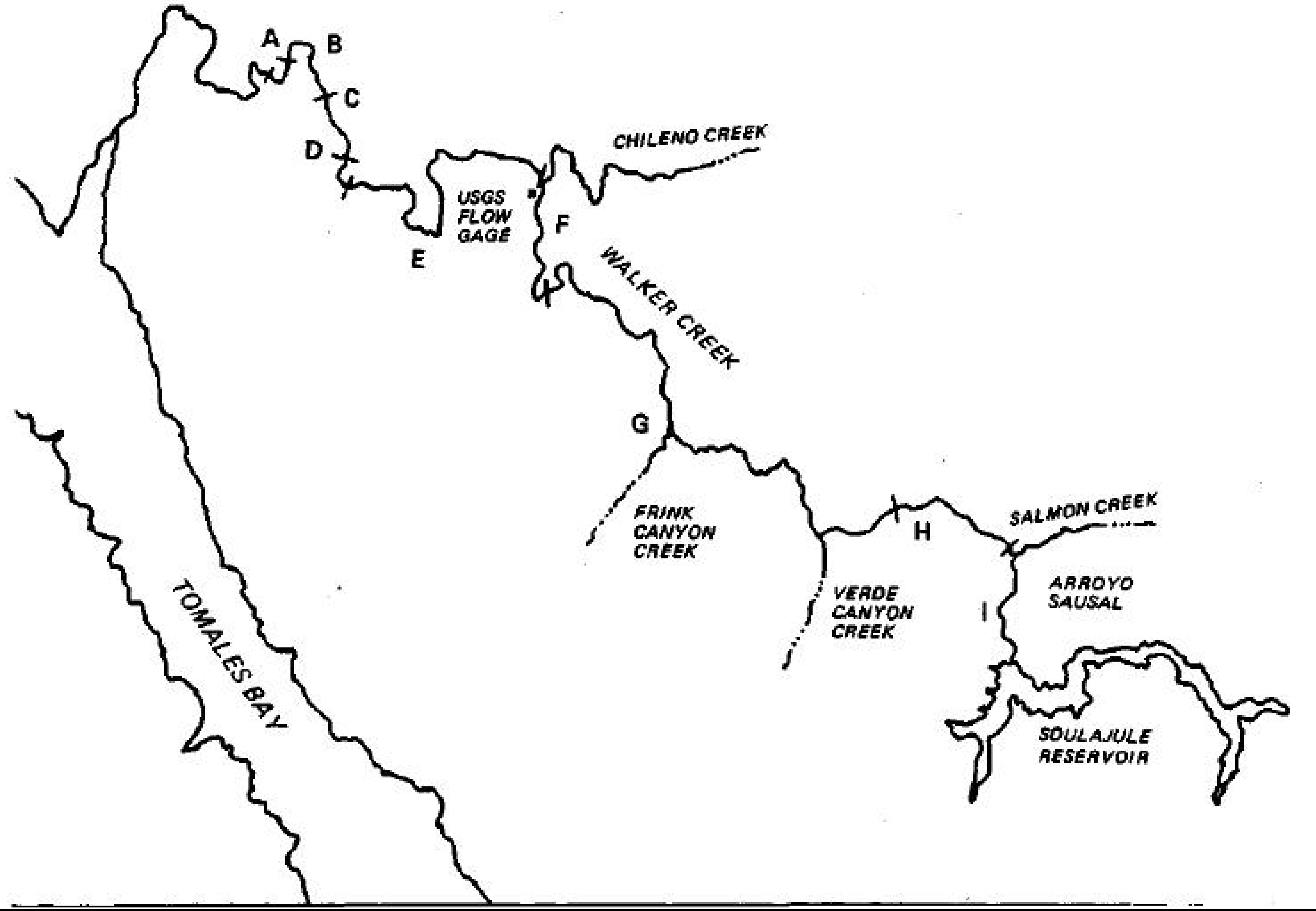
Present quality of this habitat at the lower end of Walker Creek is poor because of sand accumulation. Upstream substrate is coarser, with many reaches of good rubble and cobble bottom. Rearing habitat there is much better and is expected to improve with the reduction of bank erosion.

Because of the unprecedented dry winter, there has been no opportunity to measure salmonid habitat in Walker Creek at higher flows. Measurements on similar small, low-gradient streams in southeastern Oregon (Wesche, 1973) showed that increasing flow from 12.5 to 25 percent of the mean annual flow increased surface area by 32 percent on one stream and 61 percent on another. Generally, such wetted area changes are more rapid at lower flows when the channel is not yet full.

At the 1.5 - 3.0 cfs measures, Walker Creek averages 24.4 feet wide in a low water channel that is in most places 50 - 70 feet across. We believe that increasing the summer flow to 5 cfs (a rise from 10 to 20 percent of the mean annual flow) will increase the surface area we measured by at least 50 percent. Velocities and the amount of usable salmonid rearing area will increase more than that but we have no data to use for even a conservative estimate.

Estimated Production of Juvenile Salmon and Steelhead

During the July 23 to 25 search for young salmon and steelhead in Walker Creek, we made estimates of the existing population density 3 miles below the Marshall-Petaluma Road near the lower end of the Synanon property



SECTION	A	B	C	D	E	F	G	H	I	TOTAL
Length in miles	0.5	0.8	0.5	0.3	3.4	1.1	5.2	1.3	1.1	14.2
Mean width in feet	25	26	33	19	20	18	25	25	29	
Area in acres	1.52	2.52	2.00	0.69	8.24	2.40	15.76	3.94	3.87	40.94
Acres of rearing habitat	0.97	0.78	1.21	0.40	4.94	1.50	5.04	1.73	3.07	19.64
Mean quality[1]	1.0	2.0	1.0	3.5	2.0	3.2	2.0	3.5	2.3	

[1] On following scale: 1 = poor, 2 = fair, 4 = good, 8 = excellent.

FIGURE 13. Salmonid habitat provided in Walker Creek and Arroyo Sausal at flows of 1 .4 and 3.0 cfs at the USGS gage.

Table 11. Quality of salmonid rearing habitat in Walker Creek and Arroyo Sausal below Soulajule Dam at flows of 1.5 - 3 cfs.

QUALITY	ACRES	PERCENT
poor	5.3	27.1
fair	10.2	52.0
good	3.4	17.5
excellent	0.7	3.4
	19.6	100

and near the USGS gage just above Chileno Creek. Using the method developed by Seber and LeCren (1967), we estimated that these reaches, which we judged to have fair-to-good-quality rearing habitat, had standing populations of 761 and 914 juvenile salmonids per acre. All but a very few were young-of-the-year steelhead. These densities are small compared to most estimates from streams where there are viable salmon and steelhead runs. This is because Walker Creek dries up each summer. The numbers of young salmonids that survive the dry season, migrate to the ocean, and return to spawn are insufficient to produce normal concentrations of progeny.

Table 12 describes the density of mixed populations of juvenile salmon and steelhead found in a number of West Coast streams and reported in the scientific literature. Summer populations have been reported from 688 to 6,921 juveniles per acre.

On the basis of this information it seems reasonable to believe that Walker Creek would support between 1,000 and 4,000 juvenile salmonids per acre, depending upon the quality of the habitat.

Table 13 is our estimate of the numbers of juvenile salmon and steelhead that Walker Creek could support at the three rates of summer flow scheduled to occur with the Soulajule Project.

These estimates are based upon (i) our measurement of the area covered by a flow of 1.4 to 3.0 cfs, (ii) our interpretation that 5 cfs will cover 50 percent more area, and (iii) measures of summer standing populations found in the literature. They also assume that a permanent flow will reduce bank erosion and encourage shade along all of Walker Creek downstream to tidewater.

Production of Adult Silver Salmon

Figure 14 is a model of silver salmon that can reasonably be expected to be produced and caught as a result of the scheduled operation of Soulajule Reservoir. It is based upon our previous estimates of the number of summer juvenile salmon and steelhead that will be produced in the stream, and survival rates of those juveniles until they become adults and are either caught by the commercial or sport fishery or returned to Walker Creek to spawn. The survival rates have been obtained from the scientific literature; principally the studies of Salo and Bayliff (1958) on Minter Creek in Washington, and Shapovalov and Taft (1954) on Waddell Creek, California. The catch-to-spawning escapement ratio of 3 to 1 is somewhat high for California silver

Table 12. Numbers of mixed young-of-the-year juvenile steelhead and silver salmon found per acre in various streams.

	Summer Populations
Walker Creek (fair to good habitat)	761 to 914
San Pedro Creek, San Mateo Co., CA (Anderson)	4604
Deer Creek, Oregon (Chapman)	1445 to 2708
Flyn Creek, Oregon (")	1133 to 2104
Needle Branch, Oregon (Chapman)	728 to 2104
Casper Creek, Humboldt Co., CA (Burns)	5504 to 6921
South Yeager Creek, Humboldt Co., CA (Burns)	2428 to 3480
Godwood Creek, Humboldt Co., CA (Burns)	688 to 4763
South Alouette River, B.C. (Hartman 1965)	1093 to 2307
Salmon River, B.C. (Hartman 1965)	554 to 5471

Table 13. Estimate of potential production of juvenile silver salmon and steelhead at different summer flow releases from Soulajule Reservoir.

	Release	Acres total stream	Acres rearing area	Quality	Estimated numbers of juvenile salmon and steelhead per surface acre	
Critical year	0.5	20	10	poor	@ 500/acre	10,000
Dry year	2.0	41	21	fair	@ 2000/acre	82,000
Normal or better	5.0	61	42	good	@ 4000/acre	244,000

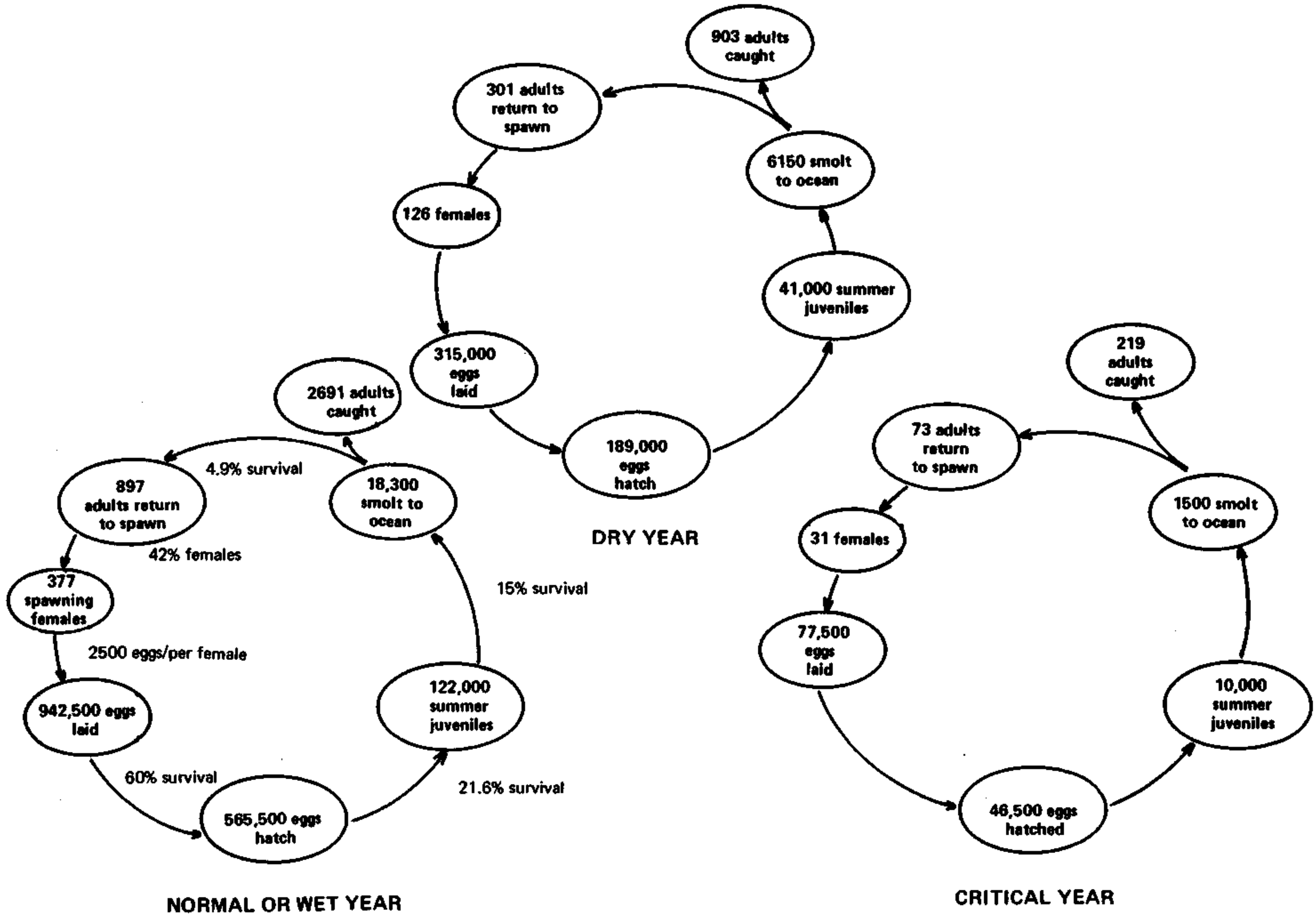


FIGURE 14. Model of Predicted Silver Salmon Production with Scheduled Operation of Walker Creek.

salmon (Jensen, 1971), but we think it is justified because intensive sport fishing for adult salmon will likely develop in Tomales Bay during the late summer and fall.

We estimate from these models that spawning runs of about 900, 300, and 70 adult silver salmon will be produced by the proposed operation of Soulajule Reservoir during normal, dry, and critical years. These runs can be expected to produce about 2,700, 900, and 200 adult salmon in the catch 3 years later.

In Table 14, we have used these models to estimate what silver salmon spawning runs into Walker Creek would have been like, if the Soulajule Project had been in operation since 1931. The rapid recovery from low production during critical years shown on Table 14 assumes that enough young will be produced by the few spawners to quickly restore the population levels to the carrying capacity of the stream when summer flows increase.

This is a reasonable expectation except for the 5 years like 1936, 1937, 1942, 1958, and 1975, when very small spawning runs might not have produced enough eggs to saturate the carrying capacity the following summers when flows would have been 5 cfs. During such years, survival of young salmon from hatched eggs to smolt size would need to be nearly 40 percent instead of the normal 3 percent.[1]

Certainly survival rates of young salmonids in such conditions would be high because competition would be reduced, but whether it would be that high, we cannot say. This, combined with the need to augment adult stocks for the fishery following critically dry years, is the primary reason why we believe that supplemental stocking of silver salmon will sometimes be necessary.

Production of Adult Steelhead

Figure 15 is a conceptual model of potential steelhead production during a normal water year with a 5 cfs summer flow in Walker Creek. Like the salmon models, it is based upon survival rates taken from the literature and our estimate that the carrying capacity of Walker Creek at 5 cfs is 2,000 young-of-the-year (mixed half salmon and half steelhead) per acre. Steelhead carry more than twice as many eggs as silver salmon and their ocean survival rate is much less.

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[1] $\frac{\text{18,300 smolts needed to produce 897 spawning escapement}}{\text{31 females x 2,500 eggs x 60 percent hatch}}$

Table 14. Theoretical number of female salmon that would have spawned in Walker Creek if Soulajule Reservoir had been in operation since 1928.

Year	Summer cfs	Number of females spawning	Year	Summer cfs	Number of females spawning
1928	5	---	1952	5	126
29	2	---	53	5	377
30	5	---	54	5	377
31	0.5	377	55	0.5	377
32	0.5	126	56	5	377
33	0.5	377	57	2	377
34	0.5	31	58	5	31
35	2	31	59	2	377
36	5	31	60	5	126
37	5	31	61	0.5	377
38	5	126	62	5	126
39	0.5	377	63	5	377
40	5	377	64	2	31
41	5	377	65	5	377
42	5	31	66	5	377
43	5	377	67	5	126
44	2	377	68	5	377
45	5	377	69	5	377
46	5	377	70	5	377
47	0.5	126	71	5	377
48	0.5	377	72	0.5	377
49	2	377	73	5	377
50	5	31	74	5	377
51	5	31	75	5	31

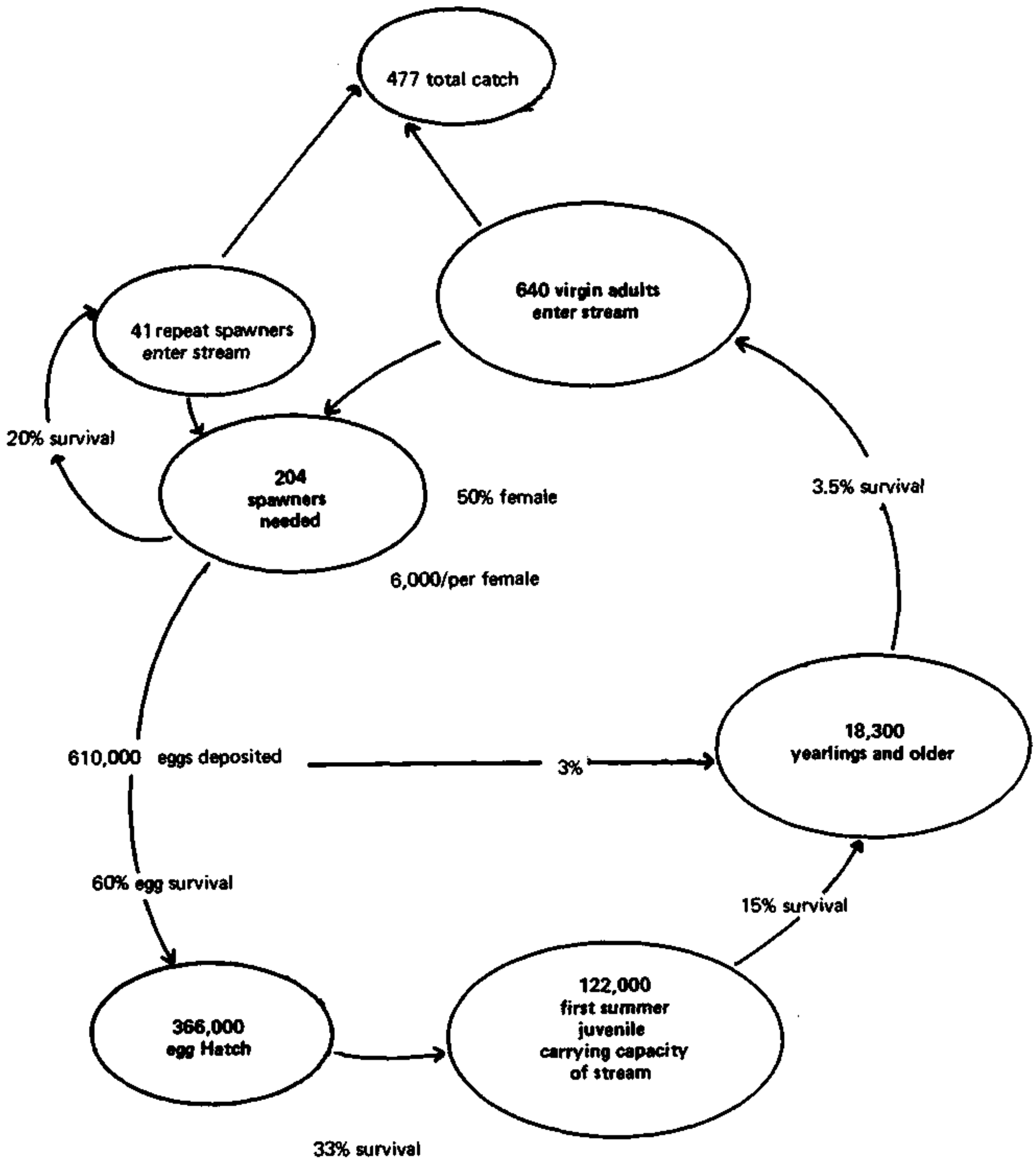

FIGURE 15. Model of Predicted Steelhead Production in Walker Creek with Soulajule Project during normal or wet years.

Unlike salmon (for which we estimate catch by applying a 3:1 (catch/spawning) escapement ratio based on real experience) , for steelhead we can only calculate the number that could be caught without reducing the spawning population. Using the model, we estimate the stream would need about 200 adults to bring it to carrying capacity. Some older adults that have spawned in previous years and survived would return to the stream to be caught. Shapovalov and Taft (1954) found that 21 percent of their spawning run in Waddell Creek were these larger and older fish. All in all, we estimate that in normal or wet years, about 700 adult steelhead would return to spawn and about 500 could safely be caught.

What happens to steelhead during dry or critical years? Because steelhead spawning runs are made up of several age classes, their populations are more resistant to occasional low water years than are silver salmon. A dry year, 2 cfs summer release, will produce enough habitat to carry 82,000 juvenile steelhead through that summer. While silver salmon would migrate downstream the following spring as water temperature warmed, steelhead would not. Nearly all will remain in the stream for a second summer and, because there are fewer of them to share existing food and space, their survival rate in the stream before migrating down will be higher. Some (Shapovalov and Taft measured 14 percent) will remain there 1 to 3 years before returning to spawn. Such variation in their life cycle tends to smooth out year-to-year variation in environmental conditions and is probably why a small steelhead population has continued in Walker Creek in spite of poor conditions there. They are uniquely able to take advantage of good times.

Calculations of the effects of dry and critical years on steelhead are, therefore, beyond the scope of this report. In Table 15 we have made an informed downward guess. Except for a long series of such years, the effects will probably be obscured by variations in streams and weather conditions that affect the anglers' ability to catch them.

NATURE OF THE FISHERY

Using the previously described models, the historical runoff data, and arbitrary downward adjustment for steelhead production in dry and critical years, we estimate that the mean annual catch of salmon produced by the project will be 1,852 salmon and 397 steelhead (Table 15).

Table 15. Mean annual spawning runs and catch of salmon and steelhead predicted as a result of operating the Soulajule Project as proposed.

Summer flow in cfs	Frequency percent of years	SALMON		STEELHEAD	
		spawners	catch	spawners	catch
5	63%	897	2691	681	477
2	11%	301	903	600	400
0.5	26%	73	220	300	200
	weighted mean	617	1852	565	397

Salmon produced by similar spawning runs in other California coastal streams are caught primarily in the ocean by both sport and commercial fishermen and in the lower ends of spawning streams by anglers as they congregate and migrate up to the spawning grounds.

Silver salmon headed for Walker Creek will congregate in Tomales Bay during the late summer and fall and we expect the sport catch to be proportionately higher than on many streams. Sport fishermen took from 6 to 42 percent of the total catch of hatchery-reared silver salmon marked and planted in several North Coast streams during the late 1950s and early 1960s (Jensen, 1971). It is reasonable to expect about 40 percent of the total catch to occur in the sport fishery at it did on the Mad River and the South Fork Eel River where angling is popular and public access easy.

Steelhead will be caught almost exclusively in the tidewater reach of Walker Creek as they gather and migrate upstream to spawn in the late winter and early spring. We assume that Walker Creek above tidewater will be closed to salmon and steelhead during the fall and winter, as spawning area, and during other times of the year to protect the young-of-the-year, yearling, and older steelhead that are being reared there and have not yet migrated downstream.

VALUE OF THE FISHERY

Assigning dollar values to fisheries damaged or enhanced by environmental change provides useful criteria for planning. Usually recreational fisheries are assessed a certain value per angler-day and commercial fisheries the current wholesale price per pound landed. The techniques, the values, and the philosophy of such assessments are all controversial and it is beyond the scope of this report to argue them.

We believe it reasonable to assume that 60 percent of the salmon catch produced by reproduction in Walker Creek will be taken by ocean commercial fishermen, almost all of whom will be California fishermen fishing off the California coast. Our estimate, based upon the previously described models, is that on the average 1,111 additional salmon will be caught in that fishery each year because of the project. Silver salmon landed by commercial fishermen in the San Francisco area weigh, when dressed and with head on, 9.12 pounds each (Heiman and Frey) and now bring the fishermen about $1.00 per pound. Using these data, we estimate that the Walker Creek Project will increase the value of California ocean salmon landings by about $10,000 per year.

Evaluation of the sport fishery is more difficult. We estimate that, on the average, 741 more silver salmon will be caught by anglers in the ocean, in Tomales Bay, or in the estuary of Walker Creek below Highway 1. The California ocean salmon catch rate for a long time has been about one fish per angler-day. The salmon fishery will support about 741 more angler-days because of the project.

On the average, 397 steelhead will be caught from Walker Creek below Highway 1. The steelhead catch rate is unlikely to be more than 0.2 fish per angler-day. The mean catch in the Sacramento River during 1964-65 was, for instance, 0.19 fish per angler-day (Van Woert, 1966). At this rate, 1,985 angler-days of steelhead angling will be created by the project.

The value of an angler-day of salmon or steelhead fishing depends on the assessor (Table 16). Depending upon which set of figures used, the Soulajule Project will increase the value of the salmon sport fishery by from $6,669 to $20,748 and create a new steelhead fishery worth from $13,398 to $39,700 per year.

Estimates of total values of the salmon and steelhead fisheries enhancement by the Soulajule Project range from about $30,000 to $70,000 per year, depending on the figures used to assess the value of a day's angling..

These estimates are for the fish produced by the project alone and do not include the values of those that would be produced by supplemental stocking.

Table 16. Economic net values of an angler day of sport fishing for salmon and steelhead.

Assessor	Ocean fishing for salmon	steelhead
California Department of Fish and Game (Jones 1968)	$ 9	$6.75-8.25
Washington Dept. of Fisheries (Mathews and Brown 1970)	$28	
Oregon Game Commission (Brown, Singh and Richards 1972)		$20
U.S. Fish & Wildlife Service (1972)[1]	$16.10	$16.10

[1] The 1970 values have here been multiplied by 1.5 to account for inflation.

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