State of California
The Resources Agency

Department of Fish and Game

Instream Flow Requirements
Anadromous Salmonids Spawning and Rearing
LAGUNITAS CREEK, Marin County

STREAM EVALUATION REPORT 86-2

APRIL 1986

IFIM study site near Tocaloma at about 35 cfs.

IFIM study site near Gallager Ranch at about 22 cfs.

ERRATA

Page i Author Gary E. Smith[2]

Page 2 Paragraph 2, 14th line to Syncaris, it seems probable that the proposed summer and early

Page 32 Recommendations, 3.a., first line If Nacasio Reservoir inflow during the preceeding month is

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Department of Fish and Game
Stream Evaluation Report
Report No. 86-2

Instream Flow Requirements, Anadromous Salmonids Spawning and Rearing, Lagunitas Creek, Marin County

April, 1986

Gordon K. Van Vleck
Secretary for Resources
The Resources Agency

George Deukmejian
Governor
State of California

Jack C. Parnell
Director
Department of
Fish and Game

Instream Flow Requirements, Anadromous Salmonids Spawning and Rearing Lagunitas Creek, Marin County, I/

By Gary E. Smith [2]

Abstract

The Instream Flow Incremental Methodology was used to assess steelhead and coho salmon spawning and rearing streamflow/habitat relationships and requirements in Lagunitas Creek, Marin County, California. The annual flow regime developed considers individual species life stage needs. Approximately 37% of the average annual runoff is identified as being needed for spawning and rearing purposes. Typically, natural summer flows need augmentation and natural winter flows more than meet fishery needs.

1_/ Stream Evaluation Report No. 86-2, April 1986. Stream Evaluation Program.

2/ Environmental Services Division, Sacramento, California

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FOREWORD

California's waterways historically provided substantial habitats for numerous and diverse fish and wildlife resources. With the state's settlement and development, however, demands for various offstream water uses and hydroelectric power generation have generally conflicted with habitat needs and requirements of indigenous resources. Consequently, many of California's resources and habitats have experienced significant losses. These losses have been particularly acute for steelhead (Salmo gairdneri gairdneri) and salmon (Oncorhynchus spp.). Steelhead, coho salmon (O. kisutch) and king salmon (O. tshawytscha) are important, indigenous fisheries in California. These species support a large and popular anadromous sport fishery. In addition, coho and king salmon support a substantial commercial fishery. Unfortunately, these important resources are experiencing a decline in abundance and in capacity to naturally propagate. California Department of Fish and Game and U.S. Fish and Wildlife Service studies show that 95% of California's historic steelhead and salmon habitat has been lost (Fisher 1979). In response to this habitat loss, steelhead and salmon populations have dwindled to only 20% and 35-40%, respectively, of their historic numbers (Anon. 1982; Fisher 1979).

The importance of the State's steelhead and salmon resources has been clearly affirmed by the California Legislature and Governor (Anon. 1982). By overwhelming bipartisan vote, the Legislature has enacted and the Governor has signed a number of bills authorizing and funding an unprecedented foundation for steelhead and salmon resource restoration and enhancement during the next 2 decades. Included in this foundation are the Forest Improvement Act, Forest Resources Development Fund, Renewable Resources Investment Fund, Geothermal Resources Fund, and the Energy Resources Fund.

The California Fish and Game Commission and the California Resources Agency recognize steelhead and salmon as valuable resources with strict environmental requirements and limited ranges (Anon. 1982; Anon. 1985). It is the Fish and Game Commission's policy to provide vigorous and healthy steelhead and salmon populations. The policy emphasizes that steelhead management shall be directed toward maintaining vigorous and healthy steelhead populations by maintaining adequate breeding stocks, suitable spawning areas, and by providing natural rearing of young fish to migratory size. Habitat maintenance, restoration, and improvement are also emphasized. Further, this policy mandates the Department of Fish and Game to develop and implement such programs by measuring and, wherever possible, by increasing steelhead abundance. Protection is to be provided by assessing habitat status and adverse impacts and by alleviating those aspects of projects, development, or activities which would, or already do, adversely impact steelhead habitat or steelhead populations.

In recognition of the value and losses of steelhead and salmon resources and habitats, the Resources Agency has developed a set of long range goals to aid in restoration of these species (Anon. 1982). These goals include increasing steelhead and salmon spawning populations by 300,000, increasing the fishery catch by 600,000 fish, and reestablishing 500 miles of historic spawning and nursery areas.

In view of the value of the State's steelhead and salmon resources and of the above mandates and policies, clearly the Department of Fish and Game is mandated to make every effort to effectively manage, maintain, and wherever possible, restore these valuable anadromous resources. Nowhere is the implementation of this effort more critical than in California's coastal streams and rivers. Water development, urbanization, and other activities have drastically depleted these resources and habitats, particularly in the southern portion of their range. Lagunitas Creek, Marin County, falls into the depleted category. This creek once supported substantial runs of steelhead and coho salmon. Water projects and other factors have contributed to the fishery's virtual demise, and today, only remnant runs remain. Thus, the Department developed the objective to restore the Lagunitas Creek steelhead and salmon resources and habitats. This report presents the results of the Department's assessment of steelhead trout and coho salmon spawning and rearing streamflow needs in Lagunitas Creek.

INTRODUCTION

Lagunitas Creek, Marin County, California (Figure 1), supports several important aquatic resources. These resources have been adversely affected by settlement and development of the watershed. The stream once supported a significant steelhead trout and coho salmon spawning escapement and fishery. A railroad track paralleled much of the stream, and in the 1900's, special trains would bring anglers from the San Francisco Bay Area to fish for juvenile and adult steelhead and salmon. Today, the railroad is gone and the fishery is greatly reduced. Steelhead and coho salmon escapements are substantially reduced and necessary protective regulations have limited the fishery to a short segment of stream upstream from the creek's mouth.

In addition to remnant steelhead and salmon populations, Lagunitas Creek also supports one of the two truly viable populations of <u>Syncaris pacifica,</u> the endangered California freshwater shrimp. The status and life cycle requirements of this species are not clearly understood. However, it appears that this species may be suffering the same fate as the steelhead and salmon.

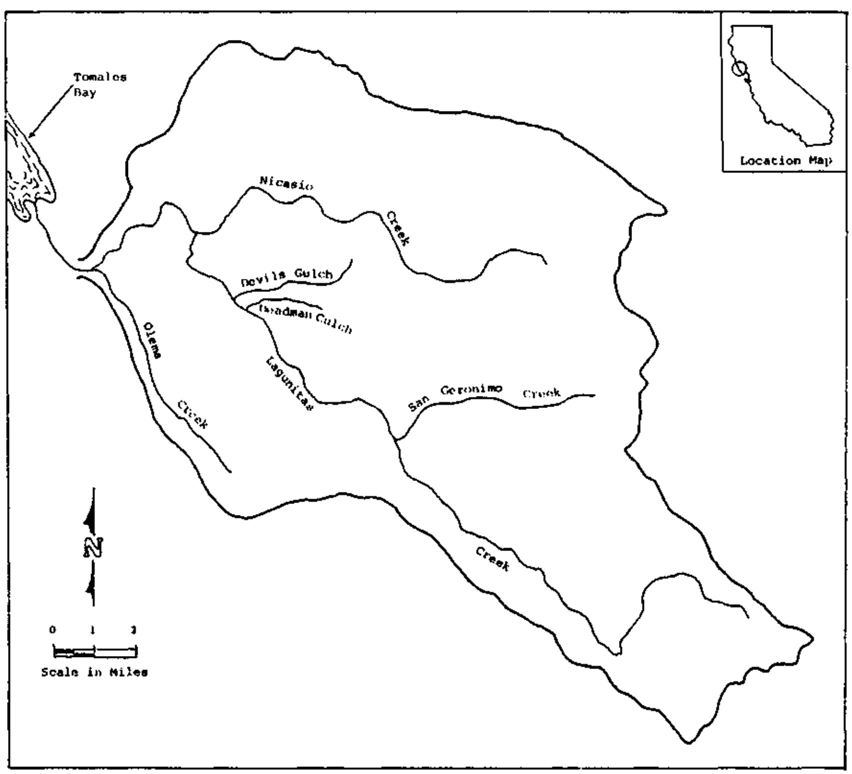


FIGURE 1. Lagunitas Creek watershed, Marin County, California.

The current condition of Lagunitas Creek has been brought about by a variety of factors. Significant portions of the relatively unstable watershed have been disturbed by grazing, urban development, and road construction. As a result, substantial amounts of sediments have been eroded from the surrounding hills and carried into the stream and its tributaries. This is particularly evident in San Geronimo Creek. This 9.2-square mile watershed contributes some 700 tons of sediment per year per square mile to Lagunitas Creek approximately 13.4 miles upstream from Tomales Bay (Esmaili and Associates 1979). In addition to agricultural and urban development within the watershed, the Marin Municipal Water District (MMWD) has constructed several water projects and diversion facilities on Lagunitas Creek and Nicasio Creek, a major tributary (Figure 2). These facilities and resultant out-of-basin diversions for municipal and industrial purposes in eastern Marin County have significantly reduced discharge in Lagunitas Creek, degrading the aquatic habitat and compounding watershed/stream sedimentation problems. Typically, the projects have reduced downstream flow volume and freshet frequency and duration. Hence, Lagunitas Creek has insufficient flow to cleanse itself. Consequently, pools have become filled with sediments and riffles have become embedded with fine materials. Reduced flows and increased sediments have adversely affected steelhead and coho salmon spawning and rearing habitats, and have contributed to the reduction in the salmonid population and fishery the stream system once supported.

Although MMWD diverts substantial amounts of water from the Lagunitas Creek drainage, its ability to provide sufficient water to meet all the needs within its service area is limited. In 1973, a moratorium on new water connections was declared. Even with the moratorium, MMWD was unable to meet its needs when California experienced a severe drought during 1976-77. Subsequently, an emergency pipeline was constructed across the Richmond-San Rafael Bridge to transport California State Water Project water to eastern Marin County.

MMWD's predrought net safe yield was estimated at 30,000 acre feet annually (AFA), and the drought reinforced the need for MMWD to develop more reliable water supplies. MMWD proposed to increase the capacity of Kent Reservoir, an existing facility on Lagunitas Creek, by raising the spillway crest of the dam from 355 to 400 ft (mean sea level). Holding capacity would increase 96% or from 16,700 to 32,900 acre feet (AF). Existing permits authorized MMWD to store 24,600 AFA at Peters Dam - State Water Resources Control Board Water Rights (SWRCB) applications 9892 and 14278. Thus, the enlarged reservoir would enable MMWD to store the remaining 7,900 AFA authorized by existing permits and to store an additional 8,300 AFA. Subsequently, MMWD filed Application 26242 with the SWRCB for a water right to store the additional volume.

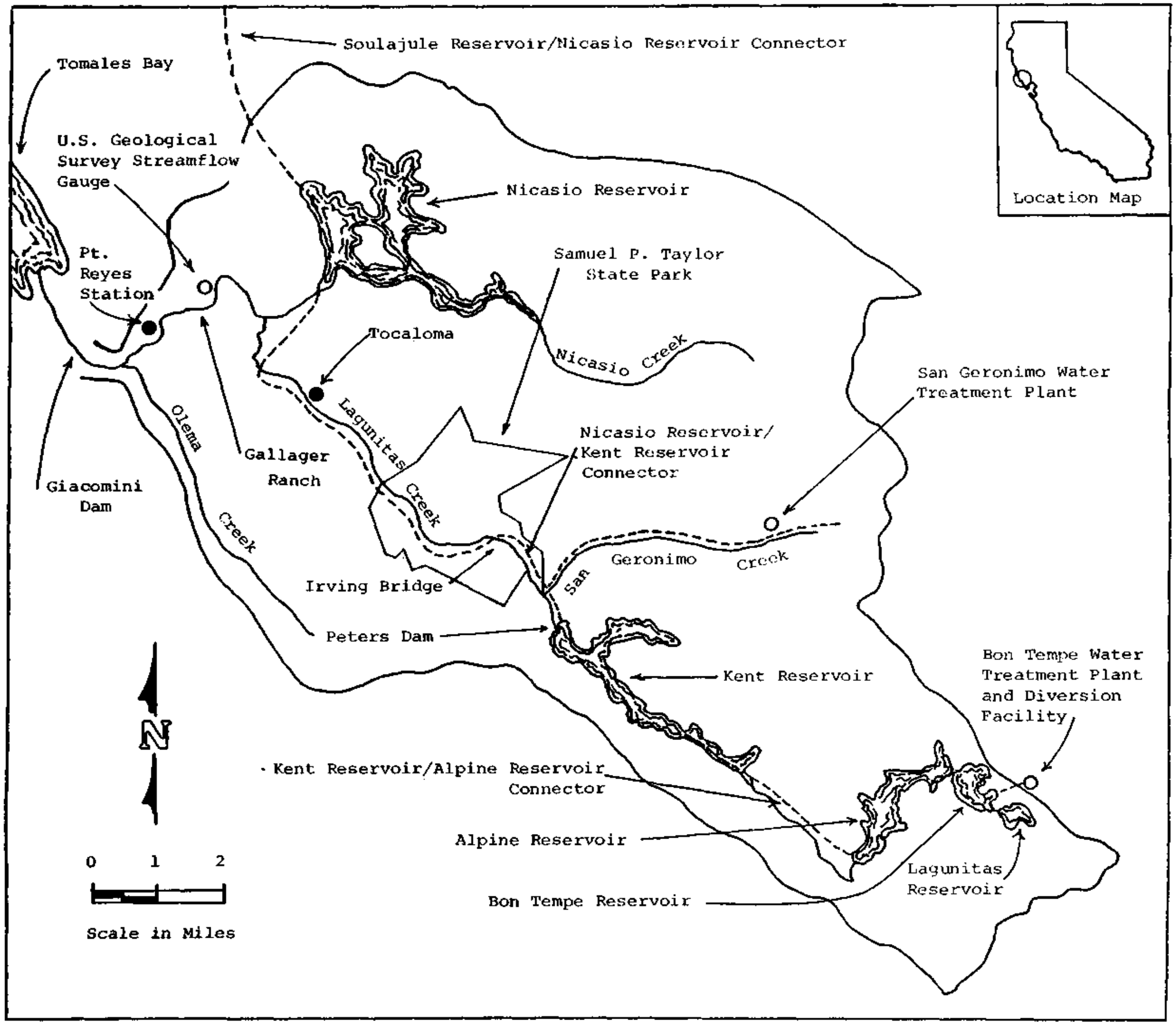


Figure 2. Water projects and diversion facilities and urban development within the Lagunitas Creek watershed.

In response to the application to appropriate more Lagunitas Creek water and to export it out of basin, the decision was made to identify environmental problems downstream of Peters Dam (i.e. Kent Reservoir), to develop measures to reduce the erosion/sedimentation problem, and to identify flow regimes which would restore Lagunitas Creek's steelhead and coho salmon resources and habitats. This report presents information on spawning and rearing streamflow needs of the anadromous salmonid resources downstream from Kent reservoir to the tidal estuary. The Department of Fish and Game (DFG) conducted the investigation in 1982 and used the Instream Flow Incremental Methodology (IFIM) to assess the fish habitat/streamflow relationship, and to develop a flow regime which would lead to restoration of the anadromous resource.

DESCRIPTION OF STUDY AREA

Drainage Description

Lagunitas Creek is located in the coastal mountains of northern California, about 20 miles north of San Francisco. The creek begins on the northern slopes of Mt. Tamalpais (2,600 ft elevation) and flows in a northerly direction for about 25 stream miles (SM), entering the Pacific Ocean at the southern end of Tomales Bay near the village of Point Reyes Station. In its upper reaches, Lagunitas Creek flows through a fairly narrow and steep canyon bordered by an evergreen forest. Downstream of the settlement of Tocaloma, the canyon widens and deposition of alluvial terraces noticeably increases.

The original Peters Dam spillway was at an elevation of 355 ft and streambed elevation at the base of the dam is 200 ft (Table 1, Figure 3). The stream descends relatively rapidly to an elevation of about 160 ft near its confluence with San Geronimo Creek about 2,275 ft downstream from Peters Dam (a gradient of about 2%). Downstream from San Geronimo Creek to about Nicasio Creek, the gradient is less steep, and from Nicasio Creek to tidal influence, the gradient is considerably less than in upstream areas. Downstream from San Geronimo Creek, gradient averages about 0.2%.

TABLE 1. Peters Dam and Kent Reservoir physical characteristics Lagunitas Creek, California.*

	Streambed elevation (ft)	Spillway elevation (ft)	Reservoir capacity (AF)	Reservoir system net safe yield (AF)
Original dam	200	355	16,700	21,400
Post-expansion enlarged dam	200	400	32,900	26,800

* Data source: CH2M-Hill (1982).

Several major tributaries comprise the 103-square mile Lagunitas Creek watershed. Olema Creek enters Lagunitas Creek near its confluence with Tomales Bay (SM 1.8) and comprises 20 square miles of the total watershed. Nicasio Creek, a major tributary, enters Lagunitas Creek at SM 6.2 and has a 36-square mile drainage. Devil's Gulch and Deadman Gulch, considerably smaller tributaries, have a total watershed area of about 5 square miles and join Lagunitas Creek near SM 10.3. San Geronimo Creek, the major upper watershed tributary, has a 9.2-square mile drainage and enters Lagunitas Creek at about SM 13.1. Lagunitas Creek drainage upstream of the confluence with San Geronimo Creek consists of about 22 square miles.

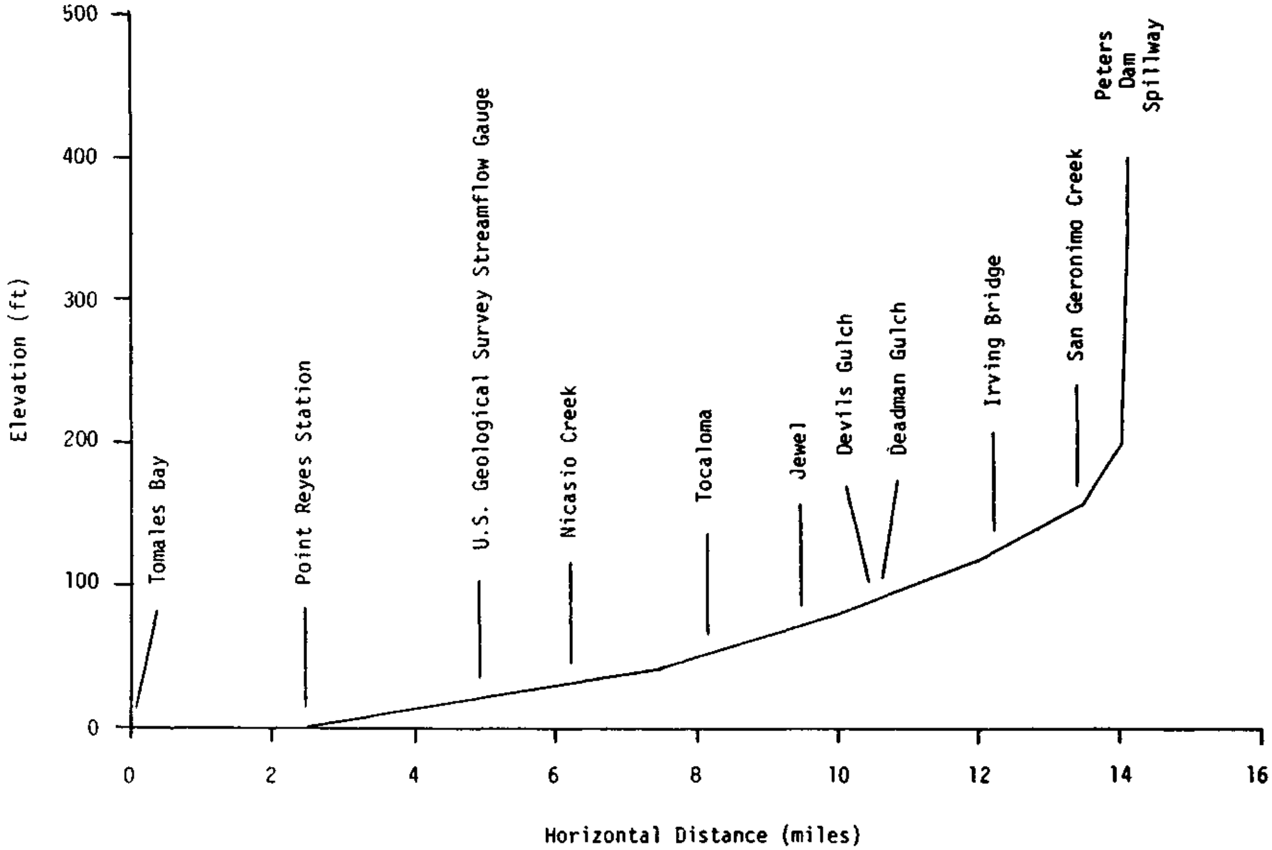


FIGURE 3. Lagunitas Creek longitudinal profile downstream of Peters Dam.

Land Use and Development

Land use and development within the Lagunitas Creek watershed includes substantial open space recreation within Samuel P. Taylor State Park and the Golden Gate National Recreation Area, water project development, agriculture, watershed wildlands, and moderately dense development. Most residential development within the basin is concentrated in the San Geronimo Creek drainage (the villages of Lagunitas, Forest Knolls, San Geronimo, and Woodacre) and at Point Reyes Station near Tomales Bay. Developments range from single family homes to more extensive developments. Water needs within the Lagunitas Creek drainage are fulfilled by MMWD, North Marin County Water District, direct diversion from the system, and/or from private groundwater/ underflow wells (Table 2).

TABLE 2. Water diversions within the Lagunitas Creek Basin, excluding Marin Municipal Water District diversions, Marin County, California.*

Current diverters	Yearly average (cfs)	May through October average (cfs)	Maximum monthly average (cfs)
Lagunitas Creek			
Del Ganado Ranch	0.08	0.15	0.23
Gallagher Ranch	0.08	0.17	0.24
Genazzi	0.15	0.24	0.33
Giacomini	—	2.67	2.67
North Marin County Water District	1.67	1.67	1.67
Zanardi	<0.01	0.01	<0.01
Misc. Diverters	0.01	0.02	0.02
Lagunitas Creek Tributaries			
Hermann	0.05	0.09	0.13
Olema	0.05	0.07	0.07
Fink	<0.01	0.01	<0.01
Pack	0.02	0.04	0.06
McIssac	0.09	0.11	0.13
Samuel P. Taylor State Park	0.03	0.04	0.04

* Data source: CH2M-Hill (1982) and State Water Resources Control Board.

There are five MMWD dams and reservoirs in the Lagunitas Creek basin, one on Nicasio Creek and four on upper Lagunitas Creek. Approximately 56% of the total watershed lies upstream of these projects. Nicasio Dam is located on Nicasio Creek about 1 mile upstream from the confluence with Lagunitas Creek. The 22,400 AF reservoir was constructed in 1961 and has a 36-square mile drainage. Kent Reservoir at SM 14.1 was constructed on Lagunitas Creek in 1954 with a 16,700 AF capacity. After enlargement, capacity increased to 32,900 AF. Twenty-two square miles of watershed are upstream of Peters Dam. Alpine, Bon Tempe, and Lagunitas reservoirs are upstream of Kent Reservoir and were constructed in 1918, 1948, and 1873, respectively. These three reservoirs have a total capacity of 13,590 AF. All of MMWD's reservoirs and appurtenant facilities within the basin are connected by a complex system of pumps and pipelines, enabling MMWD to transfer water from facility to facility and to eastern Marin County. In addition, MMWD is also able to transport water from Soulajule Reservoir on Walker Creek, a tributary to Tomales Bay, to its facilities within the Lagunitas Creek basin.

In addition to MMWD's permanent dams, a local dairy rancher installs a summer dam (referred to as Giacomini Dam) near Tomales Bay each year to provide a small reservoir to irrigate adjacent pasture land.

Wastewater disposal includes domestic waste disposal to treatment plants or septic systems, and agricultural wastewater runoff from agriculture/dairy lands.

Climate

Lagunitas Creek's climate is typically cool with moderately wet winters and temperate, dry summers (Lehre 1974). Nearly all precipitation in the basin occurs as rainfall. Mean annual precipitation averages 25-30 inches at sea level and increases to 50-55 inches near 2,000 ft. Most precipitation (85-90%) occurs between November 1 and May 1, typically peaking in December and January. Summer air temperatures along the coast are cool due to the cooling influence of ocean and summer fog. Temperatures increase inland.

Geology

The Lagunitas Creek basin is largely underlain by Franciscan graywackes, sandstones, shales, greenstones, and serpentinites (Esmaili and Associates 1979). Soils and slopes in the watershed have variable erodibility. Esmaili and Associates (1979) provide more extensive information on the watershed's erosion and resultant stream sedimentation problems.

Hydrology

Streamflow in Lagunitas Creek typifies many coastal California streams, high winter flows and low summer flows, and variable annual discharges. Although most flow occurs in the winter, stream discharge tends to be somewhat flashy and generally reflects precipitation patterns, raising rapidly with rainfall and rapidly receeding to a lower level after rainfall ceases.

From 1974 to October 1983, mean monthly discharge at the U.S. Geological Survey streamflow gauge near Point Reyes Station ranged from 162 AF in September to 19,071 AF in February (Table 3, Figure 4) (U.S. Geological Survey 1974-1983). Total annual discharge for this 9-year period (excluding water exports) ranged from 1,836 AF to 196,690 AF and averaged 72,861 AF. Although this period is relatively short, it is unique since it includes the driest (1976-77) and wettest (1982-83) water years on record. Furthermore, it also includes the period (October 1974 to September 1978) used by CH2M-Hill (1982) to develop a project net safe yield analysis for an enlarged Kent Reservoir.

Even though predevelopment flow data are not available, it is possible to synthesize a pre- and post-development unimpaired mean monthly flow regime based on the relationship between recorded runoff in Lagunitas Creek and in other streams for the period of record. From this relationship, MMWD staff developed a mathematical model which estimates unimpaired monthly discharge

TABLE 3. Lagunitas Creek mean monthly streamflow at the U.S. Geological Survey streamflow gauge near Point Reyes Station, California, October 1974 through September 1983.*

Water	Mean monthly discharge (AF)												
year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total
1974-75	205	169	1,030	837	15,420	31,280	3,280	505	283	211	207	180	56,607
1975-76	321	219	171	146	496	705	652	124	68	109	91	121	3,223
1976-77	12	80	93	556	195	455	94	41	27	109	107	67	18,36
1977-78	20	3.380	4,100	22,660	25,920	18,380	6,900	647		153	187	137	82,770
1978-79	94	135	146	8,910	17,320	7,760	1,710	540	173	201	174	158	37,321
1979-80	472	1,630	11,020	32,280	35,690	10,710	2,370	720	140	123	151	129	95,435
1980-81	169	124	596	8,580	1,750	7,290	782	215	109	142	190	127	20,074
1981-82	216	3,380	20,250	60,960	22,810	25,550	31,610	854	427	304	227	193	166,781
1982-83	533	10,530	16.680	650	52,040	68,180	8,680	5,310	841	534	365	347	196,690
Mean	227	2,183	6,020	18,398	19,071	18,923	6,231	995	252	210	189	162	72,861

* Data source: U.S. Geological Survey streamflow reports, 1974-1983.

in the Lagunitas Creek system upstream of Peters Dam. When tested, the model accurately predicted October through May monthly discharges, but tended to overestimate June through September (i.e., low-flow months) discharges (Dana Roxon, MMWD, pers. comm.). Hence, MMWD developed the following correction (i.e., multiplication) factors: June, 0.60; July, 0.40; August, 0.30; September, 0.75, to modify model predictions and obtain more accurate estimates of low-flow month discharges. Summary of the adjusted estimated unimpaired inflow data indicates that runoff at Peters Dam for water year 1928 to 1983 was highly variable, with monthly discharge ranging from 1 to 25,939 AF (Table 4). The mean annual discharge was also highly variable, ranging from 3,716 AF in 1976-77 to 78,223 AF in 1982-83 and averaging 33,772 AF.

To construct an unimpaired flow regime downstream of Peters Dam, estimated un-impaired runoff data are

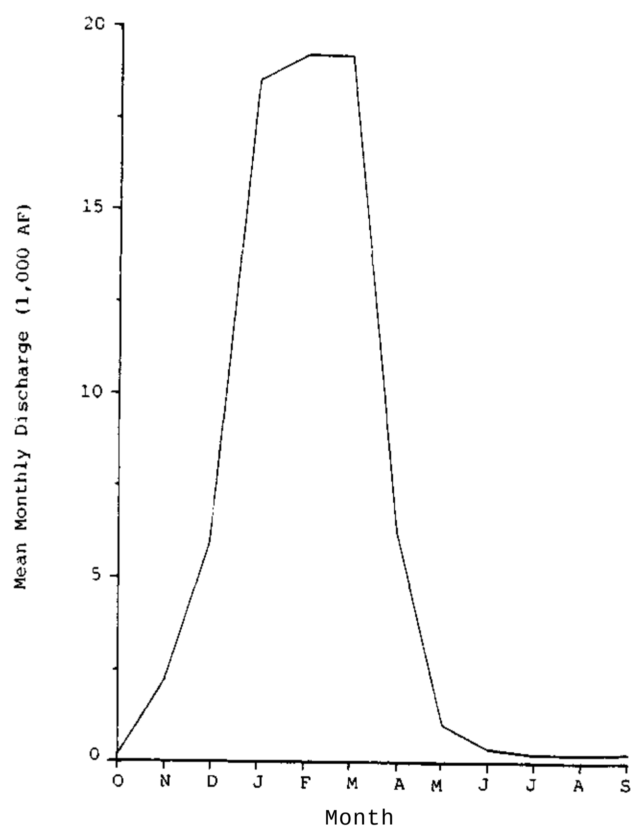


FIGURE 4. Lagunitas Creek mean monthly discharge at the U.S. Geological Survey streamflow gauge near Point Reyes Station, October 1974 through September 1983.

TABLE 4. Estimated unimpaired mean monthly inflow into Lagunitas Creek upstream of Peters Dam, September 1927 through October 1983.*

Water Year	Mean monthly flow (AF)												Year
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	
1927-28+	1,357	1,765	5,200	9,550	6,007	2,453	3,323	867	299	172	96	131	31,220
1928-29	833	1,082	3,188	5,855	3,683	2,354	2,038	532	248	134	72	87	20,160
1929-30	188	501	9,805	6,622	5,303	5,816	1,098	933	452	216	154	200	31,288
1930-31	329	586	624	1,566	960	1,365	968	841	386	193	135	163	8,116
1931-32	193	396	10,679	5,613	3,754	1,083	921	886	455	252	145	145	24,522
1932-33	232	523	2,236	4,043	1,470	2,471	1,171	927	394	223	157	174	14,021
1933-34	231	520	3,231	3,733	2,610	1,583	924	745	392	222	156	173	14,520
1934-35	212	1,069	962	9,360	1,572	9,038	8,709	1,737	493	204	143	159	33,659
1935-36	212	646	834	6,016	17,466	3,472	3,362	971	508	204	143	158	33,992
1936-37	215	480	1,230	978	11,364	9,258	2,950	978	443	208	145	161	28,410
1937-38	203	876	7,689	4,524	18,824	14,486	4,612	1,472	513	195	137	152	53,683
1938-39	329	784	900	1,079	711	1,497	901	665	532	238	167	185	7,977
1939-40	169	391	431	9,072	16,507	13,461	4,073	973	505	295	196	284	46,357
1940-41	349	638	10,793	15,162	11,839	9,719	12,292	1,559	515	306	209	379	63,760
1941-42	397	681	9,867	10,630	15,667	4,078	7,301	1,958	527	306	202	312	51,926
1942-43	393	976	3,438	13,955	4,273	4,704	1,793	970	499	296	193	252	31,742
1943-44	300	608	888	1,009	6,655	7,877	1,098	937	502	286	189	242	20,591
1944-45	350	1,006	1,668	1,977	10,397	5,507	1,948	983	485	286	185	290	25,082
1945-46	416	1,707	14,449	5,335	1,855	1,853	1,674	900	451	257	172	216	29,285
1946-47	329	932	1,880	877	4,017	4,971	1,846	908	468	245	174	182	16,829
1947-48	621	785	797	2,243	900	3,388	7,573	2,479	575	312	204	289	20,166
1948-49	346	653	1,085	1,269	3,673	12,041	1,454	929	431	267	185	227	22,560
1949-50	276	538	728	6,831	9,934	3,399	1,913	939	454	247	172	224	25,655
1950-51	485	2,976	12,805	10,964	5,337	4,140	1,024	964	458	268	176	262	39,859
1951-52	365	949	10,509	16,221	8,536	8,087	1,752	906	448	263	176	269	48,481
1952-53	296	620	12,880	17,113	1,746	4,017	2,433	1,437	510	274	184	294	21,807
1953-54	467	889	843	9,004	9,037	6,395	6,039	1,022	482	260	179	263	34,880
1954-55	154	1,225	3,418	4,944	1,316	737	2,729	764	125	61	77	70	15,620
1955-56	206	860	25,939	9,360	8,661	2,918	2,038	1,828	297	245	169	270	62,791
1956-57	721	409	549	1,670	6,168	6,666	1,504	4,705	712	307	184	555	24,150
1957-58	3,038	1,231	4,211	15,407	25,677	7,209	10,943	942	749	147	98	34	69,686
1958-59	1	337	556	3,101	6,218	1,209	488	89	40	123	58	490	12,709
1959-60	83	234	169	3,183	11,440	7,765	1,089	412	70	202	9	1	24,956
1960-61	273	611	976	2,165	4,364	5,564	1,178	521	98	261	50	147	16,208
1961-62	224	479	1,642	2,176	12,428	5,874	691	522	172	298	166	64	24,736
1962-63	5,938	593	5,782	6,503	9,154	4,472	9,946	1,514	429	212	187	209	44,939
1963-64	279	3,290	783	4,870	755	976	159	285	234	1	1	49	11,680
1964-65	270	1,688	11,036	10,364	2,283	2,090	7,402	879	359	246	64	141	36,819
1965-66	252	802	1,771	11,085	6,464	2,574	754	374	221	1	67	218	24,582
1966-67	172	3,820	8,239	33,021	3,327	5,316	9,170	1,802	2,185	218	187	114	67,571
1967-68	190	555	954	3,760	6,475	4,742	586	341	101	107	125	154	18,090
1968-69	614	1,461	10,557	19,284	14,562	4,158	1,725	396	190	157	64	258	53,426
1969-70	647	411	11,558	36,097	4,625	4,155	593	288	145	160	77	111	58,867
1970-71	267	4,588	15,136	6,258	1,403	3,775	1,230	715	175	1	43	55	33,645
1971-72	110	335	3,182	1,805	3,652	1,032	1,087	282	104	6	I	123	11,718
1972-73	1,503	7,970	6,205	32,272	13,929	8,599	1,480	491	138	28	1	107	72,722
1973-74	59	16,078	9,513	16,280	4,787	15,501	8,621	682	132	543	86	55	72,871
1974-75	353	307	1,338	1,970	12,491	10,578	2,676	810	279	86	15	43	30,946
1975-76	847	822	737	316	927	1,485	1,020	92	I	86	67	141	6,540
1976-77	49	306	227	1,280	367	580	153	107	25	1	1	620	3,714
1977-78	28	3,078	5,893	12,743	10,628	101,142	4,118	776	235	43	71	307	48,620
1978-79	55	516	218	6,719	6,849	3,557	1,080	928	200	101	301	289	20,813
1979-80	1,061	2,417	5,368	13,032	11,379	4,641	1,418	521	316	150	101	223	40,627
1980-81	229	263	410	3,739	1,092	5,711	765	174	278	214	226	122	13,234
1981-82	544	3,837	15,986	19,843	8,764	8,647	11,099	848	248	230	404	492	70,942
1982-83	808	7,813	7,014	8,093	18,829	27,272	4,167	3,071	526	376	141	113	78,223
Average	529	1,606	5,161	8,606	7,198	5,651	3,127	975	379	201	134	205	33,772

* Data source: Marin Municipal Water District.

+ Data from October 1927 through September 1954 are synthesized by Marin Municipal Water District.

increased by downstream accretion factors. These accretion factors, which were developed by CH2M-Hill, are based on tributary watershed area and, when applied (i.e., multiply) to reservoir runoff data, estimate discharge and, hence, incremental increases in flow at various locations between Peters Dam and Giacomini Dam. Application of the incremental accretion factors to data in Table 4 indicates that average annual runoff at the Taylor State Park streamflow gauge ranged from 5,497 AF to 115,770 AF and averaged 49,981 AF for water years 1928-83 (Table 5, Figure 5). Downstream of the confluence with Nicasio Creek, flows ranged from 6,607 AF to 230,017 AF and averaged 88,928 AF over the same 56-year period.

TABLE 5. Estimated unimpaired Lagunitas Creek mean monthly discharge at Peters Dam, Taylor State Park, Nicasio Creek, and Giacomini Dam, water years 1928-83.

Location	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total
Peters Dam	529	1,606	5,161	8,606	7,198	5,651	3,127	975	379	201	134	205	33,772
Taylor State Park	783	2,377	7,638	12,737	10,653	8,363	4,629	1,443	561	297	198	303	49,981
Nicasio Creek	1,091	3,667	13,806	23,902	20,162	14,815	7,632	1,943	778	416	329	387	88,928
Giacomini Dam	1,276	4,516	18,170	31,892	26,983	19,349	9,682	2,228	907	487	344	432	116,257

Fishery Resource

Lagunitas Creek once supported a substantial run of steelhead trout and an annual escapement of 3,000 to 5,000 coho salmon. The creek now supports significantly reduced numbers of these species. An unestimated number of steelhead and from few to about 400 coho enter the creek each year to spawn. Data presented by Emig (1985) and Kelley and Dettman (1980) suggest that relatively more steelhead than salmon enter the creek each year and/or that steelhead egg and fry survival is higher. Roach (*Hesperoleucus symmetricus*), sculpin (*Cottus asper* and/or *C. aleuticus*) threespine stickleback (*Gasterosteus aculeatus*), pacific lamprey (*Entosphenus tridentatus*), Sacramento sucker (*Catostomus occidentalis*), bluegill (*Lepomis macrochirus*), and the endangered California freshwater shrimp (*Syncaris pacifica*) are found in the stream.

Steelhead and coho salmon are anadromous members of the salmonid family. They spend their adult life in the ocean and return to freshwater to spawn. Adult steelhead generally enter freshwater between December and May (Figure 6). Coho salmon may enter freshwater as early as the season's first major runoff (generally in October or November) and may continue to enter the stream until late February. Both species spawn in gravel areas of the stream, generally at the tail of pools or the head of riffles, where water depth and velocity and substrate composition are suitable. Eggs are deposited in a series of depressions (i.e., redds) dug by the female adults, then covered with gravel. The eggs generally hatch between 80 and 120 days, depending upon water temperature. The newly-hatched fry remain in the gravel until the

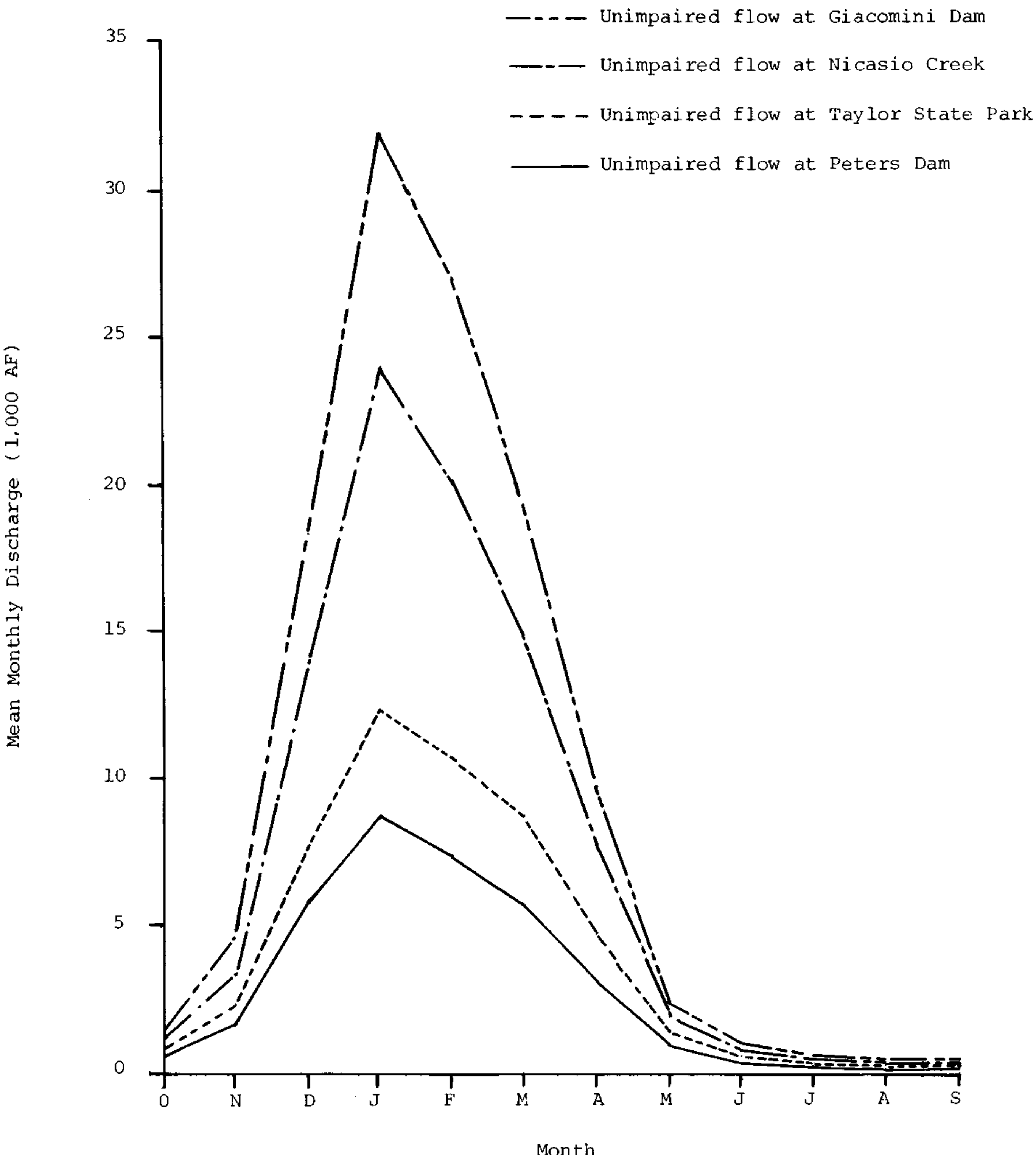
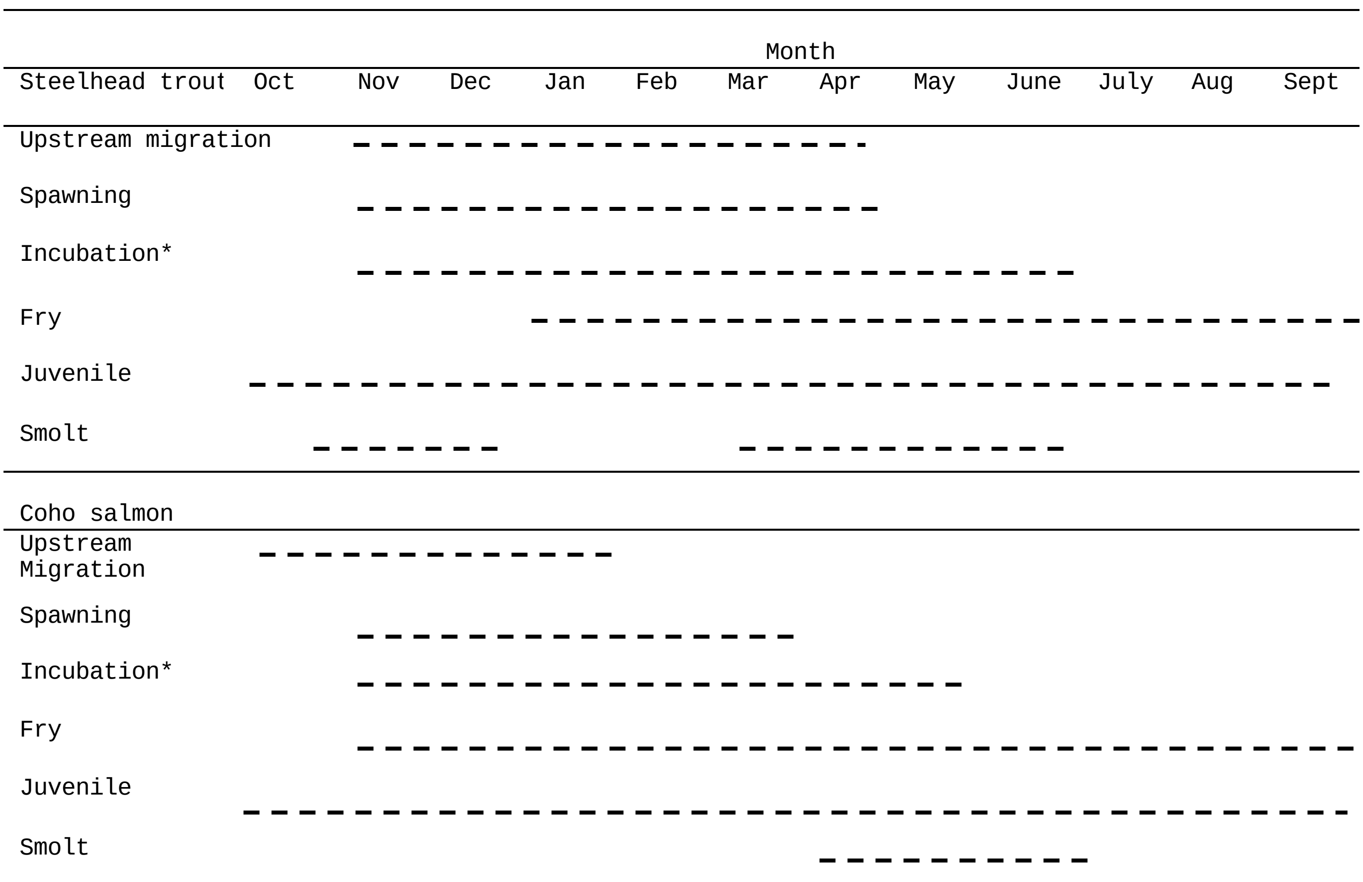


FIGURE 5. Estimated unimpaired Lagunitas Creek mean monthly streamflow at Peters Dam, Taylor State Park, Nicasio Creek, and Giacomini Dam.

yolk-sac is absorbed. Upon emerging from the gravels, fry typically move into riffles close to the spawning area. By fall/winter, the juveniles, as the young fish are now called, seek habitat more suited for their larger size (typically deeper water in downstream areas with abundant cover). The fish generally reach 5 to 7 inches before smolting (a physiological change preparing the fish for life in the sea) and migrating to the ocean. Young coho salmon normally leave their natal stream as 1+ fish. However, they may emigrate as 0+ fish due to the lack of "large fish habitat, or due to exceptionally rapid growth, which stimulates early smolting.

Survival rate from smolting to spawning is directly related to smolt size at emigration, the larger the smolt at migration, the greater its chances of survival. Thus, the more large fish habitat, the more large smolts, and, consequently, the more adults returning to spawn.



* Incubation includes the sac-fry lifestage.

FIGURE 6. Steelhead trout and coho salmon species periodicity

MATERIALS AND METHODS

The Instream Flow Incremental Methodology (IFIM) (Bovee and Milhous 1978; Milhous, Wegner, and Waddle 1981; Bovee 1982) was used to determine the steelhead and coho salmon habitat/stream discharge relationships in Lagunitas Creek, and to determine a flow regime which would maintain these resources. This methodology quantifies the effects of different stream flows on habitat for each target fish species life stage. The effects are expressed as changes in weighted usable fish habitat area per incremental change in stream discharge. It predicts the suitability of stream habitat for a given species and life stage as defined by combinations of water depth and velocity, substrate, and cover conditions at specific discharges.

Data requirements of the IFIM are specific. Briefly, it is necessary to stratify the stream under consideration into homogeneous segments and to select at least one stream reach (representative and/or critical) from each segment to model. Selected reaches are sampled by establishing a series of cross-sectional transects and measuring detailed hydraulic and physical characteristics. The resultant model simulates the hydraulic and physical characteristics of the stream under consideration. Two hydraulic simulation models are available within IFIM, IFG-4 and Water Surface Profile (WSP). IFG-4 requires hydraulic data (e.g., water depth, velocity, and discharge) for three or more discharges to develop a hydraulic simulation. WSP requires hydraulic data for only one discharge to develop the hydraulic simulation. WSP is normally usable only on low-gradient streams (less than 5%) whereas IFG-4 is more widely applicable. Once a calibrated hydraulic model (either an IFG-4 or WSP) is completed, an index of weighted usable area is developed. This index is based on the hydraulic and physical conditions predicted to be present at specific discharges, and on a particular fish species' preference (ranging from zero to one) for those predicted conditions. A flow regime is developed by comparing the amount of habitat available at specific flows for each species life stage of interest, and developing a discharge pattern which meets target species' overall needs.

Selection of Sample Reaches

Field inspection indicated Lagunitas Creek is comprised of four general and two atypical macrohabitat types. The four general habitat types are essentially distributed sequentially proceeding downstream from Peters Dam. The macrohabitat types do not differ markedly proceeding from one to another, but differences in gradient, channel shape, and substrate composition (particularly for non adjacent areas) indicated the areas should be sampled independently. The two atypical habitats (boulder outcroppings) comprise less than 1% of the total available habitat, and they were not sampled independently (Bovee 1982).

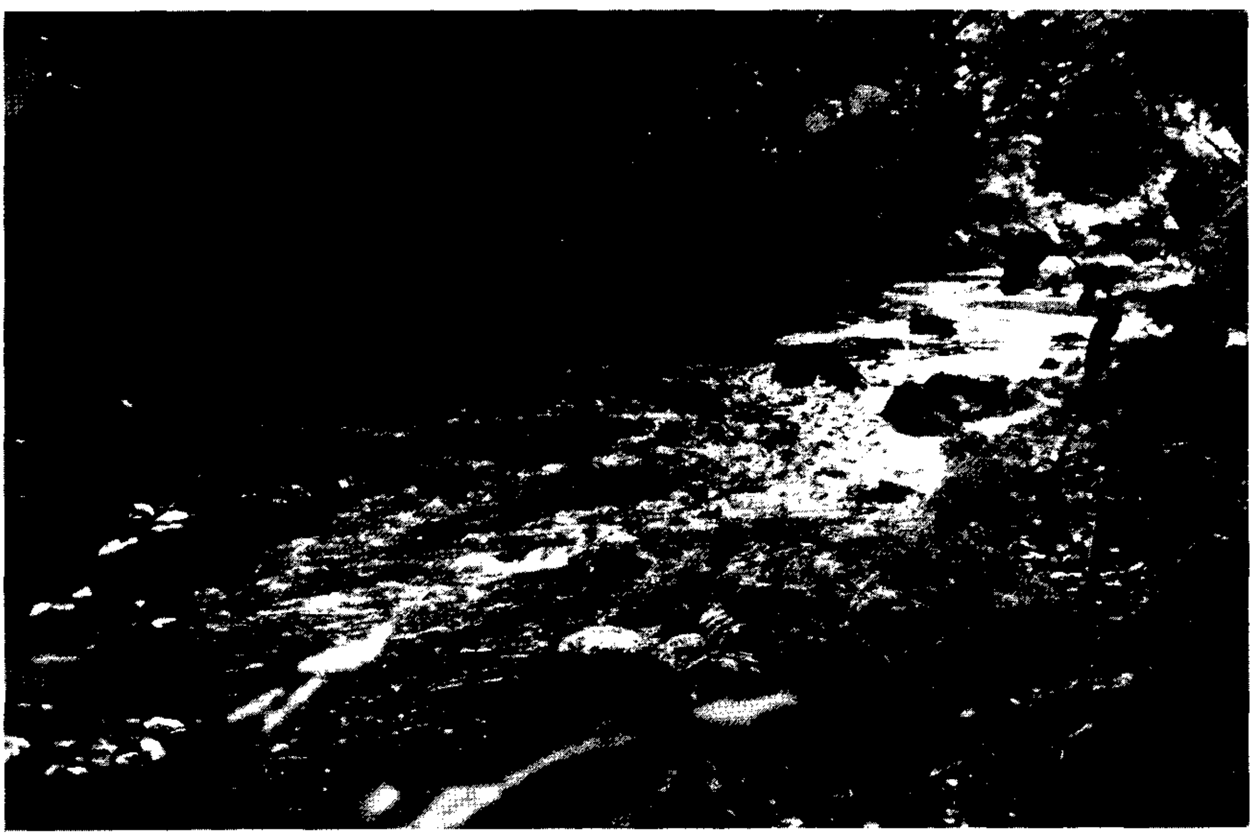
Each of the four general habitat types was divided into 500-ft intervals and three intervals were randomly selected from each as a potential area to select as a representative sample reach. Selected intervals were inspected in order of selection to determine if the area represented the general macrohabitat type. Upon acceptance of an area, a representative reach was established. Sample reach length was based on stream characteristics (i.e., pools, riffles, width, etc.) rather than on the 500-ft selection interval. Subsequent potential sample sites were not evaluated. Sample reaches selected for the instream flow analysis are:

Reach A, Irving Bridge: The sample location is located at SM 12.8 about 3,000 ft upstream from Irving Bridge on Sir Francis Drake highway. Long, slow-moving, shallow pools and short riffles generally comprise the reach. Substrate typically consists of 1-3-inch gravels; small to large cobble (3-12 inches); short areas of conglomerate and bedrock, and fines (i.e., silt and sand). Undercut banks and rootwads occur along the stream's margins. Riparian vegetation ranges from sparse to relatively abundant. Forest canopy covers virtually 100% of the study reach. The 414-ft reach represents 2.6 miles of stream.

Reach B, Samuel P. Taylor Park: This sample reach is located downstream of the entrance to Samuel P. Taylor State Park and upstream of Deadman Gulch at about SM 11.3. Aquatic habitat in this reach is similar to that in Reach A. However, there is a reduction in gradient and the shallow riffles tend to be longer and the pools not as deep as those in Reach A. Substrate in the 1- to 6-inch size range are abundant, and fines generally are reduced. Larger substrate materials are not abundant. Streamside vegetation is limited, but forest canopy covers virtually 100% of the reach. Few undercut banks and rootwads occur along the reach. A total of 5.9 miles of stream is represented by this 396-ft reach.

Reach C, Tocaloma: Reach C is located near Jewell at SM 9.3. It is typified by long, shallow pools and riffles and reduced gradient. Substrate tends to be smaller than that in Reach A and B and there are occasional gravel bars. Streambank vegetation is considerably more dense than along the upstream reaches. Canopy is less dense than along the upstream areas, but it still covers about 70-80% of the reach. The 576-ft reach represents 1.5 miles of stream.

Reach D, Gallager Ranch: The Gallager Ranch site is located at SM 4.6 and about 0.25 mile downstream from the U.S. Geological Survey streamflow gauge. The 1,119-ft reach represents 3.6 miles of stream. It is characterized by large, deep pools, few riffles, small substrate materials, dense riparian vegetation, and extensive canopy.



IFIM study site near Irving Bridge at about 22 cfs.

Data Collection

Cross-sectional transects were established to sample the various hydraulic and physical characteristics within each reach. Permanent stakes were placed at the ends of each transect to maintain transect integrity during the the investigation. Eleven transects were established in Reach A, 10 in Reach B, and 14 in Reach C and in Reach D. The number of cells per transect (i.e., partitions across each transect) in which hydraulic and physical characteristics were measure was dependent upon stream hydraulics and streambed morphology. Cell width seldom exceeded 1 ft in the waterway. Some wetted area cells were less than 1 ft, particularly along the stream's margin. Cell width never exceeded 2 ft. Transect and cell placement were pursuant to the methods described by Bovee and Milhous (1978) and Bovee (1982). Distance across each transect, between adjacent headstakes, thalweg distance between transects, and distance upstream and downstream represented by individual transects was determined to the nearest 1 ft.

Water depth and velocity were measured at stations (i.e., cell vertical) along each transect. Mean column water velocities were measured 0.6 of the distance down from the water surface if water depth was less than 2.5 ft and at 0.2 and 0.8 from the surface at depths greater than 2.5 ft. Two measurements were taken, regardless of depth, if swirling currents were present. A Teledyne Gurley flow meter (Model 622-F) was used on specific transects to determine stream reach discharge as well as cell velocities. Marsh-McBirney meters (Model 201) were used to measure all other transect cell velocities. Water velocities were measured to the nearest 0.01 ft/s with the Teledyne Gurley meter and to the nearest 0.05 ft/s with the Marsh-McBirney meters. Water depth was measured to the nearest 0.05 ft.

Depth and velocity data were collected for three discharges. Sample periods were in May (low flow), October (midflow), and November 1982 (high flow). One transect within each reach was selected to determine the actual discharge flowing through the reach during the sample period. Low discharges sampled ranged from 7.08 to 11.21 cfs middle discharges from 20.85 to 22.56 cfs and high discharges from 30.03 to 35.31 cfs (Table 6).

Transect water surface and headstake (i.e., the permanent stakes at the ends of each transect) elevations were determined at each discharge with a Lietz Model C3A Auto Level. All elevations were referenced to a benchmark within each study reach and were determined to the nearest 0.01 ft. Substrate elevations were referenced to these elevations.

Substrate composition and fish cover were assessed in each cell. Substrate assessment was based on a modified Brusven Index (Bovee 1982) (Table 7). Dominant and subdominant substrate materials were recorded for each cell in terms of percent abundance. Fish cover was divided into object and overhead cover. Object cover is defined as any obstruction which provides a break in stream

TABLE 6. Stream discharges measured during the Lagunitas Creek, Marin County, instream flow investigation, 1982.

Stream reach	Stream discharge (cfs)		
	Low	Medium	High
A	7.6	22.6	30.0
B	8.1	22.4	32.1
G	11.2	20.8	34.8
D	7.1	22.6	35.3

velocity for fish up to about 7 inches long. Overhead cover is defined as any object in or within 18 inches of the water surface which provides escape cover or protection from predation or sunlight. The presence of object and overhead cover was recorded by cell in quartiles (i.e., 1-25%, 26-50%, etc.).

Species life stage water depth and velocity and substrate habitat preference criteria for use in this investigation were determined in several ways. Steelhead fry habitat use criteria were determined from direct observations of habitat used by this life stage in Lagunitas Creek (Appendix A). Steelhead spawning and juvenile and coho salmon spawning and fry life stage habitat preferences criteria are from Bovee (1978). Insufficient numbers of these species life stages were observed during habitat use field investigations to determine site specific use criteria. Site or regionally specific habitat preference criteria are preferred for use in an IFIM analysis, but use of the general criteria included in Bovee (1978) is an acceptable alternative. However, these water depth and velocity preference curves are not conditioned by cover, but do include substrate preference. Juvenile coho salmon habitat criteria were unavailable for use during this investigation. Habitat preference criteria developed from observations of fish in Lagunitas Creek were determined specifically for use in this assessment, and do not necessarily apply to other drainages.

Procedural Evaluation

TABLE 7. Lagunitas Creek instream flow investigation substrate composition categories.

Description	Size (inches)
Fines/sand	<0. 16
Coarse sand/ Small gravel	0.16 _ 1.0
Medimum gravel	1.0 - 2.0
Large gravel	2.0 - 3.0
Small cobble	3.0 - 6.0
Medium cobble	6.0 - 9.0
Large cobble	9.0 - 12.0
Small boulder	12.0 - 24.0
Large boulder/ bedrock	>24.0

Water depth and velocity were measured at three discharges in each reach. An IFG-4 hydraulic simulation was developed for reaches A, B, and C. However, a water velocity meter malfunction prevented development of an IFG-4 simulation in Reach D. Therefore, the WSP model was used to generate the hydraulic simulation in Reach D. This latter model was highly calibrated using water surface elevation and discharge data measured for the two remaining discharges to provide an interpolation/extrapolation range similar to that generated by an IFG-4 simulation (Bovee 1982; R. Milhous, USFWS, per. comm.). A habitat time series was developed for Lagunitas Creek using procedures described by Milhous, Wegner, and Waddle (1981) and Bovee (1982) to develop a flow regime which would maintain or restore suitable habitat conditions.

No modifications were made to the measured hydraulic data to improve hydraulic model calibration. Modifications would have improved the hydraulic models to a minor degree (i.e., improved IFG-4 velocity adjustment factors and velocity prediction errors), but this improvement would be at the expense of habitat simulation (Ken Bovee, USFWS, pers. comm.). The IFG-4 model's velocity prediction errors and adjustment factors suggest that the effective interpretive range is essentially between 3 and 50 cfs. Within this range, more than 90% of the prediction errors and adjustment factors fall within the good and fair range. However, simulated flows from 1-90 cfs are included in this report solely for graphic purposes.

The fish habitat/flow relationship determined through the IFIM is in terms of square feet of weighted usable habitat per 1,000 ft of stream at a specific discharge. Since the four stream segments of Lagunitas Creek are not the same length, the habitat per linear distance indices developed for each sample reach were expanded by the total stream length represented to estimate total fish habitat within each stream segment at specific discharges. These estimates were then summed to provide estimates of total weighted usable habitat at specific discharges throughout Lagunitas Creek. Subsequent analyses are based on these latter values.

The IFIM assumes that a stream is in a state of dynamic equilibrium. If not, study results are applicable only until conditions change significantly. Lagunitas Creek experienced a series of severe winter storms and enormous discharges (up to about 22,100 cfs at the U.S. Geological Survey streamflow gauge) during January 1982. As a result, the creek appeared to experience a change in equilibrium.

High flows during the January 1982 storms eroded streambanks, disrupted riparian vegetation, and mobilized long standing instream sediment deposits. Subjective inspection of Lagunitas Creek during summer/fall 1982, however, indicated that although changes did occur, the overall impacts were not substantial. In general, the basic planometric features, although perhaps shifted, were not significantly altered; sediments flushed from the system by the storm's high flow were replaced by new materials; and disrupted riparian vegetation quickly became reestablished. Thus, although the character of the creek at specific sites may have been altered by the storms, the general micro- and macrohabitat characteristics of the stream remained basically unchanged. Consequently, IFIM data collected during the summer 1982 is applicable for assessing Lagunitas Creek's instream flow needs. Further, assessment results are applicable until such time in the future when the stream experiences a significant change in these characteristics.

IFIM study site in Samuel P. Taylor State Park at about 22 cfs (top) and 35 cfs (bottom).

RESULTS

Estimated weighted usable habitat for anadromous salmonids in Lagunitas Creek varies considerably with change in discharge. Typically, the anadromous salmonid available habitat slowly increases and then begins to rapidly increase as flow increases. After reaching maximum abundance, available habitat generally decreases as flow continues to increase. Rate of increase and curve inflection points usually are different for individual species life stages and in individual reaches. Thus, it is necessary to evaluate steelhead and coho salmon life stage instream flow needs simultaneously and to construct a flow regime which balances the needs of each the species' life stages.

Steelhead Trout

Available steelhead spawning habitat increases slowly in all reaches until discharge reaches 25 to 30 cfs (Table 8, Figure 7). As discharge increases above this level, spawning habitat in reaches A and C continues to increase slowly and then generally slowly decrease as discharge increases above 50 to 70 cfs. Spawning habitat in Reach B, however, increases rapidly after discharge reaches 40 cfs and then abruptly decrease at flows greater than 70 cfs. Spawning habitat in Reach D, however, generally decreases at discharges greater than 30 cfs. Total available spawning habitat is generally most abundant in Reach B. Reach C is intermediate in total habitat available, and reaches A and D generally contain lesser amounts of spawning habitat than the other two reaches.

Steelhead fry habitat increases much more rapidly at low flows than does spawning habitat. Maximum fry habitat occurs at flows ranging from 1-8 cfs. Reach A contains the most fry habitat at these flows, with the maximum habitat being available at 3 cfs. Fry habitat in reaches B and D is intermediate in abundance, and maximizes at 5 and 1 cfs, respectively. Fry habitat in Reach C is most abundant at 8 cfs.

The juvenile steelhead habitat/discharge relationship is similar to the steelhead spawning relationship. However, juvenile habitat increases much more rapidly at lower flows than does spawning habitat. Juvenile habitat is generally more abundant in Reach A than in the other reaches, with the most habitat occurring at 35 cfs. Reach B typically has nearly as much juvenile habitat as does Reach A, and most habitat occurs at nearly the same discharge (40 cfs). Juvenile habitat in the two downstream reaches essentially increases throughout the range of flows simulated, but less juvenile habitat occurs in these reaches at a given flow than occurs in the two upstream reaches.

TABLE 8 Steelhead trout habitat/stream discharge relationship, Lagunitas Creek

Flow (cfs)	Total spawning habitat (ft^2)				Total fry rearing habitat (ft^2)				Total juvenile rearing habitat (ft^2)			
	Reach A	Reach B	Reach C	Reach D	Reach A	Reach B	Reach C	Reach D	Reach A	Reach B	Reach C	Reach D
1	0	0	0	0	126,212	67,536	32,117	92,823	4,898	12,533	5,776	7,748
3	0	129	0	152	145,004	80,007	55,623	91,099	44,015	41,736	15,192	27,408
5	26	244	0	2,183	138,859	92,020	60,326	86,752	90,737	78,283	25,997	44,738
8	134	233	292	6,416	123,973	81,004	63,527	76,511	138,579	113,361	39,492	71,110
10	413	878	816	10,194	113,546	73,095	61,261	74,313	160,926	127,422	45,387	81,341
12	1,001	1,665	1,600	14,065	103,796	66,276	56,590	74,405	176,584	139,622	49,966	87,719
15	2,631	2,976	3,487	19,394	91,591	60,099	50,725	74,695	193,449	156,682	55,475	93,372
20	7,239	7,260	7,699	25,702	69,010	56,916	42,445	69,506	213,120	176,181	62,667	99,338
25	13,664	17,985	14,750	28,121	56,382	54,395	35,871	61,982	224,667	190,474	67,481	101,338
30	20,310	38,120	24,175	27,965	42,435	51,369	30,111	56,904	228,063	201,859	70,549	101,134
35	25,447	64,093	34,300	26,737	39,942	49,839	24,389	50,979	228,653	209,218	71,490	100,489
40	29,807	95,440	43,354	25,497	35,952	46,920	19,965	48,995	225,972	210,244	70,544	100,139
50	34,694	138,858	55,301	25,788	34,060	44,158	15,316	51,300	203,255	202,098	67,331	101,382
70	23,816	152,139	53,711	29,125	32,076	52,423	13,455	55,994	174,492	182,236	61,978	108,516
90	15,598	120,998	37,175	35,578	33,334	54,361	13,776	42,242	156,798	167,427	53,539	114,927

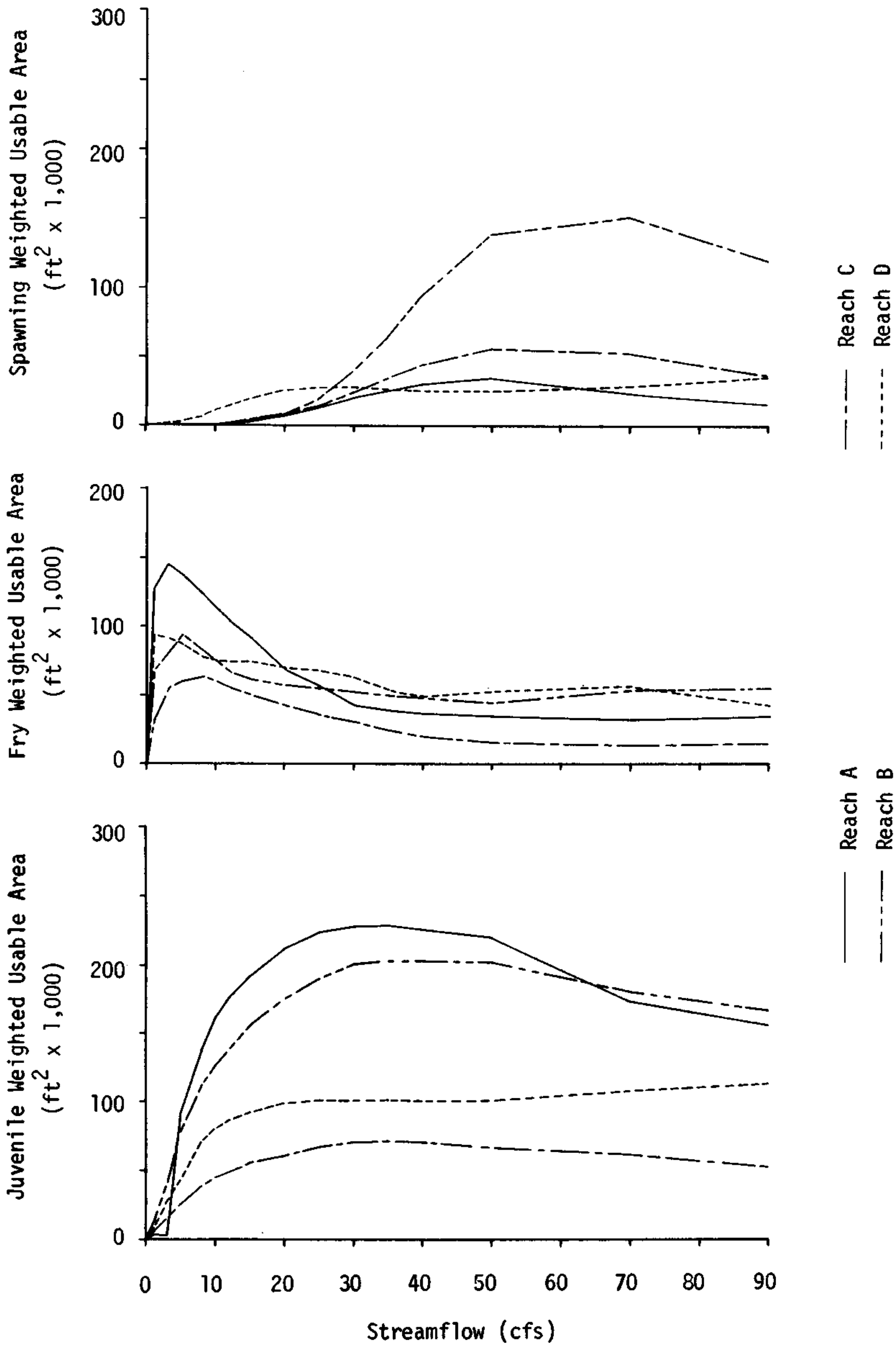


FIGURE 7. Steelhead trout habitat/streamflow relationship, Lagunitas Creek

Coho Salmon

Estimated available coho salmon spawning habitat increases more rapidly and maximizes at lower discharges than steelhead spawning habitat. Coho spawning habitat increases rapidly as discharge increases to 5 or 10 cfs, and reaches maximum availability at flows between 12 and 35 cfs (Table 9, Figure 8). Spawning habitat is generally considerably more abundant in Reach B than in the other three reaches, with the most habitat being available at 35 cfs. Reach C typically contains the next greatest amount of spawning habitat with the most being available at 35 cfs. Spawning habitat in reaches A and B generally is much less abundant than in two other reaches, and maximizes at much lower flows (20 and 12 cfs, respectively).

Available coho salmon fry habitat is most abundant in reaches B and D, with the most occurring in Reach D. Fry habitat in Reach D increases rapidly as discharge increases to 30 cfs and then decreases at higher flows. In Reach B, habitat increases rapidly as discharge increases to 15 cfs, decreases somewhat and then increases again as discharge exceeds 40 cfs. Available fry habitat in reach A and C essentially increases throughout the range of flows simulated. However, these reaches contain less fry habitat than is found in the other reaches.

TABLE 9. Coho salmon habitat/stream discharge relationship, Lagunitas Creek.

Flow (cfs)	Total spawning habitat (ft^2)				Total fry rearing habitat (ft^2)			
	Reach A	Reach B	Reach C	Reach	Reach A	Reach B	Reach	Reach D
1	0	0	596	699	469	13,873	1,656	8,301
3	351	448	1,974	16,310	3,325	19,925	3,814	15,879
5	9,903	6,072	5,343	25,493	8,077	37,639	6,983	27,293
8	8,103	22,996	14,044	34,137	15,886	58,531	12,886	52,871
10	12,704	38,649	22,196	39,029	19,763	63,125	16,390	69,405
12	16,927	57,183	32,707	40,486	23,104	67,317	18,886	82,569
15	20,732	99,769	45,268	38,725	26,296	69,982	21,389	101,383
20	24,707	170,274	64,469	34,688	29,048	66,760	23,378	127,582
25	23,440	217,379	85,562	30,860	30,388	65,386	24,399	143,364
30	20,762	244,199	97,064	27,347	31,842	65,048	24,151	143,522
35	18,838	260,124	97,564	25,106	33,033	61,982	22,868	138,549
40	17,841	250,805	92,091	25,524	35,620	62,334	21,719	131,688
50	11,241	200,611	75,516	29,682	39,540	66,965	20,782	117,004
70	8,011	111,858	60,665	36,538	42,592	83,442	23,145	98,168
90	4,193	63,878	46,069	35,909	61,763	94,293	26,187	83,118

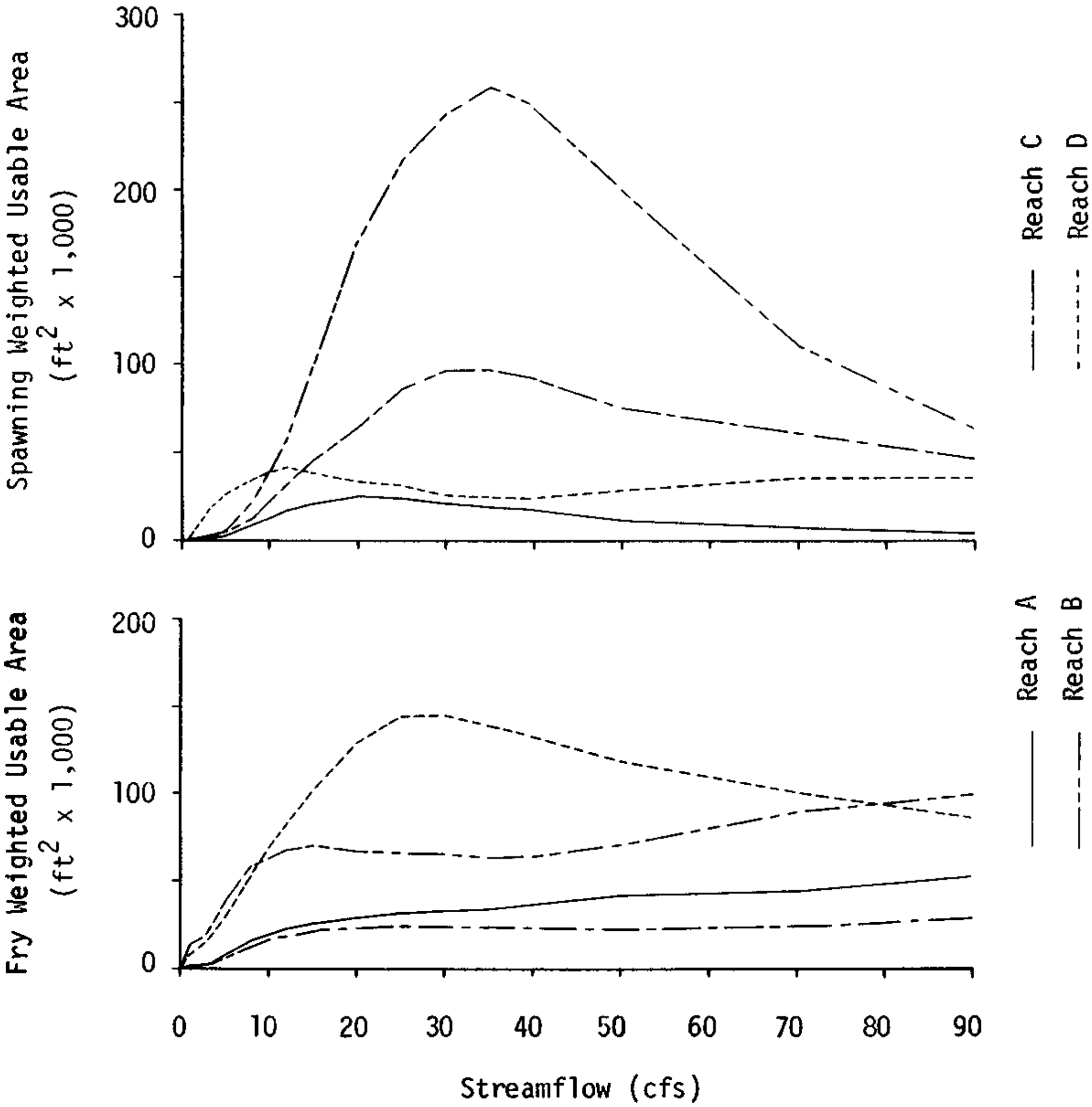


FIGURE 8. Coho salmon habitat/streamflow relationship, Lagunitas Creek.

DISCUSSION

When developing an IFIM habitat simulation model, it is necessary to balance the needs of target species life stages. There are three species of primary consideration in Lagunitas Creek, steelhead, coho salmon, and Syncaris pacifica. The IFIM model developed in this report considers steelhead trout and coho salmon spawning and rearing streamflow needs. The needs of Syncaris pacifica were not specifically addressed during model development.

Steelhead Trout and Coho Salmon

Lagunitas Creek supports two anadromous species of interest, and it is necessary to develop a flow regime which considers each species' needs. Although steelhead trout and coho salmon spawning periods overlap, these species generally do not enter the stream in great numbers at the same time on their spawning migration. Fry, juvenile, and smolt life stages, however, occur at nearly the same time. The following flow regime considers steelhead and coho salmon spawning and rearing needs. It does not, however, consider the needs for upstream or downstream migrations and sediment flushing flows. Migration needs are the subject of investigations being conducted by D.W. Kelley and Associates, and, once developed, should be included in the overall stream management plan.

Steelhead normally spend 1 to 3 years and coho salmon 1+ year in their natal stream before smolting and migrating to the ocean. Without adequate habitat for these large fish, maintenance of spawning and fry habitats without maintenance of juvenile habitat would not produce the expected number of returning adults. It seems certain that the factor limiting steelhead and coho salmon populations in Lagunitas Creek is the lack of adequate rearing areas for juveniles during summer and fall (Kelley 1978; Kelley and Dettman 1980). Thus, maintenance of juvenile habitat is crucial to the sustenance of both species, and any flow regime developed for Lagunitas Creek, must fully consider the juvenile life stage needs.

The hydraulic and physical habitat simulation results and predicted incremental increases in downstream flows indicate that discharges of 50 and 30 cfs at the Taylor Park gauge optimize steelhead and coho salmon spawning habitat, respectively, throughout Lagunitas Creek. Steelhead fry habitat is optimized at flows of about 5 cfs at the Park gauge and at somewhat higher flows in downstream areas. The coho salmon fry weighted usable area/discharge relationship, however, indicates that habitat for this species life stage is optimized at about 30 cfs. Juvenile steelhead habitat is optimized by flows of about 30-40 cfs at the Park gauge and is severely limited by flows in the 5 cfs range.

Over their range, adult coho salmon generally enter streams to spawn from September through March, with the major spawning taking place from November through January (Shapovalov and Taft 1954). The steelhead spawning season extends over a much longer period throughout its range than does coho spawning, but the bulk of the fish generally enter streams to spawn during winter and spring. All or even a majority of these species do not enter a stream at one time on their spawning migration. Typically, upstream migration is spread over an extended period and associated with storms. In Lagunitas Creek, adult coho typically migrate into Tomales Bay in late summer and early fall, assemble in the stream's 2.5 mile tidewater reach, and migrate upstream when major rains increase the flow; steelhead typically enter the stream during winter and early spring (Kelley 1978).

For this analysis, November 1 is assumed to coincide with the occurrence of the first major attraction flows (naturally or artificially induced) and, hence, the first major appearance of coho salmon on their upstream spawning migration. Since the fish may not spawn immediately after reaching suitable spawning areas, but may hold for some time, it is also assumed that spawning may take place at anytime after November 1. Although it is likely that there are periods when coho or steelhead are not actively spawning, and streamflow could be reduced to somewhat lower base level/incubation flows, it is impossible to predict the number of days and when they occur. Thus, to provide suitable habitat for coho salmon entering Lagunitas Creek, 30 cfs should be maintained in the creek beginning November 1. Adult steelhead may enter the stream as early as mid-December, and it is necessary to modify coho spawning flows to respond to steelhead habitat needs as well. Lagunitas Creek stream flow should be increased about 5 cfs December 15 and January 1, and and by about 10 cfs on January 15. Once attained, 50 cfs (optimum steelhead spawning flow) should be maintained in the stream until about March 15 since steelhead, like coho, may not spawn immediately after reaching suitable spawning areas. By mid-March, most steelhead usually have entered the stream and spawned. Although few steelhead may spawn after mid-March, streamflow should not be abruptly reduced, but should be incrementally reduced to provide late arriving fish suitable habitat and to avoid stranding recently deposited eggs.

Steelhead fry habitat is optimized at a flow of about 5 cfs. However, little juvenile steelhead (i.e., large fish) rearing habitat is available in Lagunitas Creek at 5 cfs. Maintaining large fish rearing habitat during low flow periods is critical to sustenance of the stream's steelhead and coho salmon populations. A summer streamflow of 10 cfs would substantially increase available large fish habitat with little reduction in available steelhead fry habitat. In addition, it would also substantially increase coho fry habitat. If 10 cfs rather than 5 cfs were maintained in Lagunitas Creek downstream of the confluence with San Geronimo Creek, juvenile steelhead habitat would increase 73% and coho fry habitat 111%. Steelhead fry habitat, however, would decrease only 15%. If expected average July, August, and September evapotranspiration and diversion losses and accretion gains occur (CH2M-H111 1982; Dana Roxon, MMWD, per. comm.), maintaining 10 rather than 5 cfs at the confluence with San Geronimo Creek would result in a 68% and 98% increase in juvenile steelhead and coho salmon fry habitat, respectively, and a 12% decrease in steelhead fry habitat. Increasing streamflow at San Geronimo Creek to more than 10 cfs during summer would increase juvenile steelhead and coho salmon fry habitat, but it would also begin to substantially decrease steelhead fry habitat. The relative benefit of maintaining either a 5 or 10 cfs flow in Lagunitas Creek on juvenile coho salmon habitat is unknown. However, in view of juvenile coho's general tendency to occupy pool habitat, it seems reasonable to conclude that 10 cfs would provide more available habitat for this species life stage than would 5 cfs. Thus, a summer flow of 10 cfs in Lagunitas Creek appears to balance the rearing life stage needs of both species. Beginning about October 1, streamflow should be increased to about 15 cfs. This would provide additional large fish habitat and provide a transitional period between summer rearing flows and fall/winter spawning flows.

Increasing streamflow to more than 10 cfs to accommodate coho salmon and/or steelhead spawning needs would be beneficial to juvenile steelhead. Juvenile steelhead rearing habitat would be about 45% more abundant at 30 cfs (coho salmon spawning flow) and about 38% more abundant at 50 cfs (steelhead spawning flow) than at it would be at 10 cfs.

The average percent increase in estimated juvenile salmonid rearing habitat determined using the IFIM is similar to the percent increase in the salmonid rearing index developed by Kelley and Dettman (1980). Kelley and Dettman developed salmonid rearing indices for Lagunitas Creek from San Geronimo Creek to Jewell and from Jewell downstream to Nicasio Creek. The rearing index regression equations developed by Kelley and Dettman indicate that the mean of the two indices increase about 92% as flow increases from 5 to 10 cfs. Juvenile steelhead rearing habitat estimated by the IFIM increases about 71% throughout the same *area* and over the same flow range.

Based on the species life stage habitat/streamflow relationships and integration of individual life stage needs, the flow regime presented in Table 10 provides substantial benefits to the Lagunitas Creeks steelhead and salmon resources. There would be a substantial increase in usable habitat over what was available prior to enlarging Kent Reservoir, and the steelhead and salmon resources should respond accordingly. Spawning and incubation habitat should be sufficient to fully seed the creek with fry, and, even though fry habitat would not be maximized by the flow regime, ample habitat is available and sufficient fry should survive to become juveniles and occupy the available large fish habitat.

TABLE 10. Streamflow regime for maintenance of steelhead trout and coho salmon resources, Lagunitas Creek.

Date	Streamflow (cfs)	Date	Streamflow (cfs)
Oct 1-Oct 31	15	Mar 16-Mar 31	40
Nov 1-Dec 15	30	Apr 1-Apr 30	30
Dec 16-Dec 31	35	May 1-May 31	15
Jan 1-Jan 15	40	June 1-June 30	12
Jan 16-Mar 15	50	July 1-Sept 30	10

Syncaris pacifica

Investigations by Li (1981) and observations by Dr. Larry Eng (DFG, pers. comm.) during post-drought years when populations were reduced, indicate that two stream characteristics, water depth and velocity, seem to be particularly important to Syncaris. Syncaris, particularly the younger life stages, are not strong swimmers and they are typically found in areas with no perceptible current (i.e., pools). In addition to depth and velocity characteristics, undercut banks, rootwads, and vegetation hanging into the water are also quite important. During high winter and spring flows, the shrimp are found only under submerged undercut banks where roots dangle into the water and provide cover from high velocities (Li 1981; Dr. Larry Eng, DFG, pers. comm.). During summer and fall low streamflows, Syncaris is associated with emergent and terrestrial vegetation which extends into the water (Hedgepeth 1968, 1975; Eng 1981). Hence, ideal Syncaris habitat generally consists of pools with no perceptible current (at least along their margins), undercut banks, emergent vegetation, and riparian vegetation hanging into the water near the stream[1]s margins.

Little is known regarding the full effects of discharge on Syncaris, and what flow regime would be most beneficial to the shrimp. Based on discharge/velocity relationships within a pool near the downstream end of Syncaris' distribution, D.W. Kelley and Associates (May 19, 1982 letter to MMWD) concluded that summer flows should not exceed 10 cfs unless there is evidence that doing so would not damage Syncaris. Fluctuating summer flows (especially reductions) would most assuredly be harmful to Syncaris (Dr. Larry Eng, DFG, pers. comm.). In addition to summer flow requirements, occasional high winter flows are needed to maintain undercut banks and pools for Syncaris habitat (Dr. Stacy Li and Dr. Eng, pers. comm.). Although it is impossible to fully determine if a summer flow of 10 cfs would be detrimental to Syncaris, it seems probable that the proposed summer and early fall flow regime would not be harmful (Dr. Li and Dr. Eng, pers. comm.). In addition, it also seems probable that the recommended October flows (i.e., 15 cfs) would provide an appropriate transition between summer and fall/winter flows.

Hydrology

The proposed flow regime totals 18,267 AFA at the Taylor State Park streamflow gauge. This is about 37% of the estimated unimpaired 1927-83 mean annual runoff. Review of water availability and instream flow needs indicates that typically there is substantial more inflow into Lagunitas Creek than is needed for fishery purposes from November through April (Figure 9). Over 91% (45,500 AF) of the average annual discharge occurs during this period. Over this 6-month period, fishery instream flow needs amount to about 13,884 AF. From May through October, however, instream flows typically need augmentation. For example, during average water years, instream requirements exceed natural inflow by some 797 AF from May through October.

Effective use of Nicasio Reservoir water would lessen demands on upper Lagunitas Creek water needed to meet the proposed flow regime. A 1960 agreement between MMWD and DFG provides for fishery releases up to 800 AF per month into Nicasio Creek from November through March. This amounts to a 4,000 AF block of water. Except for releases to attract upstream migrant coho salmon, these releases generally have not been requested or released. If this release commitment were transferred from Nicasio Reservoir to Kent Reservoir (including flows used to capture upstream migrant coho salmon), steelhead and coho salmon spawning flow needs in Lagunitas Creek would be partially met and demands on upper Lagunitas Creek water reduced.

Below average water years present special problems. Insufficient water is available during dry years to fully meet instream and offstream needs. Hence, it is necessary to develop dry year criteria. For purposes of this report, a dry year in the Lagunitas Creek watershed is defined as a water year which is 50% or less of the mean historical value. Under this criterion, 13 of the 56 years from 1927-28 to 1981-83 would have been classified as dry. Assessment of water year type and reservoir storage should occur continuously beginning January 1 with final determination made and concurred in by MMWD and DFG at the end of April each year. If it is determined that the preceeding monthly inflow into Kent, Alpine, Bon Tempe, and Lagunitas reservoirs from November 1 to May 1 is 50% of the mean monthly inflow for that month or if a dry year has occurred, and insufficient water is stored in MMWD's reservoirs to meet in- and offstream needs, the existing Nicasio Reservoir agreement should be implemented for Nicasio water (or water representing Nicasio water) released at Peters Dam, and Lagunitas Creek water releases (excluding water representing Nicasio water) should be reduced up to the same percentage reduction that MMWD reduces its service area deliveries. Such an approach, while not fully meeting steelhead and coho salmon needs in Lagunitas Creek during dry years, would equitably distribute available water supplies and ensure continuation of the fishery resources.

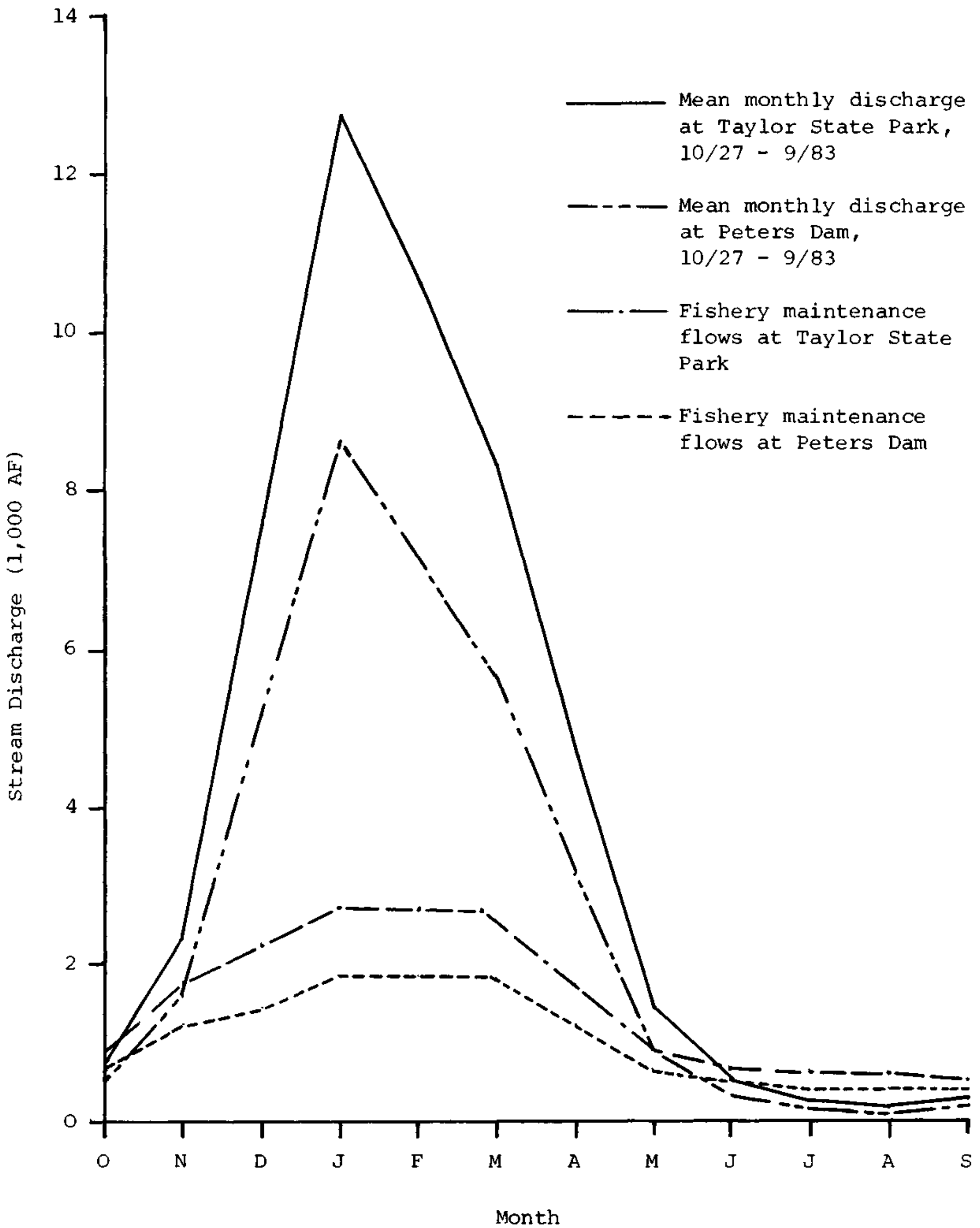


FIGURE 9. Mean monthly discharge (September 1927 - October 1983) and fishery maintenance flows at Peters Dam and Taylor State Park, Lagunitas Creek.

RECOMMENDATIONS

1. The following flow regime, measured at Taylor State Park, should be implemented:

Date	Number of Days	Discharge cfs	Discharge AF
Oct 1 - Oct 31	31	15	922
Nov 1 - Nov 30	30	30	2,678
Dec 1 - Dec 31	31	35	1,111
Jan 1 - Jan 15	15	40	1,190
Jan 16 - Mar 15	59	50	5,851
Mar 16 - Mar 31	16	40	1,269
Apr 1 - Apr 30	30	30	1,785
May 1 - May 31	31	15	922
June 1 - June 30	30	12	714
July 1 - Sept 30	92	10	1,825
Total			18,267

2. The 800 AF per month Nicasio Reservoir release requirement from November through March (totaling 4,000 AF) be transferred to, and replaced by, Kent Reservoir water and the release occur at Peters Dam. Other features of the 1960 MMWD-DFG Nicasio Reservoir Agreement be maintained intact.

3. In the event of a dry year (defined as a water year which is 50% or less of the average water year for the period of record determined mutually by MMWD and DFG on April 1 of each year), the following dry year criteria be implemented and continued until the dry year criterion is exceeded:

   a. If Nicasio Reservoir inflow during the proceeding month is less than 50% of the average inflow for that month, the release volume requirement at Peters Dam may be reduced to 600 AF per month. All other provisions of the 1960 Nicasio Reservoir Agreement remain intact.

   b. Lagunitas Creek water (excluding Nicasio Reservoir water or water representing Nicasio Reservoir water) released from Kent Reservoir for fishery management purposes may be reduced by the same percentage that MMWD reduces its service area deliveries. Flow reductions shall be mutually agreed upon by MMWD and DFG at the beginning of each month as long as the dry year conditions exists. Declaration of a water shortage emergency shall not void this criterion.

4. In the event a monthly inflow into Kent, Alpine, Bon Tempe, and Lagunitas reservoirs (between November 1 and May 1) is 50% of the mean monthly inflow for that month, the following criteria may be implemented and continue until the dry year criterion for an individual month is exceeded:

   a. The 1960 Nicasio Reservoir agreement between MMWD and DFG is implemented (see item 3 above).

   b. Releases of Lagunitas Creek water (excluding Nicasio Reservoir water or any water representing Nicasio water) may be reduced by same percentage that MMWD reduces its service area deliveries. Flow reductions shall be mutually agreed upon by MMWD and DFG at the beginning of each month as long as the monthly inflow dry conditions exists. Declaration of a water shortage emergency shall not void this criterion.

5. Syncaris pacifica life stage habitat requirements and the discharge/velocity relationship be evaluated throughout the shrimp's distribution in the Lagunitas Creek watershed.

6. Downstream and upstream anadromous salmon migration be evaluated and the recommended flow regime modified accordingly.

7. A watershed erosion and stream sediment transport/sediment flushing study be conducted on Lagunitas Creek and a program implemented to flush sediments from the Lagunitas Creek.

8. Efforts to curtail watershed erosion be continued.

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APPENDIX A

TABLE A-l. Steelhead trout habitat use criteria used for the Lagunitas Creek, California, instream flow investigation.

SPAWNING CRITERIA*

Water velocity (ft/sec)	Habitat suitability criteria	Water depth (ft)	Habitat suitability criteria	Substrate	Habitat suitability criteria
0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.40	0.00	1.00	0.00
1.15	0.08	0.50	0.20	2.00	0.80
1.50	0.60	0.85	0.60	3.00	1.00
1.60	0.80	1.00	0.94	4.00	1.00
1.80	0.98	1.15	1.00	5.00	0.25
2.00	1.00	1.22	1.00	6.00	0.25
2.20	0.97	1.40	0.88	7.00	0.00
3.70	0.00	1.90	0.40		
		2.60	0.08		
		3.00	0.04		
		3.00	0.00		

* Criteria source: Bovee (1978)

FRY CRITERIA

Cover type	Water velocity (ft/sec)	Habitat suitability criteria	Water depth (ft)	Habitat suitability criteria
Object	0.00	0.57	0.00	0.00
	0.10	1.00	0.10	0.00
	0.40	1.00	0.20	1.00
	0.80	0.25	0.50	1.00
	1.10	0.12	0.60	0.37
	2.00	0.05	1.20	0.10
	3.00	0.00	1.90	0.05
			3.50	0.00
Overhead	0.00	0.57	0.00	0.00
	0.10	1.00	0.10	0.00
	0.40	1.00	0.20	1.00
	0.60	0.23	0.50	1.00
	1.00	0.05	0.60	0.37
	2.00	0.00	1.20	0.10
			1.90	0.05
			3.40	0.00
Overhead and Object	0.00	0.57	0.00	0.00
	0.10	1.00	0.10	0.00
	0.40	1.00	0.20	1.00
	0.80	0.25	0.50	1.00
	1.10	0.12	0.70	0.37
	2.00	0.05	1.20	0.12
	3.00	0.00	1.90	0.05
			3.00	0.04
			3.50	0.00

TABLE A-2. (Continued)

FRY CRITERIA

Cover type	Water velocity (ft/sec)	Habitat suitability criteria	Water depth (ft)	Habitat suitability criteria
No Cover	0.00	0.57	0.00	0.00
	0.10	1.00	0.30	1.00
	0.40	1.00	0.70	1.00
	0.60	0.23	0.90	1.00
	1.10	0.05	1.40	0.25
	2.00	0.00	1.80	0.13
			3.00	0.05
			3.50	0.00

JUVENILE CRITERIA*

Water velocity (ft/sec)	Habitat suitability criteria	Water depth (ft)	Habitat suitability criteria	Substrate	Habitat suitability criteria
0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.00	0.25	0.20	1.00	0.00
0.20	0.20	0.60	0.66	1.20	0.18
0.28	0.90	1.00	0.96	2.00	0.46
0.45	0.97	1.20	1.00	4.00	0.46
0.60	1.00	2.00	0.64	5.00	1.00
1.15	1.00	3.00	0.35	8.00	1.00
1.40	0.97	4.00	0.13	9.00	0.00
1.50	0.96	5.00	0.00		
2.30	0.40				
2.45	0.16				
3.00	0.04				
4.20	0.00				

*Data source: Bovee (1978)

TABLE A-2. Coho salmon habitat use criteria used for the Lagunitas Creek, California instream flow investigation.

SPAWNING CRITERIA*

Water velocity (ft/sec)	Habitat suitability criteria	Water depth (ft)	Habitat suitability criteria	Substrate	Habitat suitability criteria
0.00	0.00	0.00	0.00	0.00	0.00
0.40	0.00	0.20	0.00	1.20	0.00
0.68	0.20	0.35	0.18	2.00	1.00
0.85	0.40	0.45	0.86	4.00	1.00
0.90	0.65	0.50	0.97	5.00	0.00
0.95	0.80	0.64	1.00		
1.00	0.96	0.90	1.00		
1.05	0.98	0.95	0.96		
1.20	1.00	1.15	0.36		
1.40	1.00	1.60	0.15		
1.50	0.98	2.00	0.12		
2.20	0.34	2.35	0.05		
2.70	0.13	2.50	0.00		
3.10	0.00				

*Data source: Bovee (1978)

FRY CRITERIA*

Water velocity (ft/sec)	Habitat suitability criteria	Water depth (ft)	Habitat suitability criteria	Substrate	Habitat suitability criteria
0.00	0.04	0.00	0.00	0.00	0.00
0.18	0.20	0.40	0.00	1.00	0.00
0.30	0.80	1.00	0.24	1.20	0.02
0.50	1.00	1.40	0.96	1.40	0.04
0.55	1.00	1.70	1.00	2.00	1.00
0.60	0.98	2.05	1.00	4.00	1.00
0.80	0.40	2.10	0.98	5.00	0.59
1.00	0.27	2.30	0.86	7.00	0.59
2.00	0.10	3.70	0.45	8.00	0.24
2.40	0.00	4.10	0.20	9.00	0.15
		4.50	0.08	9.50	0.00
		5.10	0.00		

* Data source: Bovee (1978).

Lagunitas Creek after the January 1982 storms debris and sediments (top) and deepend pools and cleaned substrate.