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COUNTY OF SACRAMENTO

ANALYSIS OF RIVER FLOWS NECESSARY TO PROVIDE WATER TEMPERATURE REQUIREMENTS OF ANADROMOUS FISHERY RESOURCES OF THE LOWER AMERICAN RIVER

LOWER AMERICAN RIVER COURT REFERENCE

(EDF et al. v. EBMUD)

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EXHIBIT NO. 69-A

Analysis of River Flows Necessary to Provide Water Temperature Requirements of Anadromous Fishery Resources of the Lower American River

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Analysis of River Flows Necessary to Provide Water Temperature Requirements of Anadromous Fishery Resources of the Lower American River

Under current (post-Folsom) conditions, anadromous fish in the lower American River experience chronic temperature stress. The proposed diversion of water by East Bay Municipal Utility District (EBMUD) will exacerbate these already detrimental conditions.

1.0 Background

A major issue in this reference is the setting of adequate base flows to protect the existing fish resources of the lower American River. Many fish species occur in the river and three species in particular, chinook salmon (Onorhynchus tshawytscha), steelhead trout (Salmo gairdneri), and American shad (Alosa sapidissma), have significant recreational value. Chinook salmon stocks from the American River are also of commercial importance.

The economic and other effects of losses of these fish resources could be substantial. For example, the commercial fishery for chinook salmon adults originating from the lower American River currently is estimated to be worth over $9,000,000 annually. (Sacramento County Exhibit 8A.) And the economic and social costs of a damaged recreational fishery would be considerably higher than those resulting to the commercial fishery.

The various groups concerned with EBMUD's proposed diversion project have suggested a number of base flow

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regimes to protect the fish resources of the lower American River. These flows have been designed primarily to provide adequate habitat for chinook salmon.

Less attention has been directed toward steelhead trout and American shad, despite their importance. Similarly, until now, little research has been conducted to estimate stream flows required to maintain an adequate thermal regime in the lower American River. These are unfortunate oversights, because direct and indirect mortality resulting from thermal stress can have a significant adverse impact on the population size and recruitment rates of all three species. Chinook salmon, steelhead trout, and American shad all show various levels of intolerance to high water temperatures.

The effects of water temperature on fish survival can be measured by chronic thermal stress effects. These effects include increased metabolic activity, lowered resistance to disease, and reduced growth rates. While not immediately obvious, such chronic effects ultimately result in increased mortality. The effect of reduced growth rates, while not directly fatal in themselves, lower the competitive ability of the affected fish. Because recent research has suggested that significant intra-stock competition between anadromous juveniles may occur in the estuarine environment, high levels of thermal stress during the freshwater rearing stage could permanently lower adult stock size.

This report assesses the anticipated effects of reduced stream flows on the thermal conditions and fish resources of the lower American River. It is based upon the results of detailed water temperature simulations, and upon experimental testing of optimal thermal requirements for juvenile chinook salmon from the lower American River. The objectives of the report are to:

1) Describe the existing water temperature conditions in the lower American River affecting the three anadromous fish species of concern;

2) Establish the change in water temperatures anticipated to result from the base flows proposed by the State Water Resources Control Board (SWRCB) staff for the lower American River (i.e., 800 cfs from July 15 to October 14; 1250 cfs from October 15 to July 14) (SWRCB 1987); and,

3) Assess the likely water temperature related impacts upon the anadromous fish resources of the lower American River that would result from the SWRCB staff-proposed flows.

2.0 Life Stage Periodicities of Anadromous Fish in the Lower American River

In this study, only three species (chinook salmon, steelhead trout, American shad) have been analyzed in detail. This is due to their relative economic and recreational importance, and to their intolerance to thermal stress. All three species are anadromous (i.e., migrate to sea as juveniles and return to freshwater to spawn). The following section provides a brief description of the life history of each of the three species and identifies primary periods when the river is used. A summary of the periods of river use is provided in Table 2.1.

Table 2.1 Known Use of the Lower American River by Chinook Salmon, Steelhead Trout, and American Shad

CHINOOK SALMON	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Immigration/Spawning	X	X	X	X							X	X
Incubation/Emergence	X	X	X	X	X	X						
Rearing				X	X	X	X	X	X			
Emigration							X	X	X			
STEELHEAD TROUT												
Immigration/Spawning		X	X	X	X	X	X					
Incubation/Emergence			X	X	X	X	X	X	X			
Rearing	X	X	X	X	X	X	X	X	X	X	X	X
Emigration						X	X	X	X			
AMERICAN SHAD												
Immigration/Spawing							X	X	X	X		
Incubation/Emergence of Eggs							X	X	X	X		
Emigration of Eggs							X	X	X	X		

2.1 Chinook Salmon

Chinook salmon are the largest of the Pacific salmon species. They range from Point Hope, Alaska to the Ventura River in California. The major chinook salmon stocks in the continental U.S. originate from either the Sacramento River or Columbia River systems. The lower American River stock now consists only of fall run fish (i.e., fish that return to the river to spawn in the fall). The historic American River stock of spring run chinook salmon has been extirpated from the River as a result of dam construction and habitat degradation.

The peak timing of spawning by chinook salmon varies over their range. Most of the American River stock migrate into the American River from October to December to spawn. Eggs remain in gravel over winter, and emergence of fry, which depends upon time of spawning and water temperature, occurs primarily during the months of January and February.

Use of the American River by chinook salmon juveniles for rearing is known to occur from January through June. This rearing period is critical to the ultimate survival of juvenile chinook salmon in the estuarine environment. The rate of survival appears to be size dependent. Fish of three inches in length or greater show a higher survival rate. Thus, any factor which impairs growth rates such as high water temperature, can reduce survival.

From March through June, the majority of juvenile chinook salmon begin undergoing the physiological changes required for survival in a saltwater environment (smoltification), and migrate from the American River through the Sacramento River to the Delta.

2.2 Steelhead Trout

Steelhead trout are the anadromous form of the rainbow trout. Their distribution along the Pacific Coast extends from streams of the Santa Ynez Mountains, California to the Alaskan peninsula.

Adult steelhead trout return to spawn in the American River from early November through mid-March. No data are available on the timing of adult spawning or fry emergence of steelhead trout in the American River. Steelhead trout spawning is estimated to extend between December and April. Egg incubation through fry emergence is estimated to be completed by mid-June.

The length of time that juvenile steelhead trout remain in freshwater prior to beginning their emigration to the sea is variable. Juveniles are likely to remain in the river for at least one year. In more northern latitudes, steelhead trout tend to remain in their natal streams for at least a second year, and undergo smoltification during the spring of the following year. Juvenile steelhead trout are known to emigrate at different ages (i.e., as 1, 2 or 3 year old fish). Emigration occurs from March through June.

2.3 American Shad

American shad are not native to the Sacramento River system, having been introduced in 1871. Since their introduction, their range on the Pacific Coast has increased substantially, now extending from the Mexican border to Cook Inlet, Alaska.

Spawning migrations of American shad into the lower American River occur between April and July. In a normal water year, this migration probably peaks in June. Unlike salmon and trout, which lay their eggs in nests dug into stream gravel, shad spawn by broadcasting their eggs into open water. The eggs hatch about a week after spawning, and the larval fish drift passively downstream for the next 4 to 7 days as their yolk sac is absorbed. There is no evidence that the lower American River is used as a nursery area by juvenile American shad. Rearing likely occurs in the Delta area.

3.0 Water Temperature Requirements of Anadromous Fish in the Lower American River

Water temperature is a primary factor affecting growth and survival of fishes in the lower American River. The anadromous fish species of chinook salmon, steelhead trout, and American shad are intolerant of high water temperature and are thus susceptible to water temperature-associated problems in the lower American River. As water temperatures exceed the optimum range, an increasing physiological burden is placed on the fish. If this burden becomes too great, the fish die immediately (acute temperature stress) or at some time in the future (chronic temperature stress). Chronic temperature stress is important in determining how long a population survives in the lower American River. For a detailed discussion, see Appendix I.

For each life stage of chinook salmon, steelhead trout and American shad, there is an optimum water temperature range for growth and survival. Above the optimum water temperature range, the fish compensate physiologically by increasing their metabolic rate, or behaviorally by seeking cooler water. However, as discussed above, the degree to which the fish can compensate for higher water temperatures is limited.

A critical water temperature issue regarding fish resources in the lower American River has been the water temperatures required by juvenile chinook salmon for rearing and emigration. Growth rate at this life stage is critically important (see Appendix I). East Bay Municipal Utility District's fishery consultants recommended that water temperatures not exceed 65 F at the mouth of the lower American River during juvenile chinook salmon rearing and emigration (EBMUD Exhibits 17, 68). Sacramento County's fishery consultants recommended that until site specific studies had been conducted, a water temperature of 60 F should be used as a basis for flow recommendations during the juvenile chinook salmon rearing and emigration period in the lower American River (County Exhibits 12A, 23A, see also Appendix I).

To resolve this controversy, Sacramento County authorized a laboratory bioenergetics investigation, conducted by Dr. Alice Rich, to determine the optimum water temperature range and water temperature stress zones for juvenile chinook salmon. The results of this investigation were used to determine the optimal temperature range and temperature stress zones for juvenile chinook salmon in the lower American River (Appendix I).

In addition to rearing and emigration of juvenile chinook salmon, water temperature requirements for the remaining life stages of chinook salmon and the various life stages of steelhead trout and American shad also were assessed by Dr. Rich (Appendix II).

Optimum water temperature ranges and water temperature stress zones for the various life stages of chinook salmon, steelhead trout, and American shad are presented in Table 3.1. In addition to identifying water temperature ranges corresponding to the various life stages of the three fish species, some important conclusions about chinook salmon are:

1) The optimum water temperature range for juvenile chinook salmon in the lower American River definitely is no greater than 54-60 F and may be as low as 53-56 F. A water temperature of 65 F was classified as inducing chronic medium water temperature stress in juvenile chinook salmon under natural conditions in the lower American River;

2) Within the water temperature stress zone, the severity of stress increased with increasing water temperature; and,

3) Long-term exposure of juvenile chinook salmon to water temperature stress will likely reduce the population in the lower American River.

4.0 Lower American River Water Temperature Modeling

The lower American River was modeled to demonstrate how flow releases from Folsom and Nimbus Dams affect downstream water temperatures. A dynamic water quality simulation model, the model QUAL2E, was used to determine water temperatures downstream of Nimbus Dam under various flow conditions.

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Table 3.1 Optimum Water Temperature (°F) Ranges and Chronic Temperature Stress Zones for the Various Life Stages of Chinook Salmon, Steelhead Trout, and American Shad in the Lower American River (Source: Appendix II)

Species	Temperature Zone	LIFE STAGE: Immigration and Spawning	Embryo Incubation through Fry Emergence	Fry and Juvenile Rearing	Emigration and Smoltification
Chinook Salmon	Optimum	44 - 56	46 - 54	53 - 56	46 - 56
	Chronic Low Stress	56.1 - 61.9	54.1 - 61.3	56.1 - 63.4	56.1 - 63.4
	Chronic Medium Stress	62 - 65.7	61.4 - 65.5	63.5 - 67.6	63.5 - 67.6
	Chronic High Stress	greater than 65.7	greater than 65.5	greater than 67.6	greater than 67.6
Steelhead Trout	Optimum	46 - 52	48 - 52	55 - 60	44.4 - 52.3
	Chronic Low Stress	52.1 - 57.5	52.1 - 59	60.1 - 68	52.4 - 59.3
	Chronic Medium Stress	57.6 - 61	59.1 - 63	68.1 - 72.5	59.4 - 63.2
	Chronic High Stress	greater than 61	greater than 63	greater than 72.5	greater than 63.2
American Shad 1/	Optimum	61 - 65	61 - 65		

1/ The optimum temperature range for American shad immigration, spawning and embryo incubation was estimated to be 61 - 65 F. Temperature stress zones were not established for American shad due to insufficient data. The migration impairment threshold is 68°F.

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The model was calibrated using water temperature data recorded for the lower American River during 1986. The calibrated model was used to produce dynamic water temperature simulations from flows, boundary temperatures, and climatological conditions observed during the 1957 - 1986 period, the 30-year period since construction of Folsom and Nimbus Dams. Annual and monthly water temperature-exceedance and flow-duration curves were developed from the 30 years of daily temperatures and flows in the lower American River. A complete description of model use, calibration, verification, and results is presented in Appendix III.

Because water released from Folsom Reservoir during the warm months, April through October, is normally cooler than mean atmospheric equilibrium conditions, the water gradually warms as it flows downstream. Moreover, as flows naturally decrease during the warm months, water temperatures increase further with distance downstream due to the longer time of travel and exposure to atmospheric conditions and shallower depths associated with lower flows.

5.0 Effects of Increased Stream Temperatures on Chinook Salmon, Steelhead Trout and American Shad

The extent of impact of water temperatures greater than optimum on the lower American River fisheries resources will be a product of three factors. These are:

1) The frequency of water temperature events greater than upper optimum temperature;

2) The relative magnitude of these temperature events above upper optimum temperature; and

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3) The duration of each temperature event above the upper optimum.

The analysis carried out in this study examines the likely effects of these factors. It is clear that the SWRCB staff-proposed flow levels would increase the frequency, duration and magnitude of water temperature levels associated with chronic temperature stress. Though it is known that chronic temperature stress is harmful, the exact relation between duration of exposure and the degree of injury is unknown.

Only April through October flows were analyzed in detail in this study because water released from the Folsom Dam generally is at or above atmospheric equilibrium temperatures during the other periods of the year. Flows can exhibit a cooling effect only when below atmospheric equilibrium. It should also be noted that water temperature modeling results do not incorporate the reduction in cooling effect which would occur if only hypolimnetic waters (cold) were diverted. Water diversions would further reduce the overall cooling capacity of Folsom Reservoir. Therefore, the predictions of this report regarding change in thermal conditions resulting from increased water diversion are conservative.

5.1 Frequency of Water Temperature Events Resulting in Chronic Stress

Water temperatures above the upper optimum result in chronic temperature stress. Chronic temperature stress zones are identified in Table 3.1 and in Appendices I and II. The frequency of occurrence of high water temperatures was evaluated for post-Folsom flows and for the base flows recommended by the SWRCB staff. The upper optimum water temperature for each of the three fish species of concern was derived from values set by Dr. Rich (Table 3.1), and by an analysis of the life history periods when each of the three species would be most vulnerable to increased water temperatures (Table 2.1).

It should be recognized that the management goal of the California Department of Fish and Game is to keep water temperatures in the American River within the optimal temperature range to the extent that available water resources allow.

Chinook Salmon

For chinook salmon, the upper optimum water temperature was set at 56 degrees F (Figure 5.1) because juvenile chinook salmon were believed to be at risk at temperatures above 56 F (See Appendix I). Emigrating smolts were also considered vulnerable to increased water temperatures.

Chinook salmon during spawning, incubating eggs, and fry after emergence also are seasonally exposed to chronic stress-inducing water temperatures.

Only the data for April through June are presented in Figure 5.1. This is because analysis indicated 100%

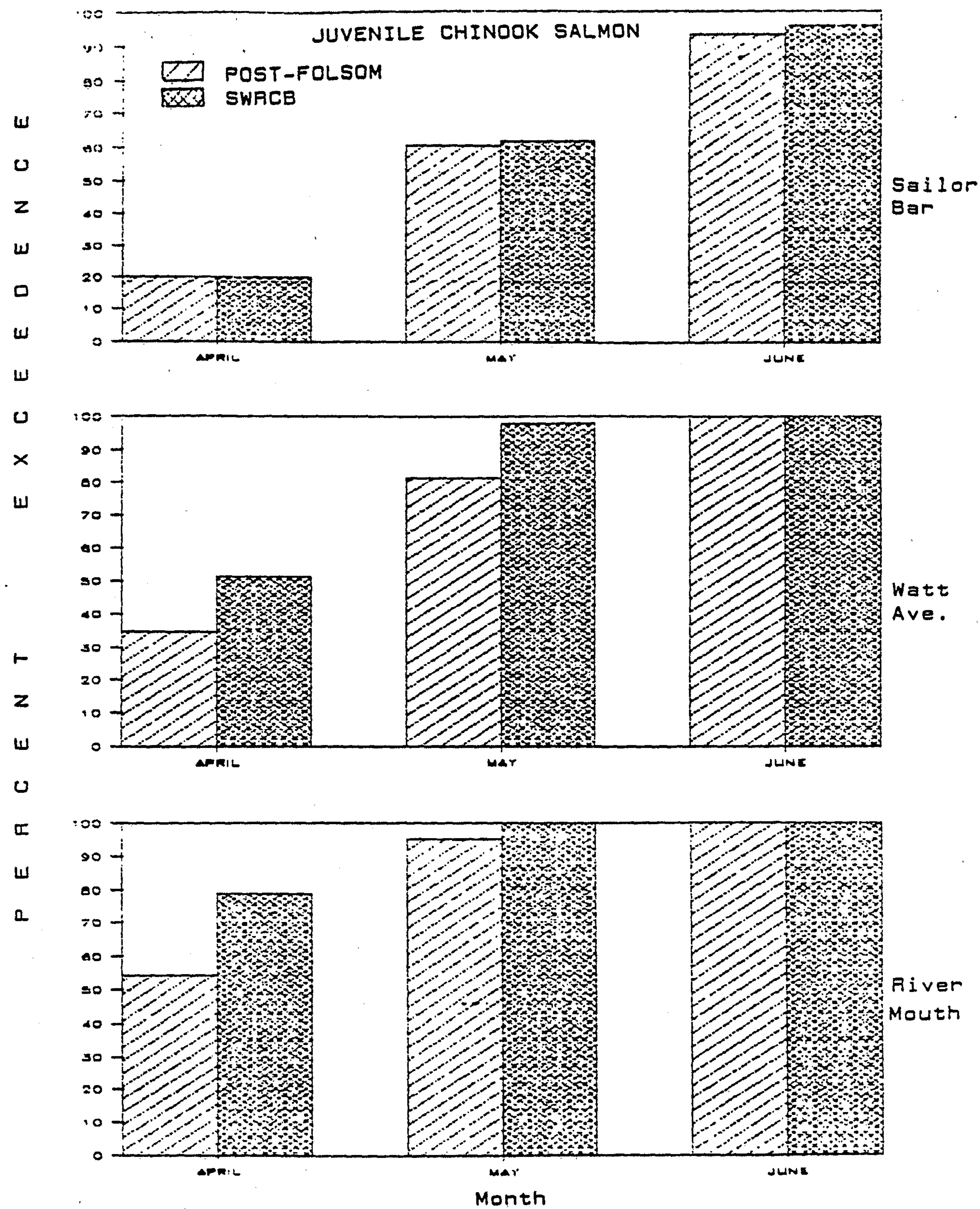

Figure 5.1 Comparison of exceedance values for upper optimum water temperature between post-Folsom flows and SWRCB staff-proposed flows for juvenile chinook salmon at three locations on the American River. The upper optimum water temperature is defined as 56 F.

exceedance above the upper optimum water temperatures for both the post-Folsom flows and the SWRCB staff-proposed flows for the months of July through October.

The analysis demonstrated that under the current (post-Folsom) flow regime, water temperatures often exceeded the upper optimum for juvenile chinook salmon in the three critical months presented, particularly June. Even at Sailor Bar, the most upstream and coldest site evaluated, the frequency of water temperatures higher than optimum under post-Folsom flows was over 90% in June.

The analysis of the effects of SWRCB staff-proposed flows demonstrates that the diminished flows would increase the frequency with which the upper optimum water temperature would be exceeded in the lower American River. For example, in April, the frequency of occurrence of stressful conditions at Watt Avenue would increase by about 50 percent (Figure 5.1).

Steelhead Trout

The months of April through October were evaluated for steelhead trout . The upper optimum temperature for steelhead was defined as 60 degrees F. Juvenile steelhead which remain in the river throughout the summer would be the most vulnerable to reduced flows and resultant rising water temperatures.

Current (post-Folsom) flows, particularly in July through September, resulted in stressful water temperature conditions for juvenile steelhead. Both post-Folsom and SWRCB staff-proposed flows for the months of July through October always exceeded the upper optimum water temperatures.

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Differences in exceedance rates produced under post-Folsom and SWRCB staff-proposed flows for April through June do exist, however, for steelhead trout (Figure 5.2), particularly in the middle and lower reaches. For example, exceedance rates at the mouth of the American River will increase from 55% to 87% during the month of May.

American Shad

The upper optimum temperature for American shad was defined as 65 F. This temperature was set as the upper optimum for migration, spawning and egg incubation (See Appendix II). Since adult American shad are generally found in the river only between April and July, the analysis was limited to those months (Figure 5.3). Two values were presented for July since the SWRCB staff-proposed flows change in mid-July, from 1250 cfs to 800 cfs.

As with chinook salmon and steelhead trout, current water temperature conditions often exceed upper optimum water temperatures for American shad. Adoption of the SWRCB staff-proposed flows would greatly increase the frequency of high water temperatures (Figure 5.3). For example, at the river's mouth, the frequency of water temperature exceedances would be almost ten times as great during April and two times as great during June. Since adult shad are attempting to enter the American River during these months, the overall effect of the reduced flows and resulting increased temperatures may be quite

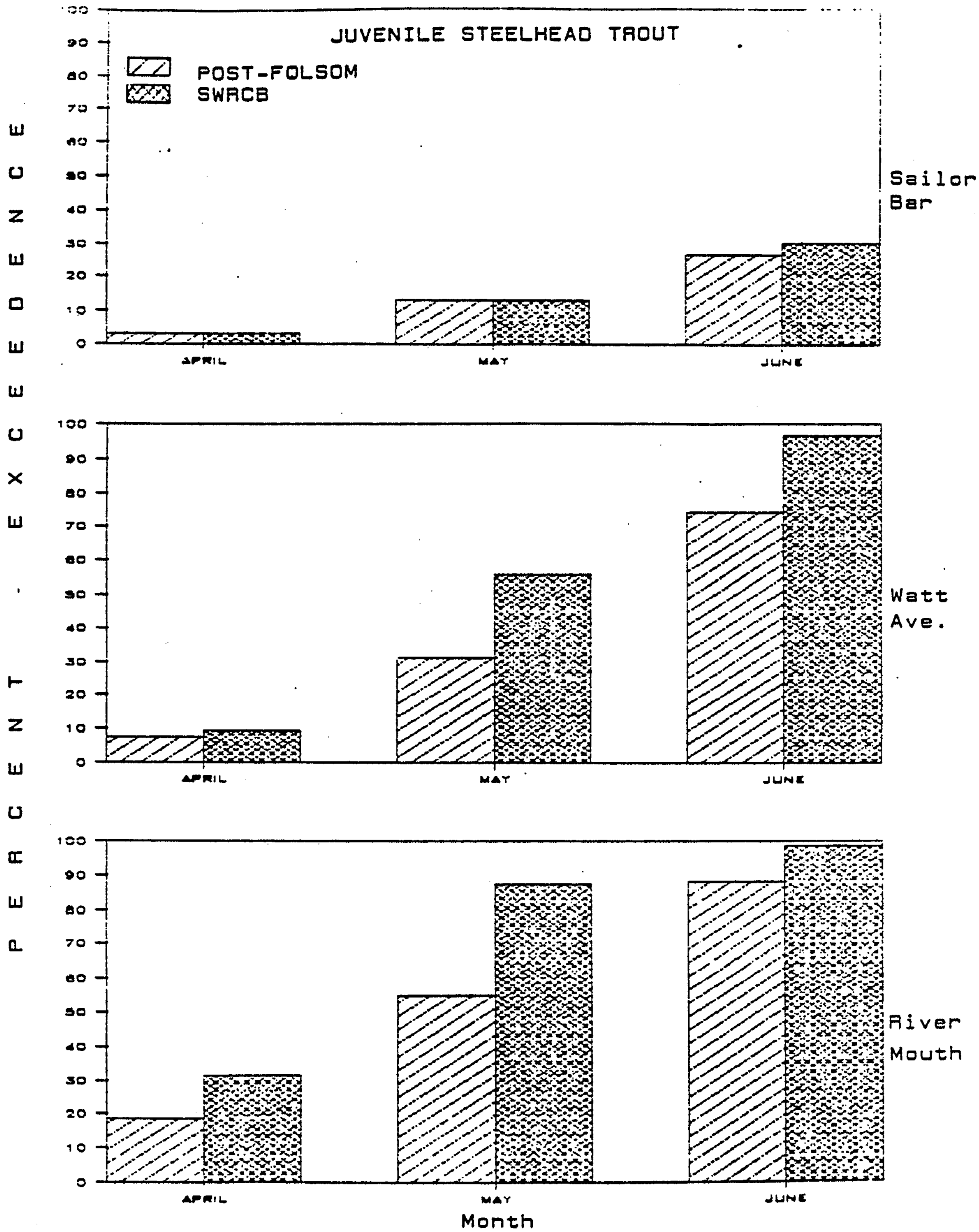

Figure 5.2 Comparison of exceedance values for upper optimum water temperature between post-Folsom flows and SWRCB staff-proposed flows for juvenile steelhead trout at three locations on the American River. The upper optimum water temperature is defined as 60 F.

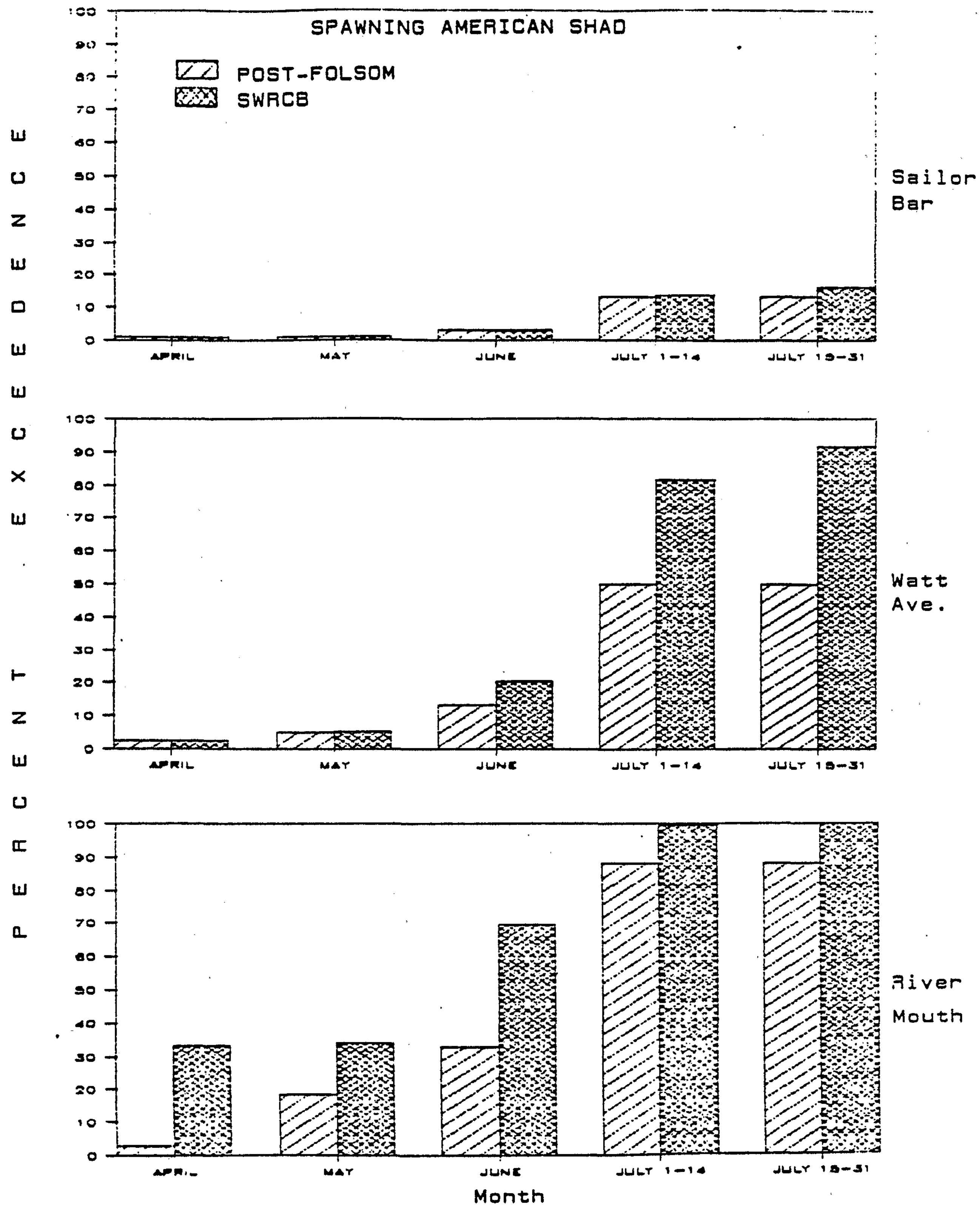

Figure 5.3 Comparison of exceedance values for upper optimum water temperature between post-Folsom flows and SWRCB staff-proposed flows for spawning American shad at three locations on the American River. The upper optimum water temperature is defined as 65 F.

severe, as the high temperatures may prevent or discourage fish from entering the river to spawn.

5.2 Magnitude of Water Temperature Events Resulting in Chronic Stress

The preceding section shows that, even under current conditions, anadromous fish experience chronic temperature stress and that the frequency of such stress would increase under SWRCB staff-proposed flows. Perhaps even more importantly, flow reduction would also increase the absolute amount by which the optimum water temperature is exceeded.

In order to examine this relationship, the median daily temperature for each month was plotted for current (post-Folsom) and SWRCB staff-proposed flows. Data for the three stations (Sailor Bar, Watt Avenue, and River Mouth) used in the previous analysis are shown in Figures 5.4, 5.5 and 5.6. Only the water temperatures which were above the upper optimum (i.e., 56 F, 60 F and 65 F for chinook salmon, steelhead trout and American shad, respectively) are presented.

Chinook Salmon

As noted earlier, the months of April, May, and June are the months of primary concern for juvenile chinook salmon rearing in the lower American River. The maximum temperature difference during the period was 3.4 F, which occurred in both May and June at the river mouth (Figure 5.4). In June, the median monthly temperature is historically 63.4 F (chronic low temperature stress) at the river mouth. Under the SWRCB staff-proposed regime, this

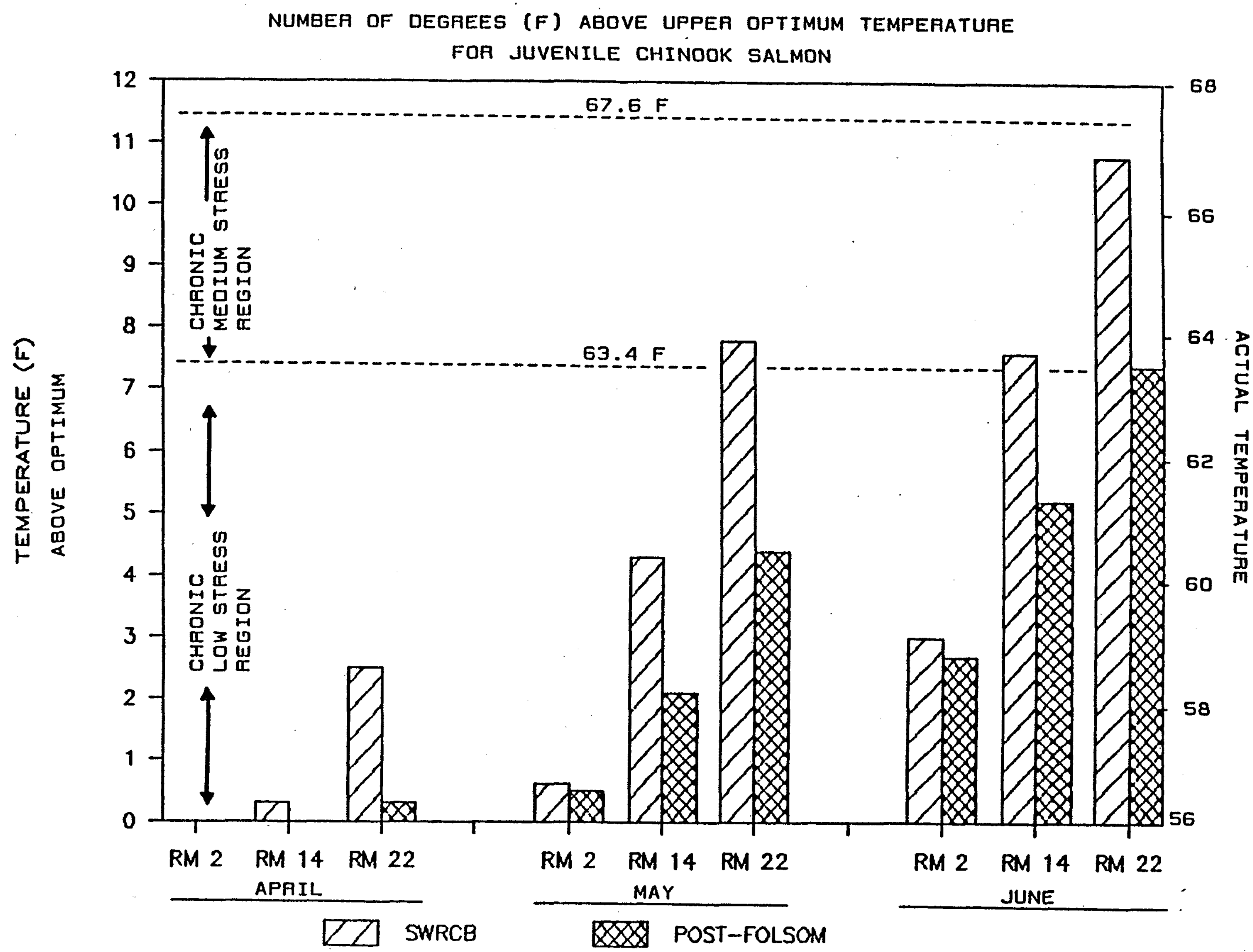

Figure 5.4 Number of degrees (F) above upper optimum temperature for juvenile chinook salmon under post-Folsom and SWRCB staff-proposed flows by month and river mile. The upper optimum temperature is defined as 56 F.

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NUMBER OF DEGREES (F) ABOVE UPPER OPTIMUM TEMPERATURE FOR JUVENILE STEELHEAD TROUT

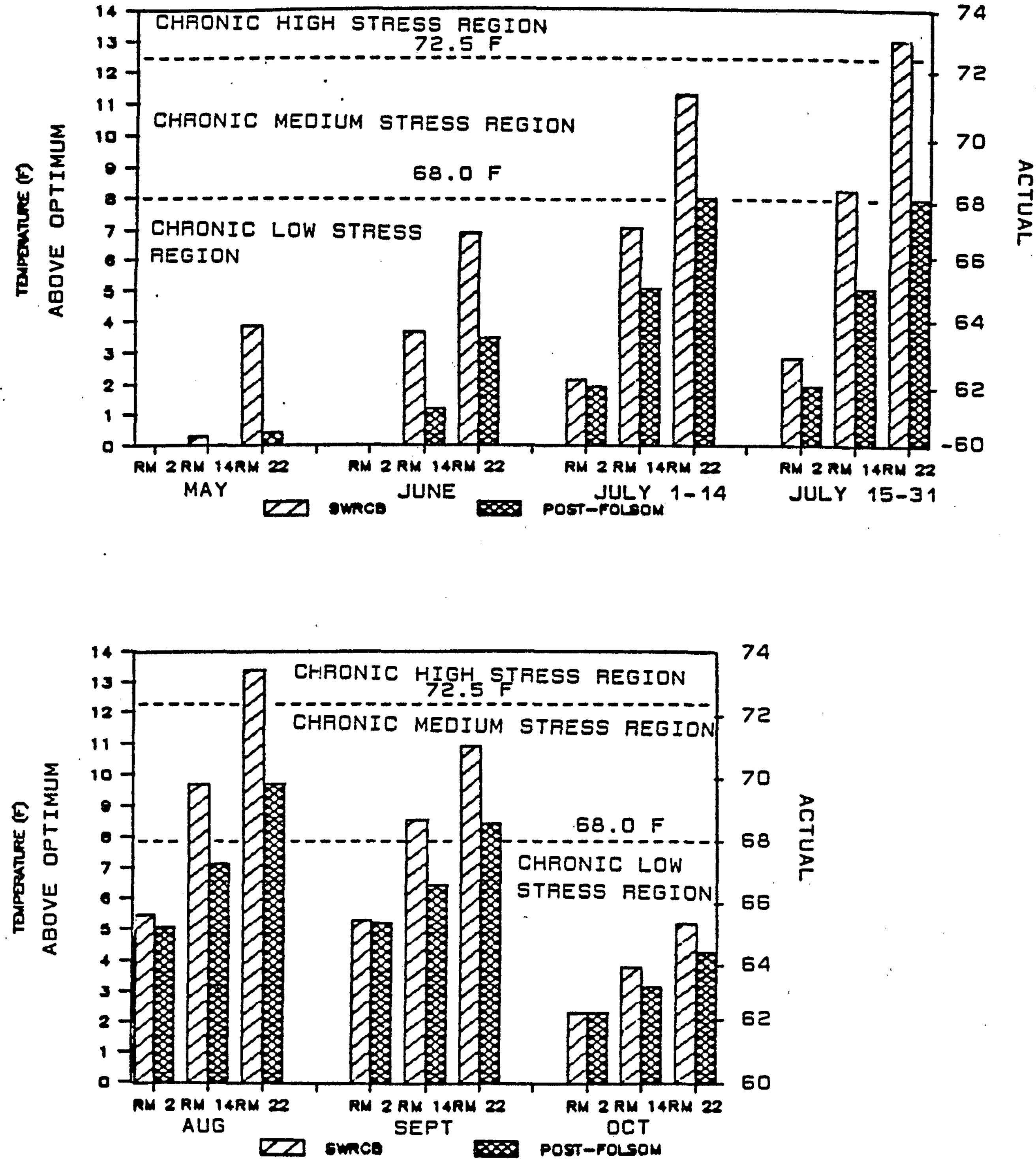

Figure 5.5 Number of degrees (F) above upper optimum temperature for juvenile steelhead trout under post-Folsom and SWRCB staff-proposed flows by month and river mile. The upper optimum temperature is defined as 60 F.

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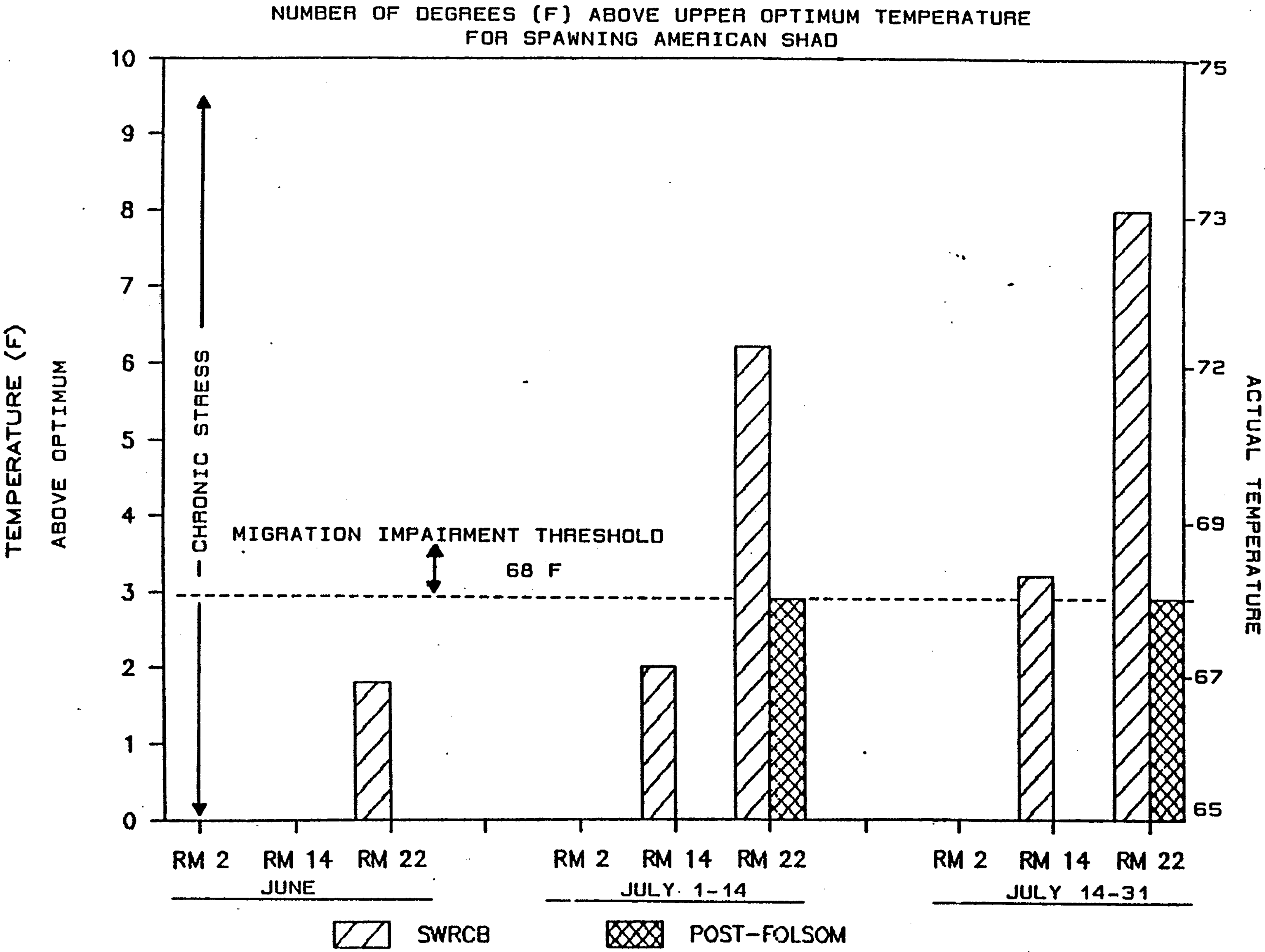

Figure 5.6 Number of degrees (F) above upper optimum temperature for spawning American shad under post-Folsom and SWRCB staff-proposed flows by month and river mile. The upper optimum temperature is defined as 65 F.

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temperature would increase to 66.8 F (chronic medium temperature stress).

Upon first examination, this temperature difference may not seem to be particularly large. However, only small increments in temperature have been shown to have severe impacts on chinook salmon growth rates, and therefore on their ultimate survival. Juvenile chinook salmon growth rates may decline significantly with a shift of only one or two degrees above upper optimum water temperatures (See Appendix I). Since juvenile chinook salmon survival is tied to growth rates, the SWRCB staff-proposed flows may reduce juvenile chinook salmon survival rates.

Steelhead Trout

Juvenile steelhead trout remain within the American River throughout the year. Summer median temperatures under the SWRCB staff-proposed flows exceed water temperatures that would cause high chronic temperature stress in steelhead trout (Figure 5.5). For example, early July median temperatures are as high as 71.2 F at the mouth, while late July temperatures at 800 cfs would be 73.0 F.

American Shad

During the May through June migration period, median post-Folsom temperatures encountered by adults migrating into the lower American River are 63.4 F. Under the SWRCB staff-proposed flow, water temperatures at the mouth of the American River will exceed upper optimum water temperatures (Figure 5.6). This could impair spawning migrations (Kuzneskus, 1977).

6.0 Conclusions

Water diversions from the lower American River during critical months would increase water temperatures in the river, exacerbating the conditions which already induce thermal stress in anadromous fish. If the diversions followed the recommendations of the SWRCB staff, the increased magnitude and frequency of stress-inducing conditions may threaten anadromous fish populations.

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APPENDIX I

REPORT ON STUDIES CONDUCTED BY SACRAMENTO COUNTY TO DETERMINE THE WATER TEMPERATURES WHICH OPTIMIZE GROWTH AND SURVIVAL IN JUVENILE CHINOOK SALMON (*ONCORHYNCHUS TSHAWYTSCHA*) IN THE LOWER AMERICAN RIVER

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I. SUMMARY

Sacramento County authorized a bioenergetics investigation to determine the Optimum Water Temperature range and Chronic Temperature Stress Zone for juvenile chinook salmon fed maximal rations under laboratory conditions. This investigation was conducted in order to better identify the water temperature requirements for juvenile chinook salmon in the lower American River. To identify optimum and sub-optimum water temperatures in chinook salmon fed maximal rations, the effects of water temperature on specific variables which are commonly used to assess the health of fish populations were analyzed. These variables included food conversion efficiencies, growth rates, daily mortalities, indicators of Chronic Temperature Stress, and condition factors. The results of the laboratory study were used to determine the Optimum Water Temperature Range and Chronic Temperature Stress Zones for the American River stock of juvenile chinook salmon fed maximal rations under laboratory conditions and under the conditions of the Lower American River.

The Optimum Water Temperature Range for the American River stock of juvenile chinook salmon fed maximal rations under laboratory conditions was 54-60 F (Figure 1). The results of the laboratory study were consistent with those of previous studies.

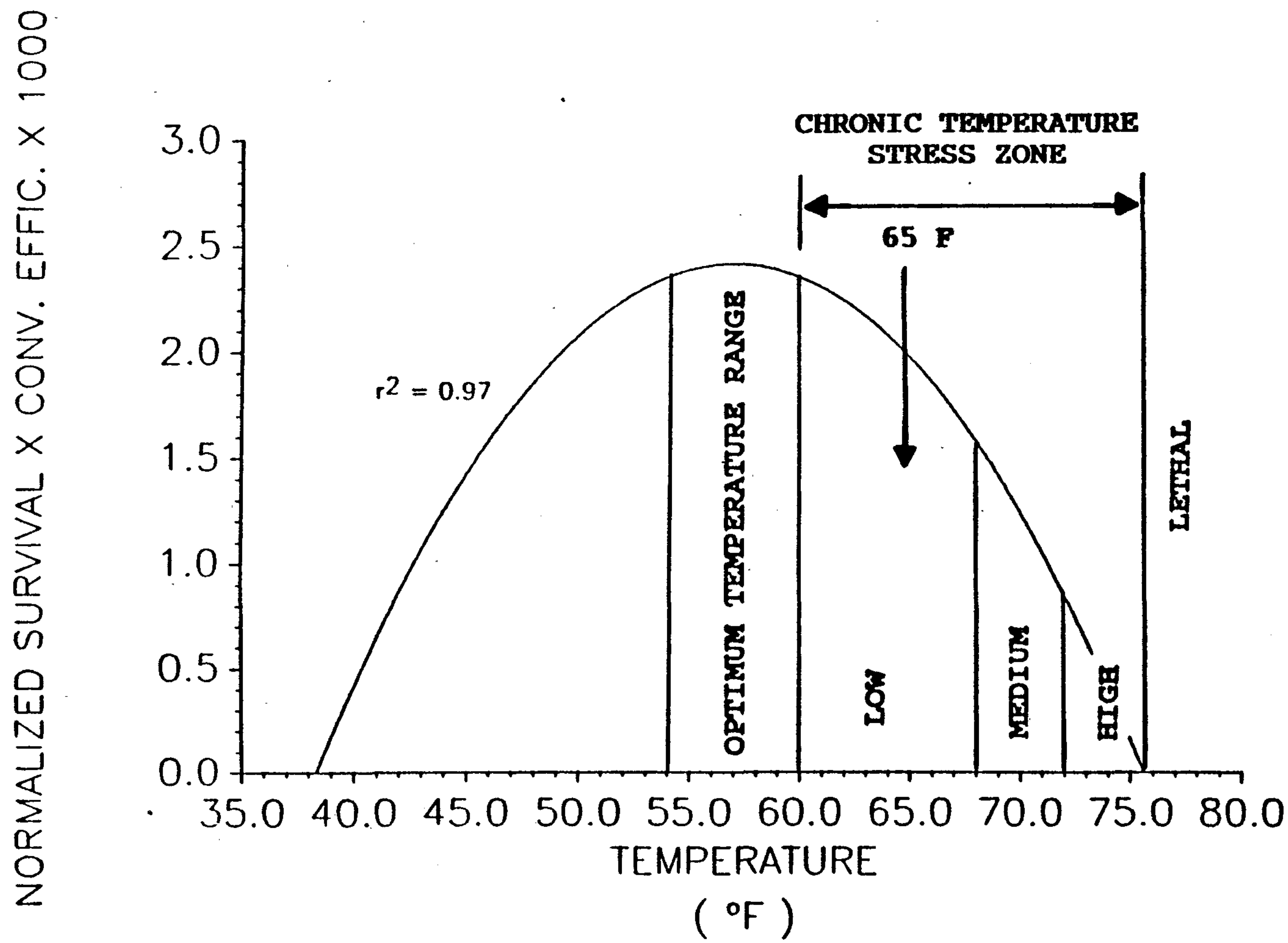

Figure 1. The Optimum Water Temperature Range and Chronic Temperature Stress Zones for the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations under Laboratory Conditions.

The Chronic Temperature Stress Zone for the American River stock of juvenile chinook salmon fed maximal rations ranged from water temperatures immediately above the upper optimum (60 F) to the water temperature which killed all of the fish (75.2 F) (Figure 1). A method was developed for identifying the relative chronic stress associated with increasing water temperatures. The following three Chronic Stress Zones were identified:

- Chronic Low Temperature Stress;
- Chronic Medium Temperature Stress; and,
- Chronic High Temperature Stress

65 F was classified as a Chronic Low Temperature Stress under these laboratory conditions.

Using data from field studies, the Optimum Water Temperature range for the juvenile chinook salmon under the conditions of the lower American River was determined to be no greater than 54-60 F and could have been as low as 53-56 F (Figure 2).

The Chronic Temperature Stress Zone for juvenile chinook salmon under the conditions of the lower American River ranged from water temperatures immediately above 56 F (the Upper Optimum) to the 75.2 F (the water temperature which killed all of the fish in the laboratory study). 65 F was classified as a Chronic Medium Temperature Stress under the conditions of the lower American River (Figure 2). Long-term exposure of

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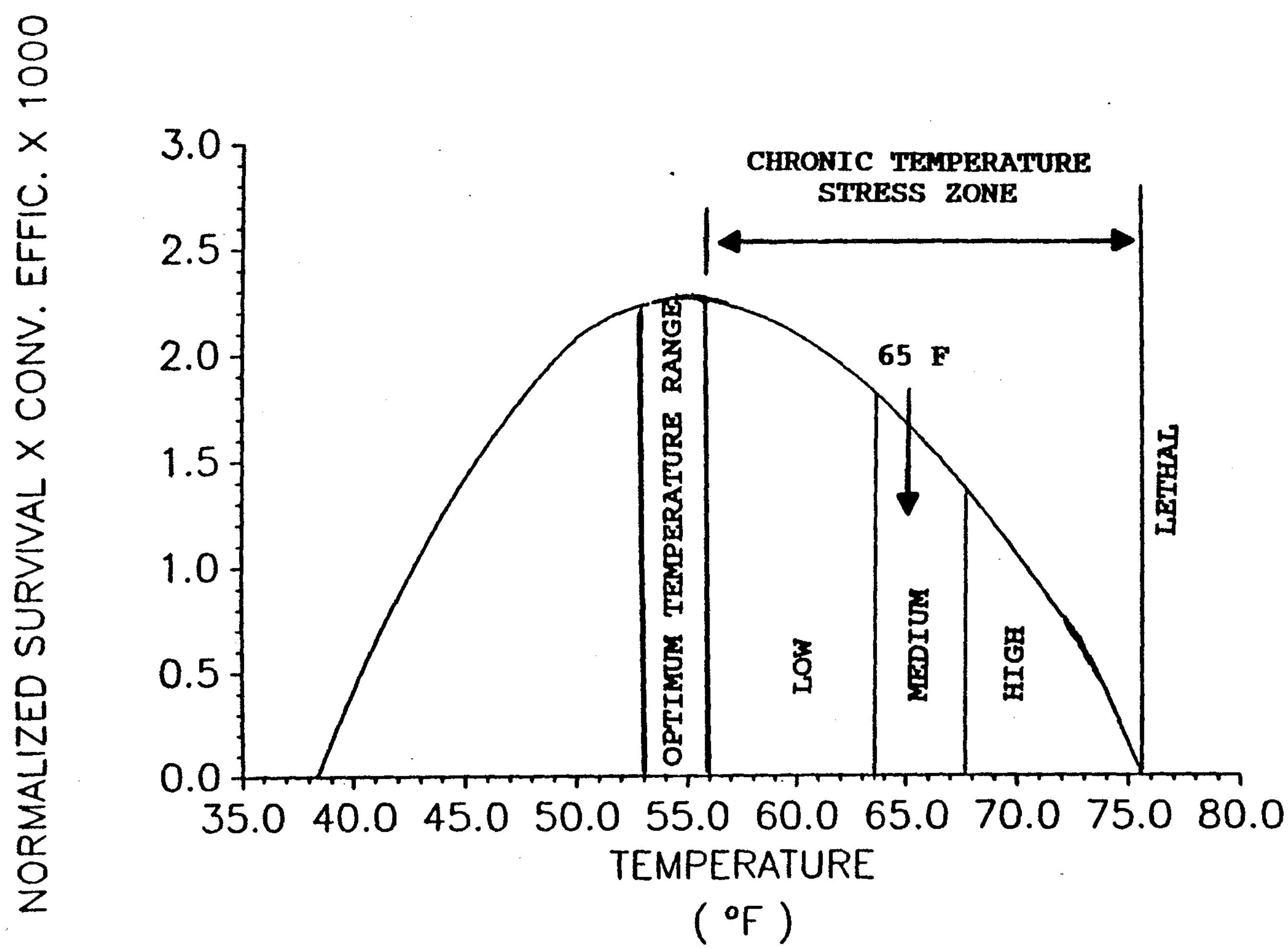

Figure 2. The Optimum Water Temperature Range and Chronic Temperature Stress Zones for the Juvenile Chinook Salmon in the Conditions of the Lower American River.

juvenile chinook salmon to Chronic Temperature Stress will reduce the population in the lower American River.

It was determined that water temperatures had no effect on condition factor for juvenile chinook salmon fed maximal rations under laboratory conditions or under the natural conditions of the lower American River.

II. INTRODUCTION

Fishery biologists for all parties have recognized that there was a lack of data concerning Optimum Water Temperatures for juvenile chinook salmon in the lower American River. Sacramento County previously submitted evidence which indicated that 60 F was a reasonable estimate of the Optimum Water Temperature for juvenile chinook salmon under maximum ration conditions (Rich, 1985; Rich and Leidy, 1985: "County"). The County's fishery consultants recommended that, until site specific studies had been conducted, a 60 F water temperature should be used as a basis for flow recommendations for this species. By contrast, EBMUD's fishery consultants concluded that 65 F was the Optimum Water Temperature for maximally fed juvenile chinook salmon and recommended that this water temperature not be exceeded at the mouth of the lower American River (Kelley et al., 1985a, b: "EBMUD").

The County's recommendation of 60 F was based upon the literature and relied upon a "margin of safety" (i.e., choosing the lowest Optimum Water Temperature when the results of studies are in conflict with one another). There were two reports which indicated that 60 F was a reasonable estimate of the Optimum Water Temperature for juvenile chinook salmon fed maximal rations. Studies on the thermal tolerance of Sacramento River chinook fry demonstrated that Central Valley stocks were not tolerant of high water temperatures (Healey, 1979). Healey (1979) predicted that if water temperatures exceeded 57.5 F, at least 80% mortality of eggs and fry could be expected to occur. Banks and his colleagues (Banks et al., 1971) reported 60 F as an upper Optimum Water Temperature for juvenile chinook salmon from rivers in Washington state. In contrast, Brett and his colleagues (Brett et al., 1982) reported that 65 F was an upper Optimum Water Temperature for the growth of chinook salmon juveniles from various Canadian rivers. Because the data from the Banks and Healey reports clearly demonstrated that 65 F was harmful, the County concluded that 60 F was closer to the Optimum Water Temperature than 65 F.

For eggs, fry or juveniles ?

EBMUD's fishery consultants stated that 65 F was the Optimum Water Temperature for maximally fed juvenile chinook salmon. But, they relied solely on the Brett study, thereby omitting crucial data (Kelley et al., 1985a, b). Furthermore, EBMUD's conclusion that 63.1 F was the Optimum Water Temperature for the juvenile chinook salmon in the lower American River was in error for the following two reasons:

(1) EBMUD inappropriately applied the American River data to Brett's growth model; and,

(2) EBMUD's field applications and conclusions were in error because the original Brett model was incorrect for field applications.

Subsequent to the 1982 report, Brett and his colleagues concluded that their original model had been incorrect for field applications and that the Optimum Water Temperature was about 4 degrees F lower than originally predicted (Brett, 1986; Clarke, 1986, 1987). Therefore, in addition to the inappropriate application of the American River data, EBMUD's field applications and conclusions were in error because the model used was erroneous.

Because there were no site-specific data for the juvenile life stage of chinook salmon in the lower American River, laboratory studies were designed for Sacramento County to answer the following questions:

(1) What is the Optimum Water Temperature range for the American River stock of juvenile chinook salmon fed maximal rations under laboratory conditions?

(2) What is the Optimum Water Temperature range for the American River stock of juvenile chinook salmon under the conditions of the lower American River?

(3) What water temperatures would produce Chronic Temperature Stress and thus reduce the chances of survival for the population?

Prior to the completion of the recent temperature bioenergetics studies reported here, the County felt that the above questions had not been adequately answered. It is common knowledge that flows affect water temperatures in the lower American River, but, until site-specific Optimum Water Temperatures had been established, only unproven hypotheses could be offered regarding the influence of instream flows on the long-term survival of the salmon populations.

III. PHYSIOLOGICAL AND METHODOLOGICAL CONSIDERATIONS WHICH MUST BE ADDRESSED BEFORE OPTIMUM WATER TEMPERATURES CAN BE IDENTIFIED

A. PHYSIOLOGICAL CHANGES ASSOCIATED WITH METABOLISM DETERMINE OPTIMUM WATER TEMPERATURES FOR FISH

As cold-blooded organisms, fish are dependent upon water temperatures. They respond immediately to temperature changes, either metabolically (through changes in metabolic rate which affect all organ systems in the body) or behaviorally (eg., moving to a cooler area if water temperatures are high). Because the immediate response is to survive, metabolic requirements are always satisfied before energy is spent on growth. At very low water temperatures, metabolic demand is low and behavioral activity is also low and fish exhibit little or no growth. As water temperature increases, the metabolic rate increases, digestive enzymes become more efficient, and, if there is enough food available, growth increases. This trend, however, does not continue, indefinitely. At some elevated water temperature, the optimum efficiency of the biochemical processes is exceeded and the fish must compensate for this in some way. Under laboratory conditions with unlimited rations, the fish compensate by eating more food. Under natural conditions, because the swimming activity associated with obtaining food uses up so much energy, the fish rarely compensate by eating more food. Instead, they compensate behaviorally by moving to an area with cooler water temperatures. As water temperatures exceed the optimum, an increasing physiological burden is placed on the fish. If this burden becomes too great, the fish die immediately (Acute Temperature Stress) or at some time in the future (Chronic Temperature Stress). Chronic Temperature Stress is extremely important in determining how long a population survives.

B. CHRONIC TEMPERATURE STRESS AND ITS RELATION TO FISH SURVIVAL

1. What is Chronic Temperature Stress?

Chronic Temperature Stress is as decisive to continued survival as more extreme temperatures are to immediate life (Brett, 1956). Chronic Temperature Stress results from any water temperature change that produces a significant disturbance in the normal physiological function of a fish and thus decreases the probability for the fish's survival (Elliott, 1981). If the Chronic Temperature Stress is of short duration, stress hormones, such as adrenaline and cortisol, are secreted to physiologically combat the stress. However, if the Chronic Temperature Stress is too great or lasts too long, the fish's response to the stress impairs survival. Symptoms of Chronic Temperature Stress include: (1) Reduction in growth; (2) Reduction in food conversion efficiency; (3) Loss of appetite; (4) Hyperactivity associated with secretion of stress hormones; and, (5) Disease outbreaks. All of these symptoms have been directly and indirectly linked with the survival of natural populations of salmonids (Rich, 1983; Pickering, 1981) and, the longer the fish are exposed to Chronic Temperature Stress, the less chance they have for long-term survival.

2. How Does Chronic Temperature Stress Impair Salmon Populations in the lower American River?

The high water temperatures which reduce growth in the juvenile chinook salmon in the lower American River will eventually reduce the population. The growth rates which occur in the first year affect subsequent growth and survival of natural populations (Neilson and Geen, 1986; Reisenbichler et al., 1982). Studies on the Sacramento River chinook salmon stocks demonstrated that the size of the fish released from hatcheries was directly related to the number of adult chinook which returned to spawn (Reisenbichler et al., 1982). Thus, high water temperatures will eventually reduce the population in the lower American River.

1. Qualify for what time of year

2.

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The diseases associated with higher water temperatures would reduce the chinook salmon population in the lower American River. Contrary to EBMUD's contention, disease inducing water temperatures are not more of a problem for hatchery fish than for natural populations. For example, columnaris, a bacterial disease which causes skin lesions and ulcers and ultimately can be lethal, almost obliterated the Columbia River run of sockeye salmon in 1941; since then, numerous outbreaks of this disease have been reported in the literature (see citations in Holt et al., 1975). The incidence and severity of columnaris is directly related to water temperature. It begins to affect chinook salmon at temperatures above 50 F, and the frequency of columnaris rapidly increases as the temperature increases.

C. <u>BIOENERGETIC STUDIES ARE THE BEST MEANS TO DETERMINE OPTIMUM WATER TEMPERATURES FOR FISH</u>

The first and most critical step in addressing the complex relation between water temperature and salmon requirements under the natural conditions of the lower American River is to ensure that the study methodology includes the criteria necessary to determine Optimum Water Temperatures. There are three types of studies commonly used to identify Optimum Water Temperatures: bioenergetic studies; temperature tolerance studies; and metabolism studies.

Bioenergetic studies provide the best information related to survival. Bioenergetic studies measure several variables, all of which are affected by water temperature: growth rate; food conversion efficiency; amount of food consumed; mortality; and, indicators of Chronic Temperature Stress (eg., appetite reduction and disease). Temperature tolerance studies provide only mortality information and thus cannot assess the results of Chronic Temperature Stress on the long-term survival of the population. Metabolism studies are inadequate because the variables studied, such as respiratory rates in relation to water temperature, reflect only instantaneous conditions. Bioenergetic studies are much more comprehensive than either temperature tolerance or metabolism studies and more effectively address survival of fish.

Although bioenergetic studies are the best means for determining Optimum Water Temperatures, the results are meaningful only when specific methodological criteria are followed. To identify the Optimum Water Temperatures for juvenile chinook salmon in the lower American River, the study methodology must proceed chronologically:

(1) First, conduct laboratory studies to determine the Optimum Water Temperature range for the fish under laboratory conditions;

(2) Second, conduct field studies to determine the Optimum Water Temperature range for the fish under the natural conditions of the lower American River.

D. INFORMATION REQUIRED TO DETERMINE THE OPTIMUM WATER TEMPERATURE RANGE IS LACKING FOR JUVENILE CHINOOK SALMON FED MAXIMUM RATIONS

Before the Optimum Water Temperature range for fish in the natural environment can be addressed, one must first know the interactive effect of ration and water temperature on growth in a laboratory setting where the environment is controlled and the fish's physical activity limited. Without first establishing this relation, there is no way to differentiate between the interactive effects of ration and water temperature with those of the activities needed to exist (i.e., swimming, escaping predators, etc.) in the natural environment. Once the ration/temperature effects have been established, then the additional interacting effects of the activities associated with survival in nature can be assessed.

The significance of the interaction between ration and water temperature is that because fish under natural conditions eat less than maximal rations, the Optimum Water Temperature range for fish under the natural conditions of the lower American River is lower than that for fish fed maximal rations under laboratory conditions. At lower rations, provided that the water temperatures are also low, the fish's metabolism slows down to conserve energy, thus enabling the fish to convert much of its limited rations to growth. By contrast, if the water temperature increases, but the rations remain limited, the fish will use its limited food reserves to sustain this elevated metabolic rate before it can grow. Thus, the Optimum Water Temperature range is lower at reduced rations than at maximal rations (Brett et al., 1969). Therefore, because fish under the natural conditions of the lower American River feed less than maximally, at low water temperature they more efficiently convert food into growth.

Determining the Optimum Water Temperature range for a specific life stage of any species is a major undertaking, encompassing years of study and fine-tuning methodology. Brett and his colleagues spent almost two decades studying the sockeye salmon before they felt confident enough in their data to construct a preliminary growth/temperature model which depicted the relation of growth to water temperature in juvenile sockeye salmon (Brett et al., 1969). Since the original model was developed, the sockeye model has undergone a number of modifications, all of which have involved validation studies (Brett and Shelbourn, 1975; Brett, 1974, 1971).

In contrast to the extensive work on sockeye salmon, a similar effort for chinook salmon has not been completed; definitive Optimum Water Temperatures have not been established. The major factors still missing for the chinook salmon model are the incorporation of low and Lower Lethal water temperatures. To obtain a true representation of a growth curve, both Lower and Upper Lethal Limits must be included[1/].

Figure 3 illustrates the bias which occurs when lower temperatures are excluded from a growth curve[2/]. In Figure 3, two sets of growth data are depicted. The first curve (labeled "All Data") includes growth rates at water temperatures ranging from the Lower Lethal to the Upper Lethal limit. The second curve (labeled "Exclude Low Temperatures") excludes a Lower Lethal Temperature and temperatures lower than 50 F. The second curve represents what was done in Brett's chinook salmon study (Brett et al., 1982); the Optimum Growth Temperature was biased towards the Upper Lethal Temperature. When all the data are plotted, the peak temperature is 55 F. If only those growth rates which occur at water temperatures at and above 50 F are plotted, the peak water temperature becomes 58 F. A difference of three degrees can determine whether or

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1/ Lower and Upper Lethal Water Temperatures are used as standards upon which other measurements are based. The Lower and Upper Lethal Water Temperatures are defined as that lower/ upper temperature at which 50% of the population is dead after indefinite exposure.

2/ Data were obtained from Brett's study on Canadian juvenile sockeye salmon (Brett et al., 1969).

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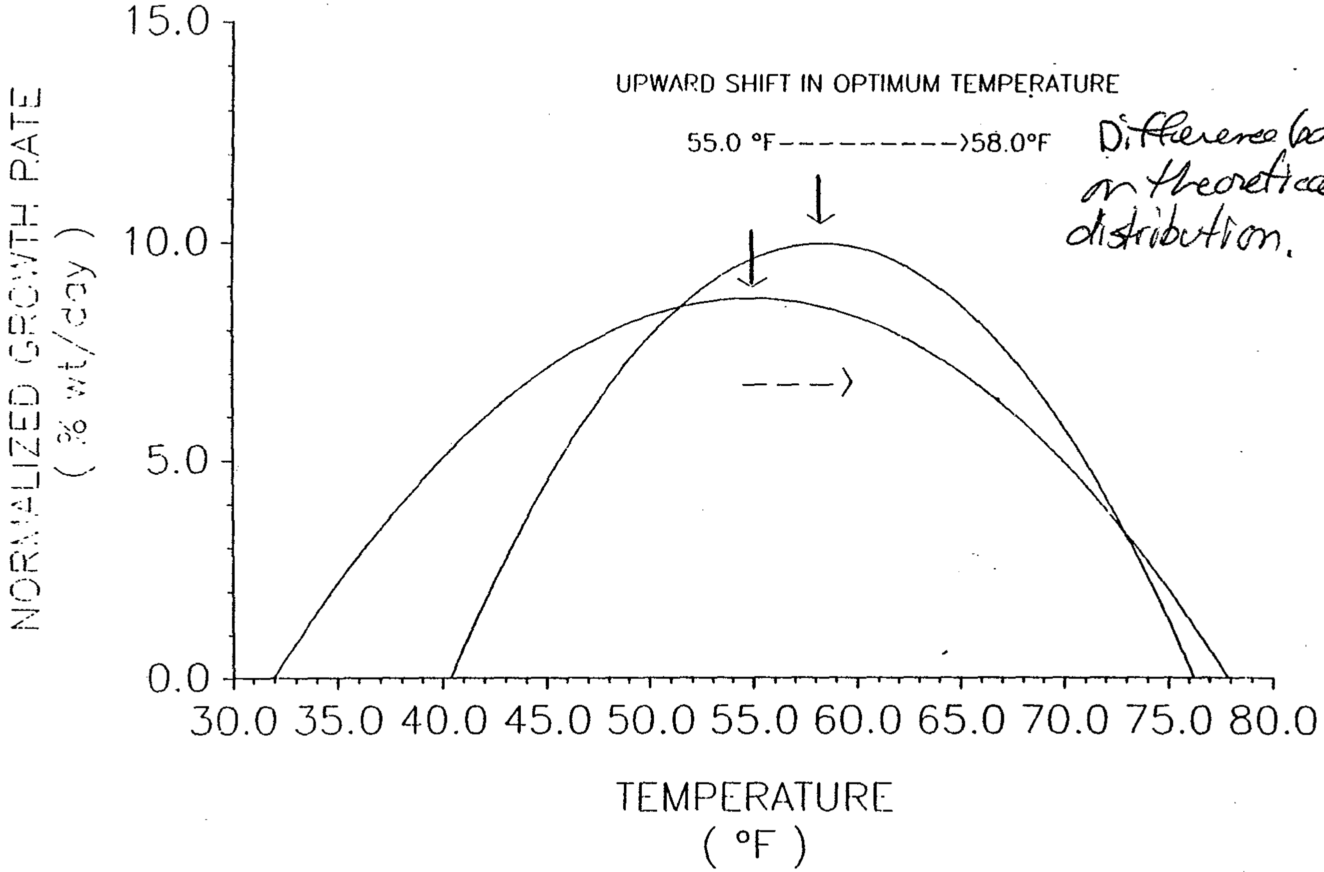

Figure 3. The Upward Shift in Optimum Temperature which occurs when Low and Lower Lethal Water Temperatures are Excluded from the Development of Growth Curves.

based on standard growth curve formulas

not a fish survives. Therefore, to develop a growth model which will provide accurate predictions of the Optimum Water Temperature, data from both temperature extremes must be incorporated into the model. If this had been done in the 1982 Brett chinook salmon study, the Optimum Water Temperature would have been lower than the 65 F determined by the study.

E. <u>METHODOLOGICAL CRITERIA REQUIRED TO DETERMINE THE OPTIMUM WATER TEMPERATURE RANGE UNDER THE CONDITIONS OF THE LOWER AMERICAN RIVER</u>

Field studies are undertaken after an Optimum Water Temperature Range has been determined for fish fed maximal rations under laboratory conditions. The results of field investigations are then compared with those from the maximal ration conditions of the laboratory. The methodological criteria required to identify the Optimum Temperature Range of juvenile chinook salmon sampled from natural populations include:

(1) Sample fish at least once/week at predetermined, multiple stations;

(2) Include sites which will represent the entire temperature range of the river during the sampling period;

(3) Use a validated growth model for comparison; and,

(4) Use a temperature model which can reliably predict mean daily temperatures at any site on the river.

IV. METHODOLOGY USED TO IDENTIFY THE OPTIMUM WATER TEMPERATURE RANGE FOR THE AMERICAN RIVER STOCK OF JUVENILE CHINOOK SALMON FED MAXIMAL RATIONS

In order to determine Optimum Water Temperatures for growth in American River juvenile chinook salmon fed maximal rations, a laboratory study was conducted from March through June 1986. Juvenile chinook salmon of the American River stock were obtained from the Nimbus Hatchery and the study was conducted at the California Department of Fish and Game Disease Laboratory in Rancho Cordova.

The experimental apparatus consisted of fourteen replicate pairs of aquarium tanks set up in a continuous-flow system. A reconnaissance-level study identified the range of water temperatures needed to determine the Optimum Water Temperature; mean water temperatures ranged from about 51.0 to 75.0 F.

The fish were initially screened for uniform size, anesthetized, weighed and measured and 160 fish were placed in each aquarium. The process of gradually acclimating the fish to the assigned temperatures began after two days of acclimation to incoming American River water.

Daily records were kept of food consumption, mortalities, and indicators of Chronic Temperature Stress (i.e., loss of appetite, hyperactivity, disease). The fish were fed Oregon

Moist Pellets (OMP) five times per day until the pellets were rejected and about 5 g of food remained in the bottom. This was determined to be the maximum ration of food required by the fish. To determine the exact amount of food consumed each day, the food was measured each day prior to feeding, excess food was siphoned, filtered, dried, and weighed.

Growth rates and food conversion efficiencies were determined from calculations using initial and final weights and the total amount of food consumed per fish. Food conversion efficiency is considered to be more useful than growth rate in determining Optimum Water Temperatures. The reason for this is that, under laboratory conditions where the fish have an unlimited supply of food, as the water temperature increases, although the fish may eat more, the food conversion efficiency is so low that little or no growth occurs.

To assess the growth rates and food conversion efficiencies during the course of the study, 15 fish were subsampled weekly, lengths and weights were taken, and a dry weight analysis performed on each of the subsampled fish. An extended explanation of the methodology is provided in Appendix A.

Condition factors were calculated to determine whether or not condition factor was influenced by water temperature. Condition factors were calculated for the fish in each of the aquaria at the beginning, the end, and for each of the subsampled fish during the study. Condition factor is calculated as follows:

$$K = \text{wet weight (g)} \times \frac{100}{(\text{length in cm})^3}$$

V. ESTABLISHING A RANGE OF WATER TEMPERATURES WHICH OPTIMIZE GROWTH AND SURVIVAL IN THE AMERICAN RIVER STOCK OF JUVENILE CHINOOK SALMON FED MAXIMAL RATIONS

A. RESULTS OF THE LABORATORY STUDY

Food conversion efficiency and growth rate are commonly used to identify Optimum Water Temperatures for fish. Food conversion efficiency represents the capacity to convert food into growth and is one of the most meaningful and simple indicators of the state of health for fish. The water temperature range at which food conversion efficiency was optimum was 58-60 F; the water temperature range at which growth rate peaked was 58-61 F (Figures 4 and 5).

The importance of Chronic Temperature Stress was discussed previously (Section IIIB). Indicators of Chronic Temperature Stress at higher water temperatures were:

(1) Increased incidence of disease[1/] (beginning at a mean water temperature of 66.2 F)

(2) Reduced growth rates;

(3) Reduced food conversion efficiencies; and,

(4) Reduced appetite (Table 1).

1/ A temperature-induced gill bacterial infection occurred at temperatures above 66.2 F. The fish pathologists at the California Department of Fish and Game Disease Laboratory at Rancho Cordova identified the disease and its cause (high water temperature).

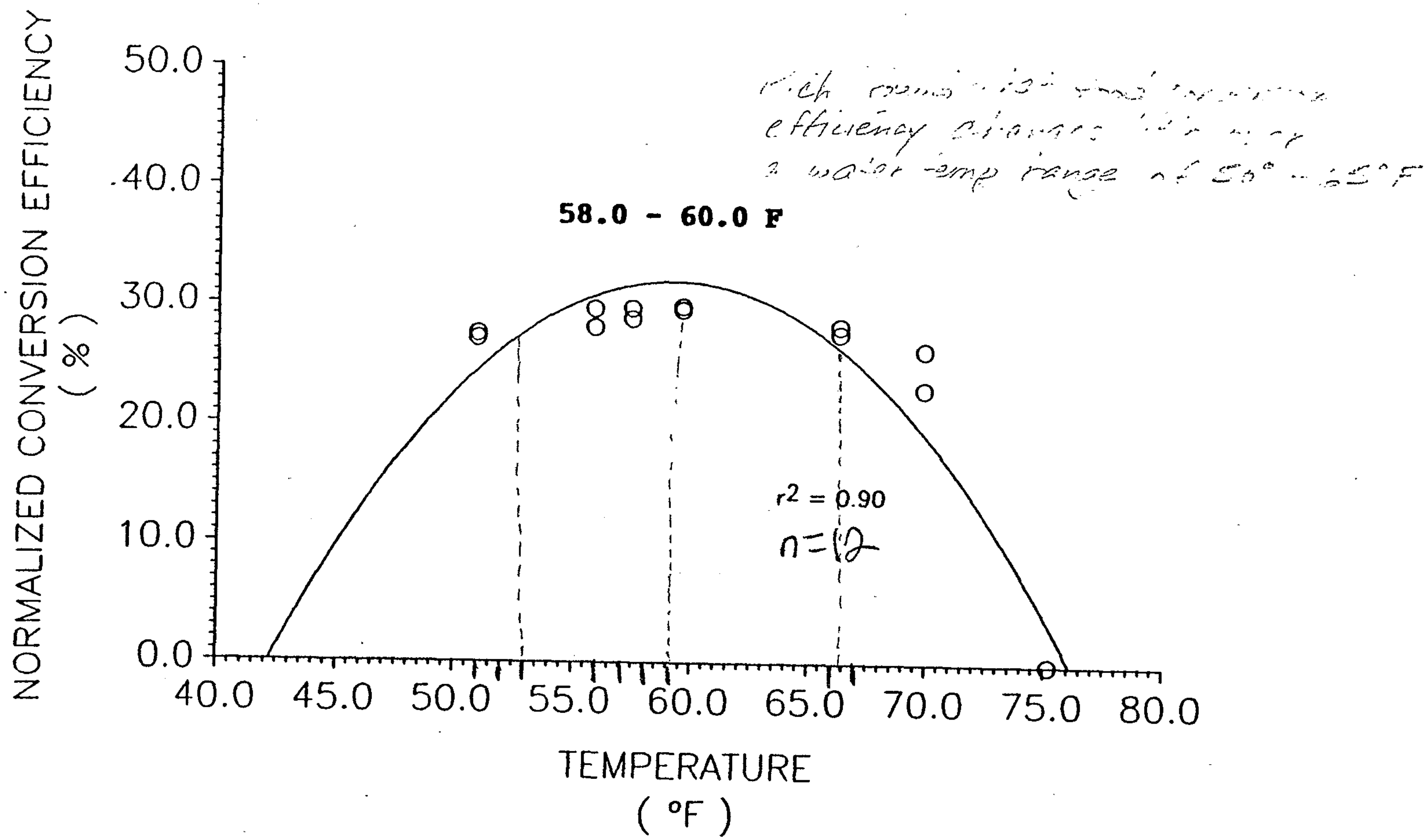

Figure 4. The Relation between Water Temperature and Food Conversion Efficiency in the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations.

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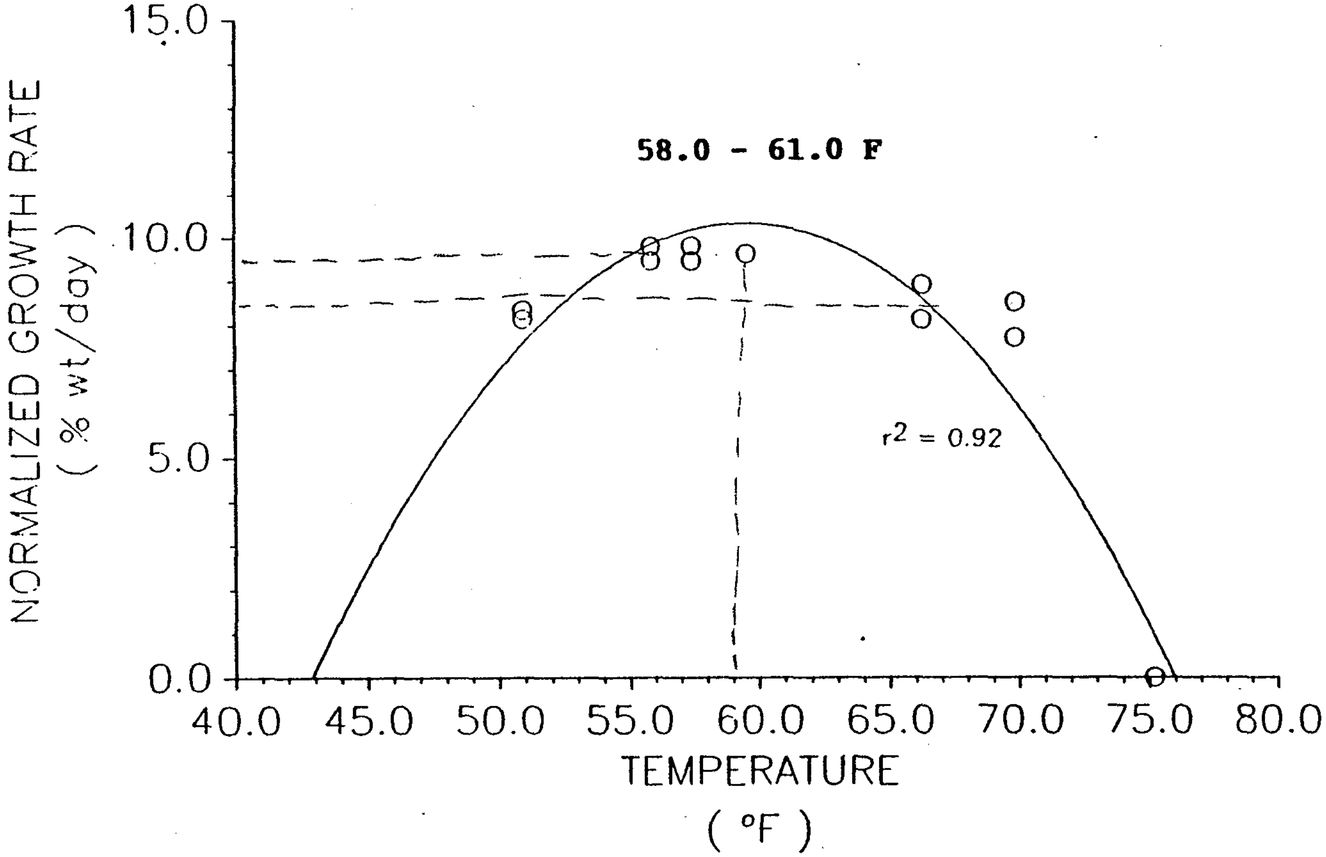

Figure 5. The Relation between Water Temperature and Growth Rate in the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations.

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Table 1. Mortalities and Indicators of Chronic Temperature Stress in the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations Under Laboratory Conditions

TEMPERATURE (deg. F)	MORTALITY (%)	STRESS INDICATORS*
50.9 ± 0.7	1.3	-------------
50.9 ± 0.7	1.9	-------------
55.8 ± 0.4	2.5	-------------
55.8 ± 0.4	2.5	-------------
57.4 ± 1.2	2.5	-------------
57.4 ± 1.2	1.3	-------------
59.5 ± 0.3	6.3	-------------
59.5 ± 0.3	9.4	-------------
66.2 ± 0.3	9.4	Disease, reduction in appetite, growth rate, and food conversion efficiency
66.2 ± 0.3	12.5	
69.8 ± 0.4	40.6	Disease, hyperactivity, reduction in appetite, growth rate and food conversion efficiency
69.8 ± 0.4	46.9	
75.2 ± 0.4	100.0	Disease, hyperactivity, death
75.2 ± 0.4	100.0	

* Assumes that fish subsampled would have survived had they remained in the aquaria.

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Consistent with the indications that the fish were being stressed at higher water temperatures was the increase in mortalities which occurred as temperatures increased (Table 1).

The results demonstrated that water temperatures had no effect on condition factor (Figure 6). These results are not surprising because, although condition factor is often used to assess the relative health of fish, it has been repeatedly criticized (for summary of authors, see Weatherley, 1972). It has been demonstrated that there is considerable variation in condition factor for any particular fish length or weight. Such variations reflect normal seasonal fluctuations in metabolic balance or the stage of fullness of the stomach. As an example, one of the manifestations of smoltifications is that the fish become long and thin, relative to the parr stage. Thus, the condition factor of these fish may be lower than those of parrs, yet these fish may be perfectly healthy and growing quickly.

B. <u>COMPARISON OF THE AMERICAN RIVER RESULTS WITH THOSE OF PREVIOUS STUDIES</u>

When both Lower and Upper Lethal Limits are added to the data in each of the studies (i.e., the County's laboratory study, Bank's 1971 study, and Brett's 1982 study), the results of the American River laboratory study are consistent with

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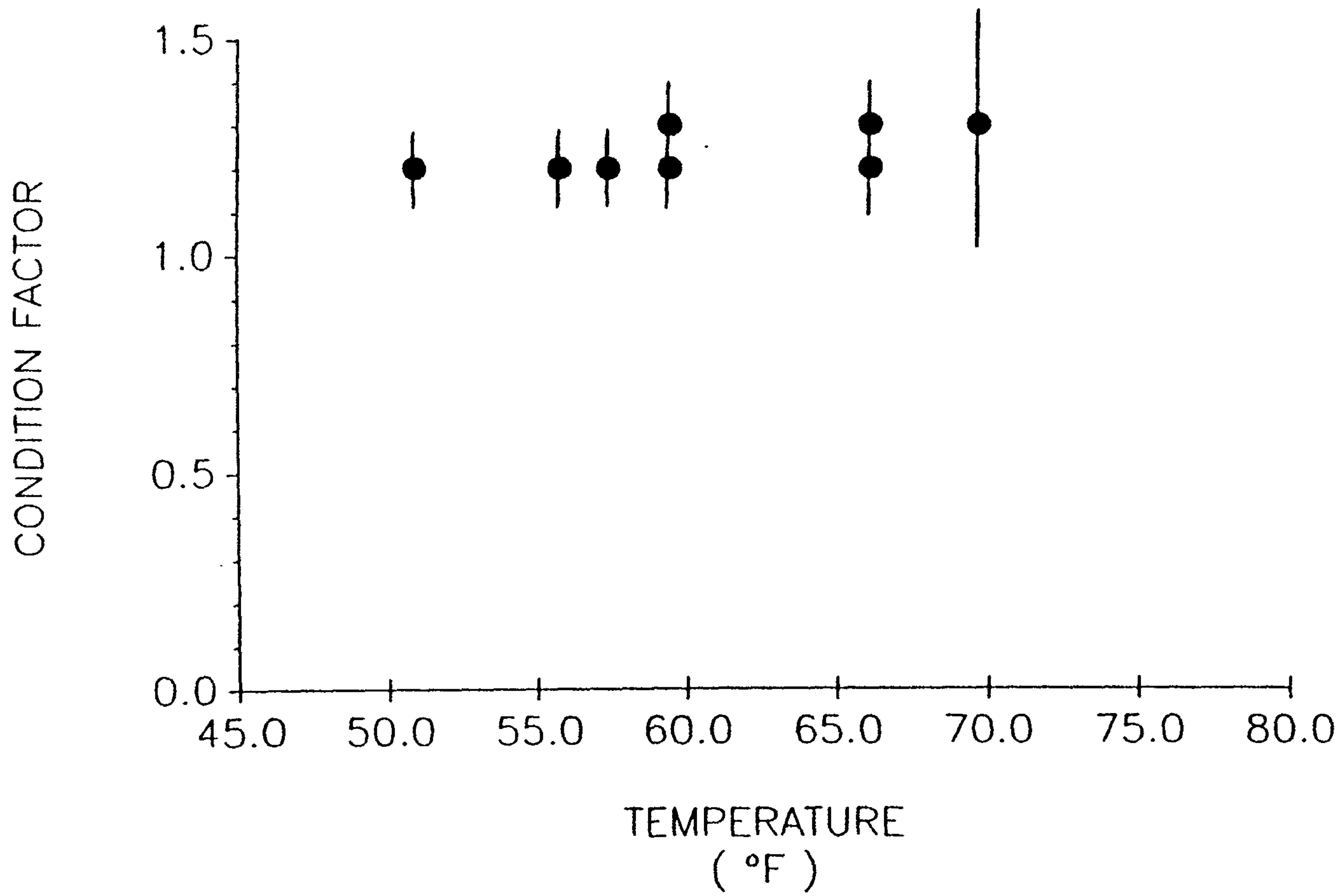

Figure 6. There was no Relation between Water Temperature and Condition Factor in the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations. Lines drawn thru data points are standard deviations about the mean.

C — 0 4 3 5 6 4

those of Banks and Brett (Figures 7 and 8)[1/]. Similar to the County's results, rates peaked in the vicinity of 60 F in the Banks study (Figure 7)[2/]. In the Brett study, incorporation of the Lower and Upper Lethal Temperatures shifted the Optimum Water Temperature down from 65 F to 63 F (Figure 8). If growth rates at temperatures lower than 50 F had been tested, the Optimum Water Temperature ranges would probably have been reduced even further in all of the studies.

Not relevant.

1/ Correcting for initial weights of 2.0 and 3.0 g, the County's study was compared with those of Banks and Brett, respectively. Brett's Big Qualicum River stock was used because they were hatchery fish and thus more comparable to the American River hatchery fish than the Nechako stock under natural conditions.

2/ Although conversion efficiencies were not calculated by Banks, conversion efficiencies peaked at the same water temperature as growth rates in the County's study. Therefore, 60 F was assumed to be the Optimum Water Temperature in the Banks study.

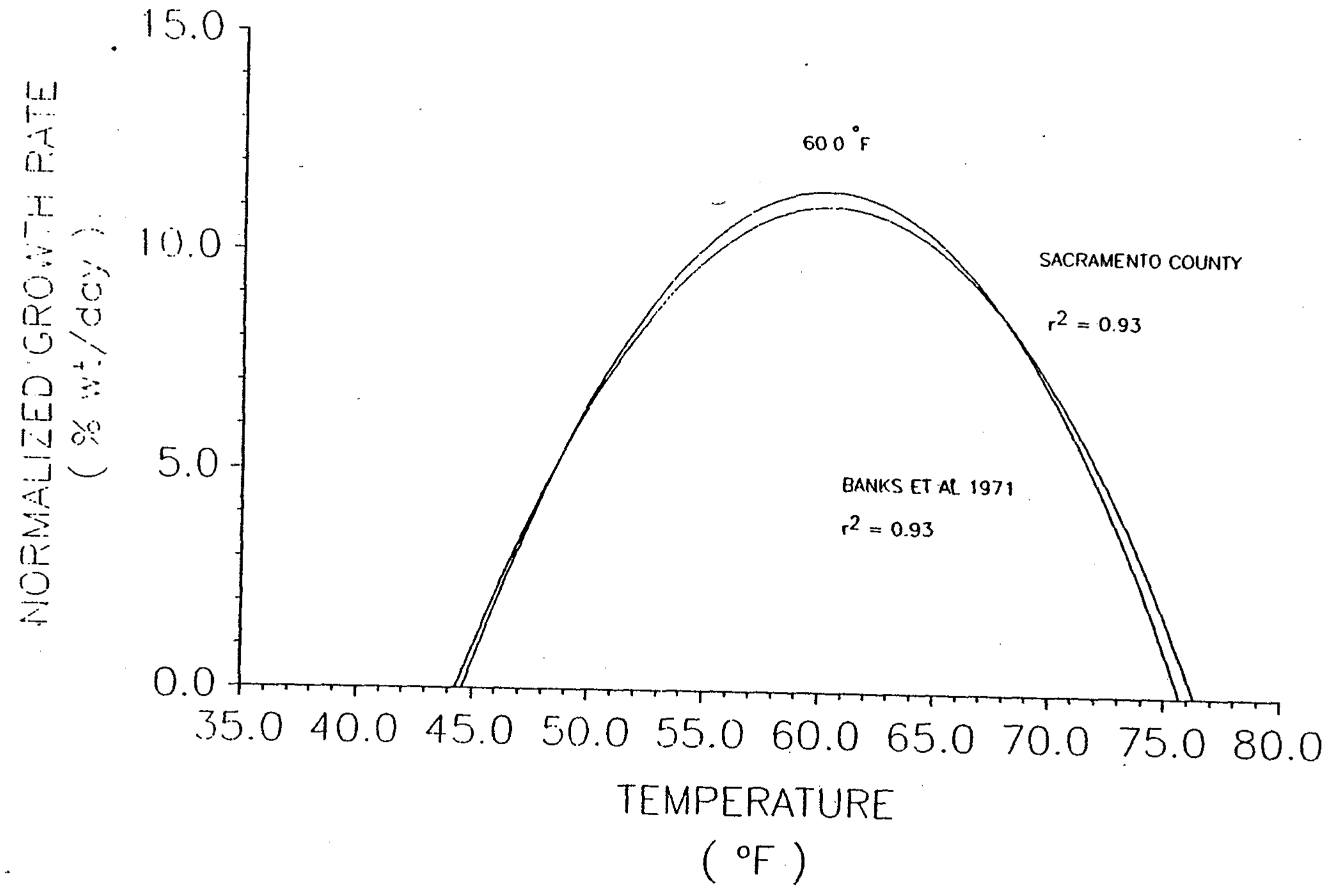

Figure 7. Comparison of the Optimum Water Temperatures for the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations with those of Bank's Fish.

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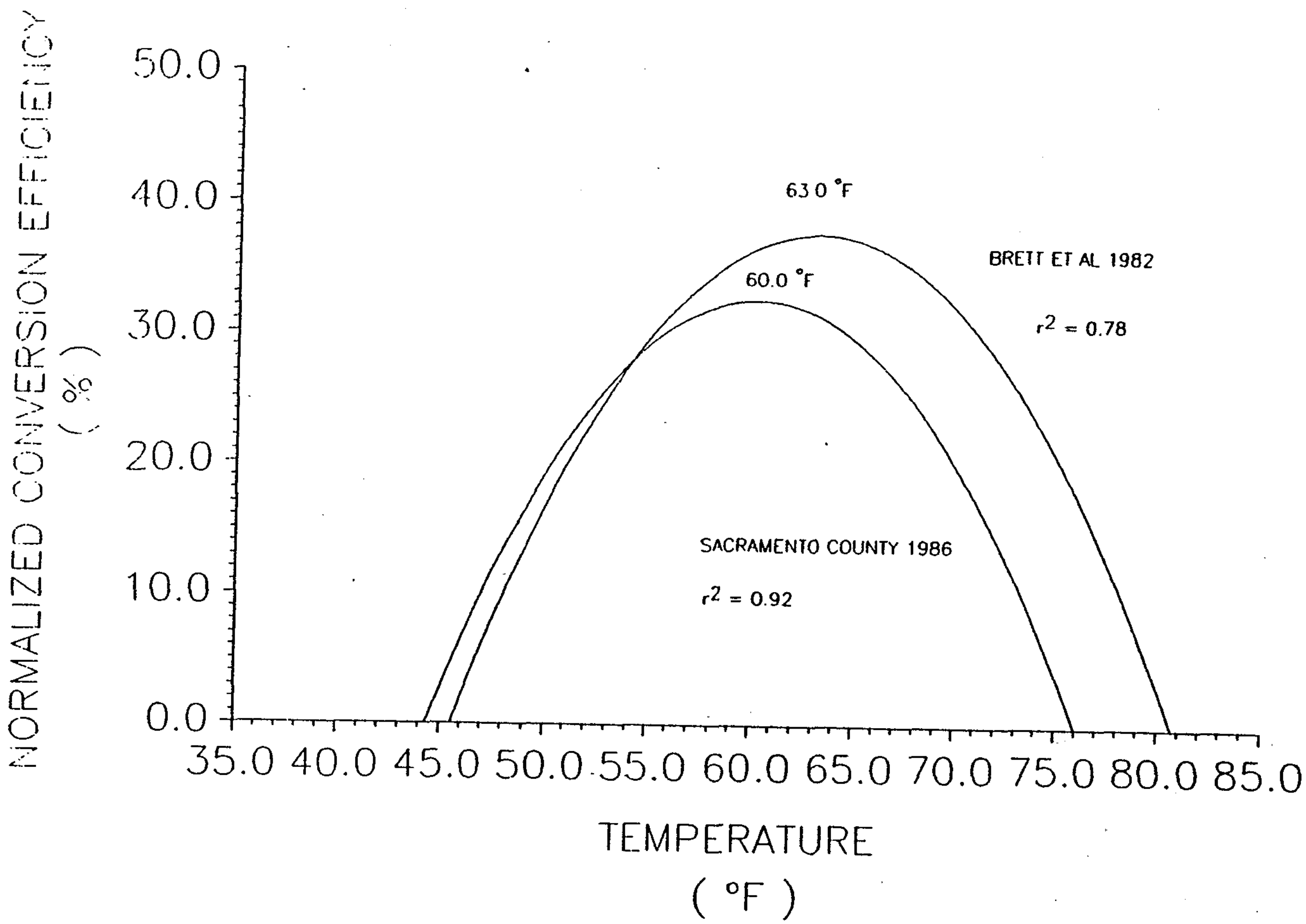

Figure 8. Comparison of the Optimum Water Temperatures for the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations with those of Brett's Fish.

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C. ESTABLISHING OPTIMUM WATER TEMPERATURES AND CHRONIC TEMPERATURE STESS ZONES FOR FISH FED MAXIMAL RATIONS UNDER LABORATORY CONDITIONS

As discussed in previous sections, identifying Optimum Water Temperatures and Chronic Temperature Stress Zones are complicated and time-consuming tasks. Because of the intrinsic complexity of such studies and because of the variations which occur, it is not practical to assign one temperature as optimum for juvenile chinook salmon fed maximal ration. A range of Optimum Water Temperatures and relative Chronic Temperature Stress Zones are proposed. Provided that the results of the interpretations of the data make physiological and biological sense, then qualitative criteria are useful for assigning relative stress levels.

A method was developed for identifying Optimum Water Temperatures and assigning relative stress levels within the Chronic Stress Zone for the American River stock of juvenile chinook salmon fed maximal rations. It was essential that the method incorporate both food conversion efficiency and the stress which occurs at higher water temperatures, as the interaction of both of these would influence the health of the fish. The method consisted of multiplying the normalized food conversion efficiency by the normalized survivorship (percent survival) and relating this product to water temperature by fitting the data to a second order polynomial regression.

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Survivorship was used as a relative indicator of the stress which occurred at each of the temperatures (Figure 9). The results of this analysis demonstrated a peak at 57.5 F; this was assumed to be the Optimum Water Temperature. However, based on the results of the laboratory experiments, a range of Optimum Water Temperatures was used and 54-60 F was determined to be the Optimum Water Temperature Range under laboratory conditions.

To categorize the relative amount of Chronic Sublethal Temperature Stress associated with rising water temperatures, the area under the curve at water temperatures greater than 60 F (Upper Optimum Water Temperature) was divided into three increments (for Low, Medium, and High Chronic Temperature Stress), based on the regression analysis. The product value (normalized survival x conversion efficiency x 1000) at 60 F was divided by three to establish the three stress zones: Low, Medium, and High Chronic Temperature Stress Zones. The calculation resulted in a value of 785 (2.355 x 1000/3). The water temperature limits for each stress zone resulted in the following Chronic Temperature Stress Zones as follows:

Low Temperature Stress: from 60.1-68.0 F;
(68 F was the resulting temperature when the product value had dropped 785)

Medium Temperature Stress: from 68.1-72.5 F;
(72.5 F was the resulting temperature when the product value had dropped 1570 (785 x 2)

High Temperature Stress: from 72.6 F to Lethal.

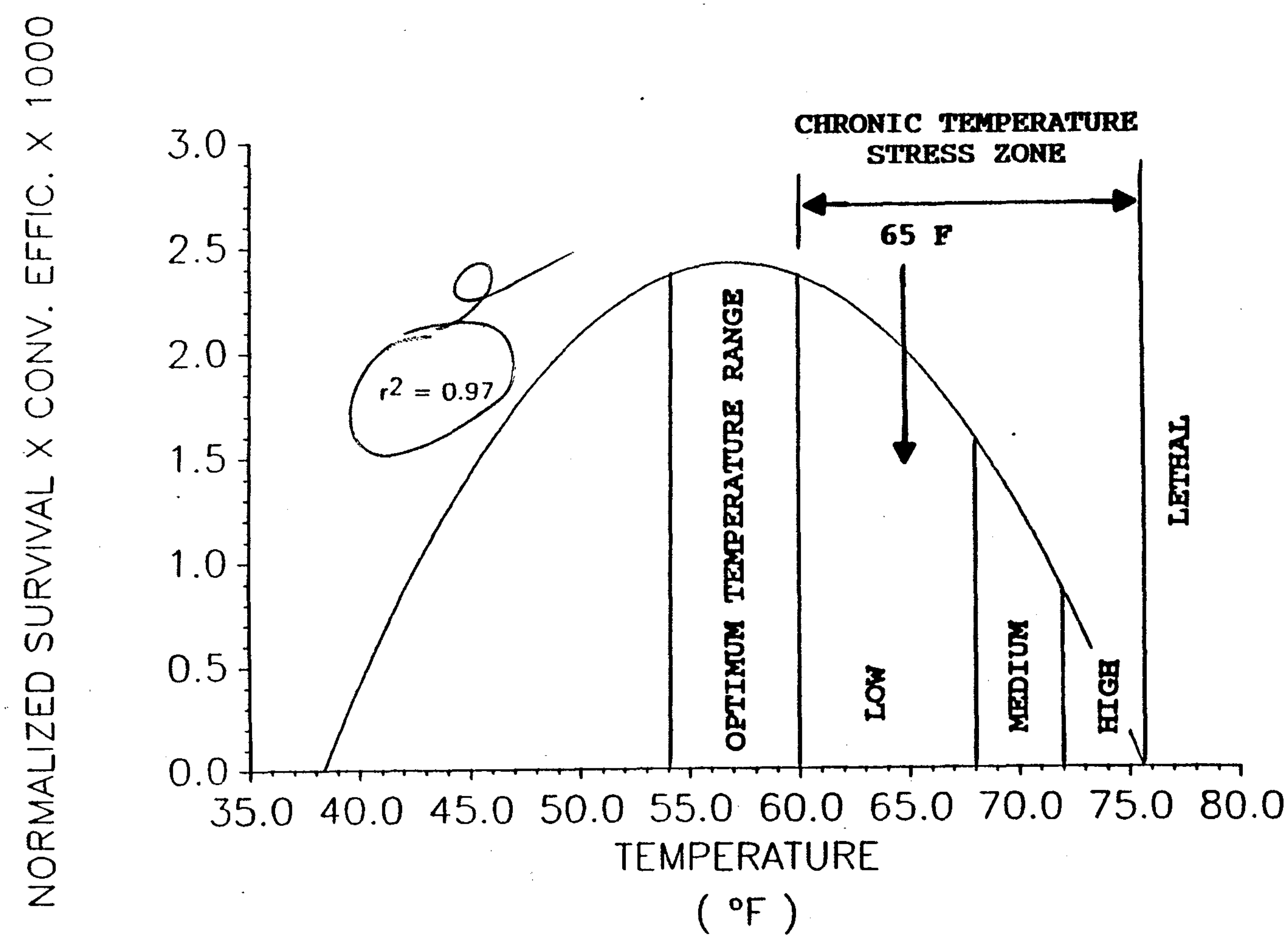

Figure 9. The Optimum Water Temperature Range and Chronic Temperature Stress Zones for the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations under Laboratory Conditions.

Chronic High Temperature Stress is often lethal and when this occurs the stress is classified as Acute Temperature Stress.

The results demonstrate clearly that 65 F is a stressful water temperature; 65 F is categorized as a Chronic Low Temperature Stress under maximal ration conditions (Figure 9). ? what results?

VI. ESTABLISHING A RANGE OF WATER TEMPERATURES WHICH OPTIMIZE GROWTH AND SURVIVAL IN JUVENILE CHINOOK SALMON UNDER THE CONDITIONS OF THE LOWER AMERICAN RIVER

A. RE-EVALUATION OF EBMUD'S 1985 JUVENILE CHINOOK SALMON DATA

1. Comparison of EBMUD's Methods with Previously Established Methods for Determining Optimum Temperatures

The study methodology is crucial for making accurate predictions of the Optimum Water Temperature range for fish of any species; salmon are no exception (See Sections II and III). A comparison of EBMUD's methods with those normally used for predicting Optimum Water Temperatures in fish sampled from natural populations (See Section IIIE) shows the EBMUD's methods were in error. Several critical ingredients were missing from EBMUD's 1985 study:

(1) EBMUD used Brett's unvalidated growth model which, when recently validated was found by Brett and his colleagues to be incorrect for field application; and,

(2) EBMUD used a water temperature model which was not sensitive to changes in daily or even weekly water temperatures.

2. Relation of Growth Rate to Water Temperature (Based on EBMUD's 1985 Data)

Because the juvenile chinook salmon in the lower American River feed less than maximally, the Optimum Water Temperature range would be lower than that established under maximal rations (54-60 F; See Section IIID). Therefore, the Optimum Water Temperature range of 58-63 F suggested by EBMUD is in error. Although EBMUD's data are limited, the sampling times far apart, the sample sizes small, and River temperatures where the data were collected were limited to 52-59 F, existing evidence indicates that the Optimum Water Temperature range may be as low as 53-56 F and that no growth occurs at water temperatures above 58 F.

When one plots all of EBMUD's 1985 data, instead of excluding some of the data as EBMUD did, peak growth rates occur in the vicinity of 53-56 F (Figure 10)[1/],[2/]. Optimum Water Temperatures also may be in the 53-56 F vicinity because food conversion efficiencies were comparable to growth rates at these same temperatures (Figures 4 and 5). These results are

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1/ Due to hatchery releases, EBMUD's 1984 American River data shuld not be used at all. The two weeks of data used by EBMUD is not of sufficient duration for this type of study (See Section IIIE).

2/ A daily water temperature model, developed by Dr. Jack Humphrey for the County, was used to predict the mean River temperatures at each of the stations during the sampling period. For purposes of this example, it is assumed that the fish remained in the sites sampled.

in agreement with recent studies by Drs. Brett and Clarke (Clarke, 1986, 1987). In subsequent validation studies, Brett and his colleagues identified 56.4 F as the Optimum Water Temperature for juvenile chinook salmon in the natural environment of the Nechako River in British Columbia. These results are also in the vicinity of the established preferred water temperature of juvenile chinook salmon (53 F), a temperature which Dr. Brett believes to be closest to the true Optimum Water Temperature for juvenile chinook salmon in the natural environment (Brett, 1952).

The 1985 data from the lower American River provide an excellent illustration of the concept of greater food conversion efficiency at lower water temperatures. Figure 11 demonstrates that at 54 F, the fish in the lower American River were growing just as well as those in the laboratory at 59 F. As discussed previously (See Section IIID), because rations are reduced in the natural conditions of the lower American River, food conversion is more efficient at low temperatures and thus the Optimum Water Temperature is lower than that established under the maximal ration conditions of the laboratory.

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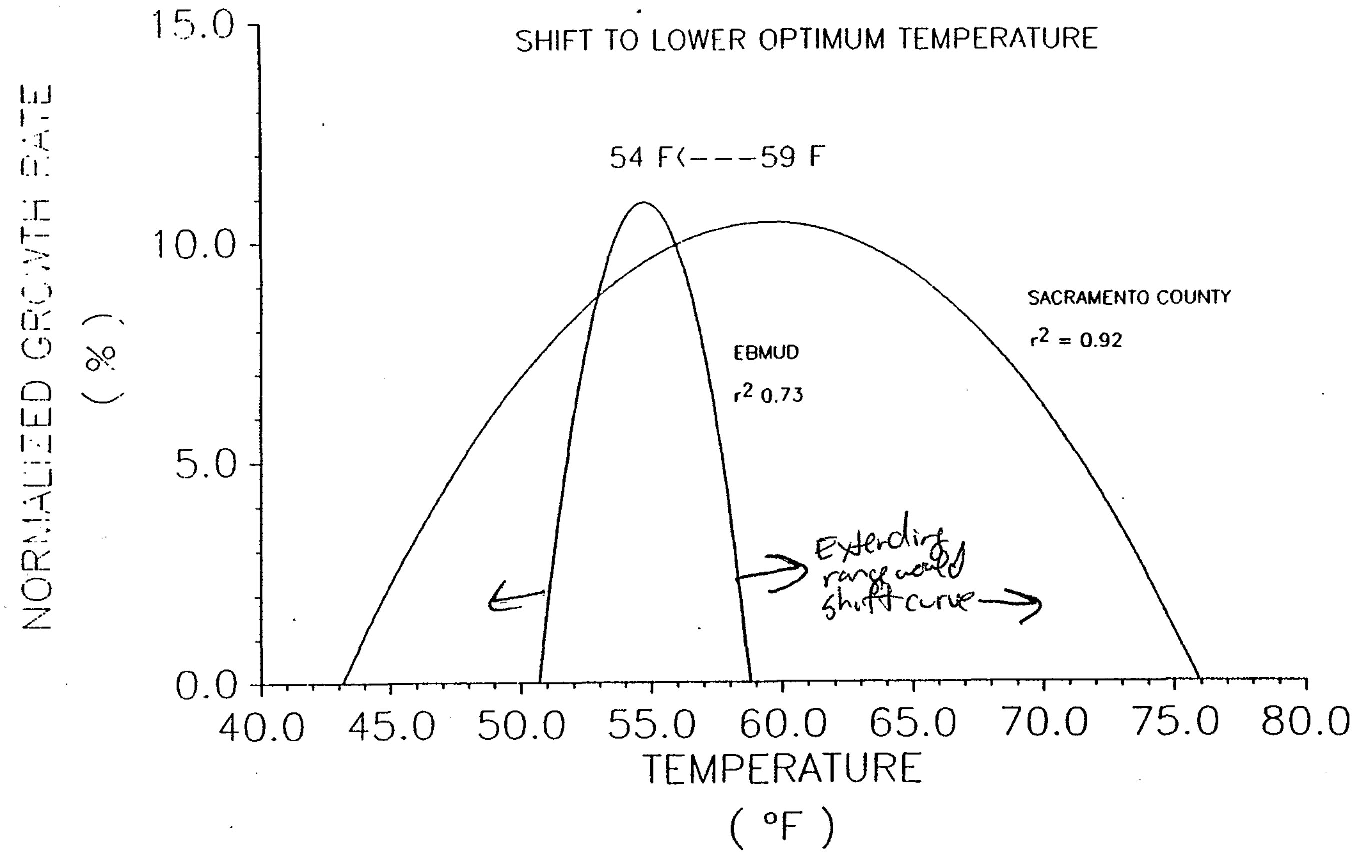

Figure 11. Comparison of the Growth Rates of Juvenile Chinook Salmon Fed Maximal Rations under Laboratory Conditions with those of Fish Under the Conditions of the Lower American River.

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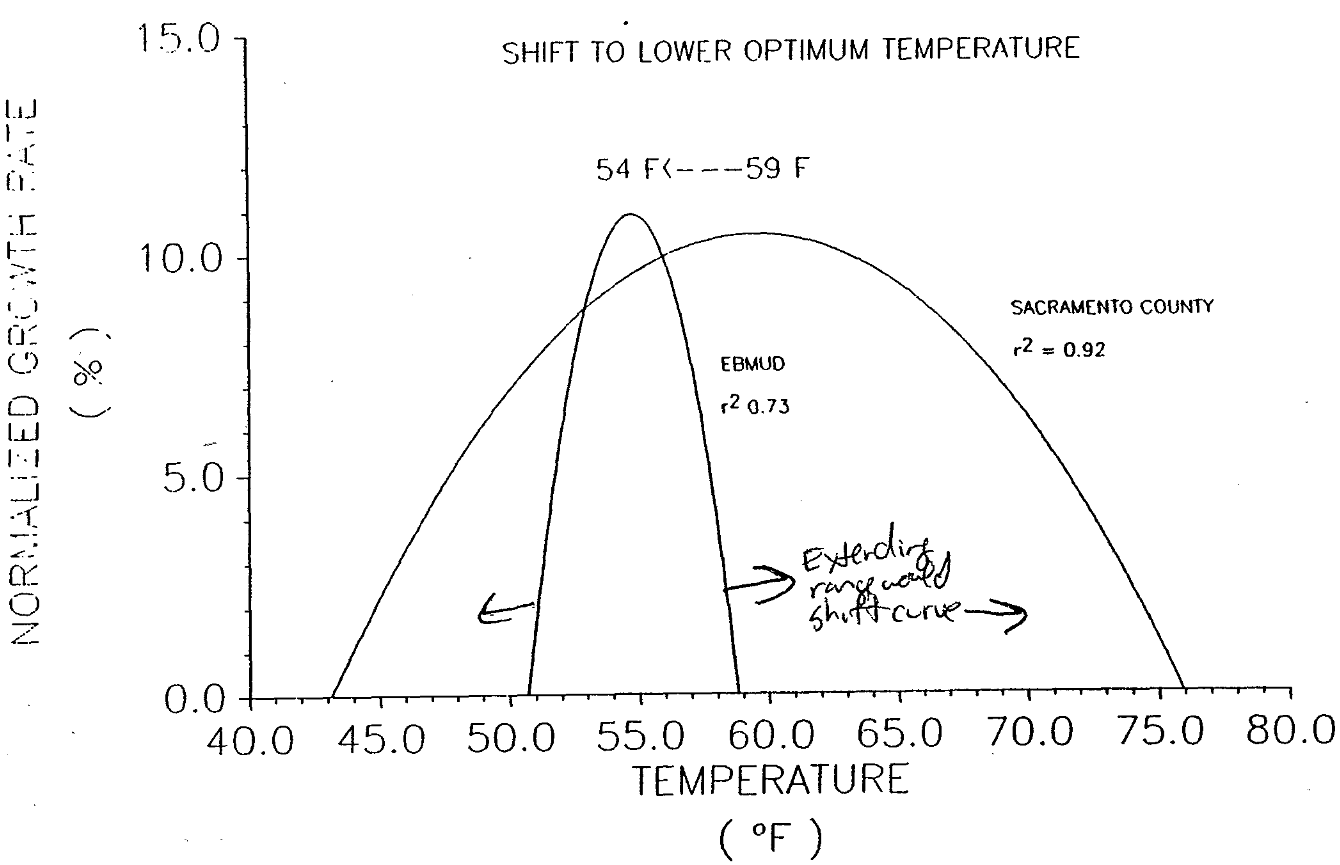

Figure 11. Comparison of the Growth Rates of Juvenile Chinook Salmon Fed Maximal Rations under Laboratory Conditions with those of Fish Under the Conditions of the Lower American River.

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3. <u>Water Temperature Increases in the Lower American River do not Shift Growth Rates Closer to the Optimum</u>

Contrary to EBMUD's contention, growth rates shift <u>away</u> from optimum as water temperatures rise (Figure 10). At water temperatures above 58 F, no growth occurred (Figure 10). In nature

4. <u>There is no Relation between Water Temperature and Condition Factor for the Juvenile Chinook Salmon Collected by EBMUD in the Lower American River</u>

Condition factor did not increase as water temperatures increased in the lower American River. Using the American River water temperature model developed by Dr. Humphrey, the results show clearly that condition factors did not change as water temperatures increased (Figure 12). These results are in agreement with the laboratory study which demonstrated no relation between water temperature and condition factor (Figure 6).

E8MUD's contention that hatchery releases explained the lower condition factors exhibited by fish sampled in mid-June of 1984 is in error. Hatchery fish, due to the high amount of fat they assimilate, normally have much higher condition factors than those from natural populations. The results from the laboratory study corroborate this -- the fish had condition factors that were 20-40% higher than those from the fish in the lower American River (Figure 6 and 12).

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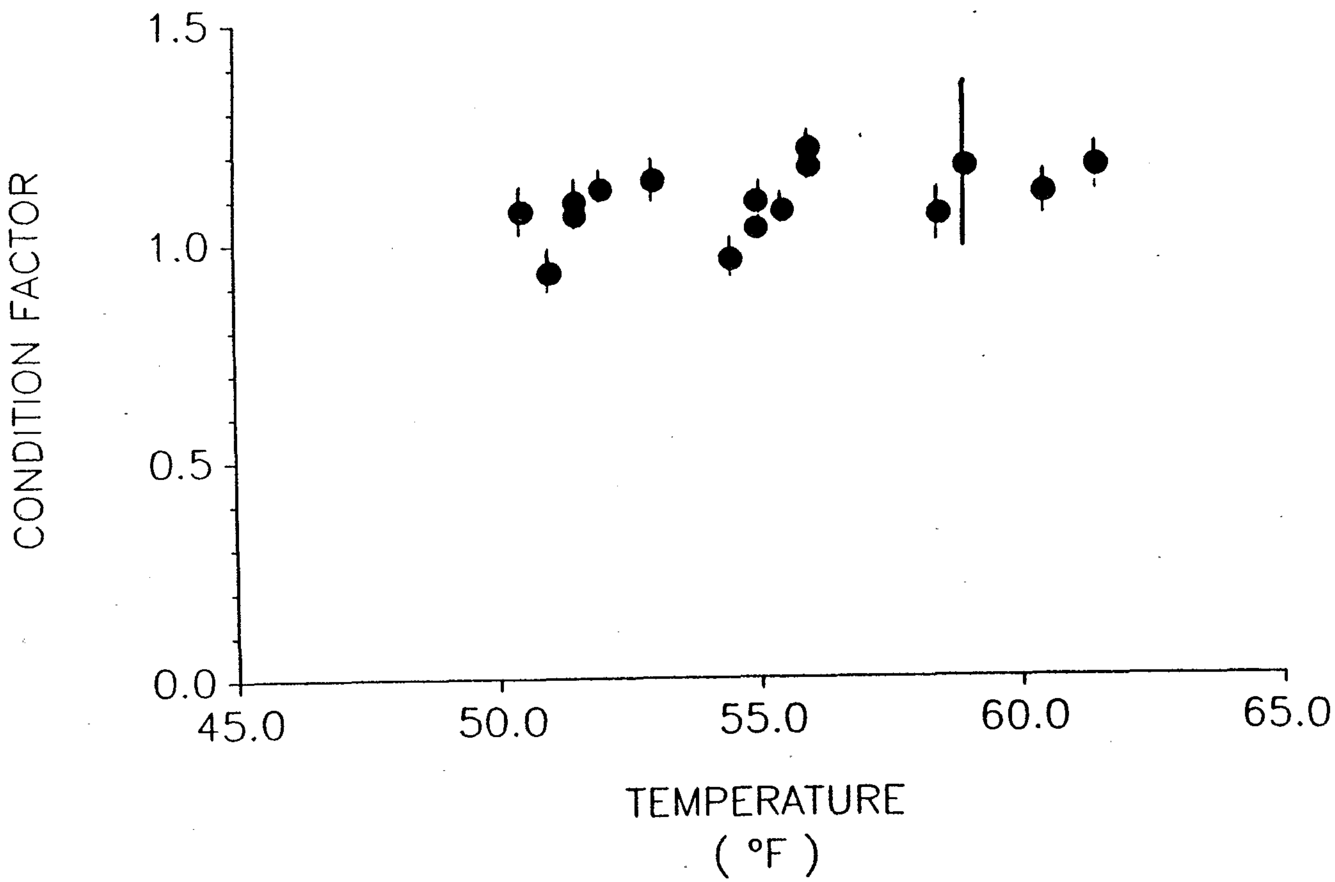

Figure 12. There is no Relation between Water Temperature and Condition Factor in the Juvenile Chinook Salmon Sampled by EBMUD. The lines drawn thru the data points are 95% confidence limits, according to Kelley et al., 1985b, p. 36.

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C — 0 4 3 5 7 8

B. <u>ESTABLISHING OPTIMUM WATER TEMPERATURES AND CHRONIC TEMPERATURE STRESS ZONES FOR JUVENILE CHINOOK SALMON UNDER THE CONDITIONS OF THE LOWER AMERICAN RIVER</u>

To establish Optimum Water Temperatures for the juvenile chinook salmon in the lower American River, EBMUD's 1985 data were analyzed in relation to existing water temperatures using Dr. Humphrey's water temperature model. As no growth occurred at water temperatures above 58 F, 56 F was selected as the Upper Optimum Water Temperature. 56 F <u>may</u> be high because if the fish were not growing at water temperatures above 58 F, then there would be Chronic Temperature Stress at 56 F. 53 F was selected as a lower Optimum Water Temperature, based on the results of the regression analysis (Figure 10). Thus, the Optimum Water Temperature range for juvenile chinook salmon in the lower American River was 53-56 F (Figure 13).

To categorize the relative amounts of stress associated with rising water temperatures in the lower American River, the results of the laboratory study were applied to EBMUD's 1985 lower American River data as follows. In the laboratory study, Chronic Low Temperature Stress occurred at water temperatures which were 1-13.3% above the Upper Optimum Water Temperature; Chronic Medium Temperature Stress occurred at water temperatures which were from 13.4-20.8% above the upper Optimum Water Temperature; and water temperatures which were greater

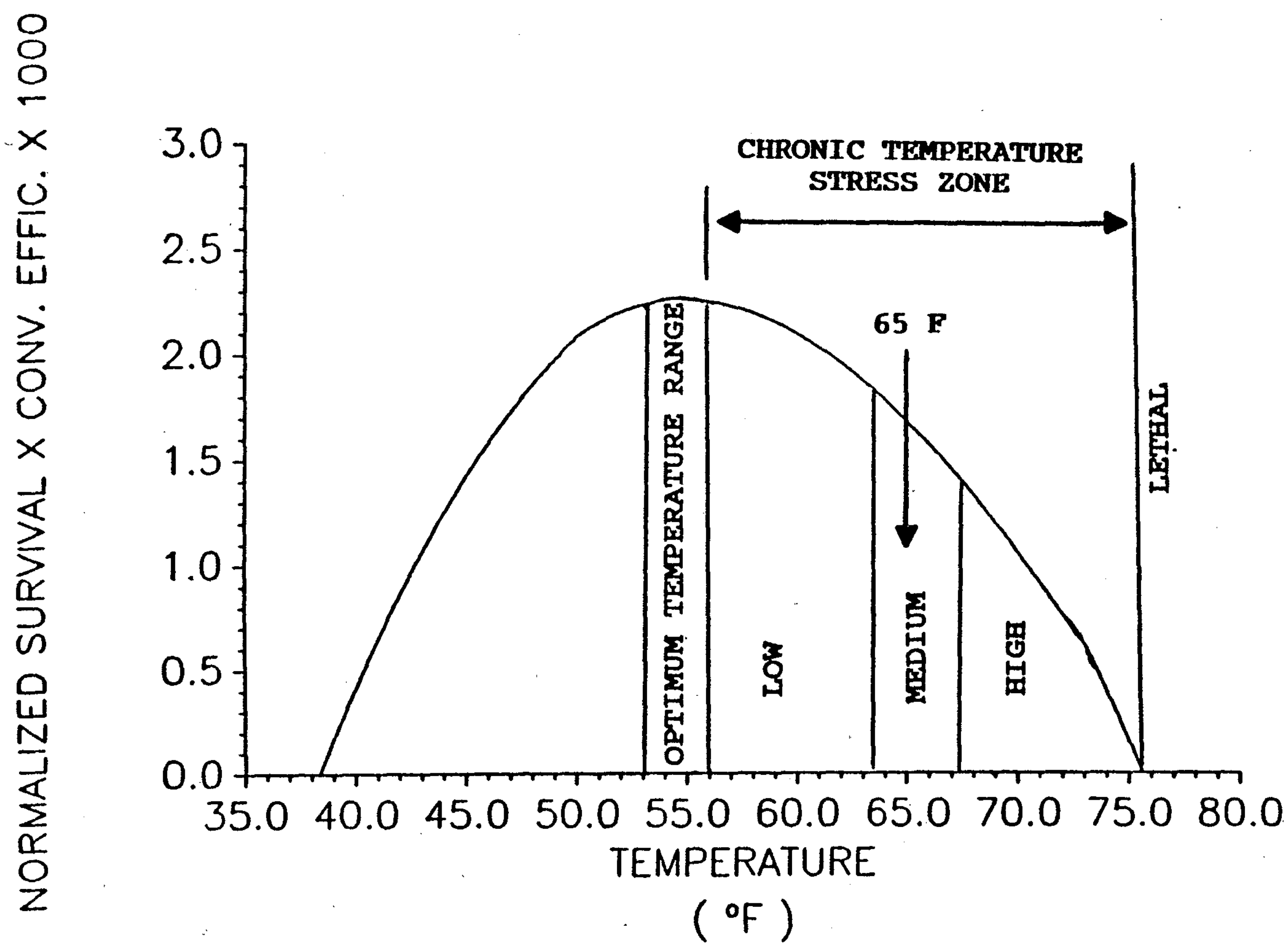

Figure 13. The Optimum Water Temperature Range and Chronic Temperature Stress Zones for Juvenile Chinook Salmon under the Conditions of the Lower American River.

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than 20.8% above the upper optimum but less than 75.2 F (lethal) were classified as Chronic High Temperature Stress (Figure 9). These same percentages were applied to the juvenile chinook salmon in the lower American River. The resultant Chronic Temperature Stress Zones for juvenile chinook salmon in the conditions of the lower American River were as follows: Chronic Low Temperature Stress-56.1-63.4 F; Chronic Medium Temperature Stress-63.5-67.6; and, Chronic High Temperature Stress-67.7 F up to Lethal (75.2 F in the laboratory study, likely less under the conditions of the lower American River) (Figure 13).

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VII. CONCLUSIONS

From the results and discussion, the following conclusions are made:

(1) The Optimum Water Temperature range in the American River stock of juvenile chinook salmon fed maximal rations under laboratory conditions was 54-60 F;

(2) The Optimum Water Temperature range in juvenile chinook salmon under the natural conditions of the lower American River was definitely no greater than 54-60 F and may have been as low as 53-56 F;

(3) When both Lower and Upper Lethal Temperature Limits were added to each set of data (County, Brett, Banks), the results of the laboratory study were consistent with those of previous studies;

(4) The Chronic Temperature Stress Zone for the American River stock of juvenile chinook salmon fed maximal rations was between 60 F (upper optimum) and 75.0 F (the water temperature which was 100% lethal);

(5) Within the Chronic Temperature Stress Zone, the severity of the stress increased with increasing water temperature;

(6) 65 F was classified as a Chronic Low Temperature Stress in juvenile chinook salmon fed maximal rations under laboratory conditions;

(7) 65 F was classified as a Chronic Medium Temperature Stress in juvenile chinook salmon under the natural conditions of the lower American River;

(8) Long-term exposure of juvenile chinook salmon to Chronic Temperature Stress will reduce the population in the lower American River; and,

(9) Water temperatures had no effect on condition factor for juvenile chinook salmon fed maximal rations or under the natural conditions of the lower American River.

C-043583

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APPENDIX A: METHODS FROM THE LABORATORY STUDY

A. LABORATORY EXPERIMENTS

1. <u>Fish</u>

All fish were obtained from the Nimbus American River Hatchery and transported to the nearby California Department of Fish and Game Disease Lab in Rancho Cordova, California. The standard method for determining specific growth rates assumes that the rate of change in size is dependent upon initial size (Ricker, 1979). Thus, upon arrival at the Lab, the fish were screened for a fairly uniform size. The fish (N=160) were then anaesthetized with buffered (sodium bicarbonate) MS-222 (50mg/l), weighed, measured (fork length), and transferred to the experimental tanks. A sample of 100 fish was taken from the remaining reserves to determine initial dry weights.

2. <u>Experimental Tanks</u>

Fourteen 57-l plexiglass rectangular aquaria (separated in pairs for duplicate tests for each temperature), equipped with a cover and a continuous flow (3.8 l/ min) of water from the American River, were used (Fig. 1). The water flow paths

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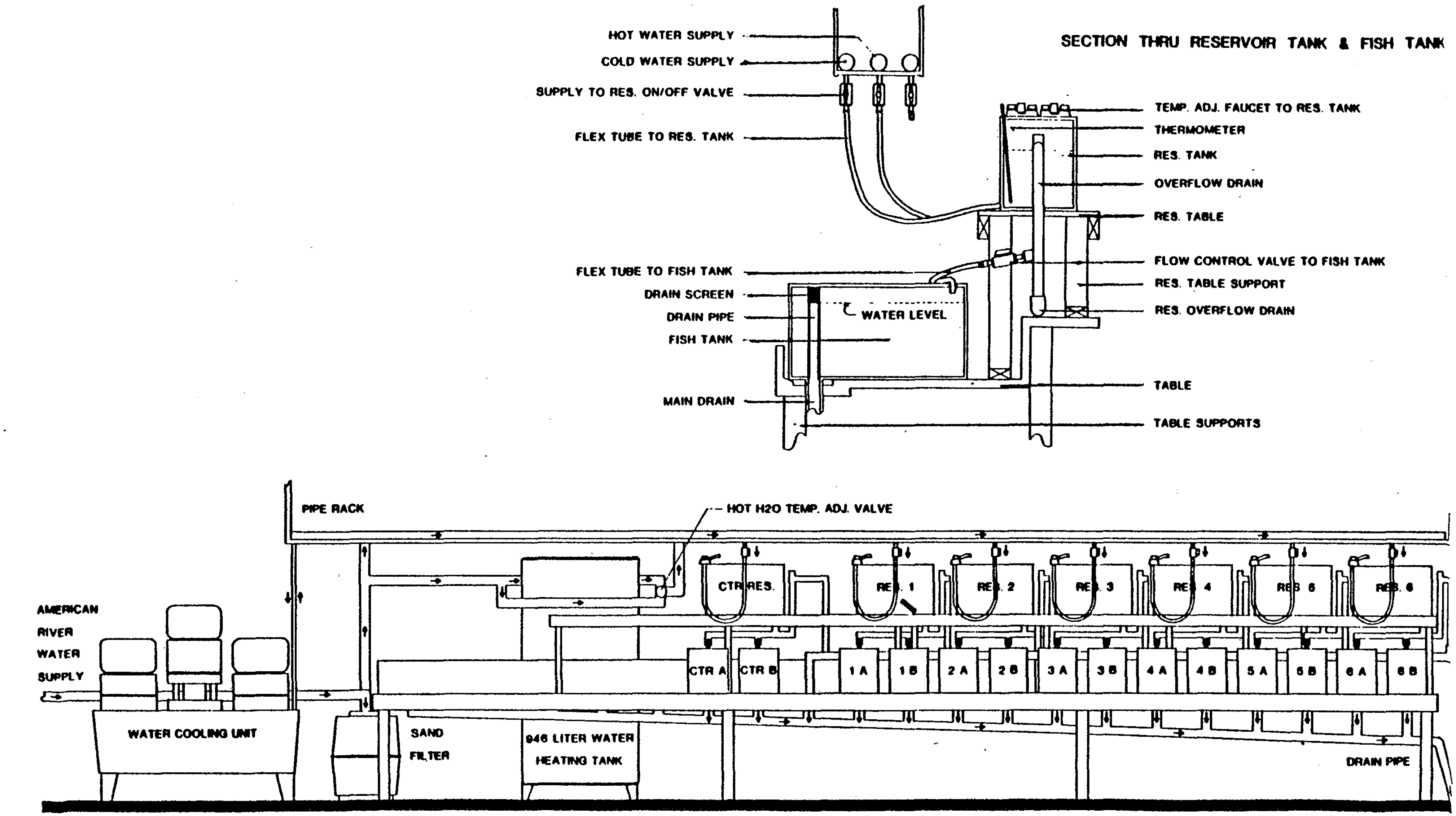

FIGURE 1. SCHEMATIC DESIGN OF LABORATORY APPARATUS USED FOR AMERICAN RIVER TEMPERATURE - GROWTH STUDIES

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consisted of the following:

Chilled Water (for Tanks 1A, 1B, and later, as the water temperature warmed up, Tanks 2A and 2B)

American River ---> Sand Filter ---> Water Chiller (via Aluminum Coil) ---> Reservoir (Temperature Mixing) ---> Experimental Tanks

Heated Water and Unaltered American River Water (for Tanks Control A and B (CTR A, CTR B), Tanks 3A - 6B)

American River ---> Sand Filter ---> Reservoir (Temperature Mixing) ---> Experimental Tanks

PVC pipe was used to connect the system and water temperatures were maintained by mixing (via the temperature mixing Reservoirs) the appropriate quantities of chilled, heated, and/or unaltered American River water (Fig. 1).

As depleted dissolved oxygen (D.O.) levels have impaired growth (Brett and Blackbourn, 1981), D.O. measurements were made weekly, throughout the experiments, using a HACH D.O. Kit (Model OX-2P).

3. Sand Filter

Due to the high sediment content in the water, as a result of the flood, a sand filter had to be fitted into the system Beginning each day of the experiment, the filter was backflushed for five minutes.

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4. Temperature and Light

The fish were first acclimated to the incoming American River water for two days. Then water temperatures were modified on a daily basis, according to Fry (1971), until the final desired temperatures in the tanks were reached.
Selected water temperatures were: 50.9, 56.3, 59.9, 65.3,4 69.8, and 75.2 F.

Normal photoperiod was provided from natural light, reflected on the tanks through the adjacent windows. Fluorescent lighting in the laboratory provided additional lighting.

5. Food and Feeding

The fish were fed maximum ration (Rmax), five times per day with Oregon Moist Pellets (OMP), as per the feeding scheule at Nimbus Hatchery (Ducey, 1986). Rmax was established by feeding until pellets were rejected.

To determine the exact weight of the food consumed/day, the following procedure was used. At the beginning of each day, the tanks were siphoned and the feces discarded. At the end of each feeding, excess food was siphoned, poured in buckets, and filtered. At the end of each day, the food filtrate from each tank was dried at 110 F for 24 hours in a drying oven (VWR model 1300U).

6. Procedure for Weight and Length Measurements

To assess the condition of the fish during the experiment, the fish were subsampled. Subsamples were made on the following dates: May 2 - 25 fish; weekly thereafter - 15 fish/tank. On each sampling day the fish were anaesthetized (as previously described), weighed (to the nearest 0.1 g) measured (fork length), and the sampled fish frozen for future dry weight analysis. Growth rates and condition factors were calculated for each subsample and dry weight analyses were made to determine the conversion efficiencies for each of the subsampled fish.

On the final day of the experiment, all fish were anaesthetisized (as described previously), weighed, measured, and the fish frozen, for future dry weight analysis. To empty the stomach contents, the fish were starved for two days prior to the termination of the experiment. Growth rates and condition factors were calculated for all the fish and dry weight analyses were made to determine conversion efficiencies.

7. Dry Weight Analysis

a. Fish

Within a week after freezing the fish the frozen fish were thawed, placed in aluminum drying pans, and dried 203.0 F for 24 hours in the drying oven.

b. Food

To determine the percentage of moisture in the food (OMP), triplicate samples (1.0 g, 3.0 g, 5.0 g, and 10.0 g) of food were placed in the aluminum pans and dried at 110.0 F for 24 hours in the drying oven. The resultant dry wights were averaged and used in the calculations for food conversion efficiency.

B. DATA ANALYSIS

1. Data Compilation

Daily water temperatures (monitored hourly), food consumption, mortalities, and indicators of sublethal temperature stress (disease, reduced appetite, hyperactivity) were recorded on a daily basis. All data were entered into the data base management program RBASE 5000, using a Compaq DeskPro computer.

2. Calculations

a. Growth Rate

Instantaneous growth rates (G) (expressed as percent body weight) (Ricker, 1979) were calculated as follows:

$$G = \frac{\log_e W_f - \log_e W_i}{t_f - t_i} \times 100$$

where,

W_f and W_i = mean final wet weight and mean initial wet weight in grams

t_f and t_i = times (days) at which experiment was terminated and initiated, respectively.

In addition, G were calculated each week.

b. Food Conversion Efficiency

Food Conversion Efficiency (CE) is the capacity to convert food into flesh or grams of growth per gram of food (Brett and Groves, 1979). Gross Conversion Efficiencies were calculated as follows:

$$CE = (G/R) \times 100\%$$

where,

R = total amount of food consumed/fish (dry weight)

G = mean dry weight gain

$$= \frac{DW_f - DW_i}{t_f - t_i}$$

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where,

DW_f = mean final dry weight (grms)

DW_i = calculated initial mean dry weight*

t_f and t_i = times (days) at which experiment was terminated and initiated, respectively

c. Condition Factor

Condition Factors (K) were calculated as follows:

$$K = \text{Wet Weight (g)} \times \frac{100}{(\text{length in cm})^3}.$$

3. Statistical Analysis

Growth rates, conversion efficiencies, and survivorship were normalized using an arcsin transformation and the resultant caculations fitted to a second order polynomial regression, using the statistical package SPSSPC+.

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* 100 fish were used to determine initial dry weights.

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APPENDIX B: RESULTS FROM THE LABORATORY STUDY

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C-043598

A.A. RICH AND ASSOCIATES

Table 1. Lengths, Weights, and Condition Factors in Relation to Temperature for the American River Stock of Juvenile of Chinook Salmon fed Maximal Rations.

Mean Temperature (deg. F)	INITIAL MEASUREMENTS LENGTH (cm)	INITIAL MEASUREMENTS WEIGHT (g)	INITIAL MEASUREMENTS CONDITION FACTOR	FINAL MEASUREMENTS LENGTH (cm)	FINAL MEASUREMENTS WEIGHT (g)	FINAL MEASUREMENTS CONDITION FACTOR
50.9 ±0.7	6.0 ±0.2	2.6 ±0.2	1.2 ±0.2	8.3 ±0.6	6.7 ±1.4	1.2 ±0.1
50.9 ±0.7	6.0 ±0.2	2.7 ±0.1	1.3 ±0.2	8.3 ±0.7	6.7 ±1.7	1.2 ±0.1
55.8 ±0.4	6.0 ±0.2	2.5 ±0.2	1.2 ±0.2	9.1 ±0.8	9.1 ±2.1	1.2 ±0.1
55.8 ±0.4	6.0 ±0.3	2.7 ±0.1	1.2 ±0.2	9.1 ±0.6	9.1 ±1.9	1.2 ±0.1
57.4 ±1.2	6.0 ±0.2	2.5 ±0.2	1.1 ±0.2	9.3 ±0.7	9.6 ±2.1	1.2 ±0.1
57.4 ±1.2	6.0 ±0.2	2.6 ±0.2	1.2 ±0.2	9.1 ±0.8	9.0 ±2.4	1.2 ±0.1
59.5 ±0.3	6.1 ±0.3	2.7 ±0.1	1.2 ±0.2	9.3 ±0.8	9.8 ±2.4	1.2 ±0.1
59.5 ±0.3	6.0 ±0.3	2.7 ±0.1	1.2 ±0.2	9.0 ±0.8	9.4 ±2.3	1.3 ±0.1
66.2 ±0.3	6.1 ±0.2	2.6 ±0.2	1.2 ±0.2	8.6 ±1.1	8.4 ±3.0	1.3 ±0.1
66.2 ±0.3	6.0 ±0.3	2.7 ±0.2	1.3 ±0.2	8.3 ±1.1	7.4 ±3.1	1.2 ±0.2
69.8 ±0.4	6.0 ±0.2	2.7 ±0.2	1.3 ±0.2	7.0 ±0.5	4.3 ±0.2	1.3 ±0.3
69.8 ±0.4	6.0 ±0.3	3.0 ±0.5	1.4 ±0.3	7.0 ±0.5	4.3 ±0.3	1.3 ±0.3
75.2 ±0.4	6.0 ±0.3	2.7 ±0.4	1.2 ±0.3	FISH DIED		
75.2 ±0.4	6.0 ±0.3	2.8 ±0.3	1.3 ±0.2	FISH DIED		

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Table 2. Growth Rates and Conversion Efficiencies in Relation to Temperature for the American River Stock of Juvenile Chinook Salmon Fed Maximal Rations.

Mean Temperature (deg. F)	Growth Rate (% wt/day)	Conversion Efficiency (%)
50.9 ± 0.7	2.1 ± 0.5	20.9 ± 1.3
50.9 ± 0.7	2.0 ± 0.6	21.4 ± 1.3
55.8 ± 0.4	2.9 ± 0.5	24.5 ± 1.2
55.8 ± 0.4	2.7 ± 0.5	22.2 ± 1.6
57.4 ± 1.2	2.9 ± 0.5	24.6 ± 1.0
57.4 ± 1.2	2.7 ± 0.6	23.3 ± 1.0
59.5 ± 0.3	2.8 ± 0.6	24.9 ± 1.6
59.5 ± 0.3	2.8 ± 0.6	24.4 ± 1.6
66.2 ± 0.3	2.6 ± 0.4	22.5 ± 1.0
66.2 ± 0.3	2.2 ± 0.5	21.6 ± 1.0
69.8 ± 0.4	2.2 ± 0.2	19.7 ± 0.7
69.8 ± 0.4	1.8 ± 0.5	15.4 ± 0.9
75.2 ± 0.4	---------- fish died	-------------
75.2 ± 0.4	---------- fish died	-------------

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December 24, 1986
R1384.03

American River Water Temperatures from QUAL2E model.

	SAILOR BAR			ANCIL HOFFMAN			ARDEN WAY			WATT AVE			HOWE AVE		
	9AM	12AM	3PM	9AM	12AM	3PM	9AM	12AM	3PM	9AM	12AM	3PM	9AM	12AM	3PM
1984 June 14	55	55	56	55	56	57	55	56	58	56	57	58	56	57	59
June 15	55	55	55	55	56	57	55	56	57	56	57	58	56	57	58
June 28	56	56	57	56	57	58	56	58	59	58	58	60	58	59	60
June 29	56	56	57	56	57	58	57	58	59	58	58	60	59	59	60
1985 April 18	51	51	51	51	50	50	51	50	50	52	51	51	52	51	51
April 30	53	53	54	53	54	55	53	54	56	53	54	56	54	55	56
May 1	54	54	55	54	55	56	54	55	56	54	55	57	55	56	57
May 16	51	52	52	51	53	54	51	53	54	53	54	55	54	55	56
May 17	51	51	52	51	52	54	51	52	54	52	53	55	53	53	55
May 30	55	55	56	54	56	58	55	56	58	55	56	58	56	57	58
June 13	58	58	59	58	59	61	58	59	61	59	60	62	60	61	62
June 14	58	58	59	58	59	60	58	59	61	59	60	62	60	61	62
July 5	60	60	61	60	61	62	60	61	63	61	62	64	62	62	64
1986 March 12	52	52	52	51	51	52	51	52	52	51	51	52	51	51	52
March 19	51	51	51	50	51	52	50	51	52	50	51	52	50	51	52
March 24	51	51	51	50	51	52	51	51	52	50	51	52	51	51	53
March 31	53	53	53	52	53	54	52	53	54	52	53	54	53	53	55
April 9	48	48	48	48	48	49	48	49	50	48	49	50	48	49	50
April 14	54	54	54	53	54	55	53	54	55	53	54	56	53	54	56
April 21	55	55	55	55	56	56	55	56	57	55	56	57	55	56	57
April 28	55	55	55	55	56	57	55	56	57	55	56	58	56	56	58

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APPENDIX III

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AMERICAN RIVER
WATER TEMPERATURE MODELING

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April 1987
R1384.03

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LIST OF FIGURES, Continued

AMERICAN RIVER
WATER TEMPERATURE MODELING

INTRODUCTION

The American River below Nimbus Dam was modeled to demonstrate how flow releases affect water temperatures during warm months. As flows are decreased throughout the warm period, water temperatures increase downstream due to the longer time of travel and shallower depths associated with lower flows. These flow conditions allow the water temperature to reach equilibrium closer to atmospheric conditions. Since the water released from Folsom Reservoir during the period from April through October is normally cooler than mean atmospheric equilibrium conditions, the water gradually warms as it flows downstream.

The model QUAL2E, a dynamic water quality simulation model, was used to determine water temperatures downstream of Nimbus Dam under various flows conditions. The QUAL2E dynamic water temperature simulation program was modified for use on IBM PC compatible computers from an earlier version called QUAL-2, by the U.S. Environmental Protection Agency in Athens, Georgia in August 1986. The dynamic water temperature simulation option of this computer program required three hourly climatological data of air temperature, dew point temperature, cloudiness, air pressure, and wind speed. The program calculates energy balance components at the water surface for convective heat transfer, evaporative heat transfer, net long wave radiation, and net solar radiation.

The American River Water Temperature Model extended from the mouth at the Sacramento River to 22.2 miles upstream at the USGS gage just downstream of Nimbus Dam. The QUAL2E model was set up with 22 reaches, each one mile in length, using representative hydraulic characteristics and upstream boundary flow and temperature condi-

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tions. The model was calibrated using water temperature data collected in a 1986 field program and was used to simulate water temperatures for historic and alternative flows.

DATA SOURCES

CLIMATOLOGICAL DATA

Hourly recorded weather observations were available at Mather Air Force Base, Sacramento Executive Airport, and Sacramento Metro (downtown) since the 1940's. These data were obtained from the National Weather Service in Asheville, North Carolina. For the calibration of the model, climatological data were obtained for all three stations from May through September 1986. Data at Sacramento Executive Airport were obtained for the 1957-1986 period on magnetic storage tape for simulation of the historic conditions. This data included air temperature, cloudiness, dew point temperature, air pressure, and wind speed.

Solar radiation data were obtained from the California Irrigation Management Information System for 1986 at Camino, Davis, and Lodi.

HYDROLOGIC DATA

A total of 30 years (1957-1986) of daily flow data were obtained from the U.S. Geological Survey in Sacramento for Gage No. 11446500, American River near Fair Oaks (2,100 feet downstream of Nimbus Dam). Flow data are available for this gage since November 1904 but only flows reflecting the regulation by Folsom Reservoir were used. A diversion to Folsom South Canal began in June 1973.

WATER TEMPERATURE DATA

Mean daily and maximum/minimum water temperature data were recorded for inflow water to the Nimbus Salmon and Steelhead Hatchery since 1956. The Nimbus Hatchery is located immediately below Nimbus Dam and utilizes water from the reservoir. These data were obtained from the California Department of Fish and Game Anadromous Fisheries Branch. The U.S. Geological Survey provided mean daily and maximum/minimum water temperatures at their Gage No. 11446500 American River near Fair Oaks. These data were available from 1960 to 1978 with some missing periods. Both the Nimbus Hatchery and American River near Fair Oaks water temperature are representative of temperatures of the upstream boundary of the river temperature model.

Daily water temperatures were recorded at the City of Sacramento water intake, approximately 15 miles downstream of the dam. This temperature data for May to September 1986 were obtained from the American River Water Treatment Plant Laboratory and were used for comparison with the calibration and verification of the model.

Water temperatures were recorded at several points on the American River beginning in fall 1985 in a program run by Beak Consultants. Six hourly water temperature data were collected from May 10 to October 4, 1986 at the confluence, 16th Street, California State University Sacramento (CSUS), and Hazel Avenue and were used for calibration and verification of the QUAL2E model.

same data for both??

HYDRAULIC DATA

Accurate simulation of water temperature required hydraulic input parameters of time of travel, depth, and associated width and velocity appropriate for a given flow for each of the 22 reaches. The hydraulic data were determined for a range of flows from 250 cfs to 10,000 cfs.

Aerial photography of the American River was used to determine the relationship of reach width with flow. Three sets of aerial photographs, as listed below, were used.

AERIAL PHOTOGRAPHY

Date	Flow	Source
March 8, 1977	250 cfs	Genge Aerial Surveys
July 6, 1985	3,500 cfs	Cal Aero Photo
April 11, 1986	6,910 cfs	Cartwright Aerial Photography

Reach slopes were obtained from the U.S. Geological Survey 7.5 minute topographic maps: Sacramento West, Sacramento East, Carmichael, Citrus Heights, and Folsom.

The Lower American River Instream Flow Studies by the California Department of Fish and Game, and Thomas R. Payne and Associates provided cross-section, depth, and velocity data at Sailor Bar, Ancil Hoffman Park, Watt Avenue, and H Street.

The U.S. Army Corps of Engineers, Sacramento District provided 36 cross-sections developed for flood studies from the mouth to 15.3 miles upstream. These cross-sections did not have accurate detail for low flows.

A bathymetric survey of the river was taken by Beak Consultants on November 11, 1986 from the mouth to 12 miles upstream.

River cross-sections were also obtained from the City of Sacramento and California Department of Transportation for various bridge crossings and pipeline routes.

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Relationships between flow and velocity, depth, and cross-section area were obtained from the U.S. Geological Survey for their gage 2,100 feet downstream of Nimbus Dam.

MODEL SET UP, CALIBRATION, AND VERIFICATION

The QUAL2E model was set up with 22 reaches, each one mile in length. All of the available hydraulic data were used to derive relationships between flow and depth and between flow and time of travel for each reach. Climatological data from Mather Air Force Base were used in initial calibration, however, it was found that Sacramento Executive Airport data were not significantly different. The Sacramento Executive data were used in the 30-year water temperature simulations since this data were available on magnetic tape allowing for quicker input to the model. The Nimbus Dam release boundary conditions of flow and water temperature were based on the recorded U.S. Geological Survey gage data and Nimbus Fish Hatchery data.

The calibration procedure involved changing convective heat transfer and evaporative heat transfer coefficients within a narrow range to reflect likely differences in wind speed between the climatological stations and the river. The model was calibrated using lower wind speeds for the river compared to the wind speed recorded at the airport. Solar radiation was reduced slightly during calibration to incorporate shading effects from riparian vegetation.

Four time periods were selected for calibration and verification of the dynamic temperature simulation model. These time periods were selected to encompass the range of flows, boundary temperatures, and climatological conditions observed in the historical irrigation season. These are shown below:

QUAL2E MODEL CALIBRATION/VERIFICATION

Time Period	Boundary Flow (cfs)	Boundary Temperature	Model
May 25-31, 1986	2,070	55.9°F	Calibration
August 31 - September 4, 1986	1,040	64.4°F	Calibration
June 17-22, 1986	2,500	57.0°F	Verification
July 29 - August 1, 1986	5,000	59.2°F	Verification

? inadequate data

Figures 1 through 4 show observed versus synthesized water temperatures at the CSUS water temperature recorder (7 miles upstream from the confluence). Maximum differences between recorded and simulated water temperatures are approximately 1°F which was attributed to inaccuracies in recorded water temperatures at the upstream boundary and at CSUS.

The calibrated model was used to produce dynamic temperature simulations for flows, boundary temperatures, and climatological conditions observed during the 1957-1986, 30-year period.

FLOW/TEMPERATURE-DURATION ANALYSIS

The 30 years of daily temperatures and flows for the American River downstream of Nimbus Dam were used to produce temperature-exceedance curves and flow-duration curves, annually and monthly. These temperature-exceedance curves are shown as Figures 5 through 17 and the flow-exceedance curves are shown as Figures 18 through 30.

ALTERNATIVE ANALYSIS

The QUAL2E model was used to simulate water temperatures downstream of Nimbus Dam for historical flow conditions and alternative flow conditions using the 30-year period of record. The model was run for the months of April through October when atmospheric conditions were expected to significantly influence the temperature of water released from Nimbus Dam. Alternative flow conditions were historic, 500, 800, 1000, 1250, 1500, 1750, 2000, 2500, and 3000 cfs. If an alternative flow exceeded the historic release for any month and year, it was not modeled since it was assumed that the mean monthly historic releases represented the largest release possible based on reservoir storage and inflow constraints. For these cases, the temperature-exceedance curves are a combination of modeled alternatives and historic flows. Daily water temperatures were determined for six locations downstream of Nimbus Dam at 2, 6, 10, 14, 18, and 22 miles. Temperature-exceedance curves were produced using the simulated 30-year daily temperature data for the months of April through November.

Tables 1 through 7 show the 10, 50, and 90 percent exceedance temperatures by flow and location. Figures 31 to 78 show temperature-exceedance curves by month and location for alternative flows. Figures 73 through 79 show 50 percent exceedance (median) temperatures versus location for each month.

Model only calibrated these months: May, June, Jul, Aug.

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TABLE 1

AMERICAN RIVER
WATER TEMPERATURE EXCEEDANCE DATA
FOR APRIL

Flow (cfs)	%	Miles Below Nimbus Dam: 2 (Sailor Bar)	6	10	14	18	22 (Mouth)
500	90	50.9	52.2	53.0	54.1	55.0	55.8
	50	54.0	55.3	56.3	57.7	59.0	60.7
	10	57.4	58.9	60.0	61.8	63.2	65.3
800	90	50.8	51.8	52.2	53.5	54.4	55.4
	50	53.9	55.0	55.8	57.1	58.1	59.7
	10	57.2	58.4	59.4	60.9	62.1	64.1
1000	90	50.7	51.5	52.3	53.1	54.0	55.0
	50	53.7	54.8	55.4	56.6	57.4	58.9
	10	57.0	58.0	58.9	60.1	61.3	63.1
1250	90	50.7	51.4	57.2	52.8	53.7	54.7
	50	53.7	54.6	55.3	56.3	57.0	58.5
	10	57.0	57.9	58.8	59.9	61.0	62.2
1500	90	50.7	51.3	52.0	52.5	53.3	54.4
	50	53.7	54.3	55.1	55.9	56.6	58.0
	10	57.0	57.8	58.6	59.7	60.7	62.3
1750	90	50.7	51.2	51.8	52.4	53.2	54.3
	50	53.7	54.3	55.0	55.7	56.4	57.8
	10	57.0	57.8	58.6	59.6	60.6	62.1
2000	90	50.7	51.0	51.5	52.1	52.7	53.8
	50	53.7	54.2	54.9	55.5	56.2	57.5
	10	57.0	57.8	58.6	59.7	60.7	62.2
2500	90	50.7	51.1	51.6	52.3	53.0	54.1
	50	53.7	54.2	54.7	55.3	56.0	57.2
	10	57.0	57.8	58.6	59.6	60.6	62.1
3000	90	50.7	50.9	51.4	51.9	52.4	53.6
	50	53.7	54.1	54.6	55.2	55.7	56.9
	10	57.0	57.8	58.6	59.6	60.5	62.2
HIST	90	50.7	50.7	50.8	51.0	51.8	52.5
	50	53.7	54.1	54.3	54.8	55.3	56.3
	10	57.0	57.7	58.5	59.5	60.5	62.0

TABLE 2

AMERICAN RIVER
WATER TEMPERATURE EXCEEDANCE DATA
FOR MAY

		Miles Below Nimbus Dam					
Flow (cfs)	%	2 (Sailor Bar)	6	10	14	18	22 (Mouth)
500	90	54.8	56.4	57.6	59.1	60.2	61.5
	50	57.2	59.0	60.6	62.8	64.5	66.9
	10	61.3	62.4	63.8	66.2	68.4	71.1
800	90	54.5	56.0	57.1	58.4	59.4	60.8
	50	56.9	58.5	59.9	61.8	63.4	65.6
	10	61.1	62.1	63.2	65.1	67.0	69.6
1000	90	54.3	55.6	56.6	57.7	58.6	60.1
	50	56.7	58.1	59.2	60.8	62.3	64.4
	10	61.0	61.8	62.7	64.0	65.7	68.1
1250	90	54.3	55.5	56.3	57.4	58.3	60.7
	50	56.6	57.9	58.9	60.3	61.8	63.8
	10	61.0	61.8	62.7	63.9	65.3	67.5
1500	90	54.2	55.3	56.1	57.1	57.9	59.2
	50	56.5	57.7	58.6	59.9	61.2	63.1
	10	61.0	61.7	62.6	63.7	64.9	66.9
1750	90	54.2	55.2	55.9	56.8	57.6	58.9
	50	56.5	57.5	58.4	59.6	60.8	62.7
	10	61.0	61.7	62.6	63.7	64.9	66.8
2000	90	54.2	55.1	55.8	56.6	57.4	58.6
	50	56.5	57.4	58.3	59.4	60.5	62.4
	10	61.0	61.7	62.6	63.7	64.9	66.7
2500	90	54.2	54.9	55.6	56.3	57.1	58.3
	50	56.5	57.3	58.1	59.1	60.1	61.9
	10	61.0	61.7	62.6	63.7	64.9	66.6
3000	90	54.2	54.8	55.4	56.1	56.9	58.0
	50	56.5	57.2	57.9	58.8	59.8	61.5
	10	61.0	61.7	62.6	63.7	64.9	66.6
HIST	90	54.2	54.3	54.7	55.2	55.8	56.9
	50	56.5	56.8	57.5	58.1	58.9	60.4
	10	61.0	61.7	62.6	63.7	64.9	66.6

TABLE 3

AMERICAN RIVER
WATER TEMPERATURE EXCEEDANCE DATA
FOR JUNE

Flow (cfs)	%	Miles Below Nimbus Dam: 2 (Sailor Bar)	6	10	14	18	22 (Mouth)
500	90	57.2	59.5	61.3	63.2	64.9	66.5
	50	59.7	62.0	63.9	66.5	68.7	71.6
	10	63.0	65.2	67.6	70.0	72.7	76.4
800	90	57.1	58.5	60.0	62.0	63.5	65.5
	50	59.3	60.9	62.4	64.3	65.9	68.8
	10	62.2	64.0	65.7	68.0	69.7	73.0
1000	90	57.0	58.5	59.9	61.4	62.8	64.6
	50	59.2	60.9	62.2	64.1	65.9	68.5
	10	62.5	64.0	65.5	67.6	69.7	72.5
1250	90	56.8	58.2	59.7	61.0	62.3	63.7
	50	59.0	60.5	62.0	63.6	65.1	66.8
	10	62.2	63.6	65.2	67.0	68.8	70.5
1500	90	56.5	58.0	59.1	60.6	61.7	63.6
	50	58.9	60.4	61.5	63.0	64.6	66.9
	10	62.2	63.7	64.9	66.6	68.2	70.7
1750	90	56.3	58.0	59.0	60.2	61.3	63.1
	50	58.9	60.2	61.2	62.7	64.5	66.2
	10	62.1	63.5	64.7	66.2	67.7	70.2
2000	90	56.3	57.8	58.8	60.0	61.1	63.0
	50	58.9	60.0	61.0	62.3	63.8	66.1
	10	62.1	63.2	64.2	66.0	67.2	69.9
2500	90	56.3	57.8	58.3	59.5	60.6	62.3
	50	58.9	59.9	60.8	61.9	63.2	65.2
	10	62.1	63.2	64.2	65.7	67.0	69.3
3000	90	56.3	57.3	58.1	59.2	60.2	62.0
	50	58.8	59.7	60.7	61.7	62.9	64.9
	10	62.0	63.1	64.1	65.2	66.9	69.2
HIST	90	56.3	56.7	57.5	58.2	59.0	59.8
	50	58.7	59.3	60.2	61.2	62.2	63.4
	10	62.0	63.1	64.1	65.2	66.9	69.2

TABLE 4

AMERICAN RIVER
WATER TEMPERATURE EXCEEDANCE DATA
FOR JULY

Flow (cfs)	%	Miles Below Nimbus Dam 2 (Sailor Bar)	6	10	14	18	22 (Mouth)
500	90	59.7	62.4	64.5	67.2	69.0	71.2
	50	62.9	65.3	67.3	69.9	72.1	75.3
	10	66.8	68.8	70.2	72.8	75.2	78.1
800	90	59.2	61.1	62.9	65.2	67.1	69.3
	50	62.8	64.5	66.3	68.2	70.1	73.0
	10	66.3	68.0	69.2	71.2	73.0	75.8
1000	90	59.6	61.2	62.6	64.8	66.5	69.0
	50	62.5	64.2	65.7	67.7	69.3	72.0
	10	66.2	67.7	69.0	70.8	72.2	74.9
1250	90	59.6	60.7	62.2	64.2	66.0	68.1
	50	62.1	63.8	65.3	67.0	68.5	71.2
	10	66.1	67.7	68.7	70.1	71.7	74.1
1500	90	58.9	60.5	62.0	63.6	65.3	67.5
	50	61.9	63.7	64.8	66.5	68.1	70.3
	10	66.0	67.4	68.6	69.8	71.3	73.5
1750	90	58.6	60.4	61.7	63.3	64.8	67.1
	50	61.8	63.5	64.6	66.2	67.7	69.8
	10	66.0	67.3	68.3	69.5	70.9	73.1
2000	90	58.6	60.2	61.4	63.0	64.4	66.7
	50	61.8	63.2	64.4	65.9	67.3	69.3
	10	66.0	67.1	68.1	69.3	70.6	72.7
2500	90	58.6	60.0	61.1	62.5	63.8	66.1
	50	61.8	63.0	64.2	65.5	66.8	68.8
	10	66.0	67.1	68.0	69.1	70.3	72.1
3000	90	58.6	59.7	60.7	62.0	63.3	65.4
	50	61.8	62.9	64.0	65.2	66.3	68.3
	10	66.0	67.0	68.0	69.0	70.0	71.6
HIST	90	58.7	59.6	60.4	61.5	62.6	64.6
	50	61.9	62.9	63.8	65.0	66.1	67.9
	10	66.0	67.0	67.8	68.6	69.7	71.6

TABLE 5

AMERICAN RIVER
WATER TEMPERATURE EXCEEDANCE DATA
FOR AUGUST

Flow (cfs)	%	Miles Below Nimbus Dam 2 (Sailor Bar)	6	10	14	18	22 (Mouth)
500	90	61.9	63.9	65.6	67.8	69.2	71.3
	50	65.7	67.4	68.8	70.7	72.3	74.7
	10	69.5	70.9	71.8	73.7	75.5	78.0
800	90	61.7	63.4	64.9	66.8	68.1	70.1
	50	65.5	67.0	68.2	69.7	71.0	73.4
	10	69.5	70.5	71.4	72.7	74.0	76.5
1000	90	61.4	63.2	64.2	65.8	67.3	69.2
	50	65.2	66.5	67.6	69.0	70.4	72.3
	10	69.5	70.3	71.0	71.9	73.3	75.4
1250	90	61.2	62.8	63.9	65.4	66.7	68.5
	50	65.2	66.4	67.4	68.6	69.7	71.6
	10	69.5	70.2	70.9	71.5	72.8	74.8
1500	90	61.0	62.4	63.6	65.0	66.2	68.0
	50	65.1	66.2	67.1	68.1	69.2	71.1
	10	69.5	70.1	70.8	71.3	72.3	74.3
1750	90	61.0	62.2	63.3	64.6	65.8	67.7
	50	65.1	66.2	66.9	67.9	69.0	70.8
	10	69.5	70.1	70.5	71.2	72.1	73.9
2000	90	61.0	62.0	63.0	64.2	65.4	67.3
	50	65.1	66.1	66.7	67.7	68.8	70.4
	10	69.5	70.0	70.2	71.1	72.0	73.6
2500	90	61.0	61.9	62.8	63.9	65.0	67.0
	50	65.1	66.0	66.5	67.3	68.3	70.0
	10	69.5	70.0	70.2	71.0	72.0	73.2
3000	90	61.0	61.8	62.5	63.5	64.6	66.5
	50	65.1	65.9	66.4	67.2	68.1	69.8
	10	69.5	70.0	70.2	71.0	72.0	73.1
HIST	90	61.0	61.8	62.5	63.4	64.3	66.2
	50	65.1	65.8	66.3	67.1	68.0	69.7
	10	69.5	70.0	70.2	71.0	72.0	73.1

TABLE 6

AMERICAN RIVER
WATER TEMPERATURE EXCEEDANCE DATA
FOR SEPTEMBER

Flow (cfs)	%	Miles Below Nimbus Dam: 2 (Sailor Bar)	6	10	14	18	22 (Mouth)
500	90	63.8	65.1	65.7	66.5	67.3	68.1
	50	65.5	66.7	67.8	69.0	70.2	71.9
	10	69.0	70.0	71.0	72.3	73.5	75.3
800	90	63.6	64.7	65.4	66.2	66.7	67.7
	50	65.3	66.4	67.2	68.5	69.6	70.9
	10	69.0	70.0	70.5	71.7	72.9	74.3
1000	90	63.4	64.3	65.1	65.9	66.3	67.4
	50	65.2	66.1	66.8	67.8	68.8	70.2
	10	69.0	70.0	70.2	71.0	72.1	73.5
1250	90	63.4	64.4	65.1	65.5	66.0	67.2
	50	65.2	66.0	66.4	67.5	68.3	69.9
	10	69.0	70.0	70.1	70.9	71.7	73.2
1500	90	63.4	64.3	64.9	65.3	65.9	67.0
	50	65.2	65.8	66.3	67.2	68.0	69.4
	10	69.0	70.0	70.1	70.9	71.7	72.9
1750	90	63.4	64.2	64.7	65.2	65.7	66.7
	50	65.2	65.8	66.2	67.0	67.8	69.2
	10	69.0	70.0	70.1	70.8	71.6	72.8
2000	90	63.4	64.1	64.4	65.2	65.6	66.7
	50	65.2	65.6	66.1	66.8	67.7	69.0
	10	69.0	70.0	70.1	70.8	71.6	72.8
2500	90	63.4	64.0	64.3	65.0	65.6	66.5
	50	65.2	65.6	66.0	66.6	67.4	68.8
	10	69.0	70.0	70.1	70.6	71.5	72.8
3000	90	63.4	63.9	64.2	64.8	65.3	66.3
	50	65.2	65.4	65.9	66.5	67.2	68.5
	10	69.0	70.0	70.1	70.6	71.4	72.7
HIST	90	63.4	63.7	64.2	64.8	65.2	66.3
	50	65.2	65.4	65.9	66.4	67.1	68.4
	10	69.0	70.0	70.1	70.6	71.4	72.7

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TABLE 7

AMERICAN RIVER
WATER TEMPERATURE EXCEEDANCE DATA
FOR OCTOBER

Flow (cfs)	%	2 (Sailor Bar)	6	10	14	18	22 (Mouth)
		Miles Below Nimbus Dam					
500	90	60.1	60.5	60.9	61.1	61.4	62.1
	50	62.3	63.0	63.5	64.1	64.5	65.4
	10	67.0	67.1	67.2	67.5	68.0	69.0
800	90	60.1	60.4	60.7	60.9	61.3	61.9
	50	62.3	62.8	63.2	63.8	64.2	65.2
	10	67.0	67.1	67.1	67.2	67.5	68.5
1000	90	60.1	60.3	60.5	60.7	61.1	61.6
	50	62.3	62.7	63.1	63.5	63.9	64.8
	10	67.0	67.1	67.0	67.0	67.1	68.0
1250	90	60.1	60.3	60.4	60.6	61.0	61.6
	50	62.3	62.7	63.1	63.3	63.6	64.7
	10	67.0	67.1	67.0	67.0	67.0	68.0
1500	90	60.1	60.2	60.3	60.5	60.9	61.5
	50	62.3	62.6	63.0	63.1	63.3	64.6
	10	67.0	67.1	67.1	67.0	67.0	68.0
1750	90	60.1	60.2	60.3	60.5	60.8	61.4
	50	62.3	62.6	63.0	63.1	63.7	64.4
	10	67.0	67.1	67.1	67.0	67.0	67.6
2000	90	60.1	60.2	60.3	60.4	60.7	61.3
	50	62.3	62.6	63.0	63.1	63.5	64.2
	10	67.0	67.1	67.1	67.0	67.0	67.5
2500	90	60.1	60.2	60.3	60.4	60.6	61.3
	50	62.3	62.5	63.0	63.2	63.4	64.1
	10	67.0	67.0	67.0	67.0	67.0	67.5
3000	90	60.1	60.1	60.2	60.3	60.6	61.3
	50	62.3	62.5	63.0	63.1	63.3	64.1
	10	67.0	67.0	67.0	67.0	67.0	67.5
HIST	90	60.1	60.2	60.4	60.6	60.7	61.4
	50	62.3	62.7	63.0	63.2	63.6	64.3
	10	67.0	67.1	67.1	67.2	67.5	68.0

TABLE 8

AMERICAN RIVER
WATER TEMPERATURE EXCEEDANCE DATA
FOR NOVEMBER

Flow (cfs)	%	2 (Sailor Bar)	6	10	14	18	22 (Mouth)
		Miles Below Nimbus Dam					
500	90	55.5	55.2	55.0	54.5	54.1	53.8
	50	57.6	57.2	57.2	57.1	57.1	57.4
	10	61.3	60.8	60.6	60.3	60.3	60.5
800	90	55.5	55.2	55.0	54.6	54.3	54.1
	50	57.6	57.2	57.2	57.1	57.1	57.4
	10	61.3	60.8	60.6	60.3	60.3	60.4
1000	90	55.5	55.2	55.1	54.7	54.5	54.4
	50	57.6	57.2	57.2	57.1	57.1	57.4
	10	61.4	60.8	60.7	60.3	60.2	60.3
1250	90	55.5	55.2	55.1	54.7	54.6	54.5
	50	57.6	57.2	57.2	57.1	57.1	57.4
	10	61.4	60.8	60.7	60.3	60.2	60.3
1500	90	55.5	55.2	55.1	54.8	54.7	54.6
	50	57.6	57.2	57.2	57.1	57.1	57.3
	10	61.5	60.8	60.8	60.4	60.3	60.3
1750	90	55.5	55.2	55.1	54.8	54.7	54.9
	50	57.6	57.2	57.2	57.1	57.1	57.3
	10	61.5	60.8	60.8	60.4	60.3	60.3
2000	90	55.5	55.2	55.1	54.9	54.7	54.8
	50	57.6	57.2	57.2	57.1	57.1	57.3
	10	61.5	60.8	60.8	60.5	60.3	60.4
2500	90	55.5	55.2	55.1	54.9	54.7	54.8
	50	57.6	57.2	57.2	57.1	57.1	57.3
	10	61.5	60.8	60.8	60.5	60.3	60.4
3000	90	55.5	55.2	55.1	54.9	54.8	55.0
	50	57.6	57.2	57.2	57.0	57.0	57.4
	10	61.5	60.8	60.8	60.5	60.3	60.4
HIST	90	55.5	55.2	55.1	54.9	54.8	55.0
	50	57.6	57.2	57.2	57.0	57.0	57.4
	10	61.5	60.8	60.8	60.5	60.3	60.4

C-043623

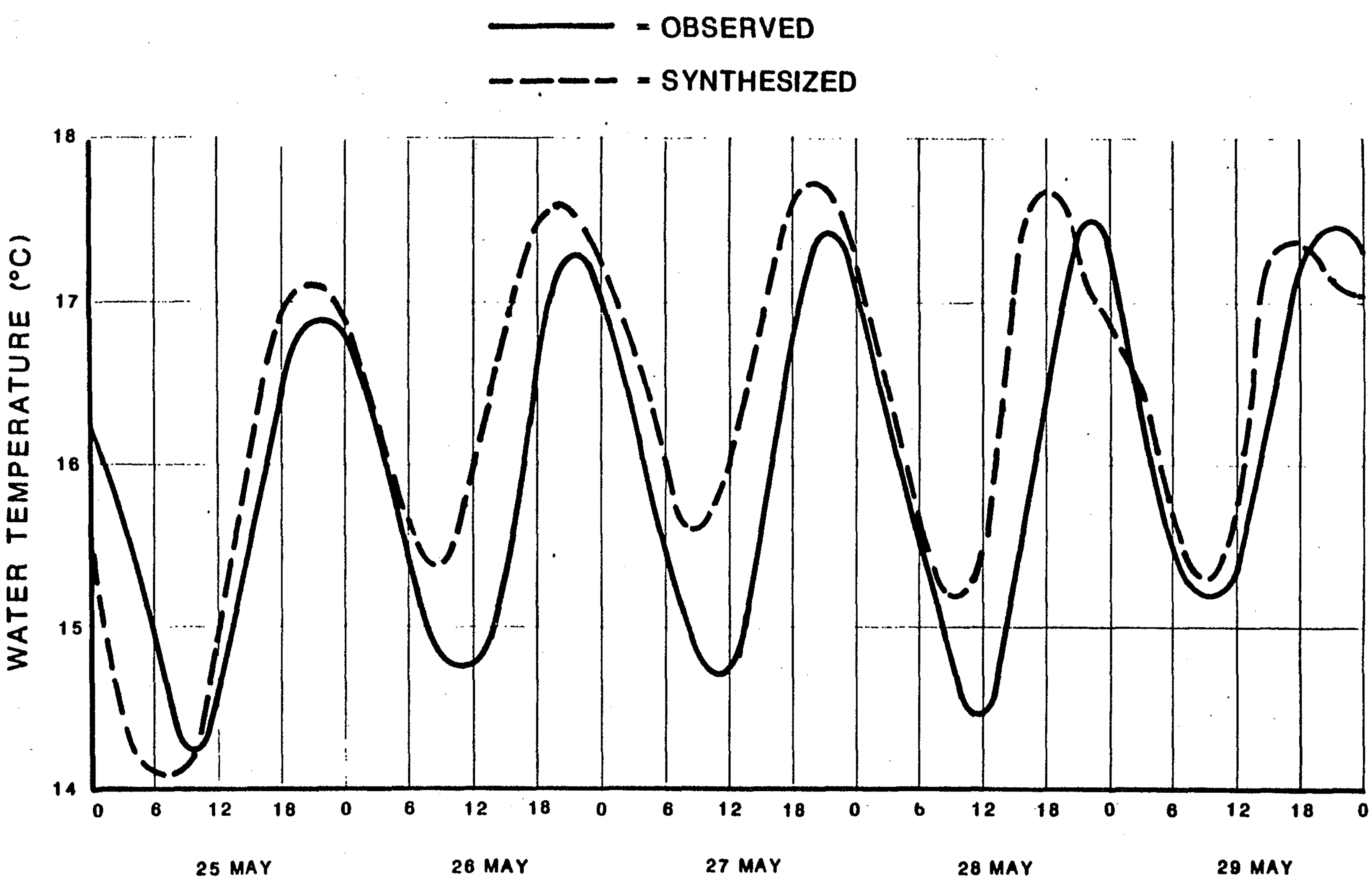

FIGURE 1

AMERICAN RIVER
WATER TEMPERATURE CALIBRATION MODEL
CSUS - REACH #15, MAY 25-29,1986

104094

C—043624

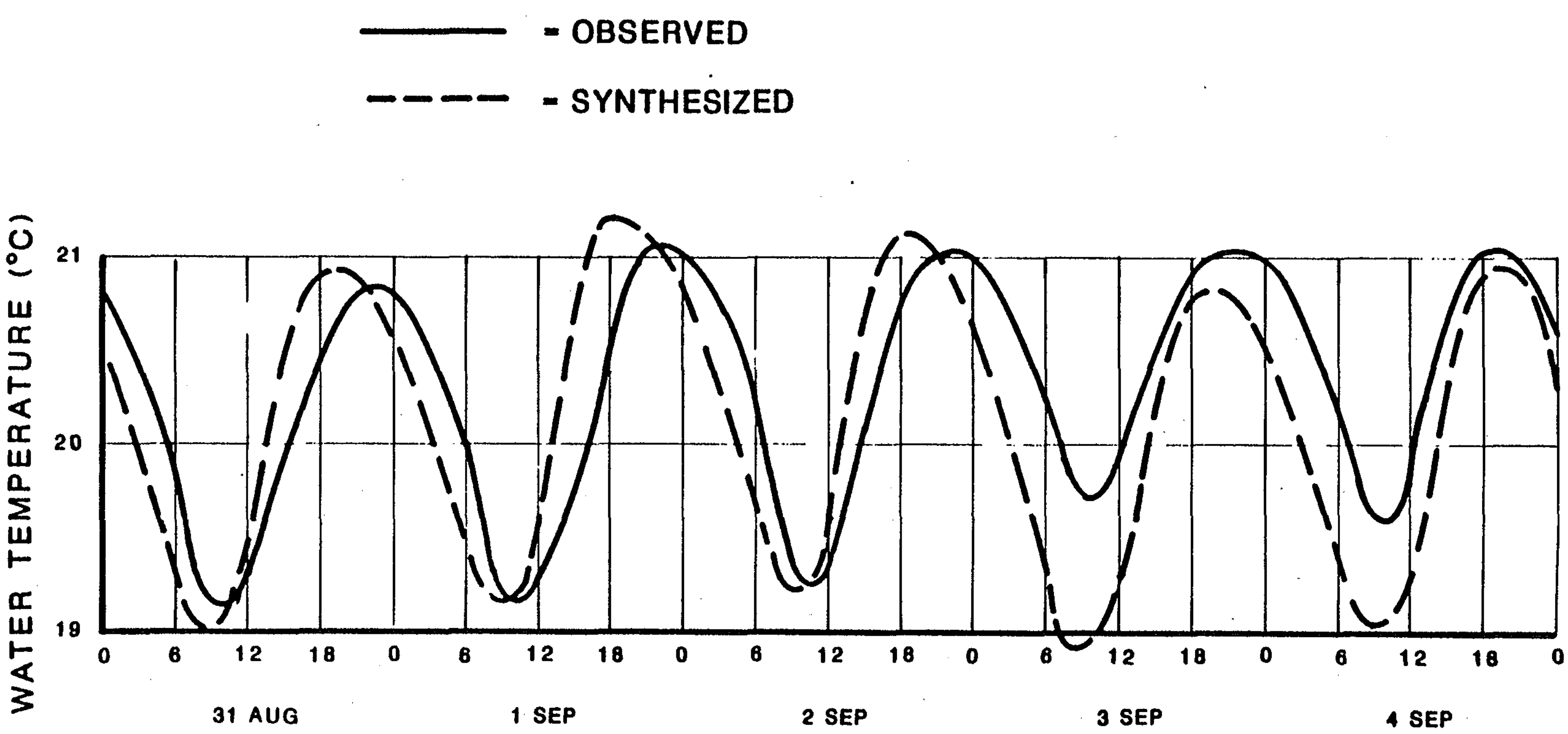

FIGURE 2

AMERICAN RIVER
WATER TEMPERATURE CALIBRATION MODEL
CSUS - REACH #15, AUG. 31 - SEP. 4, 1986

C-043625

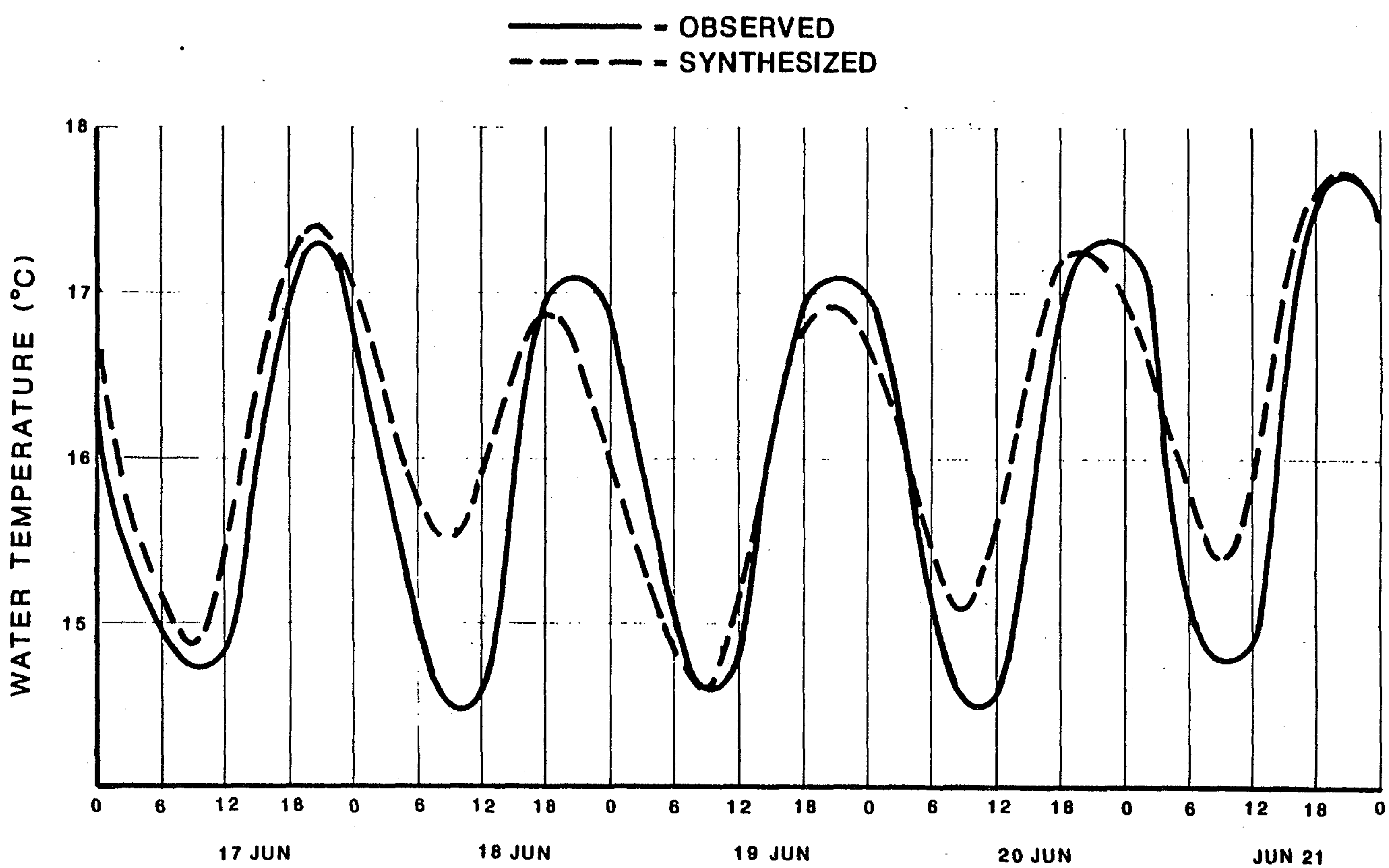

FIGURE 3

AMERICAN RIVER
WATER TEMPERATURE VERIFICATION MODEL
CSUS - REACH #15, JUNE 17-21, 1986

104094

C-043626

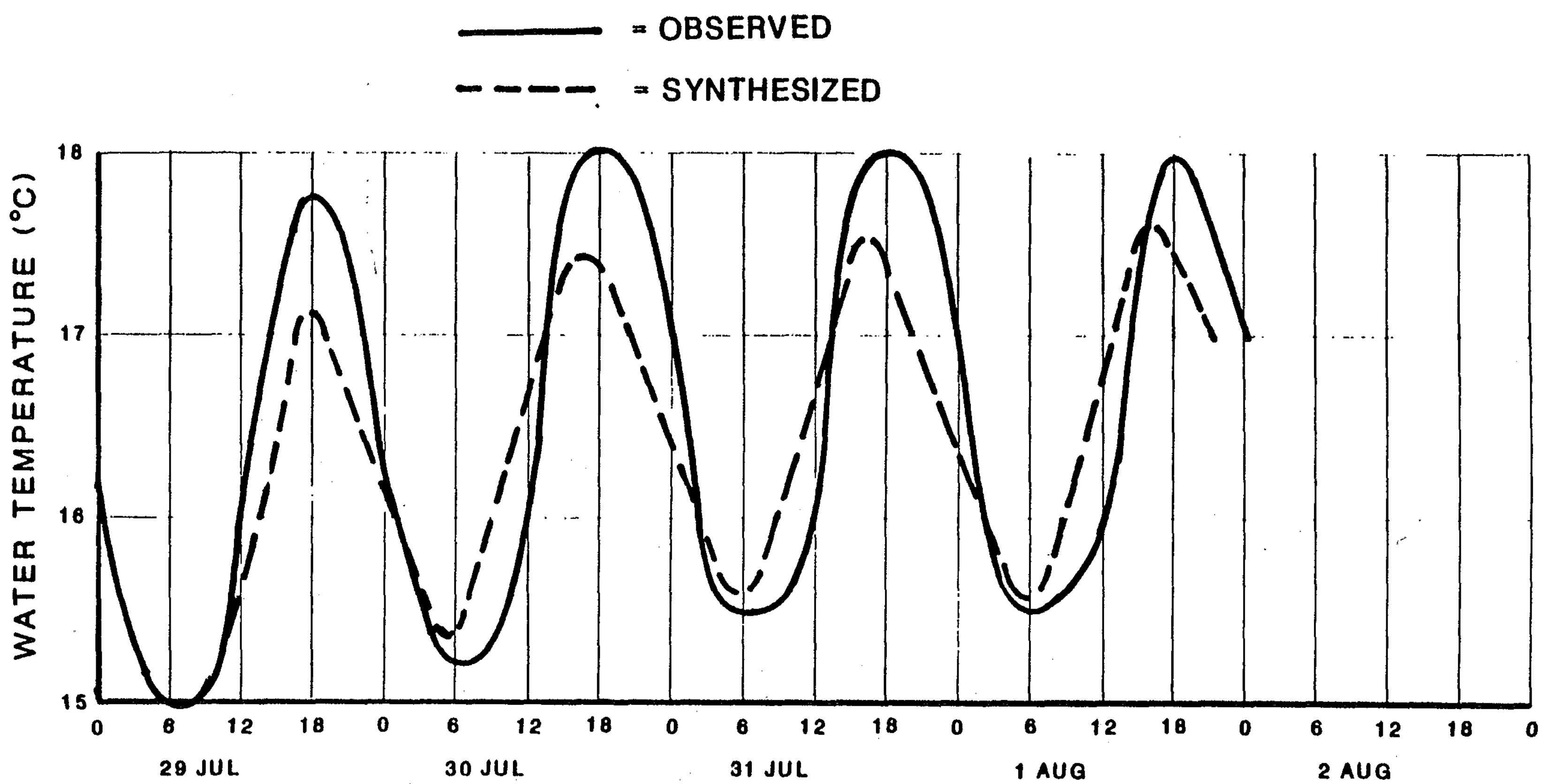

FIGURE 4

AMERICAN RIVER
WATER TEMPERATURE VERIFICATION MODEL
CSUS - REACH #15, JUL. 29 - AUG. 2, 1986

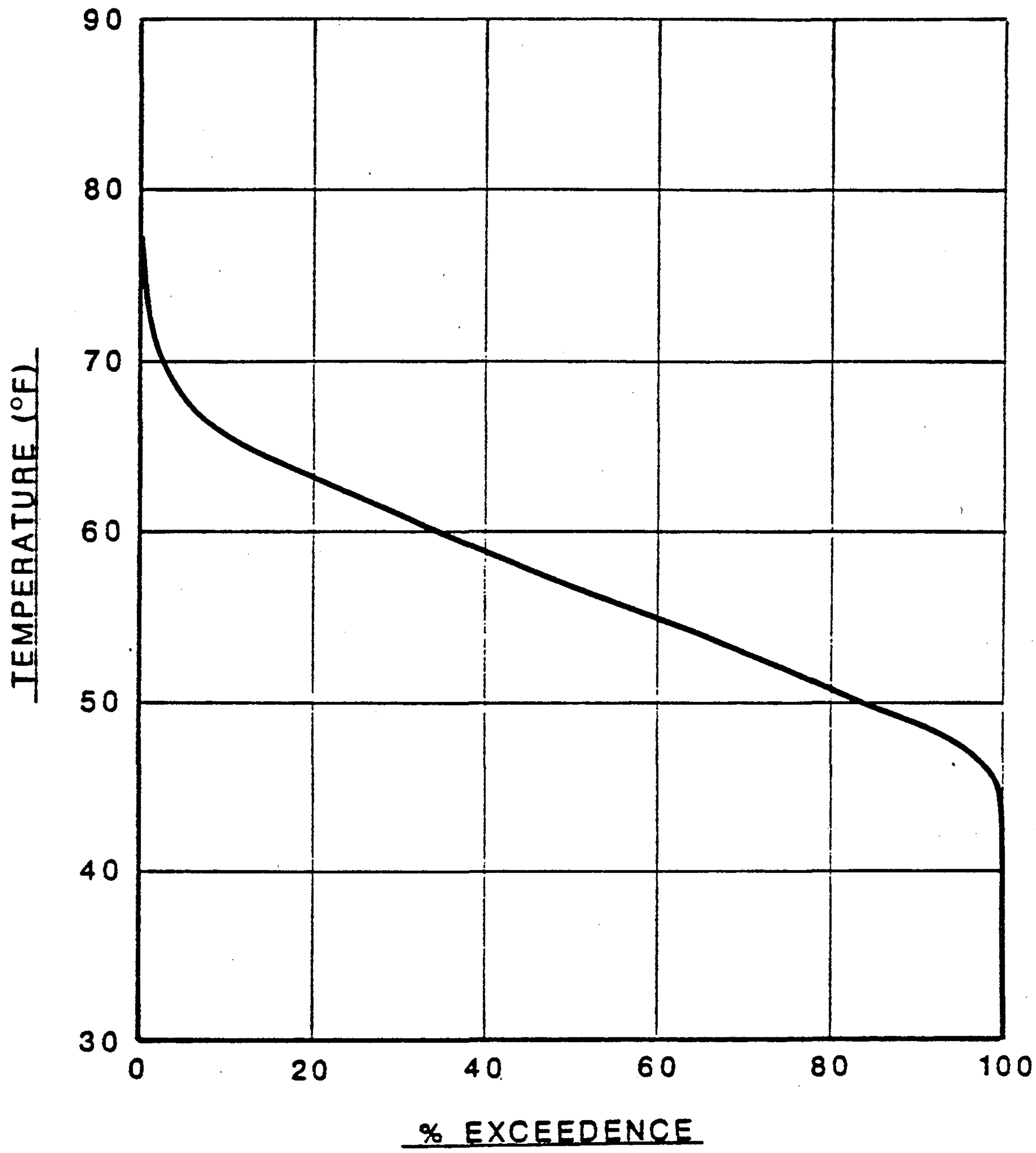

FIGURE 5

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE
ANNUAL, 1957-1986

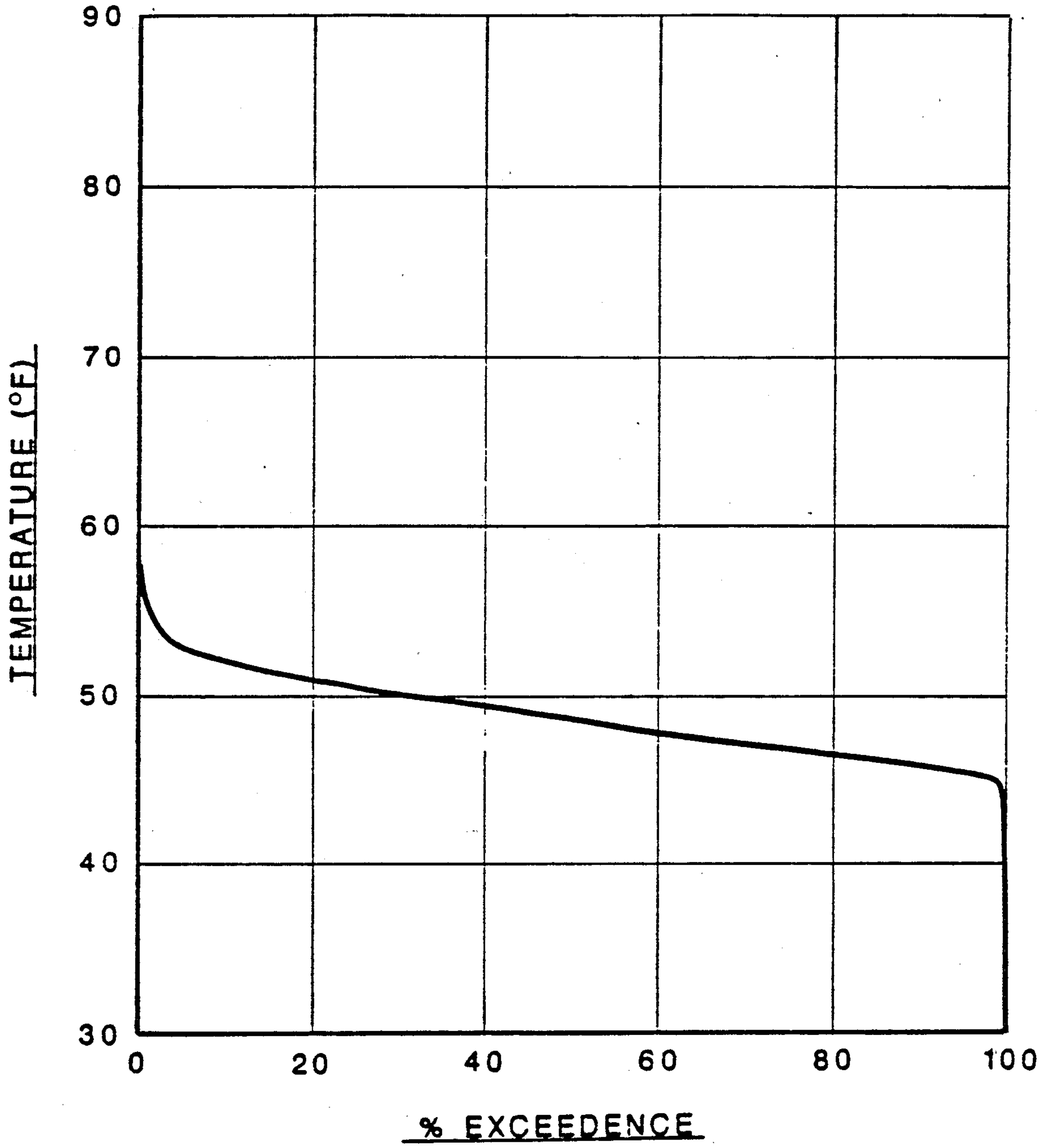

FIGURE 6

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE
JANUARY, 1957-1986

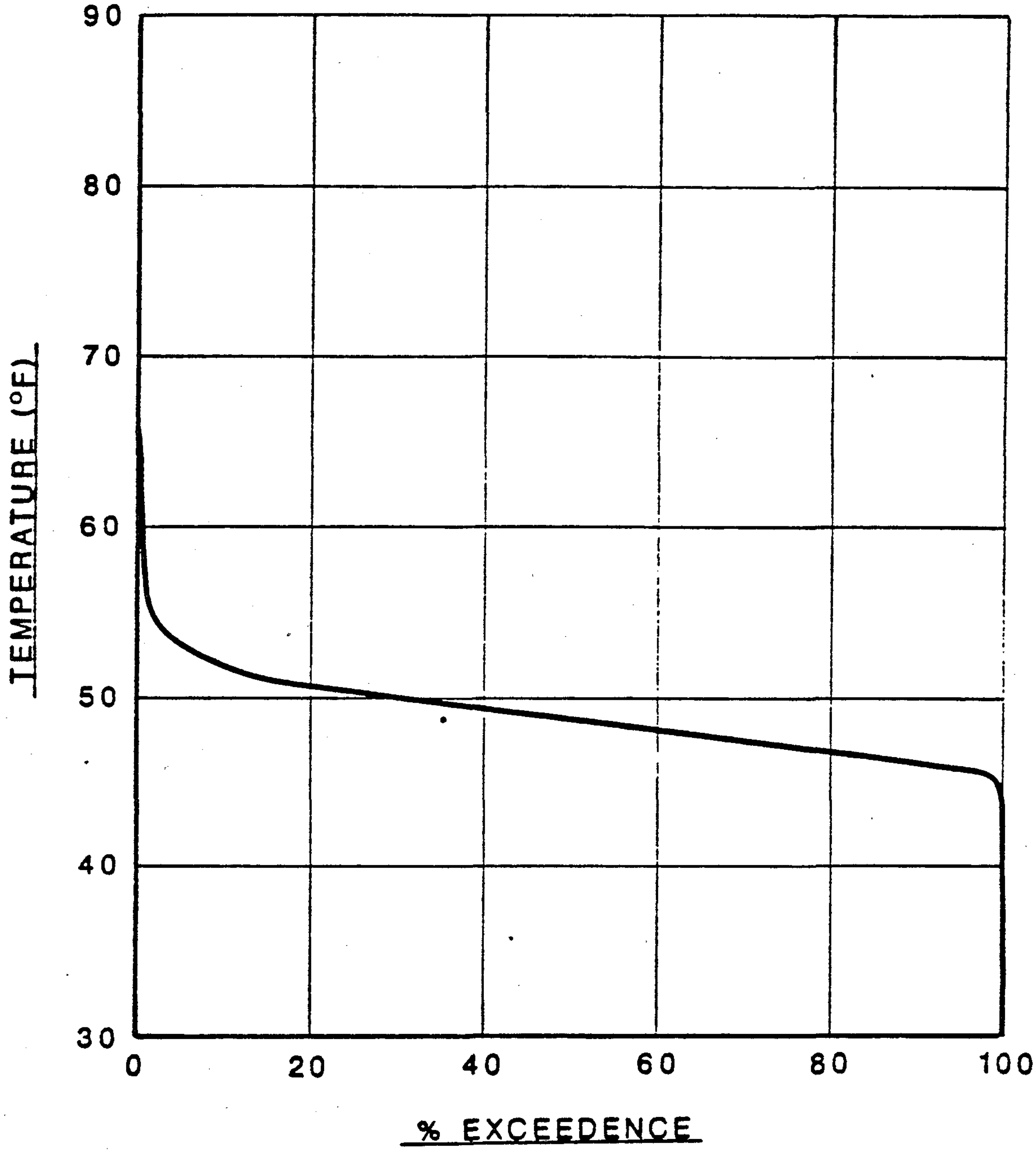

FIGURE 7

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE

FEBRUARY, 1957-1986

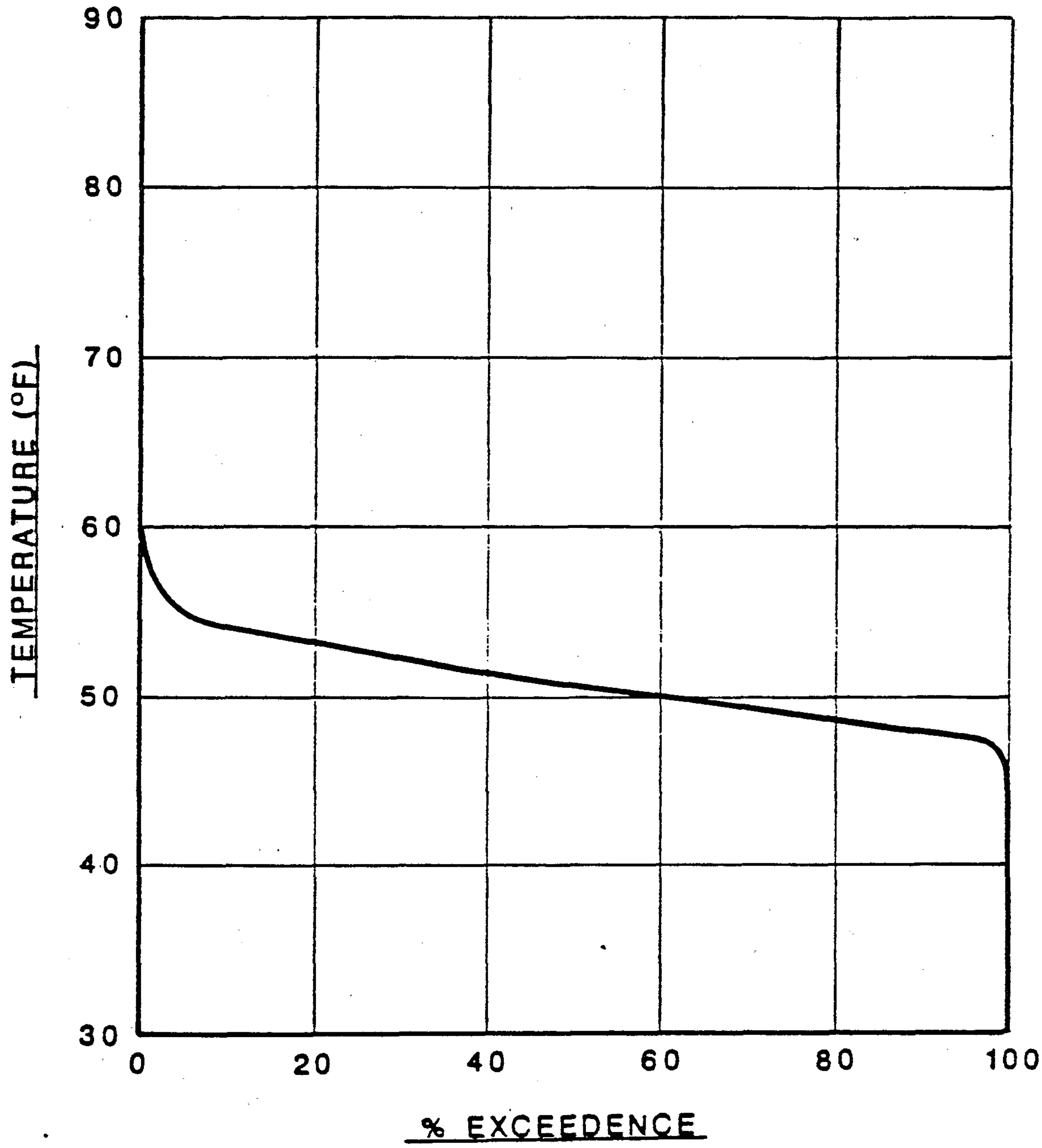

FIGURE 8

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE

MARCH, 1957-1986

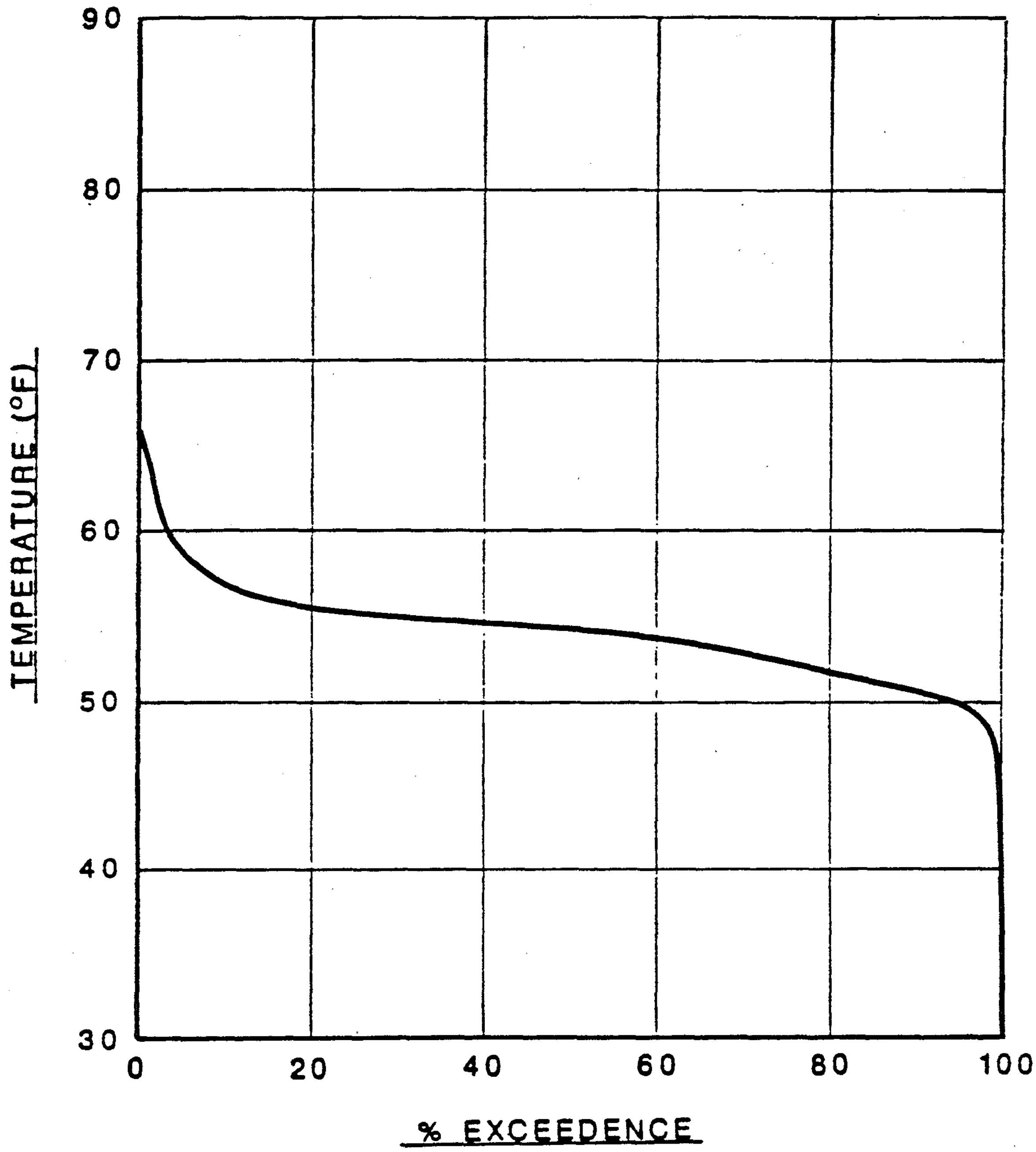

FIGURE 9

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE

APRIL, 1957-1986

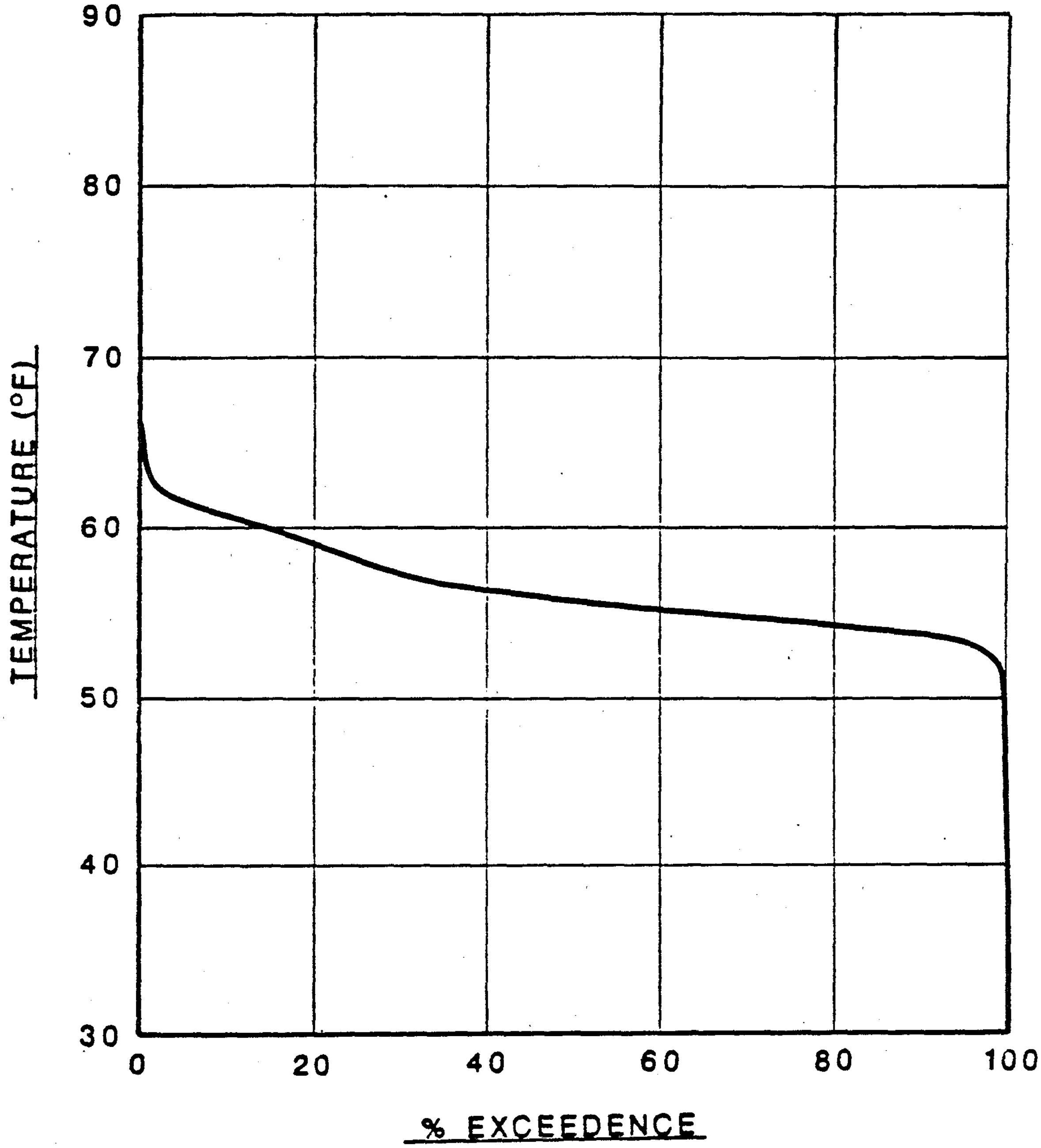

FIGURE 10

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE

MAY , 1957-1986

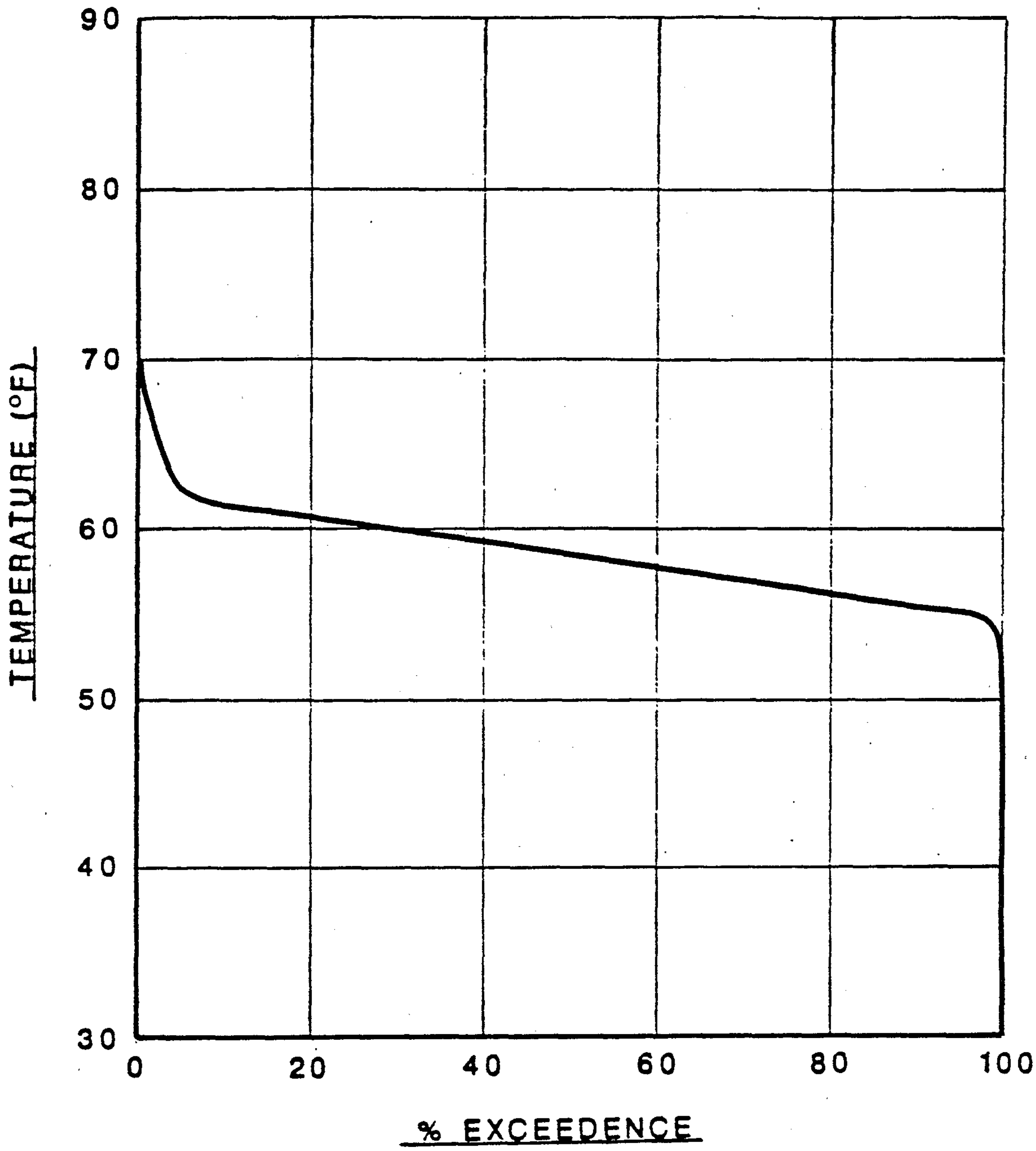

FIGURE 11

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE
JUNE, 1957-1986

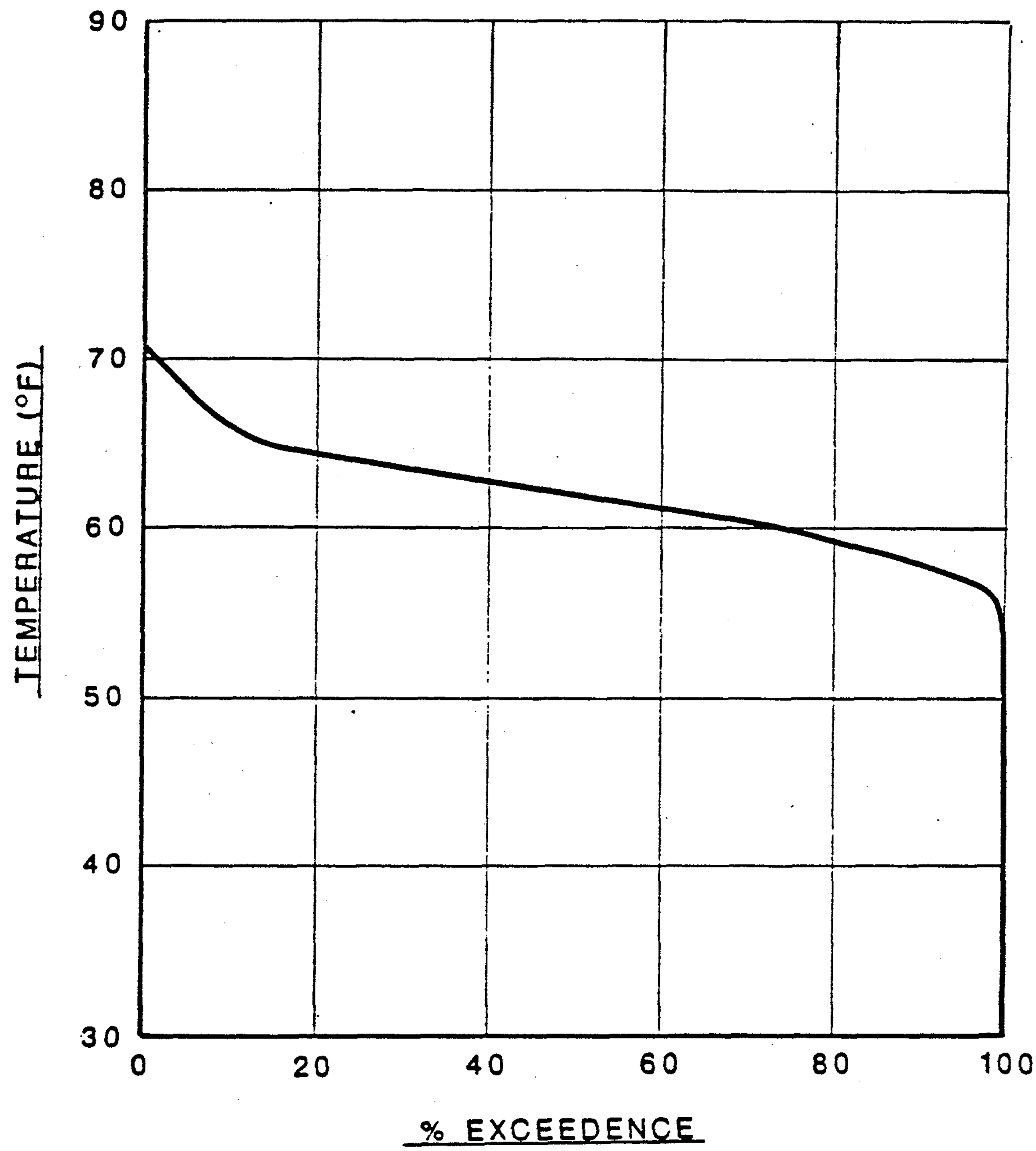

FIGURE 12

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE

JULY, 1957-1986

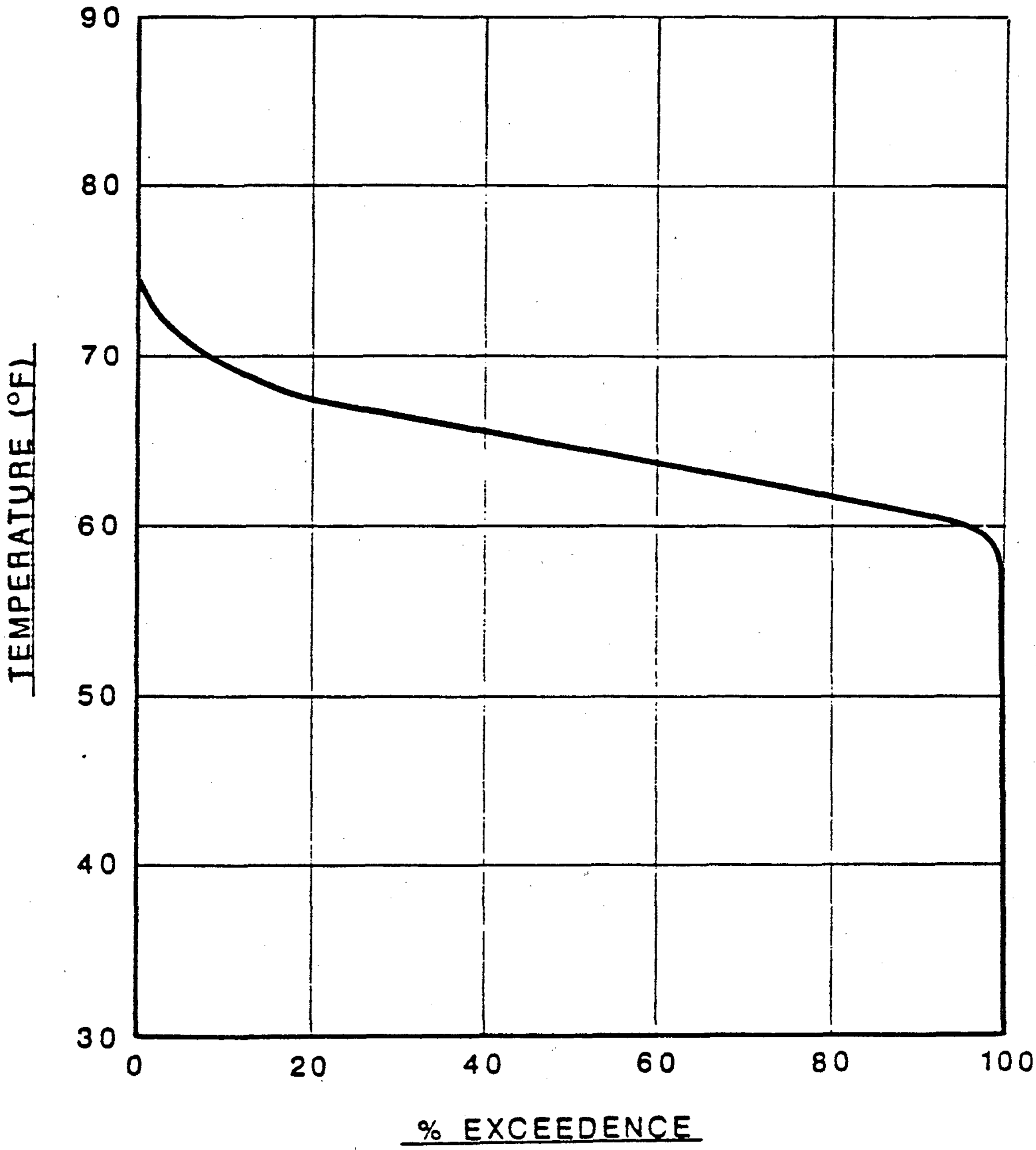

FIGURE 13

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE

AUGUST, 1957-1986

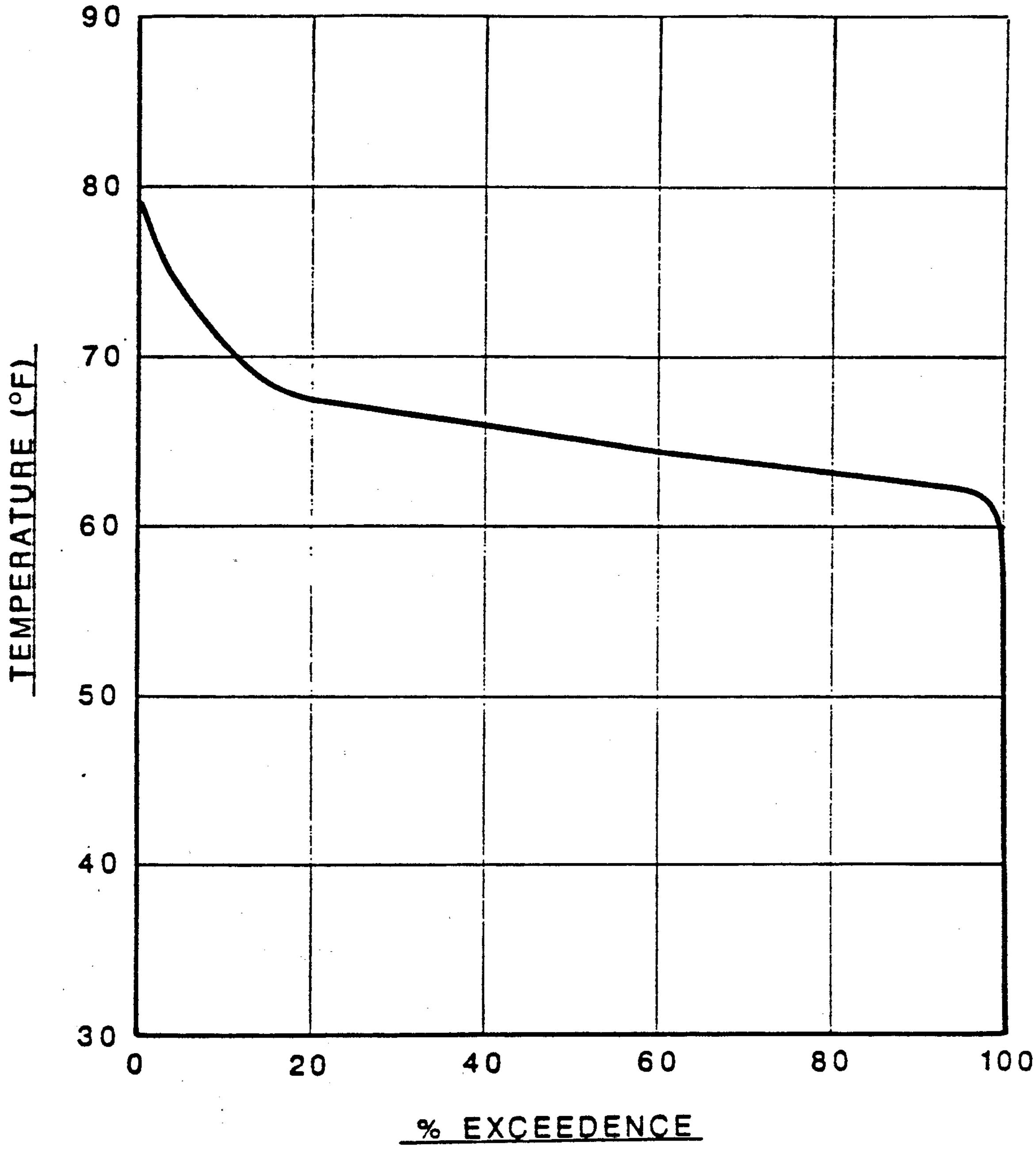

FIGURE 14

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE

SEPTEMBER, 1957-1986

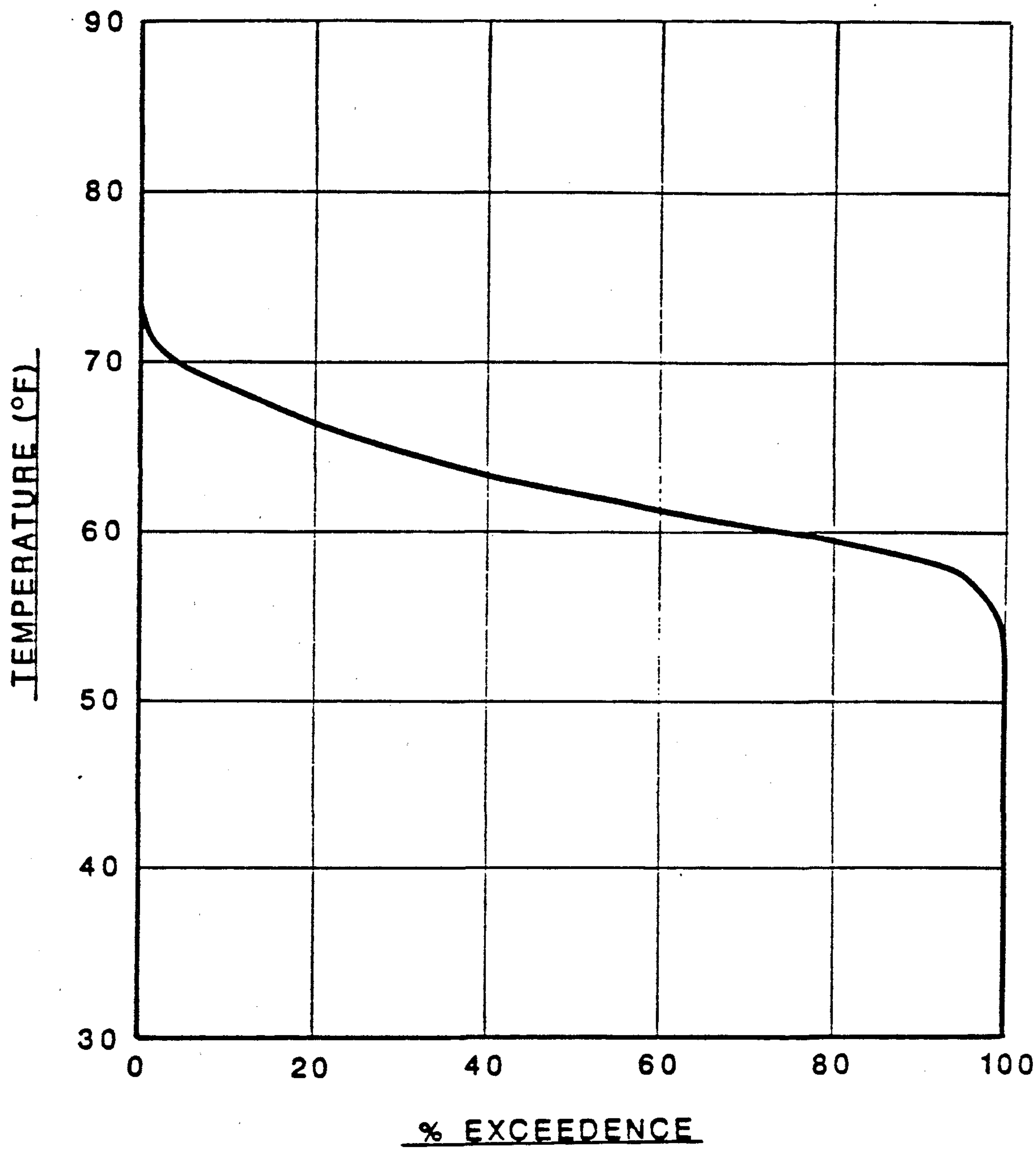

FIGURE 15

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE
OCTOBER, 1957-1986

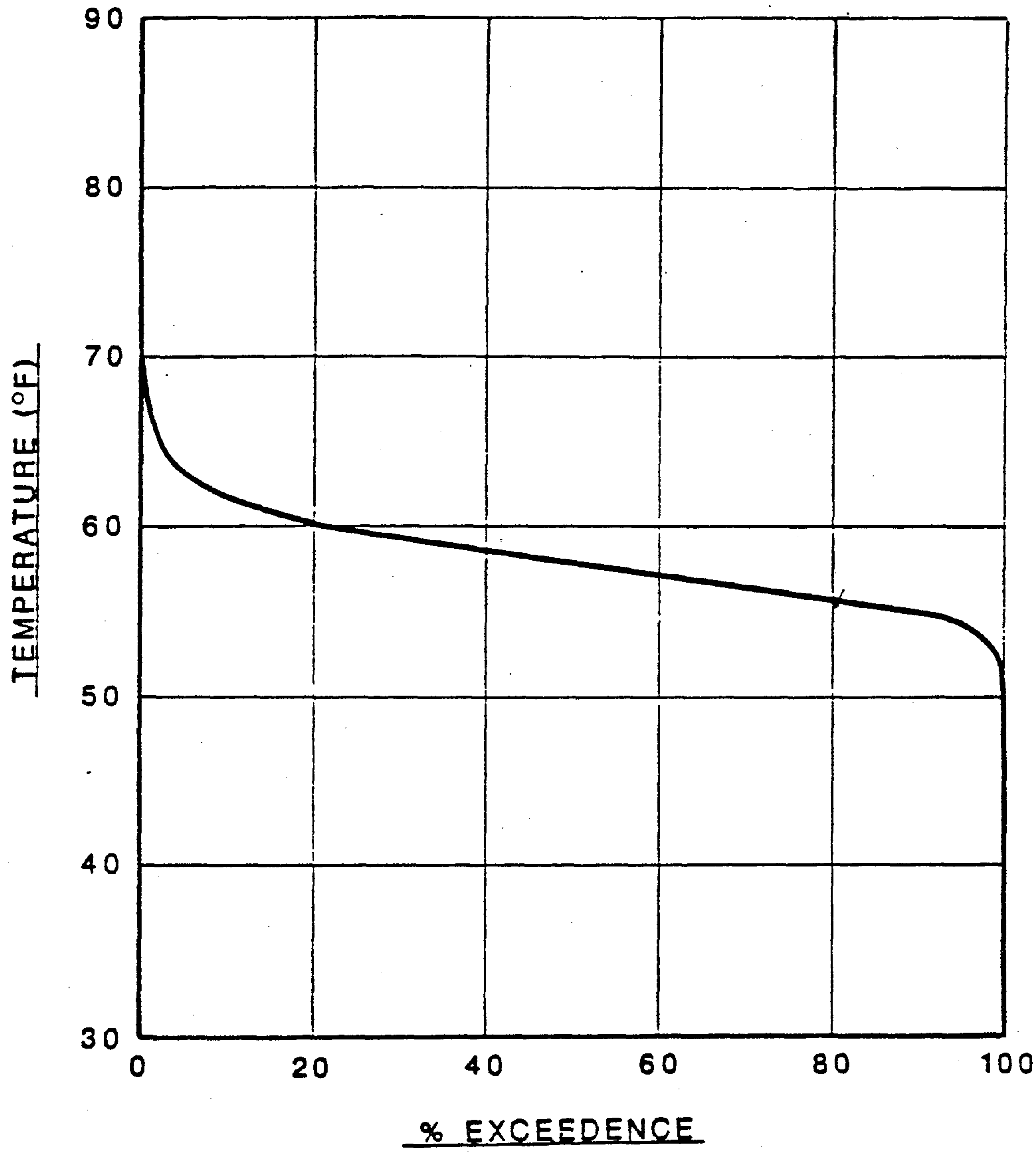

FIGURE 16

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE
NOVEMBER, 1957-1986

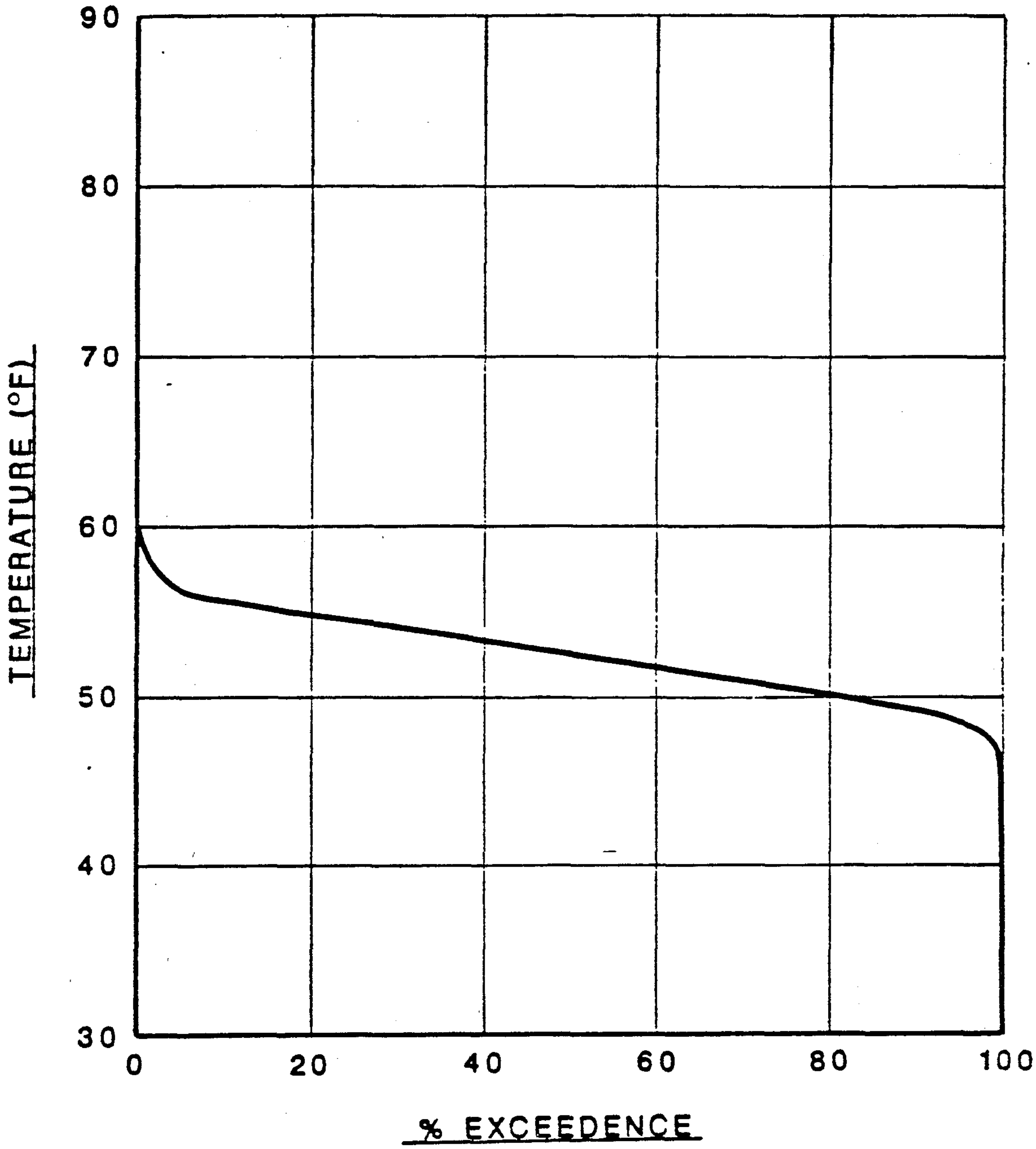

FIGURE 17

AMERICAN RIVER
BELOW NIMBUS DAM
TEMPERATURE EXCEEDENCE CURVE

DECEMBER, 1957-1986

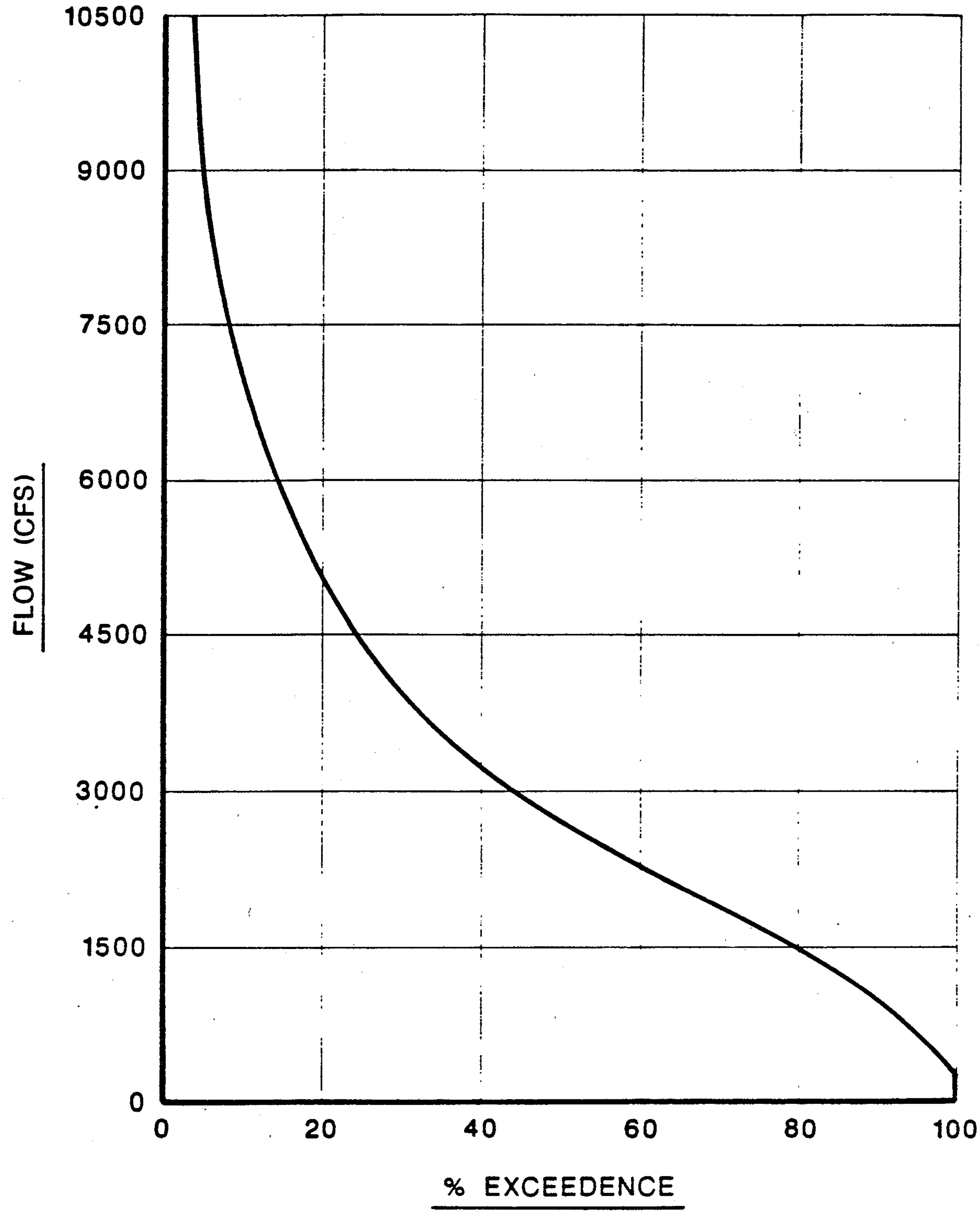

FIGURE 18

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

ANNUAL 1957-1986

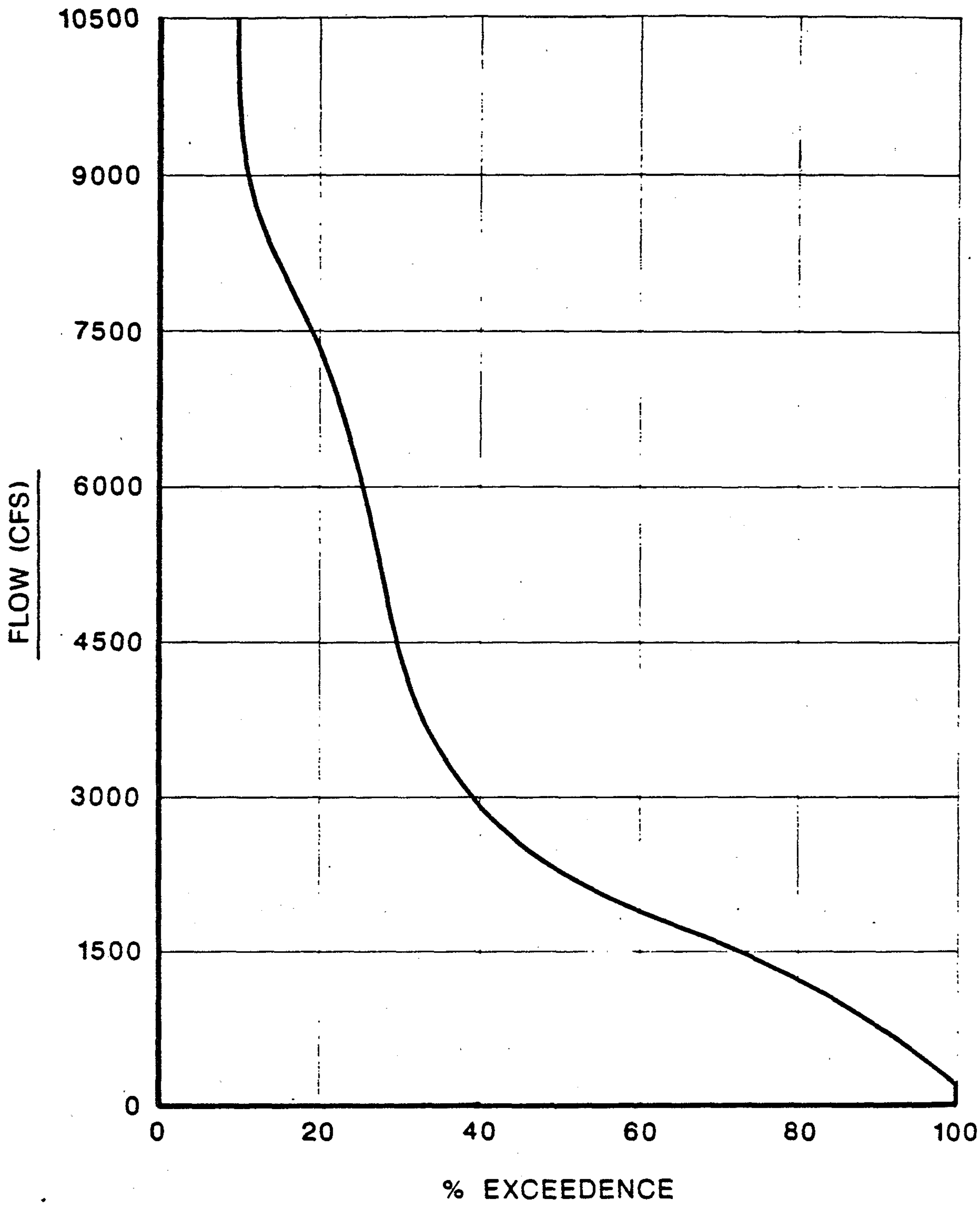

FIGURE 19

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

JANUARY 1957-1986

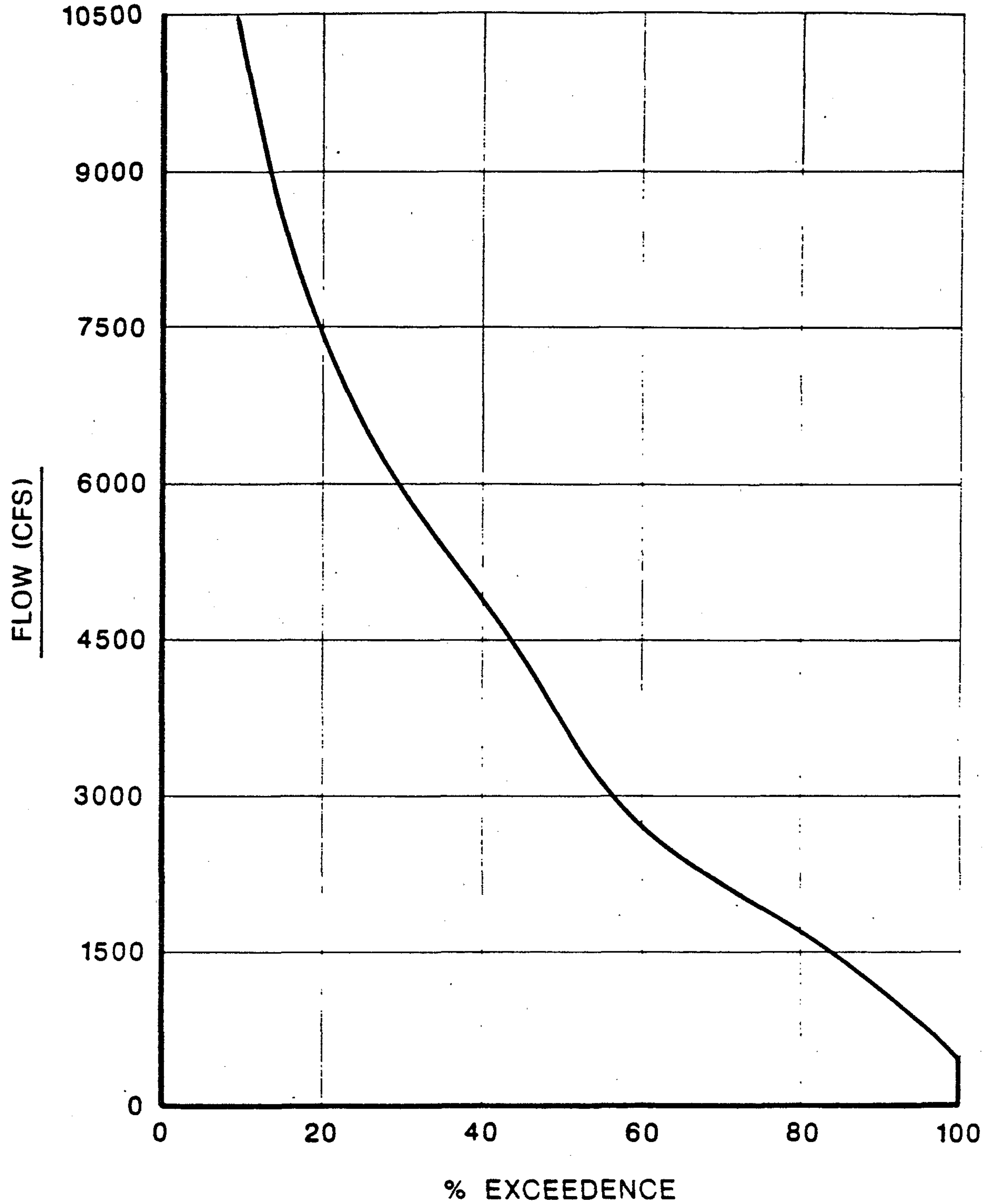

FIGURE 20

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

FEBRUARY 1957-1986

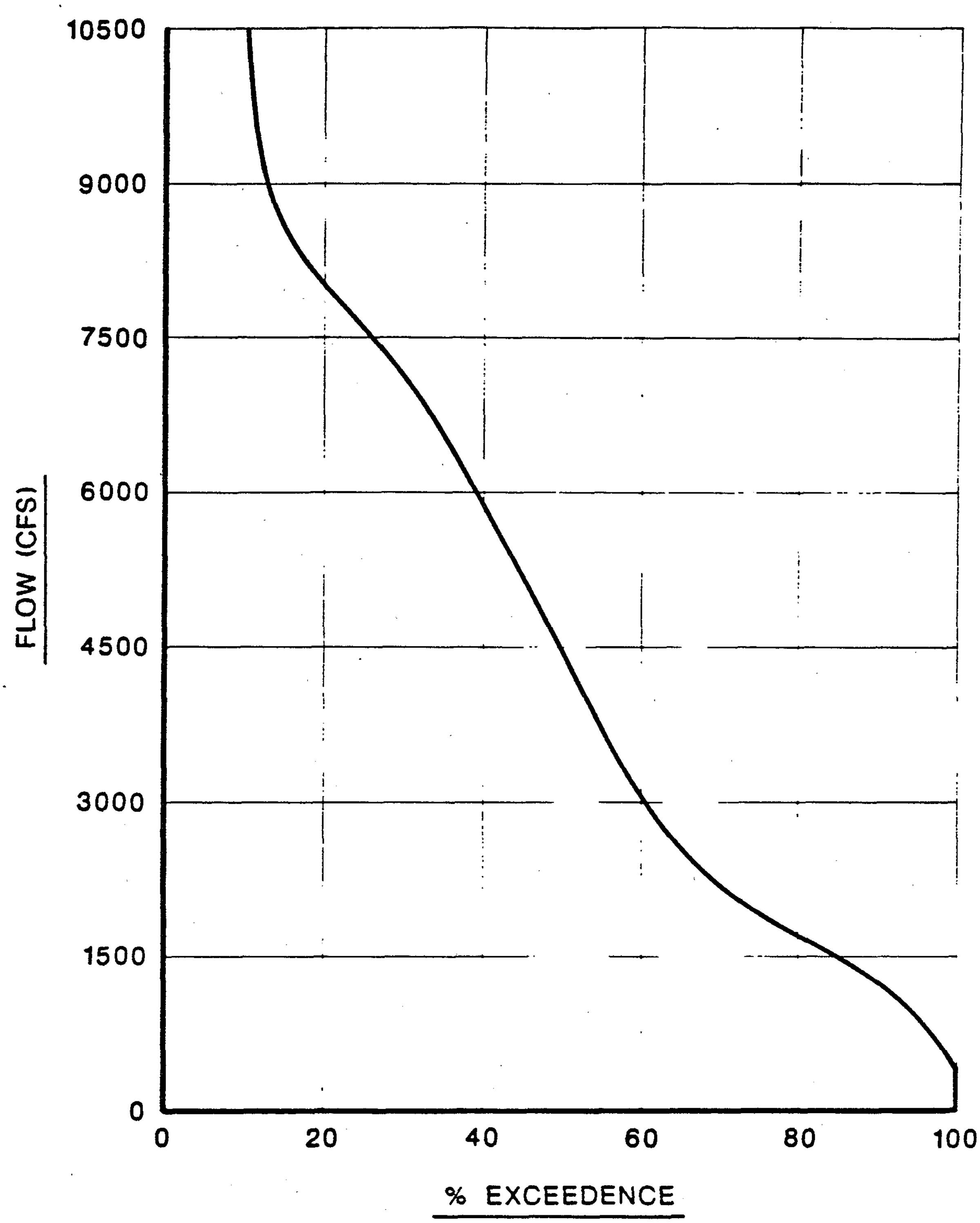

FIGURE 21

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

MARCH 1957-1986

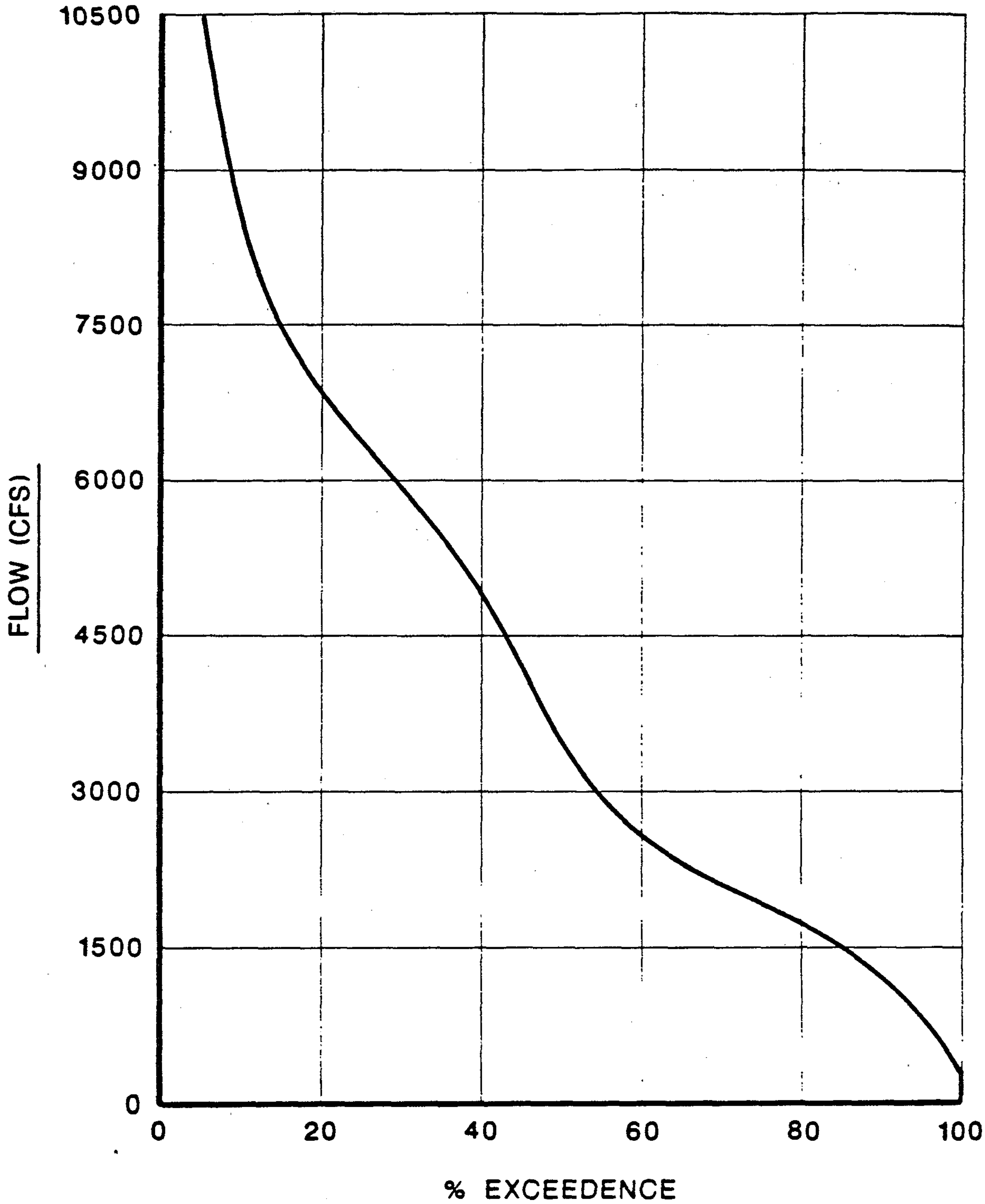

FIGURE 22

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

APRIL 1957-1986

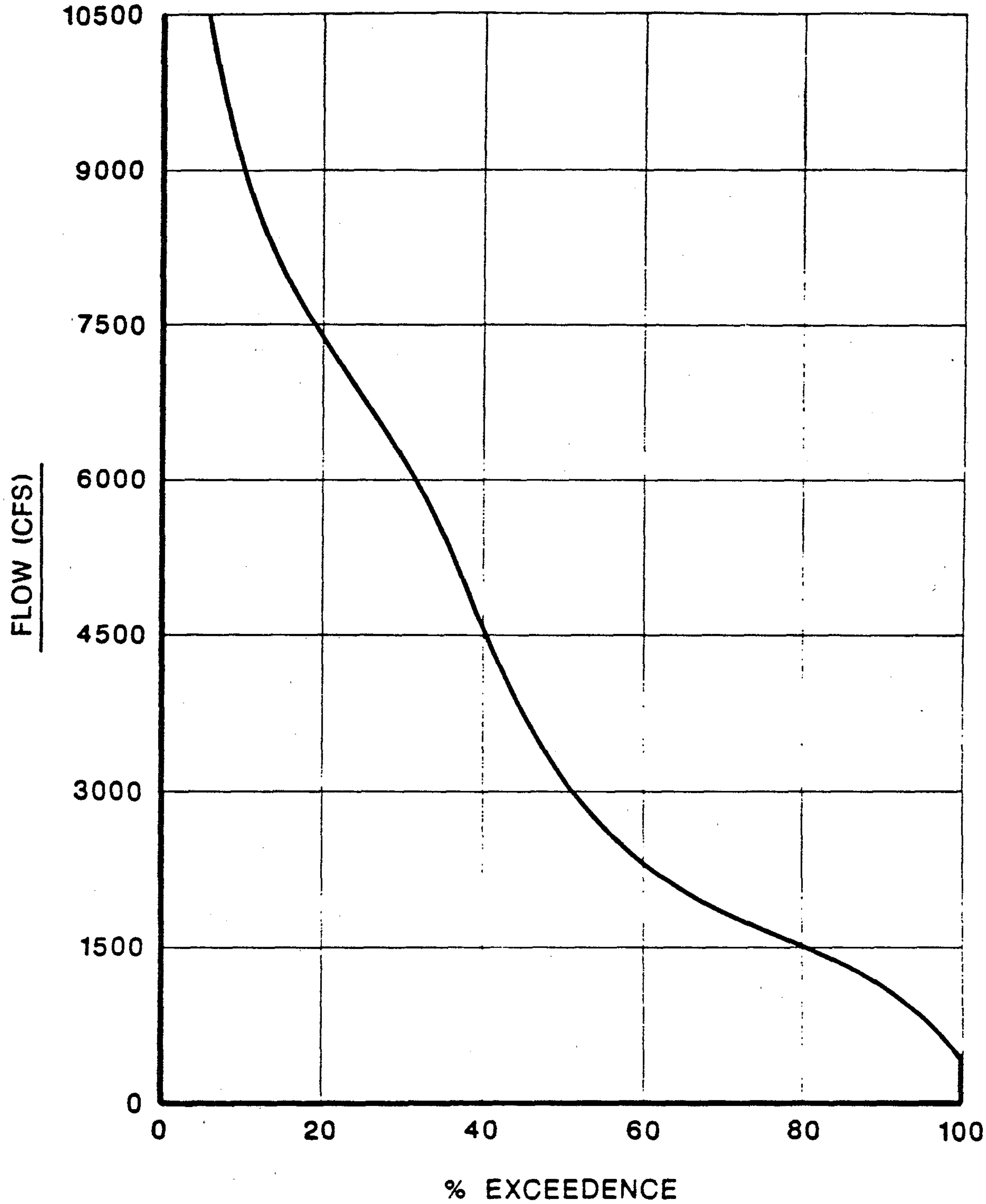

FIGURE 23

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

MAY 1957-1986

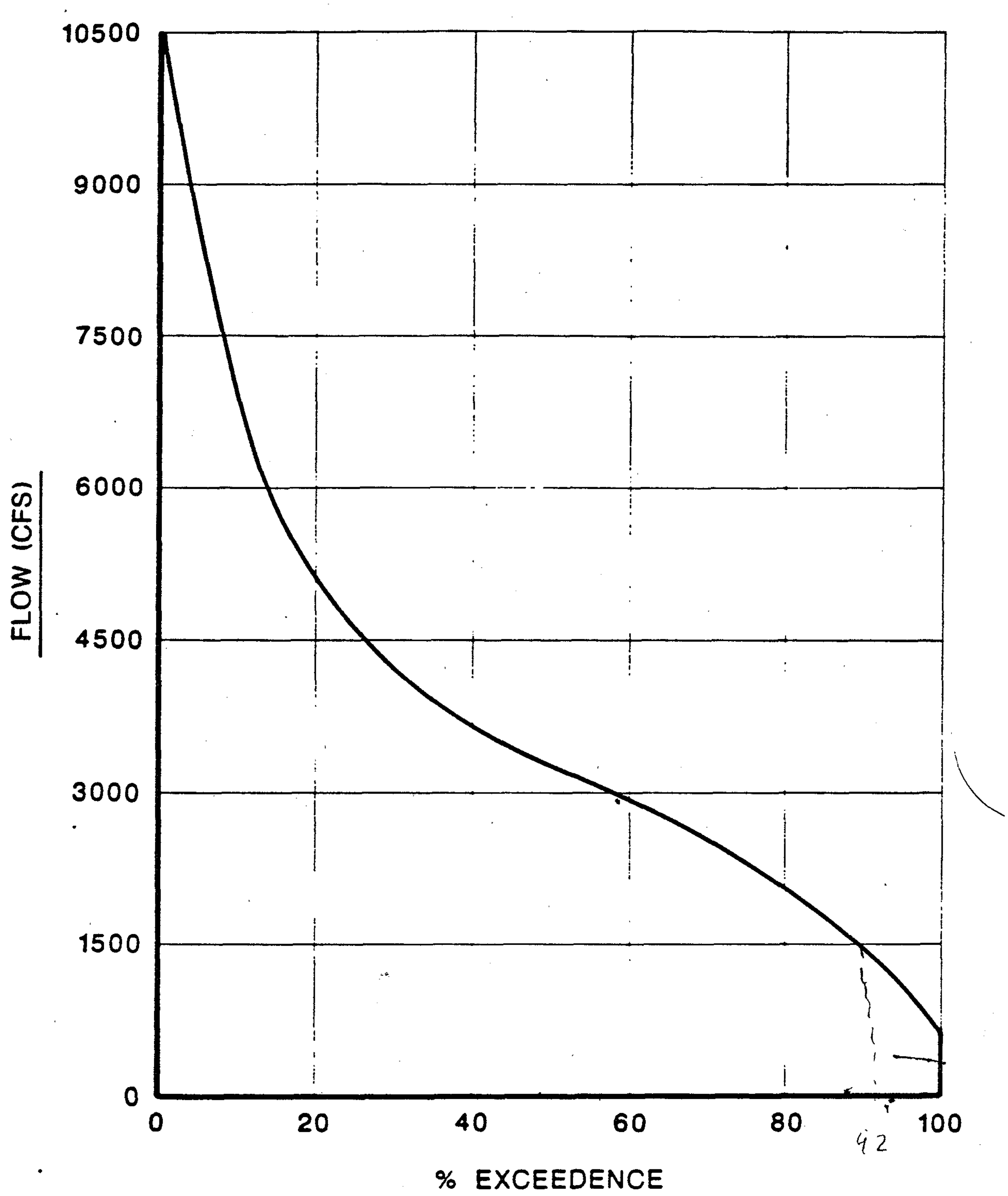

FIGURE 24

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

JUNE 1957-1986

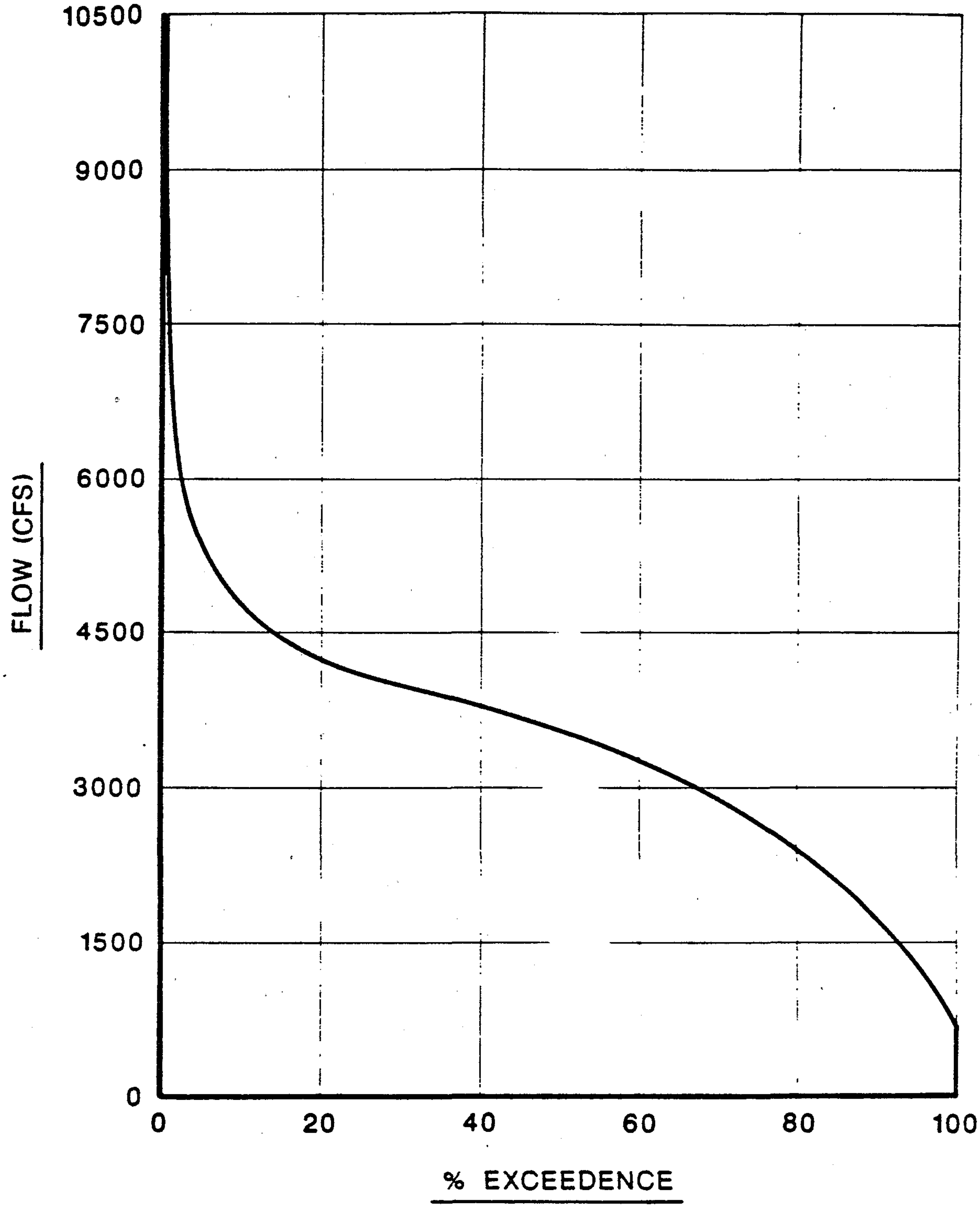

FIGURE 25

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

JULY 1957-1986

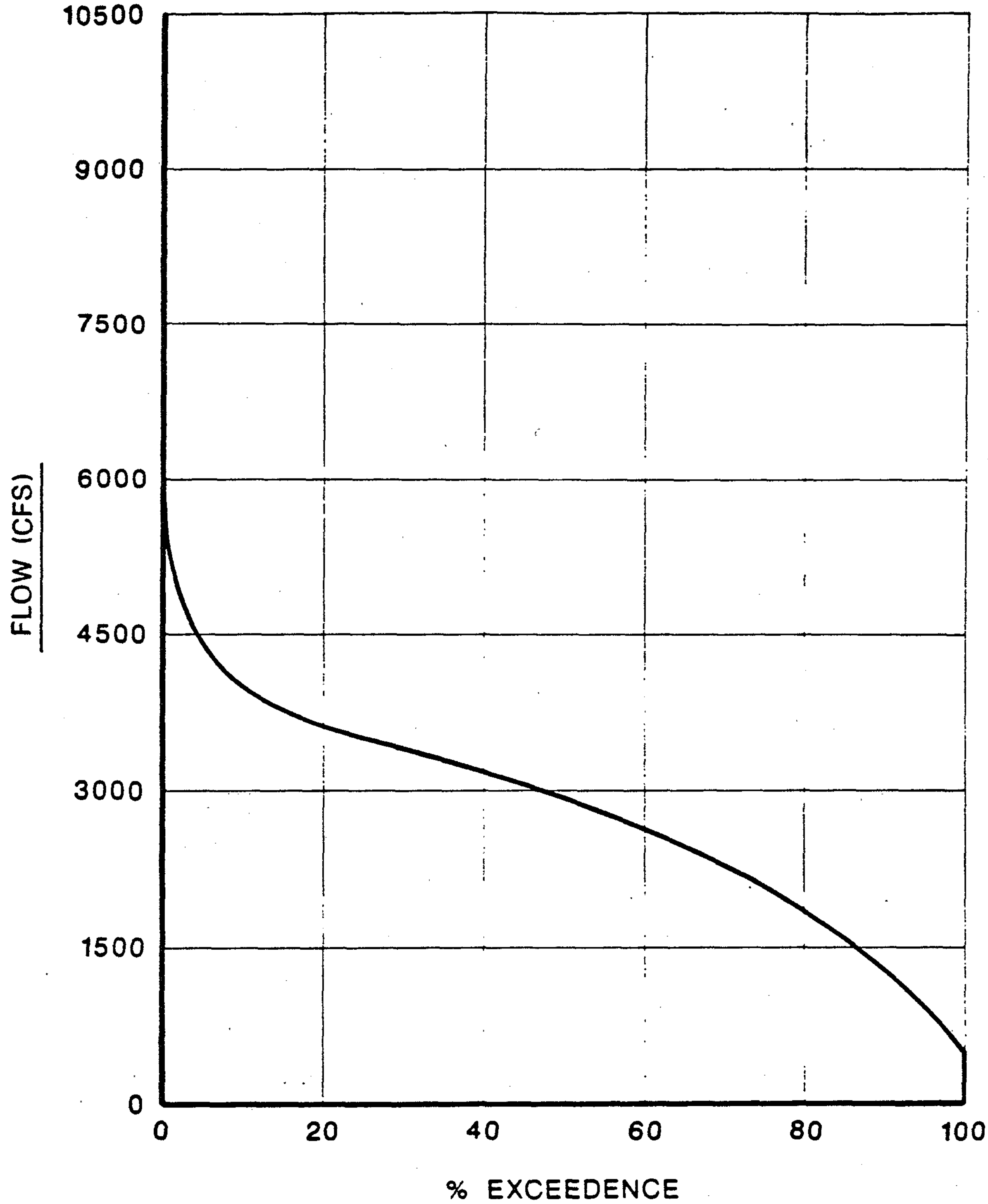

FIGURE 26

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

AUGUST 1957-1986

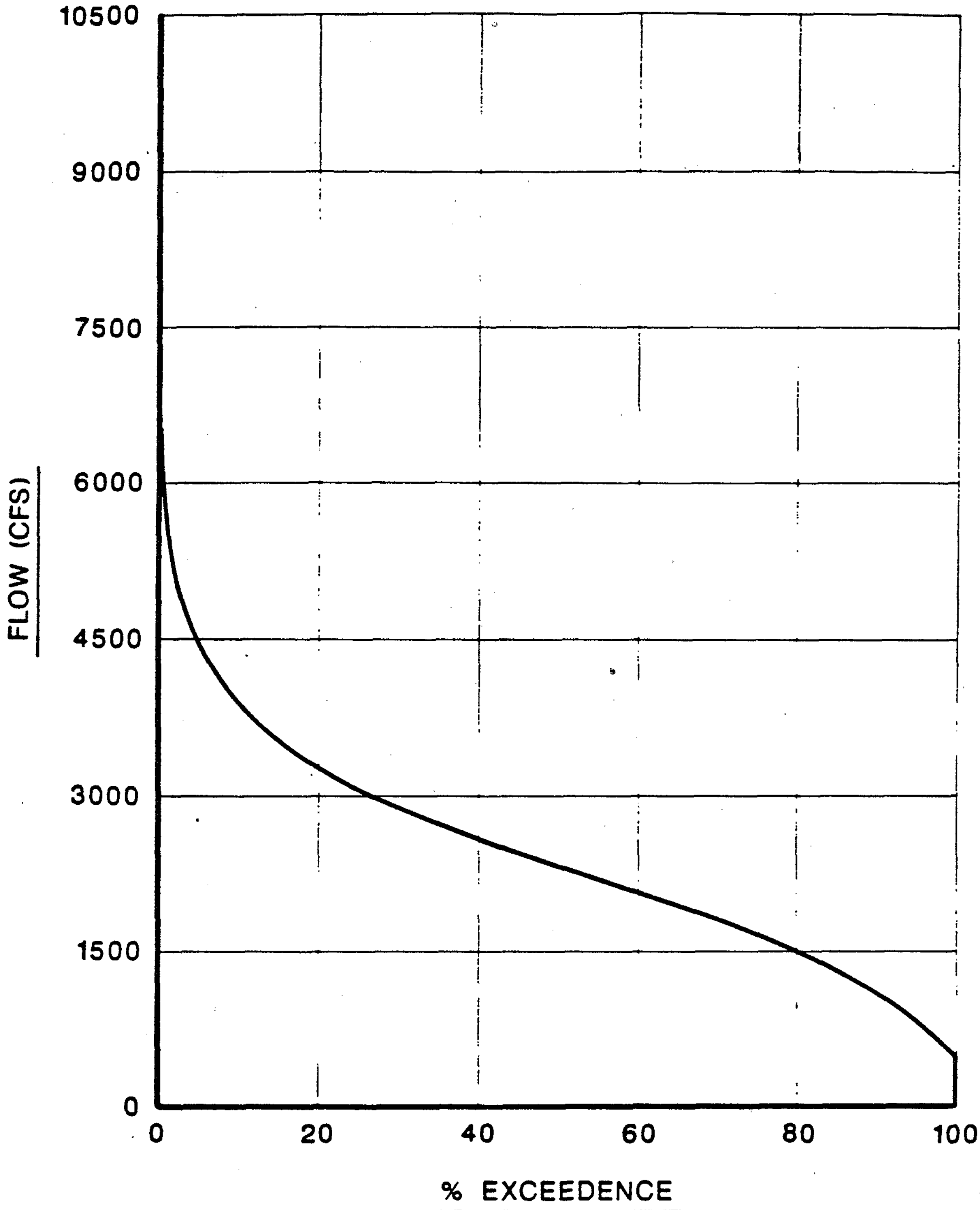

FIGURE 27

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

SEPTEMBER 1957-1986

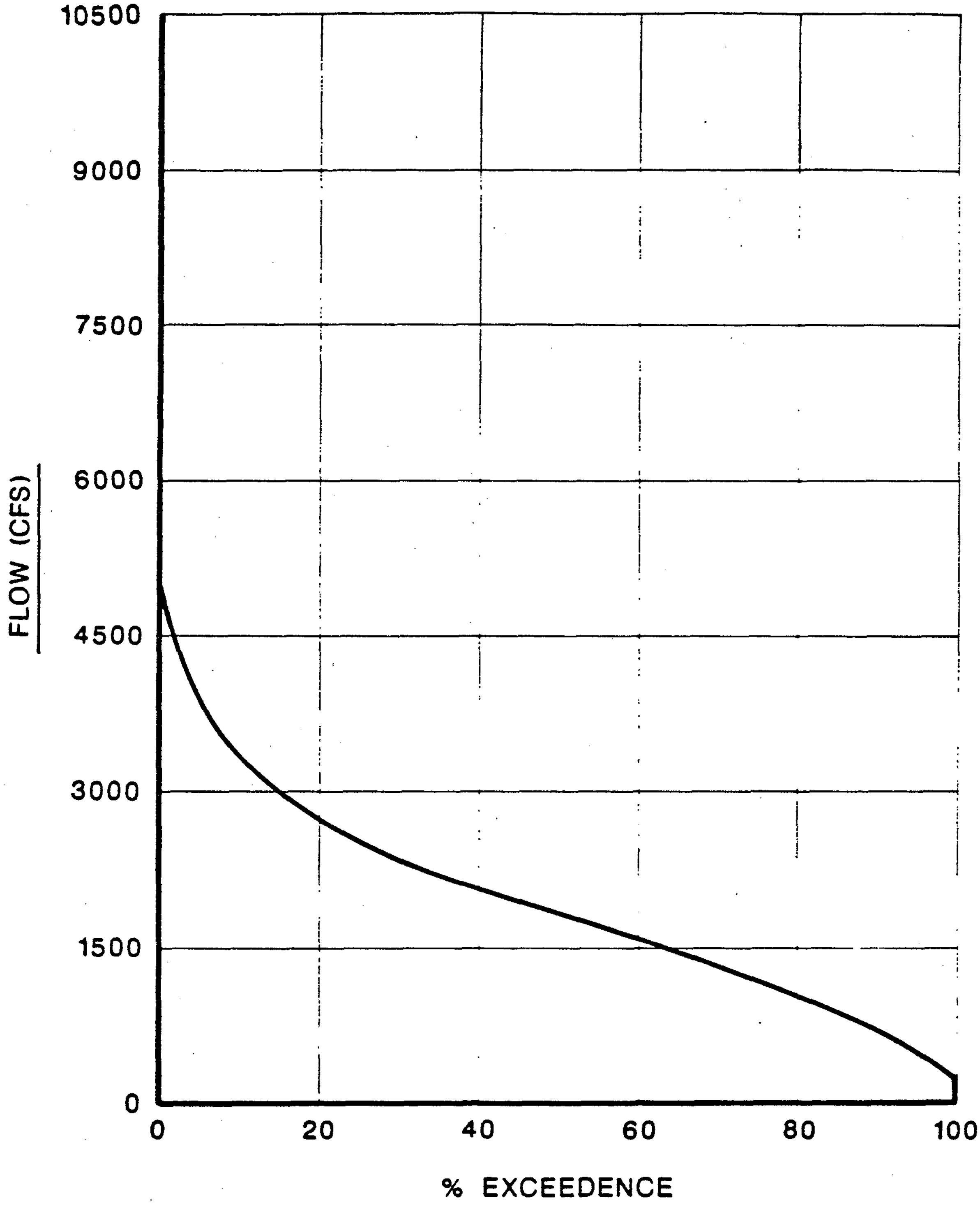

FIGURE 28

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

OCTOBER 1957-1986

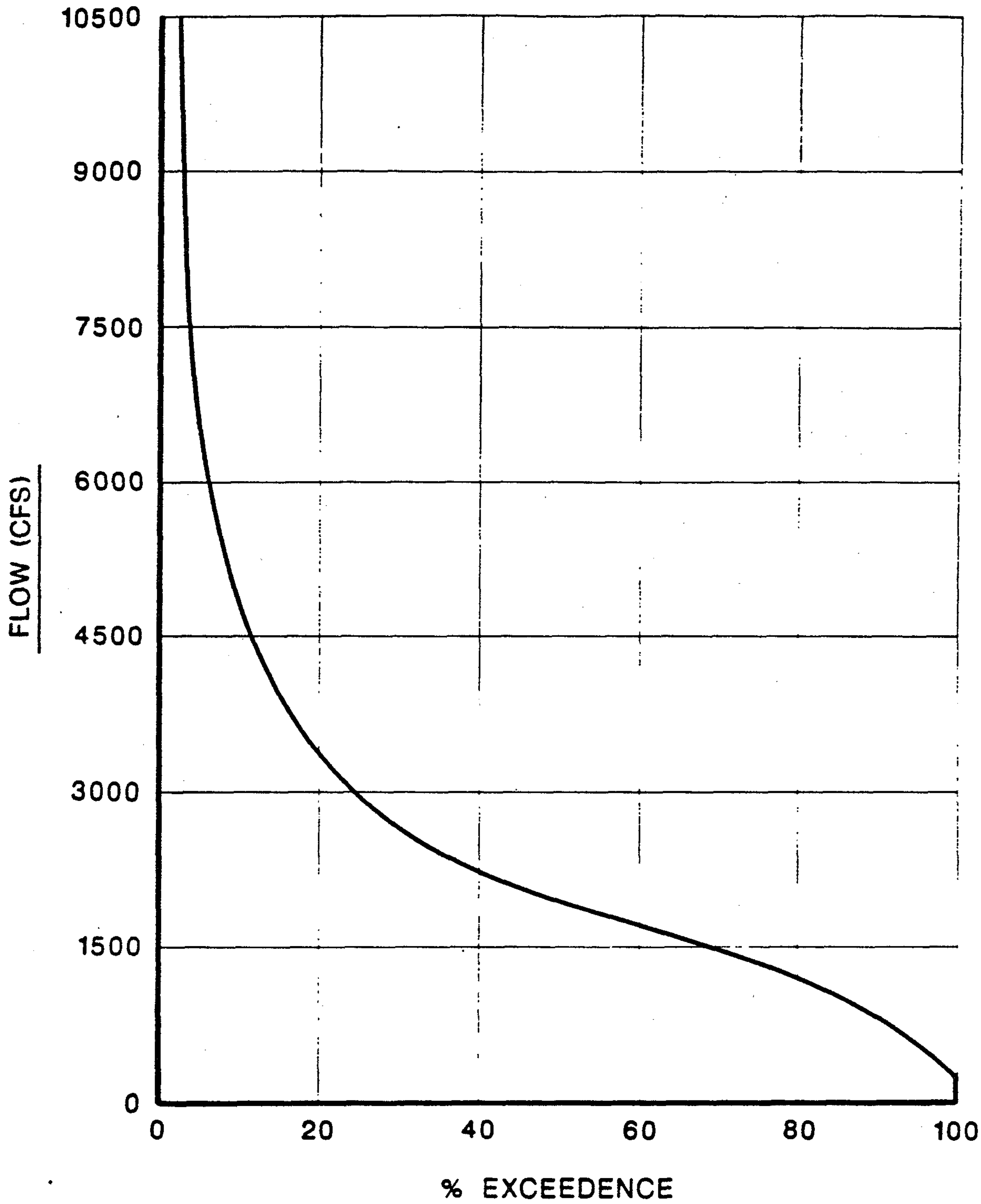

FIGURE 29

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

NOVEMBER 1957-1986

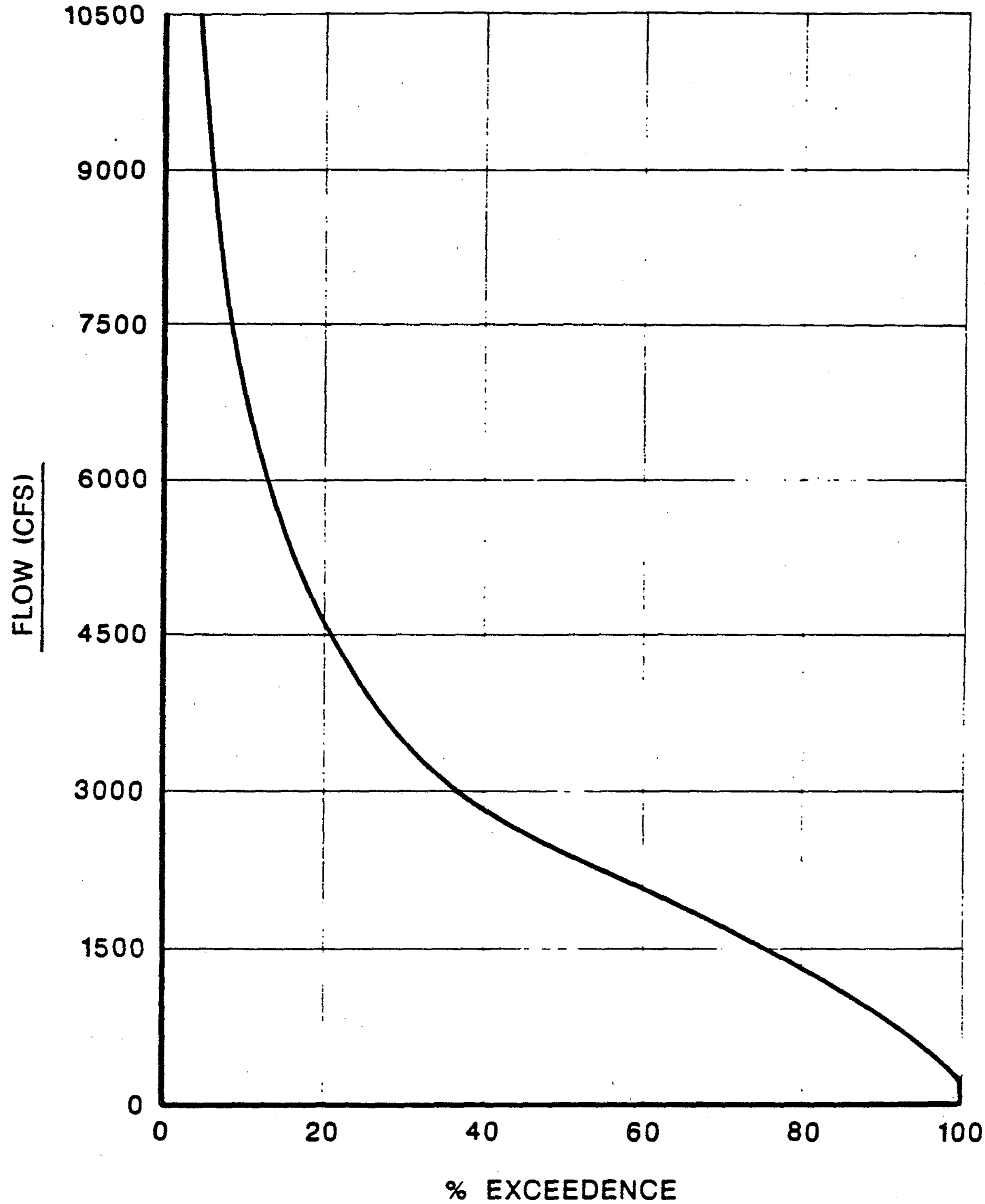

FIGURE 30

AMERICAN RIVER

FLOW EXCEEDENCE CURVE

DECEMBER 1957-1986

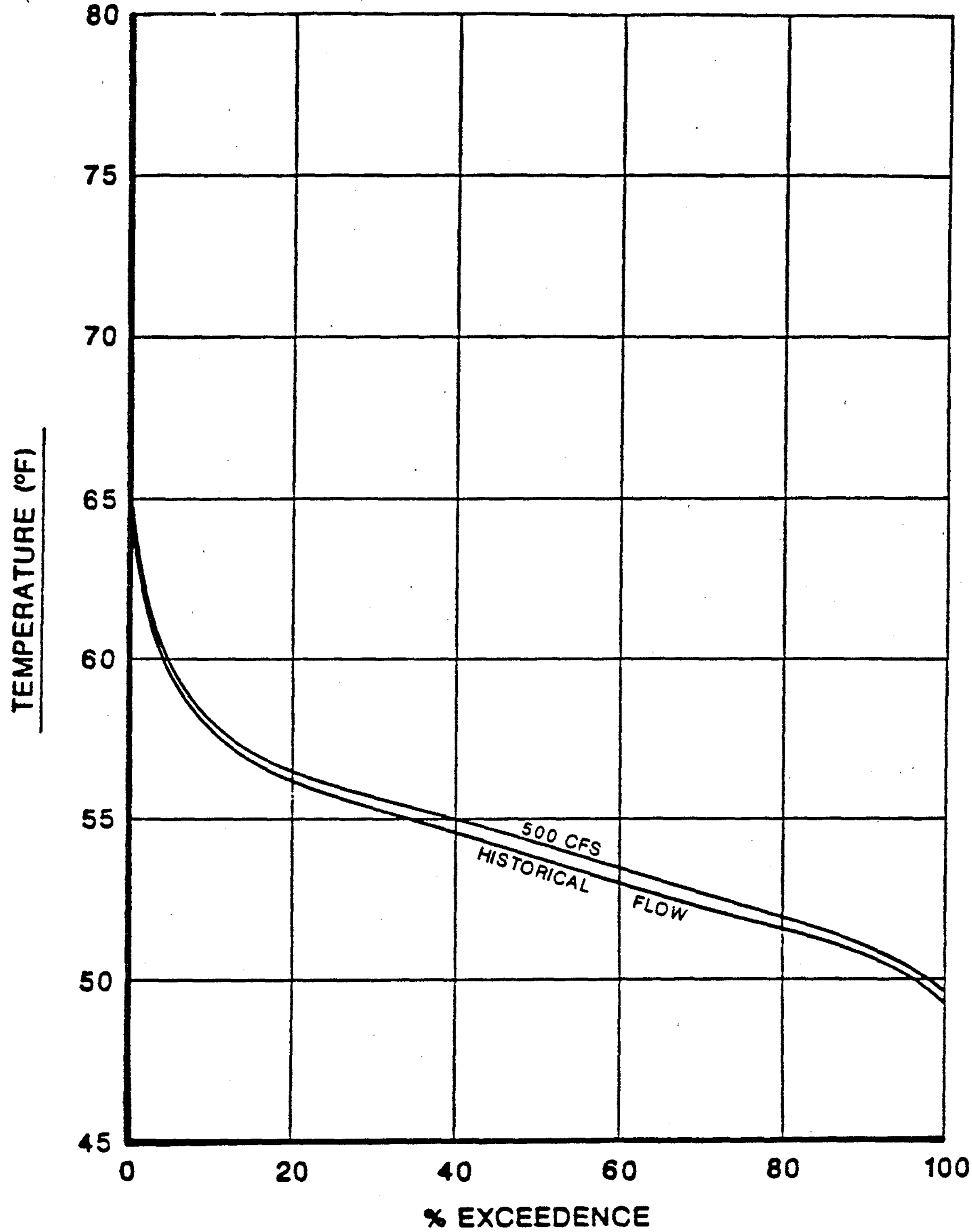

FIGURE 31

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR APRIL
2 MILES BELOW NIMBUS DAM

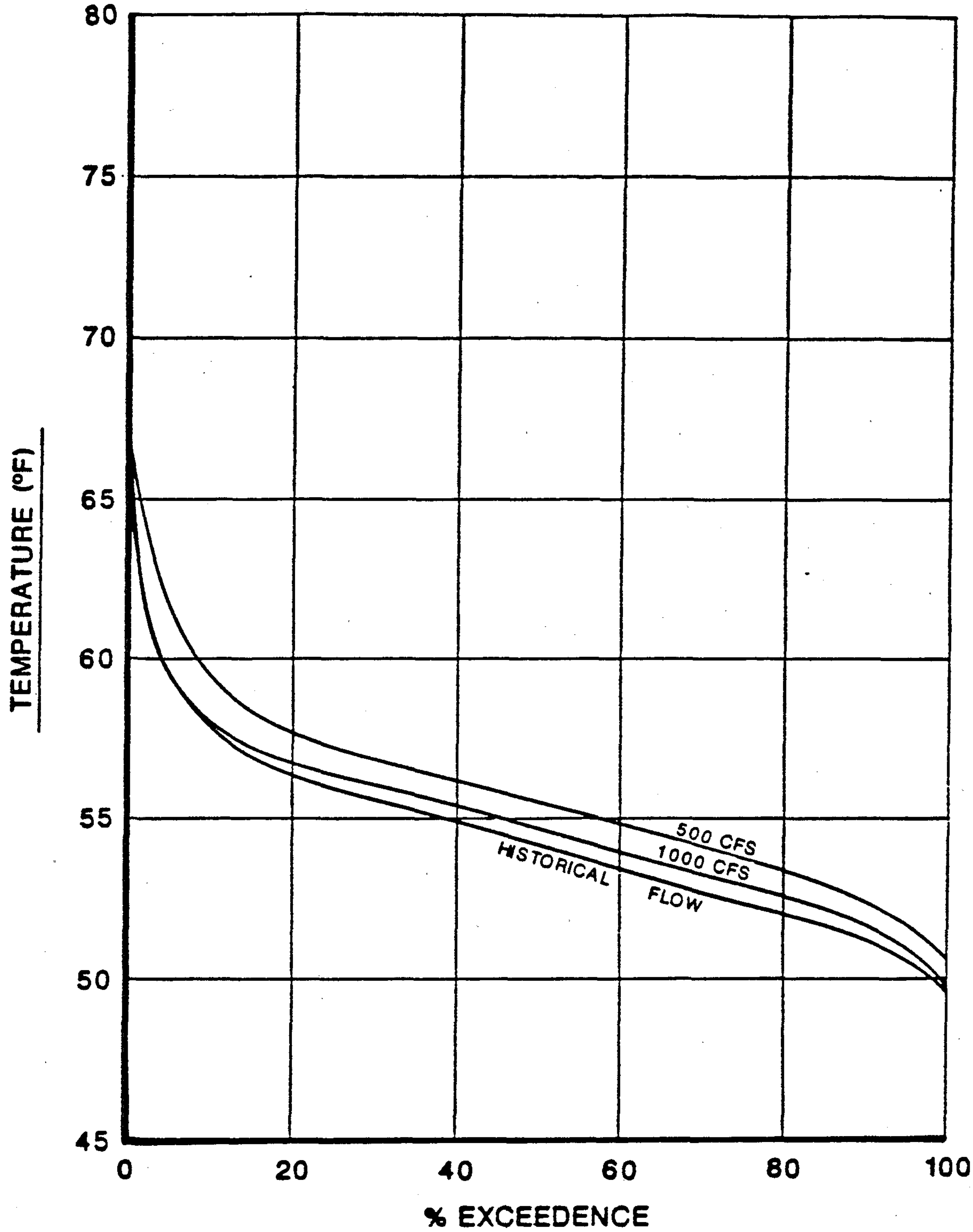

FIGURE 32

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR APRIL
6 MILES BELOW NIMBUS DAM

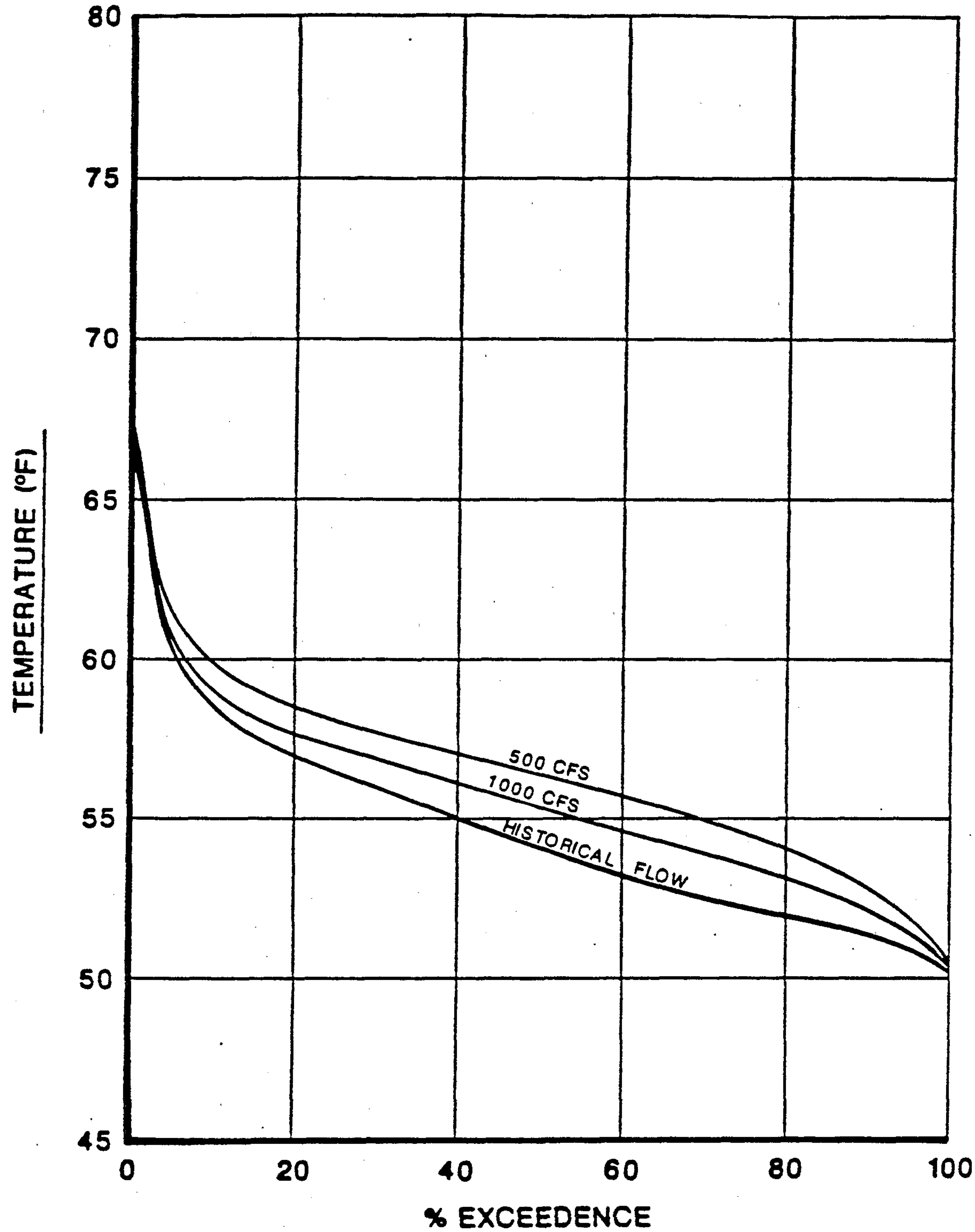

FIGURE 33

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR APRIL
10 MILES BELOW NIMBUS DAM

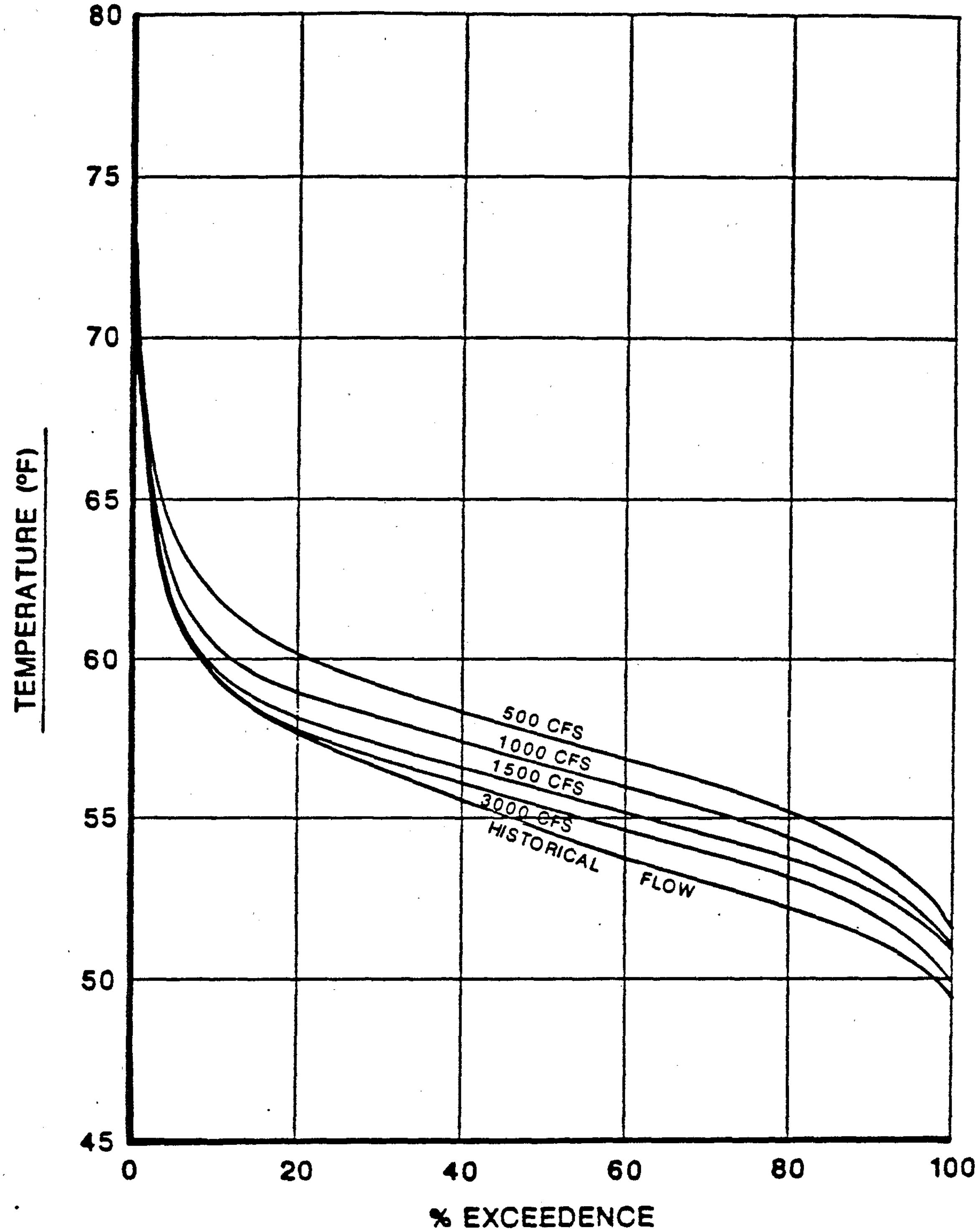

FIGURE 34

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR APRIL
14 MILES BELOW NIMBUS DAM

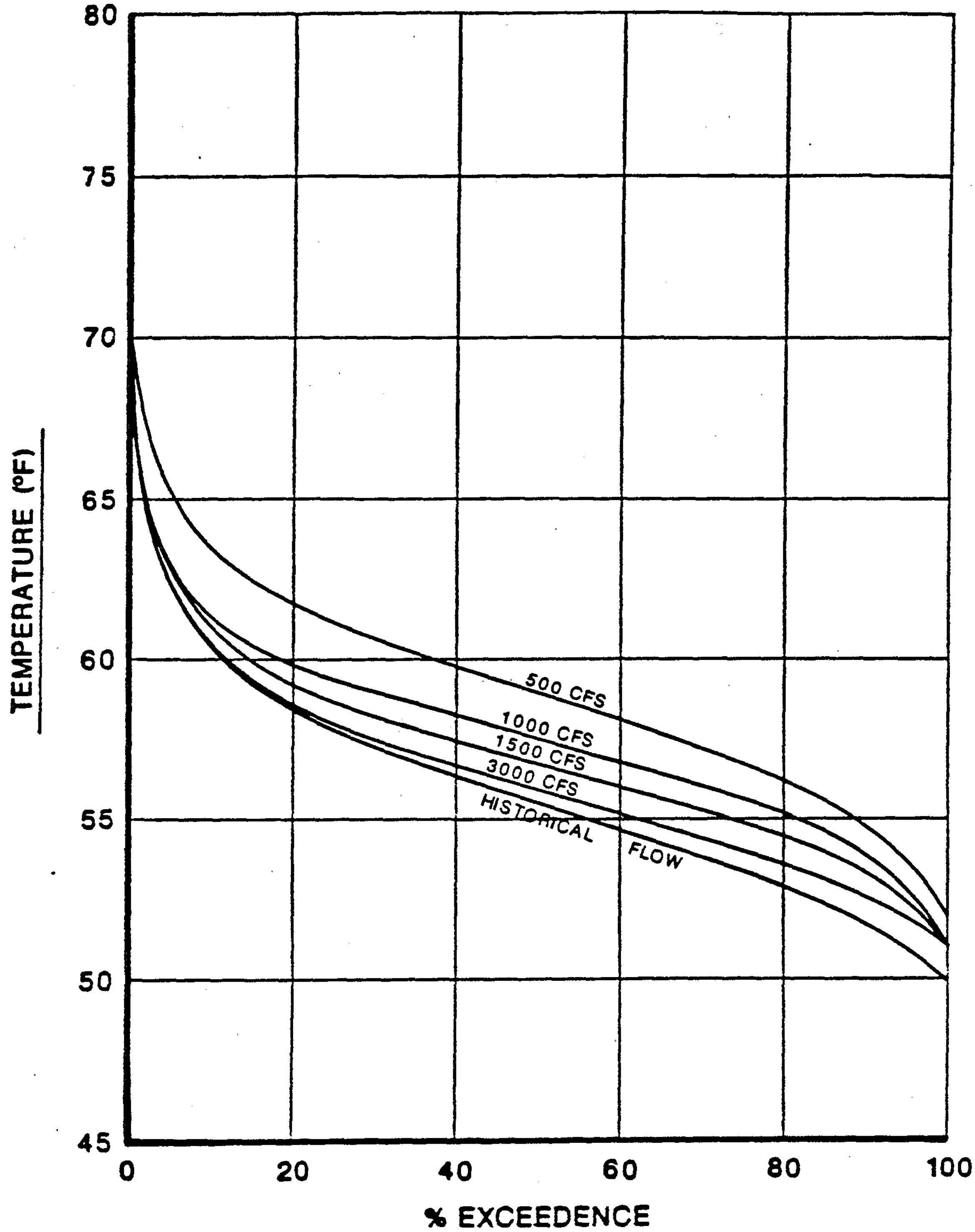

FIGURE 35

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR APRIL
18 MILES BELOW NIMBUS DAM

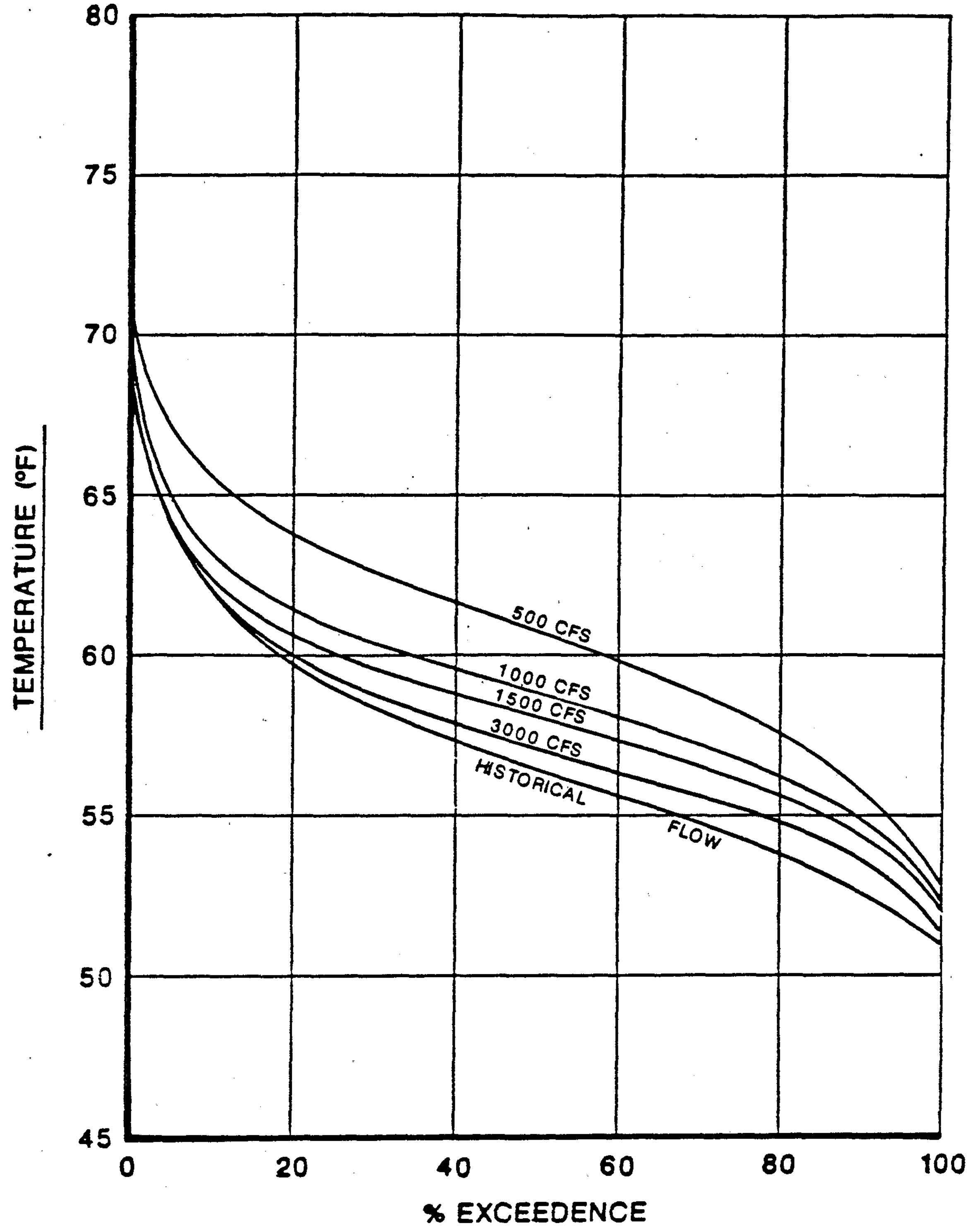

FIGURE 36

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR APRIL
22 MILES BELOW NIMBUS DAM

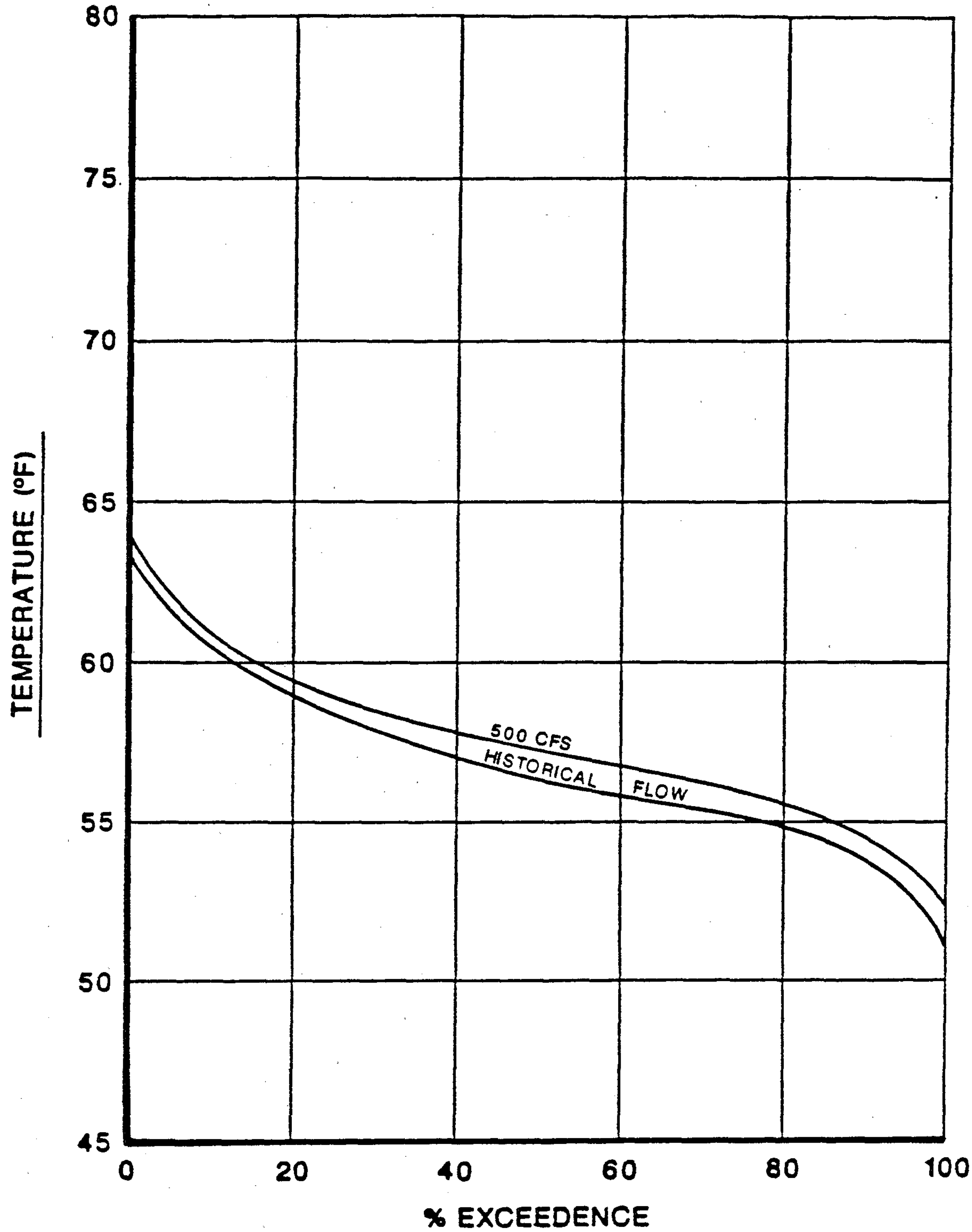

FIGURE 37

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR MAY
2 MILES BELOW NIMBUS DAM

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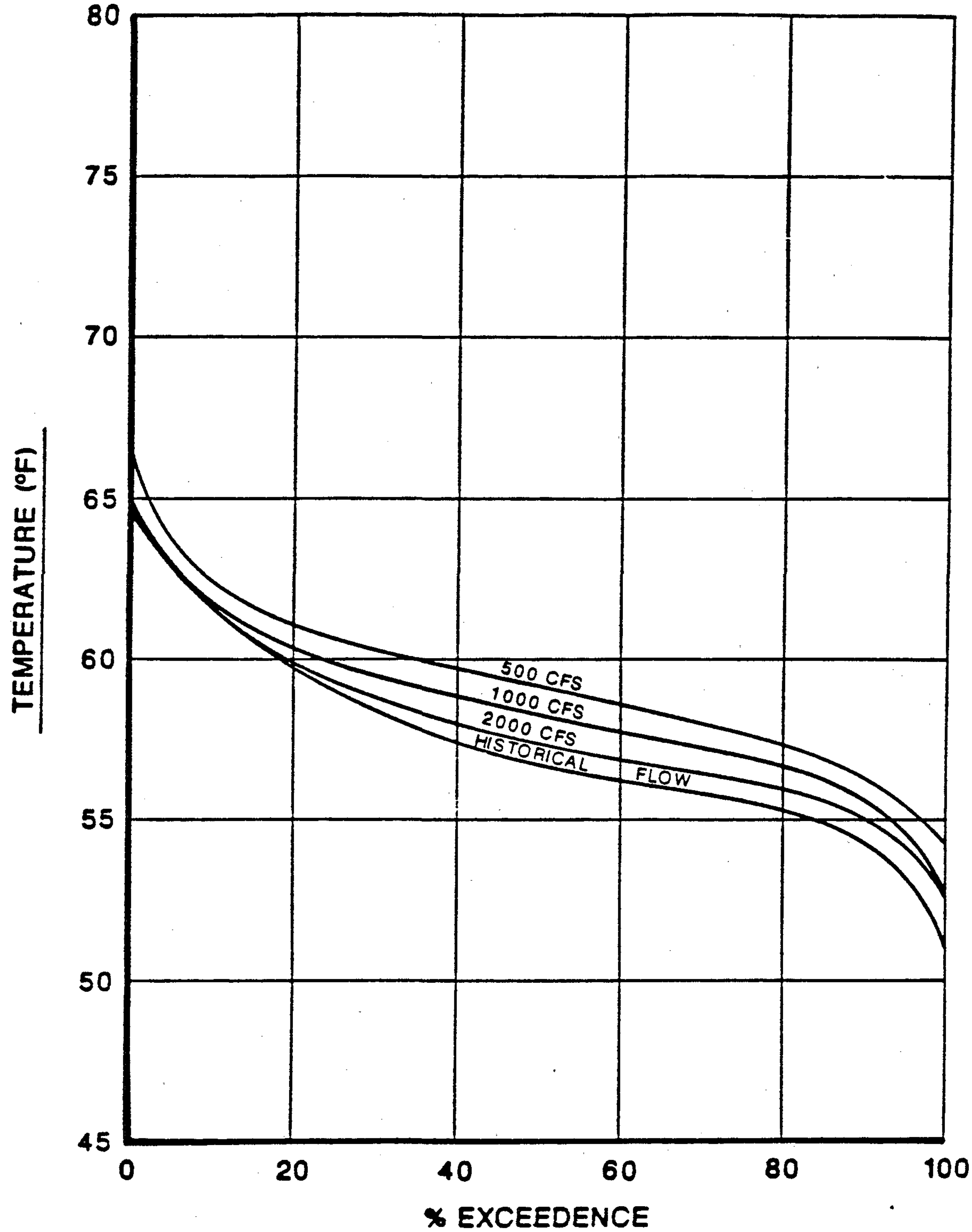

FIGURE 38

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR MAY
6 MILES BELOW NIMBUS DAM

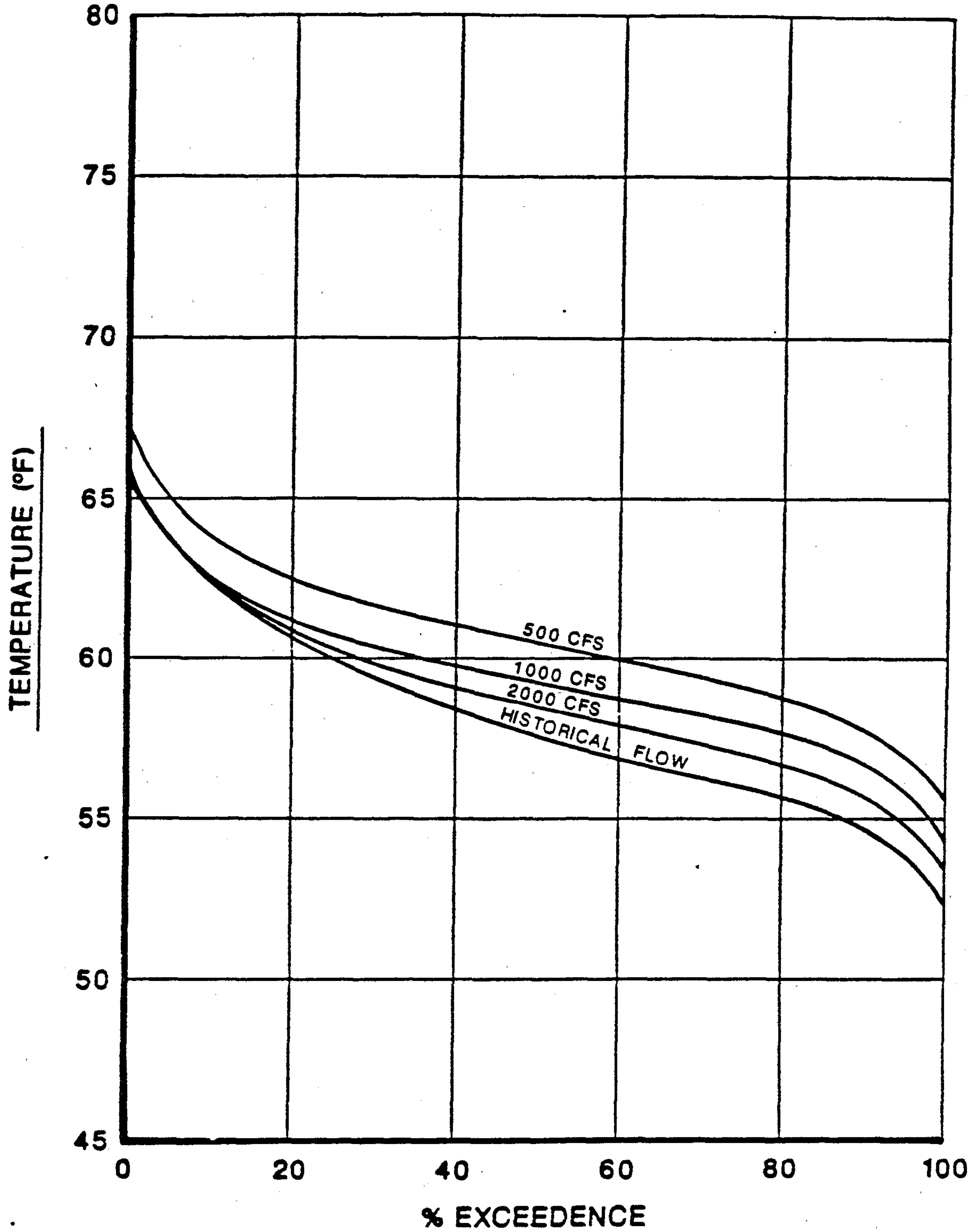

FIGURE 39

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR MAY
10 MILES BELOW NIMBUS DAM

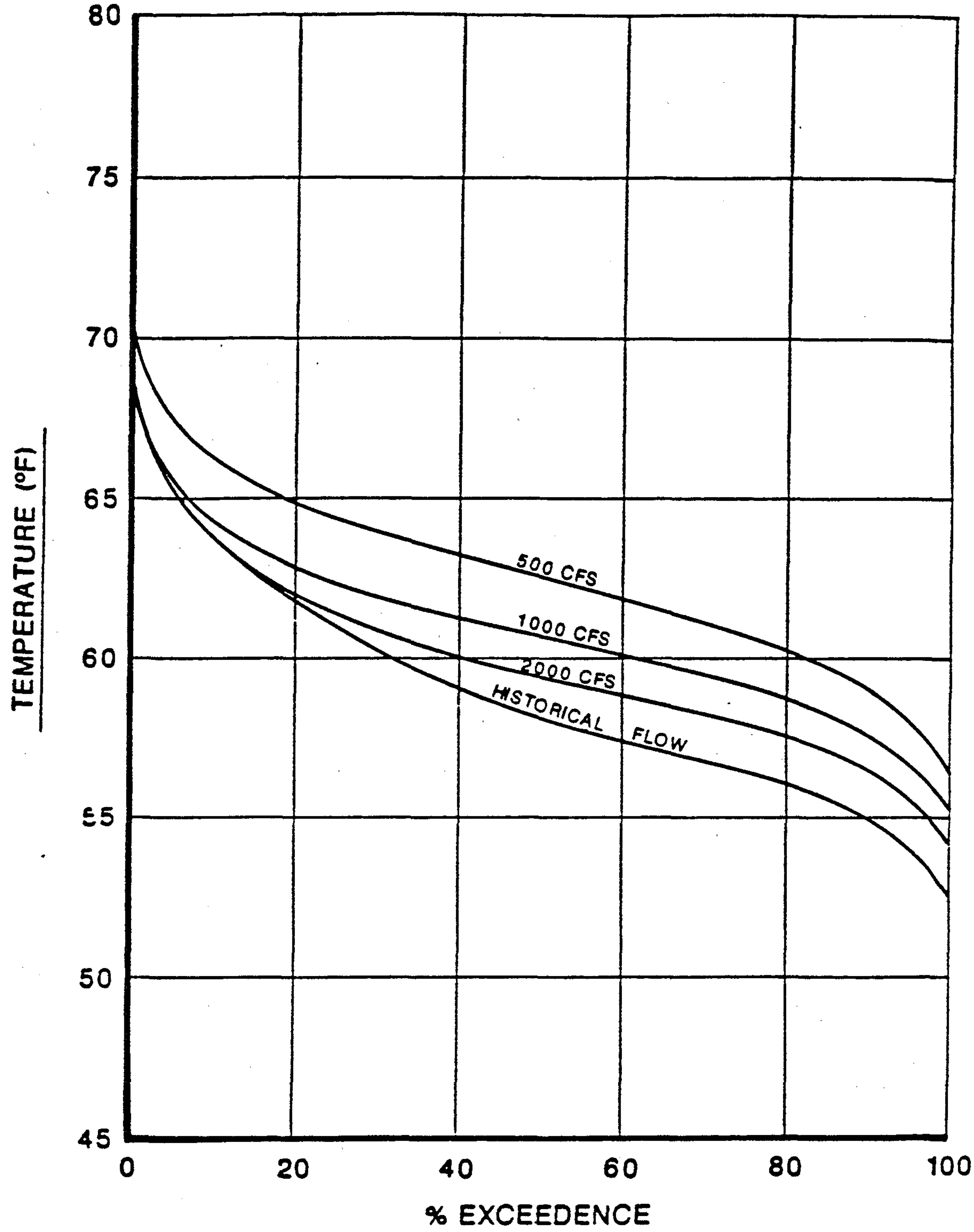

FIGURE 40

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR MAY
14 MILES BELOW NIMBUS DAM

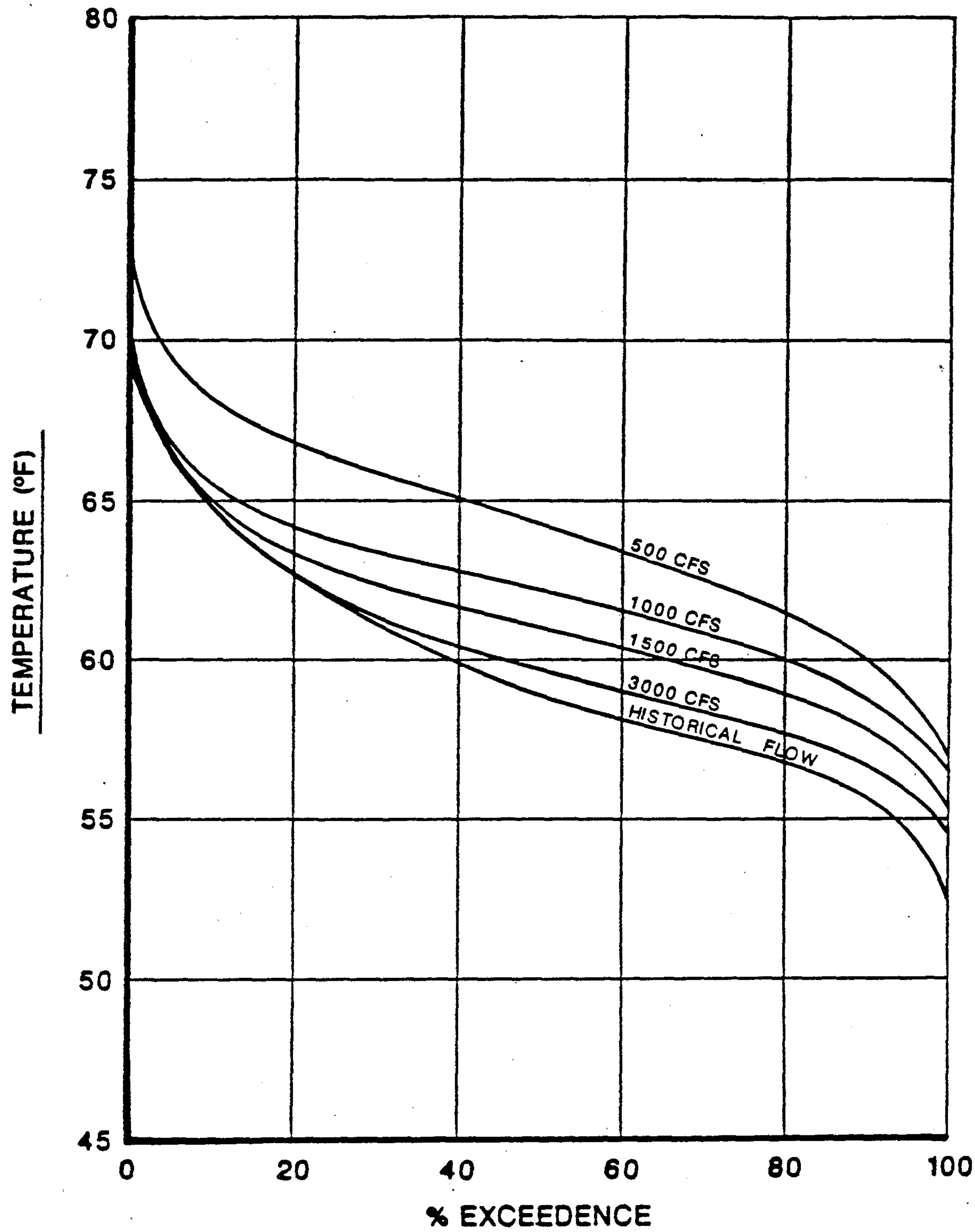

FIGURE 41

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR MAY
18 MILES BELOW NIMBUS DAM

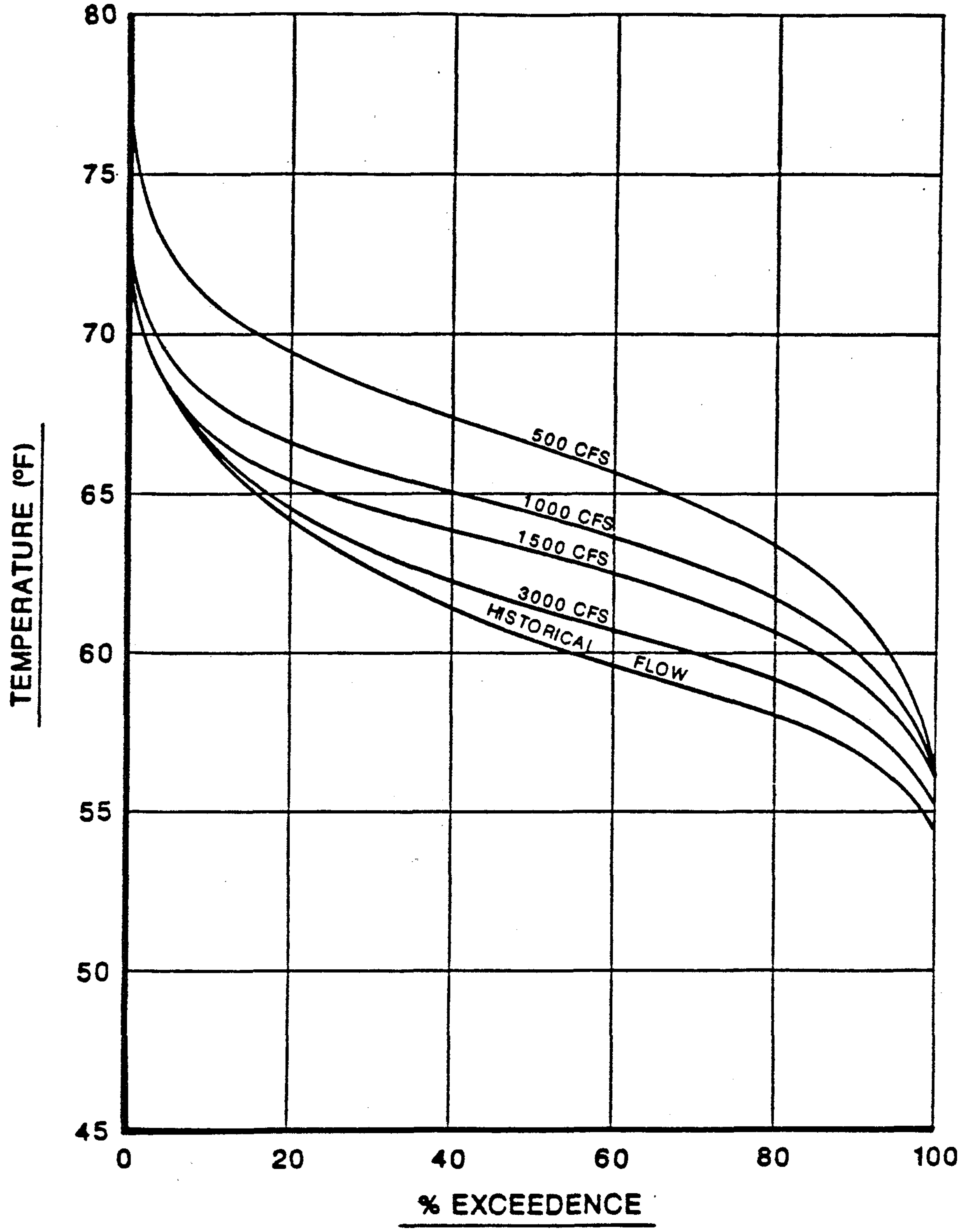

FIGURE 42

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR MAY
22 MILES BELOW NIMBUS DAM

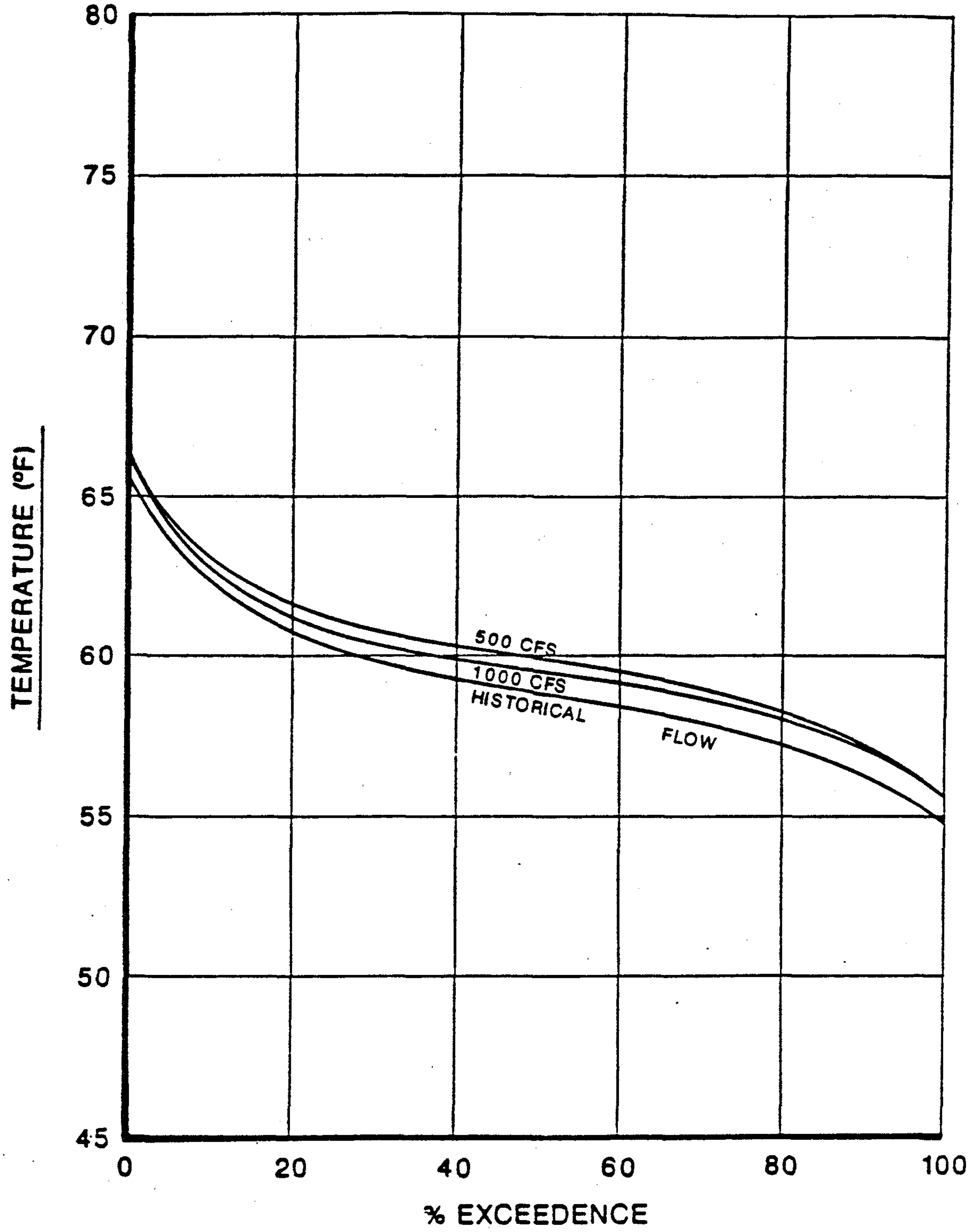

FIGURE 43

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JUNE
2 MILES BELOW NIMBUS DAM

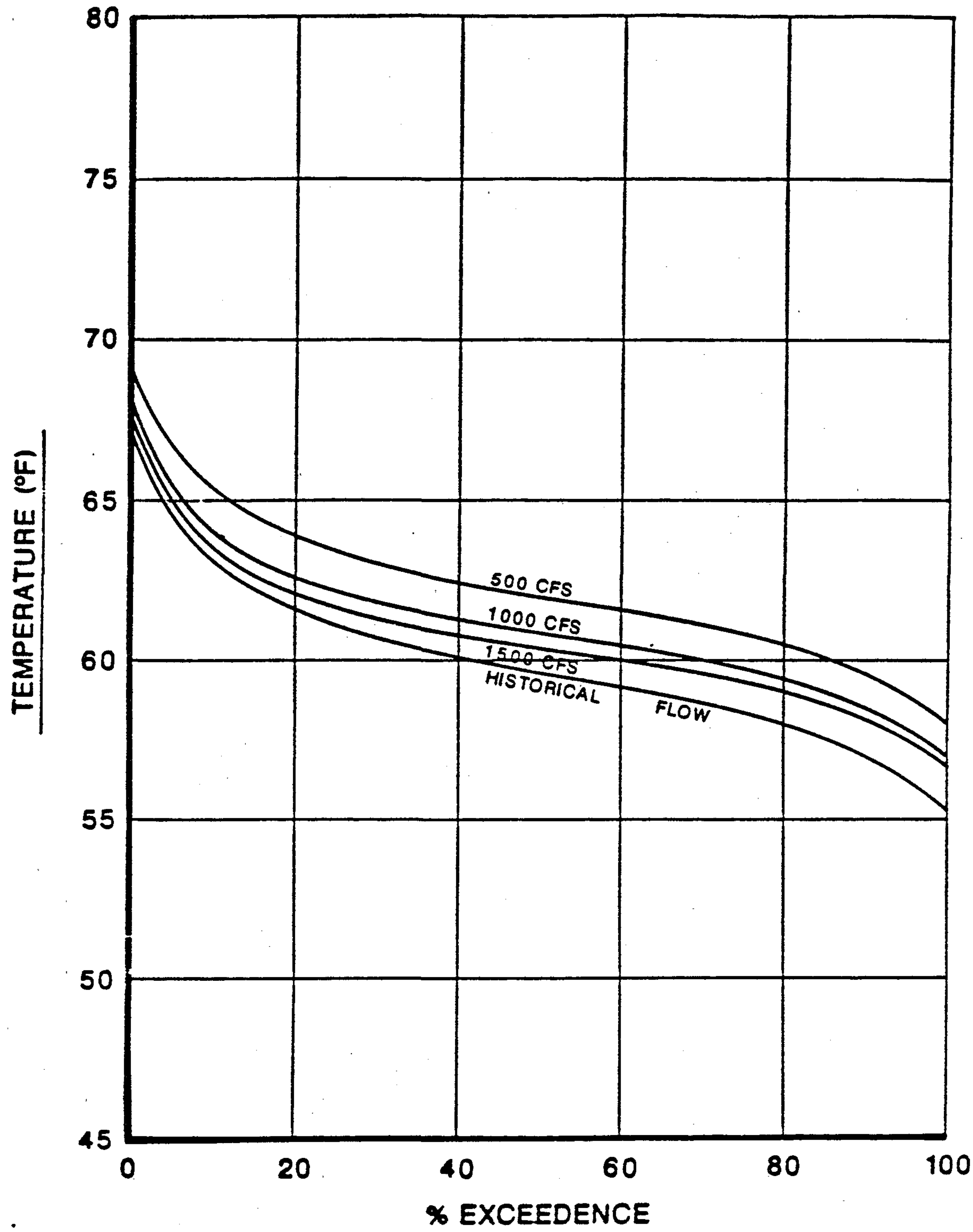

FIGURE 44

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JUNE
6 MILES BELOW NIMBUS DAM

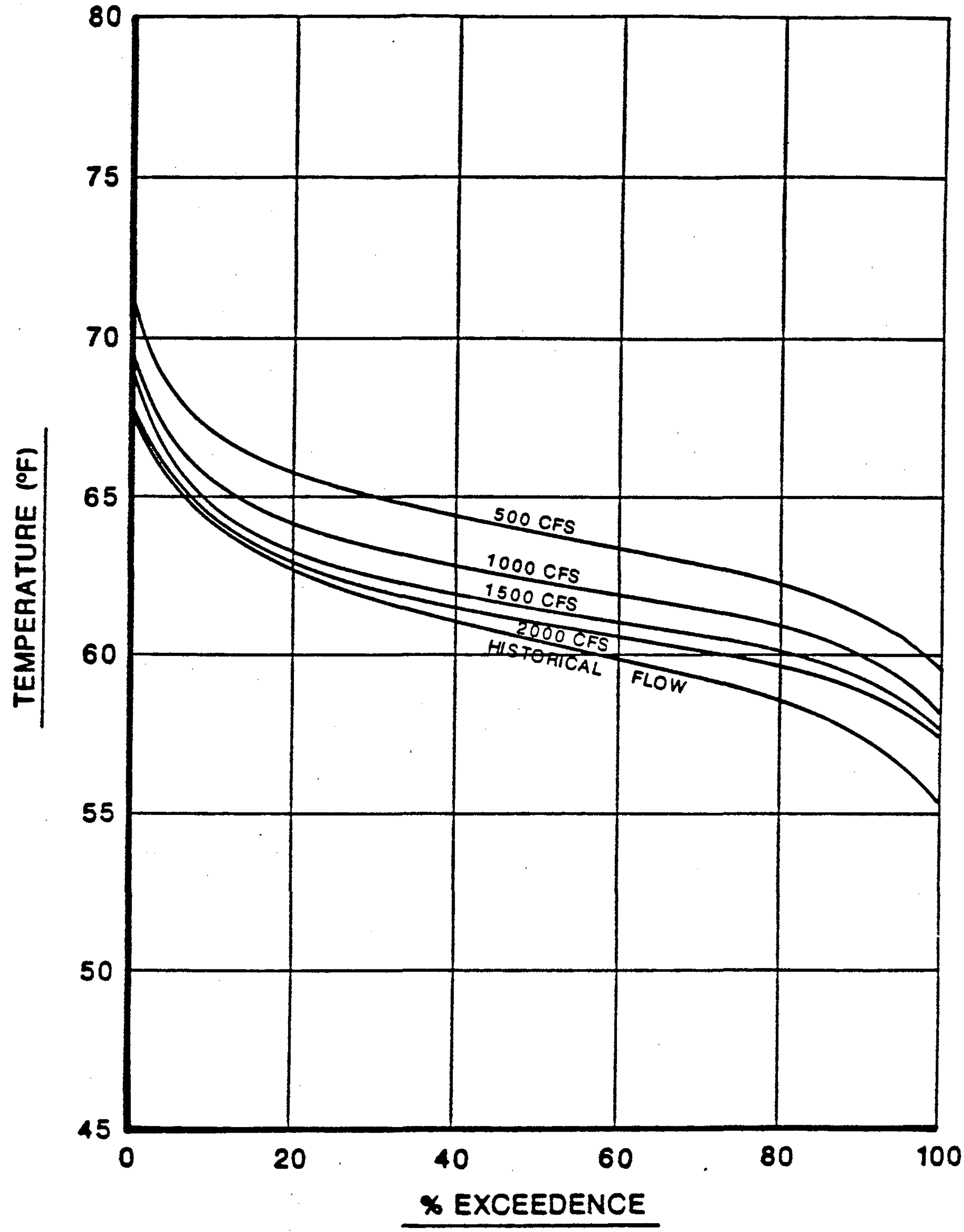

FIGURE 45

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JUNE
10 MILES BELOW NIMBUS DAM

C-043668

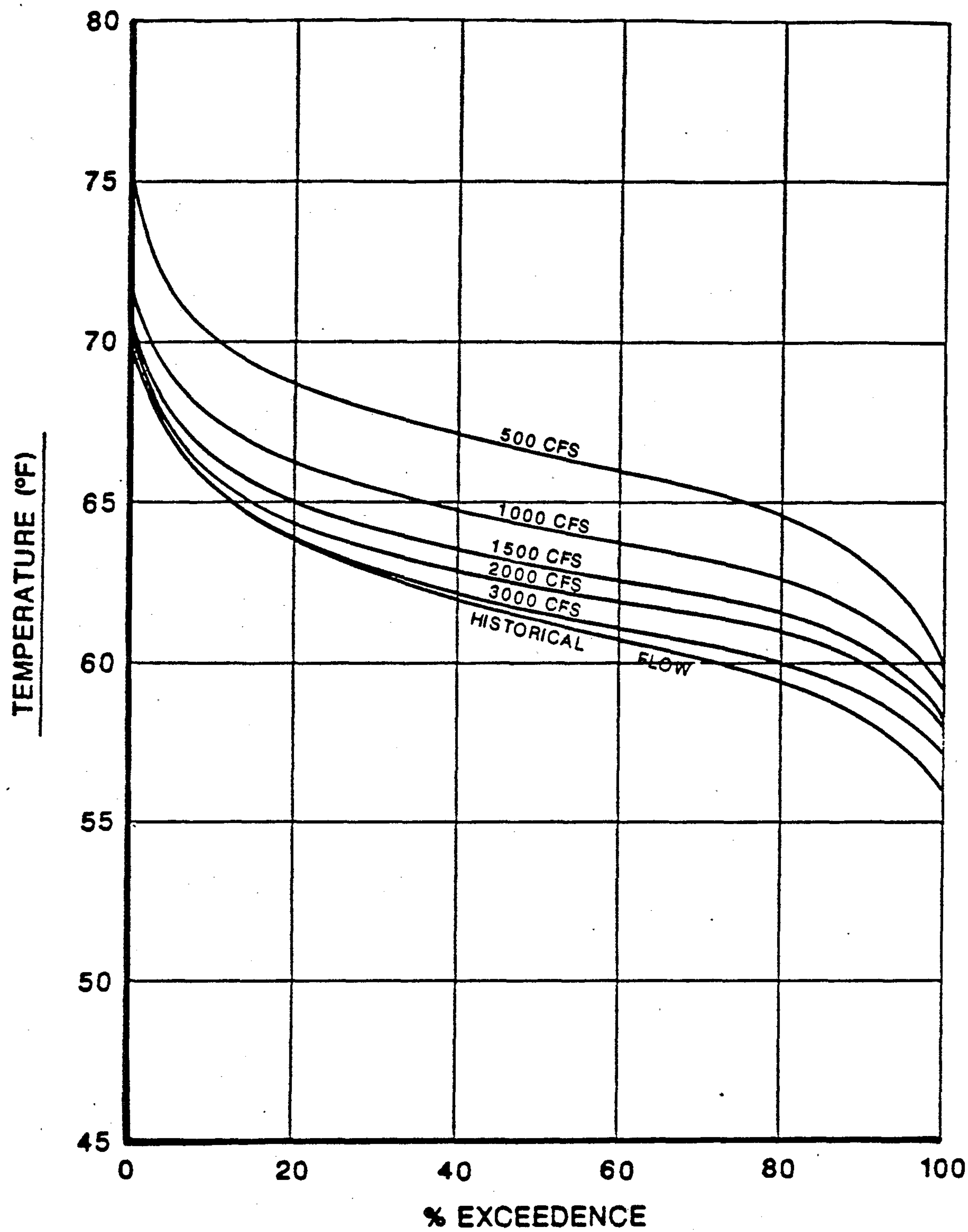

FIGURE 46

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JUNE
14 MILES BELOW NIMBUS DAM

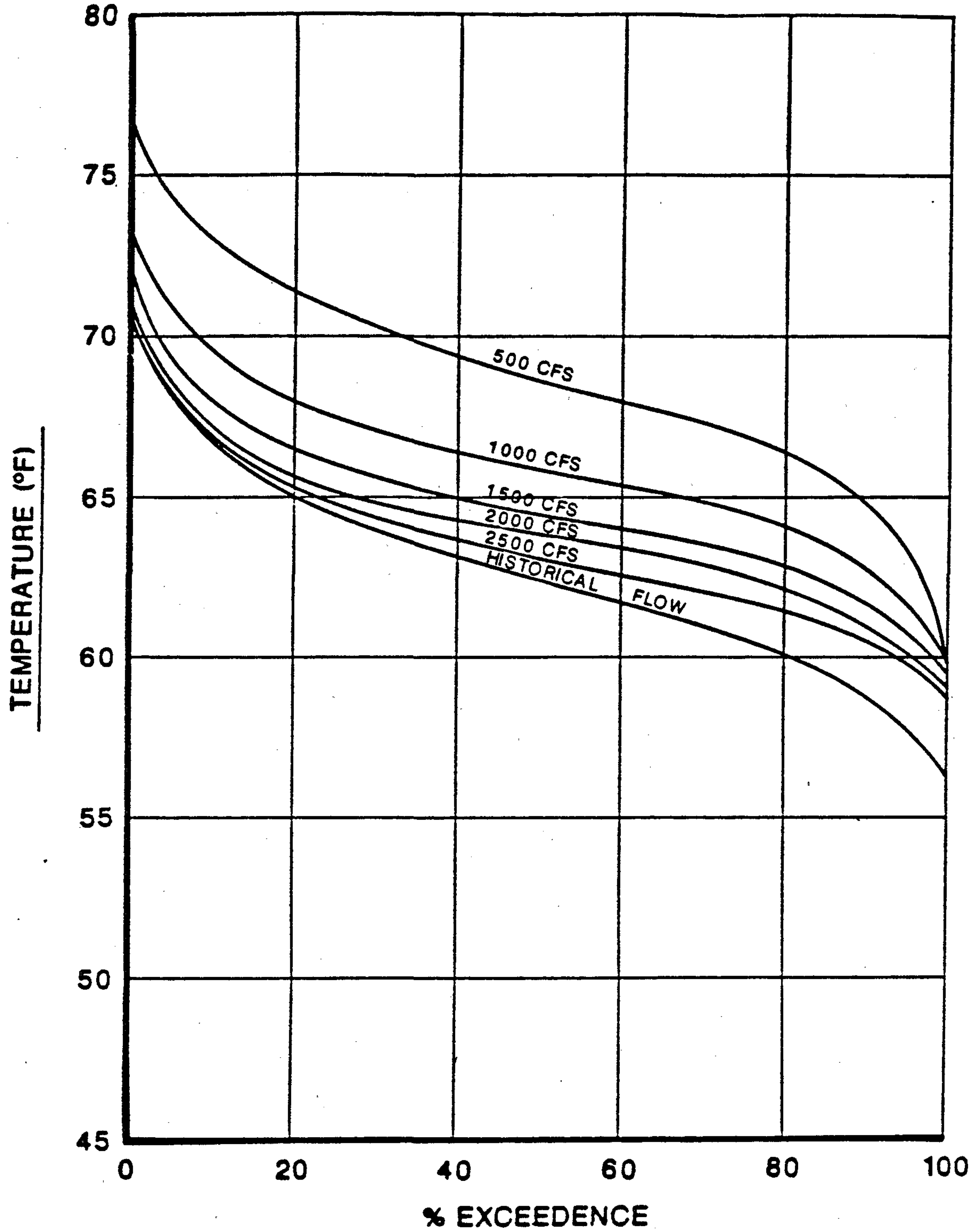

FIGURE 47

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JUNE
18 MILES BELOW NIMBUS DAM

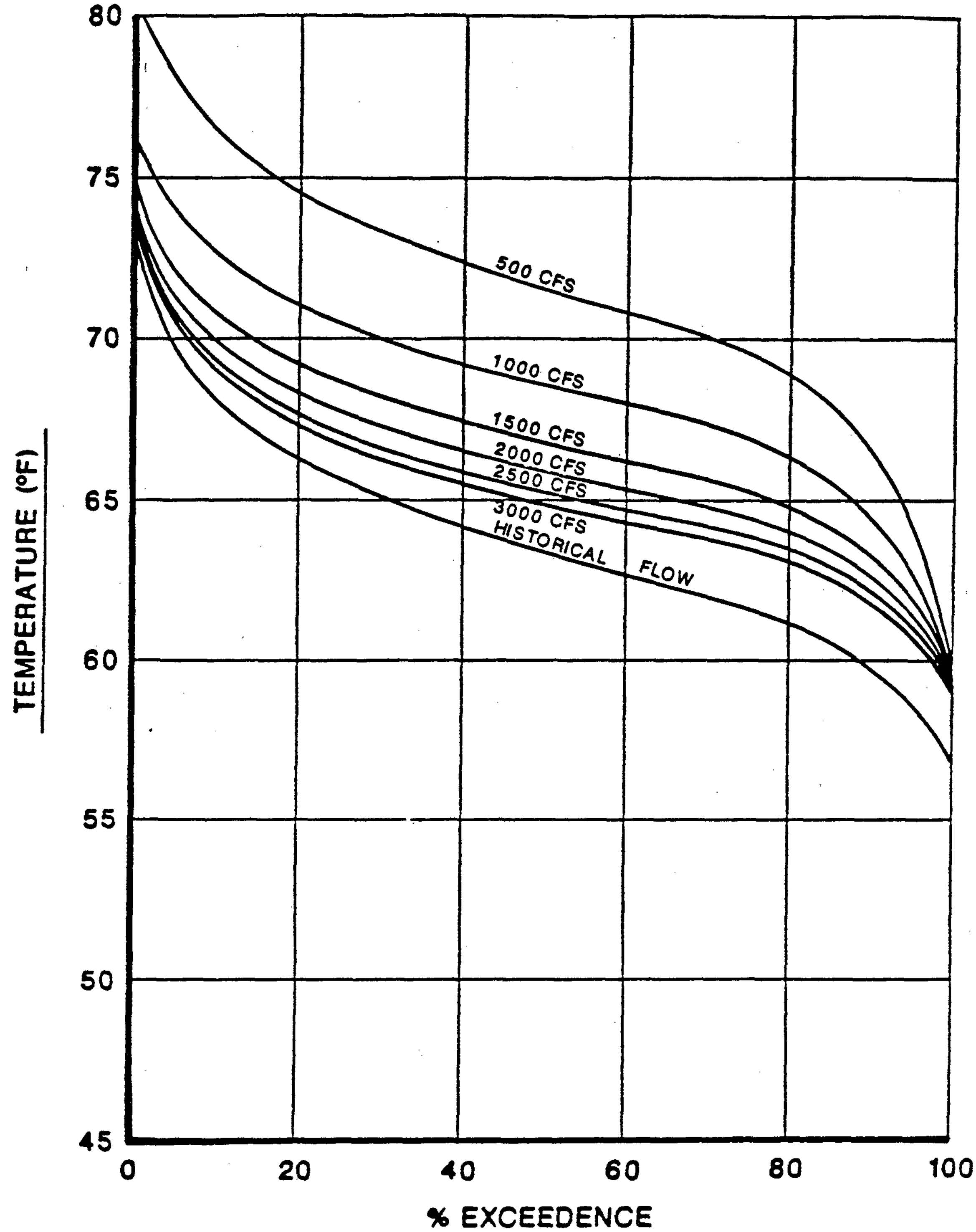

FIGURE 48

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JUNE
22 MILES BELOW NIMBUS DAM

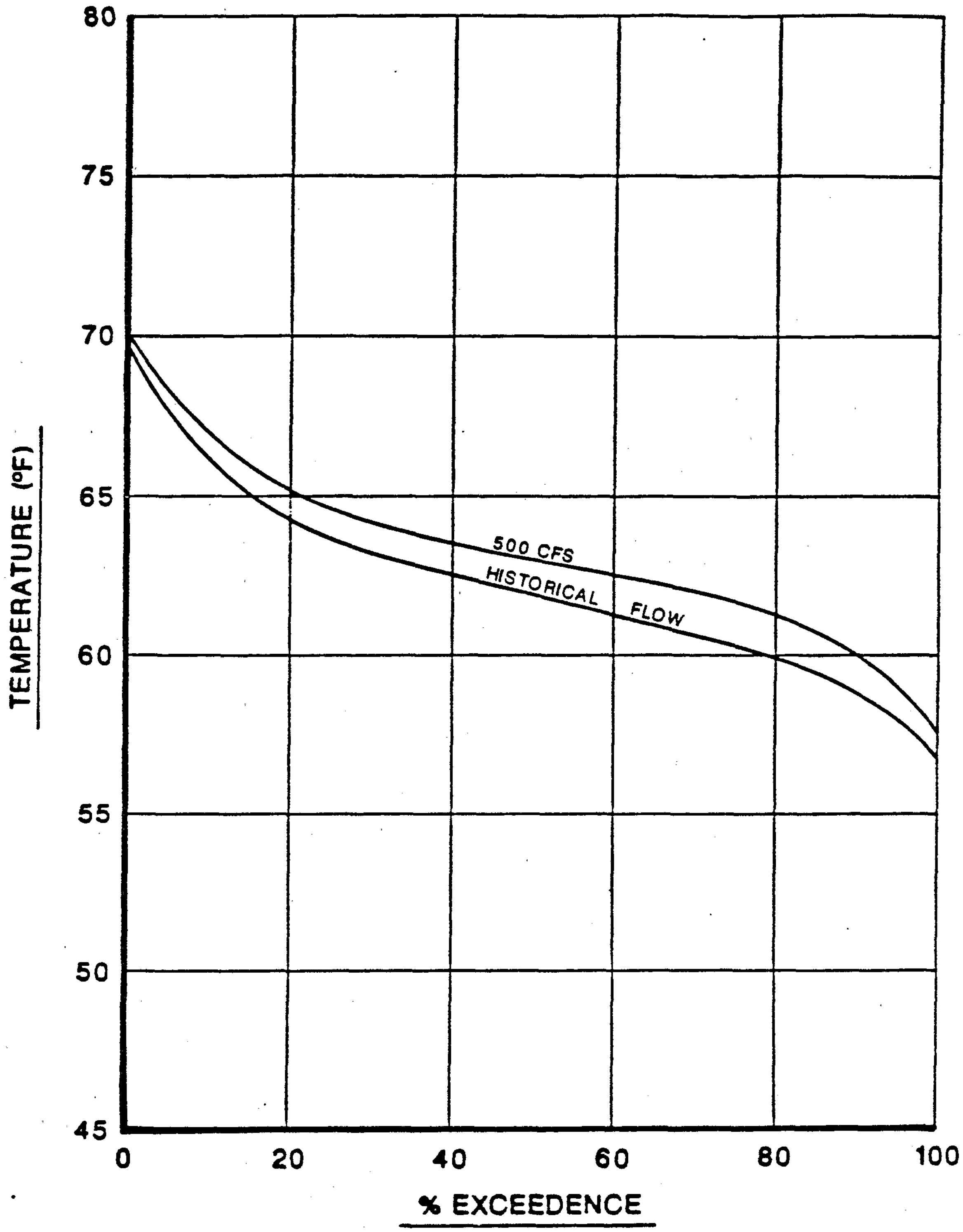

FIGURE 49

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JULY
2 MILES BELOW NIMBUS DAM

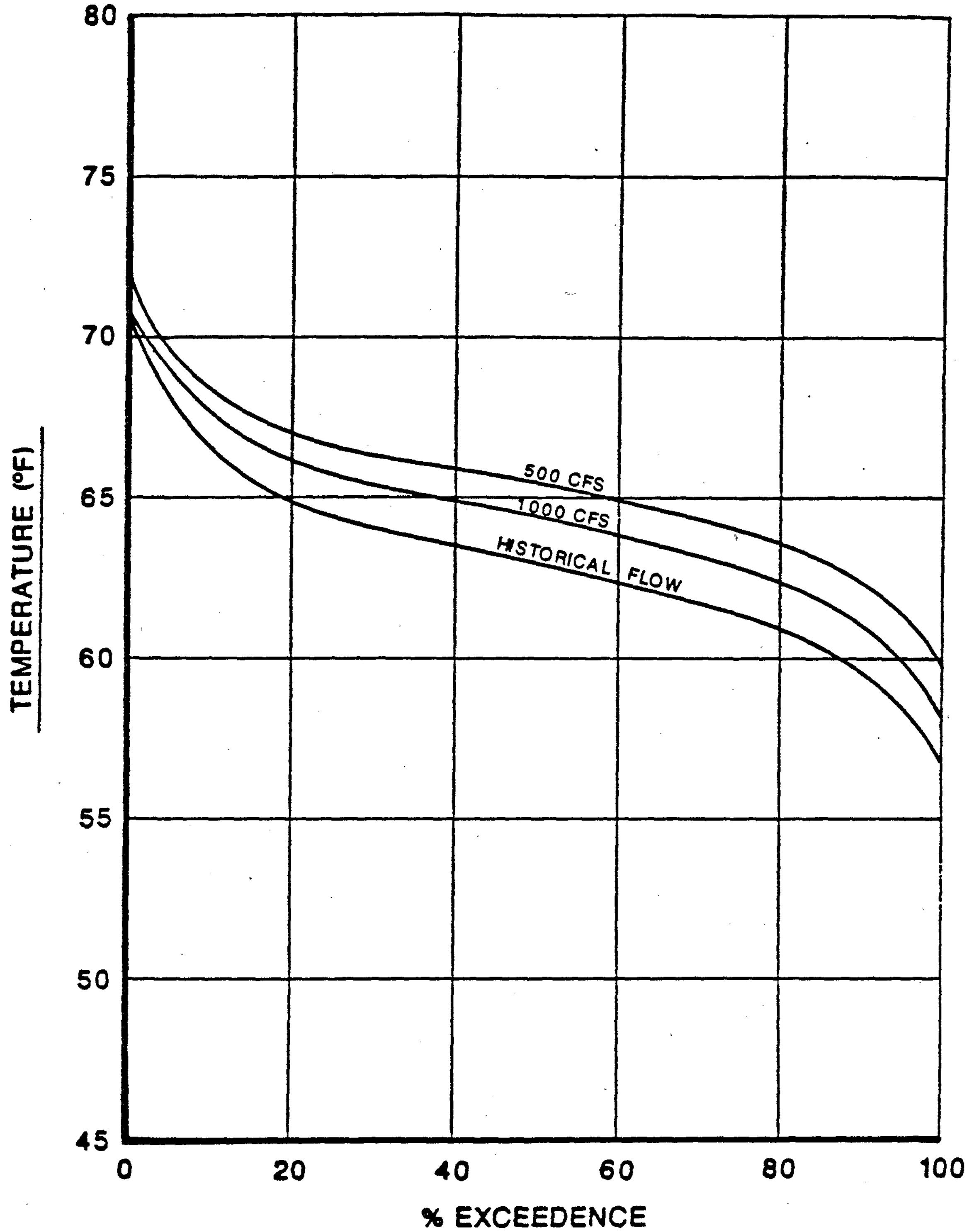

FIGURE 50

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JULY
6 MILES BELOW NIMBUS DAM

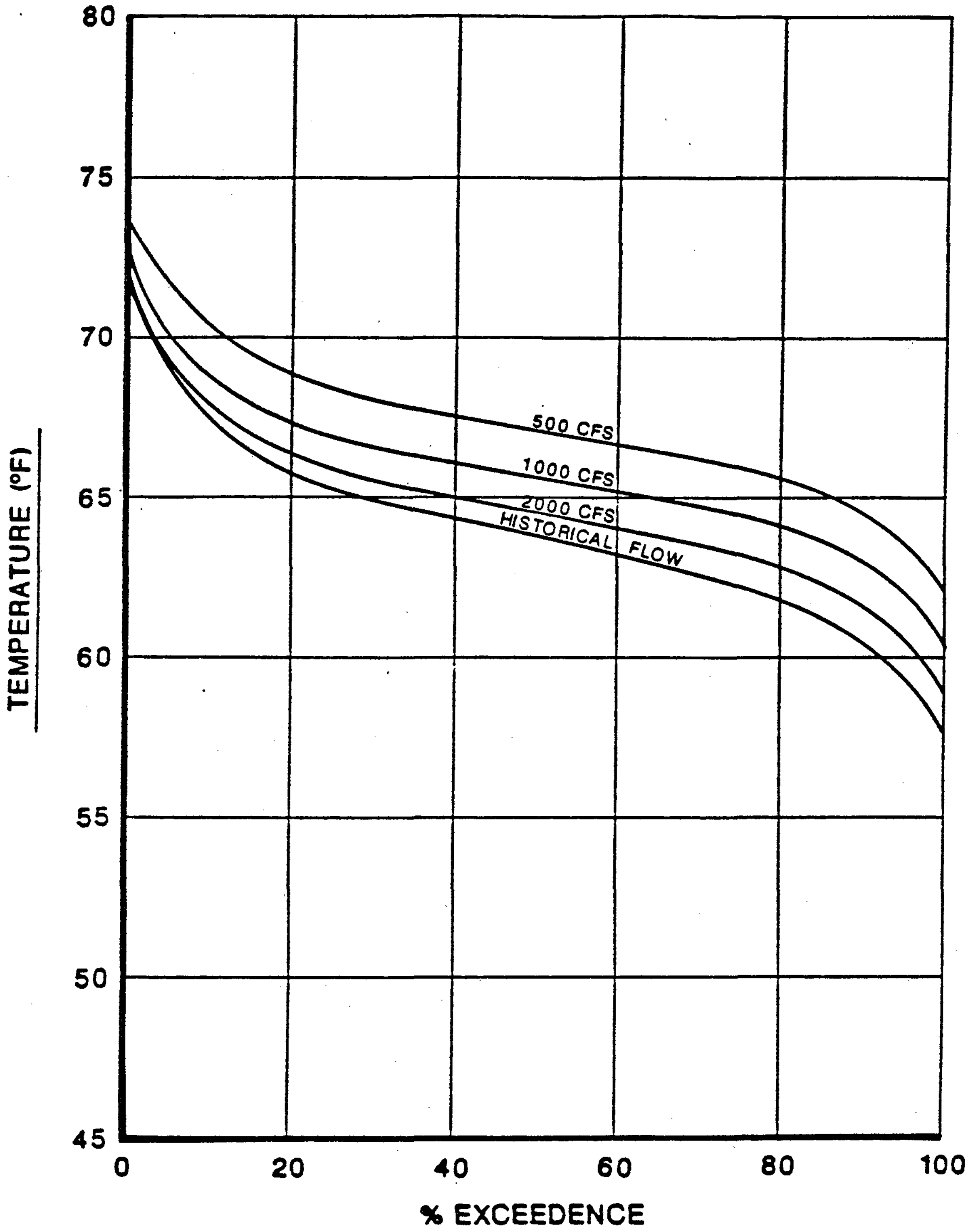

FIGURE 51

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JULY
10 MILES BELOW NIMBUS DAM

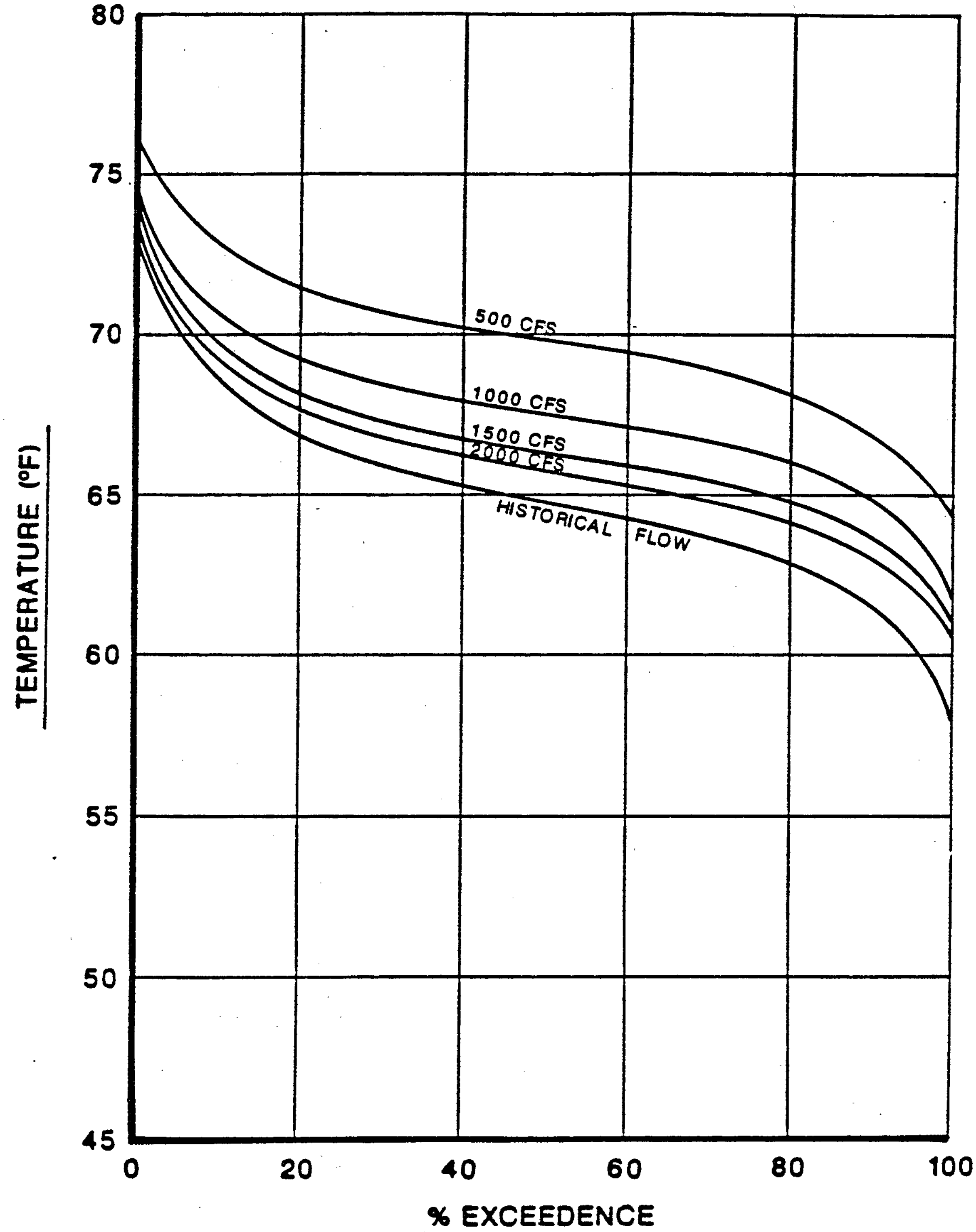

FIGURE 52

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JULY
14 MILES BELOW NIMBUS DAM

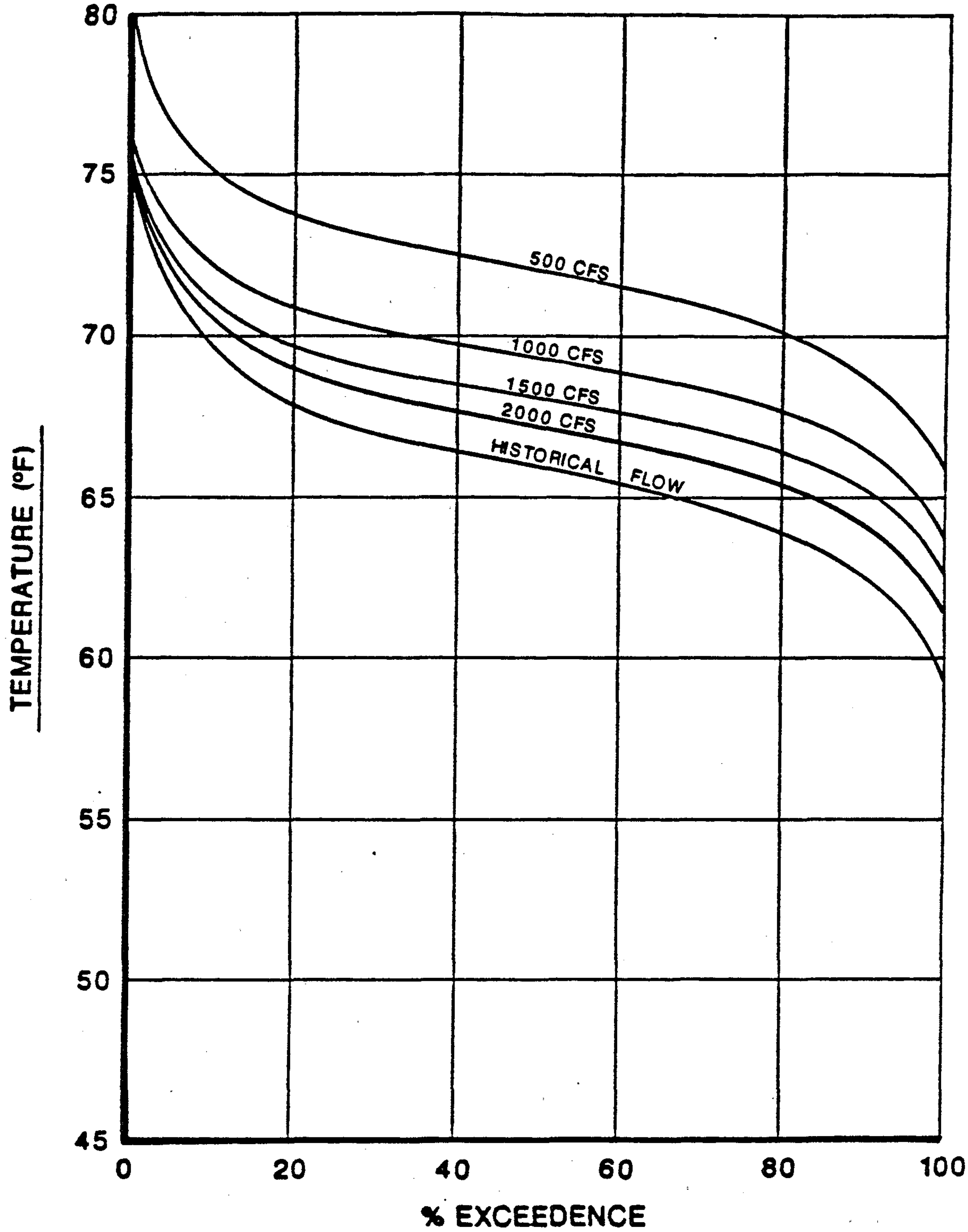

FIGURE 53

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JULY
18 MILES BELOW NIMBUS DAM

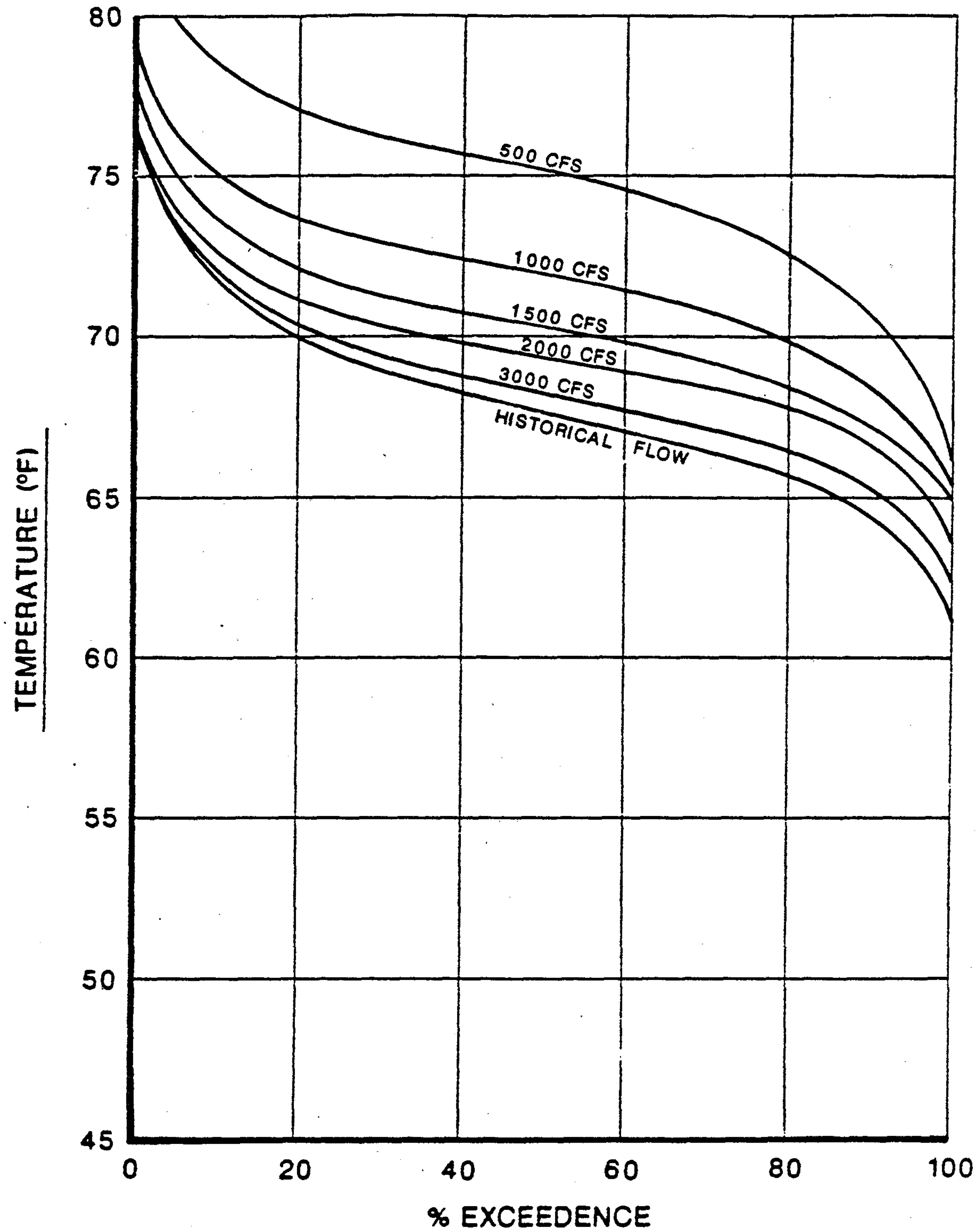

FIGURE 54

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR JULY
22 MILES BELOW NIMBUS DAM

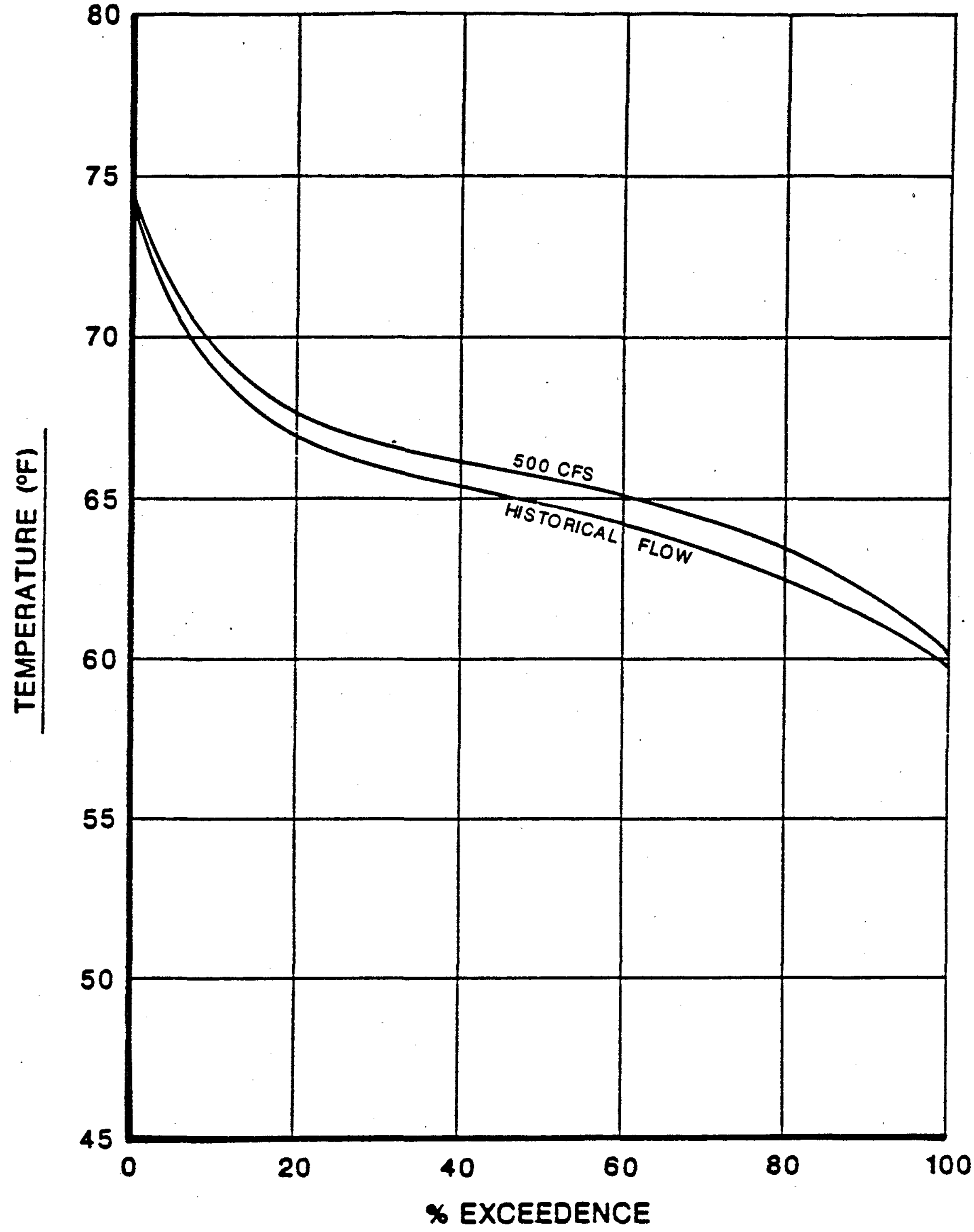

FIGURE 55

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR AUGUST
2 MILES BELOW NIMBUS DAM

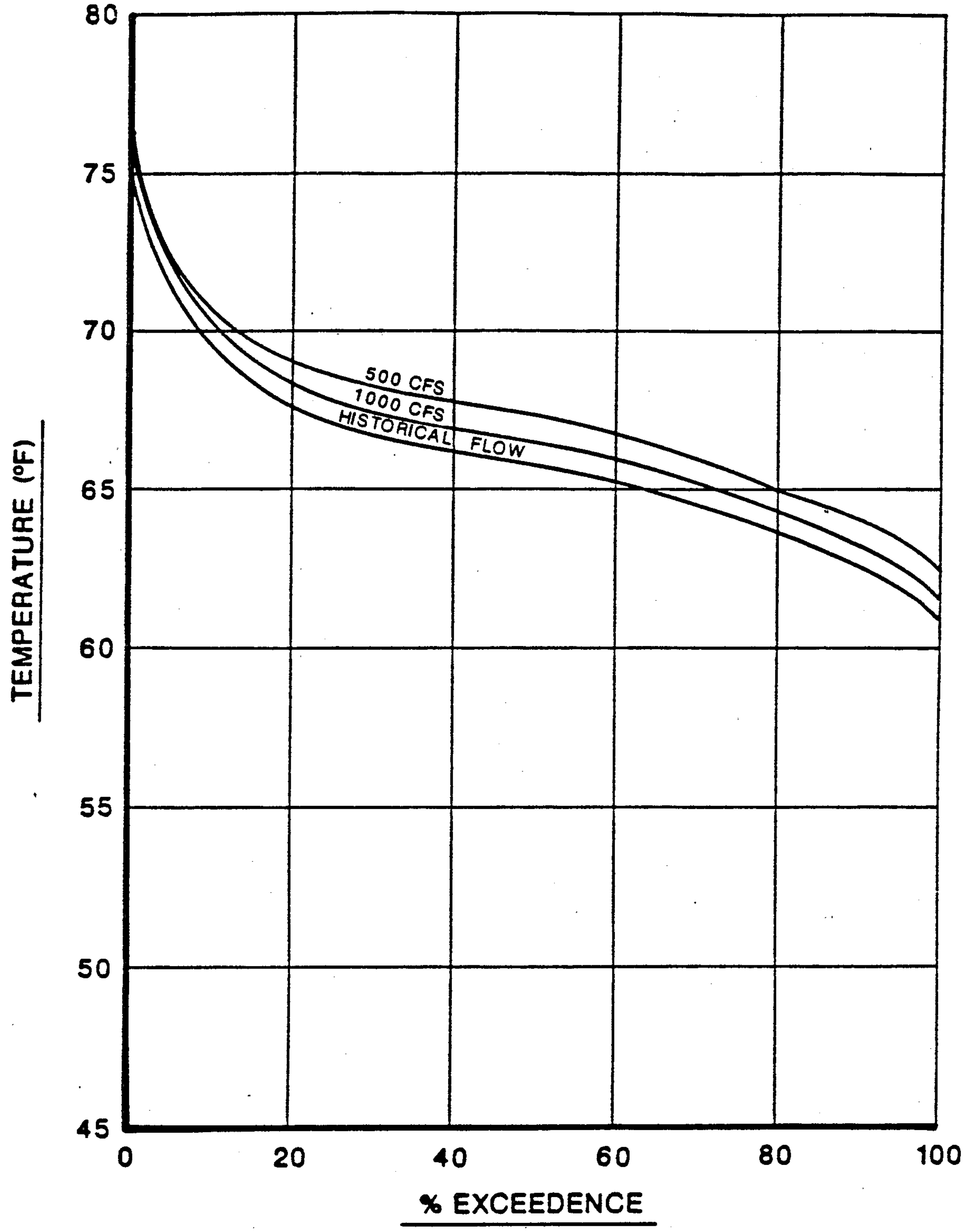

FIGURE 56

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR AUGUST
6 MILES BELOW NIMBUS DAM

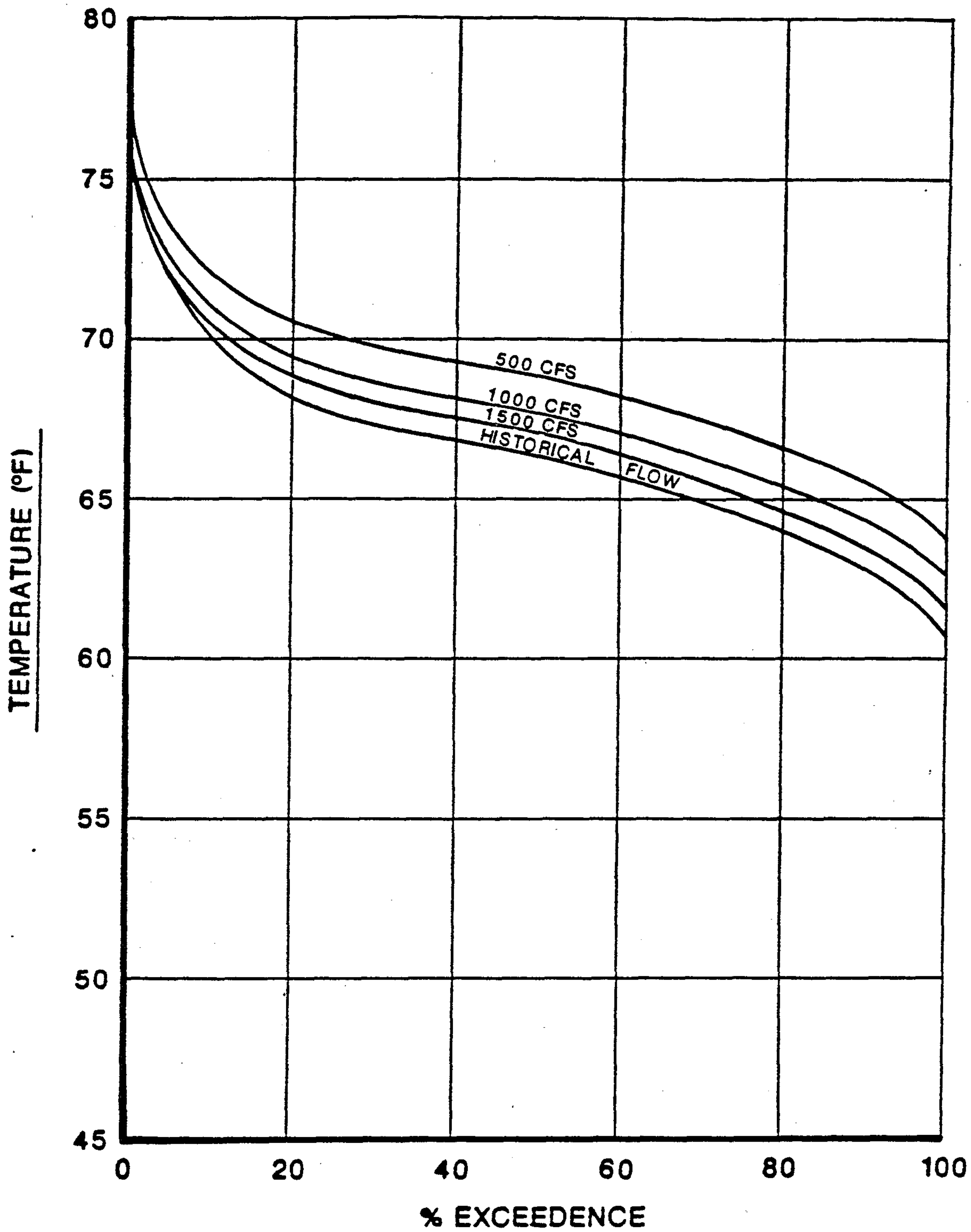

FIGURE 57

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR AUGUST
10 MILES BELOW NIMBUS DAM

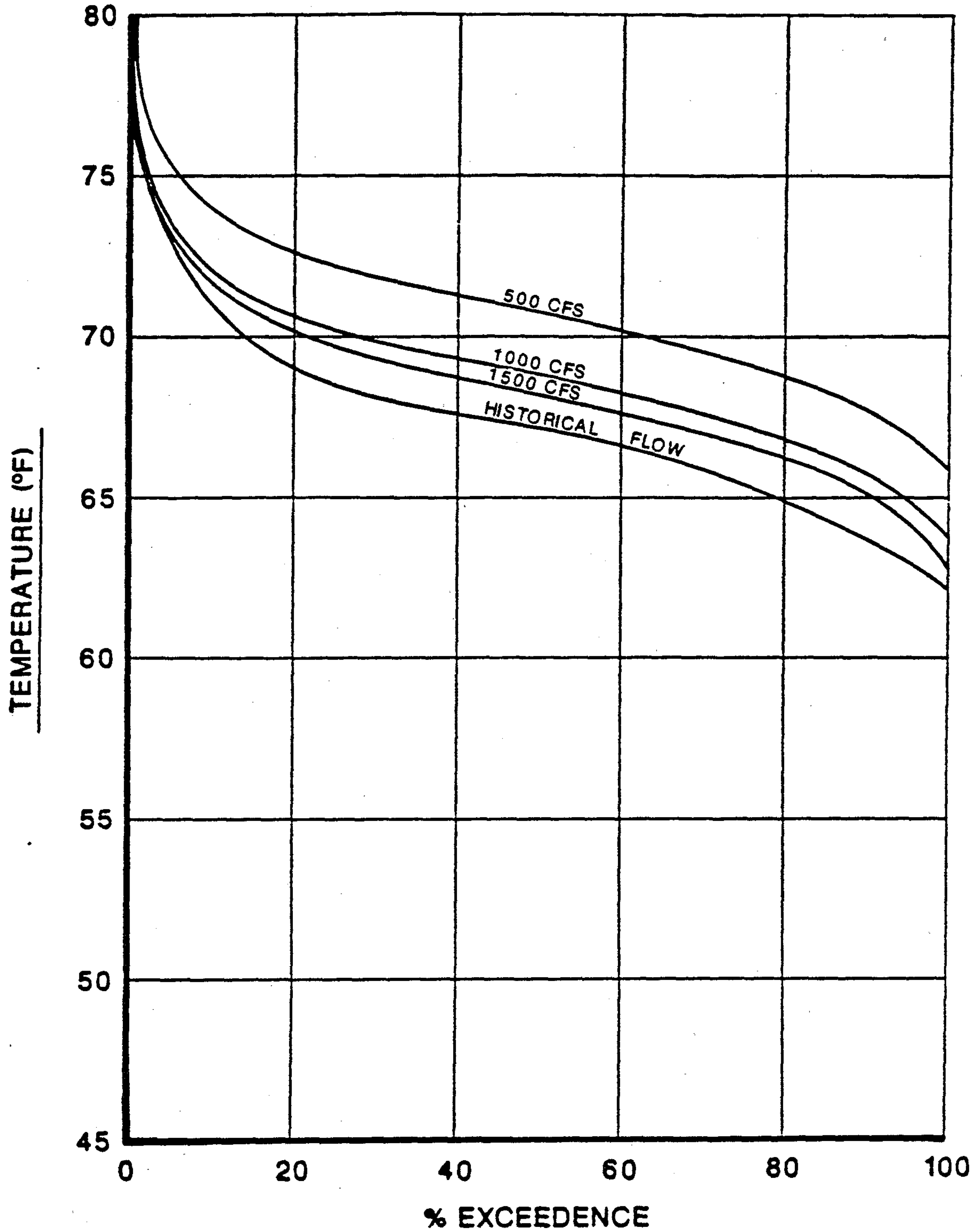

FIGURE 58

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR AUGUST
14 MILES BELOW NIMBUS DAM

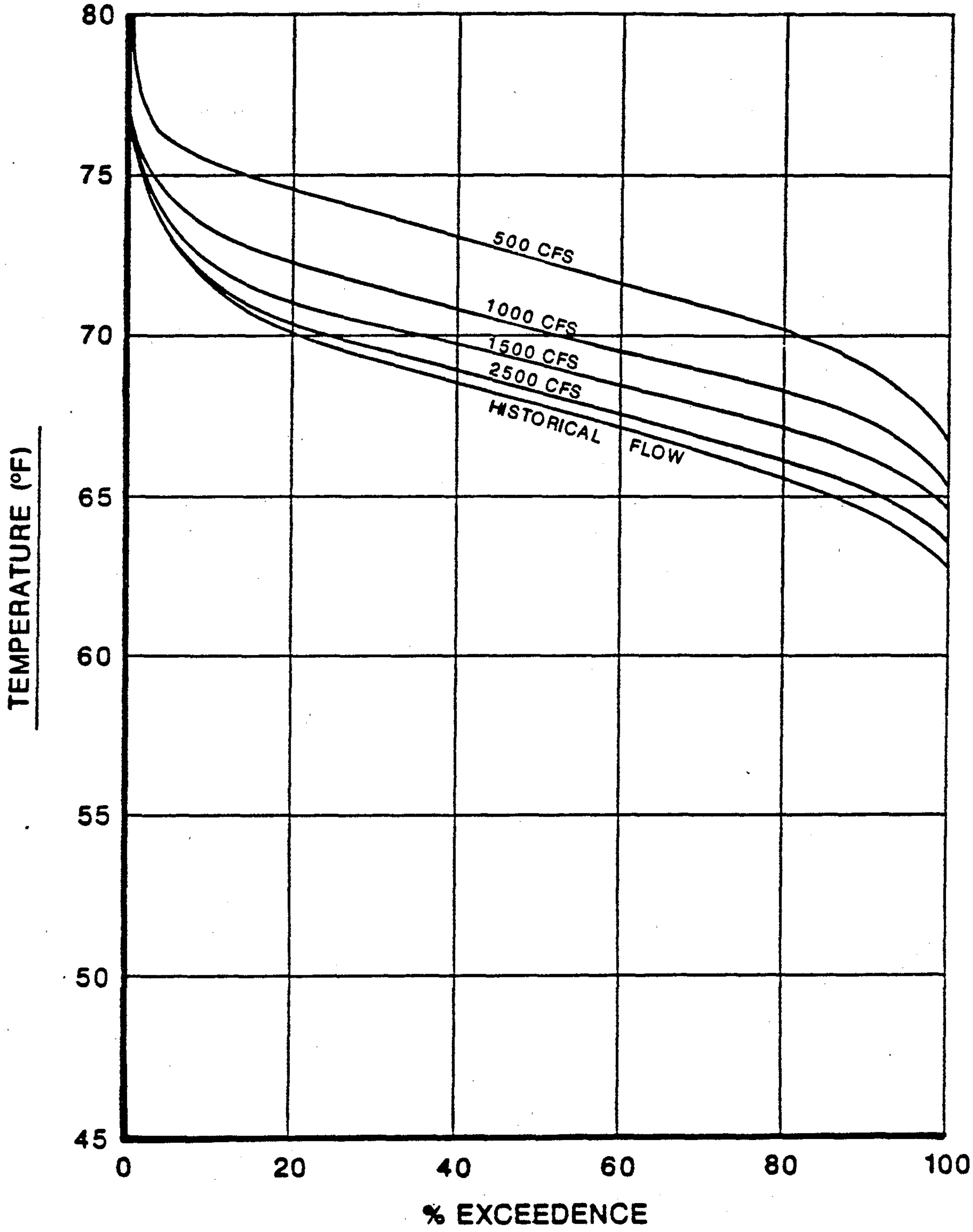

FIGURE 59

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR AUGUST
18 MILES BELOW NIMBUS DAM

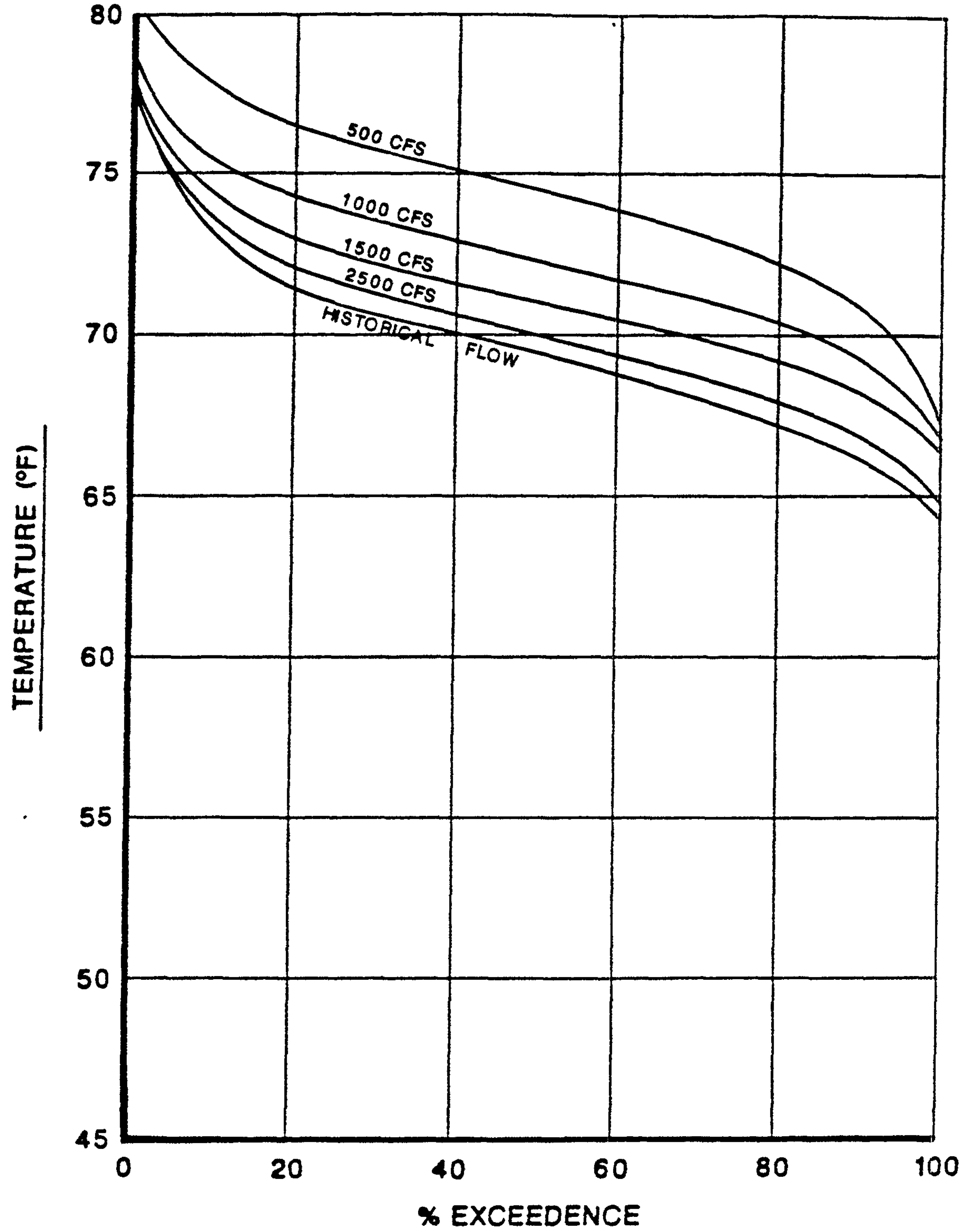

FIGURE 60

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR AUGUST
22 MILES BELOW NIMBUS DAM

10400-

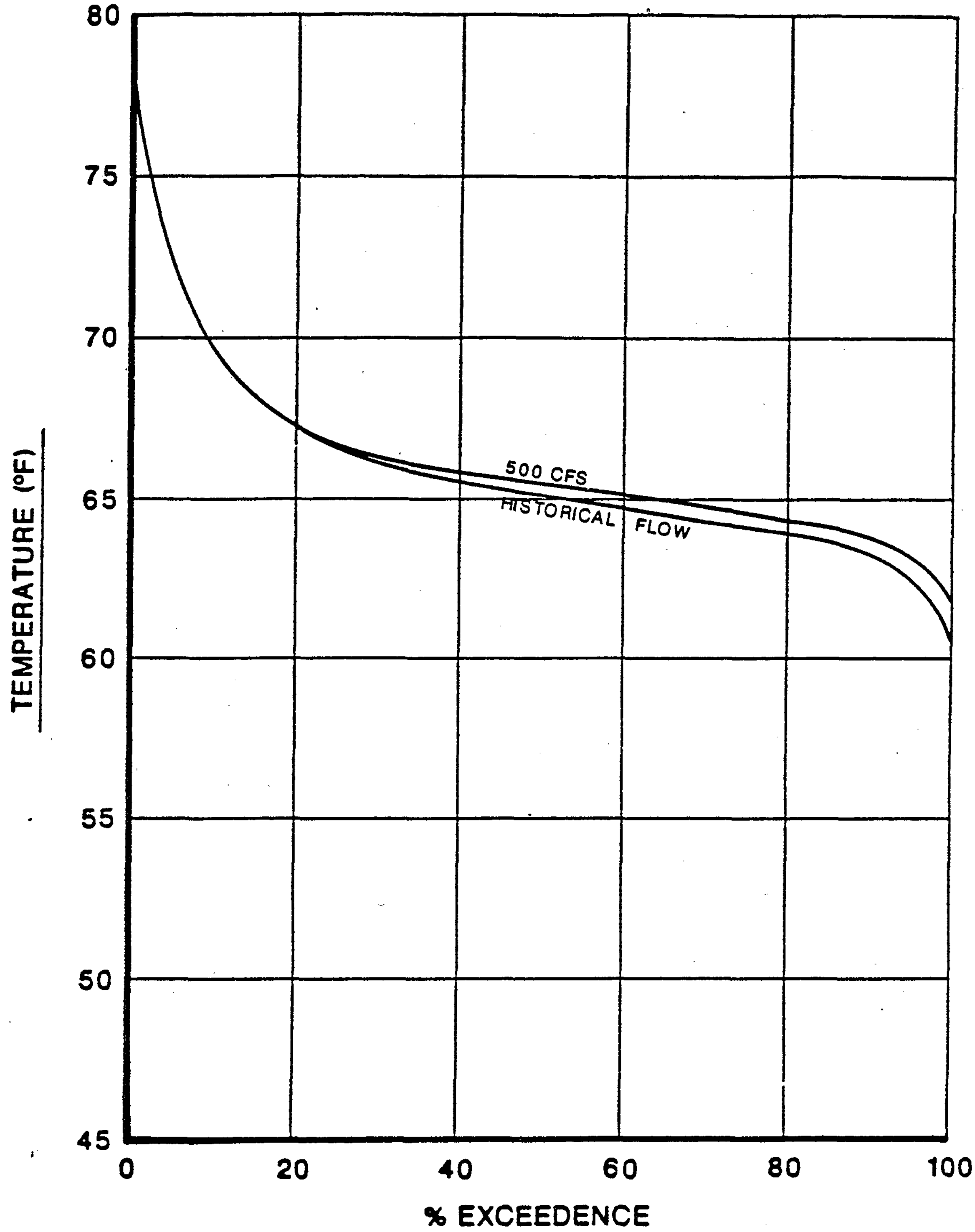

FIGURE 61

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR SEPTEMBER
2 MILES BELOW NIMBUS DAM

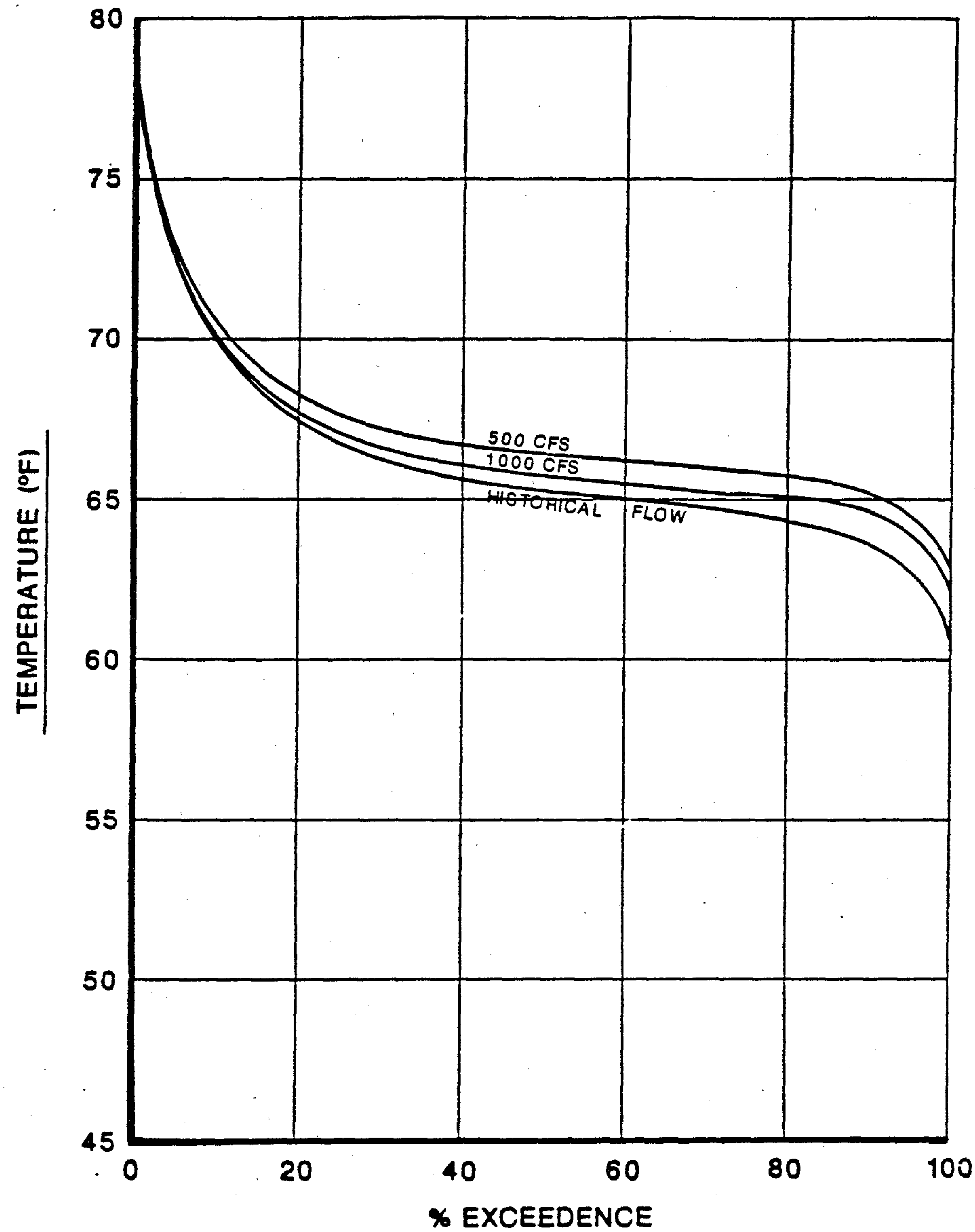

FIGURE 62

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR SEPTEMBER
6 MILES BELOW NIMBUS DAM

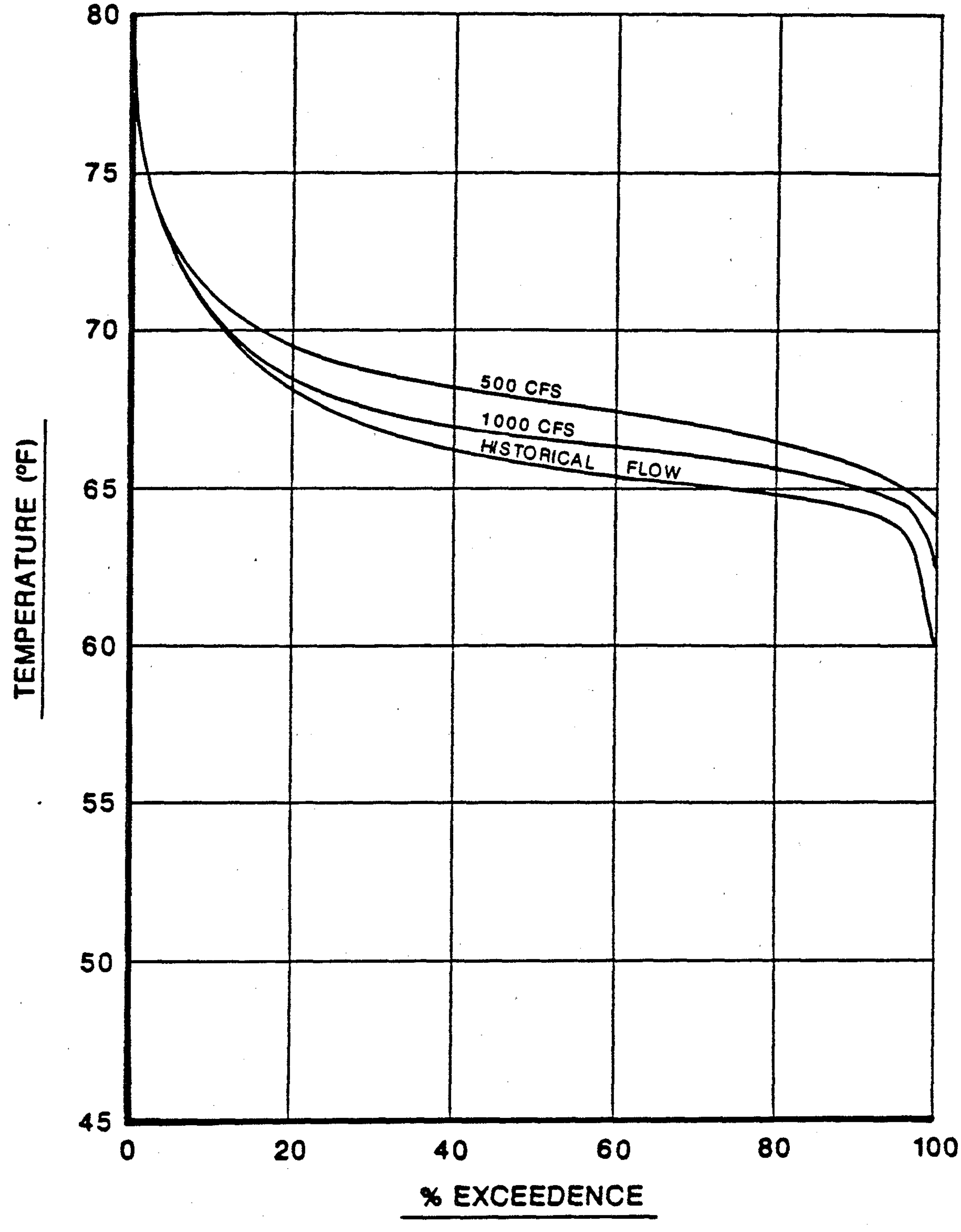

FIGURE 63

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR SEPTEMBER
10 MILES BELOW NIMBUS DAM

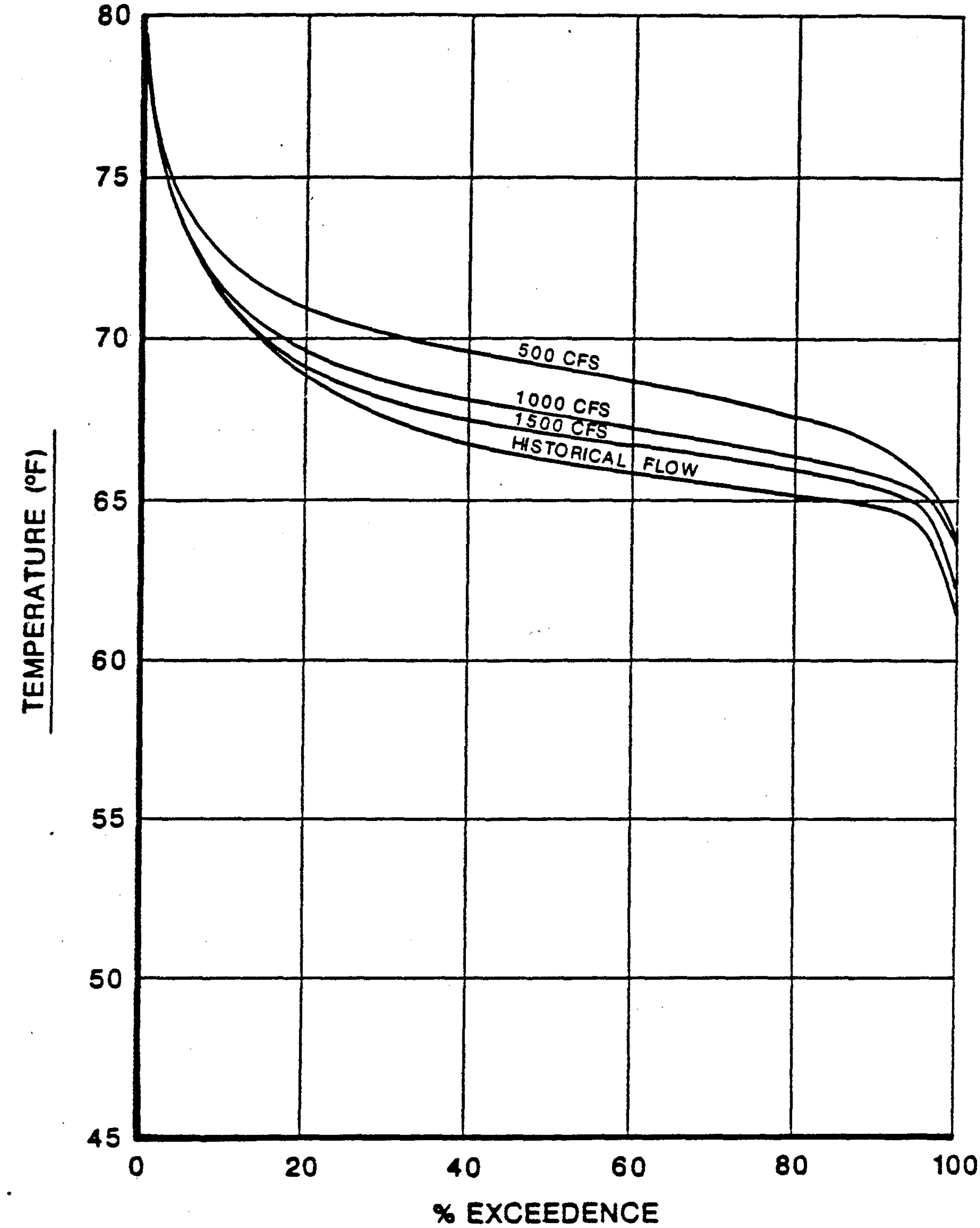

FIGURE 64

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR SEPTEMBER
14 MILES BELOW NIMBUS DAM

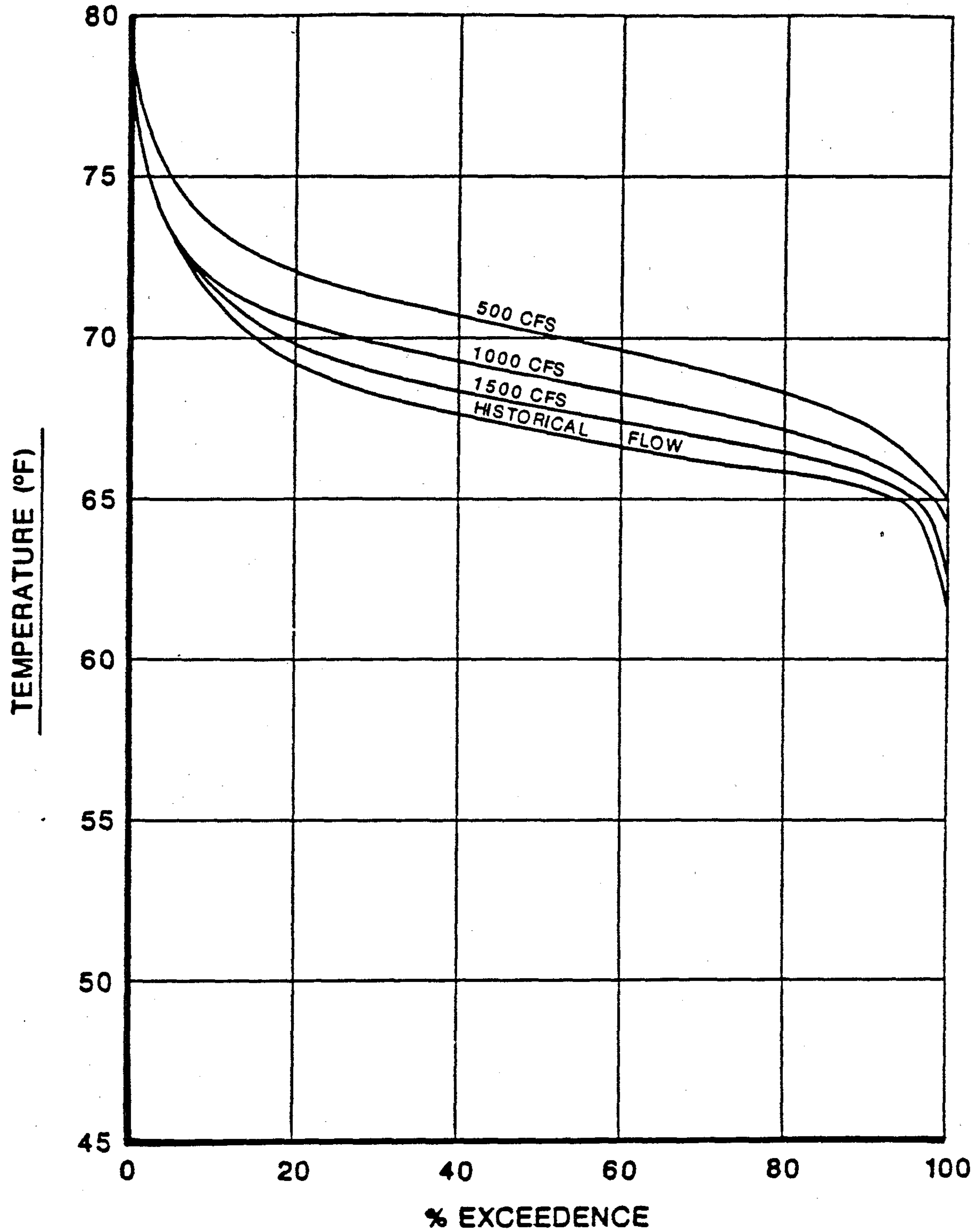

FIGURE 65

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR SEPTEMBER
18 MILES BELOW NIMBUS DAM

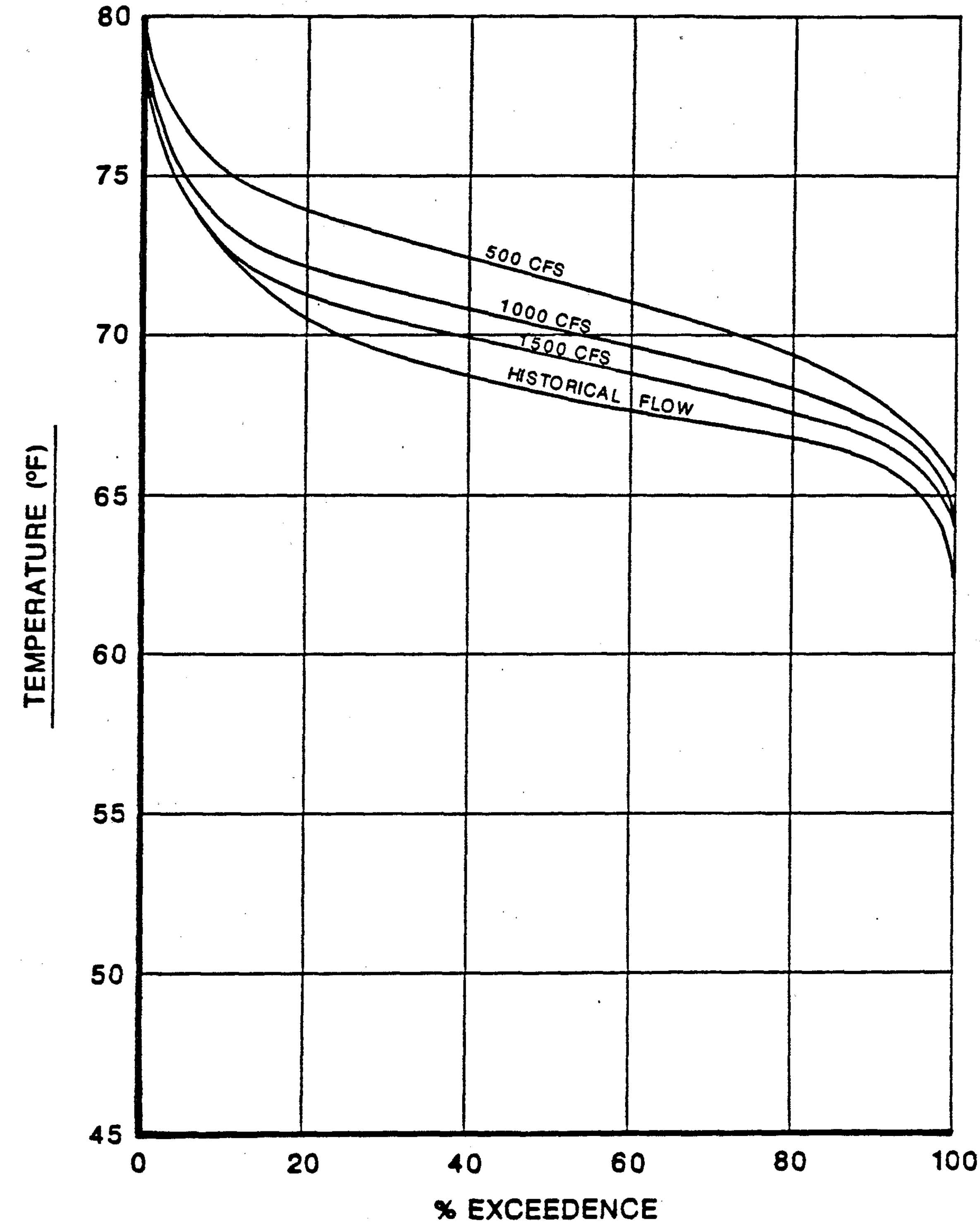

FIGURE 66

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR SEPTEMBER
22 MILES BELOW NIMBUS DAM

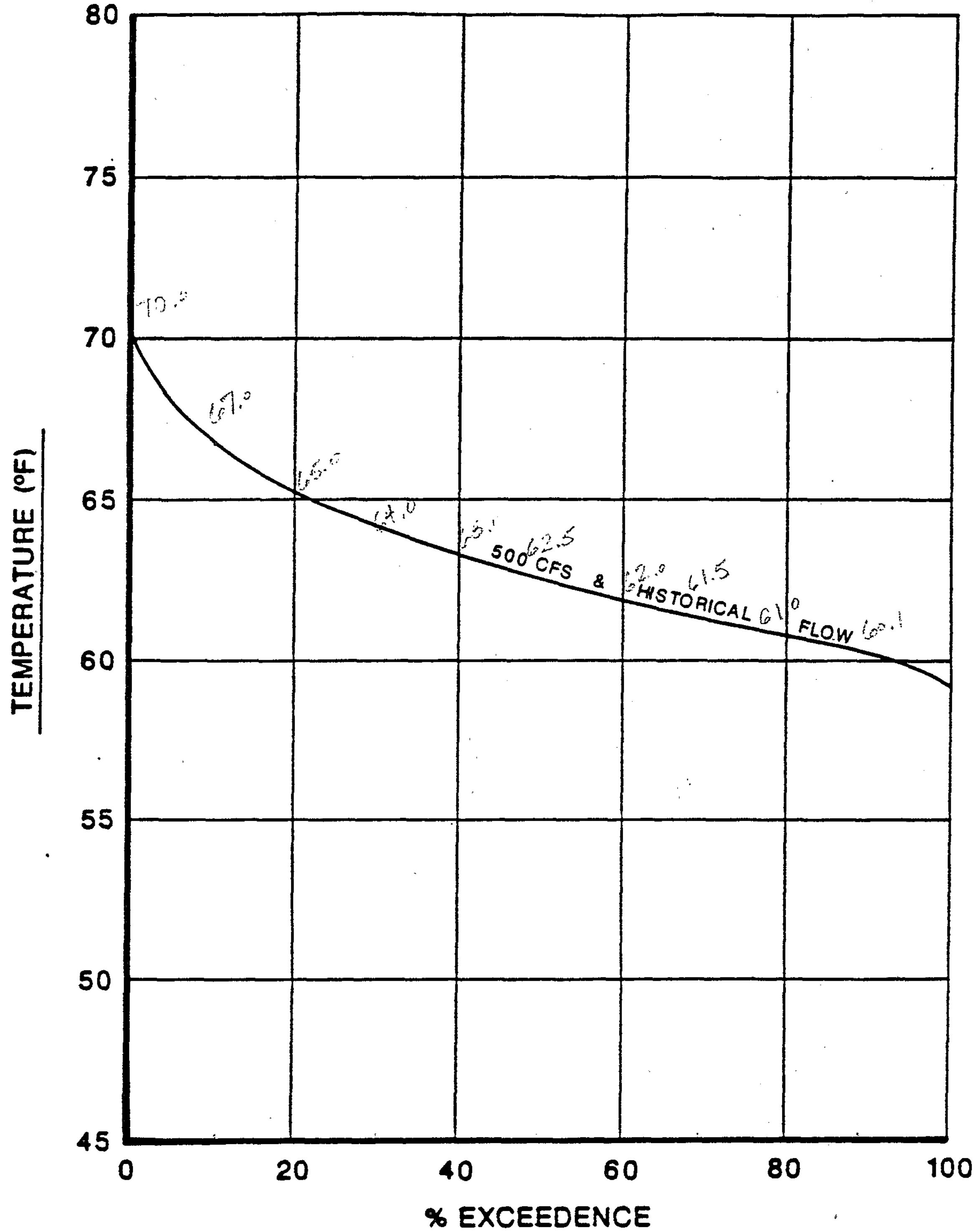

FIGURE 67

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR OCTOBER
2 MILES BELOW NIMBUS DAM

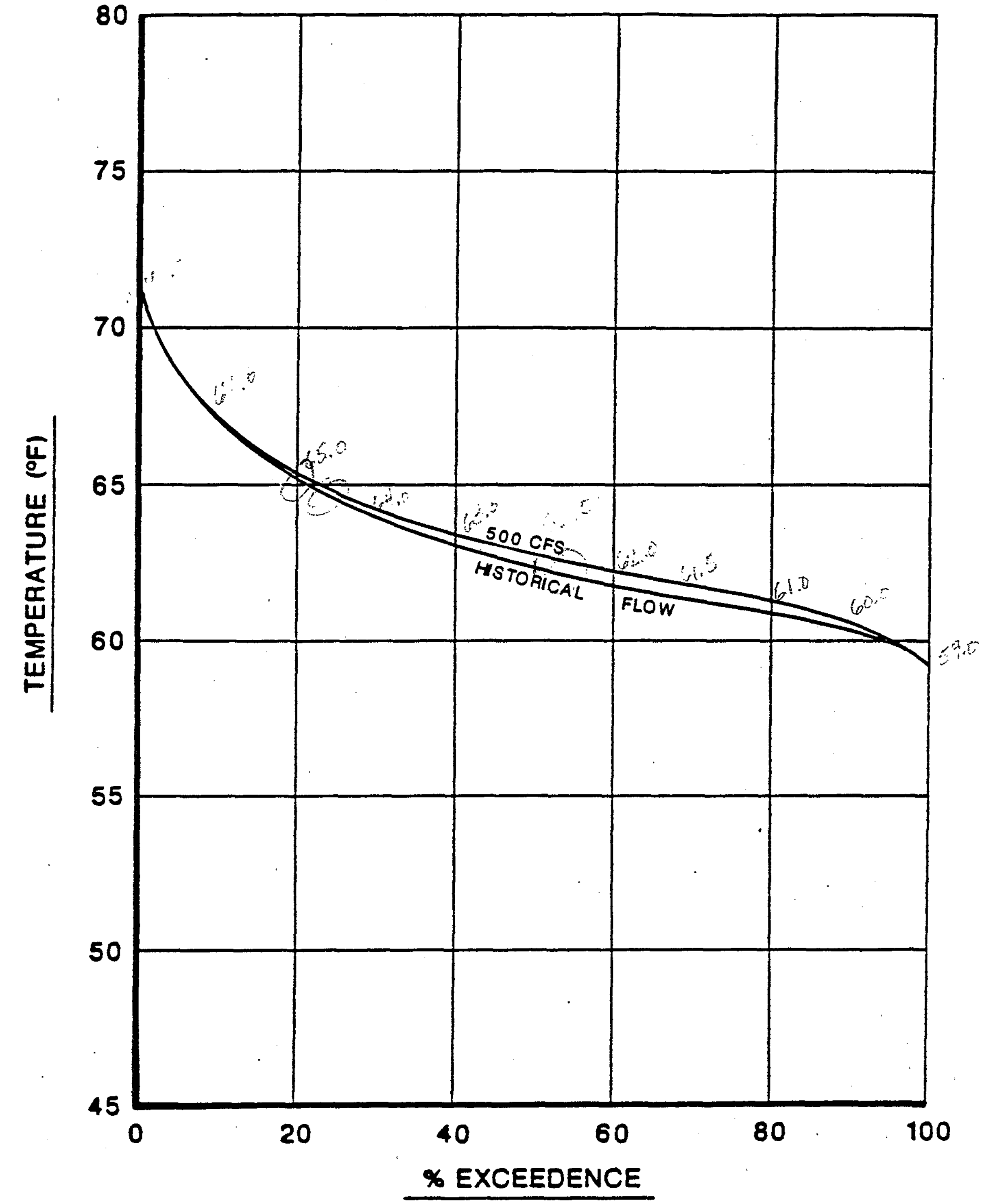

FIGURE 68

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR OCTOBER
6 MILES BELOW NIMBUS DAM

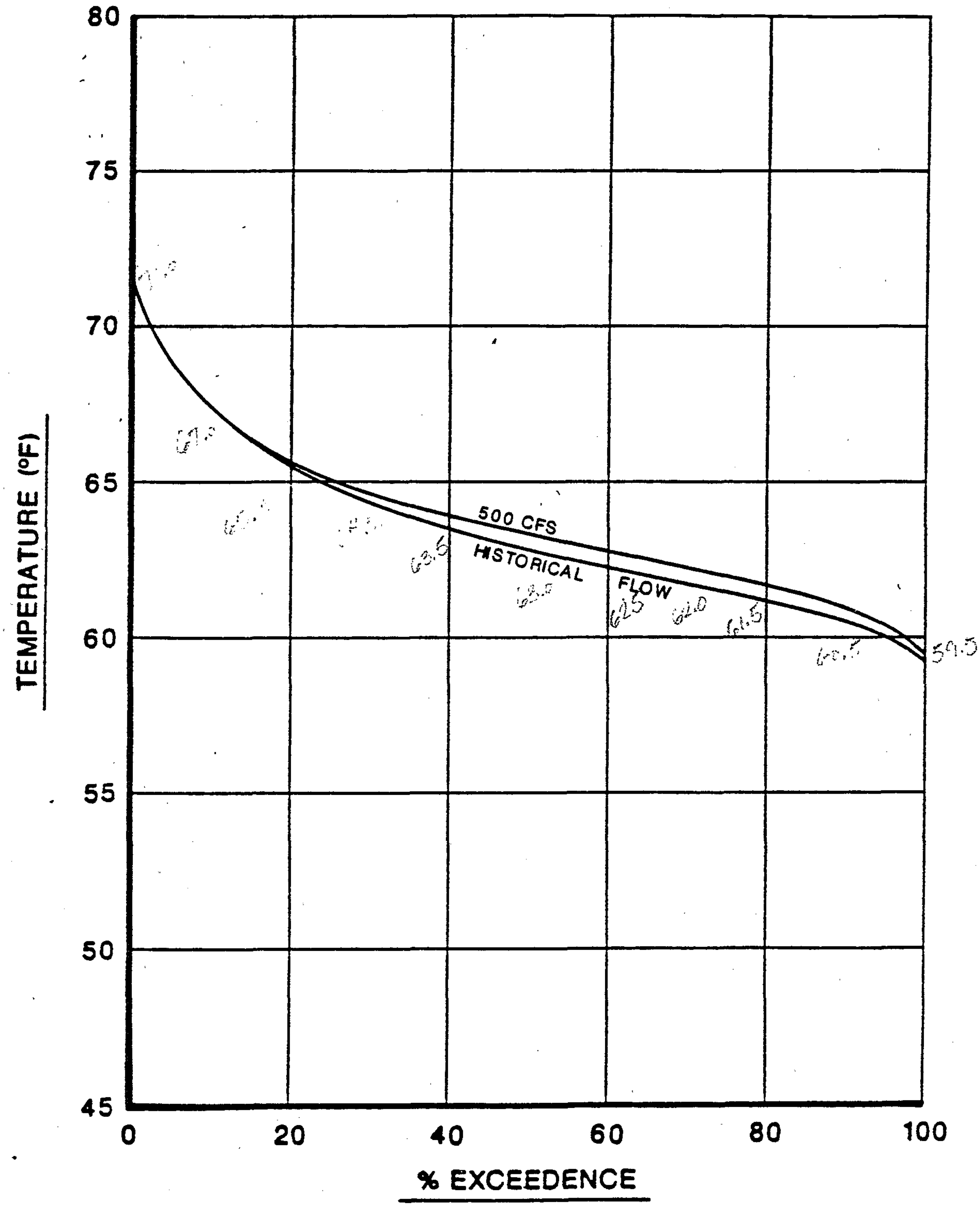

FIGURE 69

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR OCTOBER
10 MILES BELOW NIMBUS DAM

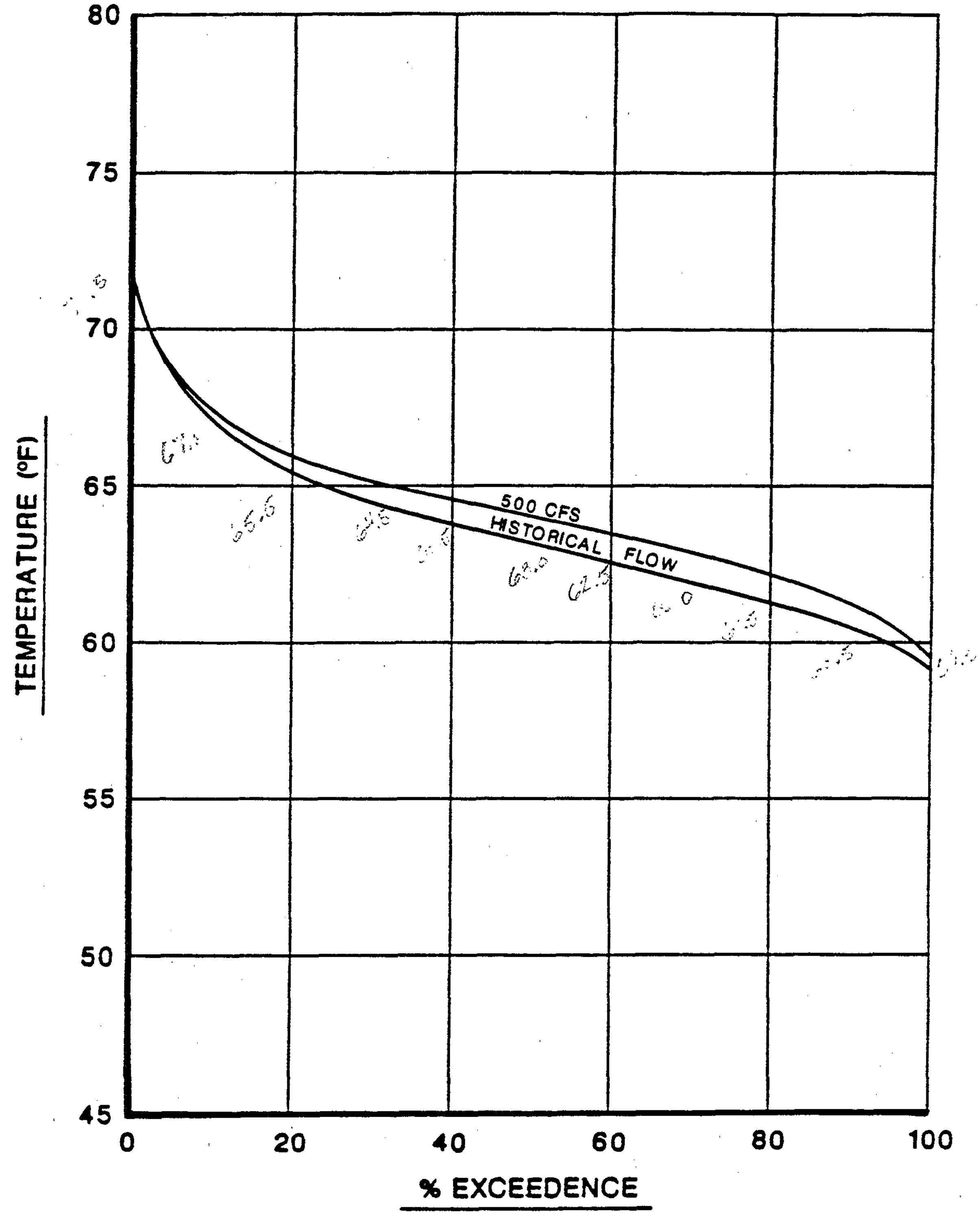

FIGURE 70

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR OCTOBER
14 MILES BELOW NIMBUS DAM

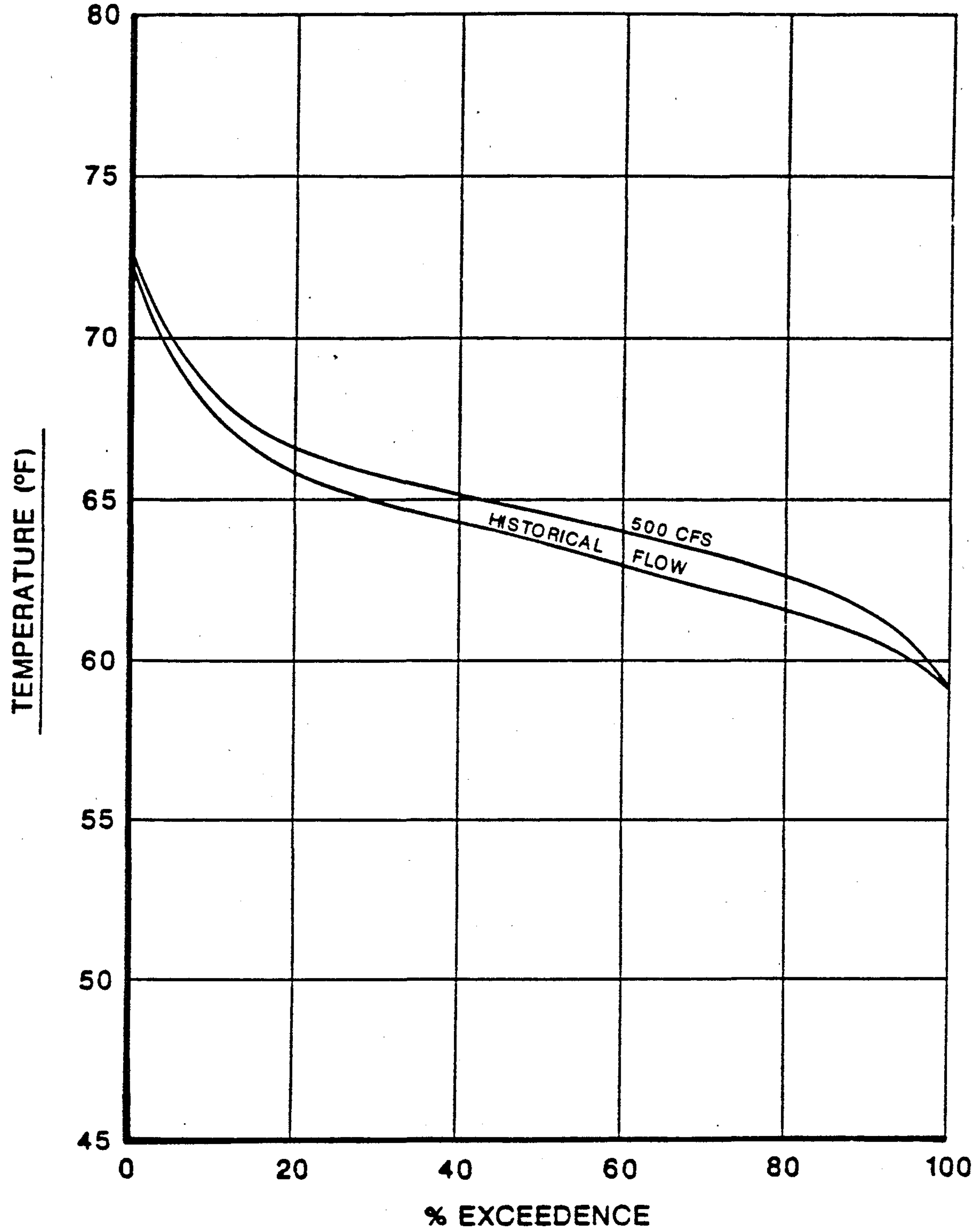

FIGURE 71

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR OCTOBER
18 MILES BELOW NIMBUS DAM

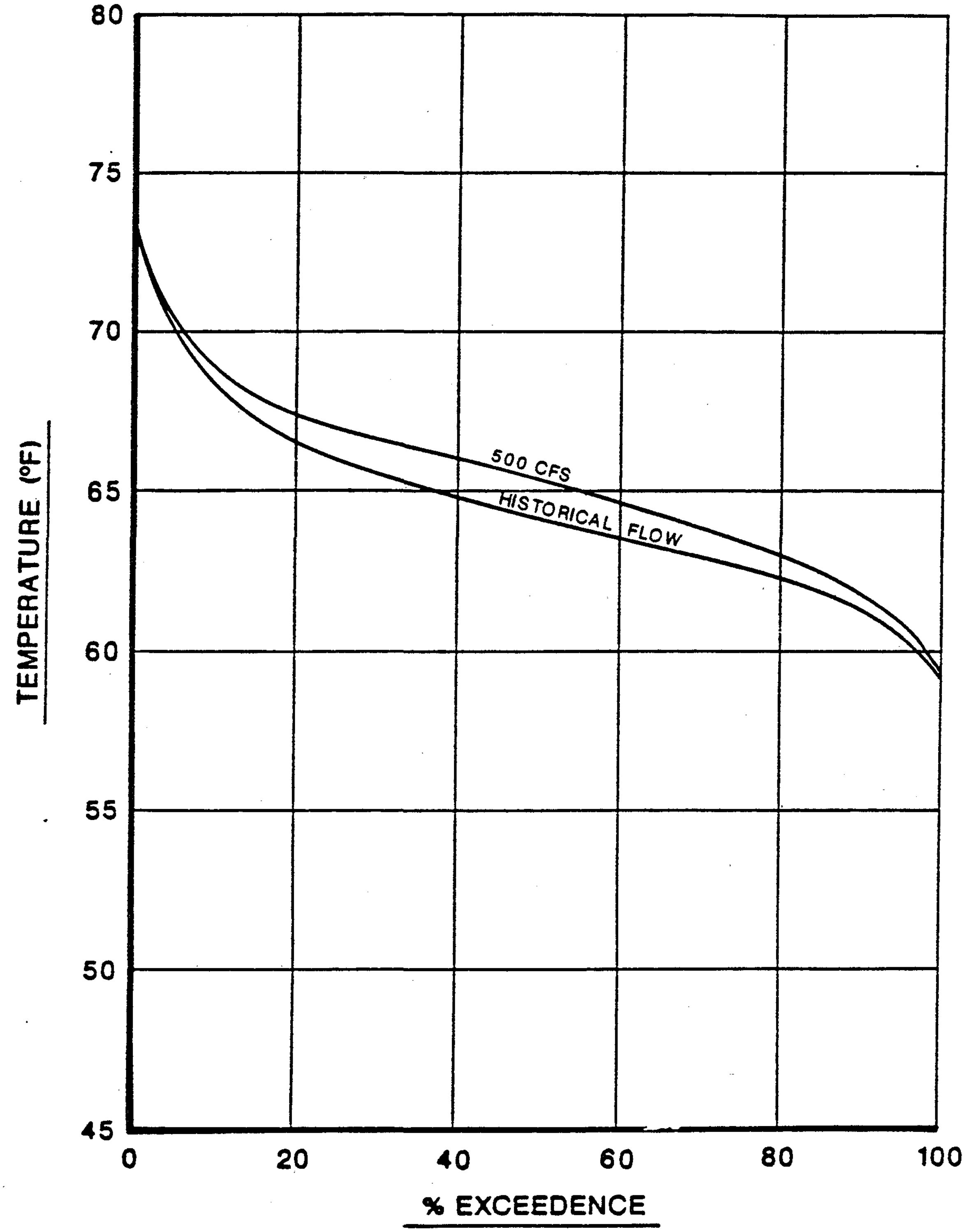

FIGURE 72

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR OCTOBER
22 MILES BELOW NIMBUS DAM

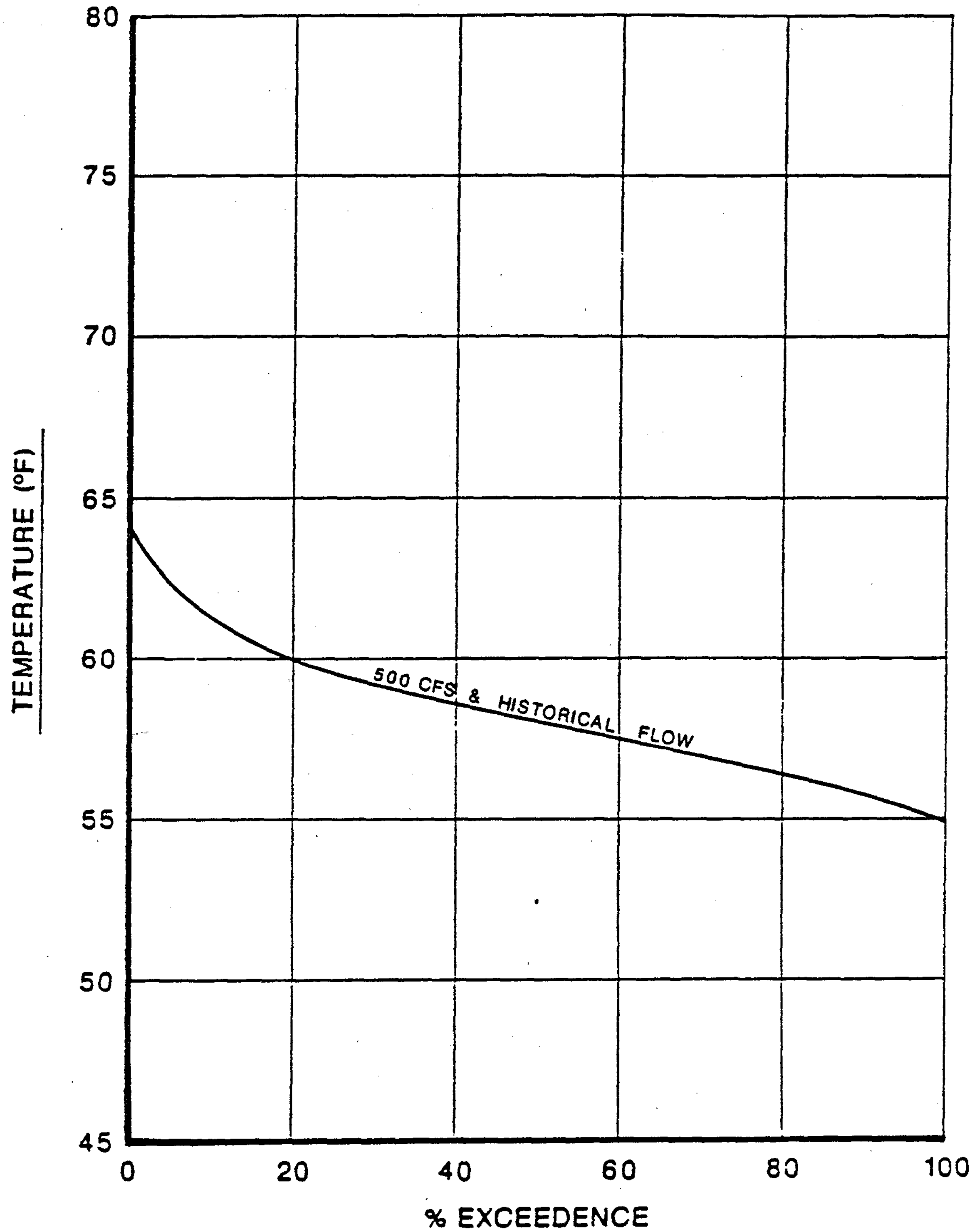

FIGURE 73

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR NOVEMBER
2 MILES BELOW NIMBUS DAM

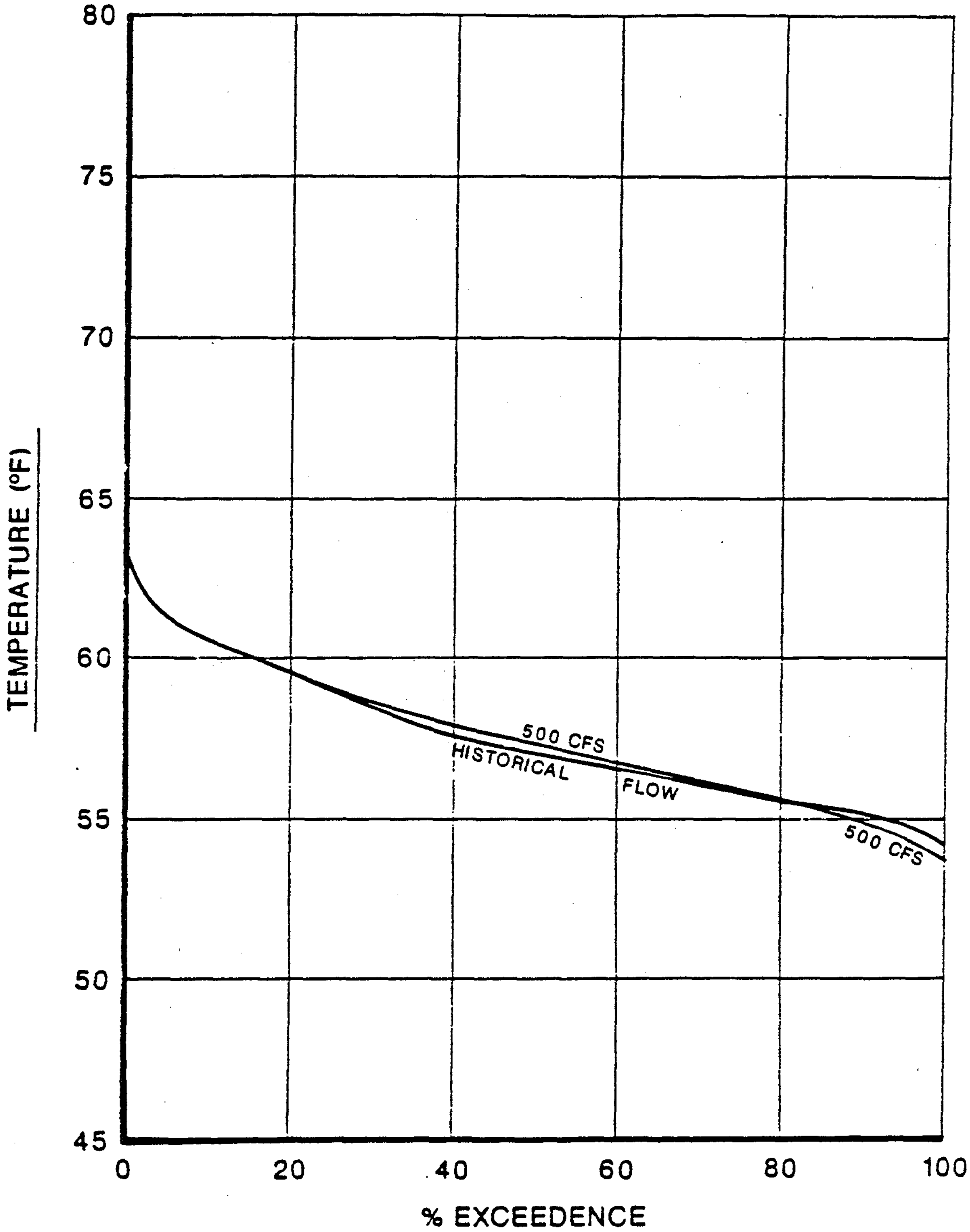

FIGURE 75

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR NOVEMBER
10 MILES BELOW NIMBUS DAM

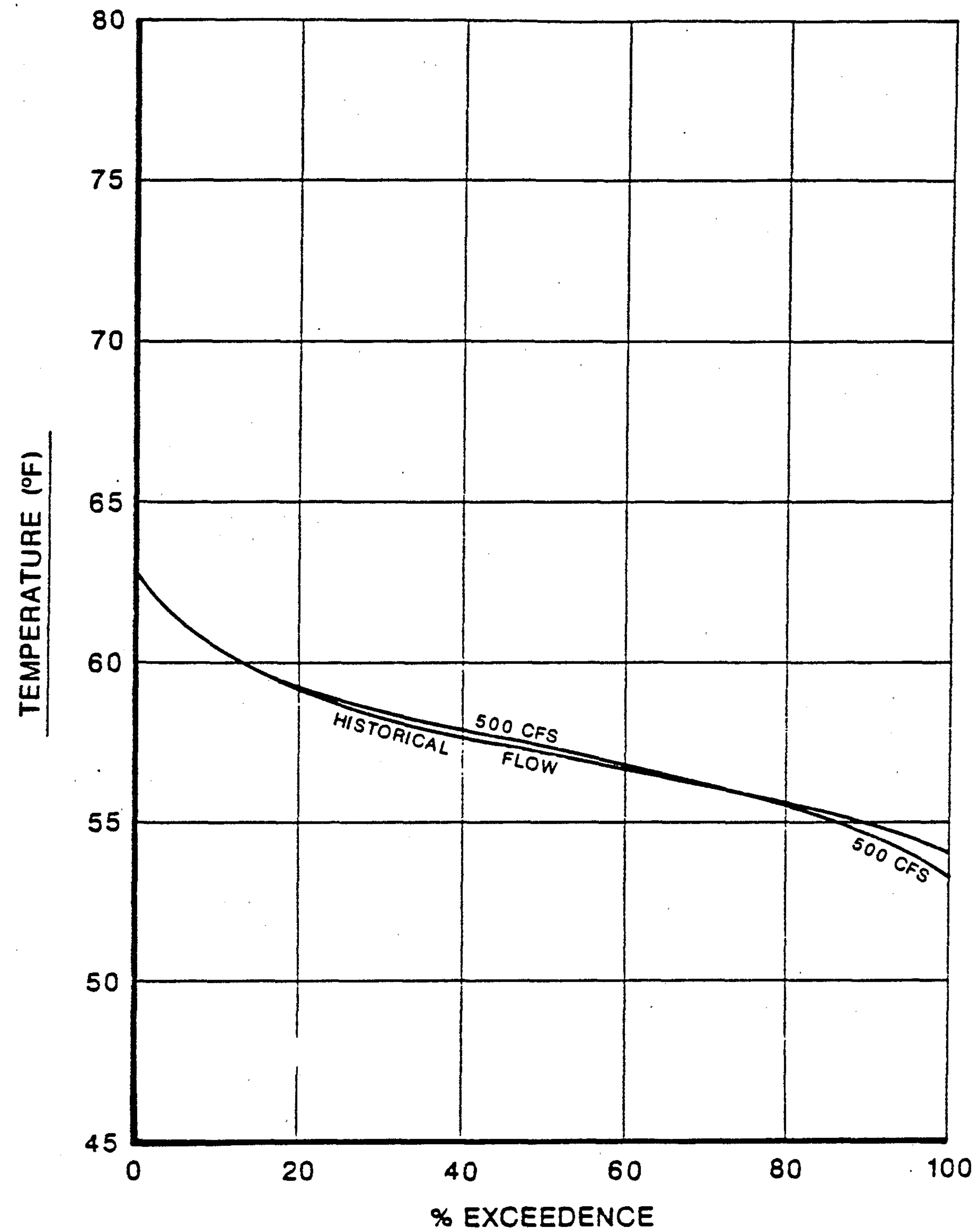

FIGURE 76

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR NOVEMBER
14 MILES BELOW NIMBUS DAM

C-043698

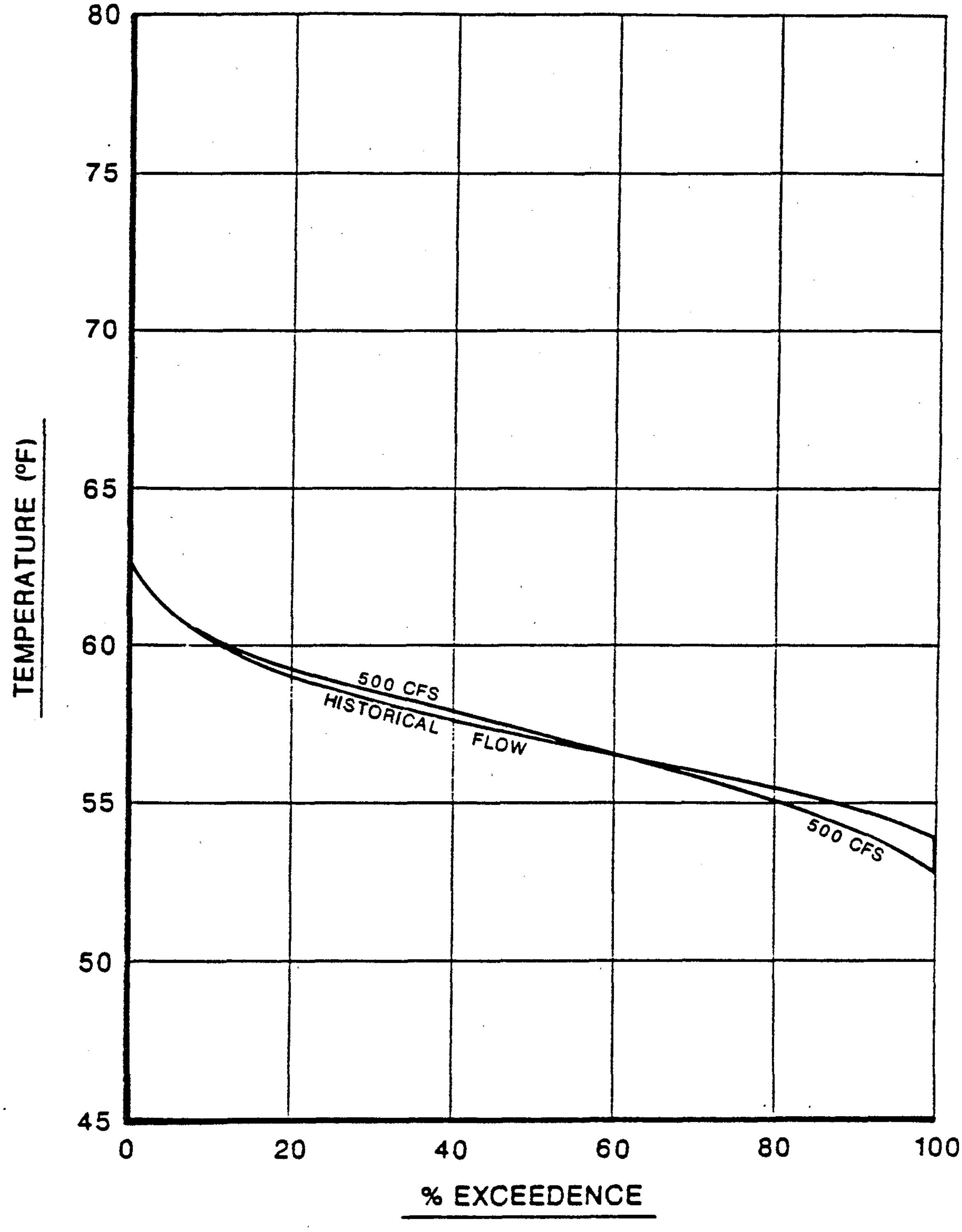

FIGURE 77

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR NOVEMBER
18 MILES BELOW NIMBUS DAM

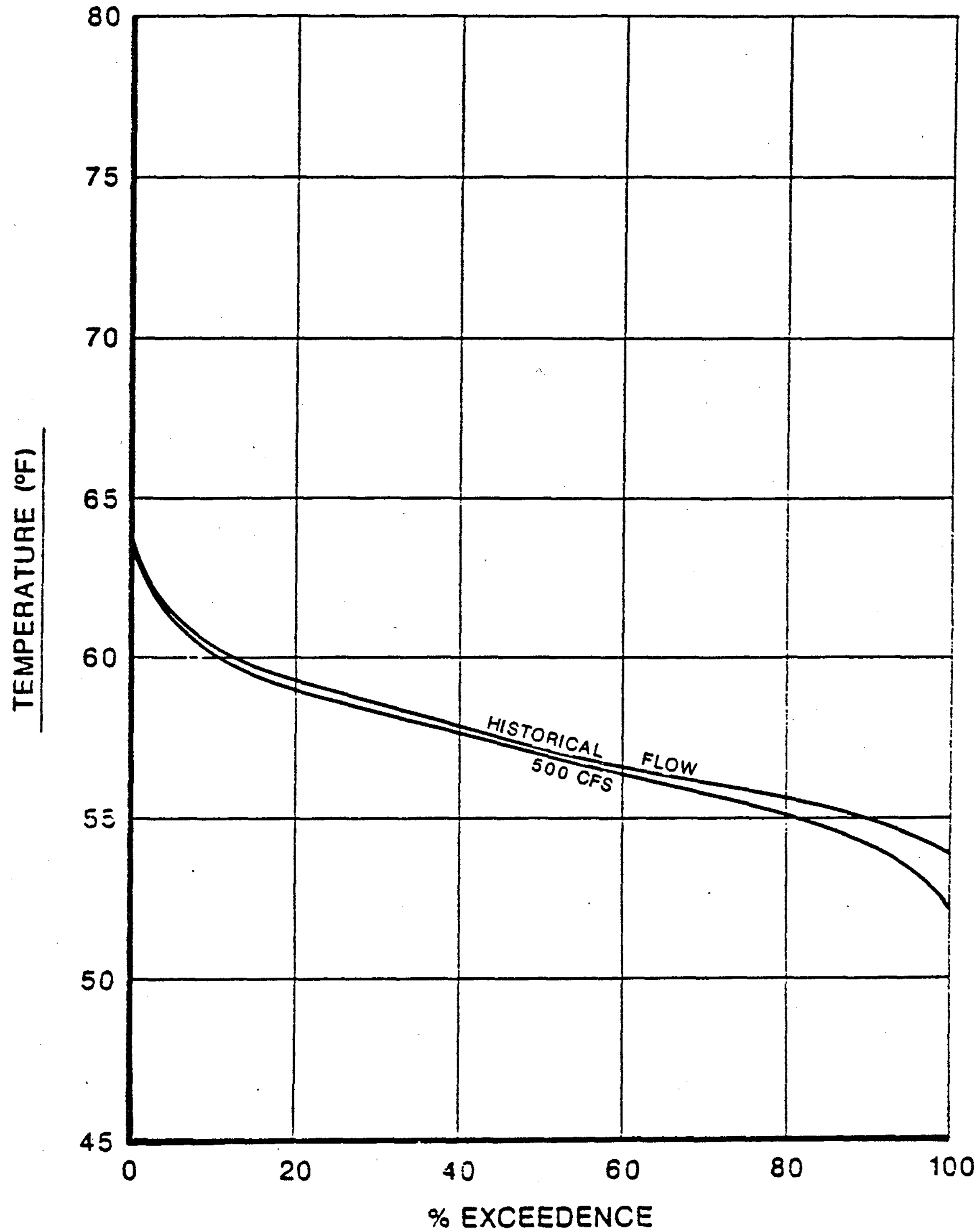

FIGURE 78

AMERICAN RIVER
TEMPERATURE EXCEEDENCE CURVES
FOR NOVEMBER
22 MILES BELOW NIMBUS DAM

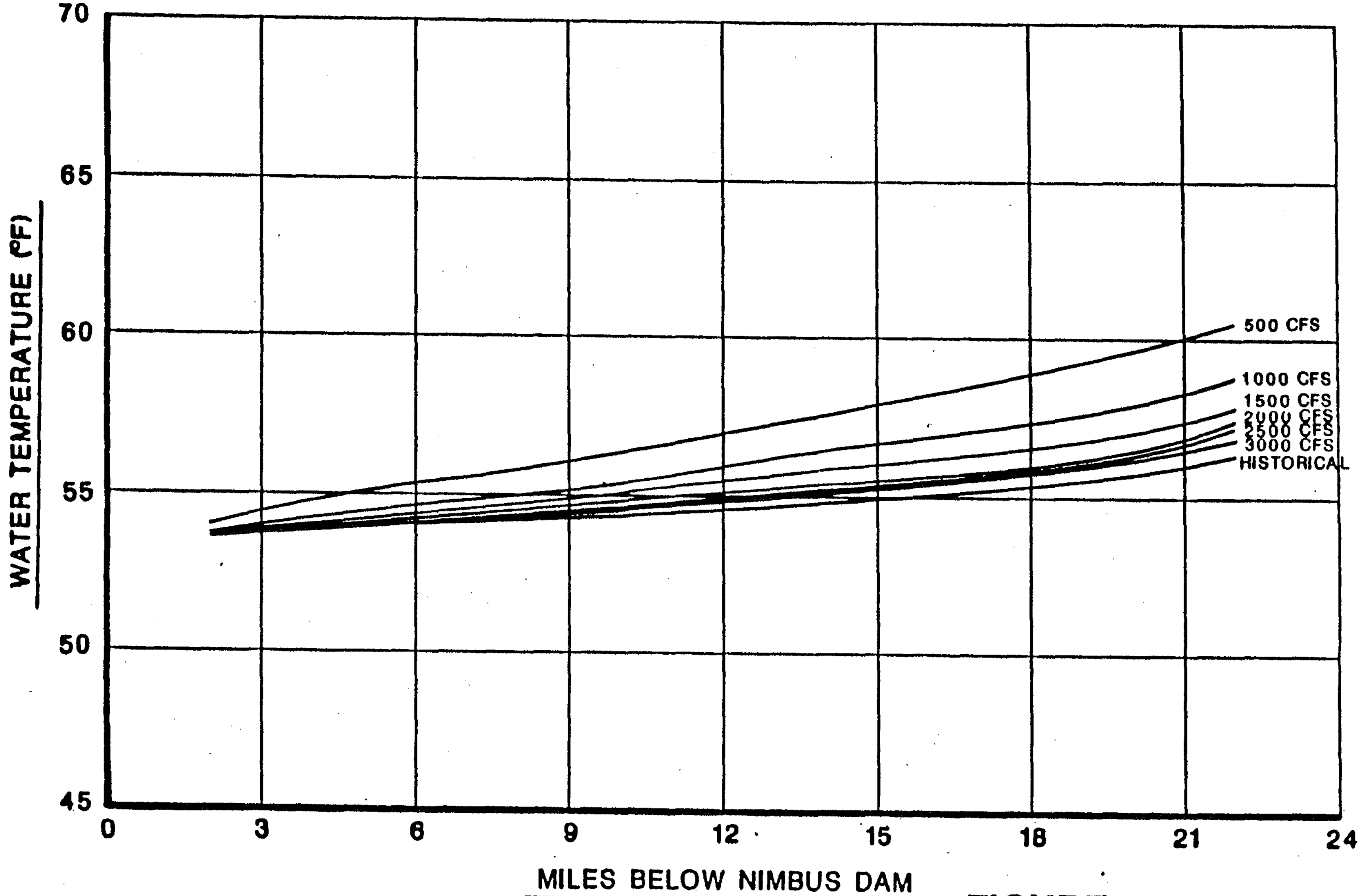

FIGURE 79

AMERICAN RIVER
MEDIAN WATER TEMPERATURES
F[illegible] APRIL

C-043701

C-043702

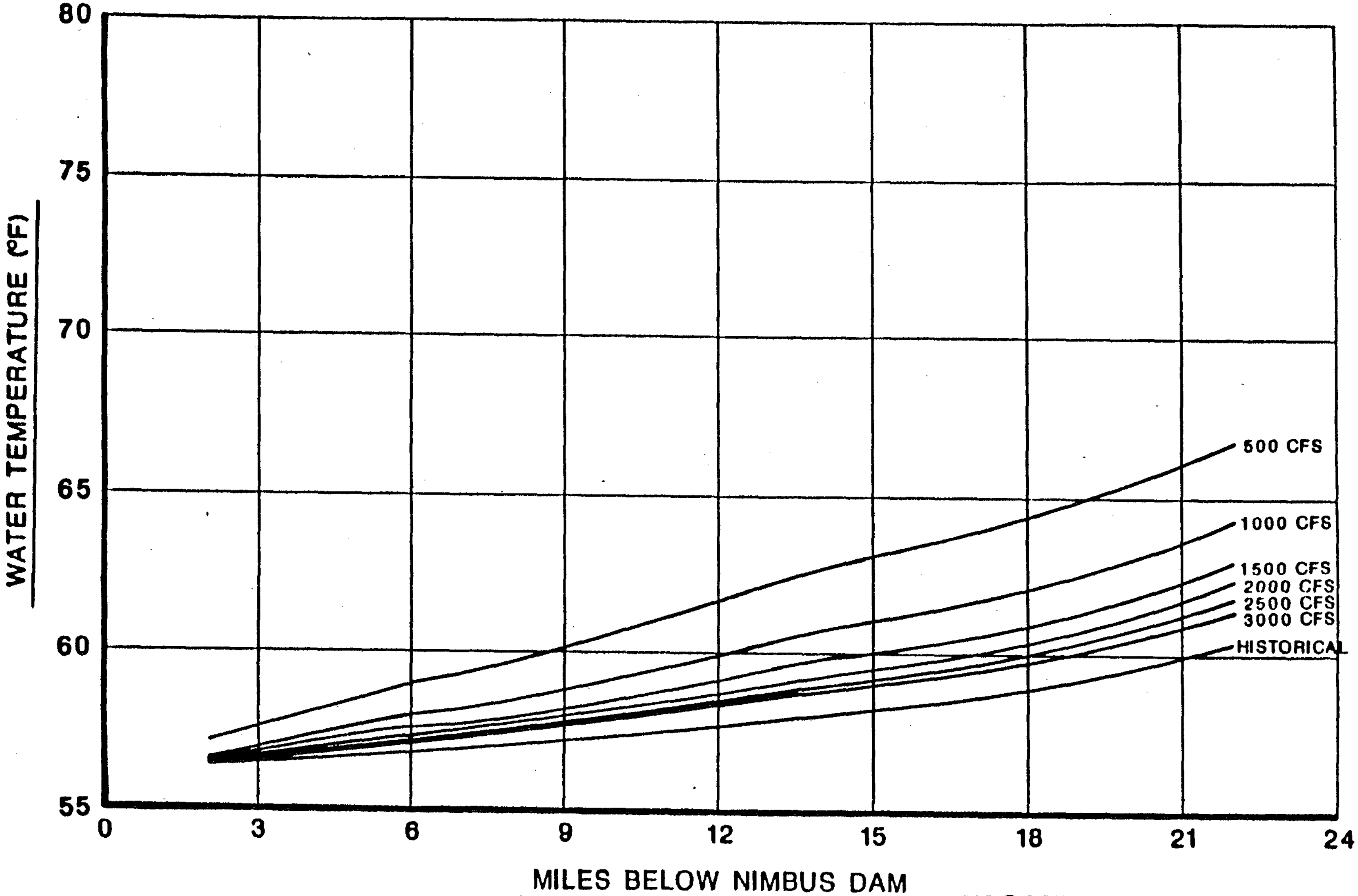

FIGURE 80

AMERICAN RIVER
MEDIAN WATER TEMPERATURES
FOR MAY

C — 0 4 3 7 0 2

C-043703

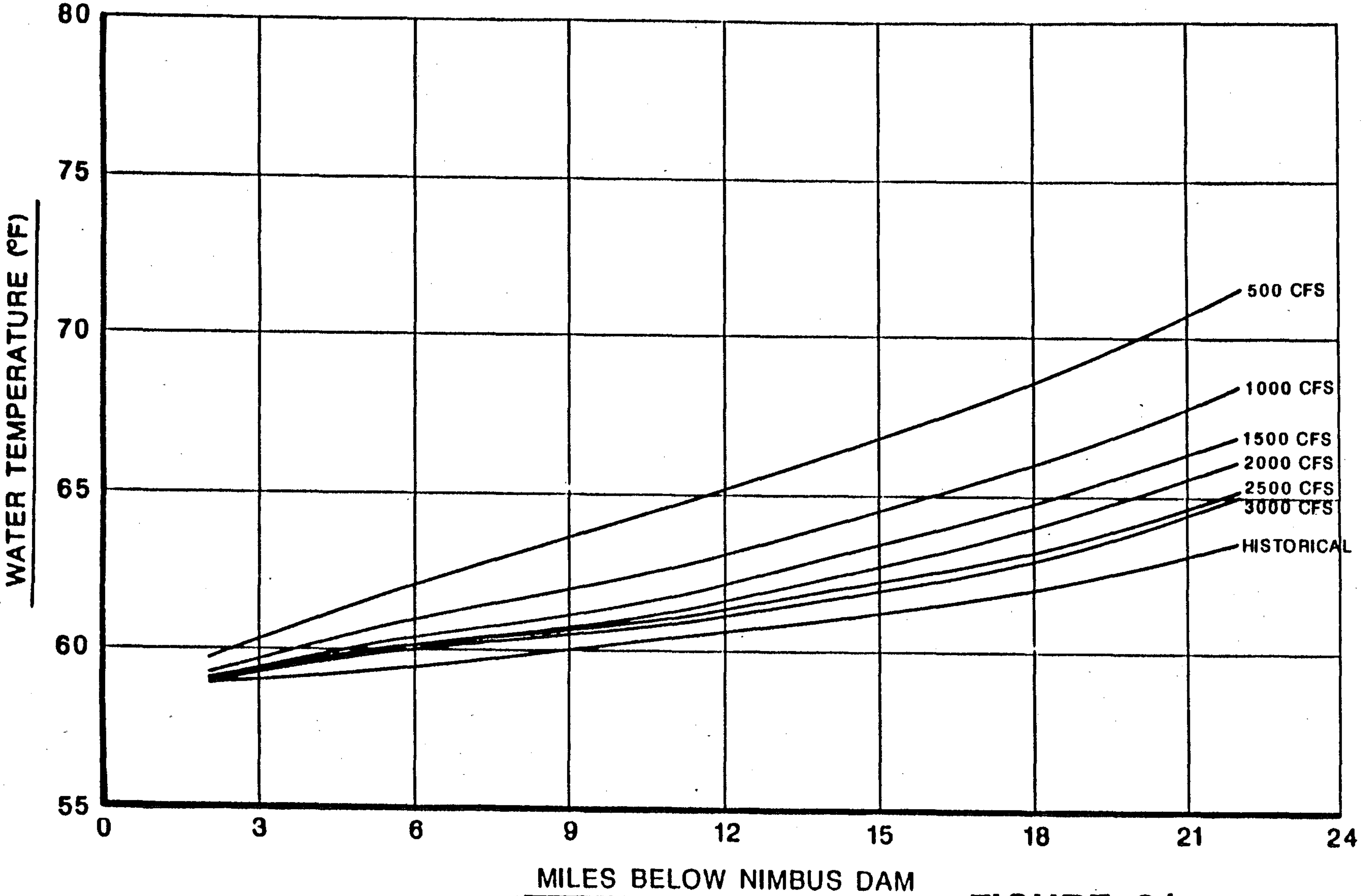

FIGURE 81

AMERICAN RIVER
MEDIAN WATER TEMPERATURES
FOR JUNE

C — 0 4 3 7 0 3

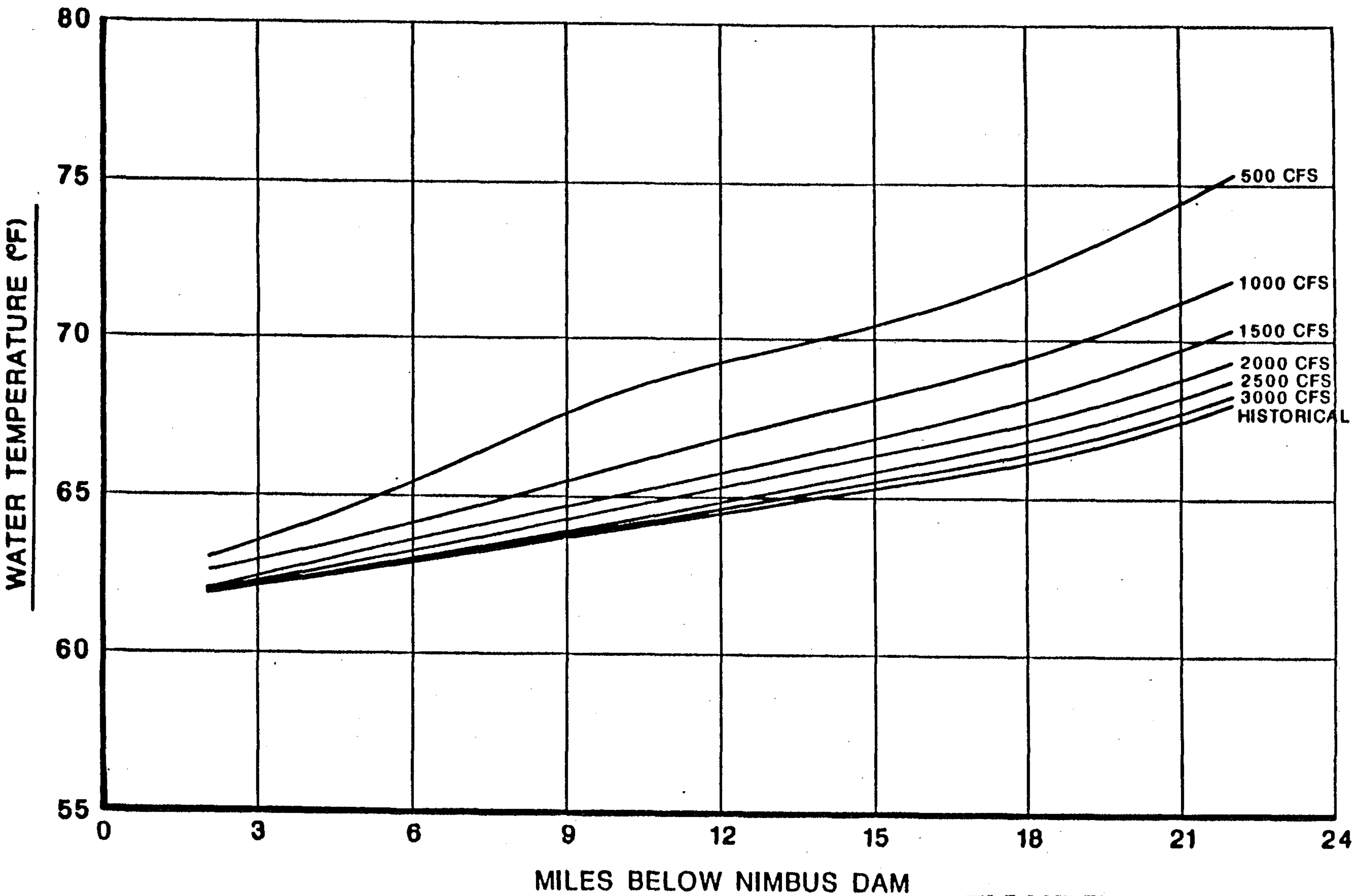

FIGURE 82

AMERICAN RIVER
MEDIAN WATER TEMPERATURES
FOR JULY

C-043704

C-043705

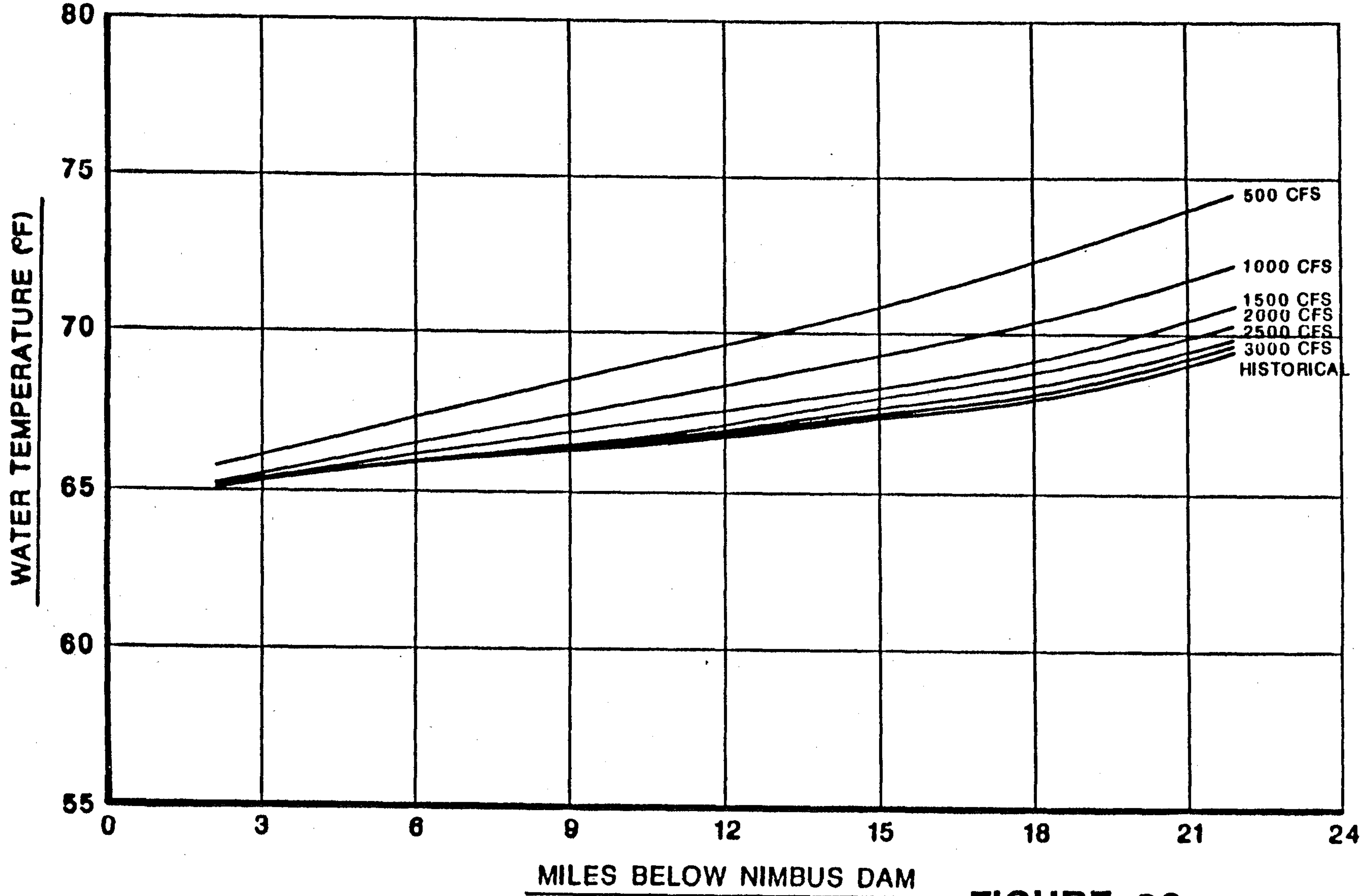

FIGURE 83

AMERICAN RIVER
MEDIAN WATER TEMPERATURES
FOR AUGUST

C-043705

C-043706

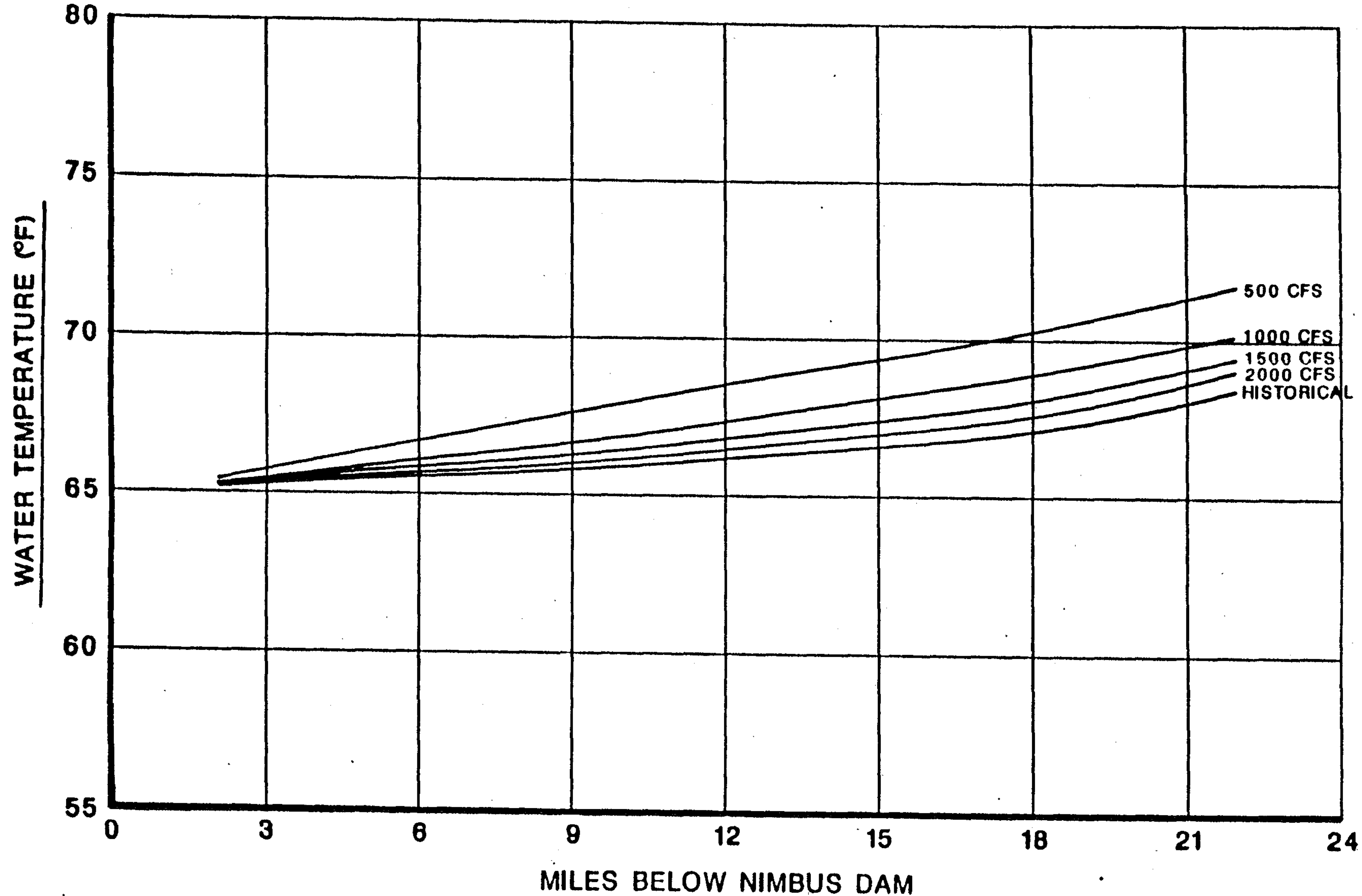

FIGURE 84

AMERICAN RIVER
MEDIAN WATER TEMPERATURES
FOR SEPTEMBER

C — 0 4 3 7 0 6

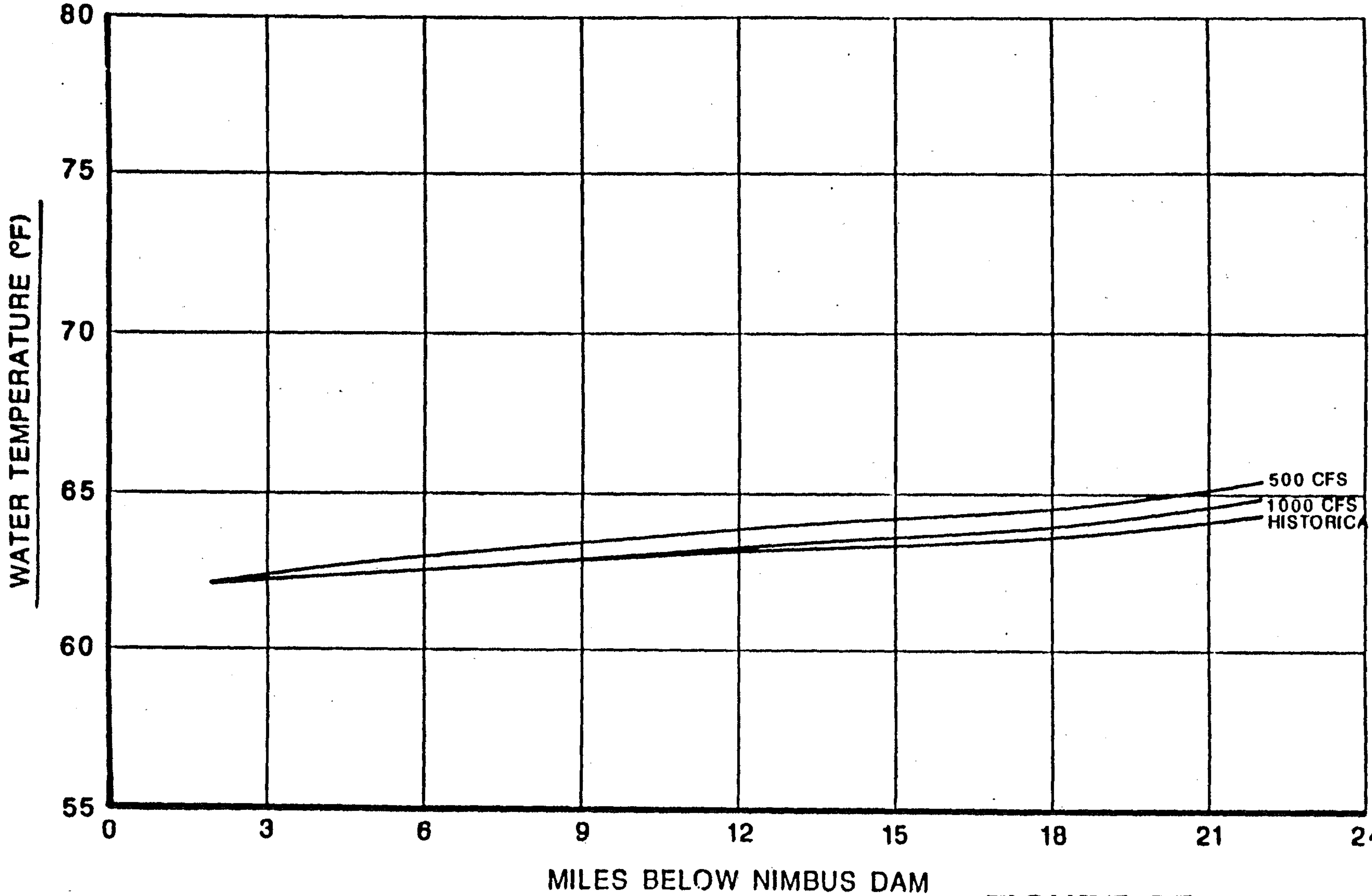

FIGURE 85

AMERICAN RIVER
MEDIAN WATER TEMPERATURES
FOR OCTOBER

C — 0 4 3 7 0 7