September 2002 Klamath River Fish-Kill: Final Analysis of Contributing Factors and Impacts

July 2004

California Department of Fish and Game
Northern California-North Coast Region
The Resources Agency
State of California

Acknowledgements:

The California Department of Fish and Game would like to thank Dr. Gary L. Hendrickson from Humboldt State University, Department of Fisheries Biology and Dr. Douglas F. Markle from Oregon State University, Department of Fisheries and Wildlife for their constructive peer review of this report. We would also like to thank Dr. Walt Duffy for his help in coordinating that peer review. In addition, we want to thank the Yurok, Hoopa Valley and Karuk tribes, the California Department of Water Resources, the North Coast Regional Water Quality Control Board, the Oregon Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, the U.S. Bureau of Reclamation, the U.S. Geological Survey, the NOAA National Climatic Data Center and the U.S. Forest Service, for their cooperation in providing data and/or for reviewing this document. Thanks also to the Klamath Water Users Association for providing the legal Declaration of their biological consultant, which expressed several alternative hypotheses related to the fish-kill. The Northern California North Coast Region of DFG would like to recognize the efforts of its Habitat Conservation Program and Fisheries Program, as well as, the Native Anadromous Fish and Wildlife Branch, and Fish Health Laboratory in Sacramento, for their efforts in the compilation of data and statistical analyses in this report. Finally, we would like to recognize the DFG staff efforts of Steve Turek, Mike Rode, Bill Cox, George Heise, Wade Sinnen, Carl Reese, Sara Borok, Mark Hampton, and Calvin Chun in the preparation of this report.

Executive Summary:

This report presents the Department of Fish and Game's (DFG) final evaluation of causative factors and impacts of the September 2002 Klamath River fish-kill and makes recommendations to minimize the occurrence of future fish-kills. This report finalizes and supercedes the January 2003 DFG report entitled: "September 2002 Klamath River Fish Kill: Preliminary Analysis of Contributing Factors". This document addresses questions and concerns regarding the preliminary report. In addition, this report was peer reviewed by academia and contributing federal and state agencies, tribes and other stakeholders.

The September 2002 fish-kill was unprecedented in that it was the first major adult salmonid mortality event ever recorded in the Klamath River. Fall-run Chinook salmon were the primary species affected, but coho salmon, steelhead and other fish species were also lost. At least 33,000 adult salmonids died during mid to late September 2002 in the lower 36 miles of river. Although a larger number of Klamath River fall-run Chinook died, a greater proportion of the Trinity River run was impacted by the fish-kill, because the Trinity run is substantially smaller than the Klamath run on an annual basis and the peak of the Trinity run was present during the height of the fish-kill.

The primary cause of the fish-kill was a disease epizootic from the ubiquitous pathogens ich and columnaris. However, several factors contributed to stressful conditions for fish, which ultimately led to the epizootic. An above average number of Chinook salmon entered the Klamath River between the last week in August and the first week in September 2002. River flow and the volume of water in the fish-kill area, were atypically low. Combined with the above average run of salmon, these low-flows and river volumes, resulted in high fish densities. Fish passage may have been impeded by low-flow depths over certain riffles or a lack of cues for fish to migrate upstream. Warm water temperatures, which are not unusual in the Klamath River during September, created ideal conditions for pathogens to infect salmon. Presence of a high density of hosts and warm temperatures caused rapid amplification of the pathogens ich and columnaris, which resulted in a fish-kill of over 33,000 adult salmon and steelhead.

Flow is the only controllable factor and tool available in the Klamath Basin (Klamath and Trinity rivers) to manage risks against future epizootics and major adult fish-kills. Increased flows when adult salmon are entering the Klamath River (particularly during low-flow years such as 2002) can improve water temperatures, increase water volume, increase water velocities, improve fish passage, provide migration cues, decrease fish densities and decrease pathogen transmission between fish.

The total fish-kill estimate of 34,056 fish, was conservative and DFG analyses indicate actual losses may have been more than double that number. If fish-kill numbers were substantially underestimated, more fall-run Chinook salmon could have been included in modeling efforts, for allocation to harvest allotments in ocean and in-river Klamath fisheries, during 2003. In addition, Klamath Basin tribal net and sport anglers may have lost the opportunity to harvest roughly 4,000 to 14,600 fall-run Chinook salmon in 2002, due to the fish-kill. This impact was more pronounced in the Trinity River than the Klamath River, because the fish-kill occurred below the confluence of the Trinity and Klamath, and precluded much of the harvest opportunity on the Trinity River.

TABLE OF CONTENTS:

List of Tables:

List of Figures:

I. Introduction:

A substantial fish-kill occurred on the lower Klamath River, California (Figure 1), in September 2002. The kill was first reported to the California Department of Fish and Game (DFG) on September 19, 2002. A cooperative effort, including DFG, U.S. Fish and Wildlife Service (USFWS), U. S. Forest Service (USFS) and the Yurok, Hoopa, and Karuk tribes, was implemented to evaluate the numbers of fish killed. Cooperators conducted surveys on September 20, 24, and 27, 2002. Results of the fish-kill surveys were summarized and reported by USFWS (USFWS 2003a).

The fish-kill took place on the lower 36 miles of the Klamath River, extending from the river's mouth upstream to Coon Creek Falls and entirely within the Yurok Indian Reservation. Actual beginning and ending dates of the fish-kill are unknown; however, dead fish were observed between at least September 18 and October 1, 2002.

The USFWS estimated over 34,000 adult fish died (USFWS 2003a). This total included: 32,553 fall-run Chinook salmon (*Oncorhynchus tshawytscha*), 344 coho salmon (*O. kisutch*), 629 steelhead (*O. mykiss*), 311 Klamath smallscale sucker (*Catostomus rimiculus*), 87 sculpin (*Cottus* sp.), nine speckled dace (*Rhinichthys osculus*), one coastal cutthroat trout (*O. clarki*), one American shad (*Alosa sapidissima*), one green sturgeon (*Acipenser medirostris*) and 120 unidentified fish (USFWS 2003a). Of the 32,553 Chinook salmon lost, a little over 7,000 or about 22 % of those fish, were of hatchery origin, with the remainder being naturally produced fish (USFWS 2003a). Estimates were considered conservative due to the nature of conducting fish-kill investigations (American Fisheries Society [AFS] 1992), observations of biologists conducting the fish-kill survey (Bairrington 2002, personal communication), and past experience by DFG in conducting surveys for carcasses of spawned-out anadromous salmonids in the Klamath Basin (DFG 2000a and 2002c).

DFG began to identify and evaluate potential causative factors and impacts of the fish-kill on September 19, 2002. This report summarizes the findings of that effort. The purposes for preparing this report were: to document conditions under which the fish-kill occurred; to assess and identify primary and underlying factors leading to the 2002 Klamath River fish-kill; to identify measures that if implemented would reduce the potential for future fish-kills; and to allow better management of the fishery resources in the Klamath Basin in the future.

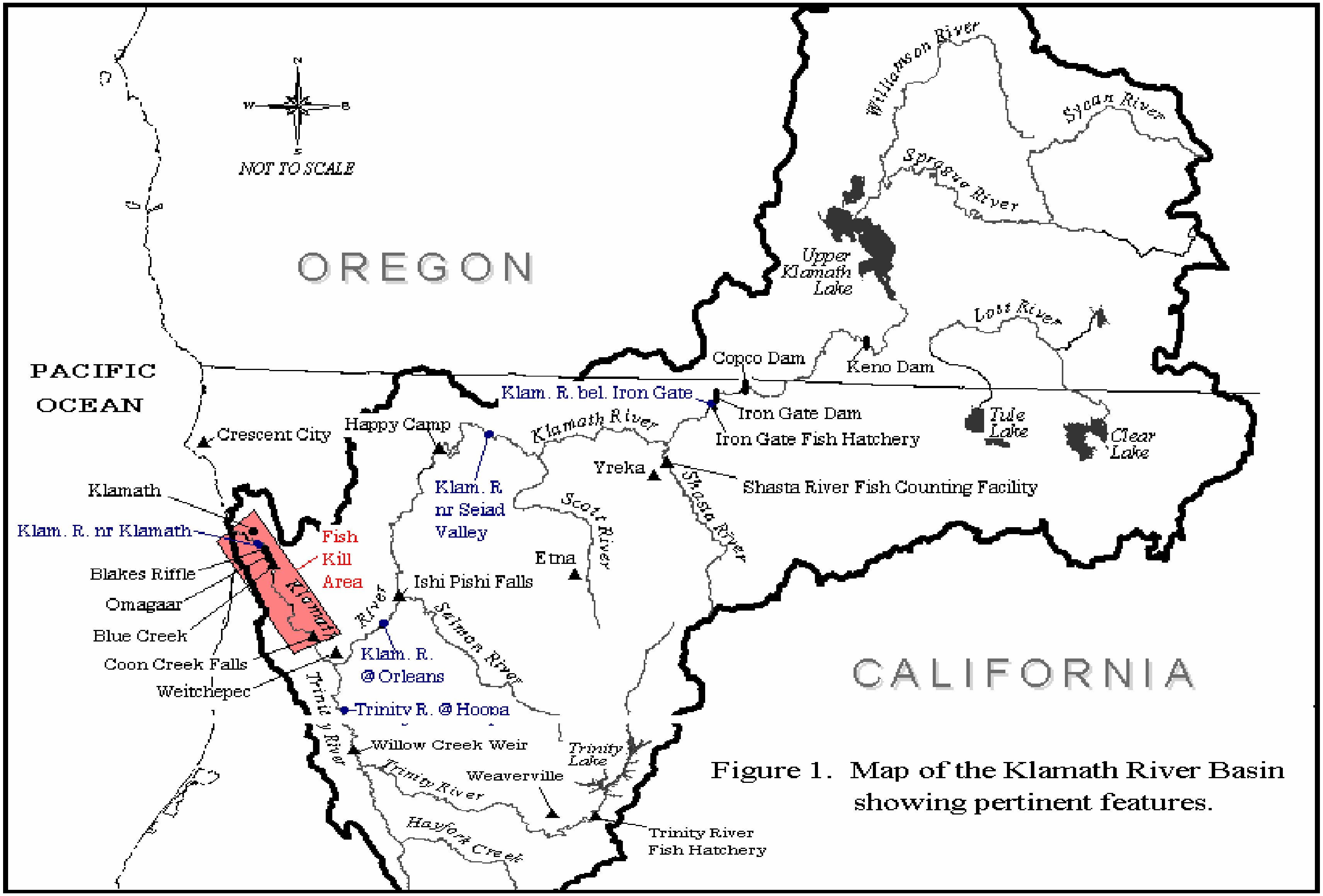


Figure 1. Map of the Klamath River Basin showing pertinent features.

From a historic perspective, the September 2002 fish-kill represented a one-time, unprecedented event on the Klamath River. The focus of this report was to analyze potential factors contributing to the fish-kill, particularly from the perspective of what made 2002 different. Factors were considered individually and collectively for their role in causing the fish-kill. Factors considered included: disease; toxic substances; flow; air and water temperature; dissolved oxygen; fish passage and river geomorphology; run-type, timing and density; and run-size. Where possible, the report identified competing hypotheses and analyzed their consistency with available data. This report also compared the Klamath River fish-kill with other fish-kills, evaluated the potential impacts of the fish-kill on fishery resources in the Klamath River Basin[1] and discussed potential fishery management implications. The report did not attempt to develop predictive models for future fish-kills, given that at least to date, this was a one-time event.

---

[1] Throughout this report, frequent references to the Klamath River Basin or Klamath River System are made. These references are meant to be inclusive of all features within the basin (Figure 1). These features include the Klamath, Shasta, Scott, Salmon and Trinity rivers in the lower basin and the Klamath, Sycan, Williamson, Sprague and Lost rivers as well as Upper Klamath Lake in the upper Basin.

II. Study Area:

II. A. General Setting;

The Klamath River originates in south-central Oregon, east of the Cascade Mountain Range. The 263-mile river flows in a general southwesterly direction, bisecting the Cascade Range as it courses through Oregon into California. Once in California, the river continues flowing southwesterly, before turning northwesterly near its confluence with the Trinity River, thence continuing to the Pacific Ocean. The Klamath River enters the Pacific Ocean about 15 miles south of Crescent City, California (Figure 1). The mainstem Klamath River drains about 5,000 square miles in Oregon and 10,000 square miles in California. The Klamath River Basin is California's second largest river system (DFG 2002a), and the state's second most important salmon-producing river (California Advisory Committee on Salmon and Steelhead Trout 1988).

The Wood, Williamson, Sprague, and Sycan rivers are significant headwater tributaries. These rivers join to form Upper Klamath Lake. Water flows from Upper Klamath Lake into Link River (approximately 1.2 miles long), and thence into Lake Ewauna near Klamath Falls, Oregon (FishPro 2000). The Klamath River officially begins at the lower end of Lake Ewauna. Significant tributaries do not enter the Klamath River until the Shasta River confluence at river mile (RM) 177 in California (Pacific Southwest Interagency Committee 1973). The Scott, Salmon, and Trinity rivers enter at RM 143, 66, and 44, respectively, as the Klamath River flows through California.

A number of smaller tributaries enter the Klamath River in California within the fish-kill area, downstream of Coon Creek Falls (RM 36). These include Ah Pah (RM 17), Blue (RM 16), Tarup (RM 8), McGarvey (RM 6), Terwer (RM 5), Waukell (RM 4), Hoppaw (RM 3), and Hunter (RM 1) creeks. These small tributaries often have very little flow during summer. However, Blue Creek accretions can range from 30 to 60 cfs during summer months.

PacifiCorp operates six hydroelectric facility dams on the mainstem system, beginning with Link River Dam (RM 253) at the outlet of Upper Klamath Lake and ending at Iron Gate Dam (RM 190). The total generating capacity of the six facilities is 153.8 megawatts (PacficiCorp 2000). Iron Gate Dam, in coordination with upriver facilities, is used to re-regulate flow in the Klamath River downstream of the hydroelectric facilities. There are no major mainstem water projects downstream of Iron Gate Dam.

Water diversions by the U. S. Bureau of Reclamation (USBR) Klamath Project, and private diversions from the Klamath River Basin in Oregon and the Trinity River in California, result in notable changes in flow of the Klamath River. Similarly, in-basin diversions from the Scott and Shasta rivers, also reduce contributory flows to the Klamath River during summer and early fall.

The Klamath River Basin encompasses three major geologic provinces: the Cascade Mountains in its headwaters region, the Klamath Mountains in the middle, and the North Coast Ranges as the river nears the Pacific Ocean (Helley and LaMarche 1973). The general topography along the upper reaches of the river ranges from relatively flat to almost vertical canyon walls. Landforms along these reaches are mostly volcanic in origin, and include transition forms between the Cascade, Klamath and North Coast provinces. Basaltic and andesitic volcanic deposits are common. Drainages within the Klamath Mountains are deeply incised, and old land surfaces are commonly exposed along river channels. Granitic and ultramafic rocks, intrude into the highly metamorphosed volcanic and sedimentary rocks that lie beneath the mountains. A combination of sheared rocks, shallow soil profile development, and steep slopes are common in the North Coast Ranges.

Downstream of Iron Gate Dam, the river generally has a cobble-bed and pool-riffle channel form. Occasionally, granitic bedrock outcroppings occur. Downstream of Blue Creek, the substrate generally includes more gravel-cobble than further upstream.

River gradient is variable and generally decreases downstream of Iron Gate Dam. Gradient averages about 17 ft-per-mile between Iron Gate Dam and the Scott River, 14 ft-per-mile between the Scott and Salmon rivers, 13 ft-per-mile between the Salmon and Trinity rivers, and 7.5 ft-per-mile between the Trinity River and Pacific Ocean. The river's gradient in its last five miles below Terwer Gage, drops only about six feet (1.2 ft-per-mile) before entering the Pacific Ocean.

Flows upstream of Keno Reservoir are largely dependent upon flows from the Oregon headwater tributaries and losses of water privately diverted for off-stream purposes. Significant water is stored and then diverted for agricultural purposes during the spring-summer growing season, by private diverters and the USBR Klamath Project (Project). The Project supplies water to approximately 240,000 acres within the upper Klamath Basin. USBR also supplies water to the Basin's Lower Klamath and Tule Lake National Wildlife Refuges. The actual acreage served by the Klamath Project from upper Klamath Lake, is about 176,000 acres. There are an additional 26,000 acres served from the Lost River watershed and 30,000 acres of non-farmed acreage in the national wildlife refuges. USBR's flow regulation at Upper Klamath Lake, typically results in higher and earlier peak flows in the Klamath River, decreased summer flows, and greater annual flow variability (Balance Hydrologics, Incorporated 1996). However, in USBR comments received on the draft of this report, they suggest any early peak flows would probably be influenced by water diverted from the Lost River to the Klamath River, to avoid flooding in the Tule Lake area. Ecological effects of these flow modifications are commingled with downstream hydroelectric generation diversions, storage, and releases.

The Southern Oregon/Northern California Coasts (SONCC) Coho salmon, was listed as threatened in 1997 and the Lost River sucker *(Deltistes luxatu*s), and shortnose sucker *(Chasmistes brevirostri*s) as endangered in 1988, pursuant to the federal Endangered Species Act. California had listed the two sucker species as endangered in 1974 and now considers coho salmon as a candidate species. All three species occur in the Klamath

Basin. Prior to the federal listings, flow regimes from Upper Klamath Lake were altered by PacifiCorp to shape water releases, in order to optimize hydroelectric energy production. This shaping for energy production has altered flows and the ability to understand historic flow regimes on the Klamath River since installation of Link River Dam in 1921.

There is ample evidence to suggest that the historic flow regime of the upper Klamath River exhibited greater flow in the late spring and summer months and had a rather "smooth" hydrograph. This historic hydrograph was attributed to hydraulic buffering from a large storage capacity of natural wetlands in and around Tule Lake, and Upper and Lower Klamath lakes (Balance Hydrologics, Inc. 1996, Hardy and Addley 2001). Although the Klamath Project now stores water in Upper Klamath Lake for spring and summer irrigation and for use on wildlife refuges, this stored volume may actually be considerably less than the historic natural storage capacity. Irrigation diversions and hydroelectric operations, contribute to altered flow regimes downstream of each impoundment and diversion facility. From 1960 to 2000, average impaired monthly flows at Iron Gate Dam ranged from 791 cfs in July to 3,733 cfs in March. Prior to the hydroelectric and irrigation projects, median monthly flows (50% exceedence values) at Iron Gate ranged from 3,640 cfs in April to 1,361 cfs in September (Hardy and Addley 2001). These flows were derived using daily flow records for the 1905-1912 period (which represented an above normal precipitation period) at the Keno gage and were corrected downward to represent a "normal year".

Substantial water diversion and water use occurs in other areas of the Klamath River Basin. The California Department of Water Resources (CDWR 1997) estimated that current annual agricultural water use in the Shasta and Scott River basins totals 110,000 acre-feet and 71,800 acre-feet, respectively. In comparison, average annual irrigation and urban water use above Keno Dam in Oregon totals 503,700 acre-feet (CDWR 1997).

Water use and diversions have significantly changed in the Trinity River over the past 50 years. The USBR Trinity River Diversion (TRD) is a feature of the Central Valley Project. The TRD was completed in 1964 and diverts a significant proportion of the Trinity River to the Sacramento River Basin, for agriculture and hydroelectric generation. From 1964 to 1986, an annual average of 1,146,800 acre-feet of Trinity River water was diverted out of the basin to the Sacramento River. From 1986 through 2000, those diversions were reduced to an average of 732,400 acre-feet annually (CH2M Hill 2000, USFWS and Hoopa Valley Tribe 1999). Prior to the TRD, summer and early fall flows in the Trinity River near Lewiston, ranged from less than 100 cfs in dry years to 300 cfs in wet years (CH2M Hill 2000, USFWS and Hoopa Valley Tribe 1999). Summer and early fall flows in the Trinity River near Lewiston, were held at 300 cfs from 1978 through the 1990s. Releases at Lewiston Dam during the 2002 fish-kill were 450 cfs. This flow was established for dry-year conditions in the Trinity River Mainstem Fishery Restoration Environmental Impact Statement/Report (CH2M Hill 2000) and by court order.

Climate in the Klamath River Drainage is generally characterized by damp, mild winters, and dry hot summers. Temperatures become more moderate and precipitation increases, as the river approaches the Pacific Ocean. Mean annual precipitation ranges from about 13.5 inches near Klamath Falls in the upper basin, to about 110 inches near Blue Creek (RM 16). The upper drainage receives most of its precipitation as winter snowfall. Rainfall dominates the lower reaches of the drainage.

Vegetation along the river reflects precipitation patterns. Upstream of Keno Reservoir, vegetation typifies river/wetland complexes and agricultural development. Down-river in the steep sided canyon, pine, oak and shrub predominate on the steep, rocky slopes. Juniper woodland communities occasionally occur. Limited stands of Douglas fir infrequently occur below upper canyon rims. Proceeding down-river, there is a slow transition from primarily mixed pine-oak-juniper-shrub stands, to conifer forest-oak woodlands, to primarily conifer forests. Upslope vegetation downstream of Blue Creek primarily is conifer forest, interspersed with oak woodlands.

II. B. Fish Resources;

Historically, much of the Klamath River was home to abundant runs of anadromous salmon, steelhead, Pacific lamprey, and other species, as they migrated to various tributaries of the river and Upper Klamath Lake (Oregon Department of Fish and Wildlife [ODFW] 1997). Fall and spring Chinook salmon are believed to have spawned within the Sprague River System of the Upper Klamath Basin (Klamath River Basin Fisheries Task Force 1992). Runs of Chinook were thought to go as far up the Sprague River as Beatty, Oregon, and spawning was reported in the north and south forks of the Sprague. These fish runs were halted as early as 1910 by the construction of Copco I Dam, which permanently blocked fish passage (City of Klamath Falls 1986). Today, Iron Gate Dam forms the upstream limit of anadromy, because this dam does not have fish passage facilities. This discussion of fish resources is limited to the river downstream of Iron Gate Dam.

Sixteen species of freshwater fishes are native to the Klamath River downstream of Iron Gate Dam, and there are at least ten introduced species (Table 1). Many of these native fishes once supported significant in-river fisheries. The Klamath River once supported a highly productive fishery for Chinook salmon, coho salmon and steelhead trout. For example, from 1918 to 1930, the annual Chinook salmon catch ranged from 11,500 to 61,500 fish annually (Snyder 1931), although the fishery had already been greatly reduced at that point. Today, Chinook salmon, coho salmon and steelhead trout are less abundant. Coho salmon are listed as threatened pursuant to the federal Endangered Species Act, and DFG was directed by the California Fish and Game Commission on February 4, 2004 to prepare a rules package for listing coho pursuant to California's Endangered Species Act. Pacific lamprey once supported a significant Native American fishery. Today, lamprey continues to be a sought-after species, but the fishery is greatly reduced.

Table 1. Fish species in the Klamath River downstream of Iron Gate Dam.

Scientific name	Common name	Anadromous/ Resident	Species Status
Native species			
Lampetra tridentata	Pacific lamprey	A	Proposed [1]
Lampetra ayresi	river lamprey	R	Proposed [1]
Lampetra pacifica [2]	Pacific brook lamprey	R	
Lampetra similis [2]	Klamath River lamprey	R	
Lampetra richardsoni	western brook lamprey	R	Proposed [1]
Oncorhynchus tshawytscha	Chinook salmon	A	
Oncorhynchus kisutch	coho salmon	A	Threatened [3]
Oncorhynchus mykiss	steelhead	A	
Oncorhynchus clarki	cutthroat trout	A	
Rhinichthys osculus	speckled dace	R	
Catostomus rimiculus	Klamath smallscale sucker	R	
Catostomus snyderi	Klamath largescale sucker	R	
Cottus aleuticus	coastrange sculpin	R	
Cottus asper	prickly sculpin	R	
Cottus klamathensis	marbled sculpin	R	
Acipenser medirostris	green sturgeon	A	
Acipenser transmontanous	white sturgeon	A	
Thaleichthys pacificus	eulachon	A	
Gasterosteus aculeatus	threespine stickleback	A	
Introduced species			
Notemigonus crysoleucas	golden shiner	R	
Pimephales promelas	fathead minnow	R	
Ictalurus nebulosus	brown bullhead	R	
Perca flavescens	yellow perch	R	
Micropterus salmoides	largemouth bass	R	
Lepomis cyanellus	green sunfish	R	
Pomoxis nigromaculatus	black crappie	R	
Archoplites interruptus	Sacramento perch	R	
Alosa sapidissima	American shad	A	
Salmo trutta	Brown trout	R	

1. Petitioned for listing as threatened in 2000 pursuant to the U.S. Endangered Species Act.
2. The distribution of Pacific brook lamprey and Klamath River lamprey in the Klamath River system is unclear.
3. Listed as threatened pursuant to the U.S. Endangered Species Act. Currently considered warranted for listing by the California Fish and Game Commission pursuant to the California Endangered Species Act.

III. Factors Investigated:

III. A. Disease;

III. A. 1. Introduction

Large adult fish-kills caused by pathogens and disease, are relatively rare in the wild and much more common in hatcheries. The 2002 fish-kill was unprecedented and represented the first recorded massive mortality of adult anadromous fish on the Klamath River. Traxler et al. (1998) reported high pre-spawning mortality during 1994 and 1995, due to ichthyophthiriasis in sockeye salmon in the Babine River (Skeena River System), British Columbia. Until that time *Ichthyopthirius multifilis* (ich), the pathogen responsible for ichthyophthiriasis, had been reported in numerous species of freshwater anadromous fish in Canada, but no epizootics had occurred in wild salmonids. Traxler et al. (1998) identified high densities of fish as the primary factor for the epizootic. In this case, sockeye salmon were held in high densities below weirs for several weeks, before they were allowed to migrate into artificial spawning channels. High densities stressed the fish and made them more susceptible to ich infection and eventual death (Traxler et al. 1998). Although ambient water temperature has been identified as an important factor in the rate of development of ich (Warren 1991), water temperatures during the epizootics in 1994 and 1995 were similar to prior years, when significant pre-spawning mortality was not evident (Traxler et al. 1998).

Similar fish-kills occurred at two widely separated spawning channels on the Frasier River, British Columbia in 1995 (Traxler et al. 1998). Losses were also attributed to ich and affected wild adult sockeye and Chinook salmon. The combination of warm water and high fish density were identified as factors related to the severe ich outbreaks (Higgins 2002, personal communication).

The Rogue River in southern Oregon has experienced extensive pre-spawning mortality of both spring and fall-run Chinook salmon (ODFW 2000). Prior to the start of operation of Lost Creek Dam in 1978, ODFW indicated at least three years in which large pre-spawning mortalities of spring and fall Chinook salmon occurred. In addition, pre-spawning mortality was mentioned in 13 of 30 years, in which reports were written (ODFW 1992). Annual rates of pre-spawning mortality were as high as 70.2% for spring Chinook (ODFW 2000) and 81% for fall Chinook (ODFW 1992). The three largest recent spring-run Chinook fish-kills were documented in 1987, 1992 and 1994, when losses were 31,579, 13,684 and 20,134 fish, respectively (ODFW 2000). Disease was implicated as the probable immediate cause of both spring and fall-run Chinook pre-spawning mortality, but death could not be attributed to any one organism (ODFW 1992, 2000). The bacterium *Flavobacterium columnare* (columnaris) was the disease pathogen most often found in dead and dying fall-run Chinook. Fall-run Chinook mortality rates were positively related to water temperatures in the Rogue River Canyon (RM 34.2 – 68.4) during late summer. As water temperatures increased, the mortality rate increased. Regression analysis, indicated mortality rates of <1% at 66.2 ºF (19 ºC), 15% at 68.0 ºF

(20 ºC) and 89% at 69.8 ºF (21 ºC) (ODFW 1992). The effect of flow on mortality was not analyzed, but flow was closely correlated to water temperature (ODFW 1992). Fish density had less affect on mortality than water temperature (ODFW 1992).

In 2002 and 2003, Butte Creek, a tributary to the Sacramento River, experienced large pre-spawn mortalities of federally and state listed spring-run Chinook salmon. DFG estimated fish losses of 3,431 salmon (21%), out of a population of 16,028 adults in 2002 and 11,231 salmon (65 %) out if an estimated population of 17,294 adults in 2003 (DFG 2004). The unique life history of spring-run Chinook includes a protracted period of adult fresh water residency, which in Butte Creek is up to seven months prior to spawning, and thus exposes those fish to a higher risk of pre-spawn mortalities. Additionally, water temperatures in the holding/spawning reach of Butte Creek, are generally higher during the months of July and August than is optimal for Chinook salmon, with average daily water temperatures during the period generally exceeding 62° F. In both 2002 and 2003 peak mortalities occurred from late July until early September (96% in 2002 and 99% in 2003) following abnormally high water temperatures. During 2002, water temperatures at a key site in the holding reach of Butte Creek peaked at 69.4° F during mid-July, while in 2003, the peak was 69.7° F in late July. While the entire holding spawning reach of Butte Creek is affected by a Pacific Gas and Electric Company (PG&E) hydropower project, DFG concluded the pre-spawning losses were primarily due to large numbers of fish concentrated in limited holding pools, high water temperatures, and an outbreak of two pathogens, columnaris and ich (DFG 2004). DFG also concluded that operation of the hydropower project provided a net benefit to salmon holding and spawning, but also identified the need to further evaluate operational changes that would potentially decrease water temperatures.

All the aforementioned wild epizootics appear to relate to at least one of four main factors. Those factors including; restricted fish passage, high densities of fish, warm water temperatures, and low-flow, can act either individually or in concert to create conditions favorable for an epizootic.

Warren (1991) stated: “Disease can occur when susceptible fish encounter virulent pathogens and adverse environmental conditions stress the fish.” Many fish pathogens are present in the Klamath River System. The major fish pathogens documented in recent years include the myxozoan parasite *Ceratomyxa shasta* (ceratomyxa), the trematode *Nanophyetes salmincola,* and the bacterium columnaris (Foott et al. 2002). When environmental conditions are not stressful to fish, disease may not occur, even though fish are infected or in contact with pathogens. However, disease can occur when environmental conditions degrade, such as with increased water temperature, decreased flow, and increased fish density (Warren 1991, Lasee 1995). Poor environmental conditions are stressful to fish and result in compromised immune function, making fish more susceptible to disease (Wedemeyer 1970). Certain protozoan parasites having direct life cycles (i.e. no intermediate host is required), can multiply to high numbers quickly, when water temperatures and flows are favorable (Noga 1996). Consequences of disease by any of the serious pathogens are lethargy, debilitation, weight loss, and mortality of the host fish.

The purpose of this section is to address the null-hypothesis; the September 2002 Klamath River fish-kill was not caused by disease. The alternative hypothesis is; the Klamath River fish-kill was caused by disease. To address these hypotheses, this section will review pathology reports prepared by DFG and USFWS on the fish-kill, and determine if disease was a major factor in the death of fish in the lower Klamath River during September 2002.

III. A. 2. Methods

On September 25, 2002, the DFG Fish Health Laboratory in Rancho Cordova was notified of a large fish-kill on the lower Klamath River, and was requested to investigate disease as a possible cause of mortality. Pathological evaluation of freshly dead and live Chinook, coho and steelhead (caught by anglers), was made on September 26 near Blake's Riffle (approximately RM 8) and September 27 near Blue Creek (RM 16). Standard necropsy procedures for evaluation of fish were followed (Thoesen 1994). Fish were observed externally for gross pathological lesions on the body surface, fins, gills and eyes. Samples were collected by Tresa Veek, DFG Associate Fish Pathologist. Tissue squash preparations were made from lesion areas of the skin and gills, on microscope slides using 22 mm^2 cover slips. Microscope slides were placed in ziplock plastic bags and stored on ice for approximately two hours prior to reading. Direct observations were made using phase contrast microscopy with a Nikon Labophot-2 compound microscope at 40x and 400x magnification. The microscope was set up at the Terwer launch site using electrical power supplied by an inverter connected to a car battery. Internal pathological lesions were recorded and squash preparations of intestinal lesions were examined as described above.

III. A. 3. Results

Concurrent investigations by DFG and USFWS, CA-NV Fish Health Center, were conducted and independent reports of the fish-kill prepared. The DFG and USFWS pathology reports are provided in Appendix A. At Blake's Riffle, heavy ich infestations of gill tissue were the predominant finding. Lesions typical of columnaris, were not seen, nor was the bacterium isolated. Intestinal lesions, typical of ceratomyxa, were not observed in any of twenty dead Chinook salmon, nor in any of four live specimens (one steelhead, two Chinook and one coho).

At Blue Creek, three freshly dead (two Chinook and one coho) and four moribund Chinook salmon were examined. Heavy ich infestations were observed in five of seven samples, and columnaris lesions and bacteria were present in seven of eight samples. Ceratomyxa was also noted in one moribund Chinook salmon of eight fish sampled. Motile protozoan parasites, such as ich, either leave fish hosts or degrade soon after death of the fish host. Only one Chinook salmon of three dead fish had ich, while four of four live Chinook were infested.

III. A. 4. Findings

The USFWS (2002), CA-NV Fish Health Center concluded: “Gross clinical signs of swollen gills containing ich and the high incidence of gill rot (columnaris) provide strong evidence that disease, induced by these two contagious pathogens, was the immediate cause of the fish-kill.” Fish examined by DFG’s Fish Health Laboratory on September 26 and 27, found ich and columnaris to be the principal causes of disease and death. Fish caught by anglers were primarily infected with ich. Moribund and fresh dead fish were heavily infected with both ich and columnaris. Fish dead for several hours or more were not examined for ich, because tissues were too degraded for analysis.

Fish entering the lower Klamath River in September 2002, encountered low-flows (in the lowest tenth percentile since 1951) and water temperatures between 65 °F and 74 °F. Temperatures in this range are stressful to coldwater fish species, and accelerate the life cycle of certain fish pathogens including ich and columnaris (Noga 1996, Post 1987). Flow and temperature data for the Klamath River will be addressed more completely in upcoming sections of this report.

Ich is one of the more prevalent diseases of fishes, is widespread (Post 1983) and is common throughout the world (USFWS 1974). It can be found on fish at any temperature, but typically causes disease and mortality at water temperatures above approximately 58 °F in salmonids. The high water temperatures and low-flows present at the time of the fish-kill, favored amplification of ich. The life cycle of the parasite is direct, with trophozoites residing on fish, cysts being formed on a substrate (which does not have to be a fish), and infective tomites leaving cysts to infect new fish (Johnson 1976). This life cycle is temperature dependent. At water temperatures of 69 °F, (encountered on the lower Klamath during the fish-kill) trophozoites will reside on fish for approximately five or six days. Mature trophozoites leave the fish and are free swimming for two to six hours. They then attach to a substrate, secrete a thin protective membrane over their body, and reproduce by multiple fission (producing up to 2,000 tomites per cyst). This process takes about 16 to 18 hours at 69 °F. Tomites then break from the cyst and swim to a new fish host. When densities of host organisms are high, the likelihood of tomites encountering a new host is also high. Those not finding a host within about 24 hours, will die. Successful tomites penetrate the skin and feed on host tissues, growing in size to adult trophozoites. Success in finding a new host is aided by low-flows and high fish density. Both conditions prevailed during late September 2002 on the lower Klamath River. Amplification of ich proceeds quickly at water temperatures present before and during the fish-kill, resulting in heavy parasite burdens on fish. When large numbers of tomites are being released, mortality can result from “super infections”. Dickerson and Dawe (1995) stated; “In early stages of infection large numbers of theronts (tomites) can actually kill a fish before the parasite becomes visible and death is caused by massive damage to the gill epithelia.”

Ich infestation of gill tissue results in epithelial and mucus cell hyperplasia (a proliferation in numbers of cells), which increases the distance between oxygen-carrying erythrocytes and oxygen-supplying water. When this is combined with lower oxygen content of warmer water, the ability of fish to obtain necessary oxygen is greatly impaired. Death is by asphyxiation. Skin infections by ich disrupt the integument, resulting in the loss of ions (Na^+, Mg^{++}) and causing osmoregulatory disturbances. Heavily infected fish have been observed to seek calmer water with low-flow (Traxler et al. 1998). This is probably due to lower levels of oxygen being supplied to muscle tissues, resulting in less energy available to swim in stronger currents.

Severe pre-spawning mortality, due to ich, was observed beginning in 1994 in sockeye salmon in the Babine River (Skeena River System), British Columbia (Traxler et al. 1998). Losses of 80% to 90% of adults occurred in spawning channels. High densities of fish were the primary contributing factor. In low-return years, fish returning into warmer water conditions did not experience significant losses. In high-return years, occasional losses were experienced even at cool temperatures (10 °C or 50 °F). This experience highlights the effects of fish density on ich infections. Similar losses have been observed in the Fraser River System in sockeye and Chinook salmon. Generally, the combination of warm water and high fish density were factors resulting in severe ich outbreaks (Higgins 2002, personal communication).

Columnaris bacteria are ubiquitous in the aquatic environment. Columnaris disease in coldwater fishes, is generally seen at water temperatures above 15 °C (59 °F), and disease can become explosive at 18 °C (64 °F) (Post 1987). In natural infections, disease is often chronic to subacute, affecting skin and gills. Columnaris lesions are commonly seen in Chinook salmon at some California hatcheries (Nimbus Hatchery on the American River, Feather River Hatchery, and Merced Hatchery on the Merced River), but pre-spawning mortality has not been a problem. During late July through early September of 2002 and 2003, spring Chinook salmon returning to Butte Creek (a tributary to the Sacramento River) became seriously diseased, resulting in mortality. Severe pre-spawning mortality was attributed to large numbers of fish concentrated in limited holding pools, high water temperatures, and an outbreak of two pathogens ich and columnaris (DFG 2004).

Fish examined by the DFG Fish Health Laboratory on September 26 and 27 and USFWS, CA-NV Fish Health Center, confirmed the ciliated protozoan ich and bacterial pathogen columnaris were the principal causes of disease and death in the fish-kill on the lower Klamath River in 2002. Consequently, DFG rejected the null-hypothesis that the September 2002 Klamath River fish-kill was not caused by disease and accepts the alternative hypothesis that the fish-kill was indeed, caused by disease. Past accounts of large adult fish-kills from ich and columnaris provide some insights into factors that create conditions favorable for an epizootic. Those factors include low-flow, warm water temperatures, restricted fish passage and high densities of fish. These potential factors can act individually or in concert to create stressful conditions for salmonids.

III. B. Toxic Substances;

III. B. 1. Introduction

An alternative hypothesis to disease being the cause of the 2002 Klamath River fish-kill has been that toxic substances were the primary cause. Major fish-kills, as a result of toxic substances, are a relatively infrequent occurrence in northern California. Chronic exposure and occasional heavy runoff, containing heavy metals in acid mine drainage from abandoned copper mines, have resulted in several fish-kills around Shasta Lake, Keswick Reservoir, and the Sacramento River below Keswick Dam (CDWR 1986b). Under these circumstances, juvenile fish were more susceptible to mortality than adult fish. Another example of a major fish-kill from toxic substances was the July 1991 spill of metam sodium into the upper Sacramento River above Shasta Lake. In this instance, the chemical contaminant was spilled from a derailed Southern Pacific Railroad tank-car. This spill resulted in indiscriminant loss of virtually all aquatic life in a forty-mile reach of the upper Sacramento River, over the course of two days. Losses of organisms included all life history stages and a broad taxonomic array of organisms from periphyton to invertebrates and fish.

The null-hypothesis that will be analyzed in this section is; toxic substances in the lower Klamath River were not a factor in the September 2002 Klamath River fish-kill. The alternate hypothesis is; toxic substances did result in the fish-kill.

III. B. 2. Methods

In order to investigate the potential that the September 2002 Klamath River fish-kill was related to a toxic substance, DFG reviewed results of water quality samples collected by the North Coast Regional Water Quality Control Board (NCRWQCB) (North Coast Laboratories 2002) shortly after the fish-kill, pathology reports (DFG 2002b, USFWS 2002), and evaluated the nature of the fish-kill. On September 26, 2002, the NCRWQCB collected water samples from five locations within the area of the fish-kill. Those sample locations were; Tectah Creek, Blue Creek, downstream of Blue Creek, Highway 101 Bridge, and Terwer. Analyses for nutrients and EPA scans 608, 619 and 547 were completed by North Coast Laboratories Ltd., and presented in an analytical report to the NCRWQCB on October 1, 2002. The EPA scans tested for a broad spectrum of pesticides including organochlorine pesticides and PCBs (EPA 608), triazine pesticides (EPA 619) and glyphosate (EPA 547).

III. B. 3. Results

No chemical contaminants were detected in the North Coast Laboratories Ltd. analysis of samples collected by the NCRWQCB on September 26, 2002, with the exception of glyphosate at the 101 Bridge. The laboratory control samples and matrix spike/matrix spike duplicate recoveries, however, were above the upper accepted limit for glyphosate, which indicated results might have been erroneously high.

DFG and USFWS pathology investigations concluded that the parasites ich and columnaris were the immediate cause of the fish-kill (DFG 2002b, USFWS 2002). These pathology reports did not specifically evaluate the presence of toxic substances in the fish carcasses, but did clearly identify ich and columnaris as the principal causes of disease and death.

III. B. 4. Findings

The fish-kill was generally confined to adult anadromous salmonids and was protracted in nature, occurring from September 18 to at least October 1, 2002. In DFG's experience of conducting fish-kill investigations caused by toxic substances in northern California, we have found when chemicals are present at acutely toxic levels, the loss of aquatic organisms is usually indiscriminant with respect to life-history stage and species. For example, the fish-kill on the upper Sacramento River, due to metam sodium in 1991, resulted in losses of periphyton, benthic macroinvertebrates, mollusks, crayfish, salamanders, juvenile and adult fish, and riparian vegetation. The fish-kill on the upper Sacramento River took place over a matter of days and recovery began almost immediately after the chemical dissipated. In the case of the Klamath River fish-kill, juvenile salmonids were observed alive, while adults were dying (Borok 2003, personal communication, USFWS 2003b). In other fish-kill investigations, where there is typically a chronic level of contaminant, the most susceptible life history stages for salmonids are fry and juveniles. Such is the case with acid mine drainage into Shasta Lake and Keswick Reservoir. This was not the case with respect to the Klamath River fish-kill, because juvenile fish were unaffected.

There is substantial overriding evidence that toxic substances did not cause the Klamath River fish-kill. Water quality sampling conducted by the NCRWQCB during the height of the fish-kill, was unable to detect toxic substances. Pathological investigations by DFG and USFWS concluded that ich and columnaris were the principal causes of disease and death. The fish-kill was generally confined to adult anadromous salmonids and was protracted in nature. If toxic substances had been present at acutely toxic levels, indiscriminate loss of all life history phases of fish, and other aquatic vertebrates and invertebrates would have occurred. If toxic substances had been present at chronic toxicity levels, then losses of juvenile fish would have been expected. Because of the overwhelming evidence that toxic substances were not present, fish loss was due to disease, and the nature of fish loss was inconsistent with the presence of toxic substances, DFG has accepted the null-hypothesis that toxic substances were not a factor in the September 2002 Klamath River fish-kill.

III. C. Flow;

III. C. 1. Introduction

Stream-flow is an integral component and contributor to the overall biophysical character and ecological health of streams and rivers. Structure and function of riverine systems are influenced by hydrology, geomorphology, water quality, biology, and connectivity (Instream Flow Council 2002). Riverine flow timing, magnitude, duration, and rate of change, directly influence channel abiotic structure, function, and dynamics (Leopold et al. 1964). Aquatic and riparian biotic components, in turn, respond to flow and channel conditions and dynamics. Altered natural flow regimes, can radically change riverine dynamics, species composition and richness, habitat diversity, habitat quality, and the natural template (Instream Flow Council 2002, Li and Li 1996, Sanford 1996). Water quality, temperature, and living space quality and quantity, are influenced by river flows.

The purpose of this section is to address the null-hypothesis; flow in the Klamath and Trinity rivers during 2002 were not out of the ordinary and should not have contributed to the fish-kill. The alternative hypothesis is; flows in 2002 were atypical and could have contributed to the fish-kill. To address these hypotheses, this section will characterize and evaluate flow conditions existing in the Klamath River and Trinity River, immediately before and during the 2002 fish-kill, compare those flow conditions to past years, and identify years during which river discharges were similar or less than those in 2002.

Another flow related concern was whether events in the fish-kill area would have been significantly different in 2002, if higher flows had been released from upstream sources. To address this concern, we must first address the null-hypothesis; there was no additional water available to increase flows in the lower Klamath River during September 2002. The alternative hypothesis was; there was additional water available to increase flows in the Klamath River during September 2002. To address these hypotheses, this section will compare actual 2002 flow conditions existing in the Klamath River, to unimpaired flows modeled by Hardy and Addley (2001). These competing hypotheses only address whether more flow could have been available in September 2002 and not if more flow would have created better conditions for downstream resources. Hypotheses related to the benefits or detriments of increased flows for fishery resources in the Klamath Basin during 2002, will be addressed in later sections of this report.

III. C. 2. Methods

Mean daily flow data for four gaging stations on the Klamath River from Iron Gate Dam downstream to Klamath, and for the Trinity River at Hoopa, were obtained from the U.S. Geological Survey (USGS) web page (www.usgs.gov). Gaging stations included:

Station Number	Station Name	Abbreviation	Period of Record Analyzed[1/]	River Mile
11516530	Klamath River Below Iron Gate Dam	KIG	1961 to present	190
11520500	Klamath River near Seiad Valley	KSV	1952 to present	129
11523000	Klamath River at Orleans	KAO	1951 to present	59
11530500	Klamath River near Klamath	KNK	1951 to present[2/]	6
11530000	Trinity River at Hoopa	TRH	1951 to present	12

1. Flow records for 2001 and 2002 are provisional and subject to change.
2. River flows for the near Klamath gage are missing for 1996 and 1997.

Average daily flow data for the Klamath River are relatively complete for the Iron Gate gage from 1961 to present, for the Seiad Valley gage from 1952 to present, for the Orleans gage from 1928 to present, for the Klamath gage from 1951 to present, and for the Trinity River at Hoopa gage from 1932 to present. Flow data from water year 2001 onward, are provisional and may be subject to change.

Average September flow was examined for the KIG gage from 1961 to 2002, and for the KNK, KAO, and KSV gages from 1951 to 2002. Average September flow for 2002 was provisional and does not reflect daily flows after September 26, 2002. After September 26, 2002, USBR directed Pacificorp to increase releases from Copco and Iron Gate reservoirs from 760 cfs to 1,300 cfs, in an effort to abate the fish-kill. This 540 cfs increase in flow at the end of September, would have introduced a positive bias and inflated the average September 2002 flow.

The KNK average September flow data was sorted and ranked to identify other low-flow years (1988, 1991, 1992, and 1994) that were either similar to, or less than, those occurring during the 2002 fish kill. Although flows reported for KNK were substantially higher in September 2001 than 2002, 2001 was actually a drier year and has been included in this analysis.

A similar sorting and ranking of the September flow data was performed for the KAO, KSV, KIG and the combined KAO+TRH gages. Analysis of KAO+TRH was conducted as a result of a USGS report evaluating the historic context of flow conditions in Klamath River (USGS 2003). In this report, USGS evaluated flow downstream of the confluence of the Klamath and Trinity rivers, by summing Trinity River flows at the TRH gage and Klamath River flows at the KOA gage. One of the report's authors indicated the KNK gage was omitted from analysis, because of the potential for inaccuracies in the data (i.e., greater than 15% error). Error bars on the data were much larger than for the vast majority of USGS gages (Lynch 2003, written communication). In addition, Lynch (2003) indicated the KNK gage was tidally influenced and resisted development of an accurate and stable rating curve. Thus, USGS considered summing flows, at the Orleans gage on the Klamath and near Hoopa on the Trinity, to be the best method to estimate river flows within the fish-kill area. As a result of the KAO+TRH ranking, 1981 was added to our low-flow years, because combined flows were below 2002. Finally, an analysis of daily flow data for the lower river was also made by comparing daily data from August 1 to October 15 of 2001 and 2002, for KNK and for KAO+TRH.

Average daily flows for USGS stations KIG, KSV, KAO, TRH, KAO+TRH and KNK, were plotted for August 1 through October 15 of 1973, 1981, 1988, 1991, 1992, 1994, 2001 and 2002, to evaluate day to day changes in flow during low-flow years.

III. C. 3. Results

The five years with lowest average September flows at KIG, were 1973, 1991, 1992, 1994, and 2002 (Table C1). September flows during these years fell in the lowest tenth percentile and were below the 90 % exceedence value for the period of record from 1961 to 2002 (Figure C1). The average monthly flow for September 2002 was 760 cfs, and ranked fourth lowest for the period of record (Table C1). The lowest average flow (538 cfs) occurred in September 1992 and was 29% lower than the September 2002 average flow. September flows in 1973 (725 cfs) and 1991 (749 cfs) were 5% and 1% lower than 2002, respectively. Average flow during September 2001 (1,026 cfs), was the eighth lowest flow year, and was near the 80% exceedence value (in the lowest twentieth percentile) for the period of record.

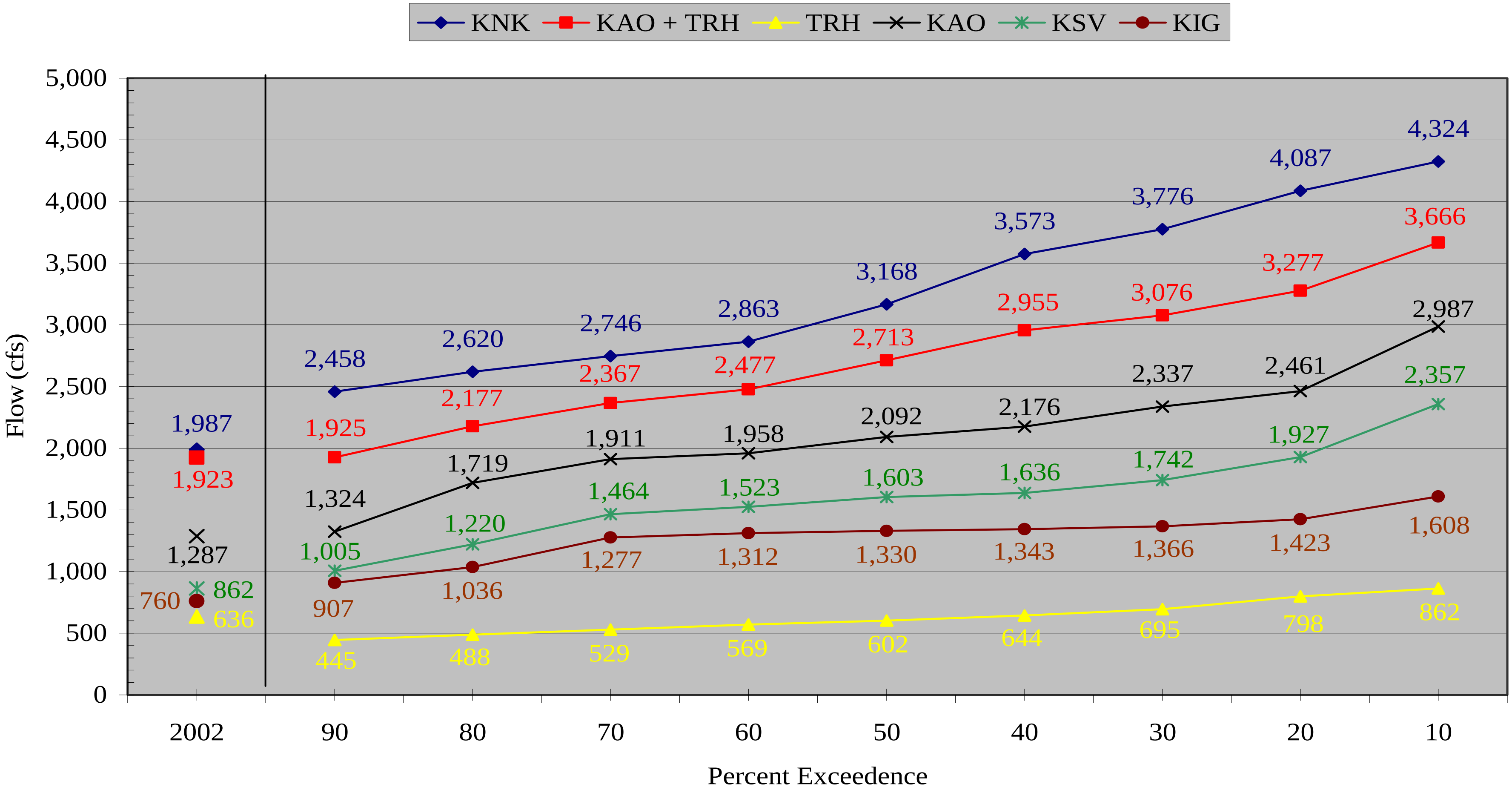
Six years fell in the lower tenth percentile for average September flows at KSV for the period of record from 1951 to 2002. These low-flow years were, 1973, 1981, 1991, 1992, 1994, and 2002 (Table C1). Average monthly flow at KSV for September 2002 was 862 cfs and was the third lowest flow for the period of record (Table C1). The lowest average flow occurred in 1992 (604 cfs) and was 30% lower than the September 2002 average flow. September flows in 1973 (915 cfs), 1981 (995 cfs), 1991 (849 cfs), and 1994 (1,005 cfs), ranged from 2% lower in 1991 to 17% higher in 1994 than in 2002. The average flow in September 2001 (1,070 cfs), ranked as the seventh lowest year (Table C1), was 24% higher than 2002, and fell between the 80% and 90% exceedence values for the period of record (Figure C1).

The average monthly flow at KAO for September 2002 was 1,287 cfs, and ranked as the fourth lowest year for the period of record (Table C1). Six years fell into the lowest tenth percentile and included, 1981, 1991, 1992, 1994, 2001, and 2002 (Table C1). These years were below the 90 % exceedence value for the period of record from 1951 to 2002 (Figure C1). September 1992 had the lowest average flow (790 cfs) and was 39% lower than September 2002. Average September flows in 1981, 1991, 1994, and 2001, ranged from 1,204 cfs in 1991 to 1,311 cfs in 1981. KAO flows in 1991 were 6% less than September 2002, while 1981 flows were 2% greater than in 2002. September 2001 was inconsistent with other Klamath gages with a flow of 1,224 cfs, and falling in the lower tenth percentile for the period of record from 1951 to 2002. This is the only individual Klamath gaging station where data for 2001 showed lower average September flows than in 2002 (Table C1).

Table C1. Ten lowest average September flow years sorted by Klamath River gaging station. * = Flow falls in the lowest tenth percentile for the period of record (1951-2002 for KNK, KAO, KSV, TRH and TRH+KAO and 1961-2002 for KIG). 2002 data is in bold-red and 2001 is in bold-blue.

Klamath River below Iron Gate Dam (KIG)		Klamath River near Seiad Valley (KSV)		Klamath River at Orleans (KAO)		Trinity River at Hoopa (TRH)		Klamath River near Klamath (KNK)		KAO+TRH		TRH flow corrisponding to TRH+KAO years	
Year	Flow (cfs)	Year	Flow (cfs)	Year	Flow (cfs)	Year	Flow (cfs)	Year	Flow (cfs)	Year	Flow (cfs)	Year	Flow (cfs)
1992	538*	1992	604*	1992	790*	1969	336*	1991	1977*	1992	1489*	1992	699
1973	725*	1991	849*	1991	1204*	1967	399*	**2002**	**1987***	1991	1771*	1991	567
1991	748*	**2002**	**862***	**2001**	**1224***	1964	408*	1994	1990*	**2001**	**1857***	**2001**	**633**
2002	**760***	1973	915*	**2002**	**1287***	1987	445*	1992	2007*	1994	1894*	1994	593
1994	906*	1981	994*	1994	1301*	1970	449	1988	2103*	1981	1918*	1981	608
1981	916	1994	1004*	1981	1311*	1951	467	1968	2,523	**2002**	**1923***	**2002**	**636**
1977	1,014	**2001**	**1,070**	1968	1,438	1962	477	1973	2,538	1968	1,938	1968	500
2001	**1,026**	1988	1,143	1987	1,516	1988	483	1964	2,544	1987	1,961	1987	445*
1997	1,035	1977	1,159	1973	1,542	1966	487	**2001**	**2,601**	1988	2,026	1988	483
1988	1,038	1968	1,199	1988	1,543	1965	491	1987	2,625	1973	2,147	1973	605
Avg. for Period Record	1,279	Avg. for Period Record	1,624	Avg. for Period Record	2,136	Avg. for Period Record	639	Avg. for Period Record	3,338	Avg. for Period Record	2,774	Avg. for Period Record	639

Figure C1. Average September flow values corresponding to the percentage of years those average flows are exceeded for selected Klamath and Trinity River stations during the period of 1951 - 2002. Note that Iron Gate period of record is 1961 - 2002.



The lowest flow years on the Trinity River do not correspond to the lowest flow years identified on the Klamath River (Table C1). The average monthly flow at TRH for September 2002 was 636 cfs, and does not fall in the lowest ten years for flows since 1951 (Table C1). Four years fell into the lowest tenth percentile and included, 1964, 1967, 1969, and 1987 (Table C1). These years were below the 90 % exceedence value for the period of record from 1951 to 2002. Average September flows in 1964, 1967, 1969, and 1987, ranged from 336 cfs in 1969 to 445 cfs in 1987. TRH flows in September 2002 (636 cfs) were nearly equal to the long-term September average of 639 cfs since 1951 (Table C1). The September 2002 flow falls between the 40% and 50% exceedence values for TRH data, indicating that over 50% of the years have had lower flows at TRH between 1951 and 2002. The September 2001 flow was 633 cfs and also falls between the 40% and 50% exceedence values for TRH.

Flows at KNK averaged 1,987 cfs for September 2002 and ranked as the second lowest average flow for September from 1951 to 2002 (Table C1). Years where average September flows fell in the lowest tenth percentile for the period of record included, 1988, 1991, 1992, 1994, and 2002. These years were below the 90 % exceedence value for the period of record from 1951 to 2002 (Figure C1). Of the five lowest flow years, average September flows ranged from 1,977 cfs in 1991 to 2,103 cfs in 1988. Flows in 1991 were 0.5% lower than in 2002, while 1988 flows were about 6% higher than 2002. The average flow in September 2001 (2,601 cfs), represented an estimate rather than actual gage measurements (USGS data at www.usgs.gov) and fell outside of the lowest tenth percentile of flows at KNK. Estimated September flows in 2001 at KNK were 31% higher than in 2002, ranked as the ninth lowest flow year (Table C1), and were near the 80% exceedence value (in the lowest twentieth percentile) for the period of record from 1951 to 2002.

When combining flows at KAO and TRH to represent conditions in the fish-kill area as recommended by USGS (2003), six years (1981, 1991, 1992, 1994, 2001 and 2002) fell into the lowest tenth percentile for average September flows (Table C1). These years were below the 90 % exceedence value for flows during the period of record from 1951 to 2002 (Figure C1). The combined average monthly flow for KAO+TRH for September 2002 was 1,923 cfs and ranked sixth lowest for the period from 1951 to 2002 (Table C1). The lowest year was 1992 (1,489 cfs) and was 23% lower than 2002. Flows in 2001 fell within the lowest tenth percentile and ranked third lowest with an average September flow of 1,857 cfs, which was 3% lower than 2002. The lower percentile ranking of flows in September 2001 was due to Klamath flows at the KAO gage and not Trinity flows. KAO was the only individual Klamath gaging station where data for 2001, showed lower average September flows than in 2002, and fell within the lowest tenth percentile for the period of record from 1951 to 2002 (Table C1). September 2001 flow at TRH (633 cfs) was near the long-term average of 639 cfs for 1951-2002, and fell between the 40% and 50% exceedence values for TRH data.

Analysis of average September flows for the period of record (1961-2002 for KIG and 1951-2002 for KSV, KAO and KNK) at various Klamath River gaging stations, showed eight years that fell in the lowest tenth percentile at one or more stations (Table C1). DFG designated these as low-flow years for further analysis. Average September flows in 1991, 1992, 1994 and 2002 consistently ranked in the lowest tenth percentile at each Klamath River gage location (Table C1). Average flows for September 1973 were in the lowest tenth percentile at KIG and KSV, and 1981 flows were in the lowest tenth percentile at KSV and KAO. September flows only occurred in the lowest tenth percentile for 1988 at KNK and for 2001 at KAO.

September flows during low-flow year's increase as the Klamath River moves downstream from KIG to KNK (Table C2). The lowest accretion rate occurs between KIG and KSV. A more substantial level of accretion takes place between KSV and KAO. The years of 1992 and 2001 were unusual, because the increase in flow between KSV and KAO was much lower compared to other low-flow years (Table C2). The most notable increase in flow occurred between KAO and the lower river, due to a fairly consistent contribution from the Trinity River. Trinity contributions during low-flow years were usually around 600 cfs, and ranged from 483 cfs in 1988 to 699 cfs in 1992 (Table C2).

Low-flow years were compared between stations to identify differences between using KNK data versus TRH+KAO data to characterize flow in the fish-kill area (Table C2). USGS (2003) did not use KNK data, due to concerns with accuracy of the gage in 2001 and 2002. The years of 1981 and 2001 showed the greatest discrepancies between use of KNK versus TRH+KAO data to characterize flow in the fish-kill area, followed by 1992, 1973, and 1991. Flows in 1988, 1994, and 2002, compared more closely using the two separate estimates and showed a difference of less than 10% (Table C2).

Mean daily flow data, from August 1 to October 15, 2001 for KNK, indicated flow in the lower river remained above 2,500 cfs throughout August and September (Figure C2). In 2002, flow began dropping in mid-August to approximately 2,000 cfs, and remained at that level until flow releases were increased at Iron Gate Dam to abate the fish-kill in late September. A similar comparison of combined KAO+TRH flows, indicated flow in the lower river, through the fish-kill reach, was slightly lower in 2001 than in 2002 (Figure C3). Until August 15, 2002, reported flows at KNK were approximately 500 cfs greater than the combined KAO+TRH gages (Figure C4). After August 15, 2002, KNK flow dropped off until it approximated the combined KAO+TRH gages around September 1. KNK and combined KAO+TRH flows then coincide until flow was increased in late September (Figure C4).

Average daily flows for USGS stations, KIG, KSV, KAO, TRH, KAO+TRH, and KNK, for August 1 through October 15 of 1973, 1981,1988, 1991, 1992, 1994, 2001, and 2002, showed day-to-day changes in flow for low-flow years (Figures C5–C10). KIG showed the least day-to-day changes in flow, with occasional sharp increases or decreases representing flow schedule changes at Iron Gate Dam (Figure C5). Notable increases in flow were evident at KIG for the first four days in September 1981, early August 1988, mid-August and late September 1991, mid and late September 1992, late September and early August 2001, and late September 2002. A two-week increase in flow of about 600 cfs to abate the fish-kill was clearly evident starting September 27, 2002 and ending in early October (Figure C5). The fish-kill was first reported on September 19, 2002. Flows were not increased at KIG until ten days after the first reports of dead fish, and did not fully reach the fish-kill area until October 1, 2002 (Figure C10).

Table C2. Comparison of average September flows for low-flow years at various Klamath River and Trinty River Stations with means, maximums and minimums for the period of record of 1951-2002 at all stations except KIG. KIG period of record is 1961-2002.

Year	Klamath River below Iron Gate Dam (KIG)	Klamath River near Seiad Valley (KSV)	Klamath River at Orleans (KAO)	Trinity River at Hoopa (TRH)	Trinity River + Klamath River (KAO + TRH)	Klamath River near Klamath (KNK)	Percent Difference KNK to KAO + TRH
1973	725	915	1,542	605	2,147	2,538	15
1981	916	995	1,311	608	1,919	2,732	30
1988	1,038	1,143	1,543	483	2,026	2,103	4
1991	749	849	1,204	567	1,771	1,976	10
1992	538	604	790	699	1,489	2,007	26
1994	906	1,005	1,301	593	1,894	1,990	5
2001	1,026	1,070	1,224	633	1,857	2,601	29
2002	760	862	1,287	636	1,923	2,129	10
Mean	1,279	1,624	2,136	639	2,774	3,338	
Maximum	2,052	2,861	3,807	1,308	4,750	5,923	
Minimum	538	604	790	336	1,489	1,976	

Table C3. Comparison of average September flow exceedence values (cfs) for modeled unimpared flows from Hardy and Addley 2001 with actual average September flows for the Klamath River below Iron Gate Dam, near Seiad Valley and at Orleans.

Percent Exceedence	Klamath River below Iron Gate Dam (KIG) 1961 - 2002	KIG Unimpaired Flows, Hardy and Addley 2001 1974 - 1997	Klamath River near Seiad Valley (KSV) 1952 - 2002	KSV Unimpaired Flows, Hardy and Addley 2001 1974 - 1997	Klamath River at Orleans (KAO) 1951 - 2002	KAO Unimpaired Flows, Hardy and Addley 2001 1974 - 1997
10	1,608	2,076	2,357	2,470	2,987	3,228
20	1,423	1,843	1,927	2,323	2,461	2,909
30	1,366	1,813	1,742	2,079	2,337	2,757
40	1,343	1,754	1,636	1,995	2,176	2,423
50	1,330	1,502	1,603	1,677	2,092	2,206
60	1,312	1,377	1,523	1,512	1,958	2,084
70	1,277	1,295	1,464	1,454	1,911	1,839
80	1,036	1,174	1,220	1,274	1,719	1,652
90	907	1,021	1,005	1,092	1,324	1,403

Figure C2. Mean daily flows for the Klamath River near Klamath gage (KNK) for the period from August 1 to October 15, 2001 and 2002.

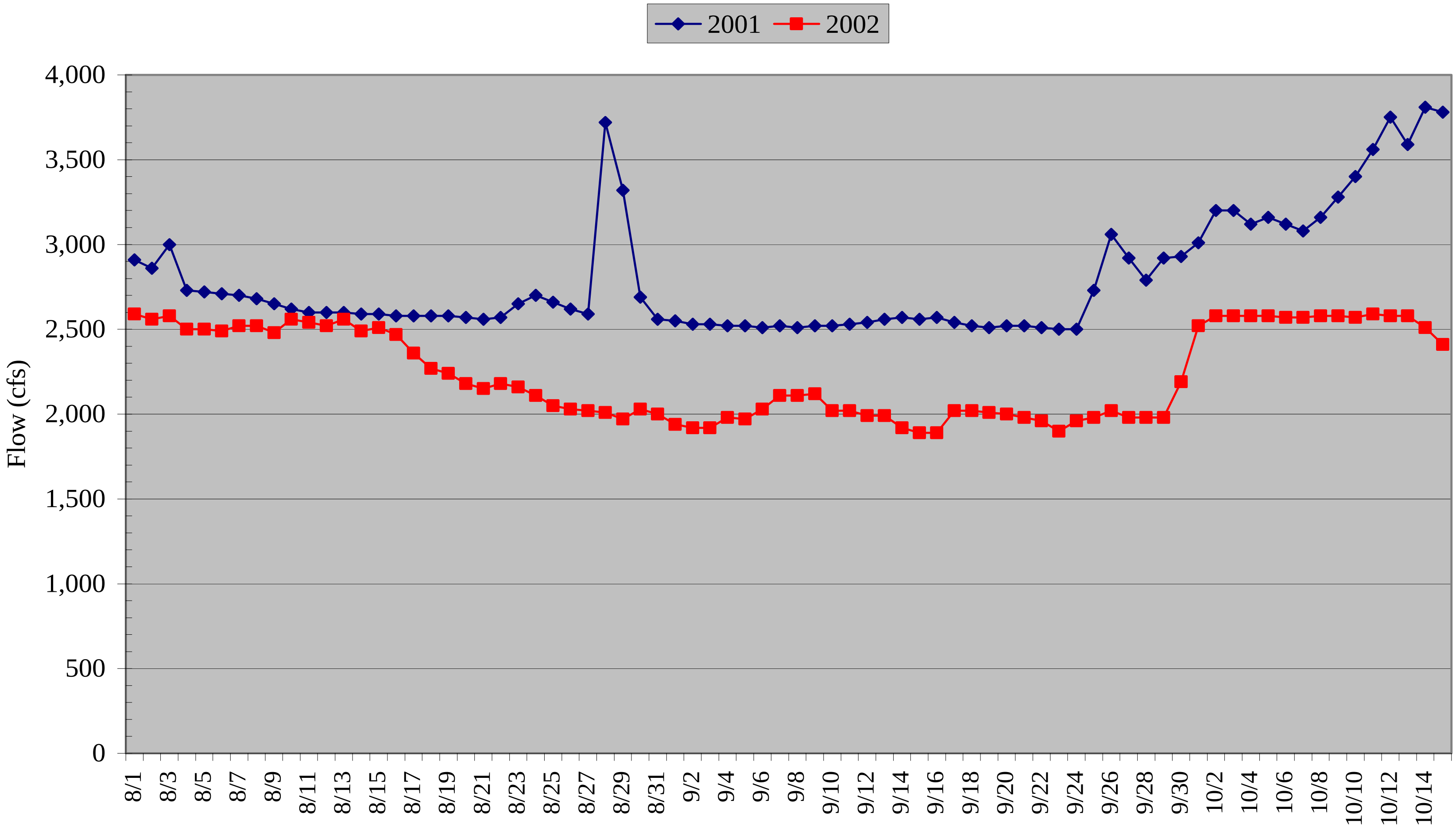


Figure C3. Mean daily flows for the Klamath River at Orleans plus Trinity River at Hoopa gages (KAO+TRH) for the period from August 1 to October 15, 2001 and 2002.

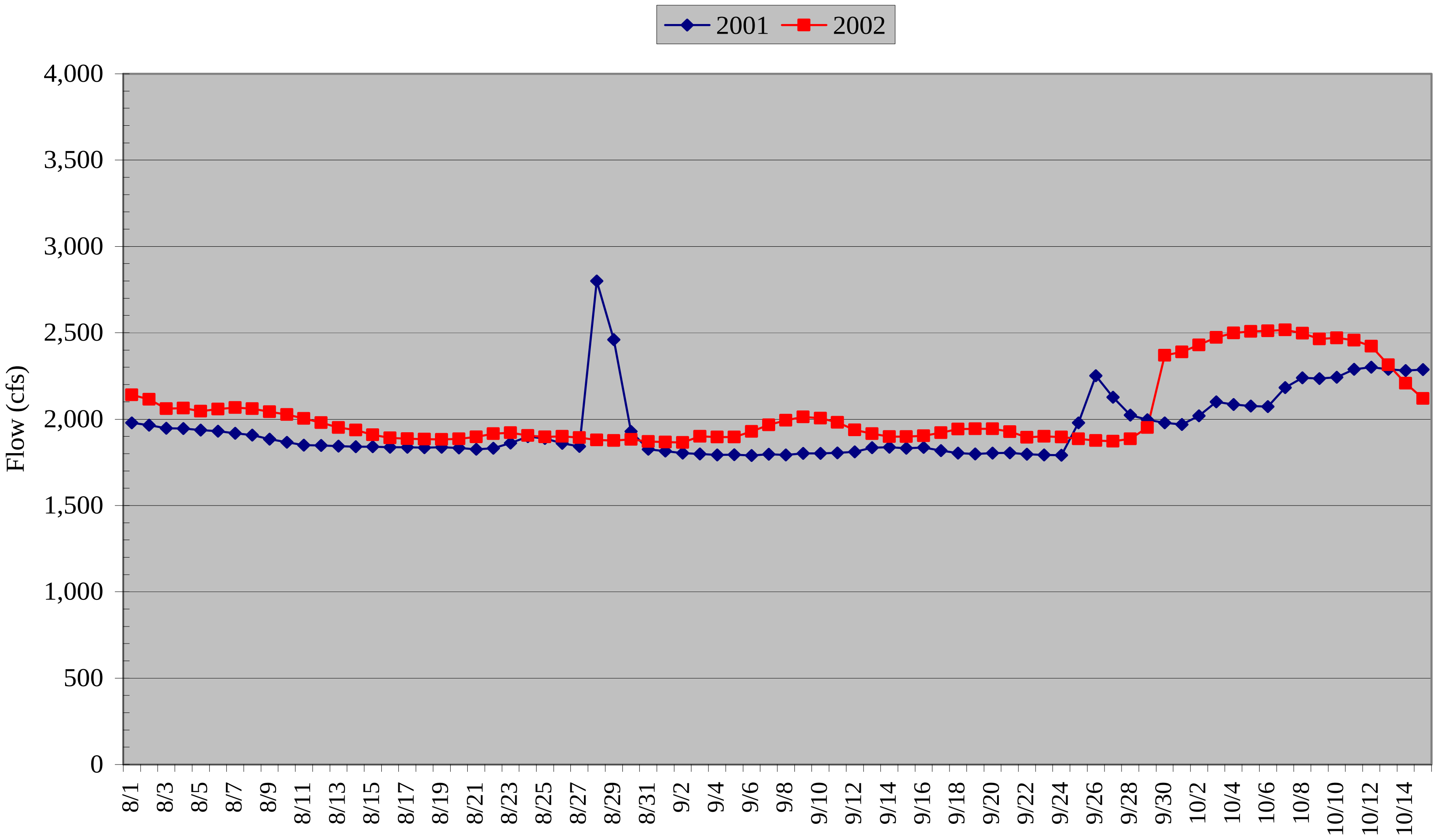


Figure C4. Mean daily flows for the Klamath River near Klamath gage (KNK) vs. the Klamath River at Orleans plus Trinity River at Hoopa gages (KAO+TRH) for the period from August 1 to October 15, 2002.

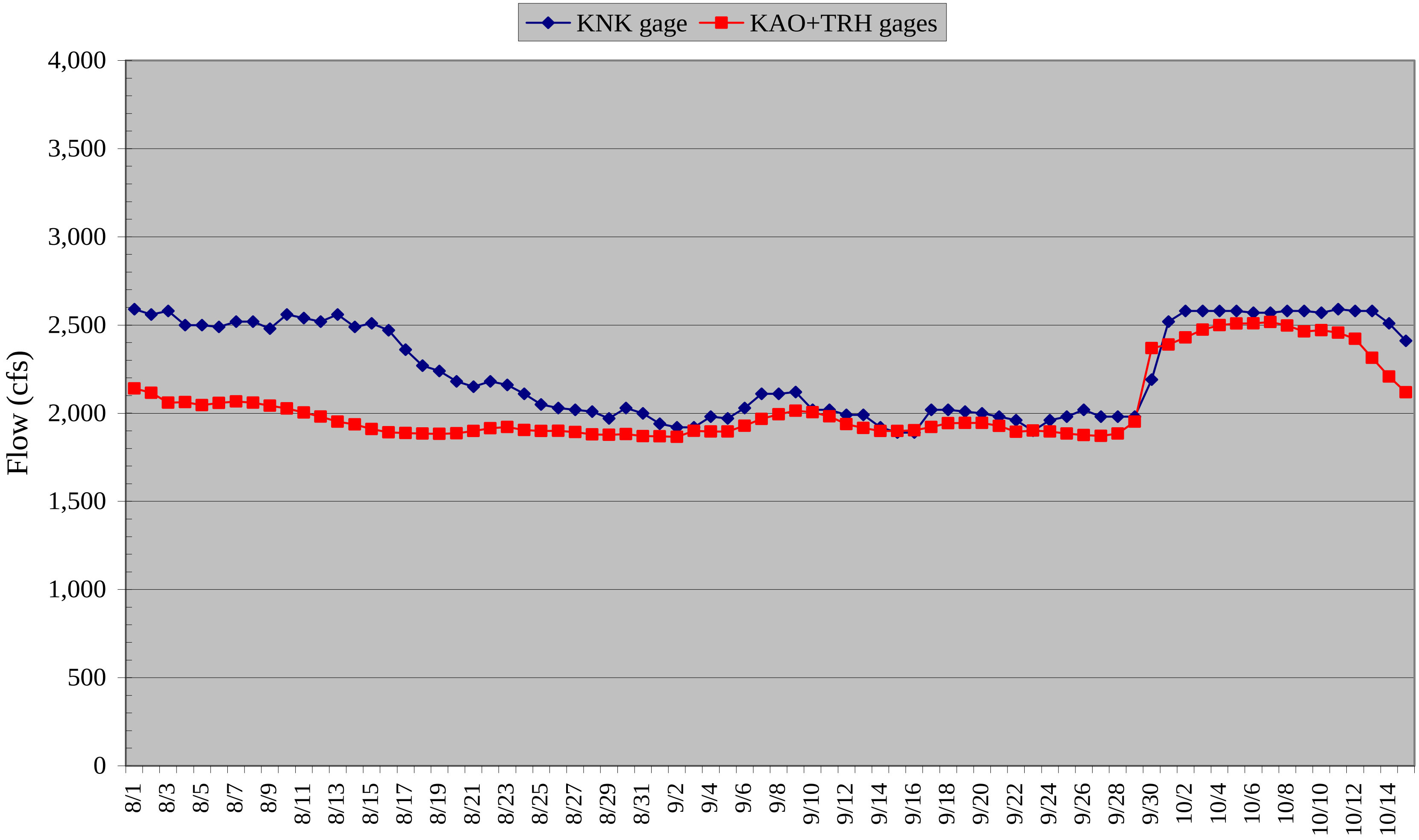


Figure C5. Mean daily flows for the Klamath River below Iron Gate Dam from August 1 to October 15 for low-flow years.

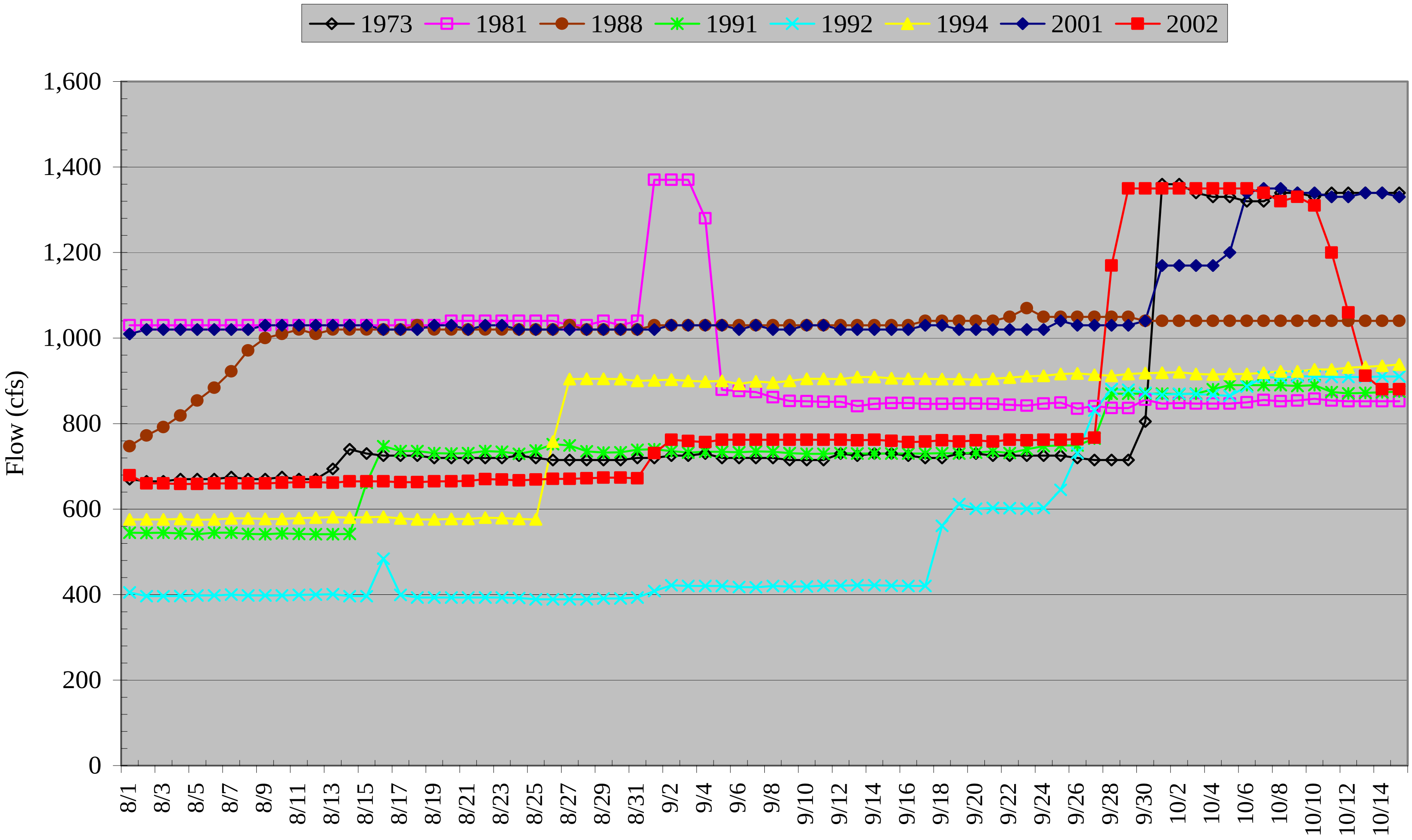


Figure C6. Mean daily flows for the Klamath River near Seiad Valley from August 1 to October 15 for low-flow years.

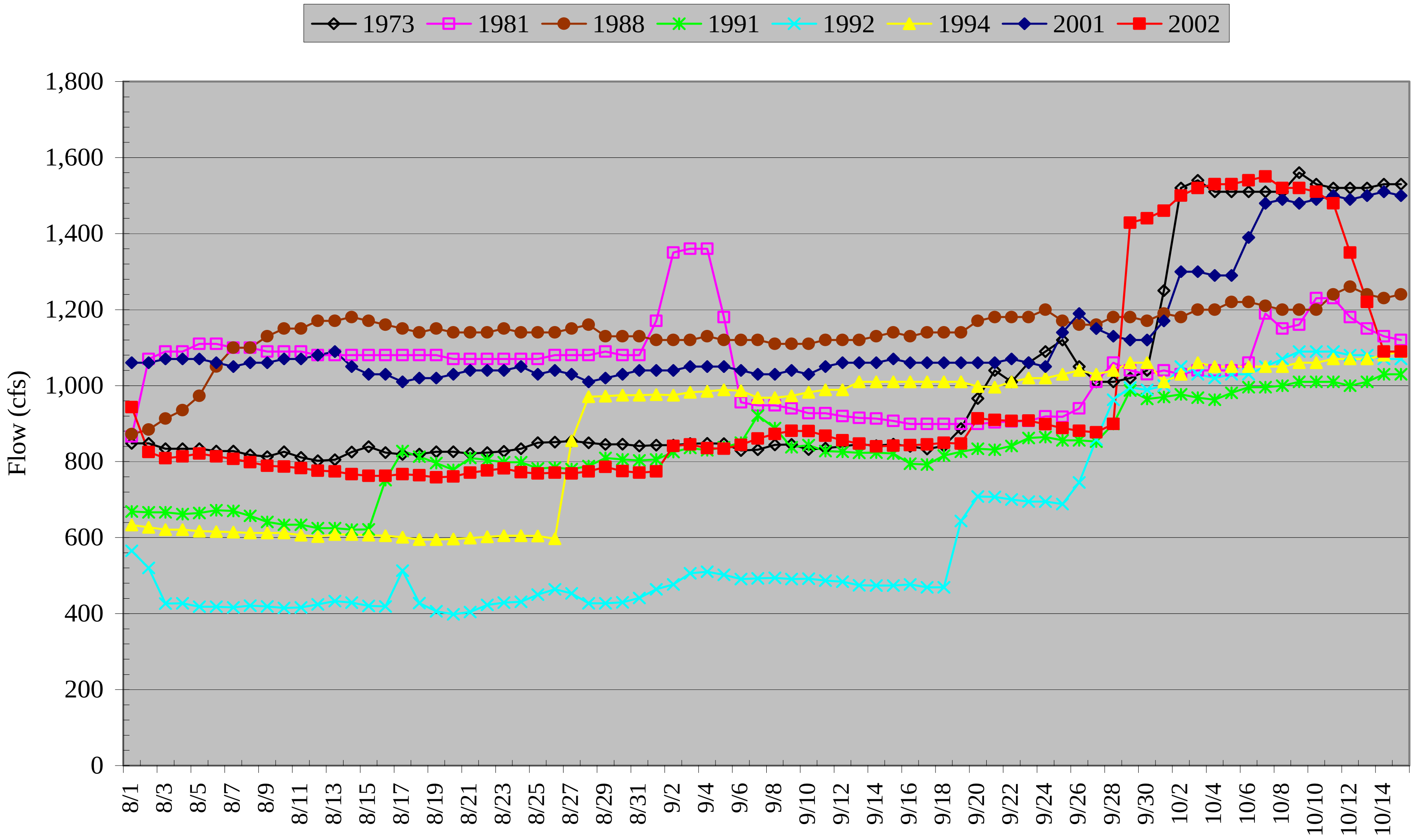


Figure C7. Mean daily flows for the Klamath River at Orleans from August 1 to October 15 for low-flow years.

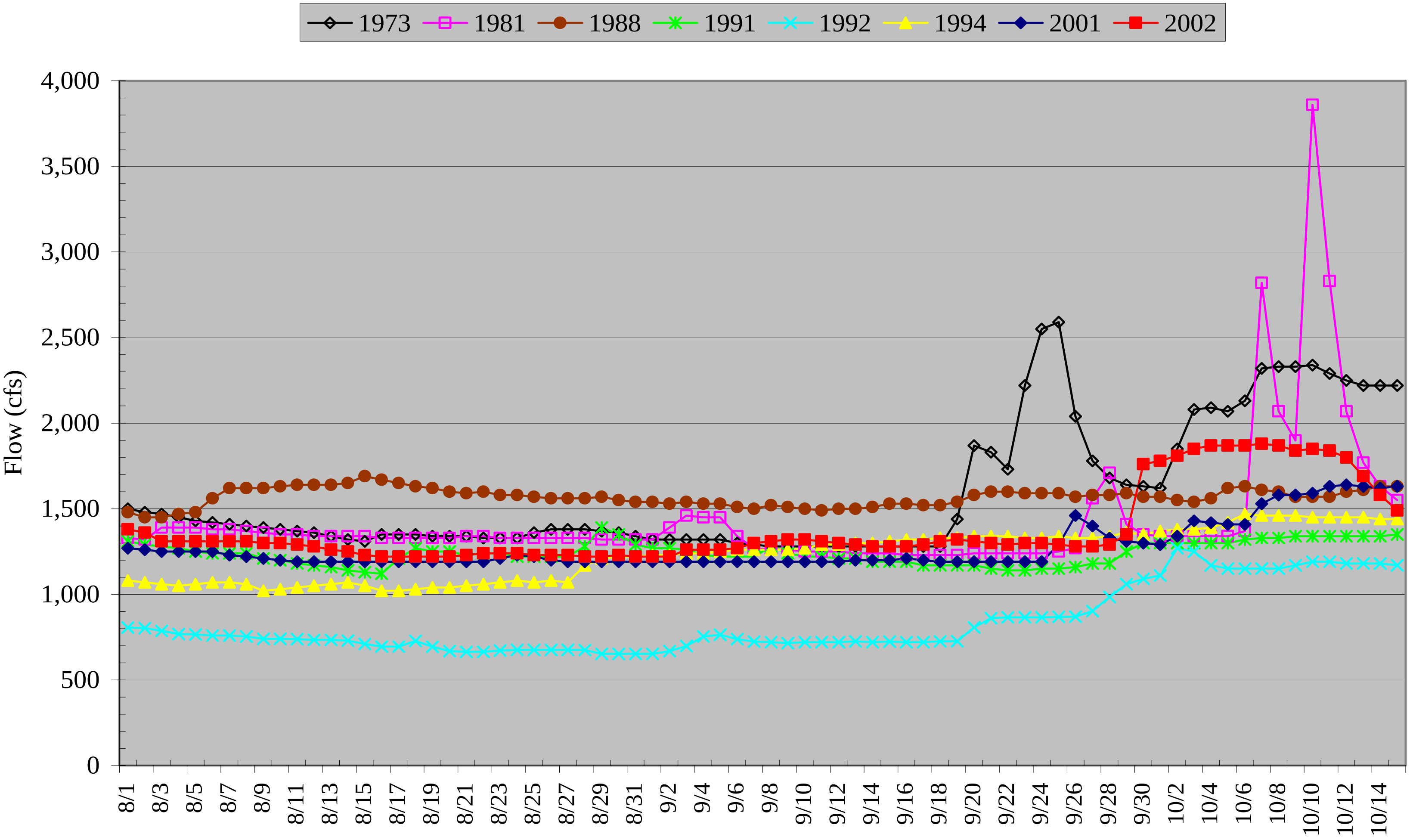


Figure C8. Mean daily flows for the Trinity River at Hoopa from August 1 to October 15 for low-flow years identified on the Klamath River.

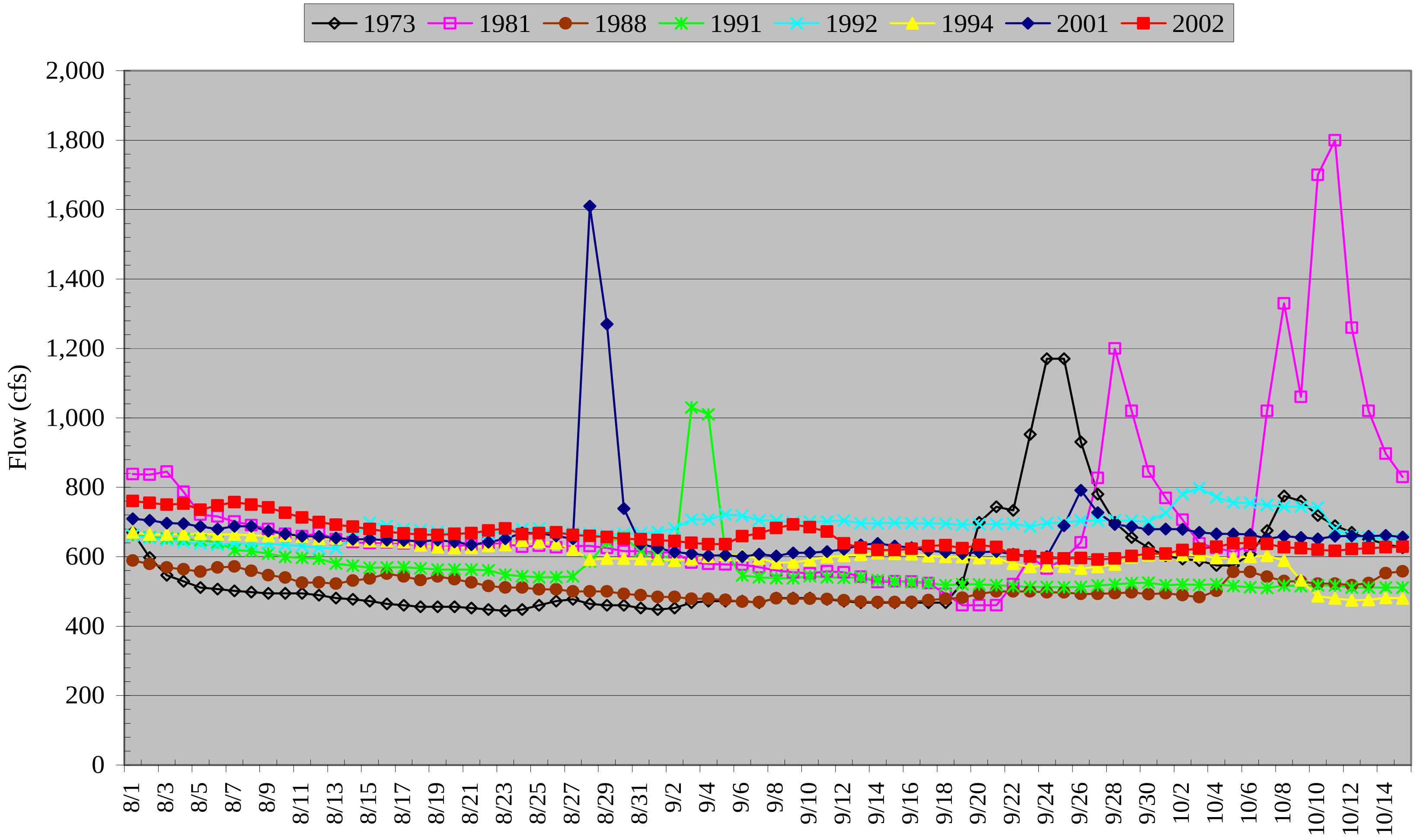


Figure C9. Combined mean daily flows for the Klamath River at Orleans and the Trinity River at Hoopa from August 1 to October 15 for low-flow years.

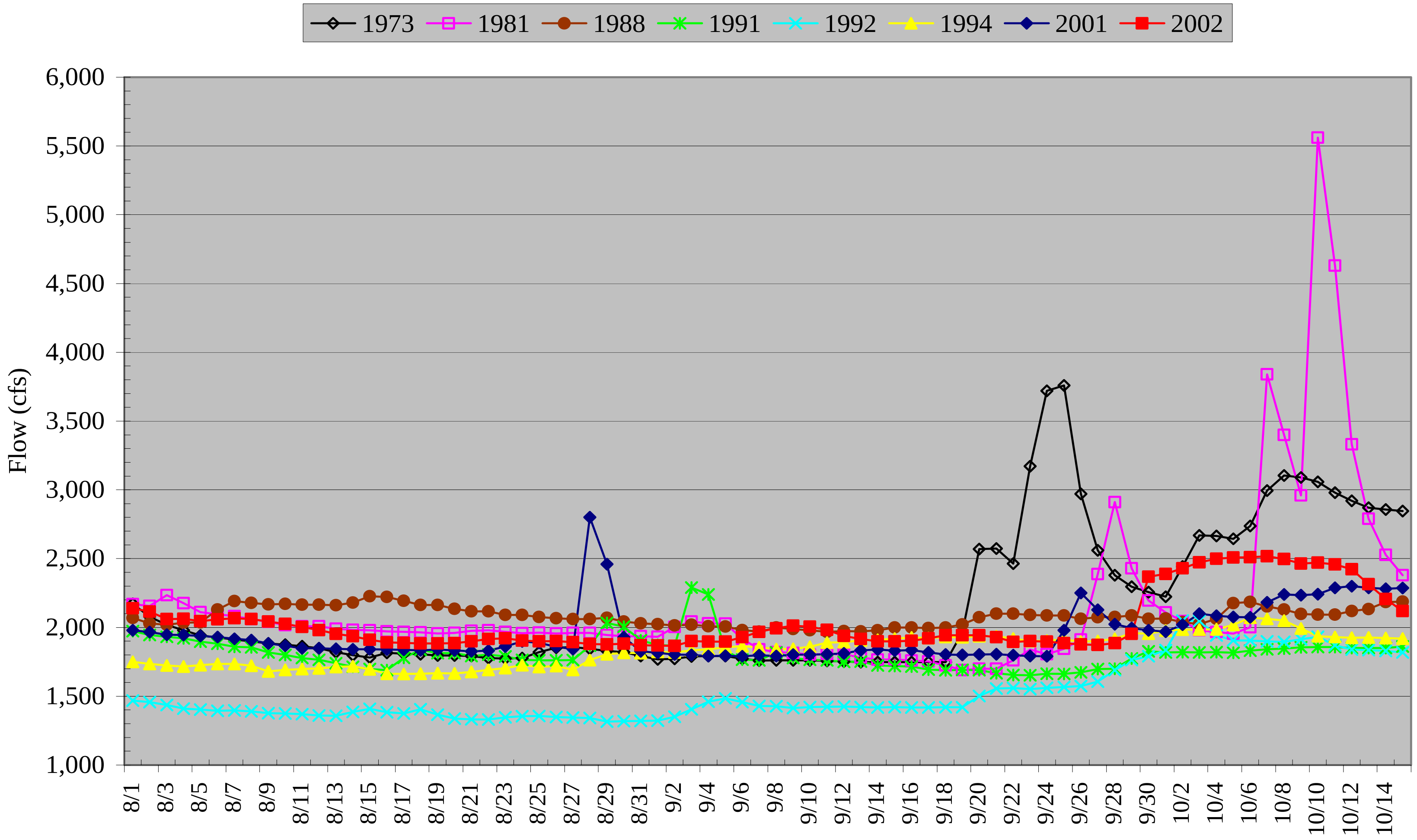
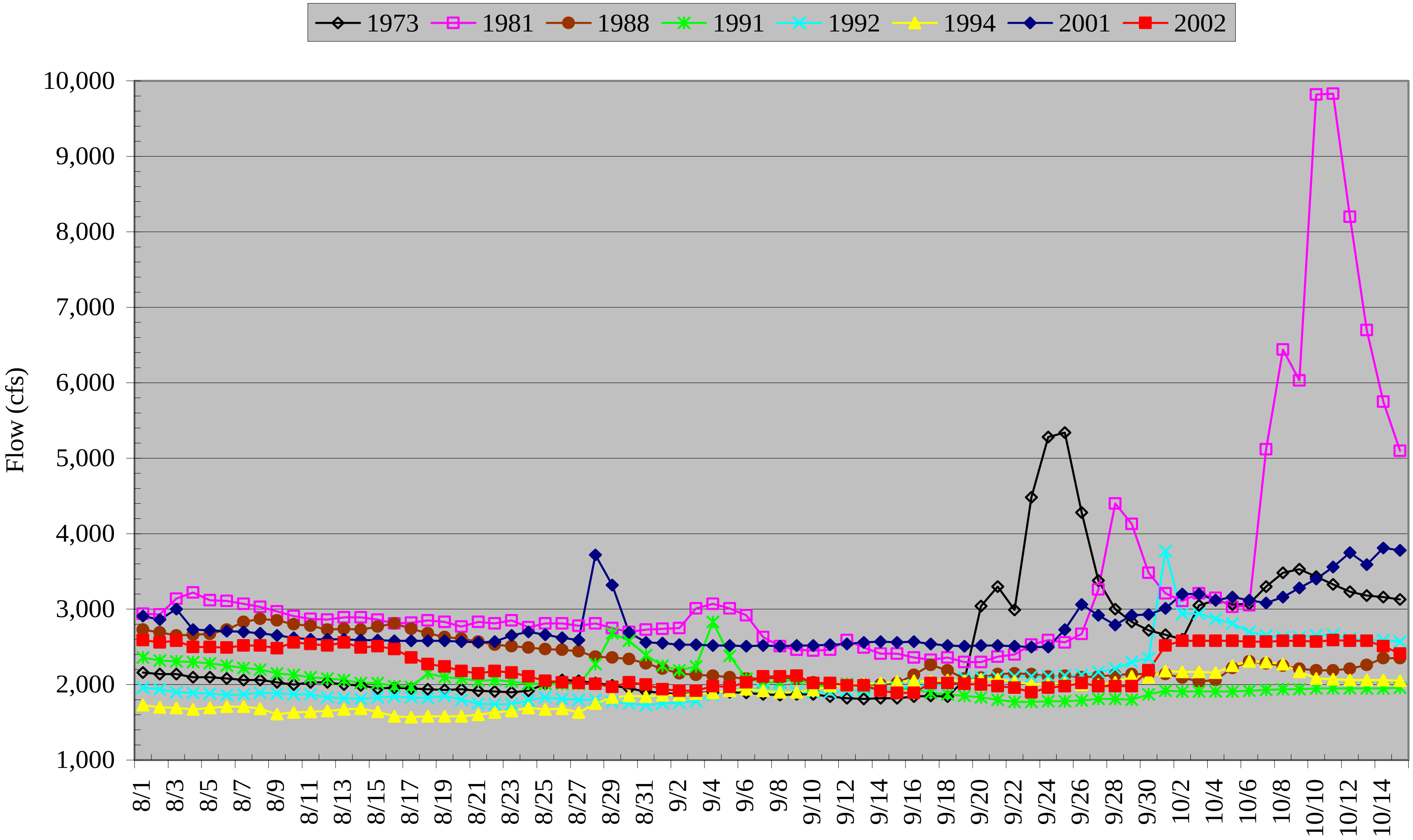


Figure C10. Mean daily flows for the Klamath River near Klamath from August 1 to October 15 for low-flow years.



As the river moves downstream to KSV (Figure C6) and KAO (Figure C7), changes in flows at KIG were evident, but subtle day-to-day variations in flow also occurred due to tributary inflows. Notable increases in flow were evident in late September 1973 and early October 1981 at KAO (Figure C7). These increases may have represented early storm events.

Daily TRH flows were quite consistent, and usually ranged between 500 and 800 cfs, from August to mid October (Figure C8). However, increased flows were evident in late September 1973, late September and early August 1981, early September 1991 and late August 2001. Flow increases in late September and October of 1973 and 1981 at TRH, probably reflected early storm events, because they were also apparent at KAO (Figure C7). Flow spikes in September 1991 and August 2001, are not apparent at KAO and likely represented upstream releases at Trinity and Lewiston dams for the Hoopa Tribe Boat Dance. All four increases in flow at TRH were evident in the Klamath River below the confluence with the Trinity River (Figures C9 and C10).

Unimpaired flows modeled by Hardy and Addley (2001), for the period of 1974 to 1997, at various percent exceedence values, were always higher than the actual flow exceedence values at KIG (1961-2002), KSV (1952-2002) and KAO (1951-2002) (Table C3). Unimpaired flows at KIG ranged from nearly 470 cfs higher at a ten percent exceedence level, to 114 cfs higher at a 90% exceedence value, when compared with actual flows (Table C3). The average flow release at KIG in September 2002 was 760 cfs. This flow was nearly 150 cfs less than the actual 90% exceedence value for the period of 1961 to 2002, and 312 cfs less than the modeled unimpaired 90% exceedence value for the period of 1974 to 1997.

III. C. 4. Findings

Average flow from September 1 to September 26, 2002, consistently fell within the lowest tenth percentile and ranked between the second and sixth lowest flows for all USGS gaging stations on the Klamath River downstream from Iron Gate Dam. September 2002 flows were consistently lower than the 90% exceedence values for these same gaging stations. Higher September flows have occurred in over 90% of years over the past half-century, than occurred in 2002 at all lower Klamath River gaging stations. These results compared favorably with USGS (2003), in which they concluded, September 2002 stream-flows in the Klamath Basin were low, and in most cases, were among the four lowest for the period of record since 1960. Average September flows for 1992 were the lowest for the period of record at all the Klamath River stations, except KNK. At KNK, the 1992 flow was the forth lowest, but only 30 cfs or about 1.5% higher than the lowest reported flow of 1,977 cfs in 1991.

Each Klamath River gaging station, showed three to five years in which the lowest average September flows were between 6% and 8% of the lowest flow. Since flow record accuracy at these gaging stations ranged from less than 5% to >15% (USGS 2003), these low-flow years were essentially the same for comparative purposes.

Average September flow records for KIG were lower in 1973, 1991, and 1992 than those observed in 2002. KIG records showed in 93% of the years since 1961, flow releases from Iron Gate Dam were higher than flows during the September 2002 fish-kill.

Although KNK data showed similar average flows in 1988, 1991, 1992, and 1994 compared to September 2002 (2002 data is provisional), these low-flows occurred in only 10% of years for the period of record since 1951. These low-flow years mostly coincided with the prolonged drought of the early 1990's. In 98% of the years since 1951, average September flows were higher at KNK than during 2002. Prior to 1988, average September flows never approached the low levels observed during 2002.

A comparison of September flow conditions in the Klamath River below the confluence of the Trinity River between 2001 and 2002 is important, because 2001 had a larger run of salmon than 2002, and a fish-kill did not occur. When flow data from KNK were used to represent flow in the river throughout the fish-kill reach, river flow was about 600 cfs greater in September 2001 than in 2002. This suggests there was more flow in the river for the greater number of fish in 2001. When combining KAO with TRH data to represent flow in the river throughout the fish-kill reach, river flow was slightly greater in September 2002 than in 2001. This suggests there was slightly less flow in the river supporting a larger run of fish in 2001.

In further analysis, DFG compared average September flows from KNK to the combined flows of KAO+TRH for low-flow years of 1973, 1981, 1988, 1991, 1992, 1994, 2001, and 2002. In five of these years (1973, 1988, 1991, 1994 and 2002), KAO+TRH flow was within 15% of the flow reported at KNK. For the other three years (1981, 1992 and 2001), reported flows at KNK were 26% to 30% greater than KAO+TRH. Since average September TRH flows were very similar in these three years (608 cfs in 1981, 699 cfs in 1992, and 633 cfs in 2001), major differences in flows must be attributed to differences at KAO.

USGS (2003) did not use KNK data for 2001 and 2002 in their analyses because accuracy was considered "poor". They instead used combined flows from KAO+TRH to characterize flows in the fish-kill area. The KAO+TRH data showed average flows in 1981, 1991, 1992, 1994, and 2001 that were less than September 2002. These low-flow years, including 2002, all fell in the lowest tenth percentile for the period of record since 1951. Notable in the KAO+TRH data, was that 2001 fell in the lowest tenth percentile for September flows, but did not at KIG, KSV or KNK.

The decision, by USGS (2003), to discard KNK data in 2001 and 2002, may be well founded due to potential inaccuracies at the gaging station, particularly for 2001 when flows were estimated. However, DFG would question whether addition of flows from two gaging stations, one with a less than 10% margin of error (KAO) plus one with a less than 5% margin of error (TRH) and both being over 50 miles above KNK, were more accurate than a single gage with a 15% margin of error (KNK). Using either method raises concerns with the accuracy of flow estimates in the fish-kill area.

KAO represents the only individual Klamath station, where 2001 fell into the lowest tenth percentile for average September flows since 1951. Average flow in September 2001, ranked as the third lowest flow year at KAO. At other Klamath River gaging stations, 2001 ranked between the seventh and ninth lowest average September flows and never fell in the lowest tenth percentile for the period of record.

Comparing KAO with the next gaging station up-river (KSV), showed a difference of 154 cfs of accretions to the river between the two sites during September 2001. This low accretion rate for September 2001 seems reasonable, because the combined inflow was only 105 cfs for the two gaged tributaries (Salmon River and Indian Creek) entering the Klamath River between KSV and KAO. Lower September accretions than in 2001, are not unprecedented, and have also occurred in 1985 (152 cfs) and 1987 (47 cfs). Past September accretions between these two gages, however, have more often been substantially higher, averaging 517 cfs since 1952, 442 cfs since 1985, and 493 cfs over the last ten years, since 1992. Average accretions to this area of the Klamath River, during other low-flow Septembers, were also higher at 627 cfs in 1973, 316 cfs in 1981, 400 cfs in 1988, 355 cfs in 1991, 186 cfs in 1992, 296 cfs in 1994, and 425 cfs in 2002. Low accretions of flow between KSV and KAO in September 2001 may be accurate, but does represent an unusual circumstance when compared to other years.

Although Klamath River flows were among the lowest on record in September 2002, Trinity River flows at Hoopa were near the long-term average of 639 cfs for the period of 1951 to 2002. September 2002 flows were 636 cfs, which was between the 40% and 50% exceedence values for TRH since 1951. These results compared favorably to USGS (2003) findings that characterized average flows from September 1-24, 2002 as being slightly less than average (96 percent) for a period of record since 1960.

Comparing unimpaired flows, as modeled by Hardy and Addley (2001), for the period of 1974-1997, with actual flow exceedence values and actual September 2002 flow at KIG (1961-2002), indicated higher flows could have been provided to the Klamath River in September 2002. Unimpaired flows at Iron Gate ranged from nearly 470 cfs higher at a ten percent exceedence level, to 114 cfs higher at a 90% exceedence value, when compared with actual flows (Table C3). Average flow releases at KIG in September 2002 were 760 cfs, which was nearly 150 cfs less than the actual 90% exceedence value for the period of 1961 to 2002, and 312 cfs less than the modeled unimpaired 90% exceedence value for the period of 1974-1997. Therefore, more flow was potentially available from above Iron Gate Dam. Increased releases at Iron Gate in September 2002, would clearly have affected deliveries to upstream water users. Increased discharge to the Klamath River below Iron Gate could also have come from other sources such as the Shasta, Scott and Trinity rivers. However, any potential benefits of increased flow in the mainstem Klamath River would be lost between Iron Gate Dam and the mouths of these respective rivers.

In summary, September 2002 flows in the Klamath River were atypically low, which led DFG to reject the null-hypothesis that flows in the Klamath River during 2002 were not out of the ordinary and should not have contributed to the fish-kill. DFG, therefore, accepted the alternative hypothesis that flows in 2002 were atypical and could have contributed to the fish-kill. Klamath River flows in September 2002 were among the lowest recorded in the last half-century. September 2002 flows always fell in the lowest tenth percentile for the period of record at all gaging stations in the lower Klamath River during September. Depending on the gaging station, there were three to five years where average September flows were similar or less than those recorded in 2002. From this analysis, DFG identified seven other potential low-flow years for further analysis, in which fish-kills did not occur. Therefore, low-flows in the river may have been an important factor in creating conditions that facilitated the outbreak of disease, and culminated in the fish-kill.

In contrast to the Klamath River, Trinity River flows during September 2002 were near the long-term average for the period of record from 1951 to 2002. Lower flows at TRH have occurred in more than 50% of the years over the past half-century than occurred in September 2002. This led DFG to accept the null-hypothesis that flows in the Trinity River during 2002 were not out of the ordinary and should not have contributed to the fish-kill.

The data and analyses in this report and by Hardy and Addley (2001), indicated that unimpaired flows in the Klamath River would have been higher in September 2002. In addition, USBR directed Pacificorp to increase flows, from Iron Gate Dam in late September and early October 2002, to abate the fish-kill. Pacificorp also took independent steps to extend those higher flows for several days after USBR directed had directed them to reduce the flows in October. This information led DFG to reject the null-hypothesis that there was no additional water available to increase flows in the lower Klamath River during September 2002. We accepted the alternative hypothesis that there was additional water available to increase flows in the Klamath River during September 2002. The Klamath Project is one, but not the only potential source of increased flows in the Klamath River. Our analysis of these competing hypotheses showed more flow could have been available in September 2002, but did not address if more flow would have created better conditions for downstream resources. Hypotheses related to the benefits or detriments of increased flows for fishery resources in the Klamath Basin during 2002, will be addressed in later sections of this report.

III. D. Temperature;

III. D. 1. Introduction

Water temperature plays an important role in the distribution, abundance, health, growth, behavior, and survival of salmonid fishes (USEPA 2002). High water temperature has been implicated as a potential limiting factor for anadromous salmonids in the Klamath River (Klamath River Basin Fisheries Task Force 1991; Bartholow 1995). In addition to affecting anadromous salmonids directly, high water temperature also facilitates disease outbreaks and adversely influences a number of ambient physical/chemical parameters that are important to fish, including dissolved oxygen.

A number of significant temperature-related juvenile anadromous salmonid fish-kills have occurred during the summer months on the Klamath River (DFG 2000c). However, the September 2002 fish-kill was the first involving large numbers of adult salmon and steelhead. Adult fish-kills have not occurred, even though water temperatures throughout much of the mainstem Klamath River, during the fall Chinook salmon adult migration period (late July through October), frequently exceed US Environmental Protection Agency (USEPA) recommended guidelines. USEPA (2003) has proposed several guidelines for the protection of adult salmonids. These include:

- a daily temperature consistently below 64.4 ^{o}F for reduction of high risk from disease pathogens for adult salmonids;
- a daily average temperature of 69.8 ^{o}F for protection of migrating adult salmonids;
- a seven-day average maximum daily temperature of 64.4 ^{o}F for protection of adult salmon during the summer; and
- a weekly constant temperature of 69.8 ^{o}F for reduction of lethality of migrating adult salmon.

Temperatures in the Klamath River Estuary typically approach a maximum of 70 °F or higher in August and September (DFG 2003a), and occasionally reach 80 °F in the mid-reaches of the Klamath River (USGS Data), yet significant adult fish-kills have never been reported.

There is some speculation that Klamath River Chinook salmon may have evolved higher thermal tolerances than has been found for other west coast populations, but definitive studies to confirm this have not been done. It is generally believed that thermal refugia, formed in the mainstem by cooler tributaries, spring seeps, inter-gravel flow, and deep pools, provide relief from thermal stress and allow adult Chinook salmon to successfully migrate through an otherwise thermally hostile aquatic environment (Bartholow 1995). Although adult Chinook salmon in some systems such as the Sacramento River have been observed to stop migrating at water temperatures of 70 °F, temperatures as high as 76 °F in the Klamath River apparently have not prevented upstream migration of adult Chinook (CDWR 1988). Studies are underway to describe Chinook salmon spawning migration behavior and holding habitat preferences (Belchik 2003, personal communication).

Ambient air temperature is one of the most critical factors influencing water temperature. The specific heat (that amount of heat in calories that is required to raise the temperature 1 °C of a unit weight of a substance) of water is much higher than air (Wetzel 1983). Water temperatures respond slowly to air temperature fluctuations, because large amounts of heat are required to produce relatively small changes in water temperature. Consequently, seasonal and diurnal extremes for air temperatures are both lower and higher than adjacent aquatic habitats.

Within the geographic extent of the Klamath Basin, there are a wide variety of climatic conditions. CDWR (1986a and 1987) characterized the climate above Orleans as having dry summers with high daytime temperatures, and wet winters with moderate to low temperatures. The USFS (1994) indicated water temperatures increase in the Klamath as the river flows downstream from Iron Gate Dam to about Happy Camp, where the river reaches equilibrium with the atmospheric temperature. Water temperature cools below Happy Camp to the mouth of the Klamath River, due to the influence of tributaries and a cooler climate closer to the coast (USFS 1994).

Flow levels are another factor influencing water temperature in the Klamath River. Increasing flow rates, result in a reduction of both maximum and mean daily water temperatures, in a longitudinal profile below Iron Gate Dam, downstream to at least the Scott River (Hardy and Addley 2001). This was attributed to the known relationship between higher flow volumes and dampening of the range of maximum daily temperatures, due to a higher thermal mass with increasing flow rates. It is unknown whether increased flow volumes influence water temperatures significantly below the mouth of the Scott River where ambient atmospheric temperatures may dominate. This is a critical question related to the effects of flow volumes on water temperatures in the fish–kill area during September 2002.

Water temperature records for the Klamath River and its tributaries, in most cases, are short in duration and lack continuity (USGS 2003), thus there is difficulty in comparing 2002 water temperature characteristics to historic conditions. The U.S. Geological Survey (USGS) has collected water temperature data in the past, primarily from the 1960's through the 1970's, and in some cases, the 1980's, at the following sites: Klamath River Near Klamath Calif. (Gage # 11530500), Trinity River at Hoopa Calif. (Gage # 11530000), Klamath River at Orleans Calif. (Gage # 11523000), Salmon River at Somes Bar Calif. (Gage # 11522500), Klamath River NR Seiad Valley Calif. (Gage # 11520500), Shasta River NR Yreka Calif. (Gage # 11517500) and Klamath River BL Iron Gate Dam Calif. (Gage # 11516530) (USGS 2003). Bartholow (1995) summarized temperature information from these sites prior to 1995. USGS has reinitiated temperature data collection at some gages in 2001 and 2002, but many of the records are not complete.

The U.S. Fish and Wildlife Service (USFWS), Arcata, California office, has collected comprehensive water temperature data at 11 locations on the Klamath River and a number of its tributaries in 2001 and 2002. The Yurok Tribe has also collected water temperature data in 1997, 1998 and 1999 at their Omagaar Trap, which is located upstream, three to four miles from the Terwer gage, on the lower Klamath River.

Extensive records for air temperatures are available from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) at www.ncdc.noaa.gov (NOAA, NCDC 2003). USGS flow records are also extensive (see Flow section III. C. of this report).

This section will address hypotheses relating to the influences of flow and air temperatures on water temperatures in the Klamath River, and will compare water temperature trends between 2002 and other years, when fish-kills did not occur. Specific null and alternative hypotheses to be analyzed include:

> Ho_1 - Flow levels do not influence water temperatures in the lower Klamath River fish-kill area.
> Ha_1 - Flow levels do influence water temperatures in the lower Klamath River fish-kill area. If Ha_1 is accepted then test;
> Ho_2 – The relationship between flow levels and water temperatures are the same in low-flow versus higher-flow years.
> Ha_2 – The relationship between flow levels and water temperatures are different in low-flow versus higher-flow years.
> Ho_3 – Air temperatures do not influence water temperatures in the lower Klamath River fish-kill area.
> Ha_3 – Air temperatures do influence water temperatures in the lower Klamath River fish-kill area. If Ha_3 is accepted then test;
> Ho_4 – The relationship between air temperatures and water temperatures are not different in low-flow versus higher flow years.
> Ha_4 – The relationship between air temperatures and water temperatures are different in low-flow versus higher flow years.
> Ho_5 – Water temperatures during September 2002 were not at levels that stress fish and thus were not a factor in the fish-kill.
> Ha_5 – Water temperatures during September 2002 were at levels that stress fish and thus were a factor in the fish-kill. If Ha_5 is accepted then test;
> Ho_6 – Water temperatures during the September 2002 fish-kill were not different than in past years when fish-kills did not occur.
> Ha_6 – Water temperatures during the September 2002 fish-kill were different than in past years when fish-kills did not occur.

Another hypothesis has been posed that even if fish in the lower river had moved upstream of the fish-kill area in September 2002, they would have died due to lethal temperatures in the upper river. DFG restated this concern as a null and alternative hypothesis:

> Ho_7 – Water temperatures in the Klamath River upstream of the fish-kill area, during September 2002, were not lethal to salmon and steelhead and fish moving upstream would not have died.
> Ha_7 – Water temperatures in the Klamath River upstream of the fish-kill area, during September 2002, were lethal to salmon and steelhead and fish moving upstream would have died.

III. D. 2. Methods

Water temperature data were obtained from the USFWS, Arcata, California office. USFWS has conducted a comprehensive water temperature investigation on the Klamath River and a number of its tributaries in 2001 and 2002, at stations including:

(1) Klamath River at Terwer (RM 6.7);
(2) Klamath River at Martin's Ferry (RM 40.4);
(3) Trinity River near mouth, 0.5 M upstream (RM 43.5);
(4) Klamath River at Weitchepec (RM 43.5);
(5) Klamath River at Orleans (RM 59.1);
(6) Klamath River below Happy Camp (RM 100.8);
(7) Klamath River at Seiad Valley (RM 128.5);
(8) Scott River near mouth, 1.5 M upstream (RM 143.0);
(9) Shasta River near mouth, 0.5 M upstream (RM 176.6);
(10) Klamath River above Shasta (RM 176.8); and
(11) Klamath River at Iron Gate Bridge (RM 189.8).

DFG considered the USFWS data set, the most complete water temperature information available for the 2001 and 2002 period, but these data are provisional and may be subject to change.

DFG has focused our analyses of USFWS data on daily maximum and minimum water temperatures for August and September at:

(1) Klamath River at Terwer (RM 6.7);
(2) Trinity River, 0.5 miles above mouth (RM 43.5);
(3) Klamath River at Orleans (RM 59.1);
(4) Klamath River near Seiad Valley (RM 128.5); and
(5) Klamath River below Iron Gate Dam (RM 189.8) (Figure 1).

The Yurok Tribe provided water temperature data for 1998 and 1999 at the Omagaar fish trap. Omagaar thermographs were located three to four miles above the Terwer station.

Air temperature data were obtained from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) at www.ncdc.noaa.gov (NOAA, NCDC 2003). DFG selected stations to correspond closely with water temperature stations on the Klamath and Trinity rivers. Those stations included: Yreka, Orleans, and Klamath (Figure 1). In addition, DFG selected two stations (Willow Creek 1 NW and Weaverville) to represent the lower and upper reaches of anadromous fish on the Trinity River (Figure 1). Data for August and September of low-flow and non-low-flow years were acquired when possible. For the purpose of this report, low-flow years refer to those identified in the flow section and include: 1973, 1981, 1988, 1991, 1992, 1994, 2001, and 2002. Non-low-flow years include those since 1995, that do not meet the criteria of a low-flow year in the previous section. These data have been quality controlled by NCDC, and are in the form of daily maximum and minimum air temperatures.

Mean daily flow data for four gaging stations on the Klamath River from Iron Gate Dam downstream to Klamath, and for the Trinity River at Hoopa, were obtained from the U.S. Geological Survey (USGS) web page (www.usgs.gov). These data were summarized in the previous flow section of this report.

Hypotheses 1-4 were addressed through linear regression analysis, where water temperature was the dependent variable and air temperature or flow were independent variables. Significant relationships were considered individually and through multiple regression analyses, to develop predictive models, and to construct water temperature estimates for years where water temperature data were unavailable in the fish-kill area. Water temperature estimates were compared with 2002 data to address hypotheses 5 and 6. Upstream water temperatures for September 2002, were compared against EPA standards and fishery monitoring data to address hypothesis 7.

September daily maximum water temperature data for 1998 and 1999 at Omagaar and 2001 and 2002 at Terwer, were regressed against TRH+KAO flow. The combined flows of TRH+KAO were used in these regression analyses, because of concerns with the quality of data at the KNK station during 2001 and 2002 (see Flow section III. C.). September 2001 and 2002 data represented low-flow years, and 1998 and 1999 data represented above average flow years, for the purpose of conducting regression analyses. September 2001 and 2002 flows for TRH+KAO, were below the 90% exceedence values in both years (Figure C1). September 1998 and 1999 flows below Iron Gate Dam and at Orleans, were above the 30% and 50% exceedence values, respectively; and combined flows of TRH+KAO were above the 20% and 40% exceedence values, respectively (Figure C1). September daily maximum water temperature data for 1998 and 1999 at Omagaar, and 2001 and 2002 at Terwer, were also regressed against daily and seven-day running averages of maximum and minimum air temperatures at Terwer and Orleans.

Linear and multiple regression analyses were performed using Microsoft Excel and methods according to Sokal and Rohlf (1981). The slope (m), y intercept (b), coefficient of determination (r^2), F statistic and t statistic were calculated for each regression. The coefficient of determination was used as an indication of the strength of the correlation between the independent (x) variables and the dependent (y) variable. Values for r^2, run from zero to one, with values closest to one indicating the strongest relationship. The coefficient of determination indicates the proportion of the variation in the dependent variable y that is explained by the variation in the independent variable x. The F statistic was used in an analysis of variance to test the significance of each regression analysis. The t statistic was used to test whether the regression slope coefficient for each independent variable x, was significant in estimating the dependent variable y.

Significance between simple linear regression equations was analyzed using a Student's t analysis to compare the difference between two slopes (Zar 1984). All tests were conducted at the 5% level of significance, (ie. Alpha = 0.05).

Where significant linear regression relationships existed for each year (F-test of regression and t-test for slope), but no significant difference occurred between years (Student's t test between slopes), DFG pooled data from 2001 and 2002 to represent low-flow relationships and 1998 and 1999 to represent above average flow relationships. When significant linear relationships were identified between daily maximum water temperatures and individual parameters (flow, maximum air and minimum air temperatures), multiple regression analyses were conducted to combine those parameters. This was done to develop a stronger predictive model to describe September water temperatures in the lower Klamath River. Multiple regression analyses were tested for significance using an F-test for the regression. Slope coefficients of independent variables were tested for significance using a t-test for the regression slope. Multiple regression models were rejected if the regression analysis failed the F-test, or any slope coefficient for independent variables failed the t-test. The best multiple regression model, which met these tests of significance, was identified to develop a predictive equation. This predictive equation was used to estimate maximum daily water temperatures at Terwer, for years where water temperatures were unavailable.

III. D. 3. Results

III. D. 3. a. Water Temperature and Flow Relationship

Significant relationships existed in September 1999 ($r^2 = 0.44$, $p < 0.001$), 2001 ($r^2 = 0.46$, $p < 0.001$) and 2002 ($r^2 = 0.17$, $p < 0.05$) between maximum daily water temperature at Omagaar or Terwer and TRH+KAO flow (Figure D1). There was no significant correlation for 1998. Flow explained a higher proportion of the variation in water temperature during September 1999 ($r^2 = 0.44$) and 2001 ($r^2 = 0.46$), than in 2002 ($r^2 = 0.17$). No significant difference was found between the regression slopes for 2001 and 2002, so those data were pooled to represent low-flow years for comparison with 1999, which was classified as an above average flow year (Figure D2). The regression slope for 1999, was significantly different ($p < 0.05$) than slopes for both 2001 and 2002 individually, and pooled. As flow decreased in 2001 and 2002, water temperatures increased. The opposite was true in 1999, when water temperature was positively correlated with flow (Figures D1 and D2).

Figure D1. Regression of maximum daily September water temperatures in the lower Klamath River (1998 and 1999 at Omagaar and 2001 and 2002 at Terwer) against the combined flows of TRH+KAO. Slopes are not significantly different between 1998 and 1999 ($t = 1.95$, $p > 0.05$) or 2001 and 2002 ($t = 1.04$, $p > 0.05$).

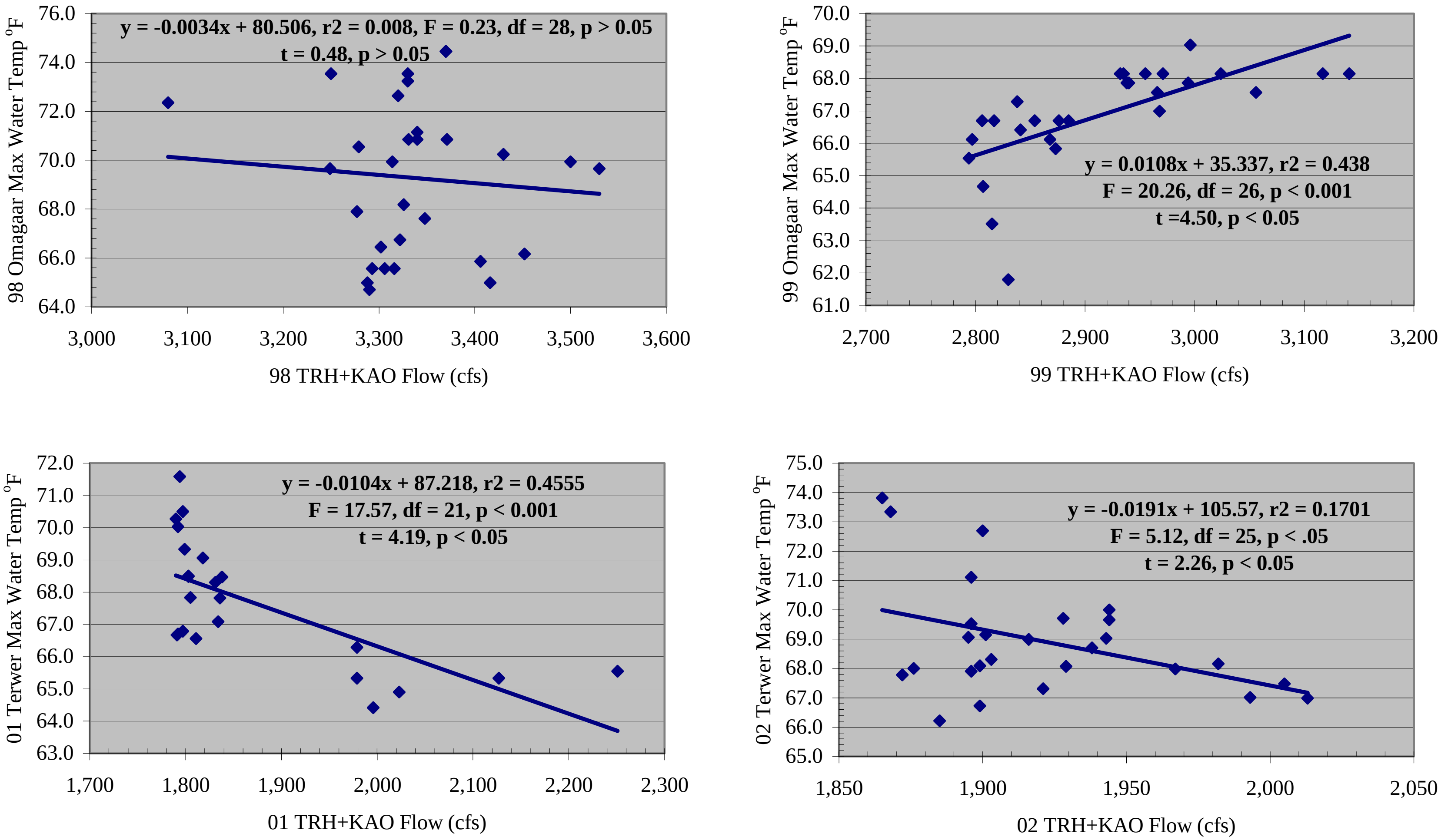
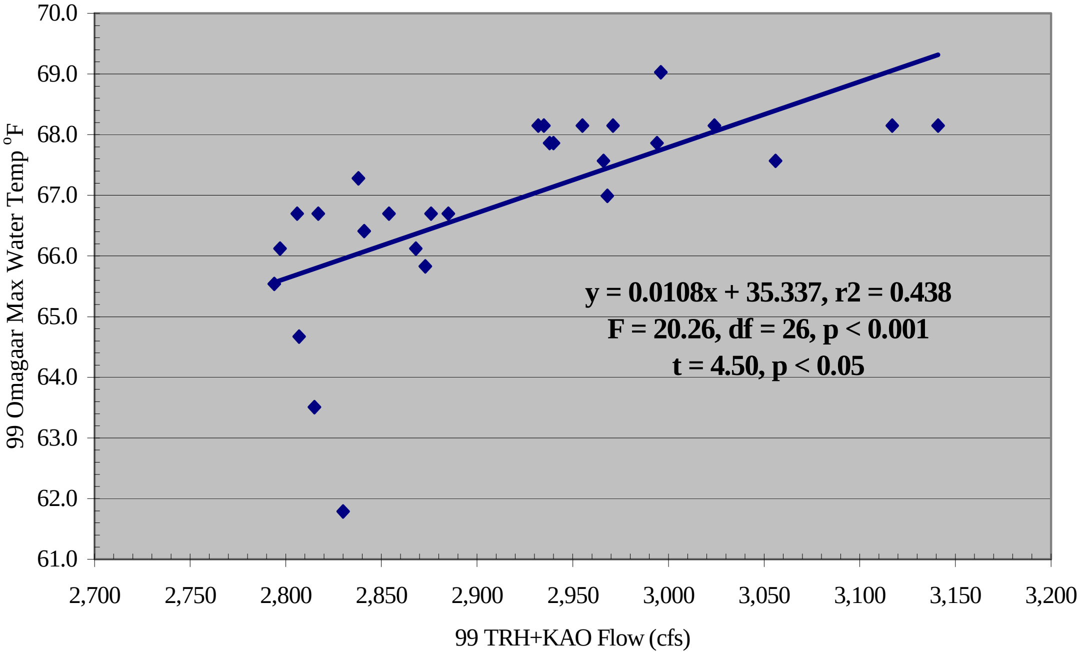
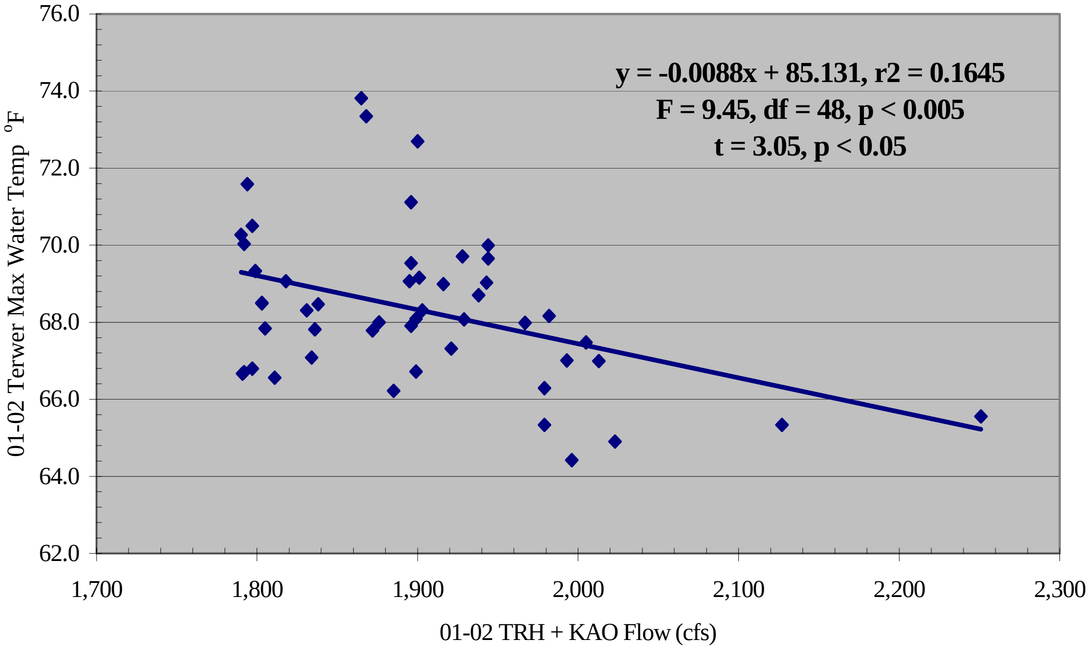


Figure D2. Regression of maximum daily September water temperatures in the lower Klamath River (1999 at Omagaar and 2001-2002 at Terwer) against the combined flows of TRH + KAO. Slopes are significantly different between 1999 and 2001-2002 ($t = 4.68$, $p < 0.05$).





III. D. 3. b. Water Temperature and Air Temperature Relationship

Significant relationships existed in September 1998 ($r^2 = 0.20$, $p < 0.025$) and 2002 ($r^2 = 0.20$, $p < 0.025$), but not in 1999 and 2001 between maximum daily water temperature at Omagaar or Terwer and maximum daily air temperature at Terwer (Figure D3). Maximum air temperature explained a relatively low proportion of the variation in water temperature during September 1998 ($r^2 = 0.20$) and 2002 ($r^2 = 0.20$). No significant difference was found between the regression slopes for 1998 and 2002.

A significant relationship existed in September 1999 ($r^2 = 0.23$, $p < 0.01$), but not in 1998, 2001, and 2002, between maximum daily water temperature at Omagaar or Terwer and minimum daily air temperature at Terwer (Figure D4). Minimum air temperature explained a relatively low proportion of the variation in water temperature during September 1999 ($r^2 = 0.23$).

September daily maximum water temperatures at Omagaar and Terwer appear to be more strongly influenced by upstream maximum and minimum air temperatures at Orleans (Figures D5 and D6). Significant positive relationships existed in September 1998 ($r^2 = 0.61$, $p < 0.001$), 2001 ($r^2 = 0.37$, $p < 0.005$) and 2002 ($r^2 = 0.27$, $p < 0.01$), but not in 1999 between maximum daily water temperature at Omagaar or Terwer and maximum daily air temperature at Orleans (Figure D5). Maximum air temperature at Orleans, explained a higher proportion of the variation in water temperature during September 1998 ($r^2 = 0.61$), than in 2001 ($r^2 = 0.37$), and 2002 ($r^2 = 0.27$). No significant difference was found between the regression slopes for 2001 and 2002, so those data were pooled to represent low-flow years for comparison with 1998, an above average flow year (Figure D7). The regression slope for 1998 was significantly different ($p < 0.05$) than slopes for both 2001 and 2002, individually and pooled.

Significant positive relationships existed in September 1998 ($r^2 = 0.56$, $p < 0.001$), 1999 ($r^2 = 0.24$, $p < 0.005$), and 2002 ($r^2 = 0.24$, $p < 0.01$), but not in 2001, between maximum daily water temperature at Omagaar or Terwer and minimum daily air temperature at Orleans (Figure D6). Minimum air temperature at Orleans explained a higher proportion of the variation in water temperature during September 1998 ($r^2 = 0.56$), than in 1999 ($r^2 = 0.24$), and 2002 ($r^2 = 0.24$). Significant differences were found between the regression slopes for 1998 and 1999, and 1998 and 2002 ($p < 0.05$). No significant difference was found between 1999 and 2002.

Figure D3. Regression of maximum daily September water temperatures in the lower Klamath River (1998 and 1999 at Omagaar and 2001 and 2002 at Terwer) against maximum daily air temperatures at Terwer.

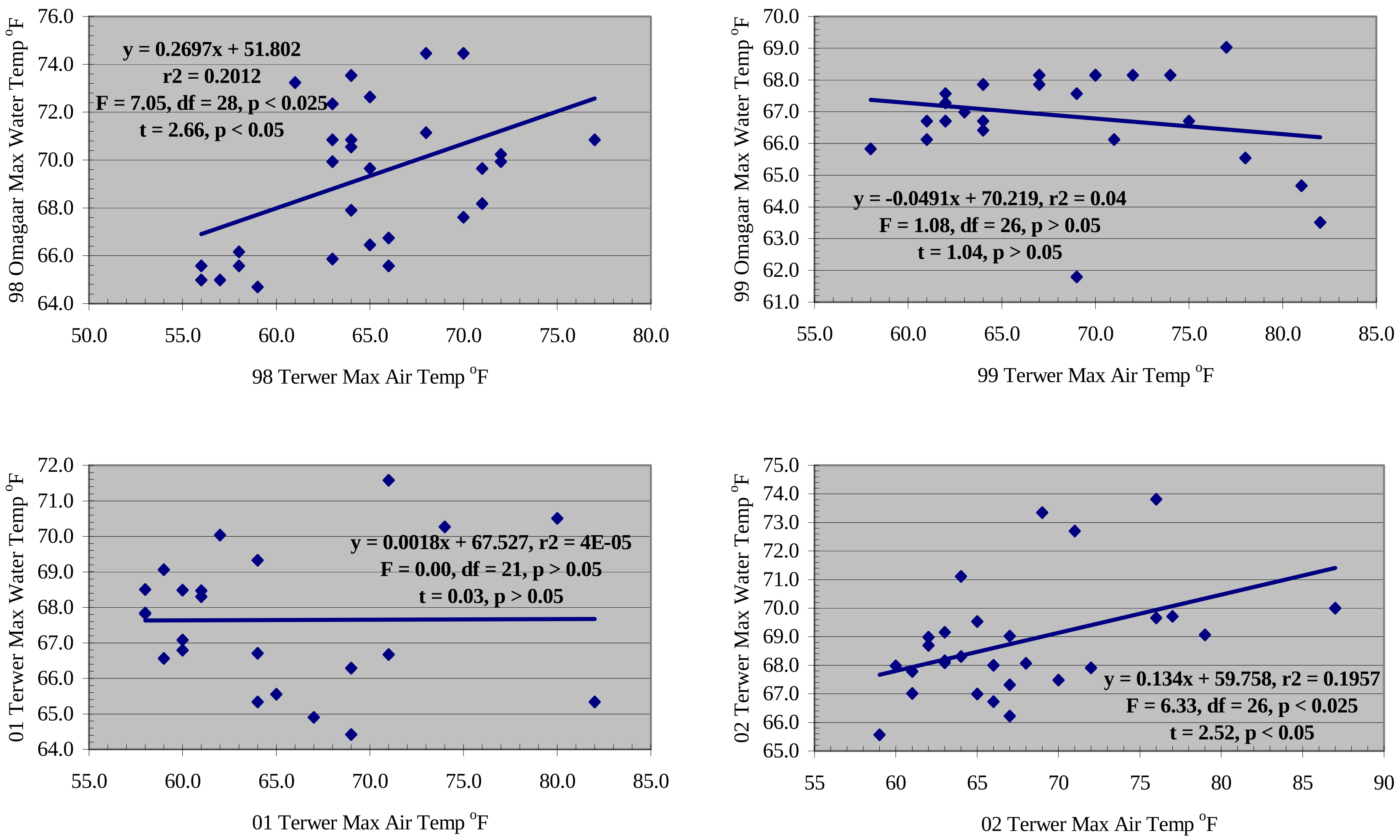


Figure D4. Regression of maximum daily September water temperatures in the lower Klamath River (1998 and 1999 at Omagaar and 2001 and 2002 at Terwer) against minimum daily air temperatures at Terwer.

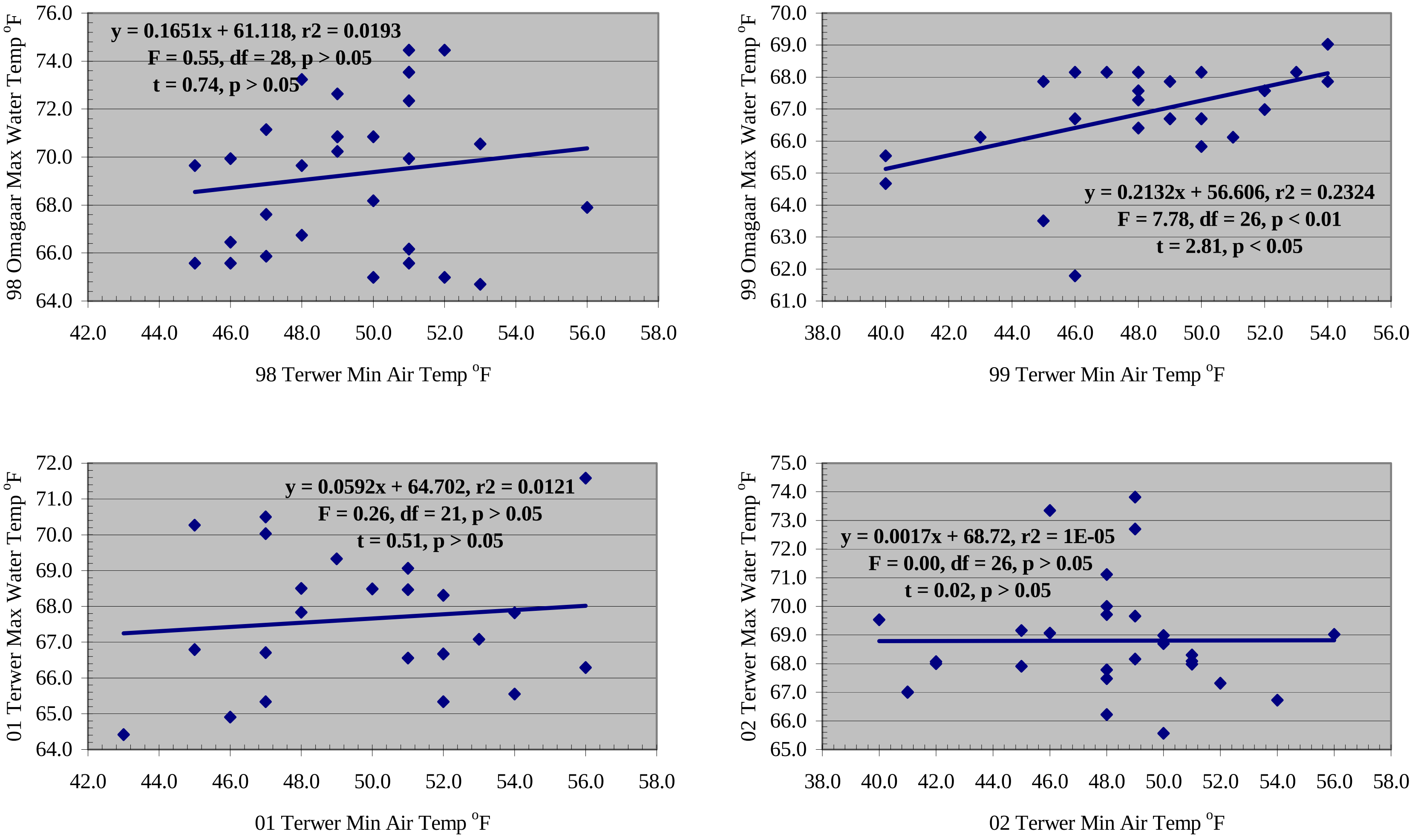


Figure D5. Regression of maximum daily September water temperatures in the lower Klamath River (1998 and 1999 at Omagaar and 2001 and 2002 at Terwer) against maximum daily air temperatures at Orleans. Slopes are not significantly different between 1998 and 1999 (t = 1.93, p > 0.05) or 2001 and 2002 (t = 0.25, p > 0.05).

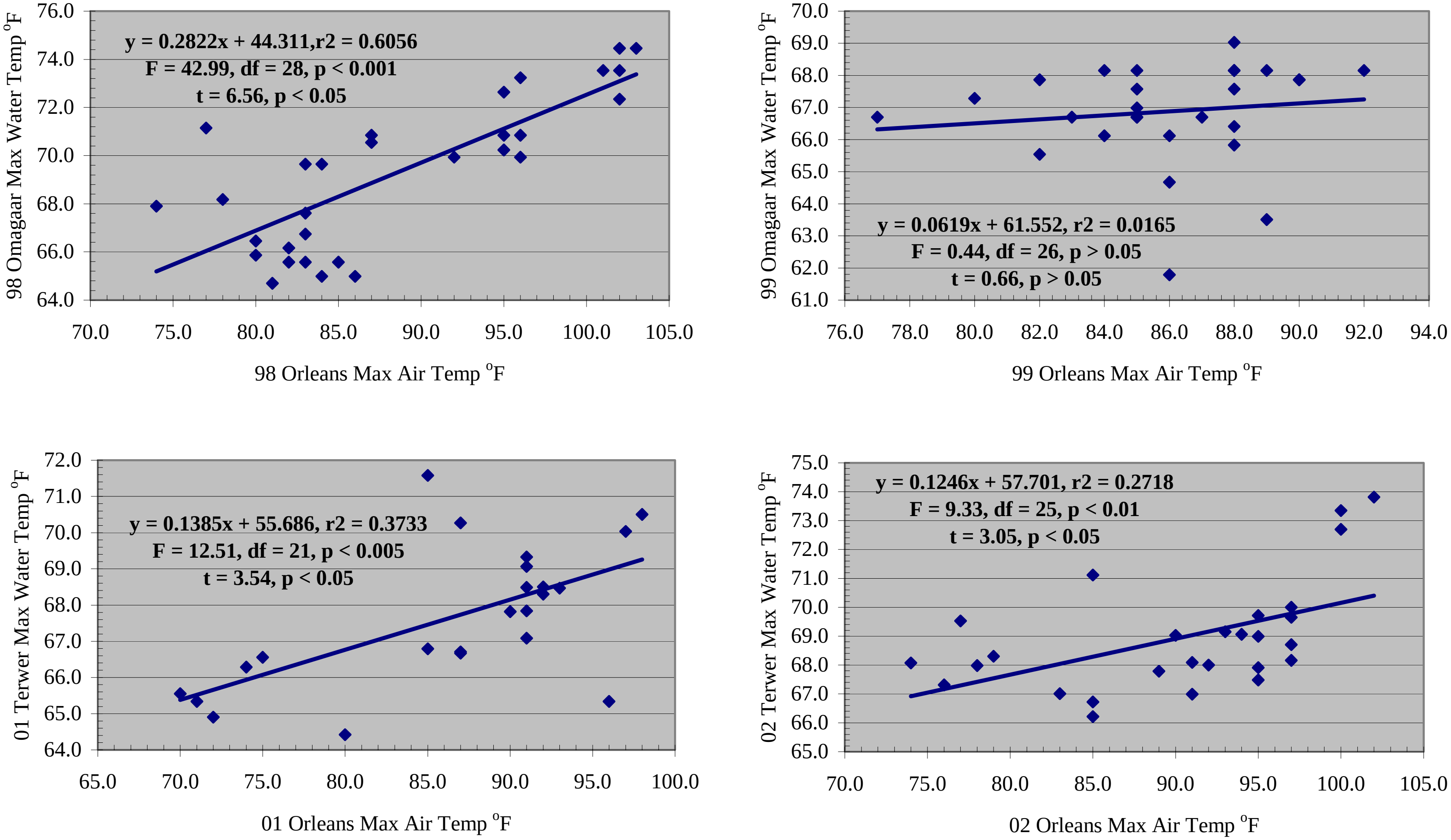


Figure D6. Regression of maximum daily September water temperatures in the lower Klamath River (1998 and 1999 at Omagaar and 2001 and 2002 at Terwer) against minimum daily air temperatures at Orleans. Slopes are significantly different between 1998 and 1999 (t = 2.04, p < 0.05) but not significantly different between 2001 and 2002 (t = 1.54, p > 0.05).

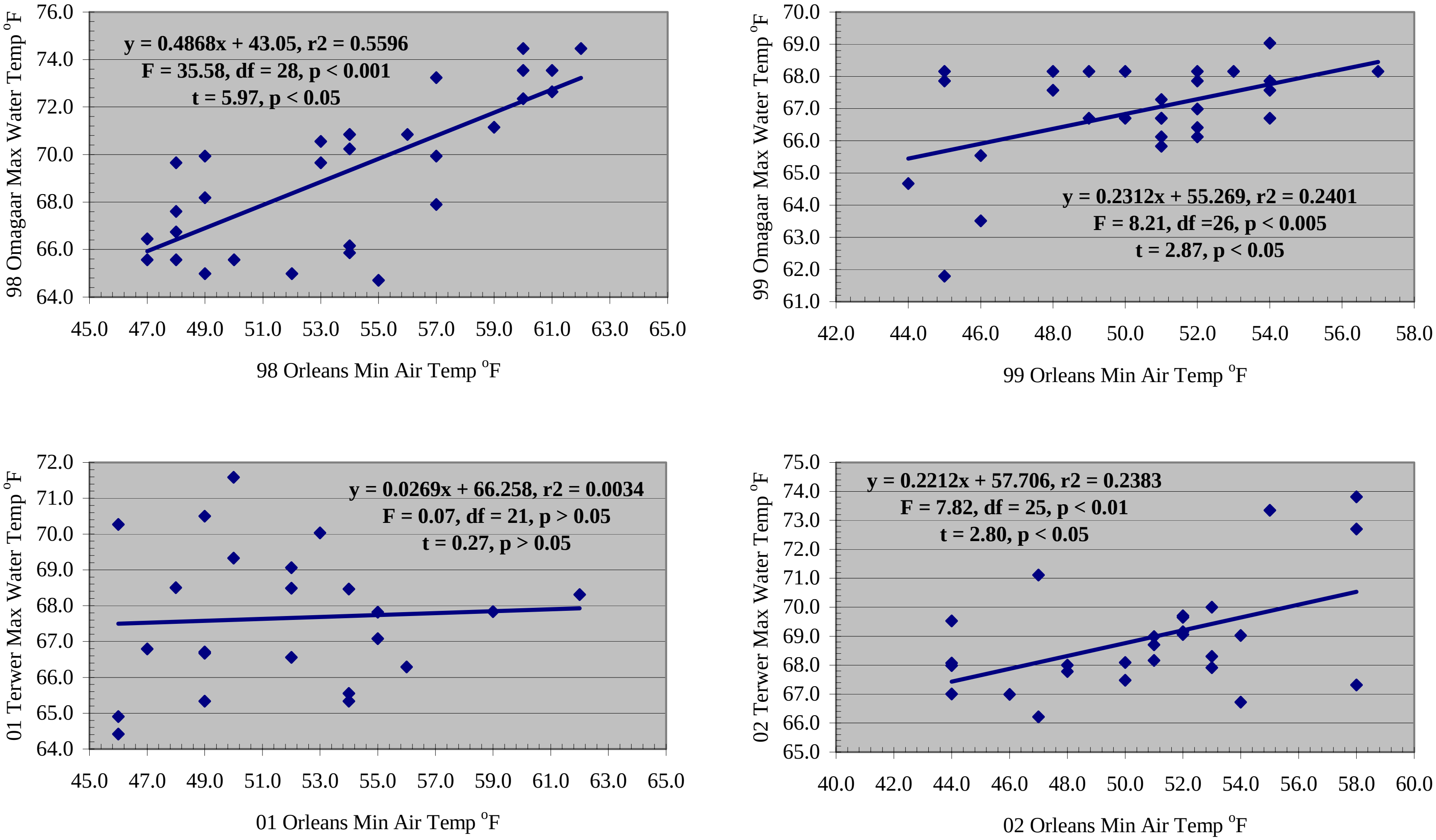
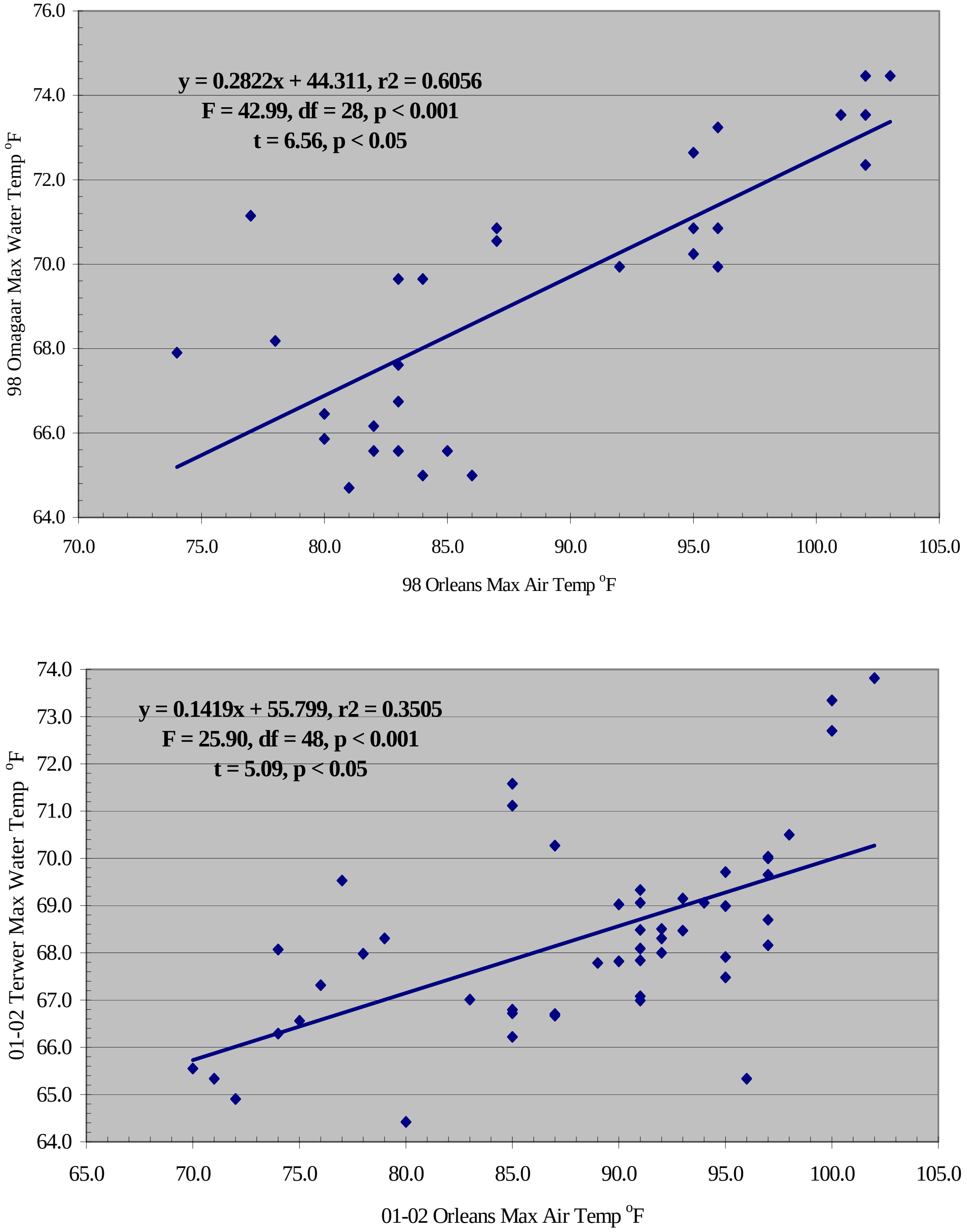


Figure D7. Regression of maximum daily September water temperatures in the lower Klamath River (1998 at Omagaar and 2001-2002 at Terwer) against maximum daily September water temperatures at Orleans. Slopes are significantly different between 1998 and 2001-2002 ($t = 2.87$, $p < 0.05$).



Using seven-day running averages of maximum and minimum daily air temperatures at Orleans provides stronger correlations with September maximum daily water temperatures at Omagaar and Terwer. Significant positive relationships existed in September 1998 ($r^2 = 0.92$, $p < 0.001$), 2001 ($r^2 = 0.50$, $p < 0.001$), and 2002 ($r^2 = 0.37$, $p < 0.001$), but not in 1999 between maximum daily water temperature at Omagaar or Terwer and seven-day average maximum daily air temperature at Orleans (Figure D8). Seven-day average maximum air temperature at Orleans explained nearly all the variation in water temperature, observed during September 1998 ($r^2 = 0.92$), but explained a lower proportion of the variation in water temperature during 2001 ($r^2 = 0.50$) and 2002 ($r^2 = 0.37$). No significant difference was found between the regression slopes for 2001 and 2002, so those data were pooled to represent low-flow years for comparison with 1998, an above average flow year (Figure D9). The regression slope for 1998 was significantly different ($p < 0.05$) than slopes for 2001 and 2002, individually and pooled.

Significant positive relationships existed in September 1998 ($r^2 = 0.78$, $p < 0.001$), 1999 ($r^2 = 0.18$, $p < 0.025$), 2001 ($r^2 = 0.19$, $p < 0.05$) and 2002 ($r^2 = 0.52$, $p < 0.001$), between maximum daily water temperature at Omagaar or Terwer and seven-day average minimum daily air temperature at Orleans (Figure D10). Seven-day average minimum air temperature at Orleans, explained a higher proportion of the variation in water temperature during September 1998 ($r^2 = 0.78$), than during 1999 ($r^2 = 0.18$), 2001 ($r^2 = 0.19$), and 2002 ($r^2 = 0.52$). No significant difference was found between the regression slopes for 2001 and 2002, so those data were pooled to represent low-flow years (Figure D11). A significant difference was found between the regression slopes for 1998 and 1999. The regression slope for 1998 was significantly different ($p < 0.05$) than slopes for both 2001 and 2002, individually and pooled, but the 1999 slope was not significantly different than 2001 and 2002.

III. D. 3. c. Actual and Predicted Water Temperature Data in the Fish-kill Area

DFG used multiple regression to identify the best predictive equation to estimate maximum daily water temperatures at Terwer from existing data during low-flow conditions. The best fitting equation to predict daily maximum water temperatures at Terwer during low-flow conditions used pooled seven-day average maximum and minimum air temperature data for 2001 and 2002 from Orleans. This equation was:

$$\text{DmaxWT} = 0.2516 \times (\text{7-DmaxAT}) + 0.2010 \times (\text{7-DminAT}) + 35.48$$

$$r^2 = 0.53 \text{ and } p < 0.001$$

Where:
DmaxWT is the September daily maximum water temperature at Terwer,
7-DmaxAT is the 7-day running average of maximum air temperatures at Orleans,
7-DminAT is the 7-day running average of minimum air temperatures at Orleans
and 35.48 is the y intercept.

Although this regression relationship was significant ($p < 0.001$), the equation accounts for only 53 percent ($r^2 = 0.53$) of the variation in water temperatures at Terwer during

Figure D8. Regression of maximum daily September water temperatures in the lower Klamath River (1998 and 1999 at Omagaar and 2001 and 2002 at Terwer) against 7-day average maximum daily air temperatures at Orleans. Slopes are significantly different between 1998 and 1999 (t = 2.90, $p < 0.05$) and not significantly different between 2001 and 2002 (t = 0.36, $p > 0.05$).

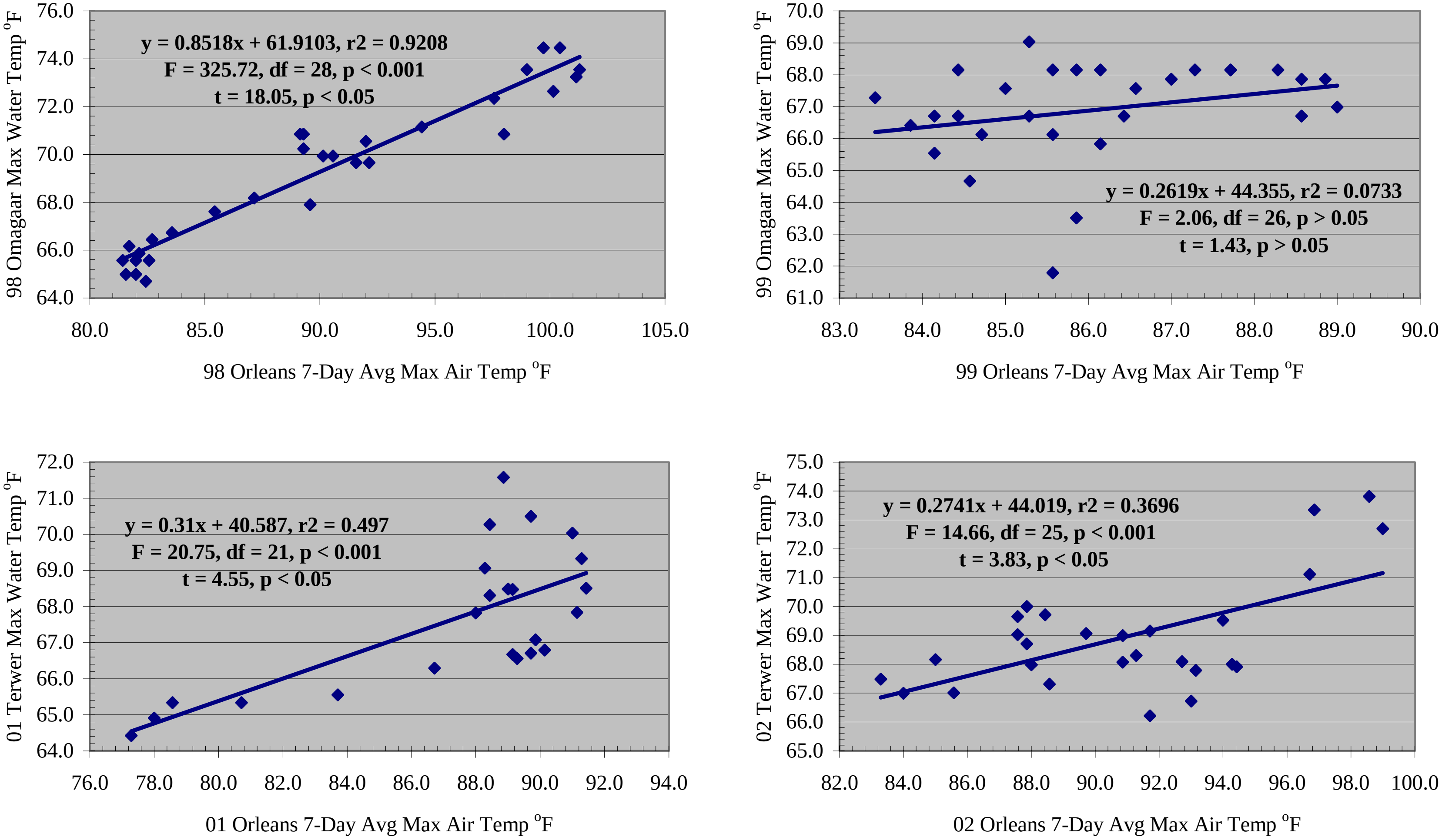
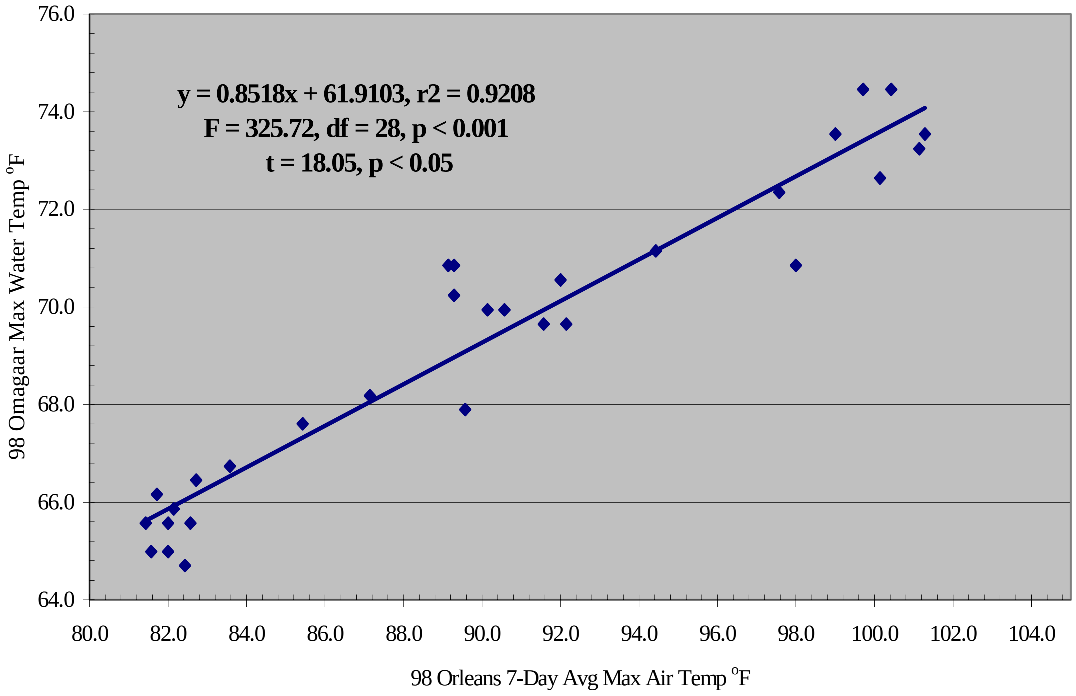


Figure D9. Regression of maximum daily September water temperatures in the lower Klamath River (1998 at Omagaar and 2001-2002 at Terwer) against 7-day average maximum September water temperatures at Orleans. Slopes are significantly different between 1998 and 2001-2002 ($t = 8.53$, $p < 0.05$).



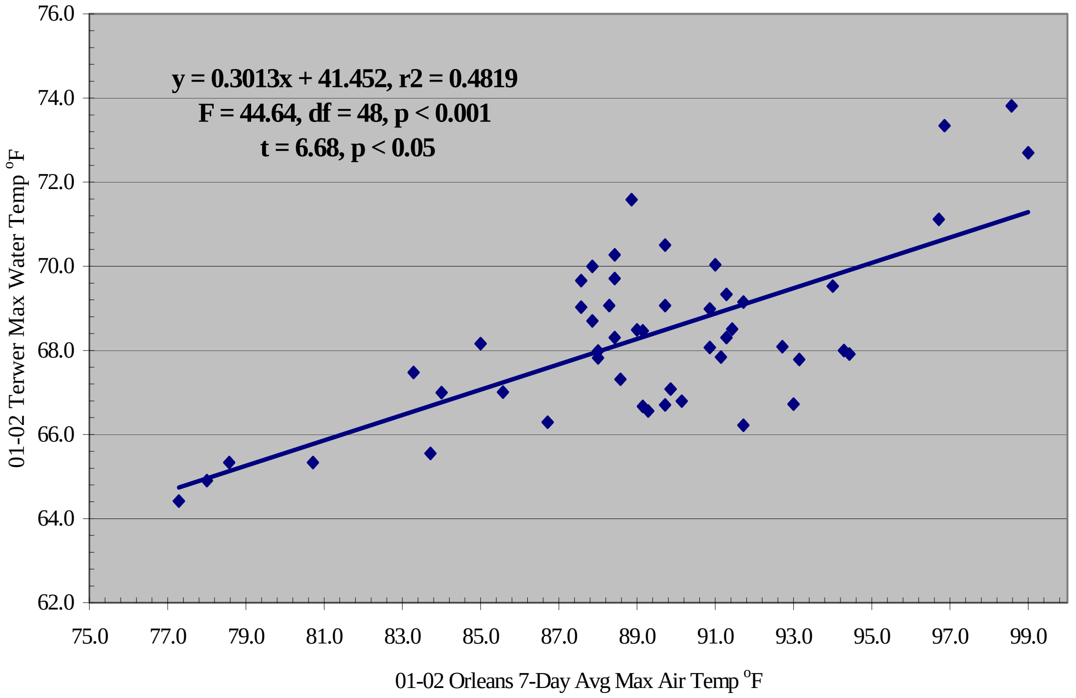


Figure D10. Regression of maximum daily September water temperatures in the lower Klamath River (1998 and 1999 at Omagaar and 2001 and 2002 at Terwer) against 7-day average minimum daily air temperatures at Orleans. Slopes are significantly different between 1998 and 1999 ($t = 2.47$, $p < 0.05$) and not significantly different between 2001 and 2002 ($t = 0.90$, $p > 0.05$).

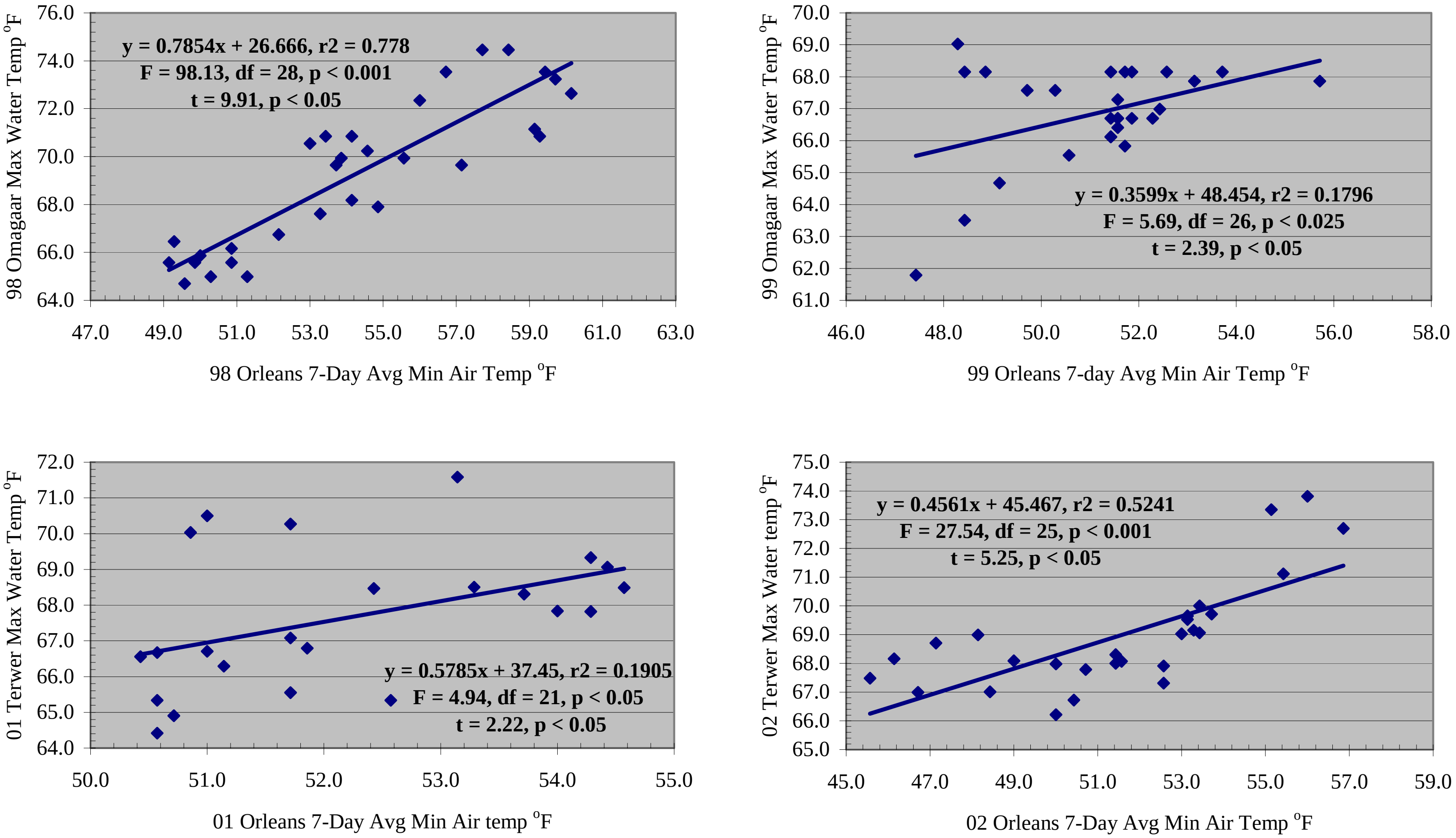
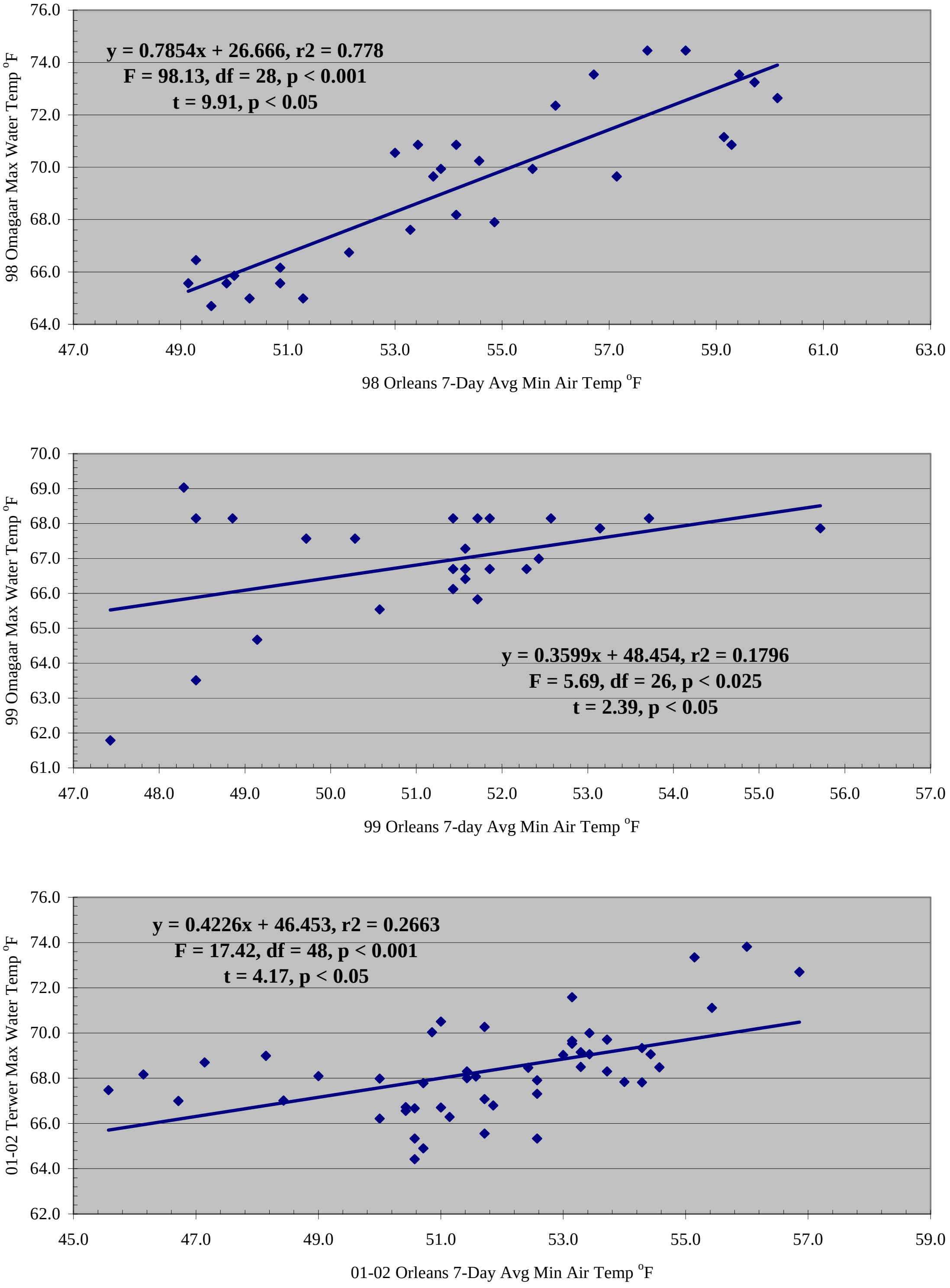


Figure D11. Regression of maximum daily September water temperatures in the lower Klamath River (1998 and 1999 at Omagaar and 2001-2002 at Terwer) against 7-day average minimum September water temperatures at Orleans. Slopes are significantly different between 1998 and 1999 ($t = 2.47$, $p < 0.05$) and 1998 and 2001-2002 ($t = 2.78$, $p < 0.05$), but not significantly different between 1999 and 2001-2002 ($t = 0.32$, $p > 0.05$).



low-flow years. This equation was used to generate predicted daily water temperatures at Terwer, for comparison with actual values for September 2001 and 2002. Predicted and actual daily maximum water temperatures showed similar trends; however, predicted values dampened some of the day-to-day fluctuations, but were usually within 2 ^{o}F of actual values at Terwer (Figure D12).

DFG also examined adding a TRH+KAO flow component to the multiple regression analysis. This was done because flow was found to explain about 16% ($r^2 = 0.16$) of the variation in maximum daily water temperatures at Terwer in September 2001 and 2002, and flow was significantly correlated with water temperatures ($p < 0.005$) (Figure D2). However, adding flow to the multiple regression analysis, did not increase the r^2 value (r^2 remained at 0.53), and the slope coefficient for the flow component was not significant ($p > 0.05$). Therefore, flow was not used in the predictive equation developed above.

The regression equation was also used to estimate September daily maximum water temperatures for other low-flow years at Terwer (1973, 1981, 1988, 1991, 1992 and 1994). The estimated values were compared with actual temperatures for 2001 and 2002. The actual daily September maximum water temperatures at Terwer in 2002, nearly always fell within the range of predicted values for other low-flow years (Figure D13). Daily maximum water temperature at Terwer, peaked on September 2, 2002 at 73.8 °F and dropped to 67.0 °F by September 9, 2002. Temperatures ranged between 66.7 °F and 69.0 °F from September 10 through September 17, and reached 69.0 °F on September 18, 2002, the day the fish-kill was first reported. Daily maximum water temperatures then rose on September 20 to 70.0 °F, before steadily dropping to 64.3 °F by September 30, 2002. Maximum daily water temperatures in 2001 were slightly warmer in early September, similar in mid-September, and a couple of degrees cooler in late September than in 2002 (Figure D13). Warming trends were apparent in late September of 1991, 1992, and 1994, with predicted temperatures often exceeding those in 2002. Cooling trends were observed in late September of 1973, 1981, 1988, and 2001, with maximum water temperatures falling below those in 2002.

Actual 7-day running averages of September daily maximum water temperatures at Terwer in 2002, nearly always fell within the range of predicted values for other low-flow years (Figure D14). Seven-day running average maximum temperatures in low-flow years ranged from a low of approximately 63 ^{o}F on September 30, 1981, to a high of nearly 73 ^{o}F on September 7, 1988. September 2002 values ranged from less than 67 ^{o}F on September 30, to nearly 73 ^{o}F on September 3 (Figure D14).

Actual daily September maximum water temperatures at Omagaar (RM 10.5) for 1998 and 1999, and Terwer (RM 6.7) for 2001 and 2002 were provided by the Yurok Tribe. These data were plotted as daily maximums (Figure D15) and 7-day average maximum water temperatures (Figure D16). During the higher flow years of 1998 and 1999, daily maximum water temperatures ranged from 61.8 ^{o}F to 74.5 ^{o}F at Omagaar (Figure D15). Daily maximum water temperatures ranged from 64.4 ^{o}F to 73.8 ^{o}F at Terwer, during September 2002 (Figure D15). Seven-day average of daily maximum water temperatures, ranged from 65.0 ^{o}F to 73.5 ^{o}F at Omagaar during September 1998 and 1999 (Figure D16). Seven-day averages of daily maximum water temperatures at Terwer during September 2002, ranged from 66.6 ^{o}F to 72.6 ^{o}F (Figure D16).

Figure D12. Comparison of actual Terwer daily max with predicted max water temperatures from regression analysis for 2001-2002. Regression uses 7-day average max and min air temperatures at Orleans as the predictor of max daily water temps at Terwer.

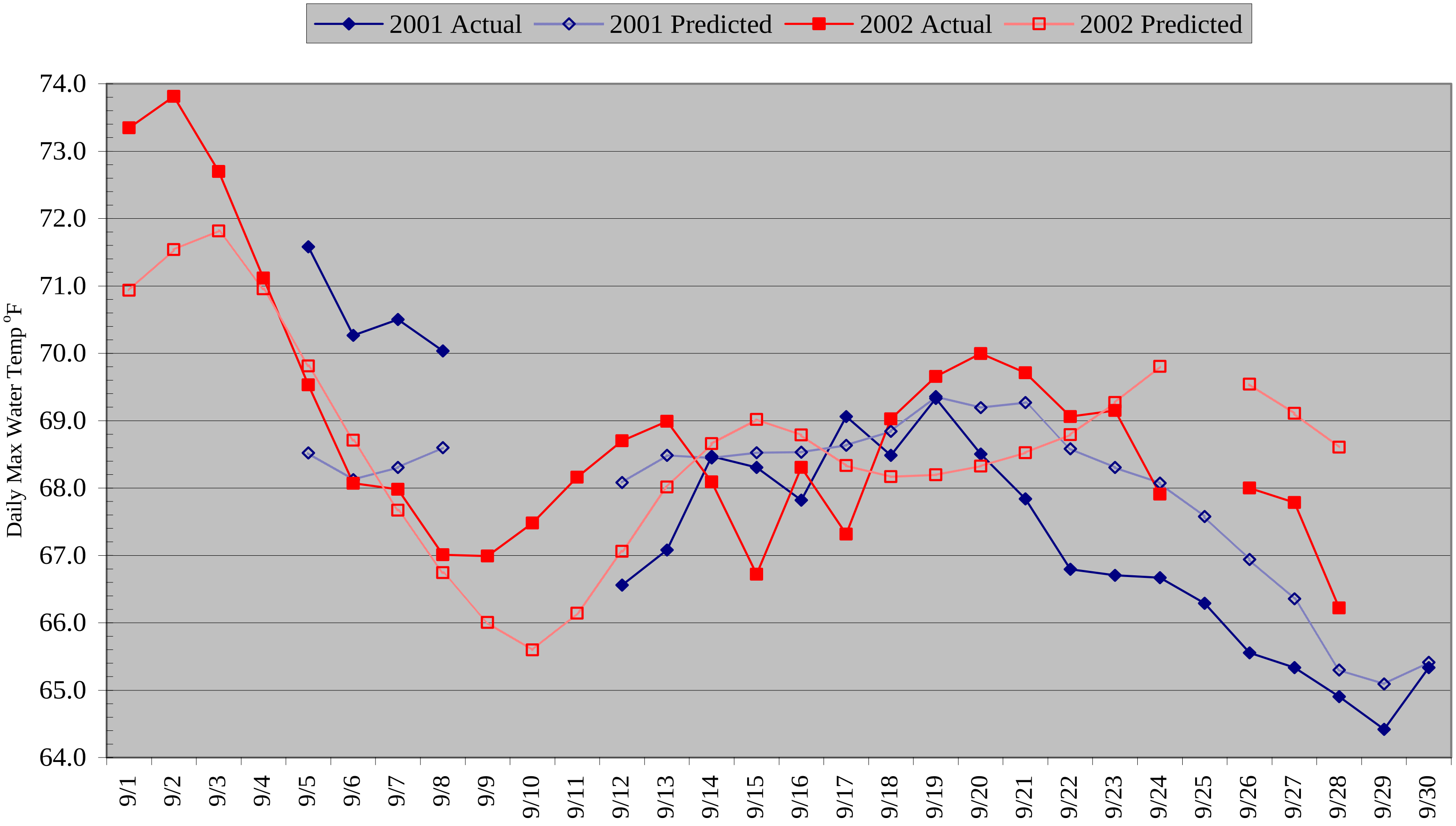


Figure D13. Actual and predicted max daily water temperatures at Terwer from 7-day running averages for max and min air temperatures at Orleans. Daily Max Wat T = 0.2516x(7-DRA Max Air T Orleans)+0.2010x(7-DRA Min Air T Orleans)+35.48, (r^2=0.53 p<0.001).

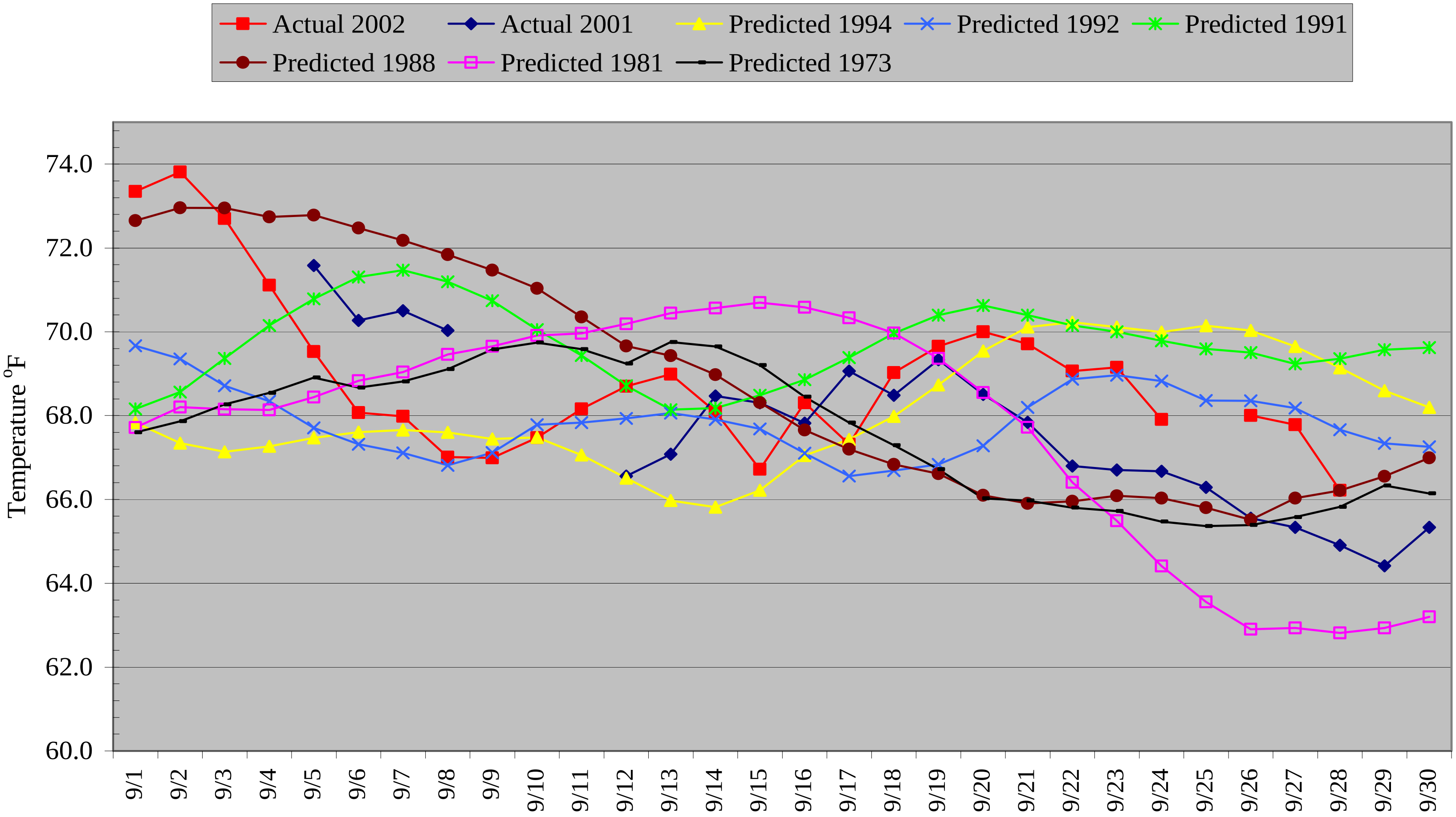


Figure D14. Comparison of actual and predicted 7-day running average of September maximum daily water temperatures at Terwer.

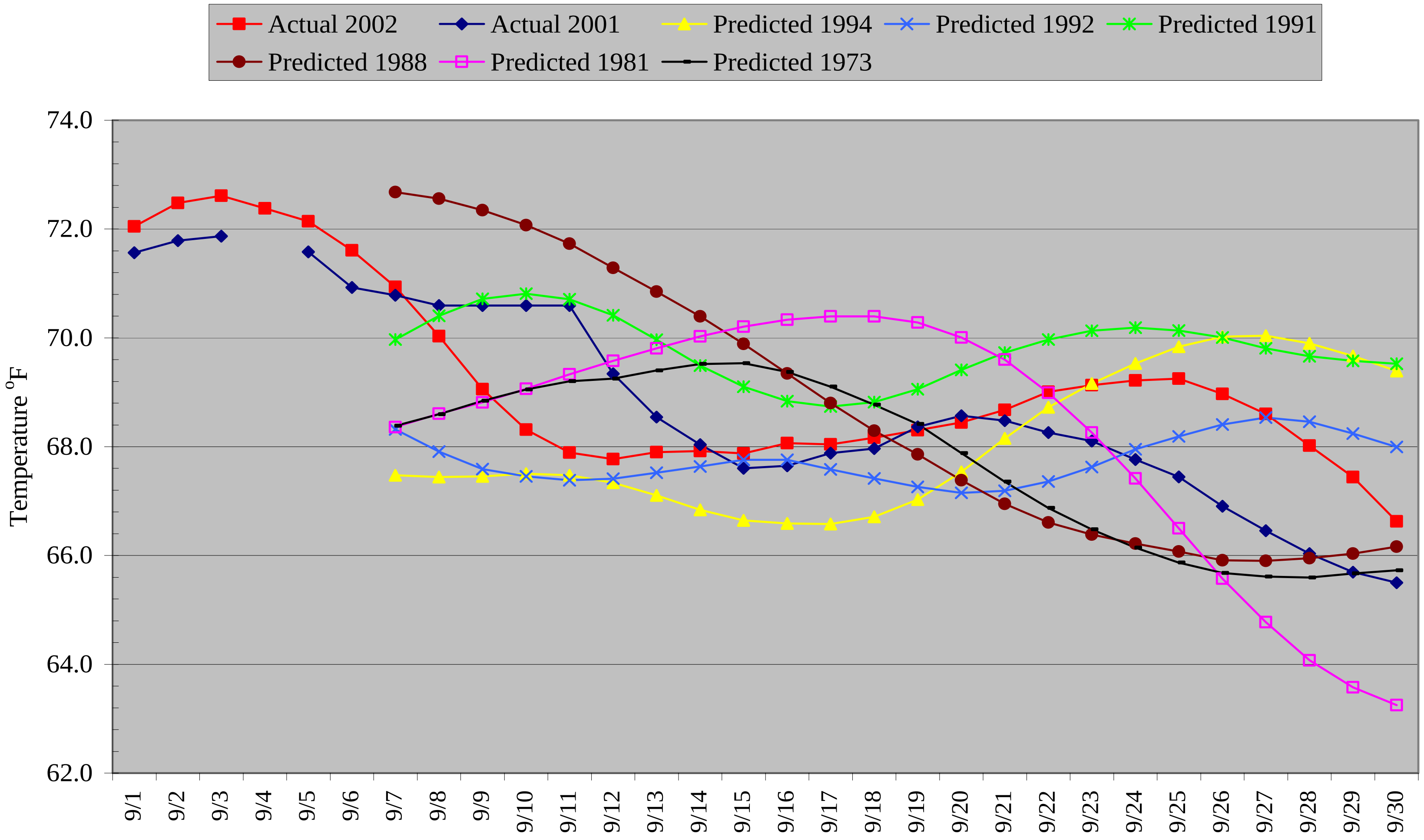


Figure D15. Daily maximum September water temperatures in the lower Klamath River at Terwer (2001 and 2002) and Omagaar (1998 and 1999).

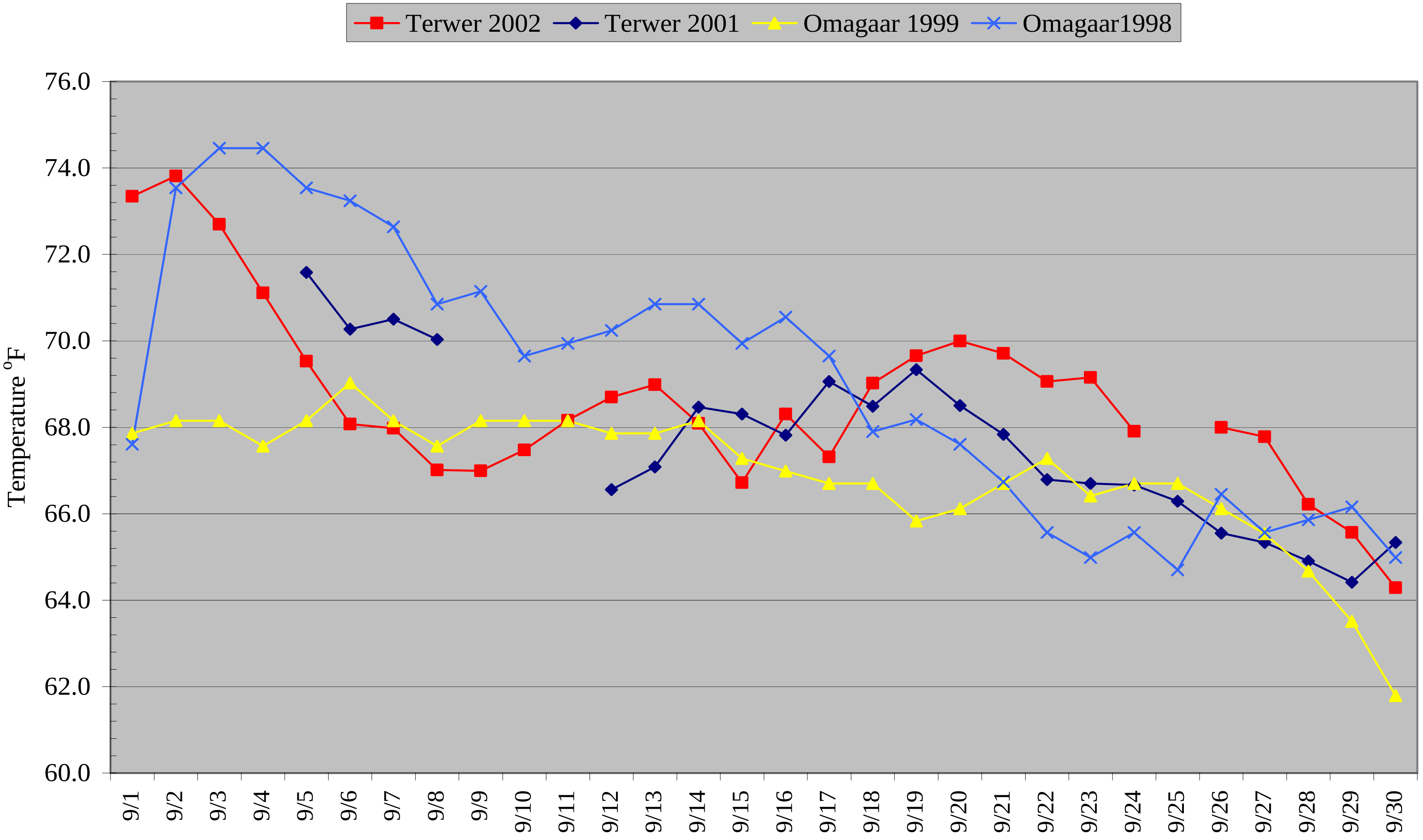
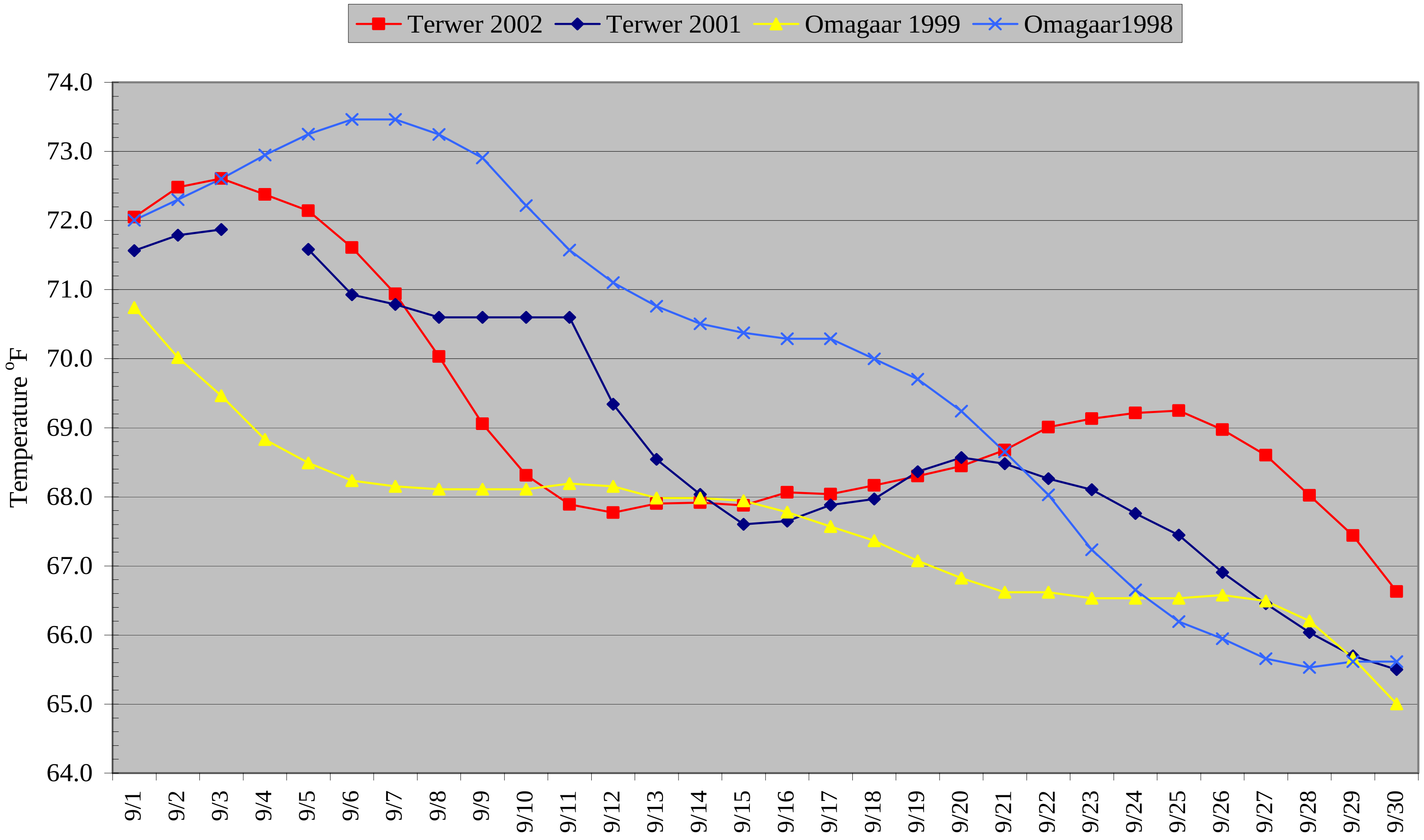


Figure D16. 7-day running average of daily maximim water temperatures for September at Terwer (2001 and 2002) and Omagaar (1998 and 1999).



III. D. 3. d. Actual Water Temperature Data Upriver

Maximum daily water temperatures at Terwer (RM 6.7), often fell in between temperatures at the upper-most and mid-river stations during the first half of September, but at times were among some of the highest temperatures observed during the last half of September 2002 (Figure D17). Daily maximum temperatures varied the least (63.9 ^{o}F – 70.5 ^{o}F), and were often the lowest in the Klamath River below Iron Gate Dam (RM 190). The greatest temperature variation occurred below Happy Camp (RM 100), ranging from 61.8 ^{o}F to 74.9 ^{o}F, and near Seiad Valley (RM 129), ranging from 62.6 ^{o}F to 75.1 ^{o}F. Water temperatures at Weitchepec (RM 43.5) and Orleans (RM 59) were similar to those at Terwer, but were slightly lower during the onset of the fish-kill (Figure D17).

Seven-day average maximum daily water temperatures followed similar trends (Figure D18) as the daily maximum temperatures (Figure D17). Seven-day averages in the lowest portions of the Klamath River at Terwer, Weitchepec and Orleans, most often fell in between temperatures at the upper-most and mid-river stations (Figure D18). Temperatures in the river below Iron Gate showed the least variation (65.2 ^{o}F to 70.3 ^{o}F) and were most often lowest. Temperatures at Happy Camp and Seiad Valley were most often the highest with the greatest variation (66.6 ^{o}F to 75.4 ^{o}F).

III. D. 4. Findings

III. D. 4. a. Water Temperature and Flow relationship

The specific null and alternative hypotheses DFG analyzed related to the effects of flow on water temperatures included:

> Ho_1 - Flow levels do not influence water temperatures in the lower Klamath River fish-kill area.
> Ha_1 - Flow levels do influence water temperatures in the lower Klamath River fish-kill area. If Ha_1 is accepted then test;
> Ho_2 – The relationship between flow levels and water temperatures are the same in low-flow versus higher flow years.
> Ha_2 – The relationship between flow levels and water temperatures are different in low-flow versus higher flow years.

Regression analysis showed that in three of the four years analyzed, there were significant relationships between average daily flows for TRH+KAO, versus daily maximum September water temperatures at Terwer and Omagaar (Figure D1). There was not a significant relationship between flow and water temperature during September 1998, which represented the highest flow year analyzed. Average September 1998 flows for TRH+KAO, fell within the 20% to 30% exceedence values for the period of record. In the moderate flow year of 1999 (average September flow falling in the 40% to 50% exceedence values), a significant positive relationship did exist between September flow and water temperature. Significant relationships between flow and water temperature also existed during September of low-flow years 2001 and 2002. These relationships

Figure D17. Comparison of September 2002 daily maximum water temperatures for various Klamath River stations.

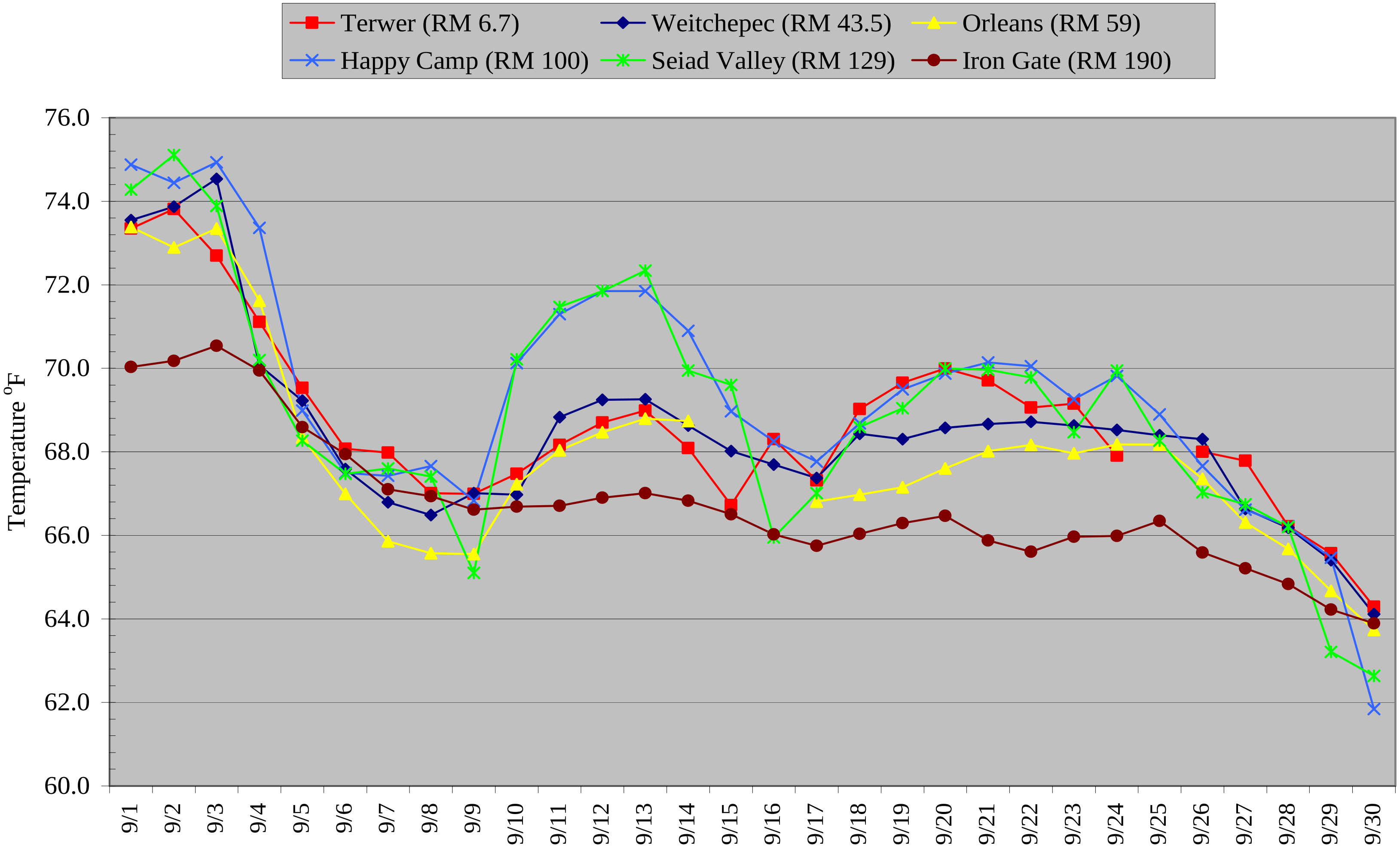
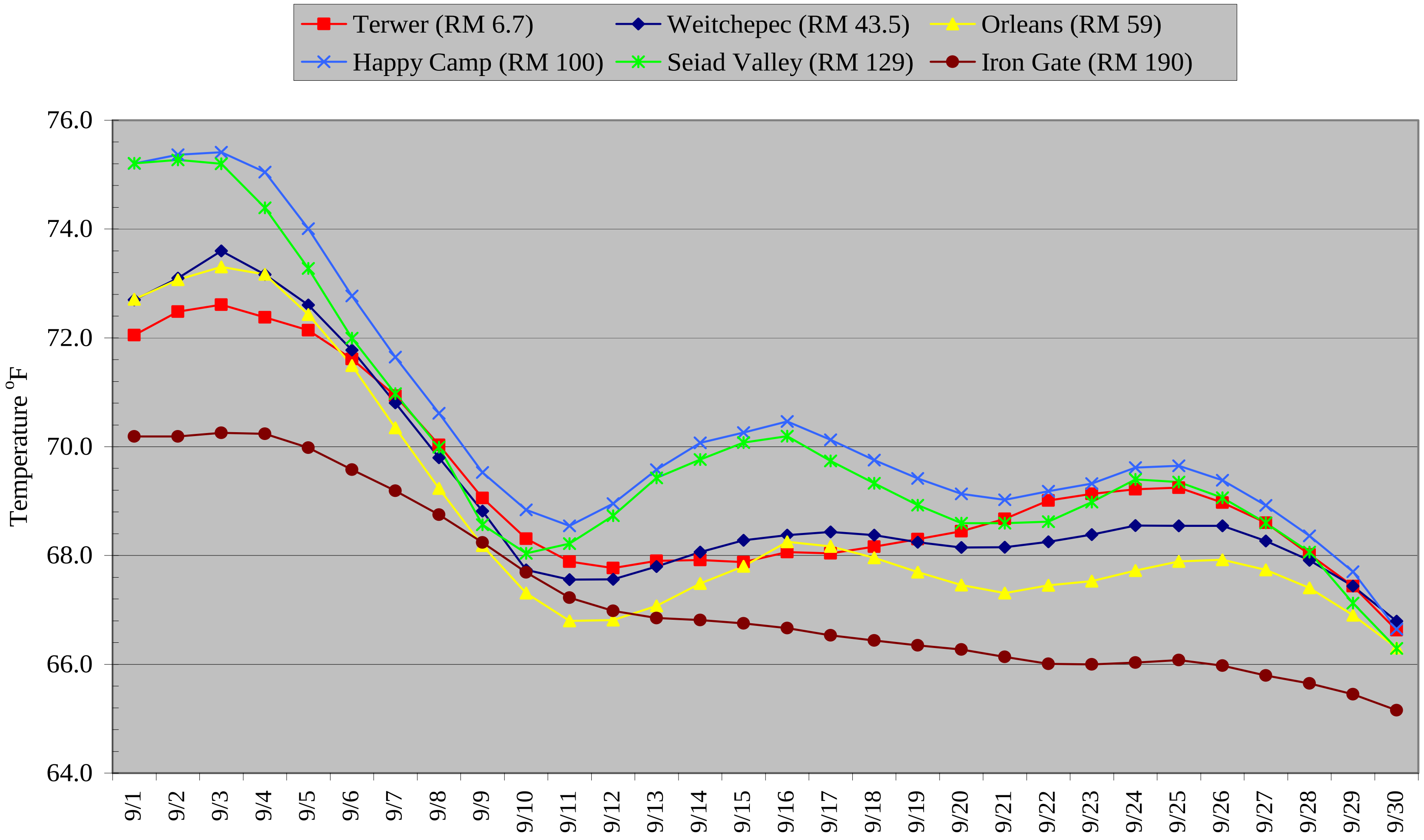


Figure D18. Comparison of September 2002 7-day running averages of daily maximun water temperatures for various Klamath River stations.



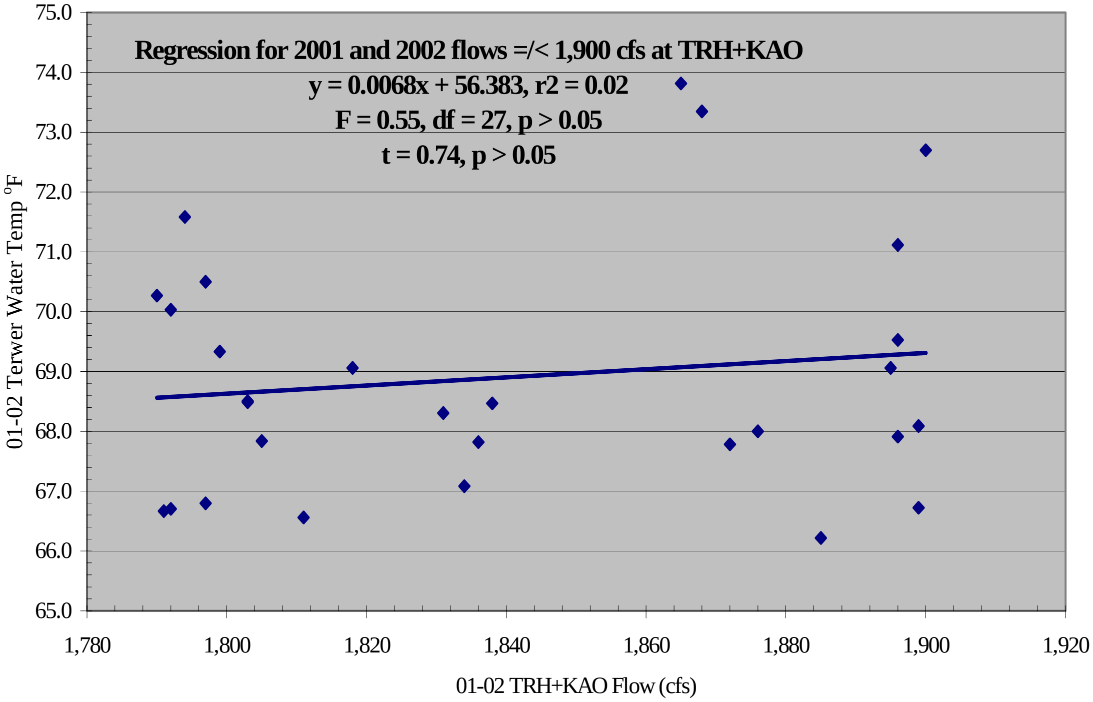
were inverse, meaning that water temperatures declined with increased flow. DFG, therefore, accepts the alternative hypothesis Ha_1, and concludes that flow levels do indeed influence water temperatures in the lower Klamath River fish-kill area during September of low (2001 and 2002) to moderate flow (1999) years. Under higher flow conditions, such as in 1998, flow does not appear to be an important factor in determining water temperatures in the lower river.

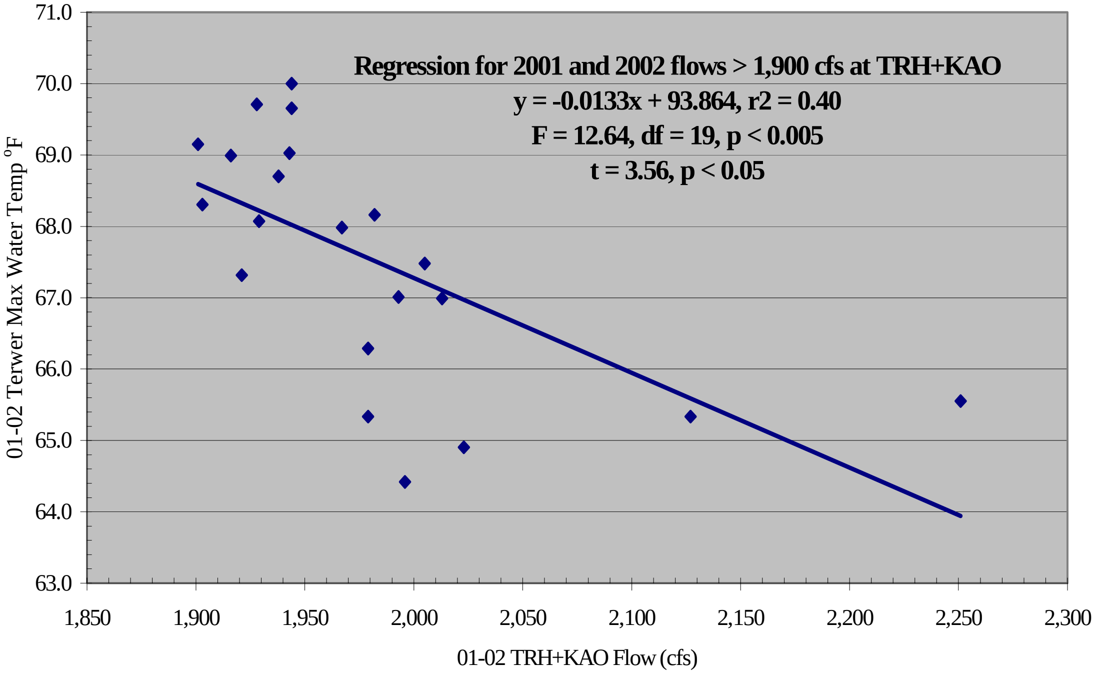
Comparison of regression slope coefficients showed the relationship between flow and water temperature for September 1999, was significantly different from the relationships in 2001 and 2002, when these low-flow years were treated individually and when data for both years were pooled (Figure D2). In the moderate flow year of September 1999, the regression equation indicated water temperatures at Omagaar increased nearly 4 ^{o}F as flow increased from about 2,800 cfs to 3,150 cfs. The low-flow years of 2001 and 2002 showed an opposite trend, with water temperatures at Terwer declining by nearly 4 ^{o}F as flow increased from about 1,800 cfs to 2,250 cfs. DFG, therefore, accepts the alternative hypothesis Ha_2, and concludes that the relationship between flow levels and water temperatures, are different in low-flow versus higher flow years.

Increased flows during September 2002 would likely have reduced water temperatures in the lower Klamath River and provided better conditions for salmonids. Increased flows may have reduced water temperatures in the fish-kill area, throughout September 2002, to levels that were more consistently below EPA guidelines (USEPA 2003) to protect adult Chinook salmon migration (69.8 ^{o}F) and reduce adult lethality (69.8 ^{o}F). However, it is unlikely that water temperatures could have been reduced below the USEPA guidelines to protect adult salmon for high risk from disease pathogens (64.4 ^{o}F). The influence of flow on water temperatures in the lower Klamath River, where the 2002 fish-kill occurred, is an important finding, because flow releases from upstream reservoirs in the Klamath and Trinity rivers represent a controllable factor in the Klamath Basin.

The scattergrams for low-flow years 2001 and 2002, showed a greater variation in water temperatures around the regression line at the lowest flows (Figures D1 and D2). At flows greater than approximately 1,900 cfs for TRH+KAO, water temperatures showed the least variation. By regressing 2001 and 2002 maximum water temperatures at Terwer against flows less than or equal to 1,900 cfs for TRH+KAO, DFG found no significant relationship (Figure D19). In contrast, at flows greater than 1,900 cfs for TRH+KAO, there was a significant relationship between flow and water temperature ($p < 0.005$) with 40 percent of the variation in water temperatures being explained by the variation in flow ($r^2 = 0.40$) (Figure D19). These data suggest there is a critical flow level between 1,900 and 2,000 cfs for TRH+KAO, at which the thermal mass of water is great enough in the lower Klamath River to reduce water temperatures and to ameliorate the influence of atmospheric temperatures on water temperatures. This relationship warrants further investigation as more water temperature data is collected on the Klamath River in the future.

Figure D19. Regression of maximum daily September water temperatures in the lower Klamath River for 2001-2002 at Terwer against average daily September flows at TRH+KAO </= 1,900 cfs and > 1,900cfs. Slopes are significantly different between </= 1,900 cfs and > 1,900 cfs plots (t = 2.13, p < 0.05).





Results of the regression analysis for September 1999 are counterintuitive, and indicate as flows for TRH+KAO increased from about 2,800 cfs to over 3,100 cfs, maximum daily water temperatures at Omagaar also increased ($p < 0.001$, $r^2 = 0.44$) (Figure D2). Out of the four years analyzed, water temperatures during 1999 at Omagaar, were often the lowest and varied the least during September, until they declined sharply in the last few days of the month (Figure D15). Average daily flows for 1999, were relatively consistent and steadily declined through September (Figure D20). It should be noted that flow levels for TRH+KAO during September 14 and 15, 1999, were not used in this analysis, because they were artificially increased by nearly 900 cfs in the Trinity River for the Hoopa Tribe Boat Dance. The combination of low variation and steady decline in daily maximum water temperatures at Omagaar (Figure D15) and average daily flow for TRH+KAO (Figure D20) through September 1999, explains the regression relationship observed between these parameters (Figure D2). This combination of low variation and declining temperature and flow through September is unusual when compared to 1998, 2001, and 2002. As future temperature data is collected under moderate flow conditions in the lower Klamath River, the relationship between flow and water temperature should be clarified to determine if results during September 1999, were due to unusual conditions or represented a predictable pattern.

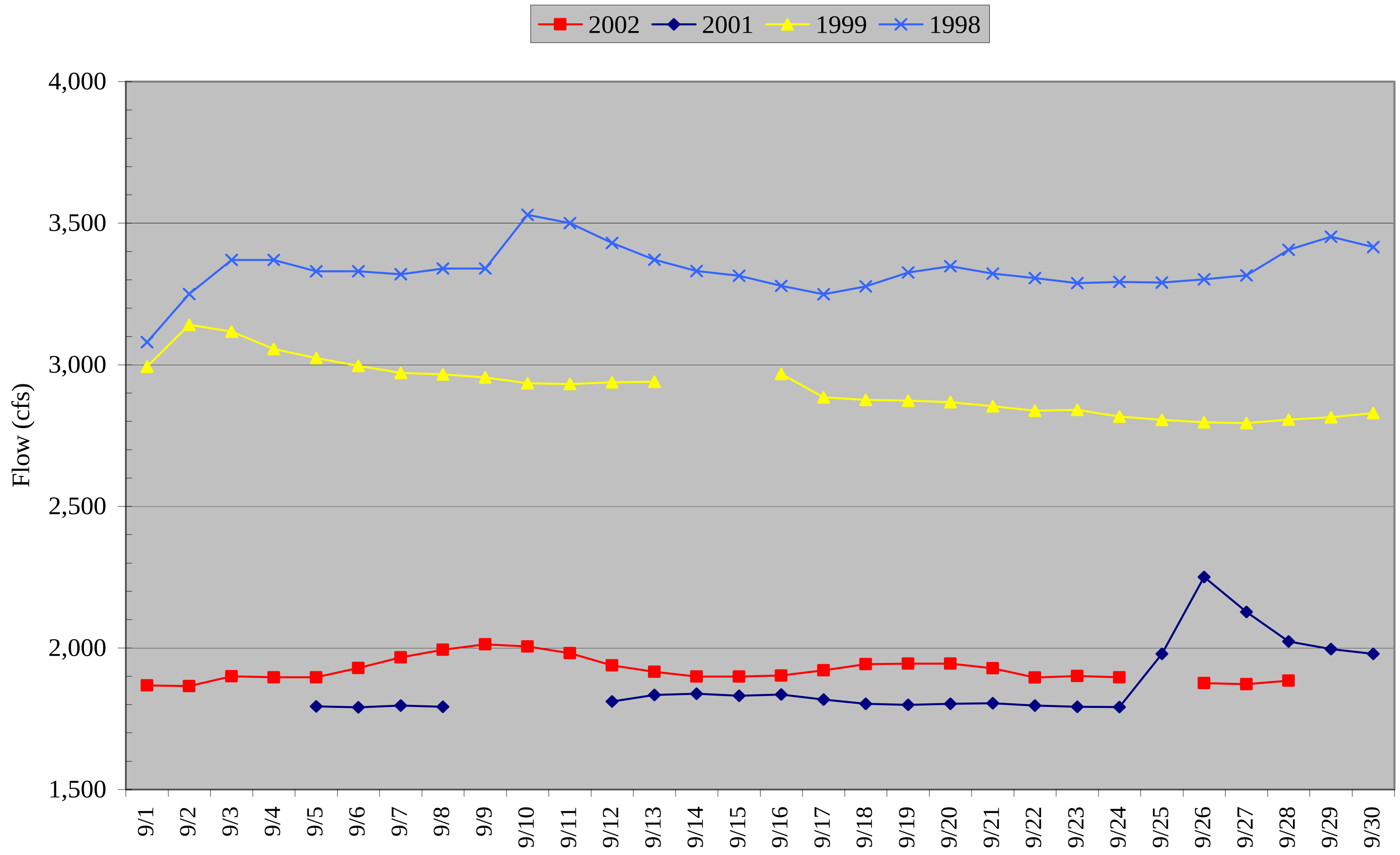
III. D. 4. b. Water Temperature and Air Temperature Relationship

The specific null and alternative hypotheses DFG analyzed related to the effects of air temperatures on water temperatures included:

Ho_3 – Air temperatures do not influence water temperatures in the lower Klamath River fish-kill area.
Ha_3 – Air temperatures do influence water temperatures in the lower Klamath River fish-kill area. If Ha_3 is accepted then test;
Ho_4 – The relationship between air temperatures and water temperatures are not different in low-flow versus higher flow years.
Ha_4 – The relationship between air temperatures and water temperatures are different in low-flow versus higher flow years.

Maximum daily air temperatures at Terwer were significantly correlated to maximum daily water temperatures during September 1998 at Omagaar ($p < 0.025$, $r^2 = 0.20$) and 2002 at Terwer ($p < 0.025$, $r^2 = 0.20$), but not in September 1999 and 2001 (Figure D3). Minimum daily air temperatures at Terwer were significantly correlated to maximum daily water temperatures during only September 1999 at Omagaar ($p < 0.01$, $r^2 = 0.23$), but not in September 1998, and not in 2001 and 2002 at Terwer (Figure D4). When September daily maximum water temperatures at Omagaar (1998 and 1999) and Terwer (2001 and 2002) were regressed with daily maximum and daily minimum air temperatures upriver at Orleans (rather than air temperatures at Terwer), DFG observed more years with significant and stronger correlations (Figures D5 and D6). Significant relationships were observed between maximum daily air temperatures at Orleans and

Figure D20. Average daily September flows for TRH+KAO during 1998, 1999, 2001 and 2002.



maximum daily water temperatures during September at Omagaar in 1998 ($p < 0.001$, $r^2 = 0.61$), and at Terwer in 2001 ($p < 0.005$, $r^2 = 0.37$) and 2002 ($p < 0.01$, $r^2 = 0.27$) (Figure D5). Significant relationships were also observed between minimum daily air temperatures at Orleans and maximum daily water temperatures during September at Omagaar in 1998 ($p < 0.001$, $r^2 = 0.56$) and 1999 ($p < 0.005$, $r^2 = 0.24$), and at Terwer in 2002 ($p < 0.01$, $r^2 = 0.24$) (Figure D6).

When September daily maximum and minimum air temperatures at Orleans were converted to seven-day running averages, and regressed against daily maximum water temperatures at Omagaar (1998 and 1999) and Terwer (2001 and 2002), DFG observed even stronger correlations (Figures D8 and D10). Significant relationships were observed between seven-day running averages of maximum daily air temperatures at Orleans and maximum daily water temperatures during September at Omagaar in 1998 ($p < 0.001$, $r^2 = 0.92$), and at Terwer in 2001 ($p < 0.001$, $r^2 = 0.50$) and 2002 ($p < 0.001$, $r^2 = 0.37$) (Figure D8). Significant relationships were also observed between seven-day running averages of minimum daily air temperatures at Orleans and maximum daily water temperatures during September at Omagaar in 1998 ($p < 0.001$, $r^2 = 0.78$) and 1999 ($p < 0.025$, $r^2 = 0.18$), and at Terwer in 2001 ($p < 0.05$, $r^2 = 0.19$) and 2002 ($p < 0.001$, $r^2 = 0.52$) (Figure D10).

As a result of these analyses, DFG accepts alternative hypothesis Ha_3 and concludes air temperatures do influence water temperatures in the lower Klamath River fish-kill area. We found that upriver air temperatures have a stronger influence on water temperatures in the fish-kill area than air temperatures in the Terwer area. This seems logical, because diel and day-to-day differences of air temperatures in the lowest reaches of the Klamath Basin are tempered by the marine layer (USFS 1994). Seven-day running averages of maximum and minimum daily air temperatures at Orleans, provided the strongest correlations, and represented our best estimators of maximum water temperatures during September in the lower Klamath River.

When regression analyses were compared using seven-day running averages of maximum daily September air temperatures at Orleans, versus daily maximum water temperature at Omagaar in 1998, and pooled data at Terwer for 2001 and 2002, there was a significant difference between slope coefficients (Figure D9). Regression analyses using seven-day running averages of minimum daily September air temperatures at Orleans, showed significant differences between slope coefficients for September 1998 versus 1999, and 1998 versus data pooled for 2001 and 2002 (Figure D11). However, there was not a significant difference between 1999 versus 2001 and 2002.

As a result of these analyses, DFG accepts alternative hypothesis Ha_4 and concludes the relationship between air temperatures and water temperatures are different in low-flow (2001 and 2002) versus the higher-flow year of 1998. However, when comparing the moderate flow year of 1999 to low-flow years 2001 and 2002, we must accept the null hypothesis Ho_4 and conclude the relationship between air temperatures and water temperatures are the same in low-flow versus higher flow years. Therefore, under highest flow conditions (1998), the relationship between air and water temperatures is significantly different than in moderate flow (1999) and low-flow years (2001 and 2002), but moderate and low-flow years are not significantly different.

The strongest correlations between air and water temperatures were observed during September 1998, which was the highest flow year analyzed. Seven-day maximum air temperatures at Orleans, explained 92% ($r^2 = 0.92$) of the variation in maximum water temperatures at Omagaar (Figure D9), and seven-day minimum air temperatures at Orleans, explained 78% ($r^2 = 0.78$) of the variation in maximum water temperatures at Omagaar (Figure D11). Regression analyses of pooled data for the low-flow years of 2001 and 2002, comparing seven-day maximum air temperatures at Orleans ($r^2 = 0.48$) (Figure D9) and seven-day minimum air temperatures at Orleans ($r^2 = 0.27$) (Figure D11), explained much less of the variation in daily water temperatures at Terwer. It is noteworthy that the strongest correlations between air and water temperatures in 1998, represented the highest flow year in our analysis, and was the only year where flow was not significantly correlated with water temperature. This may suggest that under high-flow conditions in the lower Klamath River, flow has little influence, and atmospheric temperatures become the primary factor determining water temperatures. However, it also suggests that under a low-flow scenario, flow and atmospheric temperatures play a joint role in determining water temperatures in the lower Klamath River.

III. D. 4. c. Water Temperature and Fish Stress in the Fish-kill Area

The specific null and alternative hypotheses DFG analyzed related to the effects of water temperatures on fish stress included:

> Ho_5 – Water temperatures during September 2002 were not at levels that stress fish, and thus, were not a factor in the fish-kill.
> Ha_5 – Water temperatures during September 2002 were at levels that stress fish, and thus, were a factor in the fish-kill. If Ha_5 is accepted then test;
> Ho_6 – Water temperatures during September 2002 were not different than in past years when fish-kills did not occur.
> Ha_6 – Water temperatures during September 2002 were different than in past years when fish-kills did not occur.

Daily maximum water temperatures at Terwer ranged from 64.3 ^{o}F to 73.8 ^{o}F during September 2002 (Figure D15). With the exception of September 30, 2002, these temperatures always exceeded the proposed USEPA (2003) guideline, of a daily temperature consistently below 64.4 ^{o}F for reduction of high risk from disease pathogens for adult salmonids. Daily maximum water temperatures also exceeded the proposed USEPA (2003) guideline, of a daily average temperature of 69.8 ^{o}F for protection of migrating adult salmonids, in the first four days of September and on September 20, 2002. Seven-day running averages of maximum daily water temperatures at Terwer ranged from 66.6 ^{o}F to 72.6 ^{o}F during September 2002 (Figure D16). These temperatures always exceeded the recommended guideline for protection of adult salmon during the summer (64.4 ^{o}F as a seven-day average maximum daily temperature) (USEPA 2003). Seven-day running averages of maximum temperatures also exceeded the proposed USEPA (2003) guideline, during the first eight days of September 2002, for reduction of lethality to migrating adult salmon (a weekly constant temperature of 69.8 ^{o}F). As a result of these comparisons of actual water temperatures to proposed USEPA criteria, DFG accepts alternative hypothesis Ha_5 and concludes water temperatures during the September 2002 fish-kill were at levels that stress fish, and thus, were a likely factor in the fish-kill.

Data provided by the Yurok Tribe showed daily maximum water temperatures in September of 1998, 1999, 2001, and 2002, always (with the exception of three days) exceeded the proposed USEPA (2003) guideline, for reduction of high risk from disease pathogens for adult salmonids (a daily temperature consistently below 64.4 ^{o}F) (Figure D15). Temperatures in the first half of September 2002 were often lower than in other years. Temperatures exceeded the proposed USEPA (2003) guideline, for protection of migrating adult salmonids (daily average temperature of 69.8 ^{o}F), during most of the first half of September 1998 and September 5-8, 2001. As in September 2002, 7-day running averages of maximum temperatures in 1998, 1999, and 2001, always exceeded the recommended USEPA criterion for protection of adult salmon during the summer (64.4 ^{o}F as a seven-day average maximum daily temperature) (Figure D16). Seven-day running averages of maximum temperatures in September 1998 and 2001 exceeded the proposed USEPA (2003) guideline for reduction of lethality of migrating adult salmon (weekly constant temperature of 69.8 ^{o}F) more often, than in September 2002.

Through multiple regression analysis of 2001 and 2002 data, DFG was able to estimate, predicted maximum daily water temperatures at Terwer for September in other low-flow years (1973, 1981, 1988, 1991, 1992 and 1994), where air temperature data was available. With the exception of the first two days in September, actual 2002 temperatures fell within the range of predicted temperatures for other low-flow years (Figure D13). With the exception of the last week in September 1981, temperatures in all low-flow years exceeded the proposed USEPA (2003) guideline for reduction of high risk from disease pathogens for adult salmonids (a daily temperature consistently below 64.4 ^{o}F). Furthermore, in every low-flow year except 1973 and 1992, temperatures exceeded the proposed USEPA (2003) guideline for protection of migrating adult salmonids (daily average temperature of 69.8 ^{o}F). Comparison of data with predicted values using 7-day running averages, also showed 2002 temperatures fell within the range predicted for other low-flow years (Figure D14). With the exception of the last three days in September 1981, 7-day running averages of daily maximum temperatures in low-flow years, always exceeded the recommended USEPA guideline for protection of adult salmon during the summer (64.4 ^{o}F as a seven-day average maximum daily temperature). The years of 1973 and 1992 stand out as the only low-flow years, where temperatures did not exceed the proposed USEPA (2003) guideline for reduction of lethality of migrating adult salmon (weekly constant temperature of 69.8 ^{o}F).

The preponderance of evidence, from actual and predicted temperature data in the lower Klamath River, showed temperatures leading up to and during the fish-kill in 2002 at levels stressful to salmon, but not at levels unusually high when compared to past years.

Consequently DFG cannot reject the null hypothesis Ho_6 and concludes that water temperatures during the September 2002 fish-kill were not different than in past years when fish-kills did not occur. Water temperatures in the lower Klamath River during September are nearly always high enough to be stressful to salmon and 2002 was not unusual. Therefore, water temperatures in September 2002, by themselves, cannot explain the fish-kill.

III. D. 4. d. Water Temperature and Fish Stress Upriver

The specific null and alternative hypotheses DFG analyzed related to the effects of water temperatures on fish stress upstream of the fish-kill area included:

> Ho_7 – Water temperatures in the Klamath River upstream of the fish-kill area during September 2002 were not lethal to salmon and steelhead and fish moving upstream would not have died.
>
> Ha_7 – Water temperatures in the Klamath River upstream of the fish-kill area during September 2002 were lethal to salmon and steelhead and fish moving upstream would have died.

Water temperatures throughout the Klamath River during September 2002 almost always exceeded the proposed USEPA (2003) guideline for reduction of high risk from disease pathogens for adult salmonids (a daily temperature consistently below 64.4 ^{o}F) (Figure D17). Temperatures also exceeded the proposed USEPA (2003) guideline for protection of migrating adult salmonids (daily average temperature of 69.8 ^{o}F) at all stations on the Klamath River during the first four days of September 2002, from September 10 through 14, 20 through 22, and 24, 2002 at Happy Camp and Seiad Valley. Seven-day running averages of daily maximum temperatures at all stations in the Klamath River always exceeded the recommended USEPA guideline for protection of adult salmon during the summer (64.4 ^{o}F as a seven-day average maximum daily temperature) (Figure D18). Seven-day averages also exceeded the proposed USEPA (2003) guideline for reduction of lethality of migrating adult salmon (weekly constant temperature of 69.8 ^{o}F) at most stations during the first week of September and on September 14 through 16, 2002 at Happy Camp and Seiad Valley. Therefore, temperatures throughout the Klamath River from Iron Gate Dam to Terwer during September 2002 were at levels known to be stressful to adult salmonids.

The lowest temperatures were most often observed at the upper most station on the Klamath River below Iron Gate Dam (RM 190) (Figures D17 and D18). Highest temperatures were often observed at the mid-river stations at Seiad Valley (RM 129) and Happy Camp (RM 100). In the lowest third of the river at Orleans (RM 59), Weitchepec (RM 43.5) and Terwer (RM 6.7), temperatures were often intermediate, falling between the highs observed at Happy Camp and Seiad Valley and the lows found below Iron Gate Dam. Adult fall-run Chinook salmon, migrating upstream of the fish-kill area, would have periodically encountered higher more stressful temperatures, particularly from September 10 through 14, 2002 in the mid-reaches of the Klamath River. Adult fall-run salmon were observed at the fish counting facility located on the Shasta River near its confluence with the Klamath River (about RM 177) beginning on September 9, peaking on September 28 and extending into November 2002 (DFG 2003a). Some of these fish would have migrated through the Happy Camp and Seiad Valley reaches of the Klamath River when temperatures were above 70 °F. Yet there were no reports of an adult salmon fish-kill in the middle and upper reaches of the Klamath River in September 2002. Although, temperatures throughout the Klamath River in September 2002 were at levels known to be stressful to adult salmonids, there is no evidence to suggest that upstream temperatures were lethal to adult salmon and steelhead. Consequently, DFG has accepted the null hypothesis Ho_7 and concludes that water temperatures in the Klamath River upstream of the fish-kill area during September 2002 were not lethal to salmon and steelhead and fish moving upstream would not have died.

In summary, during September of low-flow years such as 2002, there is a correlation between water temperatures in the fish-kill area and flow levels, such that increasing flows can produce lower water temperatures. There appears to be a critical level above 1,900 cfs for TRH+KAO where flow becomes an important factor in controlling water temperature. Below 1,900 cfs, there is no significant relationship. During high-flow years such as 1998, flow levels do not appear to influence water temperatures in the fish-kill area. It appears that flow, which is a controllable factor in the Klamath and Trinity rivers, could have been increased in September 2002 to reduce water temperatures and stress to salmonids in the fish-kill area. However, it is unlikely that temperatures could have been reduced below the USEPA guideline for reduction of high risk from disease pathogens for adult salmonids (a daily temperature consistently below 64.4 °F).

Air temperatures at Orleans correlated well with water temperatures in the lower Klamath River. During low-flow years, air temperatures at Orleans can account for about half of the variation in water temperatures within the fish-kill area. The correlation between air temperatures and water temperatures in the lower river is much stronger in high-flow years such as 1998, when nearly all the variation in water temperatures can be explained by air temperatures at Orleans.

Water temperatures during September 2002, were at levels known to be stressful to adult salmonids. Temperatures, however, were not unusually high when compared to past years. Temperatures in the lower Klamath River are at levels stressful to adult salmonids during September of nearly every year. Consequently, water temperatures in and of themselves, did not result in the 2002 fish-kill.

Water temperatures in the mid-reaches of the Klamath River at Happy Camp and Orleans were periodically higher than those in the fish-kill area during September 2002. Although temperatures throughout the river were at levels stressful to salmonids, there is no evidence to suggest they were lethal to salmon. Adult salmon were observed beginning on September 9 with the run peaking on September 28 and continuing through November 2002, on the Shasta River which enters the Klamath about 13 miles below Iron Gate Dam. Many of these fish had to traverse all of the mid and lower reaches of the Klamath River during September in order to reach the Shasta River. Yet these fish survived the thermal conditions in the Klamath throughout their upstream migration in September 2002, and no adult fish-kills were reported in the mid and upper reaches of the river.

III. E. Dissolved Oxygen;

III. E. 1. Introduction

Low dissolved oxygen (DO) concentrations can stress salmonids and cause mortality directly or through increased susceptibility to disease and predation (USEPA 1986 and USFWS 2001). Dissolved oxygen levels are potentially limiting salmonid production in the Klamath River (Bartholow 1995, Campbell 1995, USFWS 1997, 2001).

Oxygen dissolves in water through gas exchange at the water's surface or through photosynthesis by aquatic plants and algae. The amount of oxygen dissolved in water is a function of elevation, atmospheric pressure, and water temperature (CDWR 1986a, 1987). Decreased elevation, increased atmospheric pressure, and decreased water temperature result in higher concentrations of DO and vice versa. During daylight hours, oxygen production is at its greatest and can result in 100% saturation or even supersaturation (Wetzel 1983). Percent saturation is a measure of the potential concentration of oxygen dissolved in water at a given elevation, pressure and temperature; divided by the actual measured DO concentration and multiplied by 100.

Dissolved oxygen is removed from water through gas exchange with the atmosphere, respiration by aquatic plants, fish, invertebrates and microbes, and chemical reactions. At night and during periods of low light, photosynthesis is greatly reduced. Respiration by aquatic organisms can then cause a net decrease in the DO concentration. In water bodies where biomass and biological oxygen demands are high, DO levels may become low enough to be stressful or lethal to aquatic species (USFWS 2001).

To maintain a healthy aquatic environment, DO levels should be near saturation for coldwater systems (CDWR 1986a, 1987). CDWR (1988) reported that DO at a minimum of 6.0 mg/l, is adequate for salmon according to Davis (1975). The North Coast Regional Water Quality Control Board (NCRWQCB) Basin Plan standard, calls for a minimum DO level of 8.0 mg/l for the Klamath River below Iron Gate Dam (NCRWQCB 1994). For waters designated as cold without specific DO criteria, concentrations should not be reduced below 6.0 mg/l according to the Basin Plan. The Klamath River is on the NCRWQCB 303 (d) list for having DO levels that do not meet Basin Plan objectives. USEPA recommends a DO criterion of 4.0 mg/l to avoid acute mortality in adult and juvenile salmonids (USEPA 1986).

The purpose of this section is to address the null-hypothesis; DO concentrations in September 2002, prior to and during the lower Klamath River fish-kill, were not at levels lethal to fish and did not cause the fish-kill. The alternative hypothesis is; DO concentrations in September 2002, prior to and during the lower Klamath River fish-kill, were at levels lethal to fish and caused the fish-kill. A second null-hypothesis considered in this section is; DO concentrations in the Klamath River during August and September 2002 were not stressful to salmon and were not out of the ordinary when compared to past years when fish-kills did not occur. The alternative hypothesis is; DO concentrations in the Klamath River during August and September 2002 were stressful to salmon and unusually low compared to past years when fish-kills did not occur. These hypotheses will be addressed by characterizing and evaluating DO concentrations existing in the lower Klamath River immediately before and during the 2002 fish-kill, comparing those values to established recommendations and criteria for DO levels, and comparing 2002 data with past years where information is available.

III. E. 2. Methods

To evaluate the potential effects of DO concentrations on the September 2002 fish-kill, DFG reviewed past reports and obtained data from the Yurok Tribe and USFWS. The focus of our analysis was for data collected within or near the fish-kill area.

The Yurok Tribe provided provisional DO records that were cooperatively collected with the USFWS for August and September 2001 and 2002, in the lower reaches of the Klamath and Trinity rivers. These data were available for three stations above the area of the fish-kill and included the Klamath River at Martins Ferry (RM 40.4) and at Weitchepec (RM 43.5), and the Trinity River at the mouth (RM 0.5 above the confluence with the Klamath River at RM 43.5). Additional provisional data were provided for the Klamath River at Terwer (RM 6.7) for August 19 through September 27, 2001 and 2002. All data provided by the Yurok Tribe were provisional and subject to change after they have been quality controlled.

Dissolved oxygen records for the Klamath River below Iron Gate Dam (RM 189.5), at Seiad Valley (RM 128.5), and at Orleans (RM 59.1) were available for 2000, 2001 and 2002 (Karuk Tribe 2002, 2003). These stations are a substantial distance upstream of the fish-kill area, and were not considered in this report.

III. E. 3. Results

The Yurok and USFWS provisional DO concentrations at Terwer, in the week prior to and at the beginning of the fish-kill, never fell below 7.0 mg/l from September 12 to 19, 2002 (Figure E1). Diurnal DO fluctuations over this time period, ranged from a low of nearly 7.0 mg/l to a high of about 9.6 mg/l. Average daily DO concentrations never fell below 7.0 mg/l during mid-August through September (Figure E2). From mid-August to mid-September (before the fish-kill) and after September 18 (during the fish-kill), minimum daily DO concentrations often fell below 7.0 mg/l, but never dropped below 6.0 mg/l (Figure E2).

Provisional DO levels at Martins Ferry for August and September of 2001 and 2002 showed similar trends (Figure E3). This station is just above the upper limit of the fish-kill. Diurnal fluctuations ranged between 1.5 and 2.0 mg/l during both years. Minimum DO levels seldom dropped below 6.0 mg/l during August and 7.0 mg/l during September. Concentrations were often higher in August of 2002 compared to 2001. During September, diurnal fluctuations appeared to be somewhat greater in 2001 than in 2002.

Figure E1. Dissolved oxygen concentrations from Klamath River at Terwer on a 30 minute recording interval from September 12, 2002 at 11:00 am to September 19, 2002 at 4:00 pm. Provisional data provided by the Yurok Tribe.

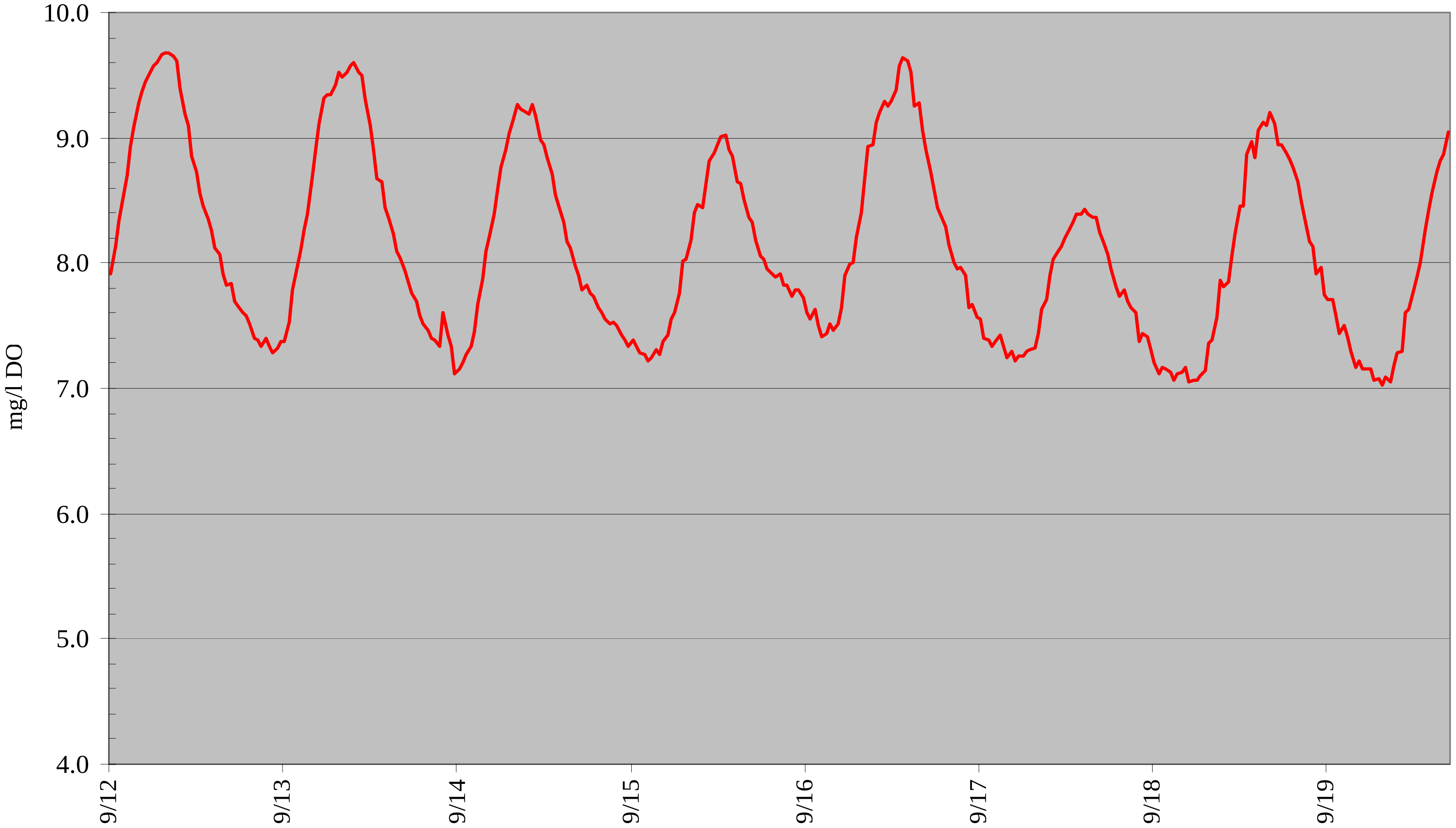


Figure E2. Minimum and average daily dissolved oxygen concentrations from the Klamath River at Terwer for August 19 - September 27 of 2001 and 2002. Provisional data provided by the Yurok Tribe.

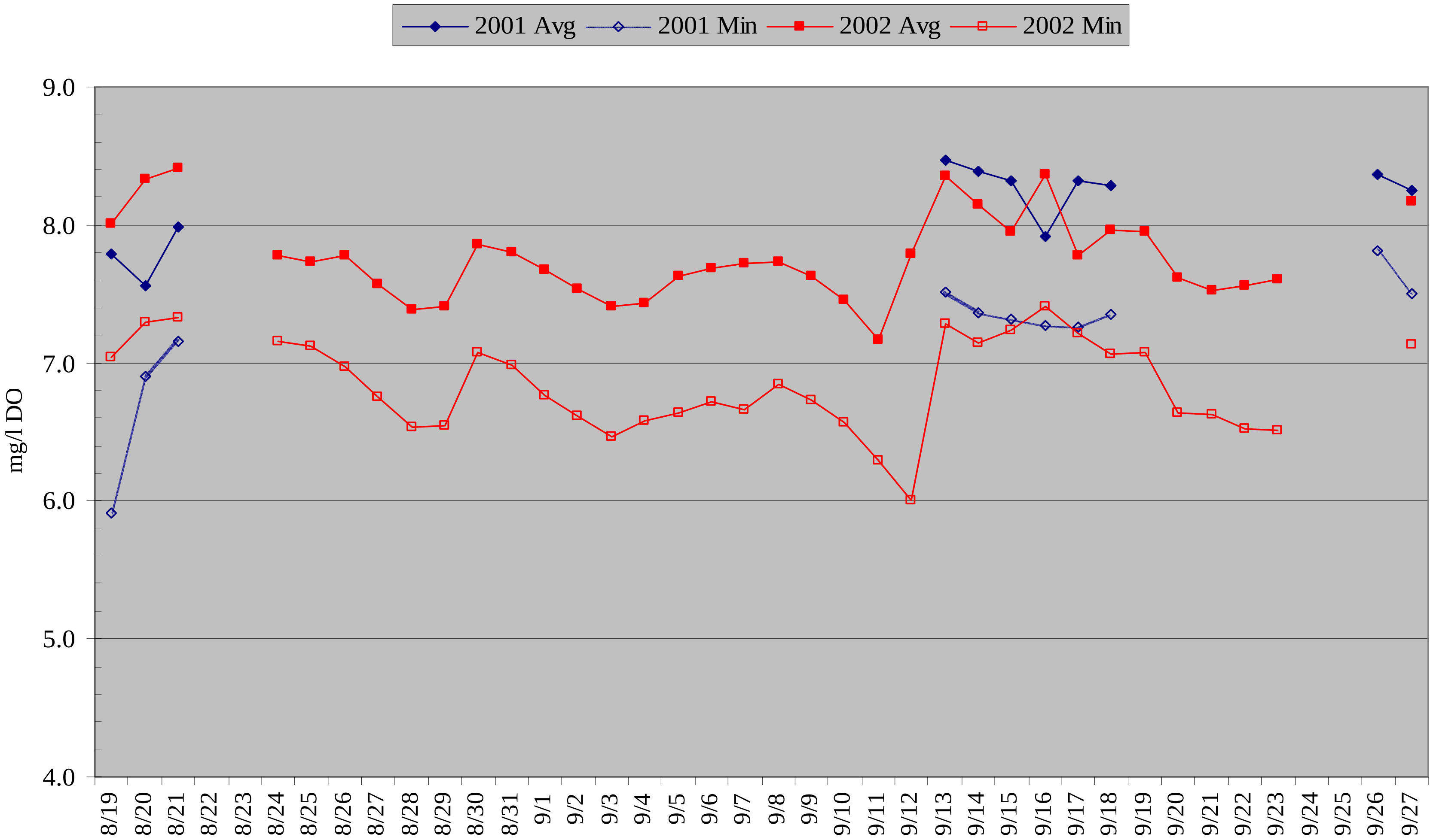
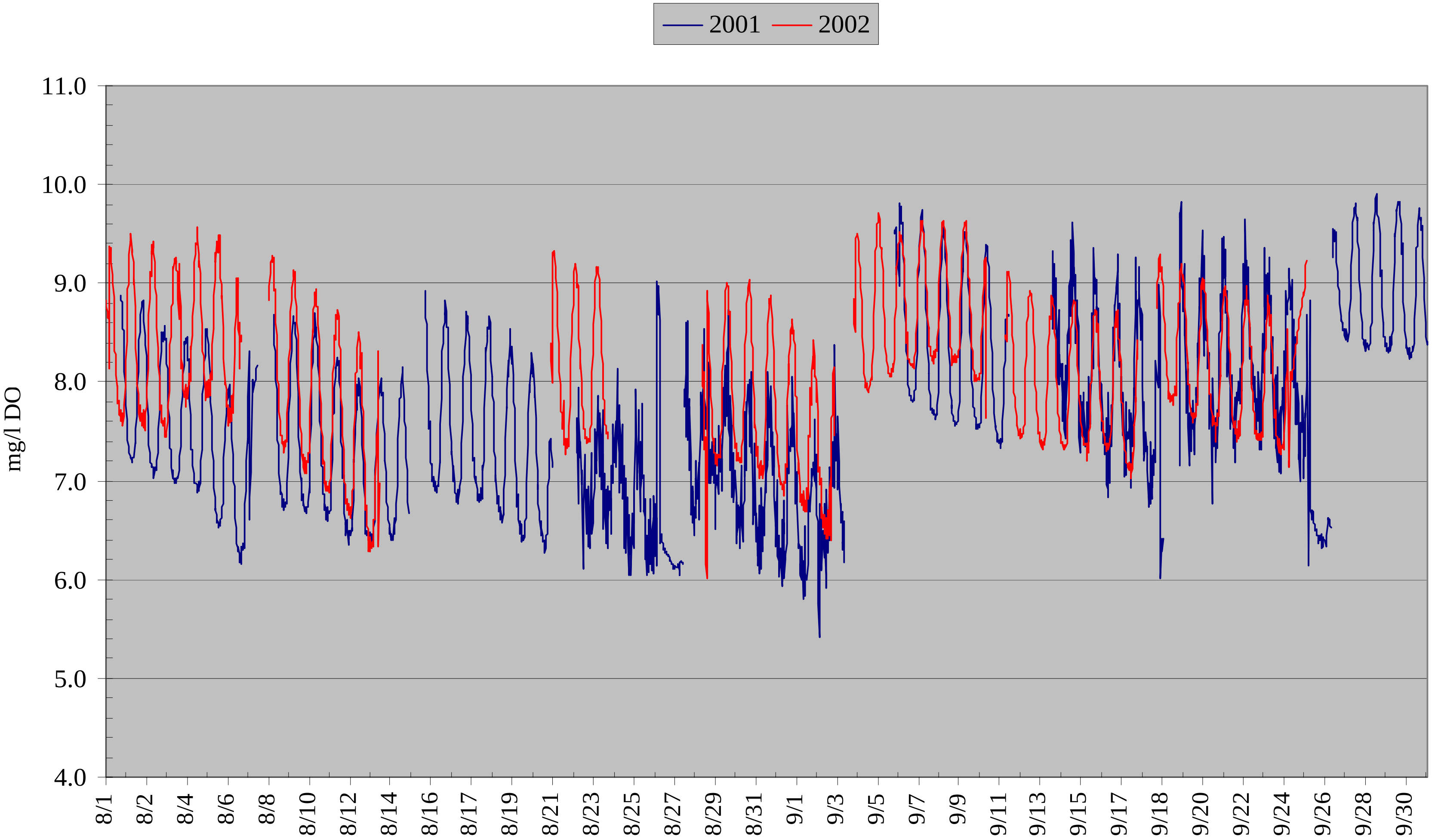


Figure E3. Dissolved oxygen concentrations for Klamath River at Martins Ferry recorded at 30 minute intervals for August - September 2001 and 2002. Provisional data provided by the Yurok Tribe.



After the first few days in September, DO concentrations never fell below 7.0 mg/l during 2002, while during mid September 2001 concentrations occasionally dropped below 7.0 mg/l, but never below 6.0 mg/l.

Provisional data for the Trinity River near the mouth was less complete for August and September of 2001 and 2002 (Figure E4). DO concentrations were somewhat higher in September than August. Daily diurnal fluctuations were less than 1.0 mg/l. With the exception of two data points in 2001, DO levels never fell below 7.0 mg/l.

Provisional DO data for the Klamath River at Weitchepec (Figure E5) showed similar trends as described for Martins Ferry. DO levels were generally less in August than September of both years. Daily diurnal fluctuations were often greater at Weitchepec than downstream and usually exceeded 2.0 mg/l. Daily minimum DO concentrations in 2001 often dropped below 7.0 mg/l and occasionally dropped below 6.0 mg/l. In 2002, DO levels were often slightly higher than in 2001 and never fell below 6.0 mg/l. Dissolved oxygen concentrations dropped below 7.0 mg/l on two days in September 2002. The highest concentrations observed for this station ranged between 10.0 mg/l and 12.4 mg/l at the end of September 2002.

III. E. 4. Findings

Dissolved oxygen concentrations in the lower Klamath and Trinity rivers, during August and September 2002, never approached the USEPA recommended criterion of 4.0 mg/l to avoid acute mortality in adult and juvenile salmonids. Dissolved oxygen concentrations for the Klamath River at Terwer (Figures E1 and E2), within the fish-kill area, and at Martins Ferry (Figure E3) and at Weitchepec (Figure E5), just above the fish-kill area, never fell below 6.0 mg/l either prior to or during the fish-kill in August and September 2002. In addition, DO concentrations at the mouth of the Trinity River (Figure E4), which enters the Klamath River at Weitchepec, never dropped below 7.0 mg/l during the same time frame. Although provisional, these data indicate DO concentrations were adequate for the survival of adult salmon in the lower Klamath River. Consequently, DFG accepts the null-hypothesis that DO concentrations in September 2002, prior to and during the lower Klamath River fish-kill, were not at levels lethal to fish, and did not cause the fish-kill.

Dissolved oxygen levels in the lower Klamath and Trinity River often dropped below the NCRWQCB Basin Plan objective of 8.0 mg/l in August and September 2001 and 2002 (Figures E1-E5). These data are consistent with the NCRWQCB decision to include the Klamath River below Iron Gate Dam on the 303 (d) list of impaired water bodies. During August and September 2002 at Terwer, at Martins Ferry, at Weitchepec and at the mouth of the Trinity River, DO concentrations never dropped below 6.0 mg/l. Dissolved oxygen levels of 6.0 mg/l have been reported to be adequate for salmon (Davis 1975) and represent the overall DO standard for cold-water habitats in California. Dissolved oxygen concentrations in the Klamath River at Martins Ferry (Figure E3), and at Weitchepec (Figure E5) in August and September of 2001 were often lower than in 2002, and occasionally fell below 6.0 mg/l. Consequently, DO conditions in 2002, just above

Figure E4. Dissolved oxygen concentrations for Trinity River near the mouth recorded at 30 minute intervals for August - September 2001 and 2002. Provisional data provided by the Yurok Tribe.

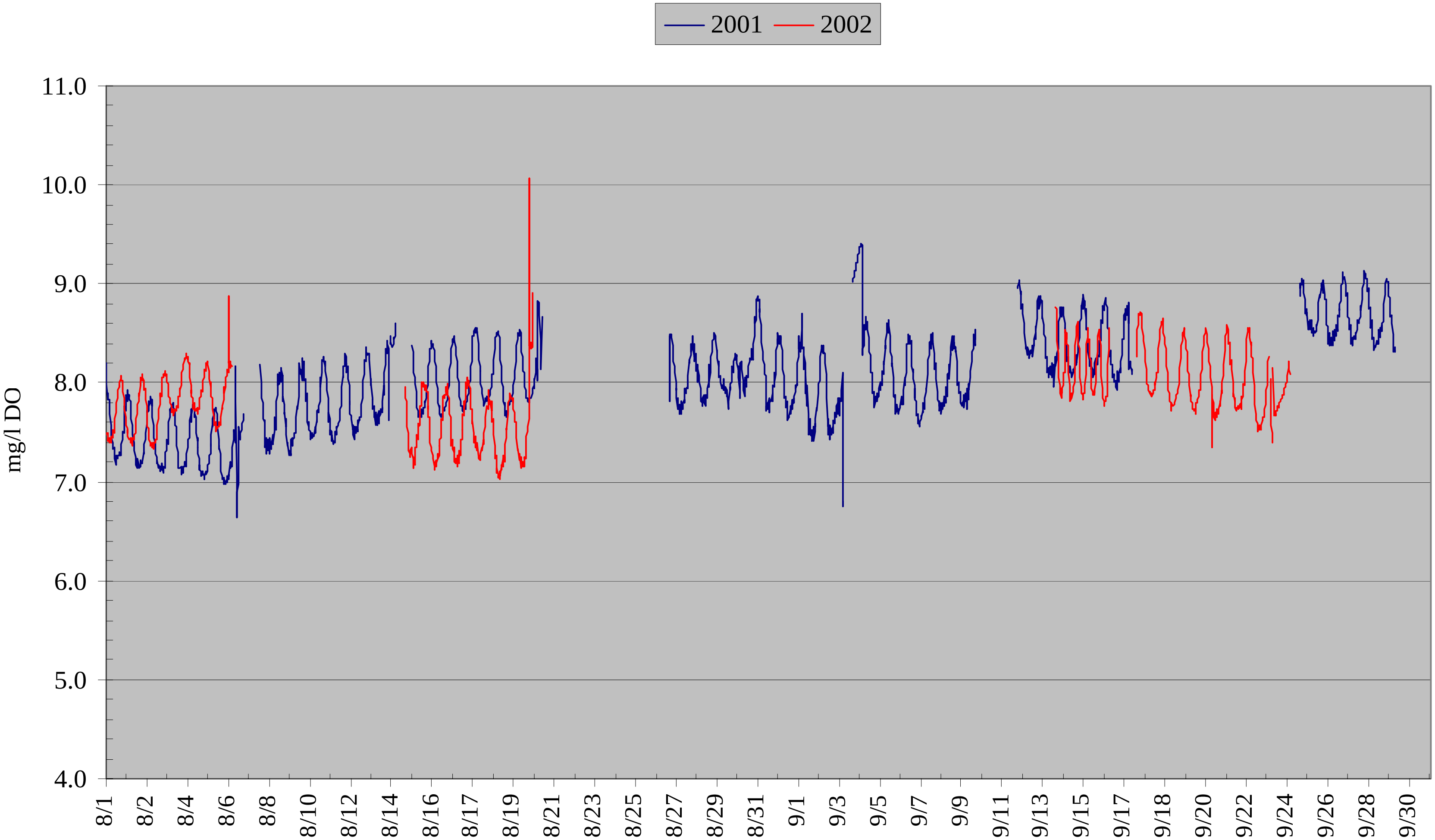
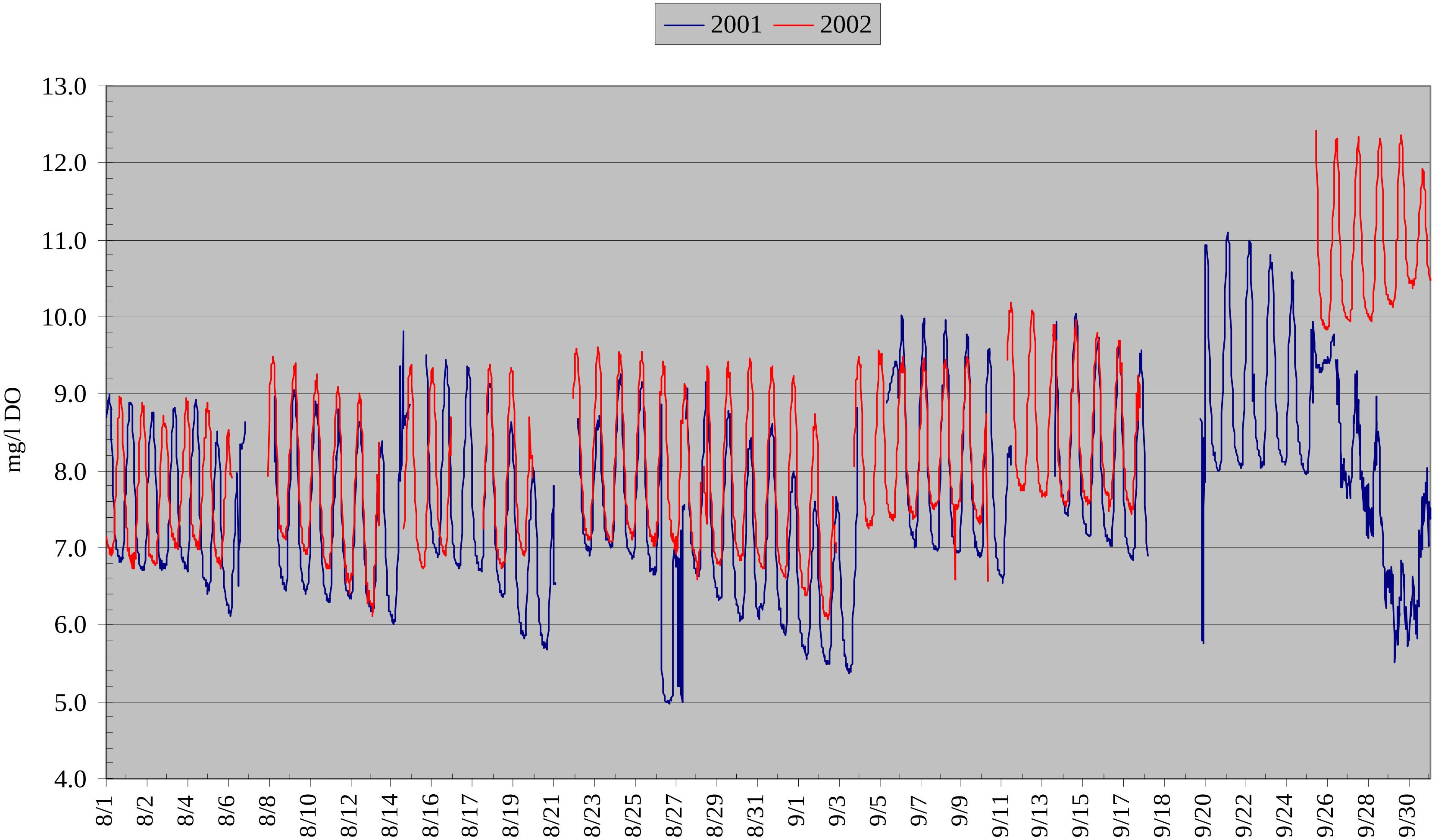


Figure E5. Dissolved oxygen concentrations for Klamath River at Weitchepec recorded at 30 minute intervals for August - September 2001 and 2002. Provisional data provided by the Yurok Tribe.



the fish-kill area, were marginally better for fish than in 2001 when a fish-kill did not take place. Dissolved oxygen records at Terwer, for August 19 through September 27, 2001were limited by equipment failures. Minimum DO levels dropped below 6.0 mg/l on August 19, 2001. Since DO levels within and just above the fish-kill area during August and September of 2002 never approached lethal levels and never fell below adequate levels for salmon, DFG accepts the first half of the null-hypothesis that DO concentrations in the Klamath River during August and September 2002 were not stressful to salmon. Although two years of data (2001 and 2002) are inadequate to draw a solid conclusion, there is no evidence with which DFG could reject the second half of the null-hypothesis that DO concentrations in the Klamath River during August and September 2002 were not out of the ordinary when compared to past years when fish-kills did not occur.

In summary, DO measurements taken prior to and during the September 2002 fish-kill, were not at levels lethal to salmon. Therefore, DO concentrations were not a likely cause of immediate mortality to salmon and steelhead within the fish-kill area. Measured DO levels, prior to and during the fish-kill, were also found to be adequate for salmon. Therefore, DO concentrations were not a likely source of stress to salmonids leading to the disease epizootic. There is no evidence to suggest that DO levels in the lower Klamath River were unusually low in 2002. Dissolved oxygen concentrations were slightly higher in 2002 than in 2001 when a fish-kill did not take place.

III. F. Fish Passage and River Geomorphology;

III. F. 1. Introduction

Physical impediments to fish passage can occur, when hydraulic conditions in a stream exceed the fishes swimming or leaping ability. A large number of fish were concentrated in the lower Klamath River at the time of the fish-kill. It has been speculated that shallow depths over riffles due to low-flow may have impaired upstream movement of salmon, and contributed to the fish-kill by causing abnormally high fish densities in pools below riffles. Thompson (1972) and Lauman (1976) have recommended minimum depth criteria for passage of adult salmon and steelhead. Those recommendations for minimum depths to allow adequate passage of fish migrating upstream were 0.8 feet (9.6 inches) for adult Chinook salmon and 0.6 feet (7.2 inches) for steelhead and coho salmon.

Physiological conditions and water quality can also impede fish passage. River conditions that present no obstacle to healthy fish may become increasingly difficult for a fish in deteriorating condition and become impediments to weaker fish. Water temperatures above 70 ^{o}F in the San Joaquin River have prevented adult Chinook salmon from migrating upstream, but temperatures as high as 76 ^{o}F in the lower Klamath River have not been an impediment to migrating adult salmon (CDWR 1988). Delays in the upstream migration of adult Chinook have been reported in the Willamette River in Oregon at DO levels below 3.5 mg/l (USFWS 2003b).

Flow conditions in the lower river were analyzed and presented in Section III. C. of this report, with emphasis on the reach in which the fish-kill occurred, from Coon Creek Falls down to the mouth of the Klamath River. A comparison of September flows for 2001 and 2002 was of particular interest because both years had large runs of salmon. River flow through the fish-kill reach was represented in two different USGS data sets, which provided differing results. The first analysis assumed the Klamath River near Klamath gage represented flow conditions in the lower river. The second analysis assumed that flows gaged at the Klamath River at Orleans combined with flows gaged at Trinity River at Hoopa, were a better representation of flow conditions in the lower river.

The purpose of this section is to evaluate two hypotheses related to potential fish passage. The first null-hypothesis is; there were no impediments to fish passage in the lower Klamath River, prior to or during September 2002, that could have contributed to the fish-kill. The alternative hypothesis is; there were impediments to fish passage in the lower Klamath River, prior to or during September 2002, that could have contributed to the fish-kill. The second null-hypothesis addressed in this section is; conditions that could impede fish passage in September 2002 were not different when compared to past years. The alternative hypothesis is; conditions that could impede fish passage in September 2002, were different when compared to past years.

III. F. 2. Methods

This section evaluates fish passage conditions on the lower Klamath River during September 2002 and previous years, based on interviews with biologists working in the area of the fish-kill, comparison of historic flows, analysis of river stage, analysis of temperature and DO conditions, and fish counting data from upstream sites. Consideration was given to potential geomorphic changes in the lower river channel resulting from 1997 and 1998 high-flow events in northern California.

DFG evaluated the potential for tidal influence and the formation of sand spits at the mouth of the Klamath River, by acquiring continuous river stage records for the lower Klamath River near Klamath gage. Data for September 1988 and 1991 through 2002 were acquired from the internet (DWR CDEC Bulk Data Selector at www.cdec.water.ca.gov). These data were provisional and may be subject to change. Data were not available before 1985, and thus, we could not include low-flow years of 1973 or 1981 in our analysis.

DFG monitoring at Willow Creek Weir on the Trinity River and the Shasta River Fish Counting Facility were evaluated for presence of returning adult salmon in 2002 prior to the fish-kill.

III. F. 3. Results

Flow conditions in the Klamath River were evaluated in section III. C. of this report. Review of flows in the lower river between 2001 and 2002 showed conflicting results, depending on whether KNK or the combined TRH+KAO gages were used to characterize the average September discharge. KNK in 2001 had a mean September discharge of 2,601 cfs, whereas 2002 had a discharge of 1,987 cfs, or 614 cfs less (Figure C2). USGS (2003) reported that flow measurements at KNK in 2001 and 2002 were inaccurate due to tidal influence and recommended using combined flows at TRH and KAO as a better indication of conditions in the fish-kill area. TRH+KAO in 2001 had a mean September discharge of 1,857 cfs, whereas 2002 had a discharge of 1,923 cfs, or 66 cfs more (Figure C2).

River stage data was plotted for low-flow years as identified in section III. C. (Figure F1), and non-low-flow years after 1993 (Figure F2). Stage shifts of several tenths of a foot each day, were apparent in September 2002 (Figure F1) and 1998 through 2000 (Figure F2). River stage in feet (Figures F1 and F2) relative to flow (Figure C1) was lower after 1997 and higher before 1996. Data for September often showed multiple-day increases in stage on the order of feet rather than tenths of feet. This was particularly apparent in low-flow years, with the exceptions of 1988 and 2002 (Figure F1). River stage in 2001 increased from about 5.2 feet on September 1, 2001 to about 11.8 feet on September 26, and then plunged to around 4.6 feet at the end of the month (Figure F1). Similar but less dramatic events were seen in September 1991, 1992, and 1994. 2002 represented the lowest September stage levels recorded for the lower Klamath River from 1988 and 1991 to 2002 (Figures F1 and F2).

Figure F1. River stage for the Klamath River near Klamath during September of low-flow years. Data were not available for 1973 and 1981.

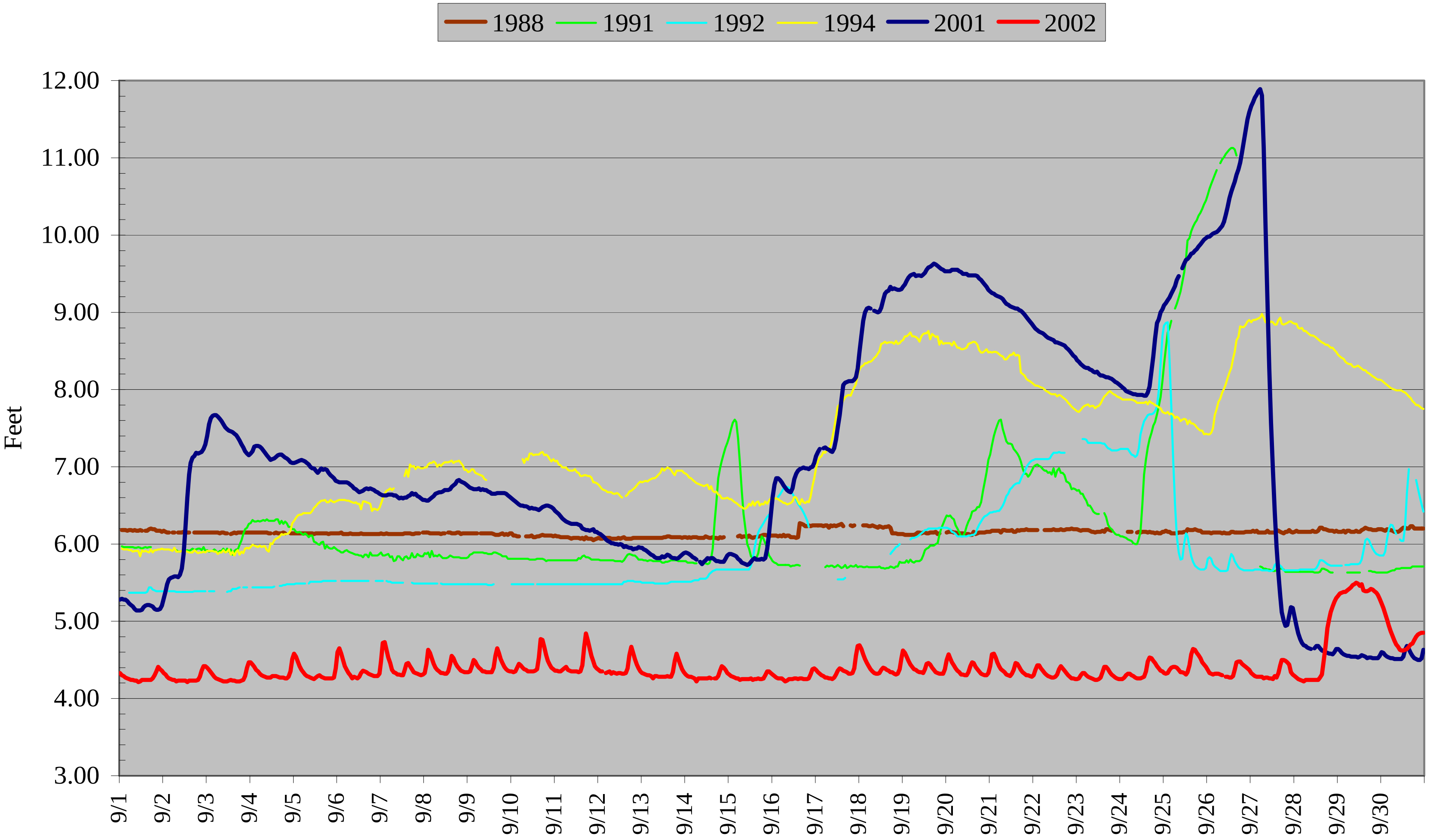
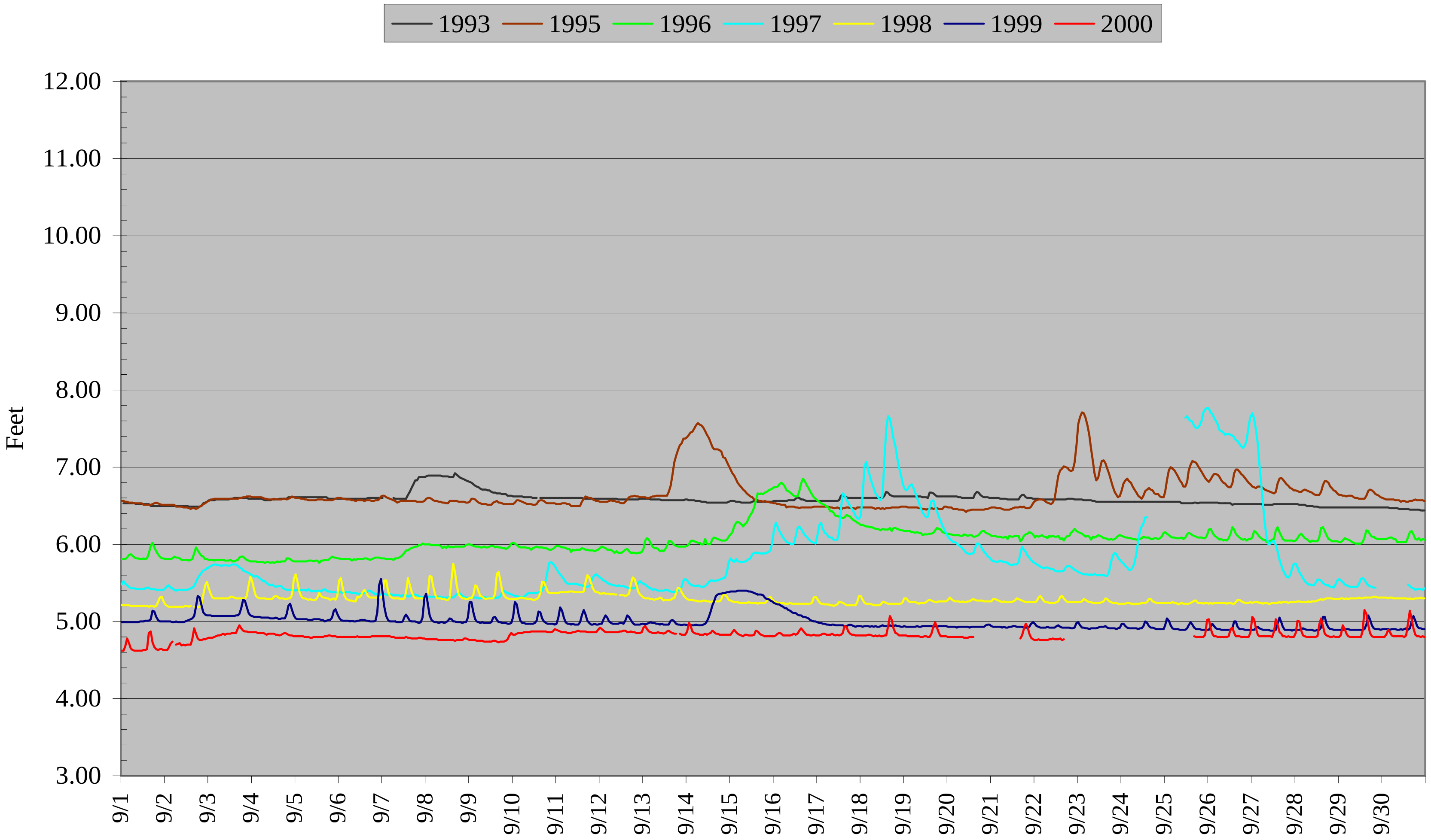


Figure F2. River stage for the Klamath River near Klamath during September of non-low-flow years since 1993.



Temperature and DO for the lower Klamath River were evaluated in sections III. D. and III. E. of this report, respectively. Water temperatures at Terwer exceeded 70 ^{o}F during the first four days of September 2002, but not during the rest of the month and never exceeded 76 ^{o}F (Figure D12). Temperatures above 70 ^{o}F in the lower Klamath River, were common in past low-flow years (Figure D13) and have been greater in higher flow years, such as 1998, than in September 2002 (Figure D 15). Dissolved oxygen concentrations for the Klamath River, within the fish-kill area at Terwer (Figures E1 and E2) and just above the fish-kill area at Martins Ferry (Figure E3) and at Weitchepec (Figure E5), never fell below 6.0 mg/l either prior to or during the fish-kill in August and September 2002.

III. F. 4. Findings

USFWS biologists working on the lower Klamath River observed low-flow conditions, making it more difficult to traverse shallow riffles in a jet boat than in previous years (Shaw 2002, personal communication). They observed that water depth at Pecwan and Ah Pah riffles appeared shallow enough, to be an impediment to adult fish passage. Yurok biologists also observed that passage over some riffles was confined to multiple small channels, in which their jet boat with a six-inch draft, would occasionally touch bottom (Belchik 2003, personal communication). A former NMFS fisheries biologist (Gilroy 2003, personal communication) with experience working on the Klamath River suggested when flows are low, fish passage over certain riffles is confined to smaller channels, representing the main thalweg and much of the riffle is too shallow to pass fish. The DFG Fisheries Biologist, who has participated in angler surveys on the Klamath River since 1985, described water levels during September 2002 in the fish-kill area as the lowest she has observed in over 20 years of experience (Borok 2003, personal communication). These anecdotal observations raised concern that shallow water depth over certain riffles might have impaired the ability of salmon and steelhead to migrate upstream.

Anecdotal observations of low-flow conditions and shallow water depth over riffles in the lower river are supported by a review of USGS flow data. Average September flows in 2002 were among the lowest reported for the past 50 years. However, the connection between low-flow conditions in the river and impaired fish passage cannot be made empirically. There were no reported measurements of flow depths or velocities over riffles that could be compared with recommendations by Thompson (1972) or Lauman (1976). There were also no reports of salmon failing attempts to move upstream through riffles, or becoming stranded on riffles because of inadequate flow depth. In addition, we know some level of adult fish passage did occur at flows present in the lower Klamath River during 2002. This was evident from DFG monitoring at Willow Creek Weir on the Trinity River and the Shasta River Fish Counting Facility when returning adults were observed prior to the fish-kill.

Examination of average September flows for 2001 and 2002 (both years with large runs of salmon) in the lower river, by combining the Klamath at Orleans gage with the Trinity River at Hoopa gage, indicated flow conditions in the fish-kill reach were similar for both years. The same examination using data from the Klamath River near Klamath gage indicated average September flows for 2002 were approximately 76% of that recorded in 2001. Because of these conflicting data, DFG cannot determine conclusively that flows were substantially different in the fish-kill area during September 2001 and 2002.

Changes in river stage of several tenths of a foot each day were apparent in September 2002 (Figure F1) and 1998 through 2000 (Figure F2) and probably represented a daily tidal influence. Beyond the tidal influence issue, continuous stage data provides some important insights into how the Klamath Estuary has changed over the years and how it functions during September of each year. River stage in feet (Figures F1 and F2) relative to flow (Figure C1) is lower after 1997 and higher before 1996. This suggests the channel at KNK may have degraded at some point in 1996 or 1997. This might be explained to some degree by the large flood events in 1997 and 1998. Susich (2003, personal communication) confirmed that since major high flows in the late 1990's, there was significant lowering of the bed at the KNK gage, on the order of one to two feet.

Also apparent in September are multiple-day increases in stage on the order of feet, rather than tenths of feet, that cannot be explained by daily tidal cycles. This was particularly apparent in low-flow years, with the exceptions of 1988 and 2002. These larger multi-day shifts in river stage indicated the presence of partial sand spits that occasionally form a constriction at the mouth of the Klamath River. The DFG fisheries biologist who currently conducts angler surveys on the Klamath River, reported high water levels and extensive flooding in the Klamath River Estuary during September 2001 (Borok 2003, personal communication). River stage data for September 2001 lends support to this observation of high water levels. River stage in 2001 increased from about 5.2 feet on September 1, 2001 to about 11.8 feet on September 26, and then plunged to around 4.6 feet at the end of the month. The sharp decline in river stage between September 26 and the end of the month reflected breaching of the sand spit at the mouth of the river in 2001. Similar sand spits likely formed in September 1991, 1992, and 1994 and would explain large changes in river stage for those years. Since the lower Klamath gage is located six miles upstream of the mouth of the Klamath River and the gage elevation is at six feet above sea level, large shifts in river stage during these years represented a substantial volume of water in the estuary and could influence stage upriver. USGS relocated the KNK gage, upstream to Blake's Riffle at about river-mile 8, in September 2003 to avoid further tidal fluctuations (Susich 2003, personal communication). Therefore, increased stage levels observed in September 2001 would likely have increased volumes in at least the lower eight miles of the Klamath River, representing the lower quarter of the fish-kill area.

Formation of sand spits and increased volumes of water in the estuary are an important difference between 2002 when the fish-kill occurred, and 1991, 1992, 1994 and 2001. Stage levels recorded for the lower Klamath River during September 2002, represents the lowest year when compared to 1988 and 1991 to 2002. September 2002 river stage (and consequently volume) was consistently low through the entire month, leading up to and including the time of the fish-kill.

There was also a clear difference in September river stage between 1988 when daily stage levels were nearly two feet higher than in 2002 (Figure F1). Both 1988 and 2002 showed relatively consistent stage levels through the month of September. It is unknown if higher stage levels in 1988 translate to a higher volume of water in the estuary than in 2002. However, since the river did down-cut during 1997 and 1998 flood events, it is possible that higher stage in September 1988 would indicate a higher volume of water.

Temperatures during the first four days of September 2002 were at levels (> 70 ^{o}F) known to restrict upstream migration of adult Chinook salmon in the San Joaquin River, but not at levels (> 76 ^{o}F) where adult salmon have been documented to migrate in the Klamath River (CDWR 1988). If salmon had been restricted in migrating upstream during the first few days of September by a thermal barrier, they would not have been restricted during the rest of the month when temperatures fell below 70 ^{o}F at Terwer. It is unlikely then, that water temperatures prior to and during the fish-kill in September 2002, represented an impediment to upstream migration of adult Chinook salmon.

Dissolved oxygen levels, prior to and during the 2002 fish-kill, never fell below 6.0 mg/l and never approached the level (3.5 mg/l) reported to impede adult salmon migrations in the Willamette River, Oregon (USFWS 2003b). Therefore, it is unlikely that DO levels in September 2002 represented an impediment to upstream migrating adult Chinook salmon.

In summary, DFG can neither reject nor accept the null hypothesis that there were no impediments to fish passage in the lower Klamath River, prior to or during September 2002, that could have contributed to the fish-kill. Temperature and DO results tend to support the null-hypothesis and DFG has concluded it is unlikely these water quality parameters were at levels to impede fish passage prior to or during the fish-kill. Upstream fishery monitoring also supports the null-hypothesis, because some adult fall-run Chinook salmon had been able to migrate through the lower river, to the Trinity and Shasta rivers, prior to and during the lower river fish-kill. On the other hand, anecdotal observations, flow levels, and river stage measurements tend to support the alternative hypothesis that there were impediments to fish passage in the lower Klamath River, prior to or during September 2002, that could have contributed to the fish-kill. A number of anecdotal observations suggested there were very low-flows and physical impediments to upstream fish passage on the lower Klamath River in September 2002. Observations of low-flow conditions and shallow depth of water over the riffles were supported by USGS flow data. Average September flows in 2002 were among the lowest reported for the past 50 years. River stage measurements also supported observations of shallow riffle depth and low-flow conditions. River stage levels at Terwer in September 2002 were the lowest of 13 years analyzed. However, no physical measurements were available to substantiate actual depth of flow over critical riffles before and during the fish-kill. Therefore, DFG cannot conclude, physical impediments to fish passage existed in the lower Klamath River at the time of the fish-kill.

With respect to temperature and DO conditions in the lower Klamath River, DFG accepts the second null-hypothesis and found conditions that could impede fish passage in September 2002 were not different when compared to past years. DFG has concluded temperatures and DO conditions were not at levels expected to impede fish passage in September 2002. Temperature conditions have been lower and higher in past Septembers, yet passage problems have not been documented. Historic references indicate salmon in the Klamath River, continue to migrate, even at temperatures greater than 76 ^{o}F (CDWR 1988). Therefore, there is no evidence to suggest that temperature levels in the lower Klamath River in 2002 and past years have been an impediment to adult salmon migration. Dissolved oxygen conditions were found to be adequate for salmon and substantially above levels where migration has been impeded in studies on the Willamette River. Dissolved oxygen levels were actually lower at times in 2001 when compared to 2002.

With respect to the combination of low river stage, constrictions at the mouth of the Klamath River, river-bed lowering, and low-flow conditions, DFG accepts the alternative hypothesis and found conditions that could impede fish passage in September 2002 were different when compared to past years. USGS confirmed that the river-bed, in the KNK reach of river, has lowered on the order of one to two feet since major high-flow events in the late 1990’s. Bed lowering and the effects of tidal influence on gage measurements have led USGS to relocate the KNK gage, upriver by two miles to Blake’s Riffle in September 2003. A combination of the lowest river stages observed through the month of September 2002 (Figures F1 and F2) with some of the lowest flows observed over the past 50 years (see Section III. C.) represented a substantial difference in conditions between 2002 and past years. September stage levels in 2002 were the lowest recorded for the lower Klamath River when compared to 1988 and 1991 to 2002. September 2002 river stage (and consequently volume of water in the estuary) was consistently low through the entire month of September, leading up to and including the time of the fish-kill. The lack of a sand spit and constriction at the mouth of the Klamath River under low-flow conditions in September 2002, was the apparent reason for low stage levels observed before and during the 2002 fish-kill. When compared to past years, September 2002 and 1988 were the only low-flow years where a constriction at the mouth of the Klamath River was not evident. 1988 stage levels were nearly two feet higher than in 2002 and differences were likely a result of river-bed lowering in the late 1990’s. Although flow levels for TRH+KAO were similar between September 2001 and 2002, the constriction at the mouth of the Klamath River in 2001 resulted in substantially higher stage and volume in at least the lower eight miles of river.

III. G. Run Types and Chinook Salmon Run Size;

III. G. 1. Introduction

Anadromous fish species and life stage periodicities for the Klamath River have been described by Leidy and Leidy (1984), Shaw et al. (1997) and modified and summarized by Hardy (1999), using input from recent Klamath River fishery investigations. Hardy and Addley (2001) further refined anadromous salmonid species distributions and life stage periodicities, longitudinally for various sections of the mainstem Klamath River from Iron Gate Dam to the mouth of the Trinity River. DFG used these reports, creel census data, Yurok tribal fish harvest reports, weir counts, and results of other investigations, to determine the potential contribution of various salmon and steelhead runs in the Klamath System, to the total number of adult anadromous salmonids present, just prior to and during the fish-kill, in the lower river.

The major natural (non-hatchery origin) anadromous adult salmonid run-types and their periods of occurrence (holding and migration) in the Klamath River are:

- coho salmon – September through December,
- spring-run Chinook salmon – February through July,
- fall-run Chinook salmon – July through October,
- late-fall-run Chinook salmon – November through January,
- summer/spring-run steelhead – March through July,
- fall-run steelhead – September through December,
- winter-run steelhead – December through April, and
- half-pounder steelhead – August through April.

Of the runs identified, only natural coho salmon, fall-run Chinook salmon, fall-run steelhead and half-pounder steelhead would be expected to be present in the lower Klamath River during the first half of September. Coho salmon are few in number during this period, because of their depleted status and the peak of their run occurs much later. Fall-run and half-pounder steelhead are typically present in the lower river in good numbers during the time the fish-kill occurred. However, steelhead have significantly different habitat preferences than do Chinook salmon. While Chinook prefer to hold in deep pools, steelhead prefer riffles and runs. This difference in habitat preference may have segregated steelhead from the heavily infected Chinook during September 2002. In addition, faster water favored by the steelhead may have made disease transmission more difficult. The relative lack in abundance of coho salmon, and habitat segregation of fall-run and half-pounder steelhead, are reflected in the fact that coho and steelhead were poorly represented in the total fish-kill numbers. Fall Chinook salmon overwhelmingly constituted the majority of adult anadromous salmonid biomass, present in the lower river in early September. Their run usually peaks in late August or early September.

Klamath Basin spawner escapement, in-river harvest, and run-size estimates for fall Chinook salmon have been produced annually by DFG since 1978 and are documented in what is referred to as the "megatable" (DFG Files, Redding). By applying scale ageing and analysis techniques, the Klamath River Technical Advisory Team (KRTAT) allocates these annual estimates into age-structured components. The KRTAT is an advisory group to the Klamath Fishery Management Council (KFMC). The KFMC makes Klamath Basin Chinook management and quota recommendations to the Pacific Fisheries Management Council (PFMC).

Use of historic in-river cohort analysis and regression techniques, allows for estimation of the following year's ocean abundance and subsequent return of adult (age 3-5) Chinook salmon to the Klamath Basin. Based on these predictions, allowable annual harvest quotas are developed for tribal (gill net) and non-tribal (ocean commercial, ocean recreational and in-river recreational) fisheries. Harvest quotas are currently split between tribal and non-tribal fisheries.

Area specific escapement and harvest estimates are produced by cooperating tribes and agencies within the Klamath Basin. Monitoring efforts are focused on estimating fall-run Chinook harvest in sport and tribal gill-net fisheries, escapement to natural areas, and escapement to Iron Gate and Trinity River hatcheries in the basin. Less intensive monitoring is applied to spring-run Chinook, coho and steelhead runs. Estimates for these runs are available for the Trinity River and the two hatcheries in the basin, but are only partially accounted for in other areas.

The purpose of this section was to address the null-hypothesis; the numbers of fall-run Chinook salmon entering the lower Klamath River during September 2002 were not unusually high when compared to previous years when fish-kills did not occur. The alternative hypothesis was; the numbers of fall-run Chinook salmon entering the lower Klamath River during September 2002 were unusually high when compared to previous years when fish-kills did not occur. To address these hypotheses, DFG characterized and evaluated annual run-size for Klamath River fall Chinook salmon, to determine if numbers of returning fish in 2002 were unusually large compared to past years, and to determine if numbers of salmon returning to the Klamath River in 2002 were large enough to have been a contributing factor in the fish-kill.

III. G. 2. Methods

Monitoring of the 2002 fall Chinook salmon run was conducted by various agencies and tribes, throughout the Klamath Basin. Various monitoring techniques were employed in different parts of the basin to produce "subsets" of harvest and escapement estimates. Individual harvest and escapement estimates were then combined by DFG for a basin-wide run-size estimate. Cooperators in this effort included the Hoopa, Yurok, and Karuk tribes, DFG, USFS, USFWS, Americorp, California Conservation Corp (CCC), and volunteers. A brief description of monitoring areas and sampling protocols are provided in Table G1.

Klamath Basin fall-run Chinook salmon escapement, harvest, and run-size estimates are subject to the vagaries of sampling and estimation methods common to all field sampling programs. Since total estimates are a compilation of component estimates developed by several agencies and tribes, applying confidence levels to the overall estimate has been impractical.

Determination of proportions of hatchery to natural fish, basin of origin, and age estimates for fall Chinook in the 2002 fish-kill, were limited by several factors. An important limiting factor was the relatively small sample size of 1,824 (5.6%) Chinook salmon collected, out of an estimated 32,553 Chinook that died in the fish-kill. In addition, there were differential marking and tagging (Adipose fin clips [AD] + Coded Wire Tags [CWT]) rates at Iron Gate and Trinity River hatcheries. Chinook salmon are marked at a rate of approximately 25% at Trinity River Hatchery, while marking rates at Iron Gate Hatchery are generally less than 5%. Another potential source of bias in the estimate was survey crew experience and knowledge. Identification of species, fin-clips, and following survey protocols are subject to each individual's unique background. However, training is provided to all individuals to help minimize this bias.

Harvest estimates for in-river sport and tribal net fisheries were generated using stratified sub-sampling, in which certain days or periods were randomly selected and intensively sampled by creel and net-harvest clerks. The resultant catch-per-unit-effort (CPUE) was expanded for unsampled periods and areas, to produce a harvest estimate. Estimated catch was reported on a weekly basis. Although angler surveys were conducted by DFG for the entire Klamath River, the most intensive sampling occurred on the lower Klamath River below Coon Creek Falls, where angling effort and catch are highest. On the Trinity River, creel surveys were conducted below the Willow Creek Weir, while harvest above the weir was based on angler tag returns.

Biological data (i.e., scales, CWTs, lengths, sex, fin clips, tags and marks) were collected and recorded from all or a subset of harvested fish in the in-river sport or tribal net fishery. Scales were collected for ageing purposes, while CWT collections provided information regarding the species, race, age, release type, and hatchery of origin for a fraction of all hatchery produced fish. Since immigration timing of spring- and fall-run Chinook overlap to some degree in the Klamath Basin, CWTs provided the means to allocate harvested Chinook salmon to each particular race.

Table G1. Documentation of the methods used to sample and estimate the 2002 Klamath River fall Chinook run size.

Sampling Location	Estimation Method	Agency /Tribe
Hatchery Spawners		
Iron Gate Hatchery (IGH)	- Direct count. All fish examined for fin clips, tags, marks. Systematic random sample ~10% bio sampled for FL, scales, sex.	DFG
Trinity River (TRH)	- Direct count. All fish bio sampled for FL, fin-clips, marks sex. Scales collected from all Ad clipped fish and ~10% of non Ads.	DFG
Natural Spawners		
Trinity River mainstem above WCW	- Peterson mark-recapture run-size estimate. All fish at weir bio sampled for FL, marks, fin-clips. Scale samples taken from all Ad-clipped fish and every other non Ad clipped fish.	DFG
Trinity River mainstem below WCW	- Adult escapement estimate based on Redd count times 2. Several surveys performed. Count is additive for survey period.	HVT
Salmon River basin	- Mark-recapture carcass estimate. River is surveyed twice weekly. Bio data (scales, FL's' marks) collected from all fresh carcasses.	DFG,USFS
Scott River basin	- Mark-recapture carcass estimate. River is surveyed twice weekly. Bio data (scales, FL's' marks) collected from all fresh carcasses.	DFG
Shasta River Basin	- Video count at lower river weir site. Bio data (Scales, FL's, sex, marks) collected from carcasses upstream of site. Attempt to recover 10% of estimate	DFG
Bogus Creek Basin	- Peterson mark-recapture estimate above weir, carcass count below weir. Fish are biosampled (scales, FL's, sex, fin-clips) during recapture spawning ground surveys.	DFG
Klamath main stem (IGH to Shasta R)	- Mark-recapture carcass estimate. River sections are surveyed once weekly. Bio data (scales, FL's' marks) collected from fresh carcasses.	USFWS
Klamath main stem (Shasta R to Indian Cr)	- Redd count based on weekly surveys. Cumulative count based on flagging old redds. Adult estimate is redds times 2.	USFWS
Trinity Tributaries above Reservation	- Only 1 trib, Horse Linto Cr. Adult estimate based on weekly redd counts. Previous weeks redds flagged to avoid double counting.	USFS
Klamath Tributaries above Reservation	- Periodic redd surveys. Prior weeks redds flagged, only new redds counted. Estimate is redds times 2 + live fish observed on last survey date.	USFS,CDFG
Hoopa Reservation Tributaries	- Adult estimate based on redd surveys. Survey redd totals are cumulative. Final adult estimate is redds times 2.	HVT
Yurok Reservation Tributaries	- Only surveyed stream is Blue Creek. Jacks and adult count based on the peak weekly snokle survey. Weekly dives performed Oct - Dec.	YT
Angler Harvest		
Klamath River (below Hwy 101 bridge)	- Estimate is based on a stratified access point creel survey. Bio data (scales, FL's, marks, fin-clips) collected during angler interviews.	DFG
Klamath River (Hwy 101 to Coon Cr. Falls)	- Estimate is based on a stratified access point creel survey. Bio data (scales, FL's, marks, fin-clips) collected during angler interviews.	DFG
Klamath River (Coon Cr. Falls to IGH)	- Estimate based on a stratified access/roving crell survey. Bio data (scales, FL's, marks, fin-clips) collected during angler interviews.	DFG
Trinity River basin (above WCW)	-Estimate is based on the return of reward tags placed on fish at weir. Return rate is applied to run-size estimate to estimate harvest.	DFG
Trinity River basin (below WCW)	- Estimate based on a stratified roving/access creel survey. Bio data (scales, FL's, marks, fin-clips) collected during angler interviews.	HVT
Indian Net Harvest		
Klamath River (below Hwy 101)	- Stratified effort/catch surveys. Bio data (FL's, scales, fin-clips) collected during net harvest interviews.	YT
Klamath River (Hwy 101 to Trinity mouth)	- Stratified effort/catch surveys. Bio data (FL's, scales, fin-clips) collected during net harvest interviews.	YT
Trinity River (Hoopa Reservation)	- Two stage stratified effort/catch surveys. Bio data (FL's, scales, fin-clips) collected during net harvest interviews.	HVT
Fish Kill	- Peak count estimate. Three separate strata surveyed between the mouth and Coon Cr. Falls. Subsampled strata expanded based on numbers/length. Bio data collected during counts and independently during supplementary surveys.	USFWS

Fall-run Chinook salmon escapement estimates, for natural areas and the two Klamath Basin hatcheries, were obtained through a variety of sampling methods. The four most common methods used, were carcass survey counts/estimates, weir counts/estimates, expanded redd counts, or direct counts.

Crews of two or more individuals conducted carcass surveys on a regular weekly basis. Chinook salmon carcasses were either counted and chopped in half, or marked with flagging or an individually numbered metal tag, as part of a mark-recapture survey. Weekly estimates were summed to produce a seasonal estimate.

In the case of weir estimates, temporary structures were deployed in the river for the purpose of either trapping a portion of the run (marking weirs), or counting all passing fish with a video system. Marking weirs were used to generate mark-recapture estimates. In areas where counting weirs were operated, supplemental carcass surveys were performed for the collection of biological data.

Redd counts were performed on certain small tributaries in the Klamath Basin. Redd counts were more effective on these smaller streams, because of smaller runs of fish, difficulty in recovering carcasses due to less frequent sampling, and lack of personnel to rigorously survey each stream. Total redd counts were expanded by a factor of two to produce adult Chinook estimates. Estimated numbers of grilse (age two salmon) were added to the expanded redd total, by using grilse proportions encountered in nearby “surrogate” areas. Age structure of adult Chinook was also derived from surrogate areas and expanded for overall redd estimates.

Hatchery escapement was a direct count of all fish entering the facilities. At Trinity River Hatchery, all fish were counted, measured, and examined for the presence of an AD fin-clip, which indicates the fish may have a CWT. All fish were also examined for tags applied at Willow Creek Weir, as part of the Trinity River mark-recapture estimate. Scale samples were collected from approximately 10% of returning hatchery fall-run Chinook salmon. At Iron Gate Hatchery on the Klamath River, similar sampling was conducted, except Chinook salmon were sub-sampled for length measurements. This was necessary because of the large number of Chinook salmon that enter this facility.

It was necessary to estimate the numbers of Chinook salmon lost in the lower Klamath River during the 2002 fish-kill, for management purposes. These fish had to be accounted for in annual fall Chinook salmon escapement estimates in the basin, and were used to help generate future harvest allotments. Thus, a collaborative effort, led by USFWS was made to produce this estimate (USFWS 2003a). DFG and Yurok Tribe personnel conducted supplemental surveys to collect biological information, for use in a cohort analysis, and to identify the basin of origin and hatchery component of the fish-kill. This effort focused on collecting Chinook salmon fork lengths and scales for ageing purposes, identifying Chinook AD-clip rates, and collecting CWTs for the purpose of identifying the hatchery of origin.

Hatchery components of the fish-kill were estimated by determining the AD-clipped component of the sampled population, multiplied by the percentage of AD-clipped Chinook salmon that contained CWTs. This rate was then applied to the overall estimate, and proportioned to the total AD-clip + CWT estimate for recovered CWTs, in relation to the number of each CWT code collected. Hatchery production multipliers were applied to each CWT code estimate to determine the total number of hatchery Chinook salmon that died.

III. G. 3. Results

The total run-size for Klamath Basin fall Chinook in 2002 was estimated at 170,014 fish (9,226 grilse and 160,788 adults). Of this total, 29,514 (17.4%) entered basin hatcheries, 69,502 (40.9%) escaped to natural areas, 11,365 (6.7%) were harvested by sport anglers, 24,700 (14.5%) were harvested in tribal gill net fisheries, 32,553 (19.1%) were estimated to have died during the fish-kill, and 2,380 (1.4%) were estimated to have died incidentally, to angler sport and tribal gill net fisheries (Table G2).

The age structure for Klamath Basin fall Chinook salmon in 2002 was estimated to be 9,246 (5.5%) age 2, 94,229 (55.7%) age 3, 62,137 (36.7%) age 4, and 3,684 (2.2%) age 5 fish (Table G2).

During the course of fish-kill investigations and supplemental fish-kill surveys, 1,824 Chinook salmon were closely examined. Of this total, 71 (3.9%) were AD-clipped, indicating they were of hatchery origin. A total of 65 heads were processed for CWT recovery, of which 56 contained CWTs. Nine Chinook salmon had shed their CWTs. A total of 15 different CWT groups, representing brood-years 1998-2000, were recorded from the 56 CWTs examined (Table G3). Trinity River Hatchery origin fall-run Chinook were represented by 12 groups (51 CWTs) and Iron Gate Hatchery by 3 groups (5 CWTs).

Based on AD-clip rates, known CWT recoveries, and production multipliers (to account for untagged hatchery releases) for each CWT code, the estimated number of hatchery produced Chinook salmon that died during the fish-kill was 7,060 fish or 21.7% (7,060/32,553) of the total (Table G3). Estimated hatchery-origin Chinook salmon mortalities were further allocated between Iron Gate Hatchery-produced fish (2,921 [41.4%]) and Trinity River Hatchery-produced fish (4,139 [58.6%]).

An effort was made by DFG and the Hoopa Valley Tribe to determine basin of origin (Trinity vs. Klamath) for all Chinook salmon that died during the fish-kill. This analysis was based on CWT to natural spawner ratios for each basin. It was estimated that 70.2% of Chinook salmon that died during the fish-kill were from the Klamath Basin and 29.8% were from the Trinity Basin.

Table G2. Age Composition of the 2002 Klamath River fall Chinook run as determined by the Klamath River Technical Advisory Team, with assistance from DFG's Klamath and Trinity River projects.

			AGE		Total	Total
Escapement & Harvest	2	3	4	5	Adults	Run
Hatchery Spawners						
Iron Gate Hatchery (IGH)	1,296	13,425	10,183	57	23,665	24,961
Trinity River (TRH)	1,034	2,431	1,004	80	3,515	4,549
Hatchery Spawner subtotal	**2,330**	**15,856**	**11,187**	**137**	**27,180**	**29,510**
Natural Spawners						
Salmon River basin	72	1,206	1,279	0	2,486	2,558
Scott River basin	47	2,479	1,656	127	4,261	4,308
Shasta River Basin	386	4,286	2,088	58	6,432	6,818
Bogus Creek Basin	305	15,373	2,130	27	17,529	17,834
Klamath River mainstem (IGH to Shasta R)	503	8513	7985	44	16,542	17,045
Klamath River mainstem (Shasta R to Indian Cr)	155	2629	2466	14	5,108	5,263
Klamath Tributaries above Reservation	44	775	551	18	1,344	1,388
Yurok Reservation Tributaries	12	165	174	0	339	351
Klamath Basin subtotal	1,524	35,426	18,329	286	54,041	55,565
Trinity River mainstem above WCW	2,217	6,741	3,327	813	10,881	13,098
Trinity River mainstem below WCW	40	120	59	14	194	234
Trinity Tributaries above Reservation	66	201	99	24	324	390
Hoopa Reservation Tributaries	42	128	63	15	206	248
Trinity Basin subtotal	2,365	7,190	3,548	866	11,605	13,970
Natural Spawners subtotal	**3,889**	**42,616**	**21,877**	**1,152**	**65,646**	**69,535**
Total Spawner Escapement	**6,219**	**58,472**	**33,064**	**1,289**	**92,826**	**99,045**
Angler Harvest						
Klamath River (below Hwy 101 bridge)	274	1,784	1,414	87	3,285	3,559
Klamath River (Hwy 101 to Coon Cr. Falls)	283	1,777	1,407	86	3,269	3,552
Klamath River (Coon Cr. Falls to IGH)	93	2,126	1,089	0	3,216	3,309
Trinity River basin (above WCW)	170	415	57	1	473	643
Trinity River basin (below WCW)	51	80	87	0	167	218
Subtotals	**871**	**6,182**	**4,054**	**174**	**10,410**	**11,281**
Indian Net Harvest						
Klamath River (below Hwy 101)	17	9,226	9,701	774	19,701	19,718
Klamath River (Hwy 101 to Trinity mouth)	41	1,713	1,440	104	3,257	3,298
Trinity River (Hoopa Reservation)	68	579	557	32	1,168	1,236
Subtotals	**126**	**11,518**	**11,698**	**910**	**24,126**	**24,252**
Total in-river Harvest	**997**	**17,700**	**15,752**	**1,084**	**34,536**	**35,533**
Totals						
In-River Harvest and Escapement	7,216	76,172	48,816	2,374	127,362	134,578
Angling Mortality (2% of harvest)	17	124	81	4	209	226
Net Mortality (8% of harvest)	10	921	936	73	1,930	1,940
Fish Die Off	2,003	17,012	12,304	1,233	30,550	32,553
Total In-river Run	**9,246**	**94,229**	**62,137**	**3,684**	**160,768**	**170,014**

Table G3. Summary of release and recovery data for coded-wire tags (CWTs) recovered during the 2002 lower Klamath River fish kill investigations.

Release data						Recovery data		
CWT Code	Hatchery of Origin /a	Release type /b	Brood Year	Production multiplier /c		Number Recovered		Estimate per CWT code /d
62641	TRH	Y	1998	2.9		21		1,187
65642	TRH	Y	1998	2.97		1		58
65643	TRH	F	2000	4.49		1		88
65254	TRH	F	1999	10.78		2		420
65256	TRH	F	1999	10.75		2		419
65257	TRH	F	1999	10.69		3		625
65259	TRH	Y	1999	2.88		14		786
65272	TRH	Y	2000	4.17		1		81
65274	TRH	F	2000	4.05		1		79
65275	TRH	F	2000	4.06		2		158
65277	TRH	F	2000	4.11		1		80
65280	TRH	Y	2000	4.03		2		157
601020311	IGH	F	1999	27.61		1		538
601020309	IGH	F	1999	27.61		3		1,615
601020307	IGH	F	2000	39.39		1		768
					Total:	56	Total hatchery:	7,060
							Total TRH:	4,139
							Total IGH:	2,921

a/ TRH=Trinity River Hatchery; IGH=Iron Gate Hatchery.

b/ F=fingerling release type; Y=yearling release type.

c/ Multiplier used to estimate unmarked hatchery releases of the same brood year and release type.

d/ Based on expansion of observed Chinook Ad-clip+CWT rates in the fish kill, relative proportion of each CWT group, and hatchery production multipliers.

III. G. 4. Findings

In 2002, the preseason adult fall-run Chinook salmon forecast for the Klamath Basin was 132,600 fish (Pacific Fishery Management Council 2002). The postseason estimate of 160,788 adult fall Chinook was approximately 21% higher than the preseason projection. Note that only adult (age three through five) fall Chinook salmon are forecasted in the preseason escapement estimate. The 2002 postseason total fall Chinook run estimate of 170,014, inclusive of age two grilse, was the eighth largest since 1978 and was approximately 40% larger than the 1978-2001 average of 120,983 fish (Figure G1). Therefore, the 2002 run can be classified as an above-average run. It should be noted that historic fall Chinook runs were probably many times larger than those observed during the 1978 to 2002 time period.

During other low-flow years identified in section III.C., the total number of fall-run Chinook salmon returning to the Klamath River Basin has been substantially higher in 1988 (215,322 fish) and 2001 (200,579 fish), than in 2002 (Figure G2). Much smaller runs occurred in 1991, 1992 and 1994 and represented some of the lowest returns since 1978, when collection of run-size information was initiated. The 1981 run (108,171 fish) was below average and about 64% of the 2002 run. No data were available for the low-flow year of 1973.

The lower Klamath River fish-kill impacted approximately 19% of the total fall Chinook run (USFWS 2003b). Dead Chinook were both Klamath River and Trinity River origin fish, of which a majority was of Klamath origin. DFG estimated that the natural component represented approximately 78% of the fall-run Chinook salmon carcasses. The fish-kill affected all age classes (brood years 1997-2000) of the 2002 fall Chinook salmon run.

While no spring-run Chinook salmon were identified, both coho salmon and steelhead were found during the fish-kill investigations. The impacts to these stocks, while less severe, are significant because these populations are not as robust as fall-run Chinook salmon in the Klamath River Basin.

In summary, the 2002 run of fall Chinook salmon was above average in size with 170,014 fish returning to the Klamath Basin. This represents the eighth largest run in the Klamath River since 1978. Consequently, DFG must accept the null-hypothesis that the numbers of fall-run Chinook salmon entering the lower Klamath River during September 2002 were not unusually high when compared to previous years when fish-kills did not occur. Therefore, we conclude that run-size, while above average, was not extraordinarily large and does not in and of itself represent the cause of the 2002 fish-kill.

Figure G1. Total in-river run-size estimates for fall-run Chinook salmon in the Klamath Basin since 1978.

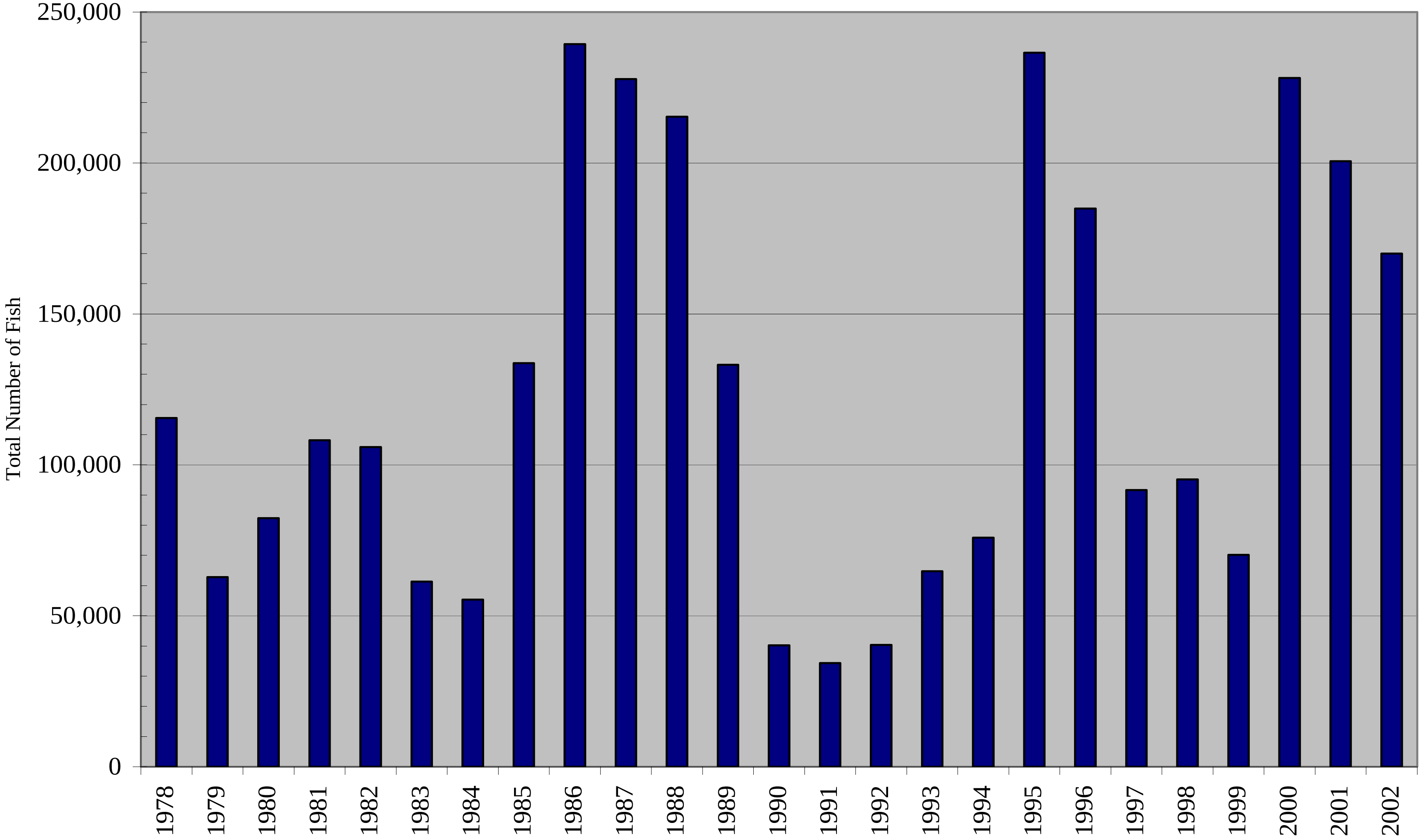
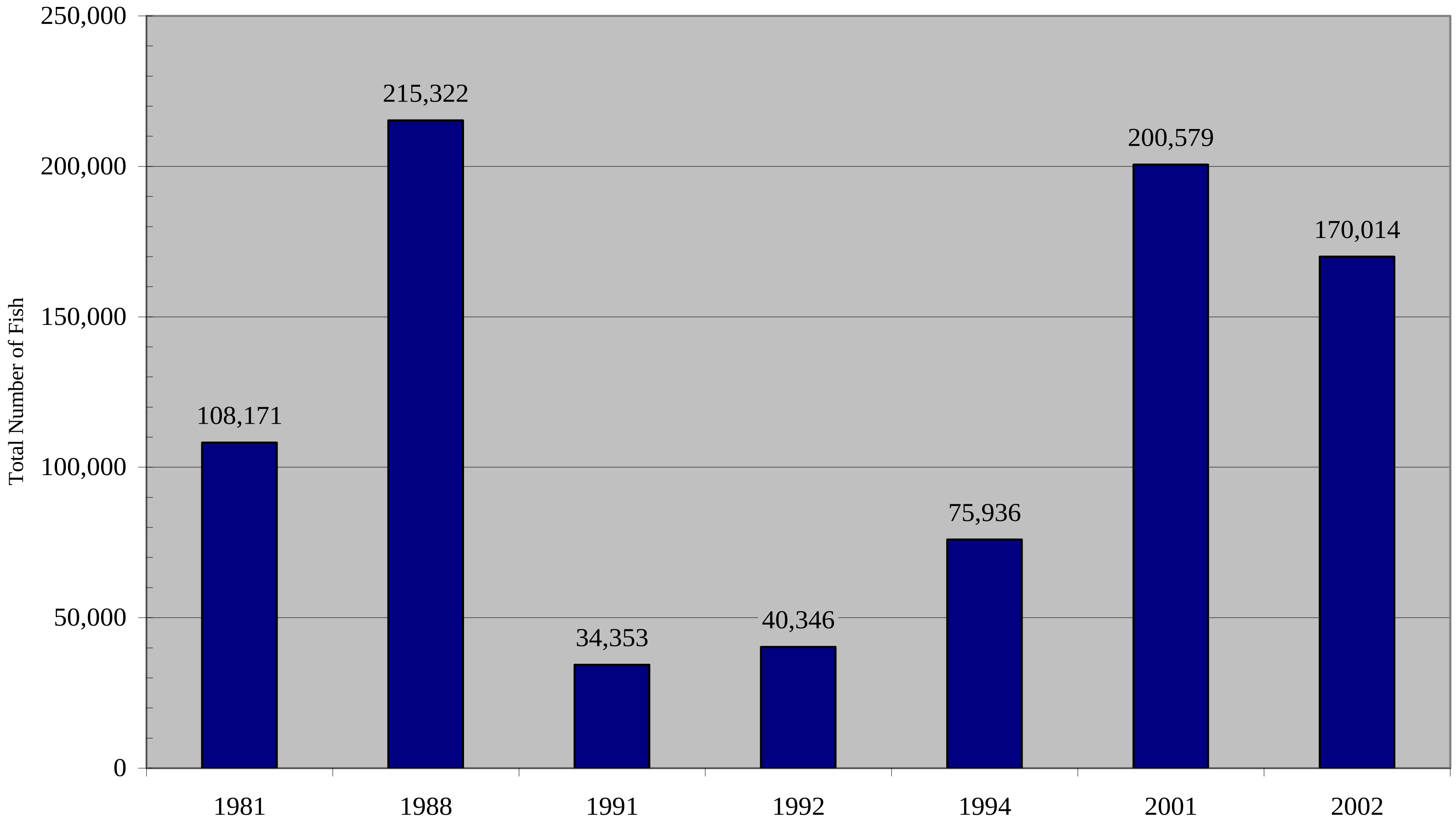


Figure G2. Total in-river run-size estimates for fall-run Chinook salmon in the Klamath Basin for low-flow years.



III. H. Chinook Salmon Run Timing and Density;

III. H. 1. Introduction

Run-timing characteristics for Klamath River Chinook salmon, such as magnitude of the peak, can have a large influence on fish density at any specific location and time and, could potentially be a contributing factor in the fish-kill. Furthermore, variable run-timing can influence how different races or stocks of Chinook salmon were affected by the fish-kill, by varying the duration of exposure to stressful conditions, which led to the disease outbreak.

The density of fall Chinook (number of fish/area of river), during their period of upstream migration within the Klamath Basin, has not been specifically targeted as a monitoring priority. However, information on relative densities can be inferred from fishery monitoring activities, such as creel surveys, net harvest surveys, and weir counts.

The density of adult fall Chinook, in any given area, is related to the size of the run, river entry timing, migration rates, and the amount of instream habitat available at any given time. The amount of adult Chinook instream holding habitat, increases with increased flow, except under extremely high flow conditions such as winter floods.

Entry timing and migration rates of Klamath River fall Chinook can be affected by a number of environmental factors such as tides, water quality, water temperature, flow, migration barriers/impediments, predators and severity of disease outbreaks. Other factors influencing entry timing or migration rates include, stock fitness or condition, genetic influences on run-timing, and state of sexual maturity.

Catch-per-unit-effort (CPUE) data, generated by various fishing and sampling methods, is related to the density of fish available at any given location and time period. CPUE can be influenced by stream flow, water volume, water clarity, gear type, expertise of fishers, and fish health. Sufficient sample sizes and sampling periods are necessary to avoid short-term catch anomalies. When densities of fish are high, CPUEs are generally high and when densities are low, CPUEs are correspondingly low.

The purpose of this section is to address three pairs of null and alternative hypotheses. The first null hypothesis is; run-timing of fall Chinook salmon entering the lower Klamath River during September 2002 was not substantially different when compared to previous years, when fish-kills did not occur. The alternative hypothesis is; run-timing of fall Chinook salmon was substantially different when compared to previous years, when fish-kills did not occur. The second null hypothesis is; run-timing of fall-run Chinook salmon entering the lower Klamath River during September 2002 was not substantially different when compared to other low-flow years, when fish-kills did not occur. The alternative hypothesis is; run-timing of fall Chinook salmon was substantially different when compared to previous low-flow years, when fish-kills did not occur. The third null hypothesis is; fish densities were not unusually high during September 2002 and not a factor in the fish-kill. The alternative hypothesis is; fish densities were unusually high in

September 2002 and may have been a factor in the fish-kill. We addressed these hypotheses, by characterizing and evaluating run-timing and fish density patterns of fall Chinook salmon over a number of years under different river, environmental, and run-size conditions, to determine if timing and density were factors influencing the fish-kill.

III. H. 2. Methods

Four techniques: beach seining, CWT recovery, sport creel census, and tribal net-harvest census were used to estimate fall Chinook salmon run-timing and fish densities for various years since 1977. Chinook salmon run-timing was determined from beach seining CPUE. CWT recoveries from Chinook harvested in the lower Klamath River sport-fishery, were analyzed to determine stock run-timing differences and relative susceptibility of different stocks to the fish-kill. CPUEs generated by sport creel and tribal net-harvest censuses were compared for 2002, low-flow years, normal and above water years, and the overall period of record to evaluate Chinook run-timing differences and fish density patterns.

DFG conducted beach seining and reward tagging in the Klamath River Estuary during 1977, 1979, 1981 and 1984–1990, as part of a study to estimate in-river sport salmon and steelhead fishing trends. This study included Chinook salmon harvest distribution and run-timing in the Klamath and Trinity rivers above Coon Creek Falls (RM 36) (Hopelain 1988). Seining generally occurred from mid-July through mid-October of each year. In three years (1977, 1979 and 1981), sampling started before the week beginning August 6. During four years (1977, 1979, 1981 and 1985), sampling ended October 14. Ten seine hauls at thirty-minute intervals, were attempted on a four-day-per-week schedule. A 350-foot seine was set by a jet-powered river boat and retrieved using gasoline-powered winches. All fish captured were identified to species and measured to the nearest centimeter fork length. All salmon were tagged with a reward tag and released (Boydston 1979). CPUE resulting from seining, represents average numbers of adult Chinook salmon caught each week. These CPUE values were used to evaluate run-timing of Chinook salmon in the lower Klamath River during the period sampled. This method did not differentiate timing of stock-specific runs.

The Chinook salmon sport-fishery on the lower Klamath River below Coon Creek Falls has been monitored annually by DFG from 1978 through 2002. Adult fish with CWTs were collected, heads retained, and tags read to determine run-timing and hatchery contributions to the overall harvest of Chinook salmon in the basin. Tag codes were expanded for production multipliers and sampling strata. Data were not stratified during years when Chinook salmon runs were small and harvest quotas were met early in the fishing season. Average CWT returns for Trinity River Hatchery spring Chinook (TRH-SC), Trinity River Hatchery fall Chinook (TRH-FC), and Iron Gate Hatchery fall Chinook (IGH-FC), were compared for a fourteen year period (1988-2001) to determine run-timing characteristics. 2001 and 2002 fall Chinook CWT returns for both hatcheries were compared to the 1988-2001 average. CWT returns of TRH-FC and IGH-FC were then compared for low-flow, versus average and non-low-flow years, to see if run-timing differences were apparent.

The total sport-catch, harvest, and effort were estimated using an access point creel census, conducted during the fall Chinook salmon migration into the Klamath River from mid- July through October. A random stratified sub-sampling effort was used, in which specific river reaches and specified days or periods, were intensively sampled by creel clerks. Catch and effort were expanded for unsampled periods and areas to produce a total harvest estimate. Total estimated catch was reported on a weekly basis. CPUE information from the creel census was generated from the total number of adult Chinook harvested, divided by total number of hours of fishing effort, and was stratified by week. Average weekly sport-fishery CPUEs from the mouth to Coon Creek Falls, were compared for run-timing and fish density characteristics during low-flow years. The focus of the sport harvest creel census was for fall-run Chinook salmon. Data on spring-run Chinook was incomplete for the entire run, and incidental to fall-run data.

Tribal gill-net harvest estimates, were derived from sampling the Yurok tribal fishery in the lower Klamath River Estuary below the Highway 101 bridge (designated as Area 1). Harvest estimates were generated by monitoring the fishery seven-days-per-week by net-harvest clerks. Catch-per-net-hour (CPUE) was calculated by dividing the total number of fish sampled, by the number of hours fished, and was reported on a weekly basis. Gill-net harvest CPUE was used to compare run-timing and fish density for the 1994-2002 period of record. Average CPUEs for the net-harvest and sport-fishery in the estuary were compared for the 1994-2001 period versus 2002, to determine whether differences in run-timing and fish density existed, and to examine the relationship between sport-fishery and net-fishery data.

III. H. 3. Results

During years when seining was conducted, the earliest that Chinook salmon were observed in the estuary was on July 22, and the latest on October 14. During the period of record (1977, 1979, 1981 and 1984–1990), annual runs peaked between the week ending August 19 through the week ending September 23 (Figure H1). Runs peaked on average from September 3-16 (Figure H2).

Average expanded CWT recovery data from the lower Klamath River sport-creel for 1988-2001, showed that TRH-SC occurred earliest in the harvest (Table H1, Figure H3). TRH-SC entered the harvest as early as the week of July 16, to as late as the week ending October 21, with peaks occurring from the week ending August 12 through the week ending September 2 (Figure H3). IGH-FC entered the sport-fishery next, beginning the week of July 30 and continued through October 21, with peak harvest occurring from the week ending August 26 through September 16 (Table H1, Figure H3). TRH-FC, on average, entered the fishery last, appearing in the lower river harvest beginning the week ending August 19 and continuing through October 21 (Table H1, Figure H3). The majority of tagged TRH-FC were recovered between the weeks ending September 16 through October 7, with the peak occurring in the third week of September (Figure H3). In six of fourteen census years, the creel was conducted beyond October 21, with no CWTs recovered past that date.

Figure H1. Run-timing for Chinook salmon in the Klamath River Estuary as the number of fish collected by beach seine during 1977, 1979, 1981, and 1984 - 1990.

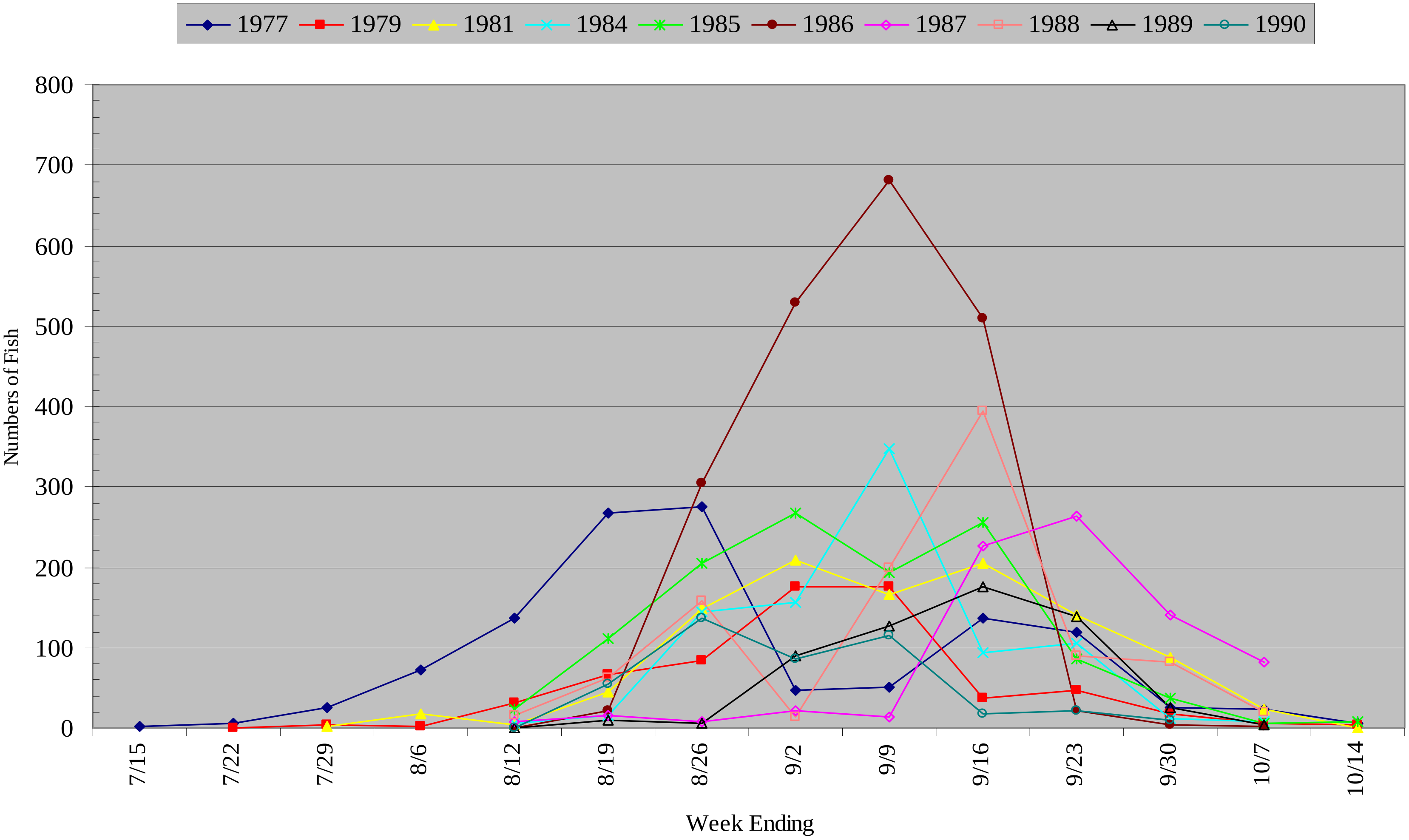


Figure H2. Run-timing for Chinook salmon in the Klamath River Estuary as a weekly average of the number of fish collected by beach seine during 1977, 1979, 1981, and 1984 - 1990.

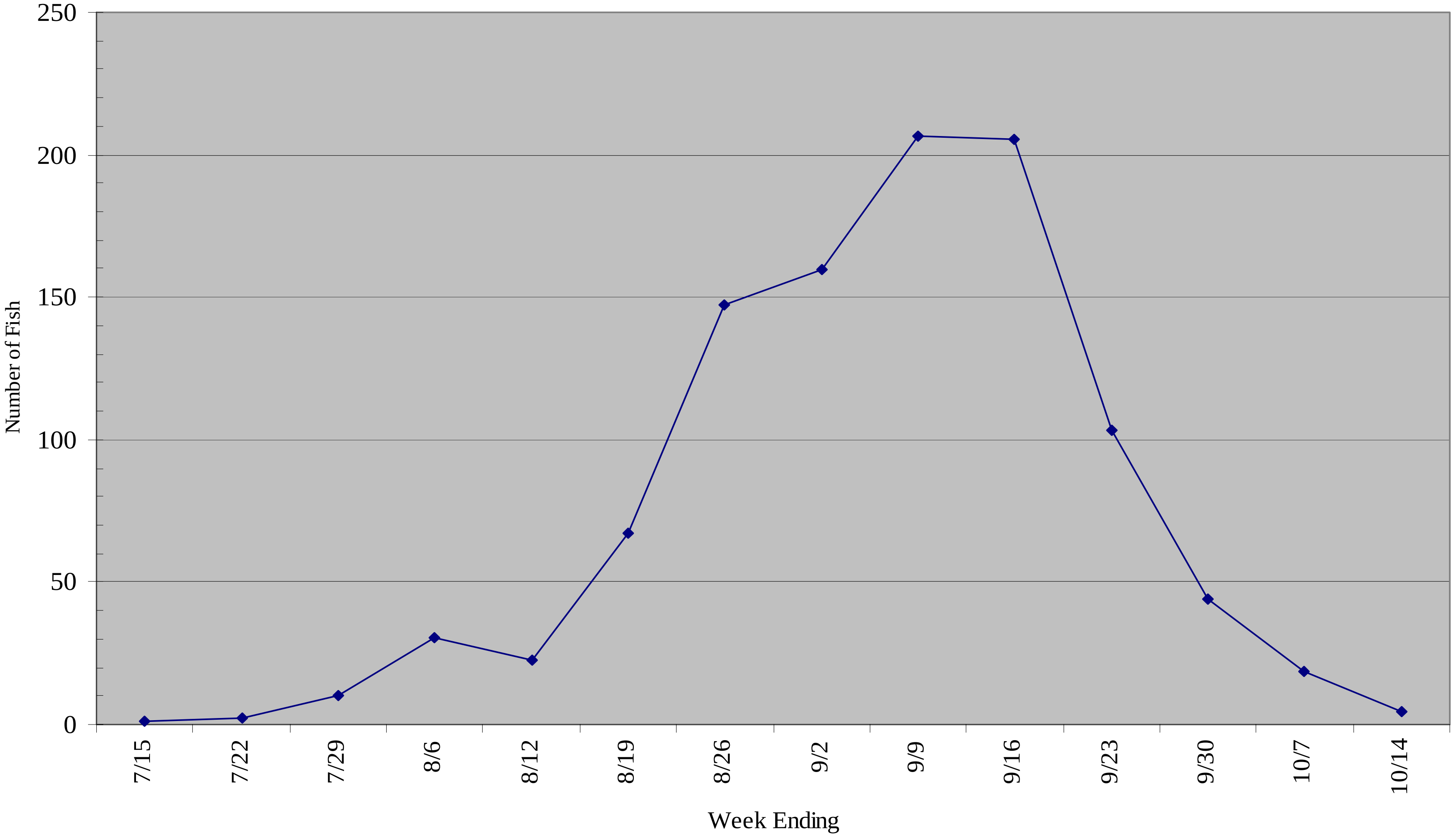
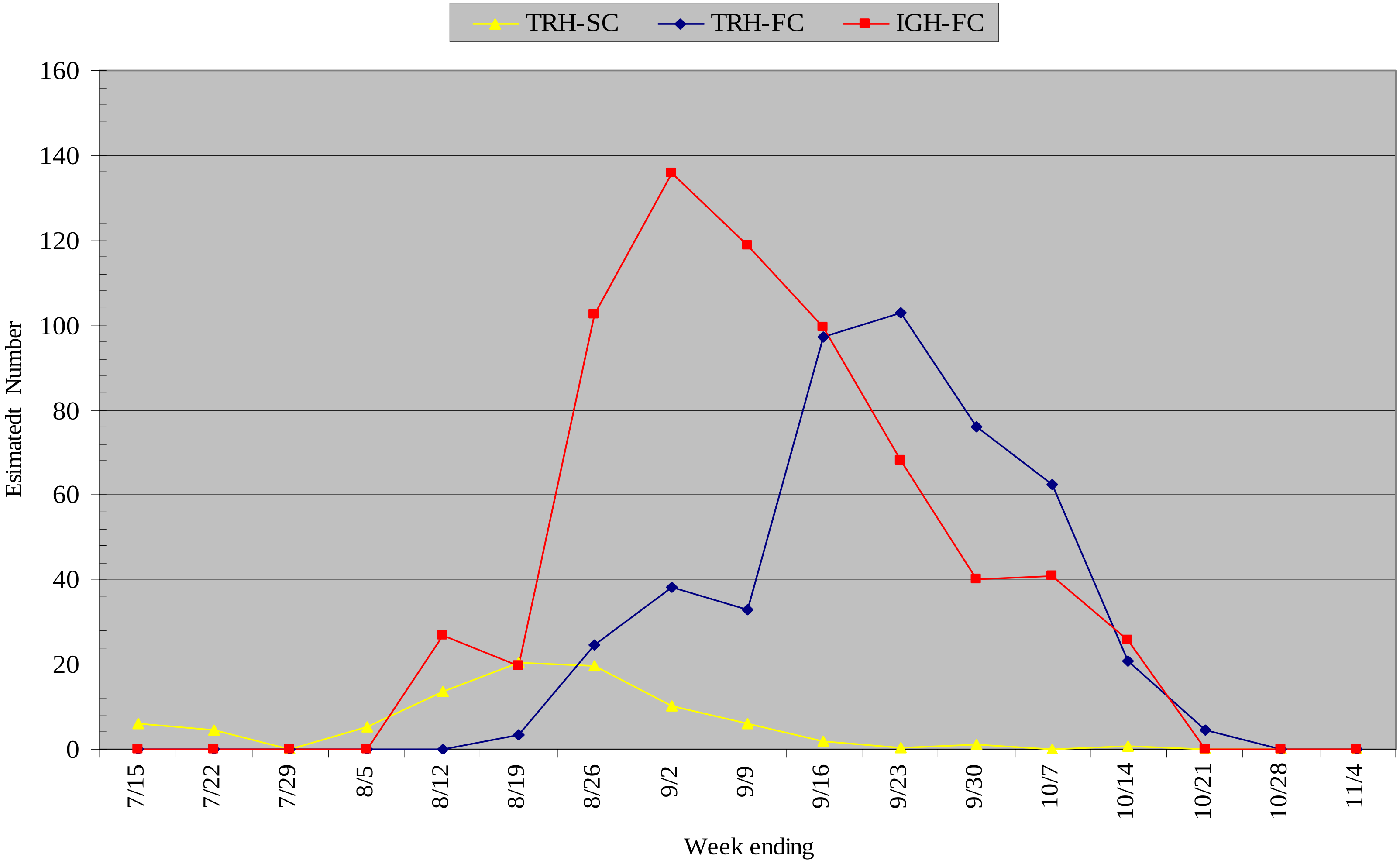


Table H1. Weekly percent composition of Trinity River and Iron Gate Hatchery coded-wire-tagged Chinook salmon recovered in the lower Klamath River sport creel harvest, 2002 and 1988-2001 average.

Week Ending	2002			1988 – 2001 Average		
	TRH-SH	TRH-FC	IGH-FC	TRH-SC	TRH-FC	IGH-FC
7/22	100	0	0	100	0	0
7/29	71.9	28.1	0	0	0	0
8/5	0	0	0	100	0	0
8/12	100	0	0	33.6	0	66.4
8/19	100	0	0	47.1	7.8	45.1
8/26	2.3	4.4	93.3	13.5	16.8	69.7
9/2	0	11.3	88.7	5.5	20.8	73.7
9/9	1.4	47.8	50.8	3.7	21.0	75.3
9/16	0	43.6	56.4	1.0	48.9	50.1
9/23	0	29.3	70.7	0.3	60.1	39.6
9/30	0	100	0	0.8	64.9	34.3
10/7	0	100	0	0	60.5	39.5
10/14	0	0	0	1.8	44.1	54.1
10/21	0	0	0	0	100	0
10/28	0	0	0	0	0	0
11/4	0	0	0	0	0	0

Figure H3. Average weekly expanded coded-wire tag returns from lower Klamath River sport creel surveys, 1988-2001, for Trinity River Hatchery spring-run and fall-run Chinook and Iron Gate Hatchery fall-run Chinook salmon.



CWT returns in 2002 indicated TRH-SC harvest, occurred over the same general period and at a similar magnitude, to the average harvest for the period of record (Figure H4). Harvest of 2002 IGH-FC was bimodal in nature in the lower river. Harvest peaked in the week ending August 26, declined the next week, and then returned to high levels through the weeks ending September 9 through 23. Harvest in 2002 ended abruptly during the week beginning September 24, representing the height of the fish-kill (Figure H4).

Based on CWT returns, the 2002 IGH-FC harvest generally occurred over the same time period, but was of greater magnitude than the average for 1988-2001. However, harvest in 2002 ended approximately three weeks earlier than average (Figure H4). When compared to annual CWT returns for 1988-2001, 2002 IGH-FC CWT returns occurred within the range of variability (Figure H5). CWT data in 2001 for IGH-FC exhibited one pronounced, narrow peak, similar in magnitude, but occurring approximately two to three weeks later than in 2002 (Figure H5). CWT data in 1988 for IGH-FC, also peaked two to three weeks later than in 2002, but at a higher magnitude (Figure H5).

Harvest of TRH-FC in 2002 started about the same time as the 1988-2001 average. Harvest peaked sharply by the week ending September 9, 2002, about two weeks earlier than average, and then declined more abruptly about two weeks earlier than average (Figure H4). When compared to the range of 1988-2001 annual TRH-FC CWT returns, 2002 TRH-FC harvest appeared to be above average in magnitude, peaked earlier than average, but occurred within the range of variability exhibited during the period of record. The peak of 2001 TRH-FC CWT returns, was about three weeks later than average. The 2001 peak was the latest recorded during the period of record, and four weeks later and greater in magnitude than the 2002 CWT returns (Figure H6). The 1988 TRH-FC CWT returns peaked on the week ending September 16, about one week later than in 2002.

Average CWT returns of IGH-FC and TRH-FC for low-flow years (1988, 1991, 1992, 1994 and 2001) were similar to each other in timing (Figure H7). However, the low-flow year peaks for IGH-FC and TRH-FC returns, were about two weeks later and about one week earlier than their respective averages for 1988-2001 (Figures H3 and H7). The peak returns for low-flow year IGH-FC CWTs, were more contracted than the 1988-2001 average. Peaks for low-flow year TRH-FC CWT returns, occurred over a similar time span as the 1988-2001 average (Figures H3 and H7). The magnitude of the peak of CWT returns for both hatcheries, was greater in low-flow years than the 1988-2001 average (Figures H3 and H5).

Figure H4. Average weekly expanded coded-wire tag returns from lower Klamath River sport creel surveys, 1988-2001 average versus 2002, for Trinity River Hatchery spring-run and fall-run Chinook and Iron Gate Hatchery fall-run Chinook salmon.

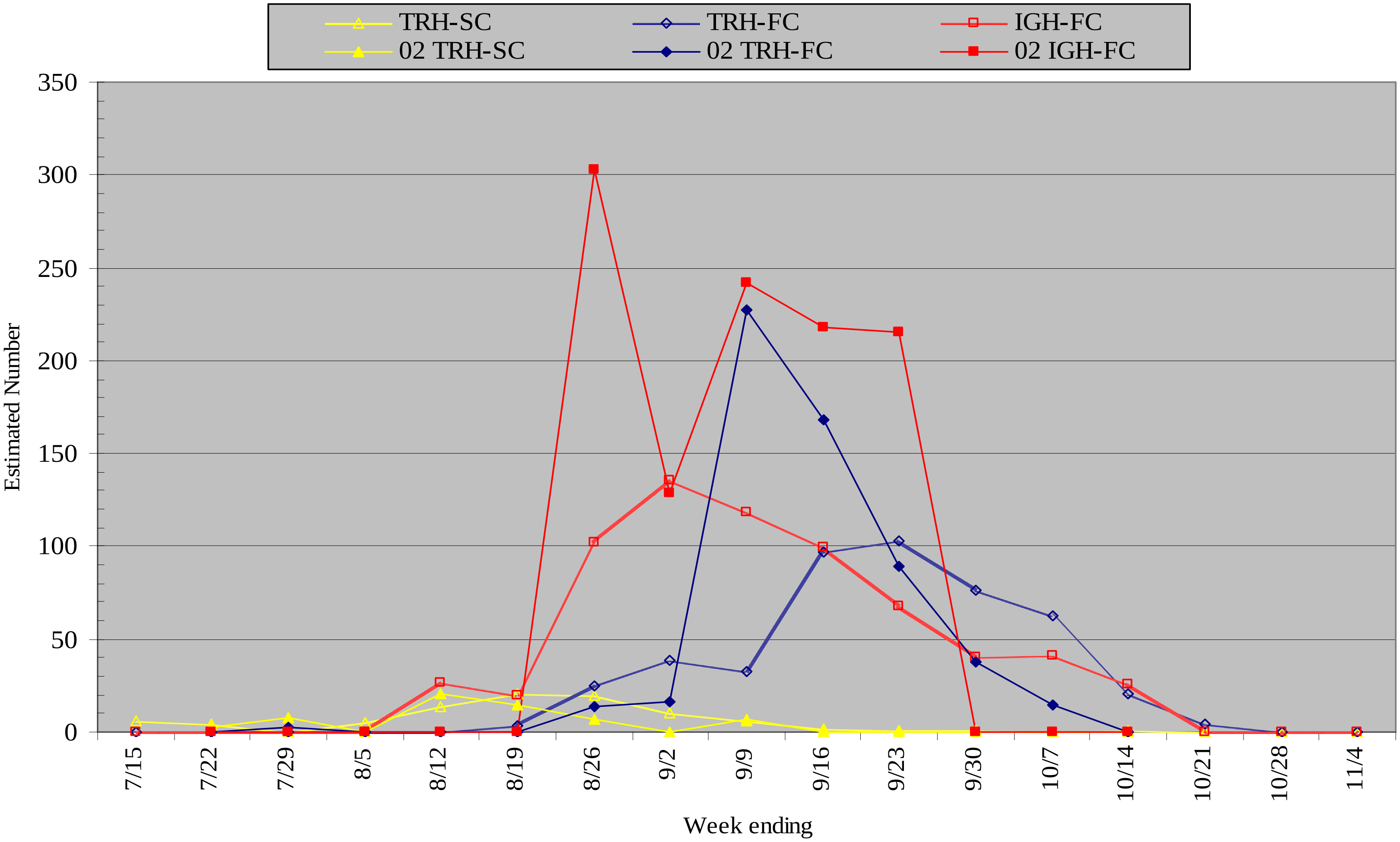


Figure H5. Average weekly expanded coded-wire tag returns for Iron Gate Hatchery fall Chinook salmon from lower klamath River sport creel surveys, 1988 - 2002 and average.

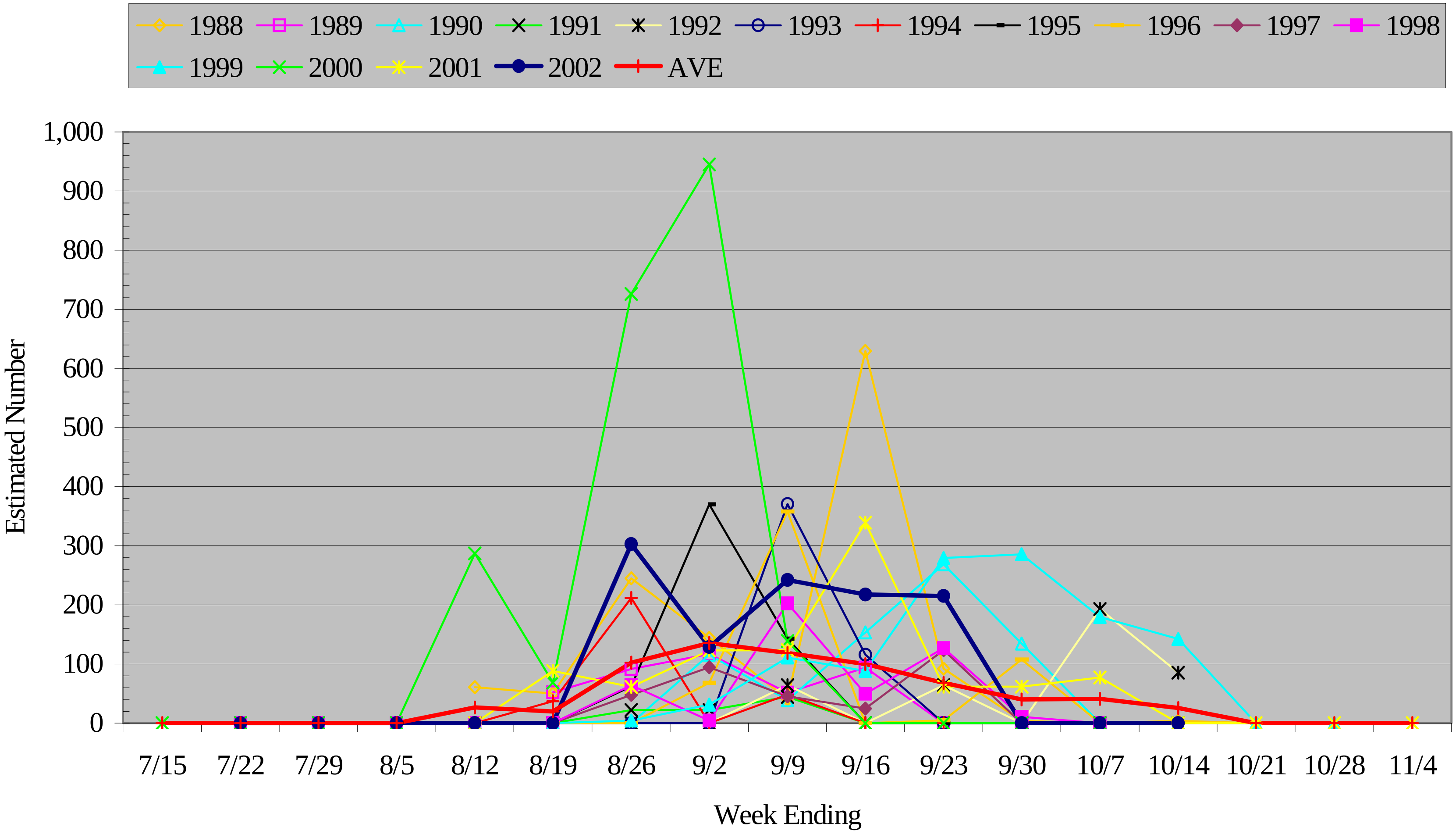


Figure H6. Average weekly expanded coded-wire-tag returns for Trinity River Hatchery fall Chinook salmon from lower Klamath River sport creel surveys, 1988 - 2002 and average.

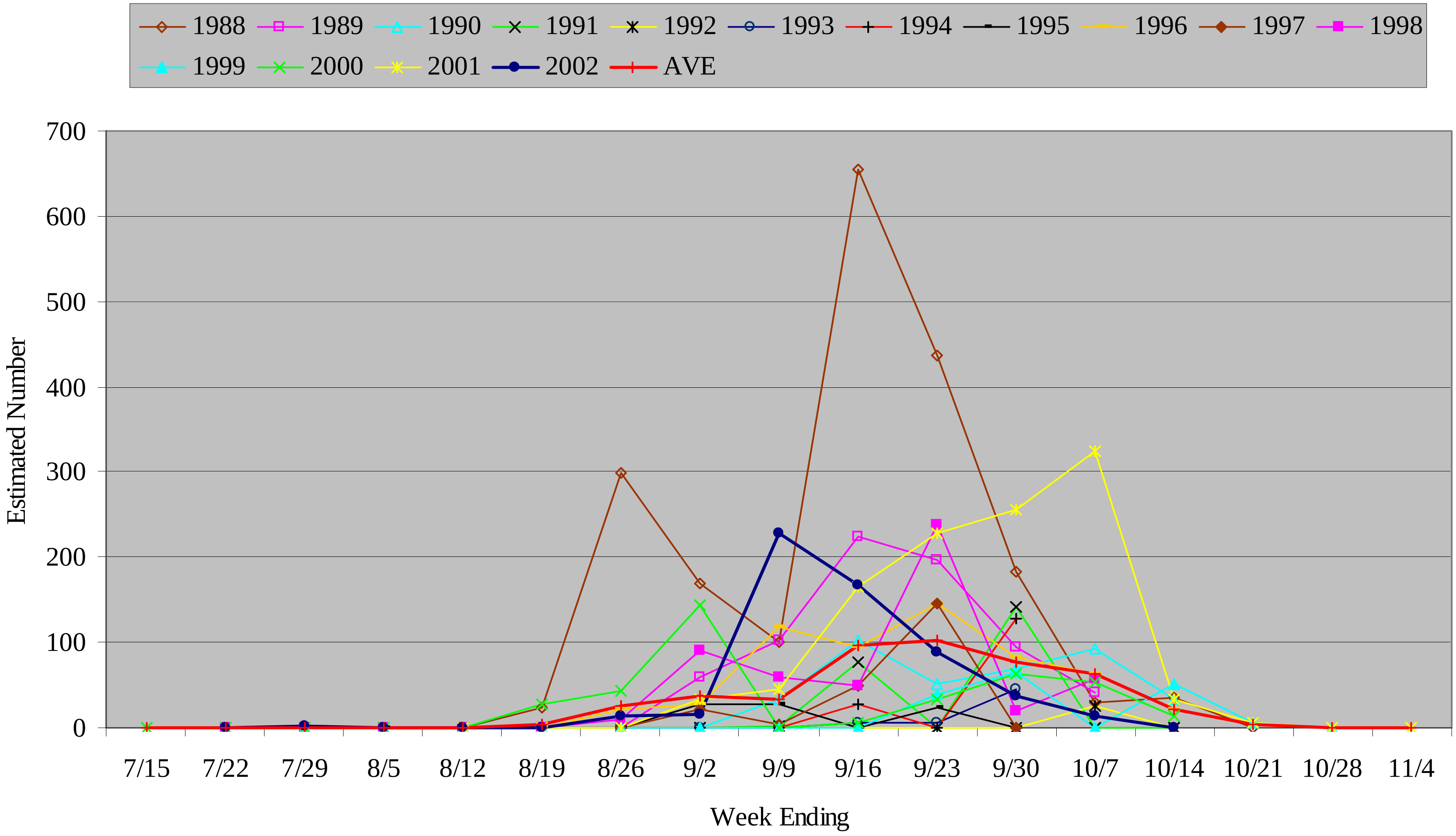
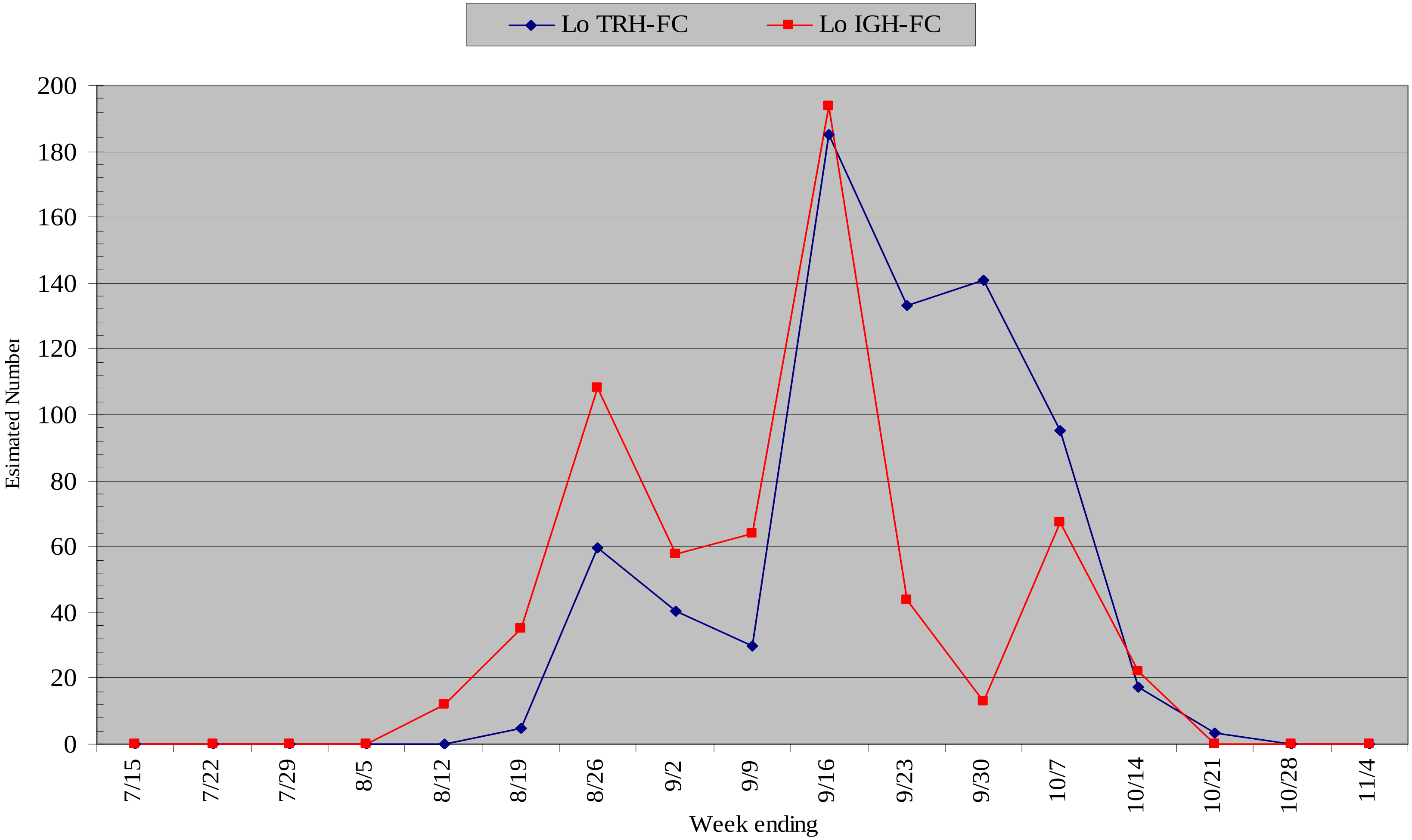


Figure H7. Average weekly expanded Iron Gate and Trinity River Hatchery fall Chinook salmon CWT recoveries for low-flow years (1988, 1991, 1992, 1994 and 2001) from the lower Klamath River sport creel census. Data for 1973 and 1981 were not available.



For non-low-flow years (1989, 1990, 1993 and 1995 - 2000), average CWT return trends for IGH-FC and TRH-FC, were substantially different from each other (Figure H8). IGH-FC CWT returns peaked on the week ending August 12 (Figure H8), three weeks earlier than the 1988-2001 average (Figure H3), and five weeks earlier than during low-flow years (Figure H7). During non-low-flow years, TRH-FC CWT returns peaked the week ending September 23 (Figure H8), similar to the 1988-2001 average (Figure H3), but one week later than during low-flow years (Figure H7). CWT returns for both hatcheries were more evenly distributed during non-low-flow years (Figure H8), than the 1988-2001 average (Figure H3), or during low-flow years (Figure H7).

CPUE for the lower Klamath River Chinook salmon sport fishery below Coon Creek Falls, was compared for low-flow years (1988, 1991, 1992, 1994, 2001 and 2002). Data for 1991, 1992, and 1994 indicated an increasing CPUE trend during mid to late September, but surveys ended at that point because sport-fishing harvest quotas were met early (Figure H9). Chinook run-sizes for those years were very small. Both 2002 and 2001 CPUE trends showed bimodal peaks, with 2002 peaks occurring one week earlier than in 2001 (Figure H9). CPUEs in 2002, first peaked during the week of August 12-18 and again on August 26-September 1. CPUEs then declined steadily, but most sharply between the weeks of September 2-15 and September 16-22. The last reported catch occurred the week of September 30 through October 6 (Figure H9). The 2001 CPUE peaked during the week of August 19-25 and again on September 9-15. It then declined at a slower rate than in 2002, with the last fish being caught during the week of October 14-20 (Figure H9). The 1988 run, which exceeded 200,000 fall Chinook, showed a relatively consistent CPUE distribution throughout the season, with peaks occurring between the weeks of September 2-8 and September 9-15. The year of 1988, also exhibited substantially lower CPUE peaks than occurred in 2002 or 2001 (Figure H9).

The pattern of average weekly CPUEs for the Klamath River Estuary, Yurok Tribal net-harvest fishery, and sport-fishery showed similar trends during 1994-2001 (Figure H10). The 1994-2001 average CPUEs for net-harvest, peaked during the week of September 3-9, and for the sport-fishery, during the week of August 27-September 2 (Figure H10). Both fisheries showed similar trends in 2002, with weekly CPUEs peaking September 3-9. However, the sport-fishery showed an additional peak on the week of August 20-26. Both 2002 net and sport fisheries, exhibited peak CPUEs two to three times higher than the 1994-2001 average (Figure H10).

Figure H8. Average weekly expanded Iron Gate and Trinity River Hatchery fall-run Chinook salmon CWT recoveries for non low-flow years (1989,1990, 1993, 1995 - 2000) from the lower Klamath River sport creel census.

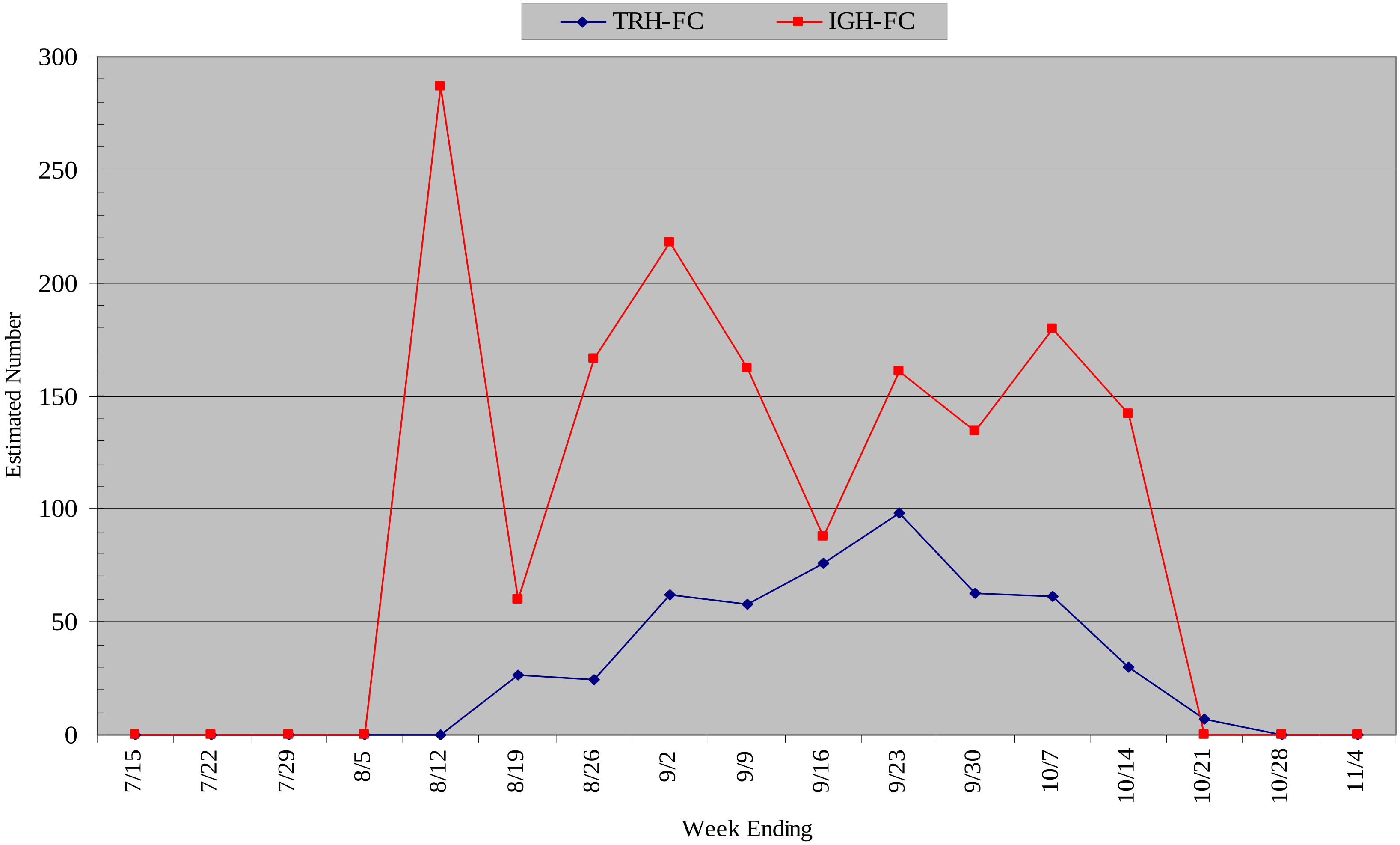


Figure H9. Average weekly catch per unit effort of adult Chinook salmon in the lower Klamath River sport creel survey during low-flow years (1988, 1991, 1992, 1994, 2001 and 2002).

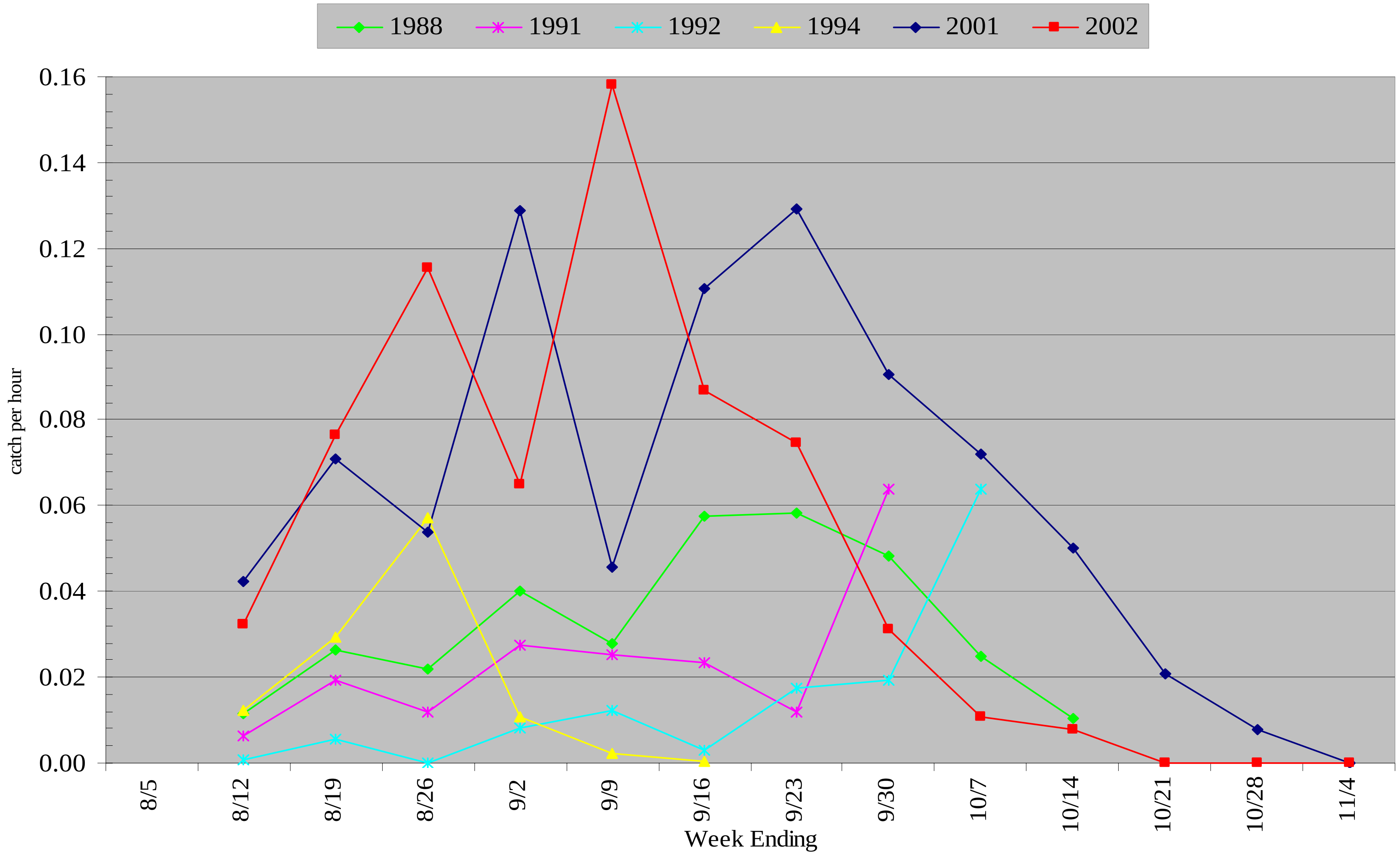
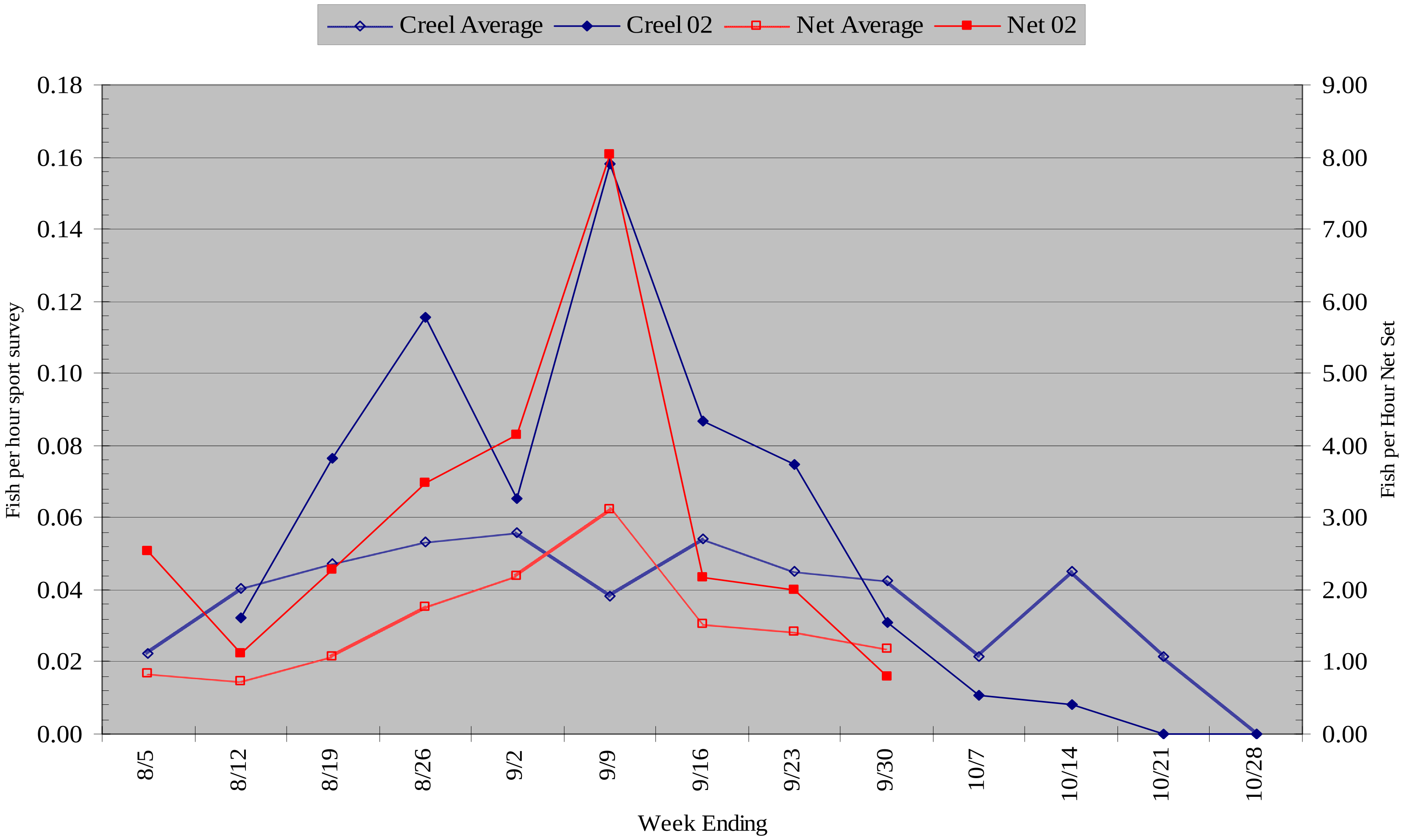


Figure H10. Comparison of average weekly catch per unit effort of adult Chinook salmon in the lower Klamath River sport creel survey and Yurok Tribal Klamath Estuary net harvest, 1994 - 2001 average compared to 2002.



III. H. 4. Findings

Based on beach seining CPUEs, yearly Chinook salmon runs from 1977-1990 peaked in the estuary at different times. Depending on the year, those peaks occurred between the weeks of August 20-26 and September 17-23 (Figure H1). On average these peaks occurred over a two week period from September 3 to 16 (Figure H2), which corresponds to the time period just prior to the beginning of the 2002 fish-kill.

Based on CWT returns, the early part of the run is made up of a relatively large component of TRH-SC, which maximizes its contribution to the salmon fishery in mid-August, but is insignificant by mid-September (Table H1, Figure H3). TRH-SC run-timing in 2002 was similar to, but peaked one week earlier than the 1988-2001 average (Table H1, Figure H4). In addition, the majority of natural spring Chinook, bound for the Salmon River (tributary to the Klamath River) and the Trinity River, passed through the lower river prior to mid-July, based on tributary weir studies. Consequently, natural spring Chinook have not been conspicuously noted by lower river studies, because those studies have been directed at harvest management of fall Chinook, and begin in mid-July or later each year. It does not appear that spring Chinook salmon were affected by the 2002 fish-kill, based on their run-timing, the absence of TRH-SC CWT recoveries in the fish-kill, and above average-sized returns of spring Chinook to the Salmon and Trinity rivers and Trinity River Hatchery in 2002.

CWT returns indicated two main stocks comprise the fall Chinook salmon run in the Klamath River Basin. The IGH-FC run, generally enters the river first, with the run peaking during the last week of August through the first week of September. Runs of TRH-FC generally peak during the second and third weeks of September. However, there is a large overlap between the two runs (figure H3) and considerable variation in run-timing from year to year (Figures H5 and H6). Although sufficient CWT information does not exist to definitively describe natural fall Chinook run-timing in the Klamath and Trinity rivers, other studies such as weir counts, have indicated that natural fall Chinook in each system, approximate the run-timing of their respective hatchery stocks. Tributary populations closest to each hatchery, have exhibited an earlier run-timing than those residing further downstream. Thus, Shasta River and Scott River fall Chinook have similar run-timing to IGH-FC, while Salmon River fall Chinook runs peak at a later date.

On average during low-flow years, IGH-FC and TRH-FC exhibited a similar bimodal run-timing, with a minor peak occurring during the week of August 20-26 and a major peak the week of September 10-16 (Figure H7). During years of average or greater flow, the two runs exhibited less similarity. The IGH-FC run showed a multi-peak nature with the major peak occurring during the week of August 6-12 and three smaller peaks, spread throughout the run until late October (Figure H8). On the other hand, the TRH-FC run during non-low-flow years, generally reflected a bell-shaped curve with the peak of the run centered during the week of September 17-23 (Figure H8).

During low-flow years (Figure H7), the IGH-FC run was more contracted and peaked two weeks later than the overall average (Figure H3), and over a month later than in non-low-flow years (Figure H8). The TRH-FC run peaked a week earlier during low-flow years (Figure H7), when compared to the overall average (Figure H3) and non-low-flow years (Figure H8). Thus, peaks of both runs nearly coincided during low-flow years (Figure H7). These data show that in non-low-flow years, larger numbers of fall-run Chinook tend to enter the river earlier, and continue to enter the river in large numbers over the entire course of their run (Figure H8). On the other hand, fall Chinook enter the river during the same general time frame during low-flow years, but the largest numbers of fish enter later, and in a more concentrated peak than during non-low-flow years (Figure H7). With IGH-FC and TRH-FC having a greater proportion of returning fish concentrated during the peak of their runs under low-flow conditions, large numbers of fall Chinook are present during short periods of time when flows are at their lowest, which may result in high densities of fish. Conversely, during years of average or greater flow, IGH-FC and TRH-FC runs were more protracted. Peaks of the runs were more widely separated, and smaller proportions of returning fish were concentrated in the lower river at any one point in time. This could result in lower densities of fish, even when runs were large during average or better flow years.

During 2002, CWT returns and sport fishery CPUE showed bi-modal peaks for the IGH-FC run. The initial 2002 peak arrived during August 20-26 (Figures H4 and H10), the same time frame as the first peak in CWT returns for an average low-flow year (Figure H7), and before many TRH-FC had entered the river (Figure H4). Therefore, the first peak of IGH-FC was present in the lower Klamath River before onset of the fish-kill. This initial peak in 2002 probably accounted for the majority of early season fall Chinook salmon escapement to the upper reaches of the Klamath River, its tributaries, and Iron Gate Hatchery. DFG believes most of these early returning fall Chinook salmon, migrated upstream and escaped the fish-kill. The second peak of IGH-FC arrived during the week of September 3-9, and was joined that same week by the peak of TRH-FC, during a time just prior to onset of the fish-kill (Figure H4).

The 2002 lower river estuary tribal net and sport-fisheries, showed similar trends, with harvests peaking September 3-9 (Figure H10). The peak harvest in the estuary was approximately three times the magnitude of the 1994-2001 average. This suggests the presence of a high density of fish, one to two weeks before the start of the fish-kill. Within one week, September 10-16, CPUEs for both fisheries dropped to near historic averages, suggesting fish had either moved upstream, were responding negatively to building fish-kill conditions (eg. becoming lethargic and less likely to be harvested), or the fish-kill had commenced earlier than reported. Sport creel and tribal net-fishery CPUEs and CWT returns support a conclusion that run-timing for fall Chinook salmon resulted in increased fish densities, far above average values, during the second and third weeks of September 2002.

Run-timing for Klamath hatchery and natural Chinook in 2002 explains why the earlier part of the Klamath run seemed to avoid the fish-kill, whereas the greatest proportion of the Trinity River run was present during the most stressful conditions, prior to and during the fish-kill. Coupled with the fact the Trinity River annually experiences smaller runs of fall Chinook than the Klamath, the high proportion of the Trinity run present in the lower Klamath River at the time of the fish-kill, explains why a greater percentage of the Trinity River fall-run were lost. However, it is important to understand that while a greater proportion of the Trinity run was lost, larger numbers of Klamath River fall-run Chinook salmon died in the fish-kill (see Section III. G.).

Magnitude and timing of the second peak of IGH-FC and TRH-FC entering the Klamath River September 3-9, indicated these were the fish most affected by the fish-kill. It appears this second peak of fall Chinook encountered stressful conditions, causing fish to initially cease or slow their migration and crowd in the lower river, thus increasing fish density. This large, concentration of fish initially increased sport angler and tribal net-fishery catch rates and CWT recoveries. Subsequently, fall Chinook densities dropped and runs quickly decreased as the fish-kill took effect (Figures H4 and H10). This was the first major adult fall Chinook salmon fish-kill on the Klamath River, and its exact influence on migration timing and fish densities is impossible to determine; but the effects may have been substantial.

In summary, spring-run Chinook salmon were not affected by the 2002 fish-kill. It appears the early peak of IGH-FC observed August 20-26 in the lower river, were able to migrate upriver and largely avoid the fish-kill. A later peak of Klamath and Trinity fall Chinook, which were present September 3-9, were most affected by the fish-kill.

Past beach seining data, and CPUE and CWT data from sport and tribal net fisheries, showed the 2002 fall Chinook salmon run in the lower Klamath River, occurred within the same time period as past runs. The peak of the 2002 run also occurred within the temporal range of past peaks in salmon runs. Therefore, DFG accepts the null hypothesis that run-timing of fall Chinook salmon entering the lower Klamath River during September 2002, was not substantially different when compared to previous years, when fish-kills did not occur. The 2002 run and its peak occurred within the temporal range of past runs. However, CPUE data from sport and tribal net-fisheries, showed the peak of the 2002 run occurred one week earlier than the average peak, as indicated from past beach seining records. On this basis of a comparison of the peak of the 2002 run compared to the average peak of runs from beach seining, DFG has accepted the alternative hypothesis that run-timing of fall Chinook salmon was different, when compared to previous years, when fish-kills did not occur. The peak of the 2002 run did occur one week earlier than the average peak for all years of beach seining.

The combined 2002 peak of TRH-FC and IGH-FC from CWT data, occurred the week of September 3-9 (Figure H4). This was one week earlier than the average peaks for low-flow years, which occurred September 10-16 for TRH-FC and IGH-FC (Figure H7). Therefore, DFG accepts the alternative hypothesis that run-timing of fall Chinook salmon was different in 2002, when compared to previous low-flow years, when fish-kills did not occur. The 2002 run peaked one week earlier than the low-flow year average, but was within the temporal range of peaks for other low-flow years.

The 2002 IGH-FC and TRH-FC runs were more contracted in time, and their peaks more pronounced, indicating high numbers of fish present at one time, when compared to non-low-flow years. The peak harvest for sport and net-fisheries in the estuary during 2002, were approximately three times the magnitude of the 1994-2001 average, and occurred September 3-9. This suggests the presence of a high density of fish. Therefore, DFG accepts the alternative hypothesis that fish densities were high in September 2002 and may have been a factor in the fish-kill. Large numbers of fish present in the lower Klamath River occurred during a period of extremely low-flows and river volume during 2002. This combination of factors, likely led to a high density of fall Chinook salmon in the river during the two weeks prior to the onset of the fish-kill.

The low-flow years of 2001 and 1988, also had above average-sized runs of fall Chinook salmon, but fish-kills did not occur. In 2001, both runs peaked late and the peaks were three weeks apart. Based on CWT returns, the IGH-FC run peaked on the week of September 10-16, and the TRH-FC run peaked on the week of October 1-7 (Figures H5 and H6). This delay in run-timing was probably caused by partial sand spit formation at the mouth of the Klamath River (Borok 2003, personal communication). Even though fish densities were relatively high, as indicated by CPUE (Figure H9), run timing was dispersed and delayed, thus avoiding conditions that would lead to a fish-kill. In 1988, CWT returns showed both the IGH-FC and TRH-FC runs peaked during the week of September 10-16 (Figures H5 and H6), but catch rates in the sport-fishery remained relatively low and steady throughout the season (Figure H9), suggesting fish densities did not reach the high levels present in 2002. Chinook salmon densities may have been significantly reduced in 1988 by a robust Yurok tribal net-fishery (Hillemeier 2003, personal communication).

IV. Factors Discussion:

IV. A. Principal Cause;

The death of over 33,000 adult salmon and steelhead in the lower 36 miles of the Klamath River in September of 2002 was unprecedented. Prior to this incident, there had never been a major fish-kill of adult salmon and steelhead recorded on the Klamath. Juvenile fish-kills have taken place further upstream (DFG 2000c), and some adult prespawning mortality has been observed for Chinook salmon below Iron Gate Hatchery (USFWS, Arcata, unpublished data) and for spring-run Chinook salmon in the Trinity River (Pisano 2003, personal communication).

In sections III. A. and B. of this report, DFG evaluated competing hypotheses about the primary cause of the September 2002 Klamath River fish-kill. The preponderance of evidence leads us to conclude, the principal cause of the fish-kill was disease from a massive infection by the ciliated protozoan ich and the bacterial pathogen columnaris. There is no evidence to support a competing hypothesis that the fish-kill was caused by toxic substances (section III. B.). Investigations of the 2002 fish-kill by DFG (2002b) and USFWS (2002) have clearly identified the cause of death, as infection by the pathogens ich and columnaris. These pathogens are found worldwide in aquatic ecosystems (Post 1983, USFWS 1974, 1976 and 1982), and thus, are present at all times in the Klamath River Basin.

It is important to understand the difference between the terms pathogens and disease. Pathogens are defined as organisms having the capability to cause disease. Pathogens can infect fish, reproduce, and be shed from their host, without causing death. Therefore, presence of a pathogen does not necessarily equate to disease. Disease outbreaks and fish-kills occur when fish are stressed and more susceptible to infection. Disease can manifest itself under certain environmental conditions including; low flows, high fish densities, and warm water temperatures (Post 1983 and USFWS 1982), such as occurred in September 2002 in the lower Klamath River. For a disease problem of the magnitude experienced on the Klamath during 2002 to occur, conditions favoring pathogens and stressing the host fish must occur several weeks in advance (Post 1983). Ich can take up to two weeks to complete its life-cycle at a temperature of 60 ºF, but only 3 to 4 days at optimal temperatures of 70 ºF to 75 ºF (USFWS 1982). In the case of columnaris, disease can take an explosive course, and cause catastrophic losses within 1 to 2 days after its appearance (USFWS 1982). Post (1983) indicates optimal temperature conditions for columnaris are about 83 ºF to 87 ºF (28 ºC to 30 ºC). Overcrowding in hatcheries, aquaria, and during spawning runs in rivers at the base of dams, can result in conditions conducive to self-perpetuating infections among fish (Post 1983).

IV. B. Related Factors;

Sections III. C. through III. H. of this report, focused on potential stressors of anadromous salmonids, to determine physical and environmental conditions present in the Klamath River during September 2002 that could have contributed to disease and the fish-kill. Specific factors analyzed were; flow, temperature, dissolved oxygen, fish passage, river geomorphology, run-size and run timing. We also analyzed these potential stressors against past years, when fish-kills did not occur, to identify the most likely factors causing the 2002 fish-kill.

There was no single factor in our analysis that was found at unprecedented levels in September 2002, and could have individually been responsible for the fish-kill. Rather, a combination of factors came together to create conditions stressful to salmonids and conducive to a disease outbreak. The evidence supports a conclusion that the September 2002 fish-kill was caused by disease from ubiquitous pathogens and stressful conditions for anadromous salmonids including: atypically low-flows and low river volume coupled with an above average run of salmon, which peaked one week earlier than average, and seasonally warm water temperatures that normally occur in September of each year in the lower Klamath River. There is also substantial anecdotal evidence to suggest fish passage was inhibited, resulting in high fish densities, before and during the fish-kill.

The factors responsible for the 2002 fish-kill, can be categorized into controllable versus uncontrollable, and atypical versus typical conditions for the Klamath Basin. NCRWRCB (1994) defines controllable factors as; “those actions, conditions, or circumstances resulting from man’s activities that may influence the quality of the waters of the State and that may be reasonably controlled”.

Atypically low-flow is one of the most likely causes of the fish-kill. Flows in the Klamath River during September 2002 were low, and always fell in the lowest tenth percentile of flows at each gaging station, for the period of record over the last 50 years. Trinity River discharges, on the other hand, were near average in September 2002 compared to the period of record since 1951. Our analyses of flow compared favorably with USGS (2003), in which they concluded stream-flows in the Klamath Basin were low, and in most cases were among the four lowest for the period since 1960. USGS also found Trinity River flows to be near average for the period of record since 1960 (USGS 2003). USFWS, through a nonparametric cluster analysis, also concluded Klamath River discharges in August and September 2002 were low, and grouped most closely to the drought years of 1991, 1992, and 1994 (USFWS 2003b). They also identified low discharges as a factor resulting in lower river volume, lower water velocity, and lower exchange/turnover rates for water in pools where salmon were holding; all factors conducive to a disease outbreak by ich (USFWS 2003b).

Low river volume was another potential cause of the fish-kill. Besides the lower volume of water expected with low discharges, our analysis of river stage indicates September 2002 volumes, in at least the lower eight miles of the Klamath River, were atypically low when compared to past years. Lower river stage and volume of water in the estuary during September 2002 appears to relate to the lack of a sand spit formation and constriction at the mouth of the river, when compared to many past years. Lower estuary stage and volumes in 2002, may also be related to a lowering of the streambed from high-flow events in the late 1990's. Low-flows and low river volume resulted in less habitat space available for fish in the river.

Flow in the Klamath and Trinity rivers is highly regulated by upstreram diversions. USGS describes flows for the Klamath River near Klamath, as considerably regulated by reservoirs, powerplants, and multiple irrigation diversions above the station (USGS 1990). Therefore, flows in the Klamath and Trinity rivers meet the definition of a controllable factor. River volume, water velocities, and water exchange/turnover rates, are all controllable to the extent that flows can be regulated.

Typical high water temperatures were also a likely factor stressing fish, and creating conditions conducive to a disease outbreak from ich and columnaris. Water temperatures in September 2002 were at levels known to be stressful to adult salmonids, but were not unusually high when compared to past years. Temperatures in the Klamath River Estuary typically approach a maximum of 70 ºF or higher in August and September, and occasionally reach 80 ºF (26.7 ºC) in the mid-reaches of the river, yet previous significant adult fish-kills have never been reported.

Our regression analyses show water temperatures in the lower Klamath River are influenced by atmospheric temperatures and flow. Atmospheric temperatures appear to exert the greatest influence on water temperature, but are beyond human control. Flow is less important, but a significant factor influencing water temperatures in the lower Klamath River (particularly under low-flow conditions), and represents a controllable factor. Our regression analyses indicate that increasing flows by at least 200 cfs for TRH+KAO in September 2002 may have lowered water temperatures at Terwer by about 4 ºF. A reduction of 4 ºF would not likely have lowered water temperatures in the fish-kill area to levels below USEPA guidelines for reduction of high risk from disease pathogens for adult salmon (64.4 ºF), but may have resulted in temperatures consistently below the guideline for protection of migrating adult salmon (69.8 ºF). Our regression analyses also indicate a critical flow level of 1,900 cfs for TRH+KAO, above which increasing flows to at least 2,250 cfs may decrease water temperatures to near the USEPA guideline for reduction of high risk from disease pathogens for adult salmon. Below 1,900 cfs flow appears to have little or no influence on water temperatures at Terwer. Water temperatures therefore, are controllable to the degree that flows can be regulated.

High fish densities appear to be another potential factor in the fish-kill. Although there is no specific empirical data, there are several lines of evidence to indicate high fish densities were present, prior to and during the September 2002 fish-kill. 170,014 fall-run Chinook salmon returned to the Klamath River in 2002. This represented an above average run-size and the eighth largest run since 1978. Although these fish returned to the Klamath during their normal migration period, it appears the peak of the run occurred one week earlier than average, and two weeks before the onset of the fish-kill. These fish entered the river under very low-flow and low volume conditions, resulting in reduced habitat space for a large number of salmon. USFWS (2003b), through cluster analysis, concluded that; "2002 featured a unique combination of low discharges (especially from Iron Gate Dam) and high run-size". Anecdotal observations by biologists from USFWS, and the Yurok Tribe, suggested flows were low enough to potentially impede upstream passage of migrating salmon at certain riffles in the lower river. USFWS (2003b) concluded; “Large numbers of fish congregated in the lower Klamath River, in part due to constant low-flows that resulted in a lack of cues for upstream migration.”

In summary, an above average number of Chinook salmon entered the Klamath River between the last week in August and the first week in September 2002. River flow and the volume of water in the fish-kill area were atypically low. Combined with the above average run of salmon, these low-flows and river volume resulted in high fish densities. Fish passage may have been impeded by low-flow depths over certain riffles or a lack of cues for fish to migrate upstream. Warm water temperatures, which are not unusual in the Klamath River during September, created ideal conditions for ubiquitous pathogens to infect salmon. Presence of a high density of hosts and warm temperatures caused rapid amplification of the pathogens ich and columnaris, which resulted in an unprecedented fish-kill of over 33,000 adult salmon and steelhead.

IV. C. Differences in 2002 Factors and Other Low-Flow Years;

The total in-river fall Chinook salmon post-season run-size estimate for 2002 was 170,014 fish. Low-flow years as defined in section III. C., included 1973, 1981, 1988, 1991, 1992, 1994, 2001 and 2002. Fall Chinook salmon runs totaled 108,171 in 1981, 215,322 in 1988, 34,353 in 1991, 40,346 in 1992, 75,936 in 1994 and 200,579 in 2001 (Figure G2). No data were available for 1973. Runs in 1991 and 1992 were the lowest ever recorded, and in 1981 and 1994 were below average (Figure G1). On the other hand, runs in 1988 and 2001 were larger than in 2002, and all three of these runs were substantially above average.

If it is assumed that runs in 1981, 1991, 1992 and 1994 were too small to have resulted in fish densities that would be vulnerable to a disease outbreak, then we can focus on differences between 1988 and 2001, when fish-kills did not occur, and 2002 when there was a major fish-kill. With respect to flow, there is uncertainty associated with the accuracy of the lower Klamath River gage, particularly in 2001 and 2002 (USGS 2003). September data reported for this gage in our preliminary report (DFG 2003a), showed average flows in 1988 (2,103 cfs) and in 2002 (2,129 cfs) were very similar and estimated flows in 2001 (2,601 cfs) were much higher. Since release of the DFG preliminary report, USGS has revised the average September 2002 flows down to 1,987 cfs, which if accurate, represents the second lowest flow ever recorded. Average 1991 flows were lower than 2002 by 10 cfs. However, USGS (2003), in their evaluation of flows from September 1 to 24, used combined flows of the Trinity River near Hoopa and the Klamath River at Orleans to characterize flows in the fish-kill area. This was done because they rated accuracy of the Klamath River near Klamath Gage as “poor” in 2001 and 2002 due to tidal influences. In their analysis, 1988 flows (2,026 cfs) were highest of the three years, followed by 2002 (1,923 cfs) and 2001 (1,857 cfs). This analysis indicates 1988 was the only year, of these three (1988, 2001, and 2002), where flow exceeded 2,000 cfs in the lower river. Consequently, flows in 1988 may not have been as low as previously believed when compared to other years. On the other hand, this analysis also indicates that flows in 2001, were actually much lower than previously thought.

Analysis of river stage at the Klamath River near Klamath Gage, lends support to USGS concerns regarding tidal influence. River stage data also points to some important differences between 1988, 2001, and 2002. The year 2002, represents the lowest September stage levels recorded for the lower Klamath River from 1988 and 1991 to 2002 (Figures F1 and F2). September 2002 river stage (and consequently the volume of water in the lower river) was consistently low through the entire month of September leading up to and including the time of the fish-kill. There was also a clear difference in September river stage between 1988, when daily stage levels were nearly two feet higher than in 2002 (Figure F1). Within each year, 1988 and 2002 showed relatively consistent stage levels through the month of September. It is unknown if higher stage levels in 1988 translated to a higher volume of water in the estuary than in 2002. However, since the river did down-cut during flood events in 1997 and 1998 (Susich 2003, personal communication), it is possible the higher stage in September 1988, translated to a higher volume of water in the estuary. River stage relative to flow was lower after 1997 and higher before 1996. This corresponds with lowering of the channel bottom at KNK, by one to two feet, after high flow events in the late 1990's (Susich 2003, personal communication).

Most notable was the difference in river stages during September 2001 when compared to 1988 and 2002. River stage at Terwer in 2001 increased from about 5.2 feet on September 1, 2001, to about 11.8 feet on September 26, and then dropped to around 4.6 feet at the end of the month (Figure F1). These high stage levels corroborate observations by a DFG Fisheries Biologist, who reported high water levels and extensive flooding in the Klamath River Estuary during September 2001, due to formation of a partial sand spit and constriction at the mouth of the river (Borok 2003, personal communication). Since the lower Klamath gage is located six miles upstream of the mouth of the Klamath River, and gage elevation is at six feet above sea level, large shifts in river stage during 2001 represent a substantial volume of water in the estuary, which could influence stage and volume at least to Blake's Riffle (RM 8). The KNK gage was relocated above Blake's Riffle in September 2003 to avoid tidal influence. Consequently, there was a much higher volume of water present in the lower Klamath River in September 2001 than in 2002, even if flows were similar. A larger volume of water in 2001, translates to more habitat area, and would decrease densities of fish present. This was an important factor in 2001, which helped prevent a fish-kill such as that which occurred in 2002. Similar high river stages were also observed in September of low-flow years 1991, 1992, and 1994, and could also be indicative of formation of sand spits and higher volumes of water in the estuary for those years.

Besides the possibility that flow was not as low in September 1988 as previously presented in our preliminary analysis (DFG 2003a), there are two other substantial differences between 1988 and 2002. First, predicted water temperatures in 1988 declined considerably through the month of September, while particularly warm periods occurred in early and mid to late September of 2002. In addition, CPUE for salmon by sport anglers was the highest recorded for the week of August 26 to September 1, 2002, when compared to any other week in 1988, 1991, 1992, 1994, 2001 and 2002 (Figure H9). CPUE data also showed the 1988 run of salmon entering the river more evenly over time, peaking at much lower level than in 2002, and peaking a week or two after the 2002 run. This indicates the density of the 1988 run was not as high as in 2002, and salmon entered the system during more favorable temperature conditions in 1988.

IV. D. Comparison with Other Fish-kills;

Large adult salmonid fish-kills from pathogens and disease are a relatively rare occurrence in the wild. The 2002 fish-kill was unprecedented, and was the first massive mortality of adult anadromous fish documented on the Klamath River. This discussion compares similarities and differences between the Klamath fish-kill, and other significant adult salmon fish-kills from the west coast of North America. Through this discussion, we may be able to identify important causes, and potential remedies to prevent future mortality events on the Klamath River.

IV. D. 1. Rogue River

The Rogue River in southern Oregon has experienced extensive prespawning mortality of both spring and fall-run Chinook salmon (ODFW 2000). Prior to the start of operation of Lost Creek Dam in 1978, ODFW reported at least three years, in which large prespawning mortalities of spring and fall Chinook salmon occurred. In addition, prespawning mortality was mentioned in 13 of 30 years, in which reports were written (ODFW 1992). Annual rates of prespawning mortality have been as high as 70.2% for spring Chinook (ODFW 2000), and 81% for fall Chinook (ODFW 1992). The three largest recent spring-run Chinook fish-kills were documented in 1987, 1992, and 1994 when 31,579, 13,684, and 20,134 fish, respectively, were estimated to have died prior to spawning (ODFW 2000).

Fall Chinook mortality prior to 1978, was positively correlated with years of summer low-flow. Mean July-August flow at Gold Ray Dam (RM 125.2) averaged 1,526 cfs in years of no mortality, and 1,247 cfs in years with mortality. The difference of 279 cfs was statistically significant ($p < 0.001$) (ODFW 1992).

During a 1978 to 1986 study, fall Chinook mortality rates were positively related to water temperatures in the Rogue River Canyon (RM 34.2 – 68.4) during late summer. As water temperatures increased, the mortality rate increased. Regression analysis predicted mortality rates of <1% at 66.2 ºF (19 ºC), 15% at 68.0 ºF (20 ºC) and 89% at 69.8 ºF (21 ºC) (ODFW 1992). The effects of flow on mortality were not analyzed, but flow was closely correlated to water temperature (ODFW 1992). Fish density had less affect on mortality than water temperature (ODFW 1992).

Disease was implicated as the probable immediate cause of both spring and fall-run Chinook prespawning mortality, but death could not be attributed to any one organism (ODFW 1992, 2000). Columnaris was the disease pathogen most often found in dead and dying fall-run Chinook. Unlike the September 2002 Klamath River fish-kill, ich was not mentioned as a causative factor in Rogue River fish-kills (ODFW 1992, 2000).

Although columnaris was found in greatest concentrations far upstream at the outflow from Cole M. Rivers Hatchery, mortalities of fall-run Chinook salmon peaked almost 124 miles (200 km) downstream of Lost Creek Dam (ODFW 1992).

Authorization for construction of the multipurpose Lost Creek Dam (RM 160) on the Rogue River, included enhancement of fishery resources in downstream areas by operating the dam to increase summer flows and decrease summer water temperatures (ODFW 2002). When the reservoir is full, 125,000 acre-feet of a total storage of 180,000 acre-feet, are authorized for fishery enhancement (ODFW 2002).

To decrease water temperatures in the Rogue River, flow must be augmented, because the effects of outflow temperature decrease rapidly with distance downstream (ODFW 2000). For instance, the outlet temperature effect of releases at Lost Creek Dam on mainstem water temperatures during the summer, are exhausted by the time the river reaches Grant's Pass (RM 107) (Satterthwaite 2003, personal communication). To reduce water temperatures at Agness (RM 27) by 1 ºF during May and June, requires the release of an additional 445 cfs from Lost Creek Dam (RM 160) (ODFW 2002).

ODFW recommended the following Lost Creek Dam water release strategy to avoid or minimize prespawning mortality of spring and fall-run Chinook salmon (ODFW 1992, 2000, 2002):

Spring Chinook Salmon

- Lost Creek Dam releases are managed so that daily maximum water temperatures at Agness do not exceed 65 ºF during May and June during years of average or above water yield.
- During years of below average water yield, maintain a maximum water temperature goal of 66 ºF at Agness in May and June. The higher temperature standard is necessary in drought years to conserve stored water for use later in the summer.

Fall Chinook Salmon

- Maintain a minimum flow of 2,300 cfs at Lost Creek Dam from August 10 through September 10 to ensure that the daily maximum water temperature at Agness averages less than 68 ºF during August and September.

In general, maintaining water temperatures below 66 ºF for spring Chinook, and in the low 70's ºF for fall Chinook by manipulating flow releases at Lost Creek Dam, have prevented disease outbreaks. However, once a disease epizootic has started, additional flow will not stop the process (Satterthwaite 2003, personal communication).

Managers have eliminated (in average or better water years) or greatly reduced (in below average water years) mortality of adult Chinook salmon on the Rogue River by reducing water temperatures, and increasing flows during periods of high stress by releasing water from Lost Creek Dam, located 124 miles upstream of the primary fish-kill area. Since the Rogue River is similar to the Klamath River in many ways (length, discharge, temperature trends in the lower reaches), similar management should be considered for the Klamath River, where flows are presently not managed to specifically address summer habitat for adult Chinook salmon.

IV. D. 2. Butte Creek

In 2002 and 2003, Butte Creek, a tributary to the Sacramento River, experienced large pre-spawn mortalities of federally and state listed spring-run Chinook salmon. DFG estimated fish losses of 3,431 salmon (21%), out of a population of 16,028 adults in 2002 and 11,231 salmon (65 %) out of an estimated population of 17,294 adults in 2003 (DFG 2004). The unique life history of spring-run Chinook includes a protracted period of adult fresh water residency, which in Butte Creek is up to seven months prior to spawning, and thus exposes those fish to a higher risk of pre-spawn mortalities. Additionally, water temperatures in the holding/spawning reach of Butte Creek, are generally higher during the months of July and August than is optimal for Chinook salmon, with average daily water temperatures during the period generally exceeding 62° F. In both 2002 and 2003 peak mortalities occurred from late July until early September (96% in 2002 and 99% in 2003) following abnormally high water temperatures. During 2002, water temperatures at a key site in the holding reach of Butte Creek peaked at 69.4° F during mid-July, while in 2003, the peak was 69.7° F in late July. While the entire holding spawning reach of Butte Creek is affected by a Pacific Gas and Electric Company (PG&E) hydropower project, DFG concluded the pre-spawning losses were primarily due to large numbers of fish concentrated in limited holding pools, high water temperatures, and an outbreak of two pathogens, columnaris and ich (DFG 2004). DFG also concluded that operation of the hydropower project provided a net benefit to salmon holding and spawning, but also identified the need to further evaluate operational changes that would potentially decrease water temperatures.

Much of the summer holding areas for spring-run Chinook salmon in Butte Creek occur in the stream bypass reach of Pacific Gas and Electric Company's (PG&E) hydroelectric facilities between Centerville Diversion Dam and Centerville Powerhouse. In 2002 and 2003, PG&E complied with the flow requirements established under their Federal Energy Regulatory Commission (FERC) license. Based upon a temperature modeling study (Kimmerer and Carpenter 1989), DFG concluded that increasing flows in the bypass reach above Centerville Powerhouse beyond those established under the 1992 FERC license amendment, would have limited benefits in reducing water temperatures and could result in increased temperatures below the powerhouse (DFG 2004). DFG also has concerns that increasing flows could attract more spring-run Chinook salmon into the bypass reach and out of areas below the powerhouse where currently 40% of the salmon hold and where there is significantly more spawning habitat (DFG 2004). Based upon a recent evaluation of spawning habitat by USFWS (Gard et al. 2003), DFG has concluded that spawning habitat within the bypass reach is limited and currently overexploited (DFG 2004). DFG is currently working with PG&E to identify ways to provide cooler water to Butte Creek through operational changes with water diverted from the West Branch of the Feather River (DFG 2004).

The Klamath River is a much larger and longer river than Butte Creek, and its flows average 20-30 times greater. Where significant water is being diverted from the Klamath River Basin upstream of the fish-kill area, Butte Creek actually has its flows augmented by transfers from the West Branch Feather River. Cooler West Branch Feather River water diversions provide approximately 40% of Butte Creek's flow above the mortality area during July through September when Spring-run Chinook are holding and spawning (DFG 2004). Compared to fall-run, spring Chinook salmon, have a different life history strategy in which they are adapted to migrating into, holding and spawning in the headwater areas of their natal streams. Spring-run Chinook have migrated (often by mid-February in Butte Creek) a substantial distance to their summer holding areas, and must remain for up to seven months before spawning during mid-September to late October. Fall-run Chinook salmon, that died in the lower Klamath River, had just entered the river from the ocean and were holding in the lower river for a matter of weeks before the onset of the fish-kill. The disease outbreak on the Klamath River occurred for about two weeks, while Butte Creek fish died over a one month period. Therefore, the Butte Creek and Klamath River events are substantially different, such that comparing the two is difficult and may not be relevant.

IV. D. 3. Babine River

High mortalities in prespawning and spawning sockeye salmon (*Oncorhynchus nerka*) occurred during September 1994 and 1995 at several spawning sites in the Babine River System, tributary to the Skeena River in northern British Columbia (Traxler et al. 1998). The cause of these fish-kills was a heavy infection of ich, the transmission of which, was aided by high densities of sockeye salmon, blocked by weirs for days or weeks prior to their entry into natural and artificial spawning channels adjoining Babine Lake (Traxler et al. 1998). Although ich has been reported from hatcheries and in numerous freshwater and anadromous fish species in Canada, this was the first report of high prespawning mortality due to ich in a wild salmonid population. Similar fish-kills occurred at two widely separated spawning channels on the Frasier River, British Columbia in 1995 (Traxler et al. 1998).

The source of infection was likely from resident fish in the Babine Lake System. These resident fish were resistant to infection themselves, but acted as a reservoir of infection for the anadromous sockeye salmon, which lacked immunity to the parasite (Traxler et al. 1998). Ich infections in sockeye salmon were not detected at downstream locations, and were not noted until fish entered Babine Lake and congregated below fish weirs (Traxler et al. 1998). Ich does not require an intermediate host to complete its life cycle, but usually requires an off-host stage of development before attaching to another host. When host densities are high, chances of encountering and successfully attaching to another host increases. High densities increase stress in fish and make them more susceptible to ich infection and eventual death (Traxler et al. 1998).

Although ambient water temperature is an important factor in the rate of development of ich (Warren 1991), water temperatures during the epizootic in 1994 and 1995 were similar to prior years when significant prespawning mortality was not evident (Traxler et al. 1998).

Unlike the Klamath River, the Babine is characterized by high year-round flows of cold, high quality water. The Babine River fish-kills illustrate that ich can be a significant cause of mortality in wild salmon, even when water quality is excellent and water temperatures are within the range of preference for salmon. When runs are large and adult salmon migrations are blocked, fish densities can become high and facilitate transmission of ich, which can lead to significant mortality. Blocking the sockeye salmon run on the Babine River by manmade weirs, had the same effects of increasing fish density and stress, as occurred on the Klamath River in September of 2002. However in the case of the Klamath fish-kill, the species affected were migrating adult Chinook salmon and no physical manmade barriers were present. Both events, encouraged ich epizootics, resulting in large fish-kills, in river systems that are vastly different in character.

The 2002 Klamath River fish-kill was somewhat unique when compared to other examples of epizootics on the Rogue, Babine and Fraser rivers, because two pathogens (ich and columnaris) were responsible for disease on the Klamath. However, the combination of ich and columnaris was also found to be responsible for the Butte Creek events. Columnaris was the pathogen identified in fish-kills on the Rogue River, and ich was identified as the responsible pathogen in disease outbreaks on the Babine and Frasier rivers.

All of these major epizootic events are related to at least one of four factors, flow, water temperatures, high fish densities and the presence of pathogens. In the Rogue River case, columnaris outbreaks in spring and fall Chinook salmon appear related to high water temperatures in the summer and early September, which are now controlled through increased flow releases from Lost Creek Dam. In the case of Butte Creek, columnaris and ich outbreaks corresponded to abnormally high water temperatures and limited holding habitat coupled with very large runs of spring Chinook salmon (CDFG 2004). Efforts have been underway to identify operational changes to hydroelectric facilities, and to provide cooler water in the spawning and holding reaches on Butte Creek. In the cases of the Babine and Fraser rivers, ich outbreaks in sockeye salmon, appear most related to high densities of fish as they congregated below spawning channels. Increased water temperatures are an important factor in the development rate of ich (Warren 1991), but high densities of the host fish were necessary for severe ich outbreaks on these rivers.

Flow management appears to be a critical consideration in the prevention of future adult fish-kills on the Klamath River. Increased flow and velocity have been used in a hatchery setting to prevent mortality in catfish from ich (Bodensteiner et al. 2000). In addition, flow is used in the Rogue River to control temperatures and prevent disease outbreaks in spring and fall-run Chinook salmon. Increased flows when adult salmon are entering the Klamath River (particularly during low-flow years such as 2002), should be implemented to improve water temperatures, increase water volume, increase water velocities, improve fish passage, provide migration cues, and decrease fish densities. Flow is the only controllable factor and tool available in the Klamath Basin (Klamath and Trinity rivers), to manage risks against another major adult fish-kill.

V. Impacts of the Klamath River Fish Kill:

The previous sections of this report were dedicated to understanding the factors resulting in the September 2002 Klamath River fish-kill. This section evaluates potential impacts of the fish-kill on the anadromous fishery of the Klamath River.

To evaluate the impacts of the fish-kill, we must first understand the reliability of the estimate of fish numbers lost. Fish-kill estimates based on the numbers of countable dead fish are inherently conservative, and seldom represent more than a modest fraction of the fish killed (AFS 1992). The USFWS has expressed that their estimate for the Klamath River fish-kill, was also conservative (USFWS 2003b).

This section of the report is divided into five subheadings. Subheading V. A. evaluates data from the Trinity and Salmon rivers, to test whether the 2002 fish-kill estimate on the Klamath River was indeed conservative. Subheading V. B. addresses potential impacts of the fish-kill on the Shasta and Scott rivers. Subheading V. C. looks at relative impacts of the fish-kill on the major subbasins of the Klamath Basin for fall Chinook salmon. Subsection V. D. addresses potential impacts of the fish-kill on hatchery production of salmonids. Subsection V. E. evaluates impacts of the fish-kill to sport and tribal fisheries in 2002, and potential impacts to future harvest allotments for ocean and in-river fisheries.

V. A. Trinity and Salmon Rivers;

V. A. 1. Introduction

Run-size depends on a number of factors including, habitat conditions during the freshwater phase, ocean habitat conditions, and ocean harvest. These conditions vary extensively, and cause run-sizes to vary substantially from year to year. However, spring-run and fall-run Chinook salmon, within the same drainage in the same year, should experience similar habitat conditions and their populations should proportionally tend to correlate.

The only tributaries of the Klamath River that have retained significant runs of spring-run Chinook salmon are the Trinity River and the Salmon River. Before construction of dams on the Trinity and Klamath rivers, spring-run Chinook salmon was the primary run in the Klamath River System (Moyle 2002). Since construction of the dams, cohorts from both spring and fall-run Chinook experienced very similar conditions in the river and in the ocean. Spring-runs on the Trinity and Salmon rivers were not affected by the fish-kill, as indicated by the timing of the fish-kill and the analysis of CWT data.

This section will examine the relationship between the numbers of spring-run to fall-run Chinook salmon returning to the Trinity and Salmon rivers annually with linear regression analysis. If a significant relationship exists, we should be able to provide an independent predictive estimate of the numbers of fall-run Chinook salmon that should have returned to these two major tributaries of the Klamath River in 2002, if there had not been a fish-kill. By comparing regression estimates of returning fall-run Chinook salmon to actual 2002 estimates of returning fish, DFG will examine specific impacts of the fish-kill on the Trinity and Salmon rivers. In addition, we hope to gain some verification on the accuracy of the USFWS fish-kill numbers.

V. A. 2. Methods

DFG has conducted population estimates on the Trinity River, for spring-run and fall-run Chinook salmon, since 1978 with the exception of 1983 and 1995 (DFG 2000b). Since 1995, the Hoopa Valley Tribal Fisheries Department has assisted DFG with data collection. Estimates for both races on the Trinity River were calculated using mark and recapture techniques. For both races, initial marks were placed on fish collected at counting weirs on the river, and fish were recaptured at Trinity River Hatchery. Population estimates represent the number of fall-run upstream of the Willow Creek Weir (approximately river mile 28), and for the number of spring-run upstream of the Junction City Weir (approximately river mile 80). Spawning occurs upstream of the Junction City Weir for most spring-run Chinook salmon on the Trinity River.

DFG with cooperation of the USFS, and Salmon River Restoration Council, have developed population estimates, using mark and recapture techniques, for fall-run Chinook salmon on the Salmon River since 1978. Populations are estimated using repeated carcass surveys, where new carcasses are marked on each survey date, and recaptured during subsequent surveys. Cooperators have also estimated spring-run Chinook salmon populations, using snorkel surveys since 1980 (Olson 2002, personal communication).

DFG used linear regression analysis, to compare the historic relationship of numbers of spring-run (independent variable) to fall-run Chinook salmon (dependent variable), returning to the Trinity and Salmon rivers. Populations for each river were analyzed separately. DFG regressed spring-run numbers verses fall-run numbers, for all years that estimates were available for both races, except for 2002 when the fish-kill occurred. The 95% confidence interval (CI) for each regression equation was calculated.

V. A. 3. Results

Trinity River fall-run Chinook salmon populations have outnumbered spring-run since surveys began in 1978 with one exception (Figure V1). The year of the fish-kill, 2002, represents the first year where spring-run Chinook outnumbered fall-run fish. There was a significant relationship between numbers of spring-run and fall-run Chinook salmon returning to the Trinity River each year ($p < 0.01$, $r^2 = 0.57$). Using the regression equation describing this relationship, we can predict the expected number of fall-run Chinook salmon returning to the Trinity River in 2002, if there had not been a fish-kill (Figure V2). The regression equations and 95% CI equations are:

Regression equation	Y (fall-run) = 1.7 (X [spring-run]) + 13,969;
Lower 95% CI	Y (fall-run) = 1.0 (X [spring run]) + 1,562;
Upper 95% CI	Y (fall-run) = 2.4 (X [spring run]) + 29,502.

The 2002 run-size estimate for spring-run Chinook salmon, upstream of Junction City weir, was 38,565 fish (Figure V1). The regression equation for the Trinity River, predicts that in absence of the fish-kill, there would have been 79,530 fall-run Chinook salmon upstream of the Willow Creek Weir. The lower 95% CI was 40,127 and the upper 95% CI was 122,058 fall-run Chinook. The actual fall-run Chinook salmon population estimate for the Trinity River upstream of the Willow Creek Weir, was 18,156 fish in 2002 (Figure V1).

Salmon River population estimates of fall-run Chinook have always outnumbered spring-run since 1980, including 2002 (Figure V3). Like the Trinity River, there was a significant relationship between spring-run and fall-run Chinook salmon returning to the Salmon River ($p < 0.01$, $r^2 = 0.48$) (Figure V4). The regression and 95% CI equations predicting fall-run numbers from spring-run Chinook salmon run-size on the Salmon River are:

Regression equation	Y (fall-run) = 2.6 (X [spring-run]) + 1,403;
Lower 95% CI	Y (fall-run) = 1.3 (X [spring-run]) + 508;
Upper bound	Y (fall-run) = 3.9 (X [spring-run]) + 2,297.

Divers estimated 975 adult spring-run Chinook salmon in the Salmon River in 2002 (Figure V3). The regression equation, predicts that in absence of the fish-kill, there would have been 3,938 fall-run Chinook in the Salmon River. The lower 95% CI was 1,848 and the upper 95% CI was 6,100 fall-run Chinook. The actual population estimate for fall-run Chinook salmon in 2002, was 2,558 fish (Figure V3).

Figure V1. Trinity River spring-run and fall-run Chinook salmon run-size estimates. No spring-run estimates were available for 1983 and 1995. 2002 estimates are provisional and may be subject to change.

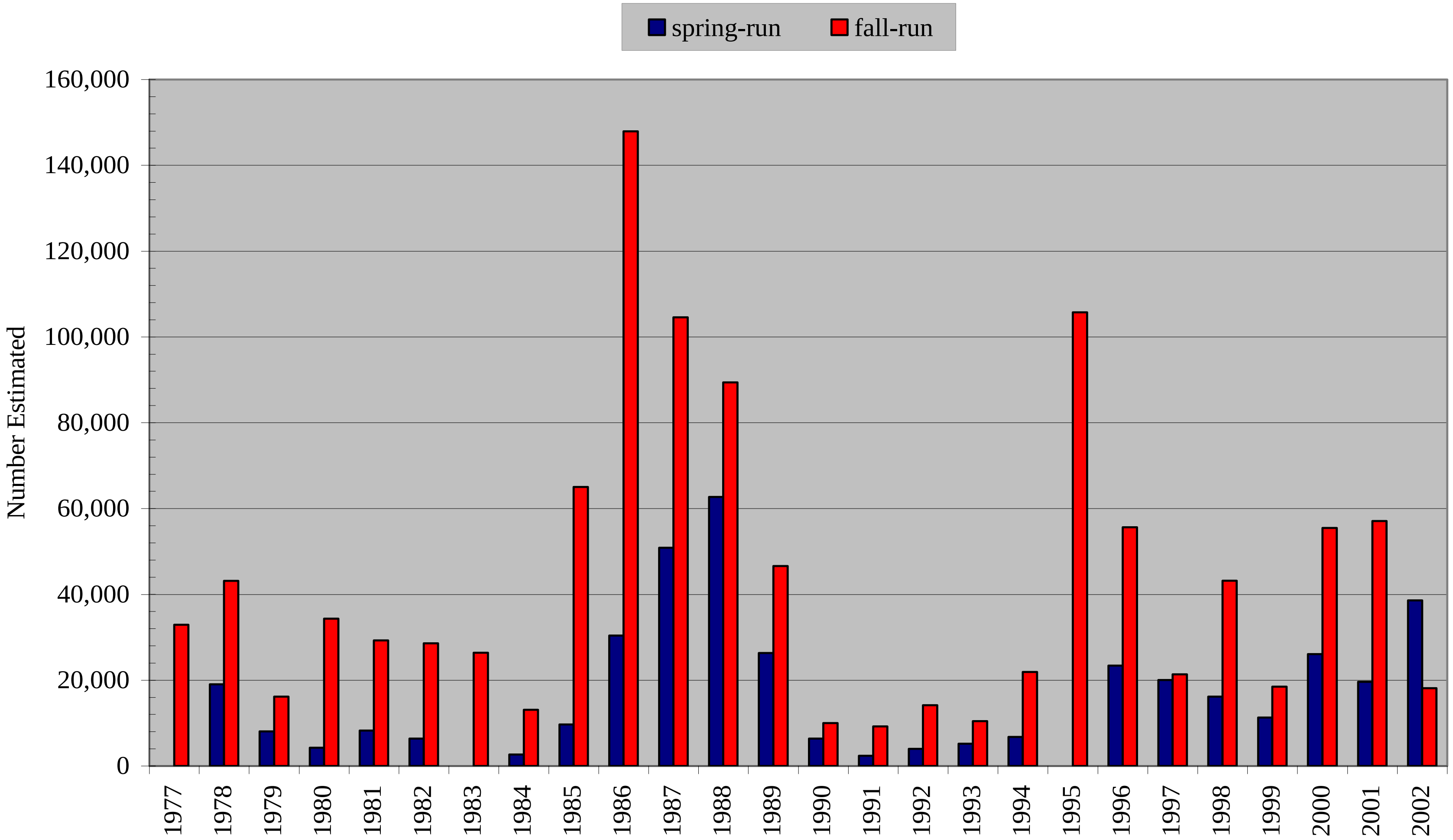


Figure V2. Regression of spring-run vs. fall-run Chinook salmon population estimates for the Trinity River since 1978. Point estimate and 95% CI is indicated for 2002 fall-run. Y fall-run = 1.7 (X spring-run) + 13,969, ($r2 = 0.57$, $p < 0.01$).

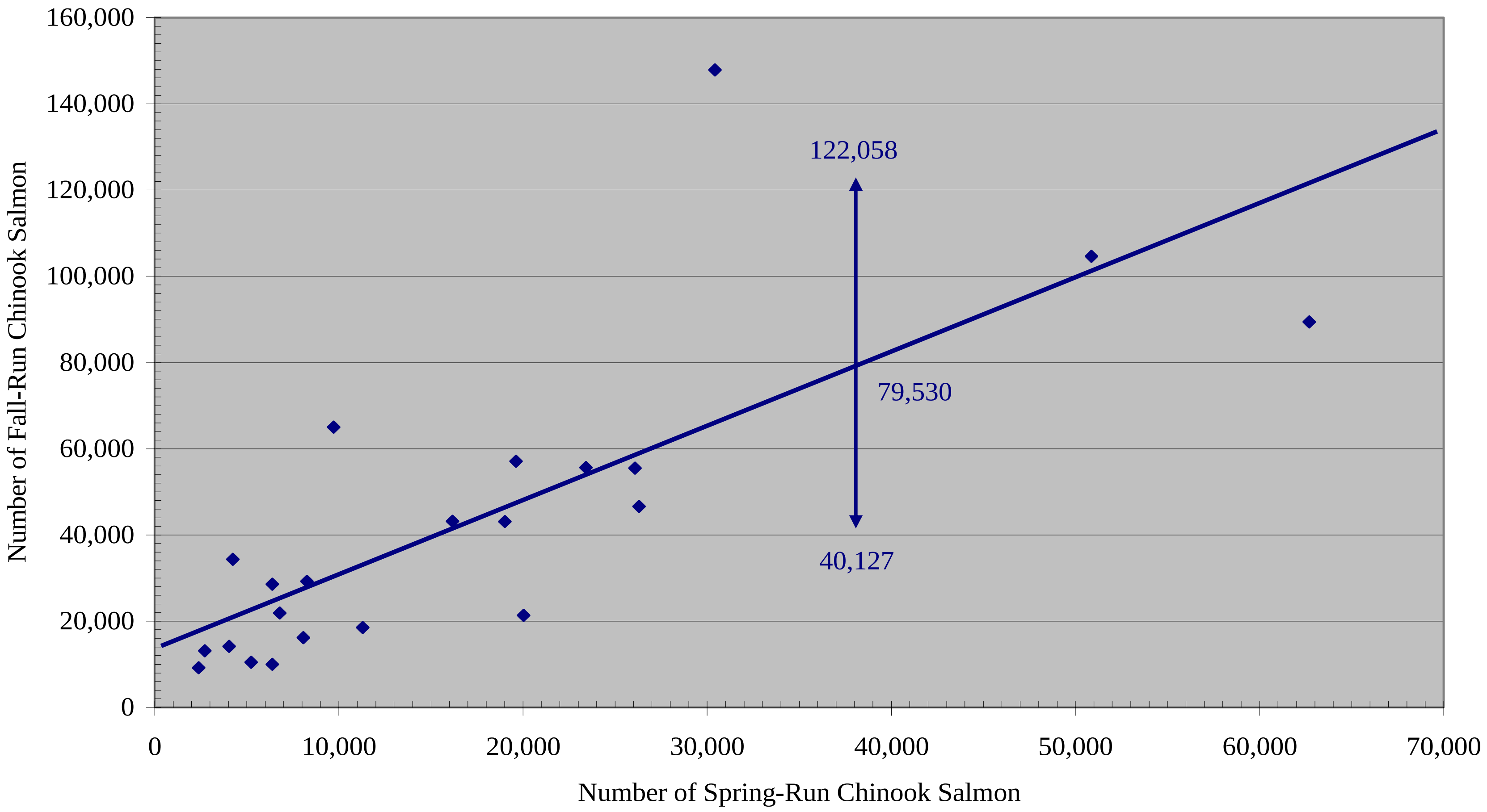


Figure V3. Salmon River spring-run and fall-run Chinook salmon run-size estimates since 1980.

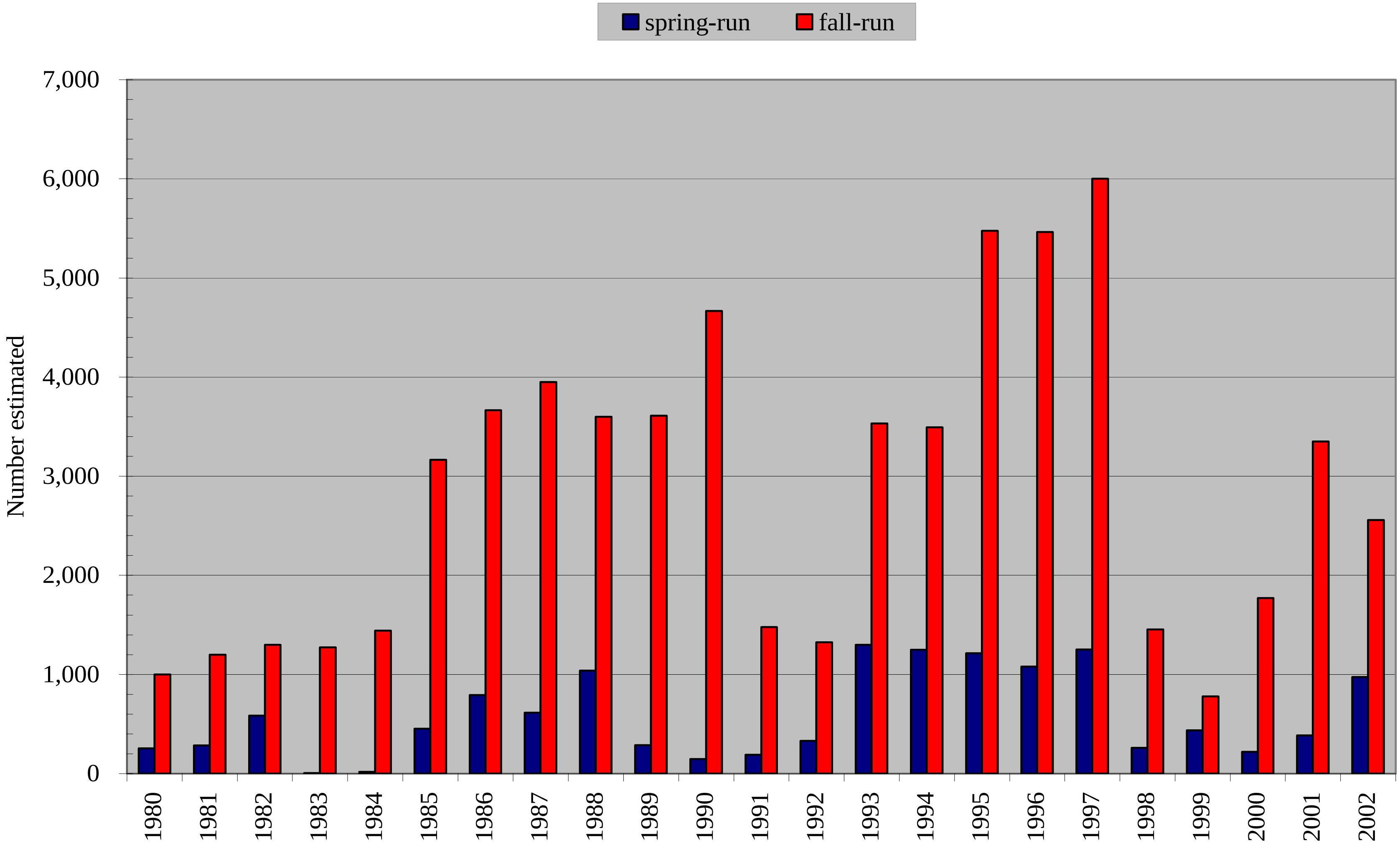
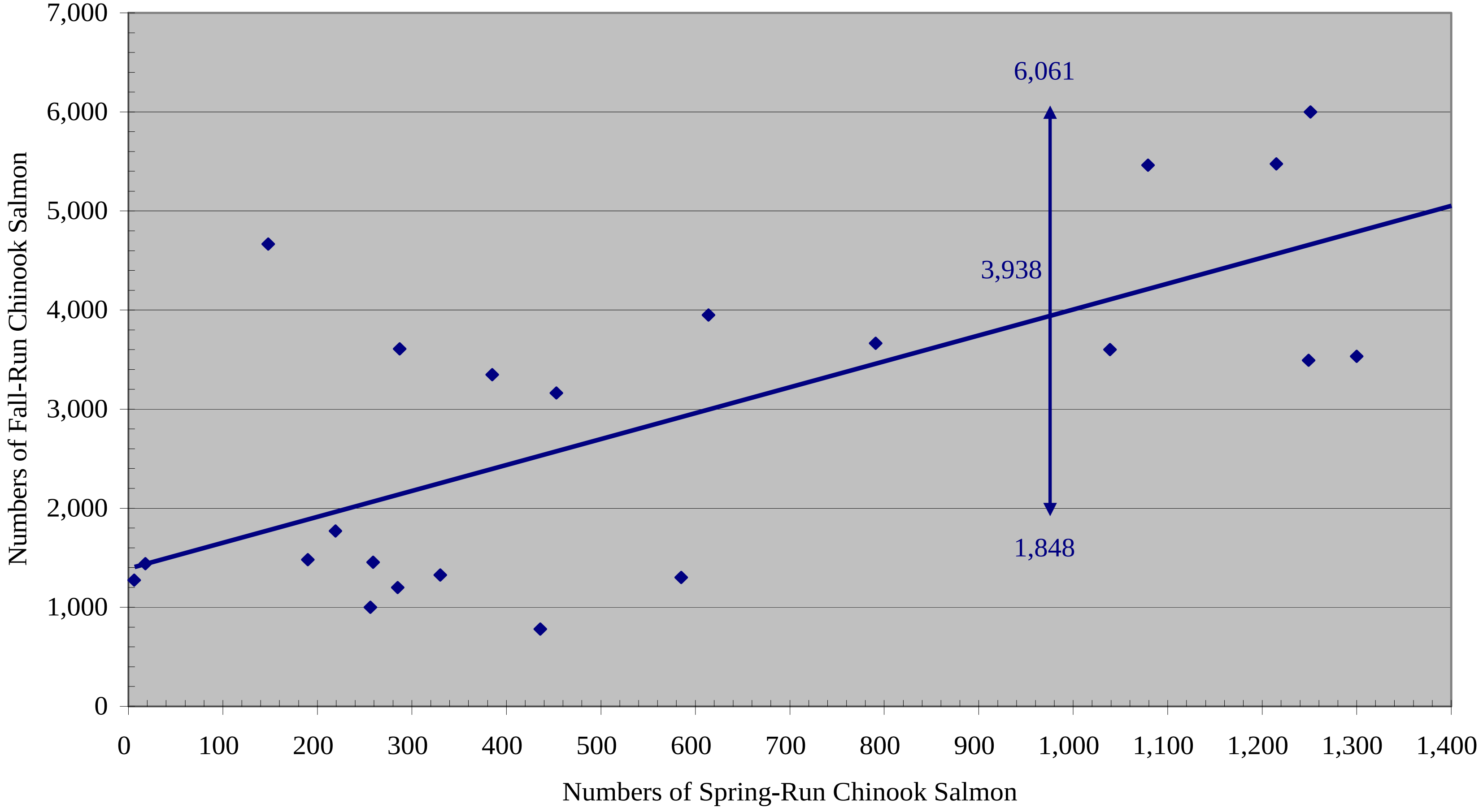


Figure V4. Regression of spring-run vs. fall-Run Chinook salmon population estimates in the Salmon River. Point estimate and 95% CIs are indicated for 2002 fall-run. Y fall-run = 2.6 (X spring-run) + 1,403, (r2 = 0.48, p<0.01).



V. A. 4. Findings

Our results support the USFWS (USFWS 2003b) and literature accounts, that fish-kill estimates are conservative (AFS 1992). The regression results for predicted numbers of fall-run Chinook salmon that should have returned to the Trinity River in 2002 were substantially larger than the 32,553 fall Chinook salmon, estimated to have died in the entire Klamath Basin, as reported by the USFWS. The point estimate of the regression equation suggests that 61,374 (79,530 [regression estimate of the number of fish that should have returned if there were not a fish-kill] minus 18,156 [actual population estimate of fish returning with the fish-kill]) fall-run Chinook died from the Trinity River alone, which represents just one major tributary of the Klamath River. Using the lower 95% CI as the most conservative estimate, there were 21,971 (40,127 [regression estimate] minus 18,156 [population estimate]) fall-run Chinook salmon from the Trinity River in the fish-kill.

In Section III. G. of this report, DFG and the Hoopa Valley Tribe estimated the numbers of Klamath River fall-run Chinook salmon lost during the fish-kill, were nearly 2 ½ times the numbers of Trinity River fish lost. Therefore, the loss of 21,971 fall-run Chinook salmon on the Trinity River, could translate to nearly 55,000 additional salmon lost from the Klamath River.

In recent years, ocean and freshwater conditions have favored above average runs for Chinook salmon throughout the Northwest. The fish-kill appears to have resulted in lower-than-average fall-run Chinook salmon returns in the Salmon and Trinity rivers during 2002. Fall-run Chinook salmon runs in the Klamath Basin overall, and for all other river systems where populations are monitored outside of the Klamath River System in California, were substantially larger than average in 2002 (PFMC 2003). In addition, 2002 was the first year since we began monitoring in 1978 that numbers of spring-run Chinook salmon returning to the Trinity River were larger than fall-run returns.

Because of low statistical power for the regression analyses, confidence intervals for both river systems were broad. Low power increases the possibility of a type II error, meaning we would not be able to detect the impact of the fish-kill, when one existed. Low power also means that in order to detect differences, the effect of the fish-kill would have to be pronounced. These results suggest the Trinity River was severely impacted by the fish-kill, despite the low statistical power of the test. The 2002 fall-run Chinook salmon estimate of 18,156 fish fell below the lower 95% confidence interval (40,127 fish) in our regression equation by 21,971 fish (45%).

The 2002 population estimate of fall-run Chinook salmon for the Salmon River (2,558 fish) fell between the regression point estimate (3,938 fish), and the lower 95% confidence interval of the regression (1,848 fish). While the population estimate for the Salmon River is less than the point estimate of the regression, the regression analysis lacked the statistical power to show a significant difference between estimates. This suggests that the impacts of the fish-kill to the Salmon River were less than those to the Trinity River. These results also suggest the impact of the fish-kill was not distributed evenly across stocks throughout the Klamath Basin.

In summary, the regression analysis indicates the 2002 fish-kill estimate for the Klamath River, of 32,553 fall-run Chinook salmon, was indeed conservative. Based on the Trinity River regression, and DFG and Hoopa Valley Tribe estimates of the proportions of Trinity and Klamath River fall Chinook salmon lost, the fish-kill estimate may have under-represented the numbers of Chinook salmon by nearly 45,000 fish (22,000 Trinity fish, plus 55,000 Klamath fish, minus the USFWS estimate of 32,553 fall-run killed). A substantial impact is evident to the Trinity River fall-run Chinook salmon population as a result of the 2002 fish-kill. Impacts to the Salmon River population may or may not have occurred and were less severe than to the Trinity River.

V. B. Scott and Shasta River;

V. B. 1. Introduction

There are no fish counting facilities present on the Scott River, to quantify the numbers or run-timing of Chinook salmon. Therefore, run-size estimates for the Scott River were derived from mark/recapture carcass surveys, which are conducted cooperatively by DFG with USFS, Yurok and Karuk tribal fishery staff, Siskiyou County Office of Education, Salmon River Restoration Council, Siskiyou Resource Conservation District, and local volunteers. These cooperative spawning ground surveys began in 1994, and have continued every year since.

Low-flow conditions in 2001 and 2002, limited the distribution of spawning Chinook salmon in the Scott River Basin. In 2001, the distribution of spawning Chinook salmon was limited to the lower six miles of river. Similar conditions were present during 2002, however, an early storm passed through the basin in mid-November, and increased river flows high enough to allow some Chinook salmon to pass further upstream to the lower end of Scott Valley, a distance of approximately 23 miles.

Chinook salmon run-size estimates for the Shasta River were derived from direct counts of salmon as they pass through the Shasta River Fish Counting Facility (SRFCF) located near the mouth of the river.

To determine whether the lower Klamath River fish-kill may have resulted in impacts to fall Chinook salmon runs in the Scott and Shasta rivers, DFG conducted a review of the spawning ground survey data for the Scott River, and video weir data for the Shasta River in 2001 and 2002. The purpose was to determine whether any abnormalities in numbers or run-timing, of Chinook salmon, were evident in the Scott and Shasta rivers in 2002 when compared to 2001.

V. B. 2. Methods

Carcass surveys were conducted twice per week in major spawning areas of the Scott River, throughout the Chinook salmon spawning season. For purposes of the mark recapture estimate, each carcass encountered during the survey was categorized into one of four pathways (Paths). Fresh carcasses, those with clear eyes and/or firm flesh, were designated as Path 1. Individually numbered jaw tags were attached to the lower jaw of all Path 1 carcasses, and they were returned to the river for later recapture. Older carcasses, those with cloudy eyes and/or mushy flesh, were categorized as Path 2. All Path 2 carcasses were cut in half, and returned to the river once all biological data had been collected. Path 3 carcasses included all Path 1 carcasses with jaw tags that were recaptured during the survey. Any carcasses that could be observed by a survey crew, but could not be retrieved for data collection because they were located in inaccessible or unsafe locations, were designated as Path 4. Path 4 designations were rarely encountered during the surveys. Run-size estimates were calculated using both Peterson and Schafer models.

Since Path 1 carcasses were sampled frequently (twice per week) during the survey, examination of timing and numbers of Path 1 carcasses sampled during each season, provided the only means to describe presence and spawn-timing of Chinook salmon in the Scott River. DFG assumed that mortality of adult salmon, from entry to the river until death, occurs at a similar rate each year, and therefore, accurately portrays the spawn-timing of Chinook in the Scott River among years. Therefore, to compare the spawn-timing and number of Chinook salmon entering the Scott River in 2001 and 2002, numbers of Path 1 carcasses recovered during each survey day were obtained from available data.

Chinook salmon run-size estimates for the Shasta River were derived from a direct count of salmon as they passed through the SRFCF, located near the mouth of the river. Prior to 1999, DFG staff conducted manual counts of salmon as fish passed through the SRFCF. The SRFCF was operated 24 hours-per-day, throughout the Chinook salmon migration season. A video camera and variable speed video recorder has been used to quantify the run since the 1999 season. Since 1999, all Chinook salmon entering the Shasta River were counted, and recorded on SVHS video tapes as they passed through the SRFCF. Numbers of Chinook salmon entering the Shasta River in 2001 and 2002, were summed on a daily basis, and compared to describe any variation in run-timing evident between the two years.

V. B. 3. Results

A total of 1,517 Path 1 carcasses were sampled in 2001, and 1,024 in 2002 on the Scott River. In 2001, recovery of Path 1 Chinook salmon carcasses, generally followed a bell shaped curve, with the greatest number of recoveries occurring between November 6 (303 carcasses) and November 13 (346 carcasses). In 2002, recovery of Path 1 Chinook salmon carcasses began on October 15, and gradually increased until October 29, following the same general trend observed in 2001 (Figure V5). However, unlike 2001, the number of Path 1 recoveries, generally remained at lower levels through the first two weeks of November (ranging between 89 and 114 carcasses), with numbers substantially less than were observed in 2001. In 2002, there were additional recoveries of Path 1 carcasses beyond November 19 that were not observed during the 2001 effort. These recoveries were made in the lower end of the Scott Valley, and reflected late spawners that were able to move upstream through the canyon during early rainstorms, which caused a slight increase in river flows.

A total of 11,093 Chinook salmon were observed at the SRFCF in 2001. The first Chinook salmon was observed on September 11 and the last was observed on November 29 (Figure V6). The run peaked on October 1, when 805 fish were observed passing through the SRFCF. The number of Chinook salmon then declined steadily through the rest of October.

A total of 6,820 Chinook salmon were observed at the SRFCF in 2002. The first Chinook salmon was observed passing through the video weir on September 9 and the last was observed on November 23 (Figure V6). The run peaked on September 28, when 853 fish were observed passing through the SRFCF. After September 28, numbers of Chinook salmon declined sharply until October 1, when only 97 fish were observed. During the first two weeks of October, numbers of Chinook salmon entering the river, remained low and fluctuated between 68 and 191 fish. On October 14, a second peak of 248 Chinook salmon was observed passing through the weir. Numbers of fish entering the weir then declined steadily, once again, until October 31, when only six Chinook were observed. Small numbers of Chinook salmon continued to pass through the weir until November 23, when the last salmon to pass was observed.

Run-timing and numbers of Chinook salmon entering the Shasta River in 2001 and 2002, were similar during the beginning of the run through late September (Figure V6). In 2002, numbers of Chinook entering the river, declined substantially when compared to the 2001 run, and numbers were lower in 2002 for the remainder of the season. Up until this point it appeared that the 2002 spawning-run would be similar to 2001, based on comparison of video run-timing records for these two years. However, the numbers of salmon entering the Shasta River in 2002, declined appreciably below those observed in 2001, during the first two weeks of October.

Figure V5. Timing of Path 1 Chinook salmon carcass recoveries (Path 1 = fresh carcasses with clear eyes and/or firm flesh) in the Scott River spawning ground surveys for 2001 and 2002.

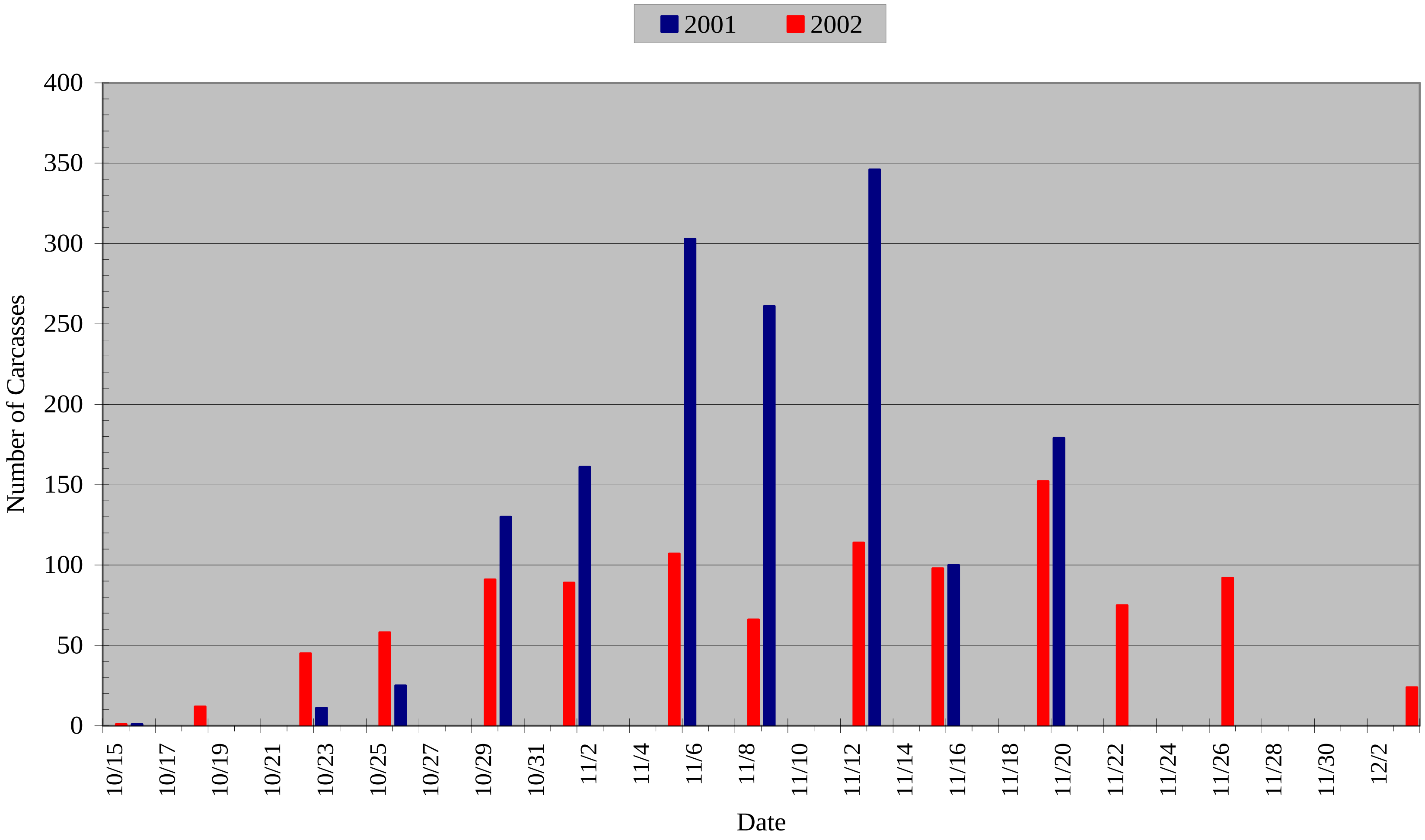
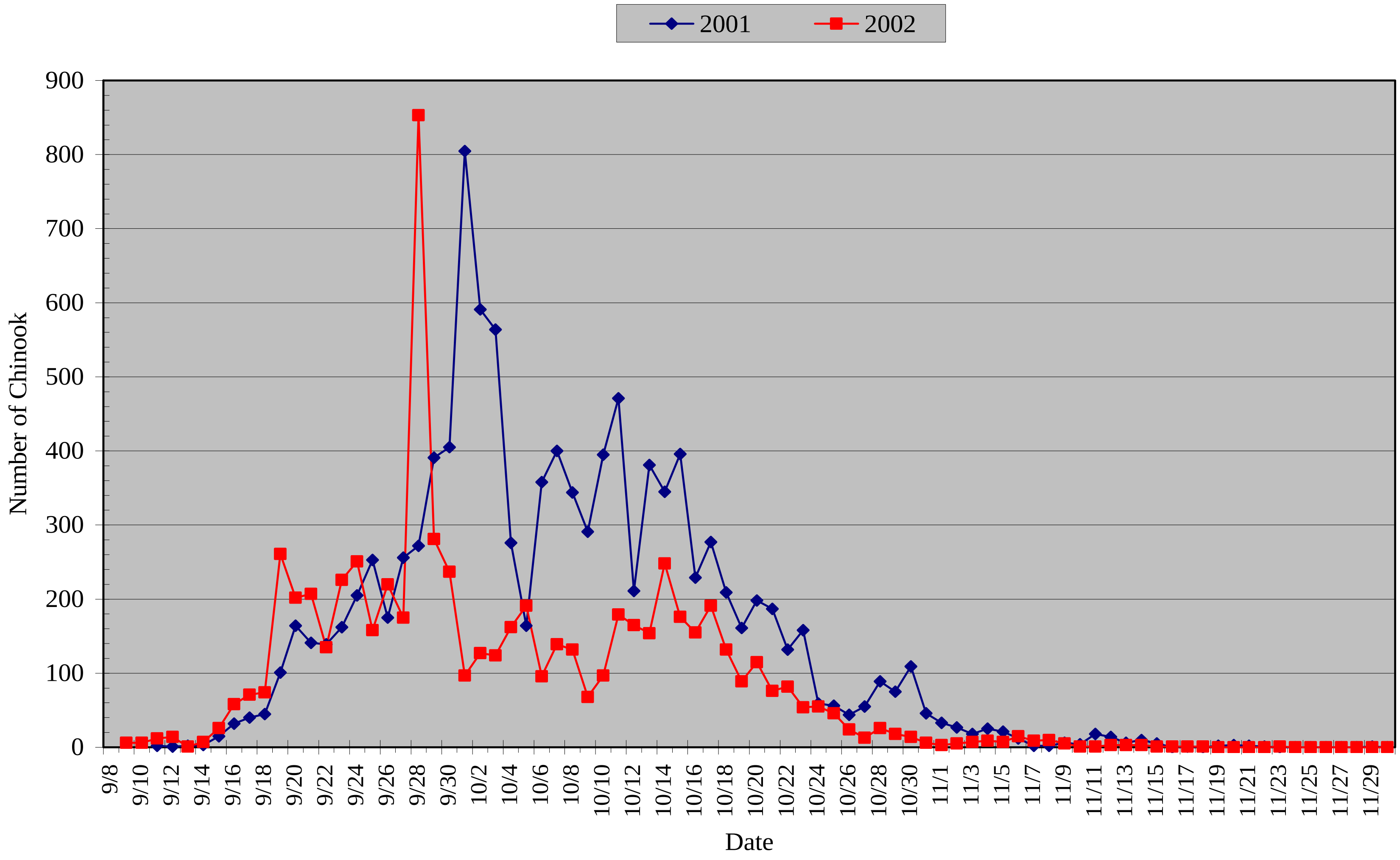


Figure V6. Run timing of Chinook salmon observed at the Shasta River Fish Counting Facility in 2001 and 2002.



V. B. 4. Findings

Timing of Path 1 carcass recoveries observed in the 2002 Scott River spawning ground survey, deviated from the normal (bell shaped) spawn-time distribution observed in 2001. Although these results are not definitive, based on the distribution of Path 1 carcasses observed during the 2002 season, a number of Scott River Chinook salmon may have been lost in the fish-kill. The final run-size estimate for Chinook salmon in the Scott River was 4,308 fish in 2002. The average run-size for the Scott River, from 1978 to 2002, was 5,579 fish. The numbers of returning Chinook salmon in 2002 were 1,271 fish less-than average.

The fish-kill was first reported on September 19 and continued through about October 1 of 2002. The number of Chinook salmon entering the Shasta River began to decline after September 28, and remained at low levels through October 12. This time frame was approximately 11 to 24 days following the first day when the fish-kill was reported in the lower river. The Shasta River is located approximately 140 river miles upstream of the area where the fish-kill was observed. Based on the rapid decline in migration timing of Chinook salmon at the SRFCF and lower numbers of returning fish, particularly when compared to the run-timing observed in 2002 compared to 2001, it appears that a portion of the Shasta River Chinook salmon run were impacted by the fish-kill in the lower river.

Although it is likely that many Shasta River Chinook salmon perished in the lower river fish-kill, the total number of Chinook salmon entering the Shasta River to spawn in 2002, exceeded the average annual run-size estimate by 1,142 fish. However, the 2002 run of Chinook salmon contained 4,273 fewer fish than were observed in 2001 (11,093 fish).

In summary, Klamath River fish-kill impacts on returns of fall-run Chinook salmon to the Scott and Shasta rivers, can be inferred by differences in run-timing between 2001 and 2002, lower returns of fish in 2002 than 2001, and below average returns to the Scott River in 2002. Although these analyses are indicative of impacts to returning fall-run Chinook salmon on the Shasta and Scott rivers, these data were not rigorous enough to be conclusive.

V. C. Impacts to Natural Production;

V. C. 1. Introduction

The numbers of naturally produced Chinook salmon that perished in the fish-kill were estimated to be 25,473 fish or 78.3% of the total fish-kill (Section III. G.). USFWS believes their estimate was conservative, and actual fish-kill numbers were likely greater than those estimated, due to the difficulties inherent in fish-kill investigations (USFWS 2003a). Total numbers of natural fall Chinook spawners entering the Klamath Basin in 2002, were estimated to be 69,535 fish, of which 13,970 returned to the Trinity and 55,565 returned to the Klamath. Although it is clear a much greater proportion of fall-run Chinook Salmon were of natural origin than hatchery origin, it is unclear where the greatest impacts of the fish-kill occurred in the Klamath Basin. The purpose of this section is to gain a better understanding of the possible impacts of the fish-kill on natural spawner populations in various sub-basins of the Klamath.

V. C. 2. Methods

A comparison was made between the natural Chinook run-size estimate in 2002, and other years since 1978, where the total run-size estimate for the basin was similar. Years selected for this comparison were 1989 (133,117 fish), 1996 (184,903 fish), and 2001 (198,393 fish).

Methodologies for adult spawner population estimates on the Trinity and Salmon rivers were presented in section V. A. 2., and for the Scott and Shasta rivers in section V. B. 2. Run-size estimate in the mainstem Klamath were based on mark and recapture of tagged carcasses, encountered during surveys conducted by USFWS since 2001. Prior to 2001, estimates were based on extrapolation of redd counts, and therefore, likely underestimated the actual run-size present. Therefore, numbers presented for 1989 and 1996, are not directly comparable to 2001 and 2002 run-size estimates.

Redd surveys have been conducted annually by DFG, USFS, and the Karuk Tribe, on several miscellaneous tributary streams within the Klamath Basin upstream of the Trinity River confluence. Tributary streams typically sampled each year include: Aiken, Beaver, Bluff, Boise, Camp, Clear, Dillon, Elk, Grider, Horse, Independence, Indian, Red Cap, Slate, and Thompson creeks. The purpose of these surveys was to estimate the number of fall Chinook salmon returning to these streams each year. Surveys were conducted weekly, in each tributary stream, where significant numbers of Chinook salmon were observed during the season. During each survey, the number and location of all redds were documented. The numbers of live Chinook and fish carcasses were also recorded. Run-size estimates for each tributary were developed by multiplying the number of redds observed by two, and adding the number of live Chinook observed during the last survey.

V. C. 3. Results

The percent of natural spawners within the total run-size, were similar in the four years examined. The percent of natural spawners present was 37.1% in 1989, 47.3% in 1996, 43.1% in 2001, and 41.1% in 2002 (Table V1). Declines in total number and percent of natural spawners returning to the basin in 2002, were evident in the Trinity River, Scott River, Salmon River, and in miscellaneous tributary streams. Increases in number and percentage of natural spawners occurred in the Klamath mainstem and in Bogus Creek. However, mainstem estimates presented for 1989 and 1996, are not directly comparable to 2001 and 2002 run-size estimates, because of changes in methodologies during 2001 to determine the numbers of spawning adults. Chinook salmon runs in Bogus Creek are heavily influenced by hatchery fish, and do not yield a reliable estimate of the true number of natural Chinook salmon returning to the creek each year.

Since 1978, average numbers of natural fall Chinook spawners in the Trinity River upstream of Willow Creek Weir, have ranged from a low of 5,249 (1991) to a high of 113,007 (1986), and have averaged 30,521 (Figure V1). The 2002 run of natural fall Chinook in the Trinity River upstream of Willow Creek Weir, (13,332) ranks as the eighth lowest run on record. Results of our regression analysis, estimated as many as 79,530 (95% CI of 40,127 to 122,058) fall Chinook salmon, would have returned to the Trinity River upstream of Willow Creek Weir, in absence of the fish-kill (Figure V2). This estimate included both hatchery and natural spawning populations. The combined estimates for hatchery and natural spawners returning to the Trinity River in 2002, were 18,156 fall-run Chinook salmon (about 75% were natural fish). Subtracting this estimate from the predicted returns calculated with our regression equation, indicates 61,374 (95% CI 21,971 to 103,902) natural and hatchery fall-run Chinook from the Trinity River, may have been lost in the fish-kill. We were not able to reliably predict the portion of Trinity River Chinook lost in the fish-kill that would have returned as natural or hatchery spawners. However, since nearly 75% of the surviving fish entering the Trinity River in 2002 were of natural origin, it appears that large numbers of natural Chinook salmon, destined for the Trinity River, were lost in the fish-kill.

Approximately 2,558 fall Chinook salmon returned to the Salmon River in 2002 (Figure V3). These fish were assumed to be natural spawners, because there is no hatchery on the Salmon River. This assumption does not preclude the possibility of some hatchery fish straying into the Salmon River, but strays were not expected to make up a significant proportion of these spawners. Since 1978, numbers of fall Chinook salmon returning to the Salmon River has ranged from a low of 780 fish (1999) to a high of 6,000 fish (1997), and have averaged 2,828 fish (Figure V3). Our regression analysis estimated that the natural fall Chinook salmon run on the Salmon River would have reached 3,978 fish (95% CI of 1,848 to 6,061), in the absence of the fish-kill (Figure V4). Subtracting the Salmon River population estimate from the predicted returns calculated with our regression equation, indicates approximately 1,380 (95% CI of 0 to 3,503) fall Chinook salmon, destined for the Salmon River, were lost in the fish-kill.

Table V1. Comparison of fall Chinook runs in the Klamath basin in 1989, 1996, 2001, and 2002.

	1989		1996		2001		2002	
Description	Total	Percent of Total In-River Run	Total	Percent of Total In-River Run	Total	Percent of Total In-River Run	Total	Percent of Total In-River Run
Trinity above Willow Creek Weir	31,988	24.0%	47,124	25.5%	37,327	18.8%	13,332	7.9%
Mainstem Klamath 1/	1,225	0.9%	3,008	1.6%	10,848	5.5%	22,308	13.2%
Bogus Creek	2,662	2.0%	10,797	5.8%	12,575	6.3%	17,834	10.5%
Shasta River	1,577	1.2%	1,450	0.8%	11,093	5.6%	6,818	4.0%
Scott River	4,188	3.1%	12,097	6.5%	6,142	3.1%	4,308	2.5%
Salmon River	3,610	2.7%	5,463	3.0%	3,350	1.7%	2,558	1.5%
Miscellaneous Tributary Stream	3,487	2.6%	6,385	3.5%	3,534	1.8%	1,778	1.1%
Hoopa and Yurok Tributary Streams	640	0.5%	1,176	0.6%	711	0.4%	599	0.4%
Total Natural Spawners	49,377	37.1%	87,500	47.3%	85,580	43.1%	69,535	41.1%
Total Hatchery Spawners	23,061	17.3%	20,825	11.3%	56,743	28.6%	29,510	17.4%
Total In-River Harvest (includes angling and net mortality est.)	60,679	45.6%	76,578	41.4%	56,075	28.3%	37,699	22.3%
Fish Mortalities in Lower River 2002							32,553	19.2%
Total In-River Run	133,117		184,903		198,398		169,297	

1/ Prior to 2001 estimate is based on redd surveys only; in 2001-02 estimate based on redd surveys and mark/recapture estimate.

The Scott River Chinook salmon run declined to 4,308 fish in 2002, down from 6,142 fish in 2001. The 2002 run was 1,271 fish lower than the average return of 5,579 fish observed since 1978. In 2002, it appears the fish-kill negatively impacted the Scott River Chinook salmon run. During 2001, without a fish-kill, spawner-timing for Chinook salmon followed a bell shaped curve through time as indicated from the recovery of fresh carcasses (Figure V5). In 2002, timing of the recovery of these carcasses was depressed during the peak recovery time observed in 2001. This may indicate the 2002 fall Chinook run on the Scott River was impacted by the fish-kill.

Chinook salmon runs in the Shasta River have varied greatly since 1978. Runs in 1989 and 1996, were the sixth and fifth lowest run-sizes for the period of record, respectively. Approximately 6,818 Chinook salmon returned to the Shasta River during 2002. The 2002 Chinook salmon run contained 5,476 fewer fish than observed in 2000 (12,296 fish), and 4,273 fewer fish than observed in 2001 (11,093 fish). The run on the Shasta River in 2002, experienced a rapid decline in numbers after September 28, similar to a decline in 2001 after October 1. However, numbers of returning fish in 2002 were much lower following this initial decline, compared to 2001. Given the migration time anticipated for adult salmon to travel from the lower Klamath River to the Shasta River, the lower numbers of fish returning in 2002 compared to 2001 after the large declines, may reflect an impact of the fish-kill. It is impossible to estimate the actual number of Chinook salmon expected to return to the Shasta River in the absence of a fish-kill with the available data. Although total Chinook salmon run-size in the Shasta River exceeded average returns of 5,678 fish by 1,140 fish, it does appear the run would have been larger in the absence of the fish-kill, based on run-timing information and overall strength of the run within the entire Klamath Basin.

In 2002, approximately 1,778 Chinook salmon were estimated to have spawned in miscellaneous tributary streams of the Klamath Basin. The 2002 run-size was smaller when compared to those years with similar total in-river run-size estimates, 1989, 1996, and 2001. Percentage of the total run present in miscellaneous tributary streams during 2002, was also smaller than observed in 1989, 1996 and 2001. Although other factors could be responsible for the lower numbers of Chinook observed in miscellaneous tributary streams in 2002, the fish-kill appears to be most reasonable explanation at this time.

V. C. 4. Findings

An estimated 32,553 Chinook salmon died in the Klamath River fish-kill. Of this, 7,060 (21.7%) Chinook were estimated to be of hatchery origin, and 25,473 (78.3%) were estimated to be of natural origin. Regression analyses conducted for the Trinity River, conservatively estimated that 21,971 (lowest bound of the 95% CI) fall Chinook salmon were lost in the fish-kill. Based on this Trinity River estimate of fish loss, as many as 55,000 fall Chinook salmon from the Klamath River side of the basin may have been lost. Losses on the Klamath side were also based on an analysis by DFG and the Hoopa Valley Tribe, which found Klamath River fall Chinook salmon comprised nearly 2 ½ times the number of Trinity River fall Chinook salmon present in the fish-kill. Although it is impossible to determine what proportion of these fish were of natural versus hatchery origin, it appears likely that actual number of natural fall-run Chinook salmon, perishing in the fish-kill, were substantially larger than the 25,473 fish estimated by USFWS.

V. D. Impacts to Hatchery Production;

V. D. 1. Introduction

Trinity River Hatchery (TRHat) is located at the base of Lewiston Dam on the Trinity River, at river mile 110. The facility was built to mitigate for lost anadromous salmonid production, resulting after construction of the Trinity River Division (TRD) of the Central Valley Project (CVP), operated by USBR. The primary function of the TRD is to store “surplus” Trinity River water, for regulated diversion to the Central Valley of California for agricultural, municipal, industrial, and power uses. Construction of the TRD in 1964 blocked access to approximately 109 miles of habitat for anadromous salmonids, located upstream of Lewiston Dam. Production goals have been established to satisfy anadromous salmonid mitigation objectives within the Trinity River (Table V2).

To obtain the required egg-take allotments necessary to meet mitigation goals, DFG has established general guidelines in regards to the number of adult spawners that are needed at TRHat each year. These guidelines provide for an adequate number of fish to spawn throughout the season, assuring that resulting progeny effectively represent run-timing characteristics for each run. Adult return goals for each run are approximately 2,000 spring-run Chinook salmon, 4,300 fall-run Chinook salmon, 800 coho salmon, and 1,400 steelhead trout, of which, each run is composed of 50% females. (Marshall 2002, personal communication).

Table V2. Production goals for anadromous salmonids at TRHat (DFG and USBR, 1996).

Species	Egg Alloment	Type	Number
Spring Chinook	3,000,000	Smolt	1,000,000
		Yearling	400,000
Fall Chinook	6,000,000	Smolt	2,000,000
		Yearling	900,000
Coho	1,200,000	Yearling	500,000
Steelhead	2,000,000	Yearling	800,000

Iron Gate Hatchery (IGH) is located at the base of Iron Gate Dam on the Klamath River at river mile 190. Iron Gate Dam and spawning facilities for IGH were constructed in 1962. Construction of rearing ponds and hatchery buildings were completed in 1966 (PacifiCorp 2000). Prior to 1966, salmon and steelhead eggs were spawned at the IGH spawning facility and reared at Mount Shasta Hatchery until release. IGH was built to mitigate anadromous salmonid production losses upstream of Iron Gate Dam to Copco Dam. Production goals have been established for operation of IGH (Table V3).

Table V3. Production goals established for anadromous salmonids at IGH (DFG and PacifiCorp, 1996).

Species	Egg Allotment	Type	Number
Fall Chinook	10,000,000	Smolt	4,920,000
		Yearling	1,080,000[1/]
Coho	500,000	Yearling	75,000
Steelhead	1,000,000	Yearling	200,000

[1/] Approximately 9000,000 shall be reared at IGH and 180,000 shall be reared at Fall Creek ponds and released at IGH

High egg-take allotment at IGH for coho salmon and steelhead, were originally established to compensate for an abnormally high mortality of eggs, caused by soft-shell disease. To control this disease problem, DFG began treating eggs with Iodine immediately after fertilization. This treatment has greatly improved egg survival at IGH, and DFG is currently in the process of updating production goals for coho salmon and steelhead egg-take allotments. Updated egg-take allotments are currently being reduced to 250,000 coho salmon eggs and 300,000 steelhead eggs. To obtain the required egg-take allotment established for each species, a minimum return of 8,000 adult Chinook salmon, 200 adult coho salmon, and 350 adult steelhead (with each species composed of 50% females), must be recovered at IGH each year (Rushton 2003, personal communication).

Adverse environmental conditions, poor nutrition, and disease can have negative impacts on embryo development and maturation (fecundity) in salmonids. Following the fish-kill, there were concerns the disease epizootic observed in the lower Klamath River, would affect fecundity and viability of eggs within surviving adult female salmon returning to TRHat and IGH. The purpose of this section is to investigate potential impacts of the 2002 Klamath River fish-kill on hatchery operations at TRHat and IGH.

V. D. 2. Methods

DFG personnel at TRHat and IGH closely monitored fish for any signs of disease (presence of cysts, lesions, pale or eroded gill filaments, etc.), during Chinook salmon spawning and recovery operations, after the 2002 fish-kill. These observations were strictly qualitative in nature, and were based on the experience of spawning and recovery crews working at each facility. In addition to these observations, both hatcheries record information on egg fertility and size, as standard hatchery operating procedures.

V. D. 3. Results

During the 2002-2003 spawning season, a total of 11,063 spring-run Chinook, 4,549 fall-run Chinook, 7,175 coho salmon, and 6,163 steelhead were recovered at TRHat. Since 1978, the number of fall-run Chinook salmon returning to TRHat, has ranged from a low of 1,551 fish in 1993, to a high of 27,046 fish in 2000, and has averaged 9,660 fish. Prior to 1995, ladder gates at TRHat and IGH were closed to returning salmon after the hatchery had recovered enough fish to satisfy their egg-take allotment. Therefore, hatchery return rates prior to 1995, do not accurately reflect the actual number adult salmon returning to the two basin hatcheries in some years. Although the 2002 return of fall-run Chinook salmon at TRHat was well below the average number of fish that have returned to the hatchery in recent years, the number of fall-run Chinook returning to the hatchery during 2002, exceeded the 4,300 fish required to safely achieve the egg-take allotment, established under the mitigation release requirements for the 2002 fall Chinook salmon brood year.

During the 2002-2003 spawning season, a total of 24,961 fall-run Chinook salmon, 1,301 coho salmon, and 495 steelhead trout were recovered at IGH (DFG 2003b). Since 1978, the numbers of fall-run Chinook salmon returning to IGH, have ranged from a low of 2,558 fish in 1979, to a high of 72,474 fish in 2000, with an average return of 15,472 fish. The number of fall-run Chinook salmon, coho salmon, and steelhead trout that returned to IGH during the 2002-2003 spawning season was more than adequate to satisfy established mitigation release requirements for the 2002 brood years.

During the 2002 Chinook salmon run, neither hatchery observed any apparent increase in diseased fish recovered during spawning operations. Fertility rates observed among the developing embryos were consistent with previous years (Ramsden 2003, and Rushton 2003, personal communication).

V. D. 4. Findings

The only discernable impact to fish returning to hatcheries in the Klamath Basin, was a lower than average return of fall Chinook salmon at TRHat. Although fall-run Chinook salmon returns to TRHat were well below the average number of fish returning in recent years, the numbers that did return during 2002, exceeded the 4,300 fish needed to safely achieve the egg-take allotment established under the mitigation release requirements. Returns of hatchery fall-run Chinook to IGH in 2002, were above average, and more than adequate to meet the egg-take allotment.

The 2002 fish-kill in the lower Klamath River had no apparent physiological impacts on salmon returning to either hatchery. Hatchery personnel did not observe any apparent increase in diseased fish recovered during spawning operations, and fertility rates were consistent with previous years.

V. E. Impacts to Fisheries;

V. E. 1. Introduction

The 2002 Klamath River fish-kill may have had impacts on in-river sport and tribal fisheries in 2002. Future effects on ocean recreational, commercial, and in-river sport fisheries and tribal net fisheries, as a result of the 2002 fish-kill, depend on several factors. These factors include; accuracy of the fish-kill estimate, lost reproductive and recruitment potential, and many environmental factors, which may affected survival of the 2002 brood year. Accuracy of the fish-kill estimate probably has the most immediate and profound effect on the short-term management of fall-run Chinook salmon fisheries. The post-season, age-structured, Klamath River fall Chinook run-size estimate for 2002, provided the basis for estimating adult Chinook salmon ocean abundance in 2003. Regression analysis, based on historic in-river return data, was used to predict ocean abundance (PFMC 2003). Ocean abundances are modeled for ocean fisheries and impacts, using the Klamath River Ocean Harvest Model (KOHM). The Salmon Technical Team (STT) affiliated with the PFMC, developed the KOHM. The KOHM is used to establish ocean and in-river harvest allotments for fall Chinook salmon.

The purpose of this section is to determine if there were any discernable impacts to sport and tribal fisheries in 2002, and to evaluate potential impacts to ocean and in-river fisheries in 2003.

V. E. 2. Methods

DFG used three separate calculations to determine a range of potential impacts to in-river fisheries during 2002, as a result of the fish-kill. The first calculation used a conservative assumption that all impacts to sport and tribal harvest were on the Trinity River, and harvest rates for the Klamath sport and net fisheries, represent the harvest rates expected on the Trinity River, if there had not been a fish-kill. Making these assumptions, we applied harvest to quota ratios for the 2002 Klamath River sport fishery, to the Trinity River sport fishery, and subtracted the actual numbers of fall Chinook harvested on the Trinity in 2002. Similarly, we applied harvest to quota ratios for the 2002 Yurok Tribe net fishery at the mouth of the Klamath, to the Hoopa Tribe net fishery on the Trinity River, and subtracted the actual numbers of fall Chinook harvested on the Trinity in 2002. A second calculation also assumed all impacts were on the Trinity River, and that harvest rates for Trinity River sport and net fisheries in 2001, were better predictors of the harvest rate expected in 2002. We applied harvest to quota ratios for the Trinity River sport and Hoopa tribe net fisheries from 2001, to 2002 quotas, and subtracted the actual 2002 harvest on the Trinity River. The third calculation was the least conservative, and used a ratio of average harvest rates, to fall Chinook run-size between 1978 and 2001, for sport and net fisheries in the Klamath Basin. We averaged the yearly ratios (1978 to 2001) of sport harvest (upper and lower Trinity and Klamath), to total run-size, and applied that ratio to the 2002 post-season run-size of 170,014 salmon. Similarly, we averaged the yearly ratios (1978 to 2001) of tribal net harvest (Yurok and Hoopa tribes combined), to total run-size, and applied that ratio to the 2002 post-season run-size of 170,014 salmon.

In section V. A. we showed the fish-kill estimate may have been substantially underestimated. To evaluate potential impacts of this underestimation to projected ocean abundance estimates, DFG used the PFMC regression analyses. We then developed a stepwise progression of 10% increases in the numbers of fish lost, to determine the 2003 age structured ocean abundance of fall-run Chinook salmon.

V. E. 3. Results

The 2002 preseason estimate for ocean escapement of Klamath Basin adult (age 3–5) fall-run Chinook salmon, was 132, 600 fish (PFMC, 2002). This was the number of adults projected to return to the Klamath Basin, following ocean fisheries and natural ocean mortality. Harvest allocations (quotas) for in-river sport and tribal net fisheries, were developed using the preseason escapement estimate. Tribal net fisheries were allocated 50,400 adult Chinook, and in-river sport fisheries 20,500 adult Chinook. Fall Chinook escapement to natural areas was expected to be 35,000 adults. Hatchery escapement of adult fall Chinook was projected to be 22,000 fish. Preseason quotas and estimated harvest of fall Chinook adult salmon for the 2002 and 2001 seasons are presented in Table V4.

The 2002 Klamath River sport and Yurok Tribe net harvest catch/quota rates were 71.1% and 56.9%, respectively (Table V4). Applying these harvest rates to Trinity River sport harvest and Hoopa net harvest quotas for 2002, resulted in a total expected harvest of 10,552 fall Chinook salmon (4,816 sport and 5,736 net) on the Trinity River in 2002, if there had not been a fish-kill. The actual numbers of fish harvested on the Trinity River in 2002, were 1,808 salmon (473 sport fishery below Hawkins Bar, 167 sport fishery above Cedar Flat and 1,168 Hoopa Tribe net fishery). The expected harvest of 10,552 fall Chinook represents an additional 8,744 fish (4,176 sport and 4,568 Hoopa net) that may have been harvested during the 2002 fall salmon fishery on the Trinity River, if there had not been a fish-kill.

The 2001 Trinity River fall Chinook sport and Hoopa Tribe net harvest/quota rates were 25.6% and 39.7%, respectively (Table V4). By applying these rates to 2002 quotas, Trinity River sport and Hoopa Tribe net fishers would have caught an estimated 5,734 fall Chinook salmon (1,732 sport and 4,002 net). Subtracting the actual numbers of salmon harvested on the Trinity River in 2002 (1,808 fish from sport and net fisheries combined) from the estimated number of fall-run that could have been harvested (5,734 fish), indicates 3,926 more salmon could have been harvested, if there had not been a fish-kill.

Klamath Basin sport and tribal net fishery data, contained in DFG’s “megatable”, were analyzed to determine mean in-river harvest rates (harvest/run-size). For the years 1978 to 2001, sport and net harvest rates averaged 0.094 and 0.195, respectively. Applying these rates to the 2002 fall Chinook run-size of 170,014 fish, results in an estimated harvest of 15,981 sport and 33,153 net-harvested fall-run Chinook. The combined estimated harvest of 49,134 fish, represents 14,598 more fall Chinook than the actual numbers of fish harvested during 2002 from the Klamath Basin (34,536 fish). Based on these three independent calculations, the Klamath Basin tribal net and sport anglers lost the opportunity to harvest roughly 4,000 to 14,600 fall-run Chinook salmon in 2002, because of the fish-kill.

Table V4. Sport and tribal net fishery quotas and estimated harvest of Klamath Basin, adult fall-run Chinook salmon, for the 2002 and 2001 seasons.

Season	Fishery	Quota	Harvest	Harvest/ Quota
2002	Sport - Lower Klamath (below Coon Cr.)	10,250	6,554	0.639
2002	Sport – Upper Klamath (Coon Cr. to IGH)	3,485	3,216	0.923
2002	Sport – Lower Trinity (below Hawkins Bar)	3,383	473	0.140
2002	Sport – Upper Trinity (Cedar Flat to Lewiston)	3,382	167	0.049
2002	Net – Yurok tribe	40,320	22,958	0.569
2002	Net – Hoopa tribe	10,080	1,168	0.116
	Totals:	70,900	34,536	0.487
2001	Sport - Lower Klamath (below Coon Cr.)	14,900	6,580	0.442
2001	Sport – Upper Klamath (Coon Cr. to IGH)	5,066	3,041	0.600
2001	Sport – Lower Trinity (below Hawkins Bar)	4,917	710	0.144
2001	Sport – Upper Trinity (Cedar Flat to Lewiston)	4,917	1,803	0.367
2001	Net – Yurok tribe	60,400	33,691	0.558
2001	Net – Hoopa tribe	12,480	4,954	0.397
	Totals:	102,680	50,779	0.495

Age-structured fall Chinook mortality estimates attributed to the fish-kill, were composed of 2,003 age-two, 17,012 age-three, 12,304 age-four, and 1,233 age-five fish (Table V5). Potential effects of underestimating the fish-kill are shown in Table V5. Output results from the projected ocean abundance regression using the USFWS fish-kill estimate of 32,553 salmon, produced an estimated 62,314 ocean abundance of Klamath River adult fall Chinook salmon for 2003. A ten percent increase in the fish-kill estimate would increase the adult ocean abundance estimate by 6,234 fish. A fifty percent increase would result in an ocean abundance of 31,160 more fish, and a one hundred percent increase would result in 62,319 more fall-run Chinook salmon, projected to be available for modeling in 2003, to determine harvest allotments for ocean and in-river fisheries. Not all of these fish would have been be available for harvest, because maturation rates, natural mortality, and fishing regulations, limit the harvest allotments. However, if the fish-kill was in fact underestimated by 100%, the projected 62,319 extra Chinook salmon in the ocean, would have led to a significant increase in tribal and non-tribal harvest opportunities in 2003.

V. E. 4. Findings

The 2002 data suggests, sport and tribal harvest within the Trinity River, was more severely impacted than on the Klamath River. Sport harvest of adult fall Chinook in the Trinity River was only 9.5 % (640/6,765) of the allotted sub-quota. Harvest of adult Chinook in the Hoopa Tribal net fishery was only 11.6% (1,168/10,080) of the allotted quota, while Klamath River sport fisheries and Yurok Tribal net fisheries, caught more than half of their respective quotas in 2002. The discrepancies between harvest rates in the Trinity and Klamath rivers, were primarily because the fish-kill occurred in the lower Klamath River, prior to the fall Chinook salmon run progressing to up-river areas, including the Trinity River. Harvest rates in 2001 were similar to 2002 by sub-quota area on the Klamath River, while they were higher on the Trinity River in 2001 than 2002 (Table V4). These data indicate that harvest of fall Chinook in the Trinity River during the 2002 season, was differentially impacted by the fish-kill.

There is evidence to suggest the fish-kill was underestimated. Fish-kill estimates based on countable dead fish are inherently conservative, and seldom represent more than a modest fraction of the fish killed (AFS 1992). USFWS acknowledged the conservative nature of the Klamath River fish-kill estimate (USFWS 2003a, USFWS 2003b). Our regression analysis for the Trinity River (Section V. A.), suggests the actual numbers of fish lost in the Klamath fish-kill, may have been more than double the USFWS estimate. A negative bias in the fish-kill estimate would translate to smaller harvest quotas for in-river and ocean fisheries in 2003. The amount of lost fishing opportunity is related to the magnitude of error in the estimate, and the age structure of fall Chinook within the estimate. Underestimating age-two Chinook in the fish-kill would have the most severe consequences, since the age-two in-river spawner escapement vs. age-three abundance in the ocean, yields a high regression output. Our results indicated that if the 2002 fish-kill estimate were doubled, which is within the realm of possibility, greater than 62,000 more fall Chinook salmon, could have been allocated for modeling purposes. This in turn, would have led to increased harvest opportunities in ocean and in-river fisheries during 2003. Larger harvest quotas, may have given DFG the option to liberalize bag and possession limits.

Table V5. Modeled effects of underestimating the 2002 lower Klamath River fish-kill on 2003 fall-run Chinook salmon ocean abundance projections.

Lower Klamath Chinook Fish Kill Estimate a/	Percent increase	Estimated 2002 Chinook fish-kill age structure					2003 Projected ocean abundance b/			
		Age 2	Age 3	Age 4	Age 5	Total	Age 3	Age 4	Age 5	Total
32,553	none	2,003	17,012	12,304	1,233	32,552	37,104	23,919	1,292	62,314
35,808	10%	2,203	18,714	13,535	1,356	35,808	40,815	26,312	1,421	68,548
39,064	20%	2,404	20,415	14,765	1,480	39,064	44,526	28,704	1,550	74,780
42,319	30%	2,604	22,116	15,996	1,603	42,319	48,236	31,095	1,680	81,011
45,574	40%	2,804	23,818	17,226	1,726	45,574	51,947	33,487	1,809	87,243
48,830	50%	3,005	25,519	18,457	1,850	48,830	55,657	35,879	1,938	93,474
52,085	60%	3,205	27,220	19,687	1,973	52,085	59,368	38,271	2,067	99,706
55,340	70%	3,405	28,921	20,917	2,096	55,340	63,078	40,663	2,196	105,938
58,595	80%	3,606	30,623	22,148	2,219	58,595	66,788	43,055	2,326	112,169
61,851	90%	3,806	32,324	23,378	2,343	61,851	70,499	45,447	2,455	118,401
65,106	100%	4,006	34,025	24,609	2,466	65,106	74,209	47,839	2,584	124,633

a/ Original preliminary fish kill estimate of 32,553 of Chinook mortality based on USFWS data.

b/ Projections based on regressions for Klamath Basin fall Chinook salmon (PFMC 2003).

VI. Conclusions:

The September 2002 fish-kill was unprecedented, and the first major mortality event of adult salmonids in the Klamath River ever recorded. Fall-run Chinook salmon were the primary species affected, but coho salmon, steelhead, and other fish species were also lost. At least 33,000 adult salmonids died during mid to late September 2002, in the lower 36 miles of river. Although a larger number of Klamath River fall-run Chinook died, a greater proportion of the Trinity River run was impacted by the fish-kill, because the Trinity run is substantially smaller than the Klamath run on an annual basis, and the peak of the Trinity River Chinook salmon run in 2002, coincided with the height of the fish-kill.

The primary cause of the fish-kill was a disease epizootic from the ubiquitous pathogens ich and columnaris. However, several factors contributed to stressful conditions for fish, which ultimately led to the epizootic. An above average number of Chinook salmon entered the Klamath River between the last week in August and the first week in September 2002. River flow and the volume of water in the fish-kill area were atypically low. Combined with the above average run of salmon, these low-flows and river volumes resulted in high fish densities. Fish passage may have been impeded by low-flow depths over certain riffles, or a lack of cues for fish to migrate upstream. Warm water temperatures, which are not unusual in the Klamath River during September, created ideal conditions for pathogens to infect salmon. Presence of a high density of hosts and warm temperatures caused rapid amplification of the pathogens ich and columnaris, which resulted in a fish-kill of over 33,000 adult salmon and steelhead.

Flow is the only controllable factor and tool available in the Klamath Basin (Klamath and Trinity rivers) to manage risks against future epizootics and major adult fish-kills. Increased flows when adult salmon are entering the Klamath River (particularly during low-flow years such as 2002) can improve water temperatures, increase water volume, increase water velocities, improve fish passage, provide migration cues, decrease fish densities, and decrease pathogen transmission between fish.

The total fish-kill estimate of 34,056 fish was very conservative. Analysis of Trinity River spring-run to fall-run Chinook returns in 2002 compared to historic returns, indicate the fish-kill estimate may have underrepresented actual fish losses by 45,000 individuals. If fish-kill numbers were indeed substantially underestimated, more fall-run Chinook salmon could have been used in the PFMC modeling efforts. This would have led to increased harvest opportunities for ocean and in-river Klamath fisheries during 2003. In addition, Klamath Basin tribal net and sport anglers may have lost the opportunity to harvest roughly 4,000 to 14,600 fall-run Chinook salmon in 2002 because of the fish-kill. This impact was more pronounced in the Trinity River than the Klamath River, because the fish-kill occurred below the confluence of the Trinity and Klamath, before there was substantial opportunity for fall Chinook to be harvested from the Trinity River.

VII. Recommendations:

1. Determine if low-flow levels create physical or water quality barriers to upstream migration of adult anadromous salmonids at key riffles and waterfalls in the lower Klamath River and Trinity River. If so, determine and implement flows necessary to allow unimpaired passage, or to provide cues for upstream migration.

2. Determine conditions and mechanisms resulting in sand spit formation and constrictions at the mouth of the Klamath River. This information should be used as a barometer of when estuary volumes may be low and more flow may be necessary to reduce fish density in the lower Klamath River.

3. Evaluate temperature tolerances of various life-history stages for anadromous salmonids in the Klamath and Trinity rivers. Results of this study should be used to establish temperature goals in the lower Klamath River to prevent future epizootics and fish-kills. If feasible, on an interim basis, temperature goals should conform to the USEPA Region 10 guidance for Pacific northwest state and tribal temperature water quality standards (USEPA 2003).

4. Determine and implement flows, necessary to meet temperature standards (if possible) to prevent future epizootics and fish-kills. On an interim basis, regression analyses in this report, indicate combined KAO+TRH flows should be at least 2,200 cfs when adult salmon are entering the Klamath Estuary. DFG bases this recommendation on Figure D19, which indicates temperatures in the lower Klamath during low-flow conditions, approach the EPA standard (USEPA 2003) to prevent high risk from disease pathogens for adult salmonids (a daily temperature consistently below 64.4 ^{o}F) as KAO+TRH flows increase from 1,900 cfs to 2,200 cfs.

5. The Hardy Phase II Study (Hardy and Addley 2001) should be finalized and flow recommendations implemented to provide adequate habitat for Chinook salmon. If the Hardy Phase II dry year flow recommendation of 1,100 cfs from Iron Gate Dam, had been met in September 2002 (rather than the actual release of 760 cfs), flows at KAO+TRH would have met the DFG interim recommendation of at least 2,200 cfs in number 4 above.

6. As is the case with the Central Valley Project on the Sacramento River, fish and wildlife resource protection, restoration, mitigation, and enhancement should be made a specific purpose for the Klamath Project. Fishery resources in the Klamath System should have equal priority, in balancing the use of limited water resources.

VIII. References:

AFS (American Fisheries Society). 1992. Investigation and valuation of fish kills. AFS Special Publication 24. AS. Bethesda, MD. 96 pp.

Balance Hydrologics, Incorporated. 1996. Initial assessment of pre- and post- Klamath Project hydrology on the Klamath River and impacts of the project on instream flows and fishery habitat. 39 pp. plus figures.

Bartholow, J.M. 1995. Review and analysis of Klamath River Basin water temperatures as a factor in the decline of anadromous salmonids with recommendations for mitigation. Pages 1-53 in Compilation of Phase I Reports for the Klamath River Basin, May 1995, River Systems Management Section, National Biological Service, Fort Collins, CO. (Plus errata)

Bodensteiner, L.R., R.J. Sheehan, P.S. Willis, A.M. Brandenburg, and W.M. Lewis. 2000. Discharging water: an effective treatment for icthyophthiriasis. Journal of Aquatic Animal Health 12:209-219.

Boydstun, L.B. 1979. FY 1978 Progress Report. Task I. Lower Klamath River steelhead and salmon tagging study. In: Paul M. Hubbell (ed.) Progress Report. Fishery Investigations– Trinity River. Trinity River Basin Fish and Wildlife Task Force Priority Work Item No. 5. Sept. 1979, 54 pp.

California Advisory Committee on Salmon and Steelhead Trout. 1988. Restoring the balance. 84pp.

CDWR (California Department of Water Resources). California Data Exchange, www.cdec.water.ca.gov.

CDWR. 1997. Office Memo: Klamath River Basin natural flows. Memo to Naser Bateni from Dan Fua. February 24, 1997. 5 pp. with attached memoranda, tables and graphs.

CDWR. 1988. Water temperature effects on Chinook salmon (*Oncorhynchus tshawytscha*) with emphasis on the Sacramento River; a literature review. 42 pp.

CDWR. 1987. Klamath River water quality study, Hamburg to Orleans. 71 pp.

CDWR. 1986a. Shasta/Klamath Rivers water quality study. 406 pp.

CDWR. 1986b. Sacramento River water quality and biology, Keswick Dam to Verona; a literature review. 100 pp.

California Water Code. 2003. California law web site; http//www.leginfo.ca.gov/cgi-bin/calawquery?codesection=wat.

Campbell, S.G. 1995. Klamath River Basin flow-related scoping study – Phase 1: Water Quality. National Biological Survey Denver, Colorado.

CH2M Hill. 2000. Trinity mainstem fishery restoration. Final draft environmental impact statement/report.

City of Klamath Falls. 1986. Application for License, Salt Caves Hydroelectric Project. Submitted to Federal Energy Regulatory Commission.

Davis, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. J. Fish. Res. Bd. Canada. 32:2295-2332.

DFG (California Department of Fish and Game). 2004. Butte Creek spring-run Chinook Salmon, *Onchorhynchus tshawytscha* per-spawn mortality evaluation 2003. 91pp.

DFG. 2003a. September 2002 Klamath River fish kill: preliminary analysis of contributing factors. 63 pp.

DFG. 2003b. Weekly anadromous fish count June 22-28, Iron Gate Hatchery. Recorded by Kimball W. Rushton, Fish Hatchery Manager II, Hornbrook, CA.

DFG. 2002a. Status review of California Coho salmon north of San Francisco. Report to the California Fish and Game Commission. 231 pp.

DFG. 2002b. Fish pathology report. Klamath River, Blakes Riffle and confluence with Blue Creek. 2 pp.

DFG. 2002c. Annual Report, Shasta and Scott River juvenile salmonid outmigrant study, 2000-2001, Study 2a1. California Department of Fish and Game, Steelhead Research and Monitoring Program, Yreka, CA. 38 pp.

DFG. 2000a. Annual Report, Study 3a1, Shasta and Scott River juvenile steelhead trapping, 2000. California Department of Fish and Game, Steelhead Research and Monitoring Program, Yreka, CA. 36 pp.

DFG. 2000b. Annual Report. Trinity River Basin Salmon and Steelhead Monitoring Project 2000-2001. Neil Manji editor. California Department of Fish and Game, Northern California North Coast Region. Redding, CA.

DFG. 2000c. Documentation of the Klamath River fish kill, June 2000. 17 pp.

Dickerson, H.W. and D.L. Dawe. 1995. Ichthyopthirius multifilis and Cryptocaryon irritans (Phylum ciliophora). In P.T.K. Woo ed. Fish diseases and Disorders. Vol. 1 Protozoan and Metazoan Infections. CAB International. ISBN 0-85198-823-7.

Fish & Game Code, unabridged California edition. 2003. LawTech Publishing Co,Ltd. 568 pp. ISBN: 1-930466-57-9.

FishPro. 2000. Fish passage conditions on the upper Klamath River. Submitted to: the Karuk Tribe and PacifiCorp. FishPro, Port Orchard, Washington. July 2000.

Foott, J.S., T. Martinez, R. Harmon, K. True, B. McCasland, C. Glase, and R. Engle. 2002. Juvenile Chinook health monitoring in the Trinity River, Klamath River and estuary, June-Aug. 2001. USFWS, CA-NV Fish Health Center, Anderson, CA.

Gard, M. et al., 2003. Flow-habitat relationships for spring-run Chinook salmon spawning in Butte Creek. U. S. Fish and Wildlife Service, SFWO, Energy Planning and Instream Flow Branch, Butte Creek 2-D modeling final report. August 29, 2003. 86pp.

Hardy, T.B. 1999. Evaluation of the interim instream flow needs in the Klamath River – Phase 1. Prepared for: U.S. Department of the Interior. Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University, Logan, Utah. 53 pp plus appendices.

Hardy, T.B. and R.C. Addley. 2001. Evaluation of interim instream flow needs in the Klamath River, Phase II - Volume I, Final Report. Prepared for: U.S. Department of the Interior. Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University, Logan, Utah. 148 pp.

Helley, E.J., and V.C. LaMarche. 1973. Historic flood information for northern California streams from geological and botanical evidence. Professional Paper 485-E. U.S. Geological Survey.

Hopelain, J.S. 2001. A four-year summary of angler creel census on the lower Klamath River with emphasis on upstream migrating fall Chinook salmon, coho salmon, and steelhead trout during July through October, 1983 through 1987. Calif. Dept. Fish and Game. Inland Fisheries Division. Admin Report No. 2001-1 Sacramento, California.

Hopelain, J.S. 1988. A four year summary of Seining/Tagging operations in the lower Klamath River with emphasis on mature fall Chinook salmon, coho salmon and steelhead trout, 1984 through 1987. Calif Dept Fish and Game. Inland Fisheries Division. Sacramento, CA.

Instream Flow Council. 2002. Instream flows for riverine resource stewardship. Instream Flow Council. 411 p.

Johnson, S.K. 1976. Laboratory evaluation of prevention techniques for Ich disease in the retail tropical fish shop. FDDL-F11. Texas Agricult. Ext. service. Texas A and M Univ. College Station, TX.

Karuk Tribe of California. 2003. Water year 2002 water quality monitoring report. Klamath River at Iron Gate, Klamath River at Seiad Valley, Klamath River at Orleans, Indian and Steinacher Creeks. 23 pp.

Karuk Tribe of California. 2002. Water years 2000 & 2001 Klamath River mainstem water quality monitoring report; Iron Gate, Seiad Valley, Orleans, Indian Creek. 30 pp.

Kimmerer, W. and J. Carpenter. 1989. DeSable-Centerville Project (FERC 803), Butte Creek interim temperature monitoring study – final Report. Prepared by BioSystems Analysis, Inc. 35pp + appendices.

Klamath River Basin Fisheries Task Force. 1992. Long range plan for the Klamath River Basin Conservation Area Fishery Restoration Program. Prepared by the Klamath River Basin Fisheries Task Force with assistance from William M. Kier Associates. January 1991.

Klamath River Basin Fisheries Task Force. 1991. Long range plan for the Klamath River Basin Restoration Area Fishery Conservation Program.

Lasee, B.A. 1995. Introduction to fish health management. USFWS.

Lauman, J. E. 1976. Salmonid passage at stream-road crossings. A report with Department standards for passage of salmonids. Oregon Department of Fish and Wildlife. Portland, Oregon 78 pp.

Leidy, R.A. and G.R. Leidy. 1984. Life stage periodicities of anadrmous salmonids in the Klamath River Basin, northwestern California. U.S Fish and Wildlife Service, Sacramento, Calif. 22 pp. plus tables and appendices.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964 Fluvial processes in geomophology. Freeman, San Francisco, California.

Li, H.W., and J.L. Li. 1996. Fish community composition. Pages 391-408 *in* F.R. Hauer and G.A. Lambert (editors) Methods in stream ecology Academic Press, San Diego, California.

Moyle, P.B. 2002. Inland Fishes of California. University of California Press. Berkeley and Los Angeles, CA. 502 pp.

National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC). 2003. Atmosheric data at www.ncdc.noaa.gov.

Noga, E.J. 1996. Fish Disease Diagnosis and Treatment. Mosbey Year-Book, Inc. ISBN 1-55664-371-8.

North Coast Laboratories. 2002. Analytical report to Water Quality Control Board on Klamath fish kill. 13 pp.

North Coast Regional Water Quality Control Board (NCRWQCB). 1994. Water quality control plan for the north coast region.

Oregon Department of Fish and Wildlife. 2002. Lost Creek Dam evaluation project. Supplemental report number 1, fish research project, Oregon Department of Fish and Wildlife.

Oregon Department of Fish and Wildlife. 2000. Effects of Lost Creek Dam on spring Chinook salmon in the Rogue River. Phase II completion report. Rogue Basin fisheries evaluation project.

Oregon Department of Fish and Wildlife. 1997. Klamath River Basin, Oregon Fish Management Plan. Klamath Falls, Oregon. August 22, 1997.

Oregon Department of Fish and Wildlife. 1992. Effects of Lost Creek Dam on fall Chinook salmon in the Rogue River. Phase II completion report. Rogue Basin fisheries evaluation project.

PFMC (Pacific Fishery Management Council). 2003. Preseason Report I Stock abundance analysis for 2003 ocean salmon fisheries. (Document prepared for the council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassodor Place, Suite 200, Portland, Oregon 97220-1384.

PFMC 2003. Review of 2002 Ocean Salmon Fisheries. Pacific Fishery Management Council. Portland, OR.

PFMC. 2002. Preseason Report III Analysis of Council adopted measures for 2002 ocean salmon fisheries. (Document prepared for the council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassodor Place, Suite 200, Portland, Oregon 97220-1384.

Pacific Southwest Interagency Committee. 1973. Basin River Mile Index- Klamath River, Pacific Slope Basin, California-Oregon. Report of the Water Management Technical Subcommittee, July 1973. 56 pp.

PacifCorp. 2000. First Stage Consultation Document, Klamath Hydroelectric Project (FERC Project No. 2082). PacifiCorp, Portland, Oregon.

Post, G. 1987. Text Book of Fish Health. TFH Publ., Inc. 256 pp.

Sanford, J.A. 1996. Landscapes and catchment basins. Pages 1-22 *in* F.R. Hauer and G.A. Lambert (editors) Methods in stream ecology Academic Press, San Diego, California.

Shaw, T.A., C. Jackson, D. Nehler and M. Marshall. 1997. Klamath River (Iron Gate Dam to Seiad Creek) life stage periodicities for Chinook, coho and steelhead. 63 pp. USFWS, Coastal Calif. Fish and Wildlife Office, Arcata, CA

Sokal, R.R., and F. J. Rohlf. 1981. Biometry, The Principals and Practice of Statistics in Biological Research, Second Edition. W.H. Freeman and Company, New York. 859 pp.

Snyder, J.O. 1931. Salmon of the Klamath River California. Calif. Dept. Fish and Game, Fish Bull. No. 31, 130 pp.

Thoesen J., ed. 1994 Suggested Procedures for the Detection and Identification of Certain Finfish and Shellfish Pathogens. American Fisheries Society Bluebook. Fourth Edition. ISBN No 0-962505-2-3).

Thompson, K. 1972. Determining streamflows for fish life. Pages 31-50. In Transcript of Proceedings, Instream Flow Requirement Workshop, Portland, Oregon. March 15 – 16, 1972.

Traxler, G.S., J. Richard and T.E. McDonald. 1998. *Ichthyopthirius multifilis* (Ich) Epizootics in spawning sockeye salmon in British Columbia, Canada Journal of Aquatic Animal Health, 10(2):143-151.

USEPA (U.S. Environmental Protection Agency). 2003. EPA Region 10 guidance for Pacific northwest state and tribal temperature water quality standards. EPA 910-B-03-002. Environmental Protection Agency, Seattle, Washington.

USEPA. 2002. Draft EPA Region 10 guidance for pacific northwest state and tribal temperature quality standards. 2nd public review draft, October 10, 2002.

USEPA. 1986. Quality criteria for water. EPA 440/5-86-001. Environmental Protection Agency, Washington, D.C. 450 pp.

USFWS (U. S. Fish and Wildlife Service). Provisional water temperature data at http://arcata.fws.gov/TempData.html.

USFWS. 2003a. Klamath River fish die-off September 2002, Report on estimate of mortality. Report Number AFWO-01-03. 28 pp.

USFWS. 2003b. Klamath River fish die-off September 2002, Causative factors of mortality. Report Number AFWO-F-02-03. 115 pp.

USFWS. 2002. Pathology report. Blue Creek mouth, Klamath R. (16rm). Case No: 2002-139. 3 pp.

USFWS. 2001. Empirical and theoretical influences of a pulse flow from Lewiston Dam on water temperature and dissolved oxygen of the lower Klamath River. Report # AFWO F2001-01. Presented to The Trinity Management Council. 28pp.

USFWS. 1997. A letter from the Arcata Fish and Wildlife Office to the California Regional Water Quality Control Board, Santa Rosa, CA.

USFWS. 1982. Fish hatchery management. Reprinted by American Fisheries Society in cooperation with USFWS. ISBN 0 - 913235 – 03 – 2. 517 pp.

USFWS. 1976. Columnaris disease of fishes. Fish Disease Leaflet 45. 10 pp.

USFWS. 1974. Parasites of freshwater fishes: II, Protozoa. 3. *Ichthyophthirius multifiliis.* Fish Disease Leaflet 2. 5 pp.

USFWS and Hoopa Valley Tribe. 1999. Trinity River flow evaluation final report. 307 pp.

USFS (U. S. Forest Service). 1994. Stream temperature analysis and data compilation, Klamath River Basin. Number two. R-5 Fish Habitat Relationship Technical Report. Happy Camp Ranger District. 5 pp.

USGS (U. S. Geological Survey). 2003. Klamath River Basin hydrologic conditions prior to the September 2002 die-off of salmon and steelhead. Water Resources Investigations Report 03-4099. U.S. Geological Survey. U.S. Department of Interior. Portland, Oregon. 10 p.

USGS. 1990. Water resources data California, Water year 1989. Volume 2. Pacific Slope Basins from Arroyo Grande to Oregon State line except Central Valley. U.S. Geological Survey Water-Data Report CA-89-2. 309 pp.

USGS. USGS data at www.usgs.gov.

Warren, J. 1991. Diseases of Hatchery Fish. USFWS.

Wedemeyer, G.A. 1970. The role of stress in the disease resistance of fishes. pp 30-35 in S.F. Snieszko ed. A symposium on diseases of fishes and shellfishes. Amer. Fish. Soc. spec. publ. No. 5.

Wetzel, R.G. 1983. Limnology – Second Edition. Chicago, Saunders College Publishing, 767 pp.

Zar, J.H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, Englewoood Cliffs, New Jersey.

Personal Communication:

Bairrington, P. 2002. DFG, Senior Fisheries Biologist, Arcata, CA.

Belchik, M. 2003. Yurok Tribe Fisheries Biologist, Klamath, CA.

Borok, S. 2003. DFG, Associate Fisheries Biologist, Arcata, CA.

Gilroy, I. 2003. Former NOAA Fisheries, Fisheries Biologist, Arcata, CA.

Higgins, M. 2002. Dept Fish and Oceans, Canada.

Hillemeier, D. 2003, Yurok Tribal Fisheries Program Manager, Klamath, CA.

Lynch, D.D. 2003. USGS, Portland, OR. Written communication via e-mail.

Marshall,L. Jr. 2002. DFG, Fish Hatchery Manager I, Trinity River Hatchery, Lewiston, CA.

Olson, B. 2002. US Forest Service, Salmon River District. Fort Jones, CA.

Pisano, M. 2003. DFG, Associate Fisheries Biologist, Yreka, CA.

Ramsden, G. 2003. DFG, Fish Hatchery Manager II, Trinity River Hatchery, Lewiston, CA.

Rushton, K. 2003. DFG, Fish Hatchery Manager II, Iron Gate Hatchery, Hornbrook, CA.

Satterthwaite, T. 2003. Oregon Department of Fish and Wildlife, Fisheries Biologist, OR.

Shaw, T. 2002. USFWS, Fisheries Biologist, Arcata, CA.

Susich, G. 2003 USGS, Eureka, CA.

Ward, P. 2003. DFG, Associate Fisheries Biologist, Chico, CA.

IX. Appendix A:

State of California
Department of Fish and Game

FISH PATHOLOGIST REPORT

Location	**Date**
Klamath River	26 & 27 September 2002
Species and Size	**Sample Area**
Chinook, steelhead, and coho Creek returning adults	Blake's Riffle and confluence with Blue

Observations and Fish Sampling:
Sept 26 - Twenty relatively fresh Chinook salmon of the 100 or more mortalities (including four coho and one steelhead which were all too decomposed for evaluation) located along an approximately half-mile section of shore near Blake's Riffle were observed for external lesions and signs of internal pathology. Best guess, these fish had all been dead for 12-24 hours. None of the fish had color left in the gills, but 12 of 20 had signs of erosion of the lamellae – the filaments appearing to be intact. No other external lesions were observed. Internally, 4 of the 20 fish had signs of mild to moderate inflammation of the lower intestine, and one of those also had mild hemorrhaging of the intestine with no other apparent tissue involvement. Tissue samples of the inflamed intestines were taken, as well as samples of the kidneys of these fish to ascertain degree of decomposition by presence/absence of bacteria. Observations were made using phase-contrast microscopy of wet mounts. No *Ceratomyxa shasta* trophozoites were observed in any of the intestinal scrapes, possibly due to degradation of the organism, and bacteria were observed in only one of the scrapes (from the hemorrhagic sample). No bacteria were observed in the kidney wet mounts, suggesting overall pathology was not due to decomposition.

Since none of the fish were in good enough condition to evaluate gill pathology, fishermen along the Riffle were asked to donate anything they caught to the analysis. Talking with fishermen I was told that most of the fish seemed unwilling to put up a fight and the gills of the fish they were catching seemed to be covered in excess mucous, and looked as if they had been "sprinkled with salt". One steelhead, two Chinook, and one coho were evaluated. One of the Chinook and the coho appeared to have just entered the river, having no signs of disease, corroborated by statements from the fishermen to the effect that the fish had given them a good fight, compared to the others. The gills of the other fish did, indeed look as if they had been sprinkled with salt, and wet mounts revealed heavy infestations of *Ichthyophthirius multifilis* trophonts – approximately 30 per scrape.

Sept. 27 – A USFW boat was taken Friday morning to the confluence of the Klamath River and Blue Creek, approximately 13 river miles from the mouth. Gill and skin scrapes, and lower intestine samples were taken from 4 moribund and 2 fresh dead Chinook, and one fresh-dead coho. Other dead coho were observed (10 or more), but none fresh enough to evaluate, other than noting the presence of typical dark yellow "scooped out" columnaris lesions on the gills of two of the fish, and erosion of the lamellae of three others. Samples were kept on ice in separate zip-loc bags for approximately two hours before being evaluated using phase-contrast microscopy of wet-mounts. Heavy infestations of Ich were present on all but two gill samples, which had large amounts of *F.columnare* and some motile rod bacteria. No other external pathogens were observed. *C. shasta* trophs were observed in the intestinal scrape of one fish. Scrapes were also taken from one fish that had an external lesion (*F.columnare*) and cloudy cornea (Ich). Summary of results follows.

Blake's Riffle - 26 September 2002

Dead Fish

# fish/species	# lamellae erosion	# columnaris lesions	# inflamed lower intestines	*C.shasta* observed
20/Chinook	12	0	4	0

Fish Obtained from Fishermen

species	lamellae erosion	columnaris observed	Ich observed	inflamed lower intestines	*C.shasta* observed
steelhead	-	-	+	+	-
coho	-	-	-	-	-
chinook	-	-	+	-	-
chinook	-	-	-	-	-

Blue Creek - 27 September 2002

species	lamellae erosion	columnaris observed	Ich observed	inflamed lower intestines	*C.shasta* observed
coho – fresh dead	+	+	-	-	-
Chinook – fresh dead	+	+	-	+	-
Chinook– fresh dead	+	+	+	-	-
Chinook- moribund	+	+	+	-	-
Chinook - moribund	+	+	+	+	+
Chinook - moribund	+	+	+	-	-
Chinook - moribund	-	-	+	-	-

Comments:

Water temps.

Blake's Riffle – 5 PM in 12" of water: 69°F

Blue Creek – 11AM in 3 ft of water: 59°F

Submitted by

Tresa Veek, Associate Fish Pathologist, CDFG

PATHOLOGY REPORT

US Fish & Wildlife Service **phone 530-365-4271**
CA-NV Fish Health Center **fax 530-365-7150**
24411 Coleman Hatchery Rd
Anderson, CA 96007

FHC Case No. : 2002-139 Submittal date: 09/27/02
Sample Collector: S Foott Sample Site(s): Blue creek mouth, Klamath R. (16rm)
Histological specimen examiner: J. Scott Foott
Species: Morubund Chinook salmon and intestine from 1 dead coho Age: Adult

Tissues: Gill , liver, kidney, spleen, and lower intestine
Fixative: Davidson (X) , PREFER-ETOH ( ), 10%BF ( ), ZFIX ( ), Bouins ( )
Stains: Hematoxylin & eosin (X), PAS ( ), Iron ( )
Block No. 4182 - 4189 Block / slide deposition: FHC

Blood Smear (Number): 4 Bloodsmear Stain: Leishman-Giemsa ( ), DiffQuick(xx)
General leukopenia in 2 of 4 smears, neutrophilia in 3 of 4 (see attached table)
No erythrocyte inclusions or blood parasites seen in smears

Clinical chemistry: 4 serum samples= osmolarity, chloride, and total protein

Hypochloremia detected in 2 of 3 samples with reduced osmolarity values (< 280 mmol/kg), one sample (male 3) cannot be evaluated due to fibrin clot. Serum protein levels were slightly elevated but within the broad "normal" range for adults (2 – 6 g/dL). See attach table.

<ins>Summary</ins>

Tissues were collected from 4 moribund adult Chinook and one hatchery coho (right maxillary clip = Trinity R. hatchery) adult that had recently died. Ich (*Ichthyophthirius multifiliis*) was observed in all 4 Chinook gill specimens and was associated with epithelial hyperplasia. While histological processing would remove the heavy mucus layer observed on the gills at the time of collection, large numbers of globlet (mucus) cells were associated with the parasites. The combination of hyperplastic epithelium and excessive mucus would act to reduce respiratory and ion control functions of the gill. Skin lesions associated with the severe Ich infection would cause ion loss as demonstrated by the low serum chloride levels (hypochloremia). One gill section showed necrotic changes consistent with the gross Columnaris (*Flavobacterium columnare)* disease signs observed at the time of collection.

Liver, kidney, and spleen specimens were normal. Three of 4 kidney sections contained 1 to 2 metacercaria (presumptive *Nanophyetus salmincola*). Little to no host response was associated with these trematodes and the infection is considered benign. Three of 5 lower intestine sections contained *Ceratomyxa shasta* trophozoites however there was only minor inflammation associated with the parasites. These infections were not deemed significant to the health of the fish *<ins>at the time of collection</ins>*. Ceratomyxosis can advance into a debilitating hemolytic condition.

While *Aeromonas hydrophilia* was isolated from 2 of 4 kidney samples, it is unlikely that an internal bacterial infection was the cause of the epizootic. Examination of gram-stained spleen imprints did not detect bacteria as would be expected in a serious bacterial infection.

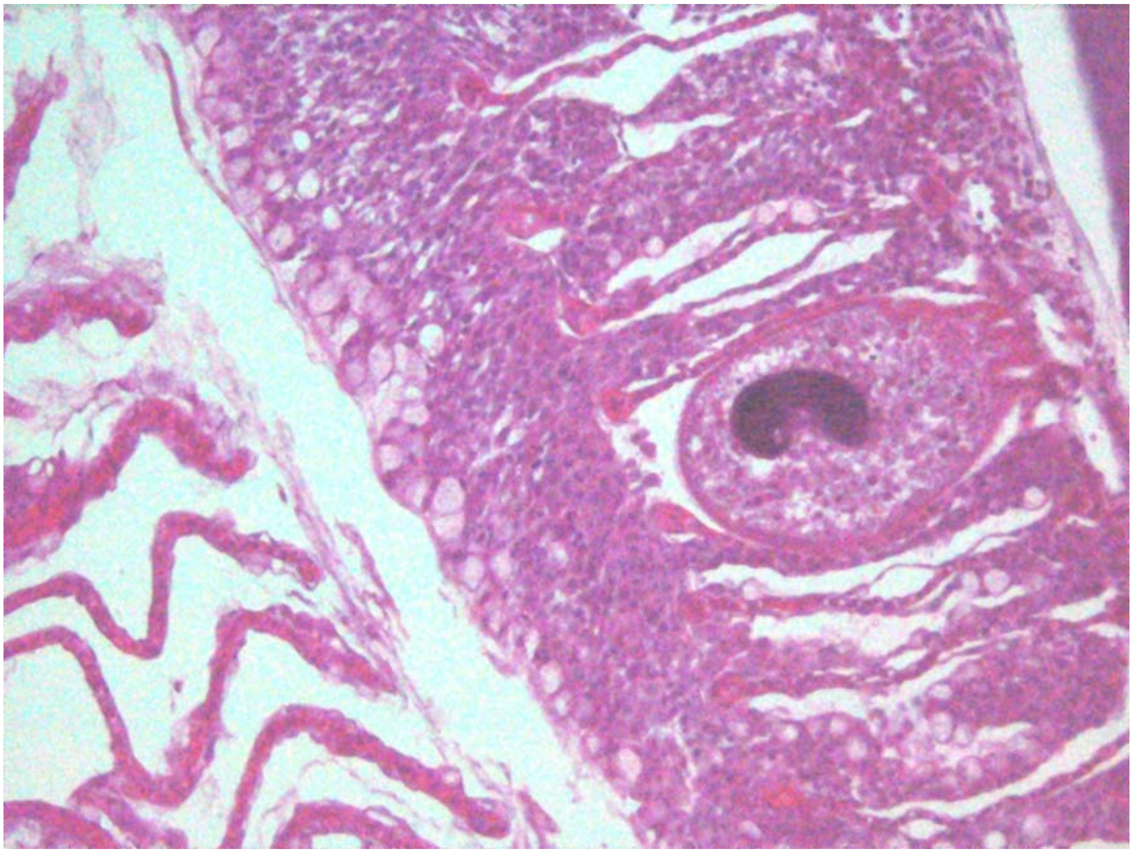
The gross clinical signs of swollen gills containing Ich and the high incidence of gill rot (columanris) provide strong evidence that the disease, induced by these two contagious pathogens, was the immediate cause of the fish kill.

Blue Creek / blue hole seep region (16 river mile) Klamath R. 9/27/02

Fish (m=male, f= female)	m1	m3	f7	m8
Swollen gill / excess mucus	y	y	y	y
Fc gill lesion	n	n	y	y
Bacteria detected in spleen imprint	n	n	n	n
Bacteria isolated from kidney (BHIA)	Ah	Ah	none	none
Ah = *Aeromonas hydrophilia*				
BLOOD				
Serum protein (g/dL)	4.6	1.5**	5.3	3.9
Serum Chloride (meq/L)	79	88**	66	86
Serum Osmolarity (mmol/ kg)	299	261**	253	272
Serum notes		**fibrin clot	hemolysis	

Normal ranges
serum chloride 120 – 130 meq/L
osmolarity 280 – 320 mmol/kg
protein 2 – 6 g/dL

Leukocyte counts / 100 WBCs	m1	m3	f7	m8
Lymphocyte	24	38	39 (55%)	46
Thrombocyte	38	61	4 (6%)	1
Neutrophil	33	1	23 (33%)	53
Monocyte	5	0	4 (6%)	0
Leukopenia	y	n	y	n
L:G ratio	0.72	38	1.7	0.86
Neutrophilia	y	n	y	y
Erythrocyte inclusion / parasite	none	none	none	none



Ich trophont (large arrow) within hyperplastic gill epithelium of Klamath R. Adult Chinook Salmon (50x mag., H & E stain). Note the contrast between normal gill lamella (arrow head) and thicken epithelium surrounding the parasite (region between small arrows).