Existing flows, ground-water and water-quality influences on habitat values in the Shasta Valley, Siskiyou County, California

Report prepared for:

Yurok Tribe Natural Resources Department

Prepared by:

Jonathan Owens

Barry Hecht

Balance Hydrologics, Inc.

February, 1998

Memo

To: Zack Larson, Yurok Tribe Natural Resources Dept.at fax: (707) 482-0384
From: Jonathan Owens
Date: 2/13/98 project # 97096

Subject: Shasta River Habitat Report

Purpose

Balance was asked to document the alteration of water flow in the Shasta River for the purpose of assessing how such alterations might affect the health and population of the several major fish species for which the Shasta River provides habitat. This work is intended to address hydrologic aspects of a larger, multidisciplinary effort identifying potential basin-scale approaches to protecting and enhancing habitat for anadromous species critical to the Yurok tribe.

Introduction

Flow can be altered in many different ways; it can be altered in volume, intensity, temperature, chemical characteristics, and other ways. We focused our efforts on changes in the volume and intensity of water flowing in the Shasta River. We assumed that flow had been altered due to the operation of Dwinelle Dam, by surface water diversions for agricultural irrigation, and by ground water pumping. We find that flow in the Shasta River has been significantly altered from its natural condition in several key aspects likely to be harmful to fish populations. The total volume of flow has been reduced, the seasonal pattern of flow has been altered, and summer flows are subject to large daily fluctuations. Our analysis investigates flow alterations at three time scales.

General Hydrology

Shasta Valley is located in Siskiyou County, in northern California. The Shasta River headwaters are near Weed, where Mount Shasta dominates the landscape; the river flows northward until, downstream of Yreka, the Shasta River empties into the Klamath River. Different locations in the Shasta Valley receive widely varying amounts of precipitation. Average annual precipitation ranges from about 10 inches in the driest locations, to approximately 18 inches at Yreka (DWR, 1976), and approximately 70 inches at the summit of Mount Shasta (Blodgett, 1988). Lake Shastina, a man-made reservoir, has stored water from the Shasta River since 1928; reports of the reservoir's storage capacity varies between 50,000 (USGS, 1997) and 72,000 acre-feet (DWR, 1976). A small amount of water has been (at least since 1988) imported into the basin for irrigation from the Sacramento River system (DWR, 1988-94).

Hydrologic data has been collected in the basin since the early decades of the century. Flow measurements by the USGS near Yreka (USGS ID# 11517500, drainage area 793 square miles), from 1933 to 1941, and from 1944 to present, are available as daily data. Flow was also measured by the USGS on the Shasta River near Montague (USGS ID# 11517000) from 1911 to 1913, 1916 to 1921, and 1923 to 1933. Substantial additional measurements were made by the water masters, other DWR staff, and federal and local agencies, notably during the early to mid 1950s. In addition to flow records, long-term rainfall records (1872-present) from Yreka document the precipitation part of the hydrologic picture.

The watershed of the Shasta Valley can be divided to two general geologic types that have distinctive effects on how precipitation ends up as stream flow. The eastern two-thirds of the basin is underlain by volcanic formations, with high infiltration rates, damped storm response, and high, sustained baseflow recharge to streams. The western side of the basin is underlain by more crystalline formations, which characteristically produce a more rapid response to storms, and baseflow recharge that declines more rapidly through the season. Precipitation that falls as snow at high elevations may not melt until late in the season; snowmelt runoff generally produces a slower hydrologic response than does rainfall. A combination of snowmelt and volcanic geologic formations can produce a very steady baseflow with a very gradual decline. These natural hydrologic patterns are important to consider because alterations in the natural patterns can affect the ecosystem which had adapted to those conditions.

Flow Alteration

We have separated our analysis of flow alteration into three categories: within-month alterations, seasonal/annual alterations, and long-term alterations. Flow alteration of the Shasta River is evident on all of these time scales.

Within-month Time Scale

Within-month flow alterations are important because they tell a story that the larger time scales gloss over. We had heard anecdotally, and then found data to support, that large, within-month flow fluctuations occur on the Shasta River.

Daily flow data illustrates this scale of flow alteration figures 1a and 2a. Note that large fluctuations occur during the summer months, but much less so during the month of October, when most irrigation has ceased for the year. The figures show data from three USGS gaging stations: the Shasta River near Yreka, the McCloud River near McCloud (USGS ID# 11367500, drainage area 358 mi^2), and the Trinity River above Coffee Creek near Trinity Center (USGS ID# 11523200, drainage area 149 mi^2) for two years, 1962 and 1996. We chose 1996 because it is the most recent year for which we obtained a complete record. We chose 1962 because it is in contrast to 1996 in two ways; 1962 is one of the earliest years of data for these three stations and is drier that 1996. Even though 1962 was a relatively average year, it was preceeded by several relatively dry years. The figures show two particular years, but we feel any of the years for which we have data would show a similar picture.

The McCloud River flow declines gradually through the summer months, demonstrating the hydrologic effect of pervious volcanic geology and soils which damp storm response and supply steady baseflow. The Trinity River demonstrates the hydrologic affect of a more crystalline watershed with rapid storm response and more rapidly declining baseflow. Without flow alterations, summer flow on the

Shasta River would be expected to be intermediate between the McCloud and Trinity River records shown. However, as can be seen in both figures 1b and 2b, fluctuations in Shasta River flow during summer months are much greater than either the Trinity or McCloud Rivers.

The daily data shown (figures 1b and 2b) are a daily average of more frequent readings. It is likely that if the flow fluctuations were plotted on an hourly basis, the magnitude of the fluctuations would be even larger than the fluctuations in the daily average of flow. Should you wish, we can seek the hourly data.

We suspect that these flow fluctuations are due to the manner in which flows are diverted, and the choice of times when diversions are made. The fluctuations could also be caused by intermittent releases from Dwinelle Dam. These fluctuations occur during both wet and dry years; 1962 represents a relatively dry year, while 1996 represents a relatively wet year. These flow fluctuations can harm the fish population, because even though the average flow for a month might be sufficient for fish survival, a few days of very low flows could cause damage. It is likely that ground water pumping could supply the same irrigation needs, while causing smaller day-to-day and hour-to-hour fluctuations. Better orchestration of diversion schedules, and coordination of timing between diverters would also reduce the magnitude of fluctuations.

Seasonal/Annual Time Scale

Several effects of flow alteration are evident on the seasonal/ annual time scale. The seasonal pattern, represented as mean monthly flow, has been altered. Agricultural uses of surface water sources evapotranspire water that has been diverted out of the Shasta River or its tributaries. Estimates of natural annual flow in the Shasta River are much lower than the flows that have been measured.

As in most parts of California, the hydrologic cycle in the Shasta Valley is highly seasonal. Most of precipitation falls during the late fall, winter and early spring; most of the river flow runoff would have naturally occurred during the winter and spring. Irrigation demand is also highly seasonal; water demand is almost exclusively during the six month period starting in April and extending through September (table 1 and figure 3). The seasonal pattern of river flow has been dramatically altered (figure 4). The "natural" river flows were developed by DWR (1964b), and are an estimate of what flows would have been without diversions from the river. The difference between the natural flow and the impaired flow quantifies altered flow in the Shasta River. Flow alteration is evident from April through September (the same period as the water demand), and is most severe during July and August. Low flow during this time of year likely affects over summering species (such as coho and steelhead), and impedes passage for spring run chinook, making it more difficult, if not impossible, to enter the Shasta River because of insufficient flow.

The water demand in the Shasta Valley is largely agricultural (DWR, 1957; DWR 1976); municipal, industrial, and rural demand is less than ten percent of the total water demand (DWR, 1976; DWR 1988-94). Agricultural water demand varies year by year demanding on the timing and amount of rainfall that year. Table 2 contains values for agricultural water estimated by DWR for a number of years.

In Table 2, the value which probably most closely reflects the magnitude of flow alteration in the Shasta River is evapotranspiration of applied water from surface water sources (surface ETAW). The actual magnitude of flow alteration could be larger than surface ETAW and might be as large as applied water from surface water sources (surface AW). Recent magnitudes of surface ETAW range between 59,000 and 92,000 ac-ft per year. If this volume of water is converted to uniform flow over the six month irrigation period, then the amount of flow alteration in recent years ranges between 160 and 255 cubic feet per second during that six month period. However, because water demand is not really constant during the six month irrigation period, at certain times the magnitude of the flow alteration will be considerably larger than the six-month average. This is probably one reason that the daily record fluctuates so much.

Surface ETAW is a conservative estimate of the amount of surface water that is lost from the Shasta River due to agricultural irrigation. Sources of surface water are the Shasta River and tributaries that flow into the Shasta River, plus a small amount (2,000 ac-ft) from the Sacramento Valley (DWR, 1988-94). Applied water from ground water sources is also lost from the Shasta basin by agricultural evapotranspiration. Ground ETAW might also be considered an alteration of Shasta River flow; ground water sustains springs which contribute to river flow, and wells that are close to river channels will likely draw from river subflow. Ground water is more fully discussed below. Increased irrigation efficiency would also decrease the amount of surface water diversions; even if surface ETAW stayed the same, increased irrigation efficiency would reduce the amount of surface AW.

Long-term Time Scale

Flow in the Shasta River was not significantly altered until agriculture, and agricultural irrigation, reached a certain scale. Flow alteration has changed as water demand and water sources have changed.

We hoped to find long-term flow records that would illustrate this change; however, it appears that substantial flow alterations were already occurring by the time the USGS began measuring flow on the Shasta River. Because diversions predate flow measurements, it is not precisely known what natural flows would have been, but the natural flows can be estimated. DWR has estimated natural flows on an annual basis for the period 1895 to 1955 for the Shasta River at Yreka (DWR, 1951; DWR 1964). These estimated "natural" flows are presented with the measured (USGS) "impaired" flow in figure 5. The natural flows are much larger than the impaired flows; the difference between them is the magnitude of the flow alteration. For the period 1921 to 1955 the average annual flow alteration was 92 cfs; if this volume equivalent is applied to flow during the six month irrigation period, then the size of the flow alteration during those six months is 183 cfs. This value is consistent with the values of flow alteration based on crop water use (surface ETAW) above.

The data presented do show that diversions have increased since 1957 through the present; in addition, DWR projections predict increased water demand in the future (table 2). Ground water usage has approximately doubled since 1976 (table 2). These increases are not smooth and regular, but fluctuate depending on factors such as agricultural commodity prices and cycles of wet and dry years.

Conclusions

Reports indicate that populations of important fish species have declined. The Shasta River provides important spawning and rearing habitat for these species. Although populations will vary due to natural conditions, human influences can also affect salmonid passage, spawning, and survival, thereby affecting salmonid populations. Flow rate, water temperature, channel morphology, and water quality can all have an influence. We only addressed changes in Shasta River flow rates.

Evidence on three time scales indicates that significant quantities of water are diverted out of (or prevented from reaching) the Shasta River during the months April through September. First, within-month fluctuations occur without natural hydrologic causes much more frequently during the six month irrigation period than during other times of the year. Second, changes in the seasonal pattern of flow in the Shasta River correspond to the seasonal pattern of water demand in the Shasta Valley. Third, a comparison of "natural" flow estimates to "impaired" flow measurements reflects the degree to which annual flows have been altered. All of these pieces of evidence indicate that large amounts of water are diverted out of the river during the six-month irrigation period. The magnitude of the flow alteration has increased from approximately 56,300 ac-ft (6-month uniform flow equivalent of 156 cfs) in 1957 up to approximately 92,400 ac-ft (6-month uniform flow equivalent of 255 cfs) in 1990, and is projected by DWR to further increase in coming decades.

Alternatives do exist, especially ways to reduce the large daily fluctuations during summer months. One alternative is increased use of ground water to substitute for surface water diversions. Another alternative is better coordination among diverters to maintain a more constant flow during low-flow periods.

Memo

To: Zack Larson, Yurok Tribe Natural Resources Dept.at fax: (707) 482-0384
From: Barry Hecht
Date: 2/13/98 project # 97096

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Ground water as an alternative source of supply

Further development of ground-water resources in the Shasta River watershed may prove a viable means of:

- stabilizing summer and fall flows in the Shasta River,
- reducing daily or monthly fluctuations in flows, and
- maintaining water temperatures suitable for spawning and rearing in the Shasta River and its larger tributaries.

To meet these goals, further development of ground water could substitute for existing diversions from the main streams. Increased use of ground water would allow existing flows to remain in the stream to sustain habitat, as well as reducing the number of diversions or the daily fluctuations in stream flow.

The geology of the Shasta Valley favors the feasibility of substituting ground water for present-day diversions. Most of the watershed is underlain by volcanic rocks of varying ages, reported to exhibit high recharge rates, transmissivity, and storage. It is thought that these geologic units are functionally interconnected. Few barriers to ground-water flow have been identified in or near the Shasta Valley. In effect, the eastern 70 percent of the watershed may act as a reservoir (or system of closely interconnected reservoirs) which yields water at a nearly-constant year-round rate to the local streams.[1] The critical role of sustained baseflow emanating from the permeable volcanic units of upper watershed (including the Shasta Valley) in supporting the anadromous fishery of the Klamath River has been described in our previous studies (Hecht and Kamman, 1996).

By pumping water from portions of the interconnected 'volcanic' aquifer system that are located away from streams, existing summer and fall baseflows might be allowed to remain undiverted, providing key aquatic habitat. Such pumping may reduce the amount of baseflow contributed from the aquifer system during subsequent summer seasons, but to a much lesser extent than the existing direct diversion of summer flows. This reduction may be offset, in part, by additional recharge of the aquifer in locations where pumping has provided additional room for recharge. It may also be mitigated through simple efforts to augment recharge, such as construction of small stockwatering ponds, which would conserve high flows for recharge to the volcanic aquifer system. Nonetheless, each well drilled to substitute ground water for surface flows has the potential to deplete the flows in the nearby streams, and should be watched for prolonged or cumulative effects.

There are already many wells in the Shasta Valley, including numerous high-capacity wells supporting irrigation.[2] Wells may also be used at present to provide a noninterruptible source of supply during droughts, when surface flows may not be available; we have heard reports that wells supported about one-third of all irrigation in the valley during the height of the 1987-1992 drought, although we have not had the opportunity to confirm these. By extending their use, especially to areas which do not presently support ground-water development, it may prove feasible to leave additional waters in the streams during the irrigation season.

[1] Local streams in this context likely include Willow Creek and other minor north-flowing tributaries to the Klamath River, which likely receive some ground-water inflow from adjoining portions of the Shasta River topographic watershed. The extent of overlap of their 'groundwatershed' with the topographic watershed of the Shasta River, if any, remains to be established; it likely does not materially change the findings of this section.

[2] See, for example, Bulletin 87, Plate 3.

Water quality

With the important exception of water temperature in streams, both surface and ground waters generally appear to be of suitable quality to support irrigation, domestic, and habitat uses. Among the main localized or potential constraints identified in previous studies are:

- elevated boron levels near Table Rock, and possibly elsewhere,
- concentrations of carbon dioxide in Big Springs (68 mg/l) and several wells far in excess of those tolerated by cold-water fish
- lack of information regarding what constituents potentially deleterious to fish might be present in irrigation return flows

It is likely that these, and other highly-localized limitations, will not significantly reduce the opportunities available for stabilizing or increasing in-stream flows within the Shasta basin. Similarly, it appears that water quality in the Klamath River downstream from the mouth of the Shasta River will be enhanced by more regular or more voluminous inflows from Shasta Valley.

Water rights considerations

Water rights in Shasta Valley are complex. Future efforts to stabilize flows for fish will likely be delayed and complicated by water-rights considerations. Nonetheless, the present allocative framework can provide information and an administrative infrastructure which may help make and maintain changes in the existing summer flows.

Rights to surface water in the Shasta River watershed were adjudicated in 1932. Exercise of water rights is supervised by a watermaster, who in turn reports to the California Department of Water Resources (DWR). The watermaster must measure flows at key locations within the stream and ditch system during the summer months. These data, on file with DWR, may provide insights into (a) sources and causes of daily and seasonal fluctuations in flows of the Shasta River and its main tributaries, (b) which water rights are being used at which frequency, and (c) other observations or measurements which may have been made by the watermaster's office.

Existing water rights are governed by the adjudication. They also include both large pre-1914 water rights and judicially decreed water rights which may not be truly subject to environmental review and consideration by the State Water Resources Control Board. Many of the post-1914 water rights have not been fully exercised, since more senior upstream or downstream rights preclude use of water flowing by points of diversion. Yet, in at least some cases, some senior rights appear to be in excess of the installed diversion capacity. Additionally, there have been many changes in acreage under irrigation, the length of ditches in use by some of the larger diverters, and major new diversions brought on line from tributaries not previously subject to diversions (c.f., Greenhorn Reservoir, or the Whitney Creek diversions from 1962-1976, described in Blodgett and others, 1985).

Among opportunities to stabilize fish flows which may be realized through the watermaster's office (and through the water-rights process in general) are possible changes in the diversion season. Most major water rights in the basin appear to begin on April 1 and extend through October 1 or October 15 (Bulletin 87). Potentially, some of the rights may be amenable to changes in the beginning and end of the diversion season if associated instream habitat benefits were substantial. Other scheduling measures might also prove agreeable and suitable for implementation.

Ground-water development is usually treated as being supplemental to the adjudicated water rights. Hence, users may add to their existing entitlements by pumping from wells, presumably unless a direct linkage between pumping and streamflow can be established by complainants. Substitution of pumped ground water for surface diversions might prove feasible as a fish-friendly exchange within the water-rights context of Shasta Valley.

Generally, the existing water-rights situation favors a basin-wide dialog and/or solution. Since 6 or 7 major rights holders account for much of the water diverted from the Shasta River and its tributaries, it may prove feasible to arrange for fish-friendly accommodations with these larger entities which may help set a basin-wide standard. We also note that basin-wide measures may be warranted since there is little sense in making changes to provide more or more-reliable flows if the additional flows are used under existing entitlements by downstream diverters.

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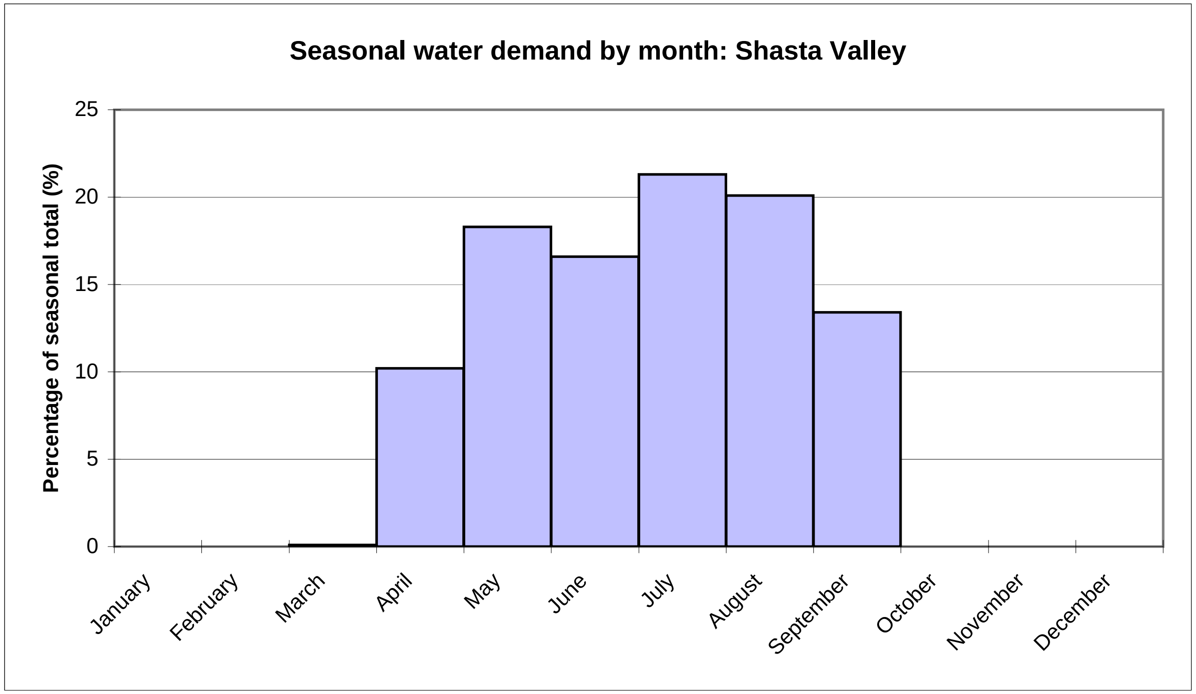
TABLES

Table 1. and Figure 3.
Distribution of Monthly Water Demands
Shasta Valley 1935-36 through 1952-53

Month	Percent of Season Total
	(%)
January	0
February	0
March	0.1
April	10.2
May	18.3
June	16.6
July	21.3
August	20.1
September	13.4
October	0
November	0
December	0



Source: DWR, 1955. Water Utilization and Requirements of California, Bulletin No. 2.

Table 2. Seasonal agricultural water use in the Shasta Valley

Period	Applied Water Total	Applied Water Surface	Applied Water Ground	ETAW Total	ETAW Surface	ETAW Ground	ETAW Total	ETAW Surface	ETAW Ground	Data Source
	(1,000 ac-ft)			*(1,000 ac-ft)*			*(6-month cfs)*			
1957				56.3			156			a
"Historic"	136.8									b
~1976 ("present")	140.1	131.1	9.0							b
"1990" (projected)	147.6									b
"2020" (projected)	153.6	113.6	40.0							b
1988	133.0	112.8	20.2	86.3	71.7	14.6	238	198	40	c
1989	133.5	112.8	20.7	86.7	71.7	15.0	240	198	41	c
1990	166.2	142.0	24.2	111.0	92.4	18.6	307	255	51	c
1991	134.3	114.5	19.8	90.2	75.1	15.1	249	207	42	c
1992	102.0	83.3	18.7	73.7	59.1	14.6	204	163	40	c
1993	109.4	92.6	16.8	75.4	62.4	13.0	208	172	36	c
1994	135.7	112.8	22.9	94.8	77.4	17.4	262	214	48	c

Data Sources:

a) DWR Bulletin #58, 1957. Northern Counties Investigation.

b) DWR, 1976. Siskiyou County, Land Uses and Water Demands.

c) DWR, Northern District, 1988-1994. data, Agricultural Land and Water Use

Notes:

ETAW is evapotranspiration of applied water (AW), or consumptive use; the difference between AW and ETAW infiltrates to ground water, or returns to the river system as return flow.

Municipal, industrial, and rural water use is not included above, but is less than 10% of agricultural water use.

The recent values (1988-1994) include 2,000 ac-ft imported from the Sacramento River watershed.

"6-month cfs" is the flow equivalent of annual ac-ft converted to uniform flow in cubic feet per second over 6 months (the assumed diversion period).

Shasta River Basin Crop Water Usage

1957 DWR Bulletin #58

Crop Type		Acreage	Seasonal Consumptive Unit Values	Seasonal Consumptive Water Use	
		(ac)	*(ft/ac)*	*(ac-ft)*	
Alfalfa		11,210	1.9	21,299	
Pasture	Improved	22,700	2.1	47,670	
Pasture	Meadow	3,930	2.6	10,218	
Grain and grain hay		1,330	0.6	798	
Truck		20	0.9	18	
Deciduous orchard		10	1.4	14	
Total Irrigated		39,200		80,017	see note (1)
Urban Lands		1,450			
Swamp		1,310			
Reservoirs		2,050			

Estimated Mean Seasonal Consumptive[2] Use (1954-56)

Irrigated lands (see note (1))	Urban, Rural, Domestic	Swamp	Reservoir Evaporation	Total	
(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	
56,300	700	3,700	3,900	64,600	
Assuming uniform consumptive use over a 6-month period					
308	4	20	21	354	*(ac-ft/day)*
156	2	10	11	178	*(cfs)*

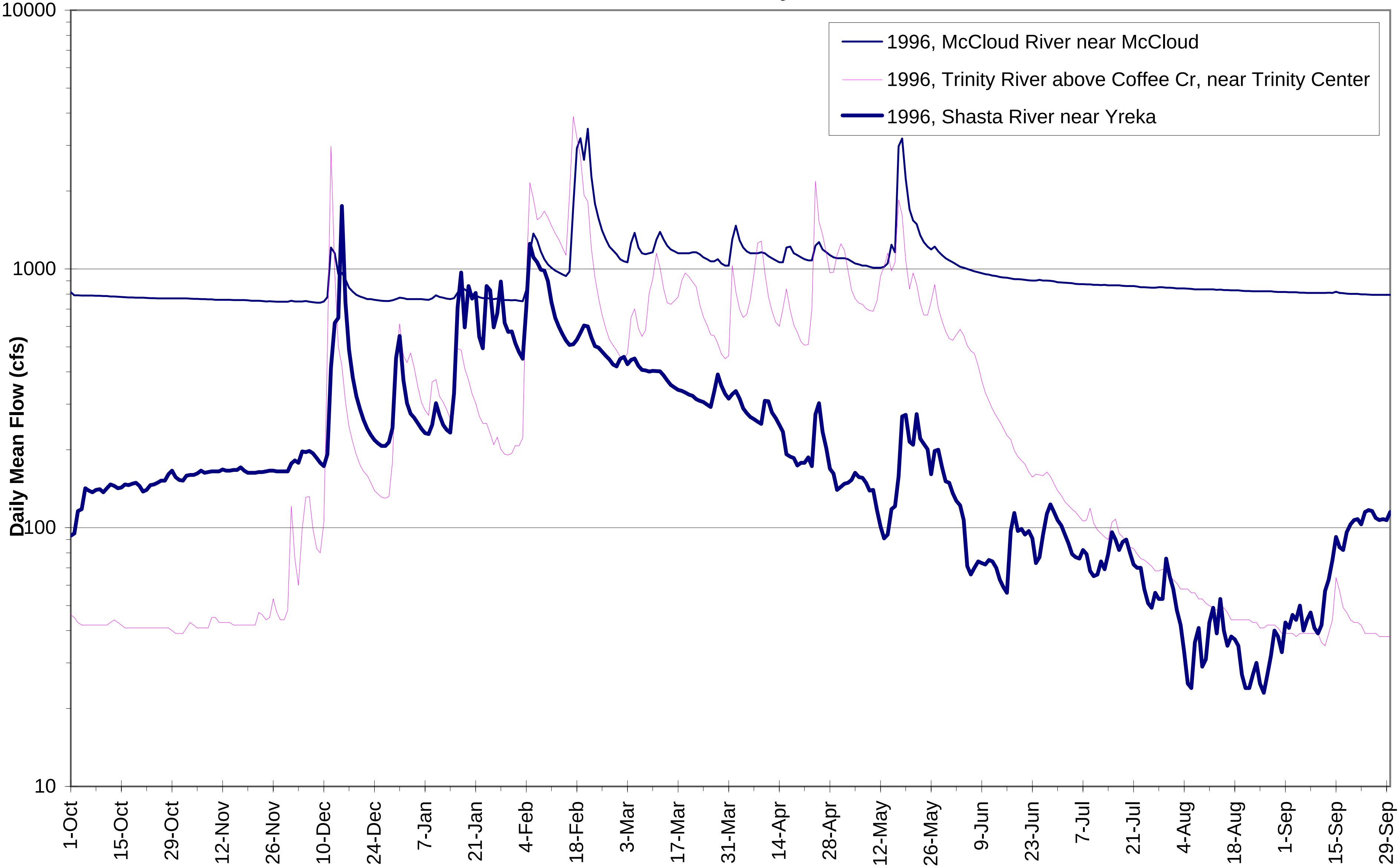
Data Source: State of California Department of Water Resources Division of Resources Planning. Bulletin No. 58: Northeastern Counties Investigation, December 1957.

(1) Likely consumptive use on irrigated lands is 56,300 instead of 80,000 because of deficient summer irrigation.

(2) Consumptive use refers to losses by evaporation and transpiration from the basin in excess of precipitation. The amount of water applied will be larger because irrigation is not 100% effiecient. Excess irrigation water that percolates into the ground water table or returns as seepage to the river is not included as part of consumptive use.

FIGURES

Figure 1a. Fluctuations in day-to-day flow during summer months: Shasta, McCloud, and Trinity Rivers, 1996



Note that flow axis is logarithmic

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Figure 1b. Fluctuations in day-to-day flow during summer months: Shasta, McCloud, and Trinity Rivers, 1996

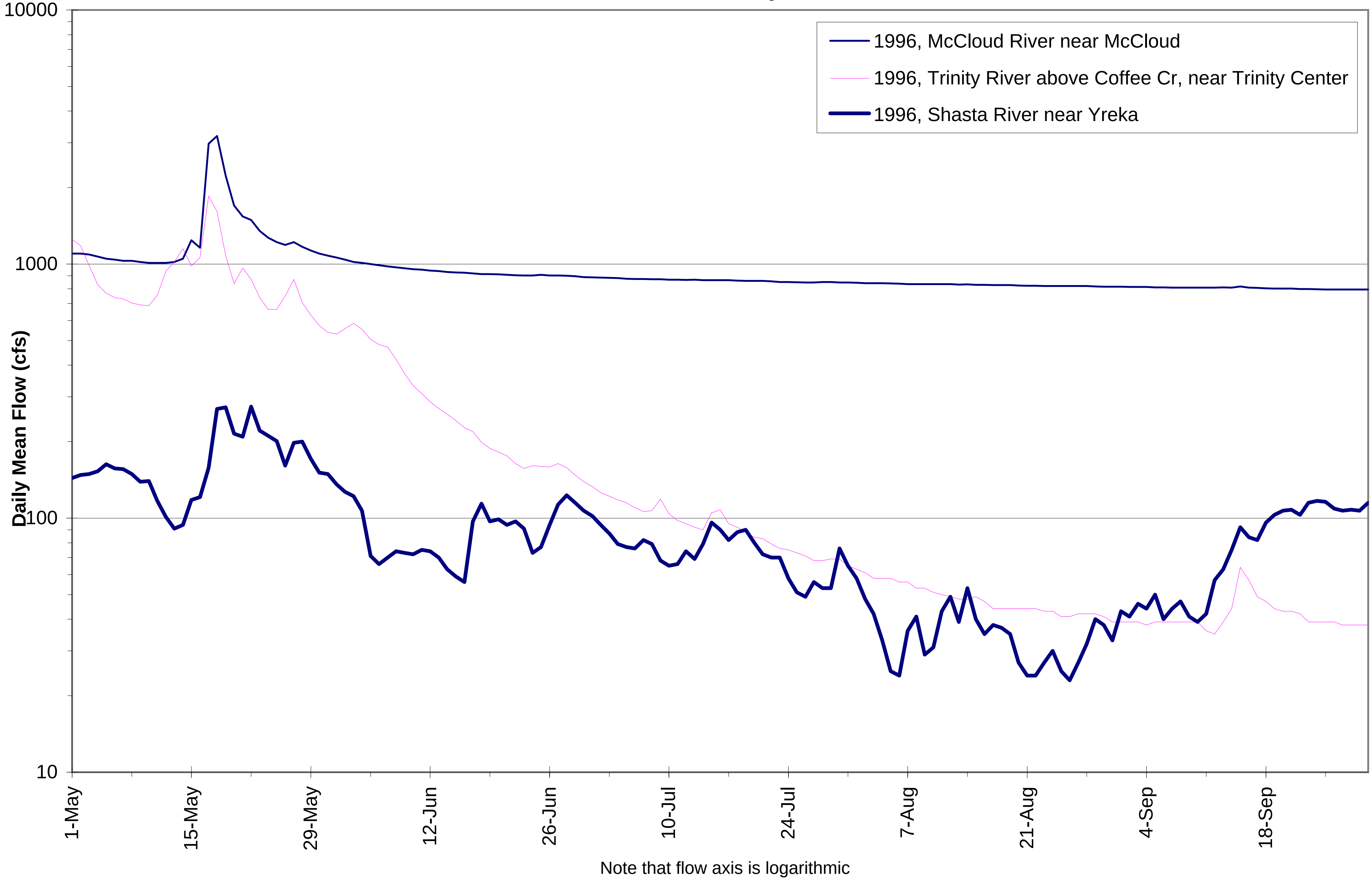

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Figure 2a. Fluctuations in day-to-day flow during summer months: Shasta, McCloud, and Trinity Rivers, 1962

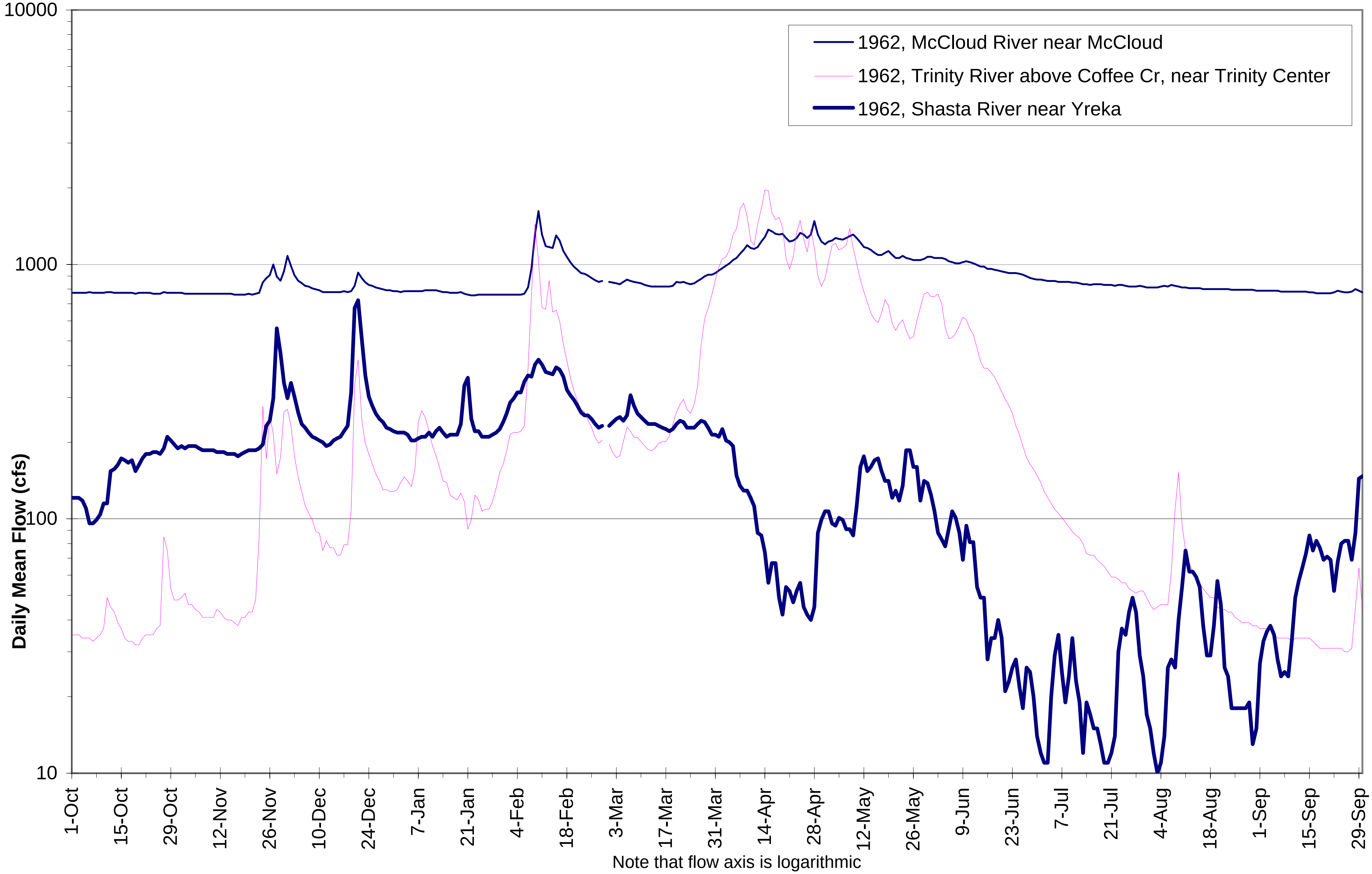

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Figure 2b. Fluctuations in day-to-day flow during summer months: Shasta, McCloud, and Trinity Rivers, 1962

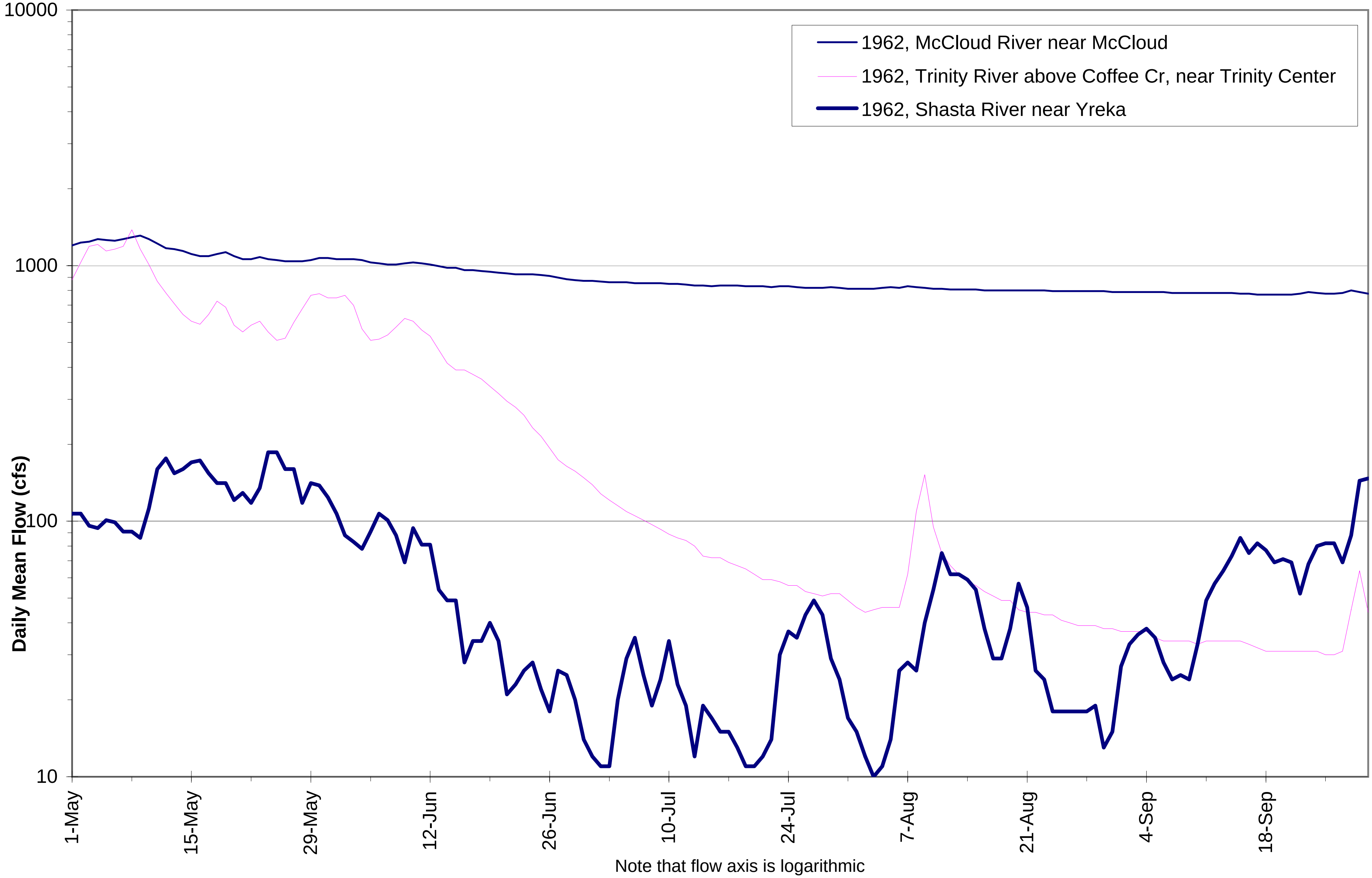

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Figure 4. Monthly Mean Flow for the Shasta River at Yreka

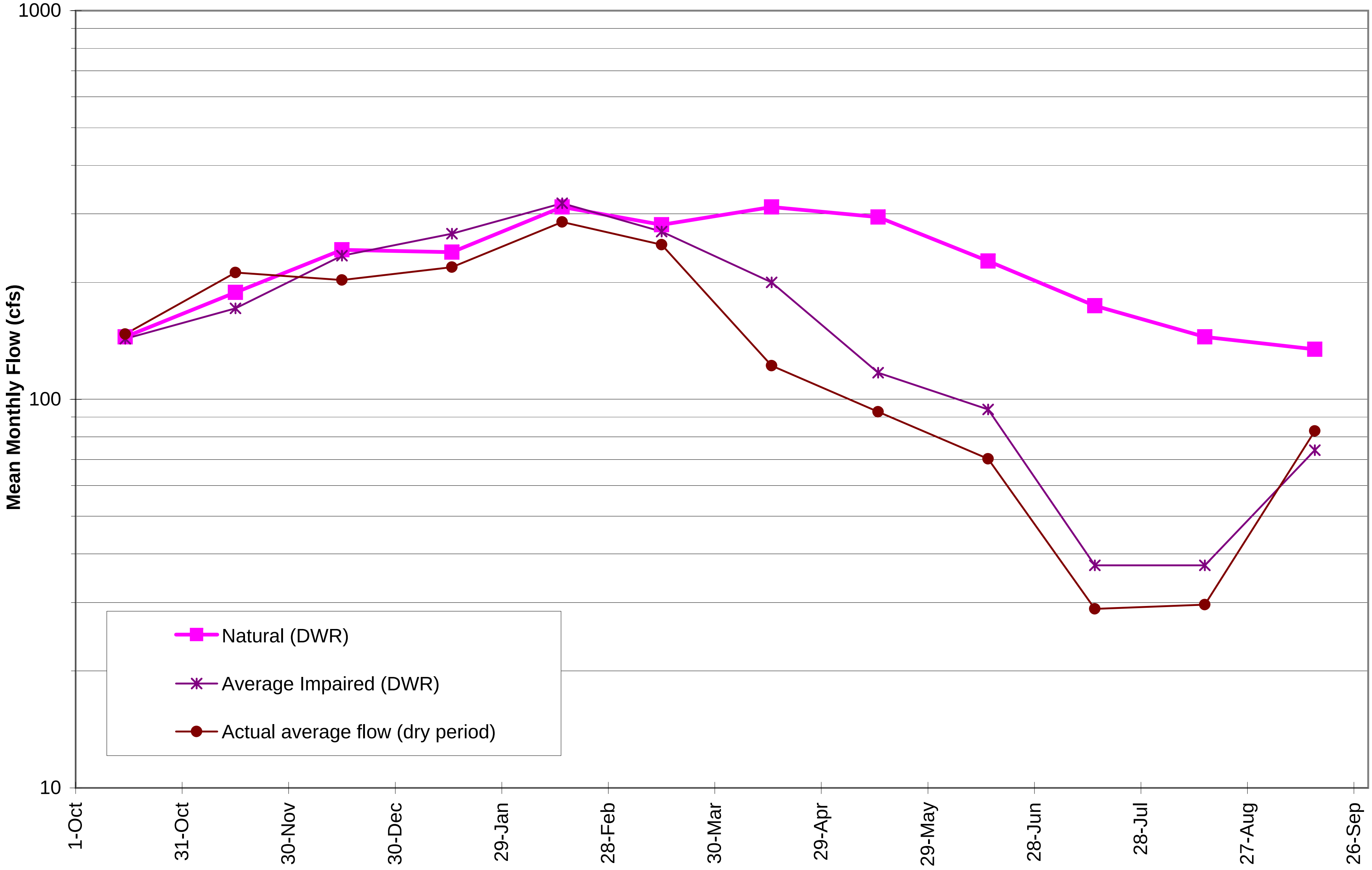

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Figure 5. Natural and Impaired Flows: Shasta River near Yreka