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The Effects of the Feather River Hatchery on Naturally Spawning Salmonids

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Executive Summary

This report has been prepared as part of the FERC re-licensing process for the Department of Water Resources' (DWR) Oroville Facilities, an integral component of the State Water Project. In this report we deal specifically with the effects of the Feather River Hatchery (FRH), a part of the Oroville Facilities, on naturally spawning Chinook salmon and steelhead in the Feather River and other streams in California's Central Valley. This report was prepared with the assistence of a FRH Technical Team established during the FERC relicensing process for the express purpose of implementing SP-F9. The opinions, findings, and conclusions expressed in this report are those of the authors or other FRH Techinical Team members. This report does not express the official position of DWR unless specifically approved by the Director or his designee.

The Department of Water Resources (DWR) constructed the FRH in the mid 1960s to mitigate partially for loss of Chinook salmon and steelhead spawning habitat above Oroville Dam on the Feather River. The hatchery opened in 1967 and since then the Department of Fish and Game (DFG) has raised and released tens of millions of spring and fall Chinook salmon and steelhead. Many of these fish have been subsequently harvested in ocean (salmon only) and inland (salmon and steelhead) fisheries, and a surplus has returned to the Feather River (and other Central Valley streams) to spawn.

For the first two decades or so of hatchery operations the philosophy of hatchery managers was straightforward – raise enough fish to help support the fisheries and a surplus that would provide for spawners, both in the streams and in the hatcheries. This can be viewed as a production mode. If survival of the juvenile fish could be increased significantly by releasing the fish off site – in the San Francisco Estuary, for example – this was an acceptable process. Although most biologists realized that off-site released fish would not be as able to find their natal stream as well as fish released on site, the increased straying was not deemed to be a serious consequence. Hatchery managers routinely transferred eggs and juvenile fish among hatcheries (even some from out of state) if the transfers appeared to provide genetic material to improve (increase) a run or to establish a desirable strain or race in a new stream. Surplus hatchery fish were routinely planted rather randomly in Central Valley streams with the hope that they might survive to establish new runs.

During the first few decades there was rather little work done by DFG or others to document the effects of the FRH, although some of the pioneering studies by Hallock and Reisenbichler (e.g. 1979, 1980) were exceptions to this general statement. The hatchery produced useful annual reports but they were essentially compilations of the numbers of fish spawned, egg take, numbers of fish reared and released, etc. These reports did not contain much of the information that would allow biologists to examine the effects of the hatchery on naturally spawning salmon and steelhead..

The attitude towards hatcheries began to change when it became apparent that salmonids were declining throughout much of their range in spite of hundreds of millions of salmon released from hatcheries. Endangered Species Act (ESA) listing of several salmon races also directed attention to hatcheries since many of the races could be affected by hatchery reared fish. The word "fitness" began to appear more often when referring to salmonids (see for example Busack and Currens 1995 and Reisenbicher 1995) with the idea that hatchery fish are less fit (less able to survive to successfully reproduce) than wild fish. Wild and hatchery fish interactions were considered to be disadvantageous to the wild fish (Lichatowich 1999).

In this report we describe the physical, institutional, biological and fisheries context in which the FRH has operated, and will operate, and examine some of its potential impacts on Central Valley Chinook salmon and steelhead. Although DWR started these studies in the early 1990s, and they still continue, many of the questions can not be answered with available data.

The FRH hatchery operates as part of the complex fabric of the Central Valley and California's water management system, and is intended to partially mitigate the effects of a major storage reservoir in that system. Water and flood management, and hydropower development, have resulted in dams on most of the streams that flow from the Sierra Nevada and Cascade mountains into the Sacramento and San Joaquin rivers. The dams have blocked access to historic spawning grounds, affected instream flows, and reduced the quality of gravel on spawning grounds below the dams. The Sacramento-San Joaquin Delta, an essential migratory pathway and rearing habitat, has been converted from tidal marshes and floodplains to a series of leveed islands and rip-rocked channels. The changes in the watershed and estuary have dramatically reduced the amount of salmonid habitat and, for many made hatcheries an attractive management and restoration option. Many questions remain regarding hatcheries and their ability to mitigate effectively for hatbitat losses. For an alternate view of the hatchery controversy, the reader is referred to Brannon et al. (2004).

There are four distinct runs of Chinook salmon that continue to inhabit the Central Valley – winter run, spring run, fall run and late fall runs, with run designations based on the time the returning adults enter the San Francisco Estuary. The winter and spring runs are listed as endangered and threatened respectively pursuant to the federal and state endangered species acts. Fall and late fall runs are federal ESA candidate species. Steelhead, the sea going form of rainbow trout, is also found in many valley streams and is listed as threatened pursuant to the federal ESA. The run timing varies from species to species and run to run but, in combination, the four runs result in juveniles and adults moving to and from the ocean during most months of the year. The fall run is the backbone of the ocean fisheries and is reared in five Central Valley hatcheries that, on average, release about 30 million juveniles annually.

The Feather River historically supported spring and fall Chinook and steelhead. The FRH has raised these two runs and steelhead since its inception. Over the years the hatchery has released at least 50 million spring Chinook, 150 million fall Chinook, and 10 million steelhead juveniles. Recent spawning escapements to the Feather River have averaged about 4,500 spring Chinook (hatchery only), 100,000 fall Chinook, and 1,800 steelhead (hatchery only). By comparison, in the decade prior to the construction of Oroville Dam the runs averaged 1,700 spring Chinook, 39,000 fall Chinook, and a few hundred steelhead (Painter et al. 1977). Based on studies that showed survival to the ocean fishery was 2 to 3 times higher if the fish were released in the estuary instead of near the hatchery, beginning in the 1970s hatchery staff trucked the juvenile salmon to San Pablo Bay for release. In addition, several hundred thousand juvenile fall Chinook salmon are used annually in various studies and released off site.

The following are some of the hatchery effects and contributions that were evaluated in the course of preparing this report.

Straying

DFG used mark and recapture data (coded wire recoveries) in the ocean fisheries, Central Valley streams and hatcheries to reconstruct the 1998 fall Chinook cohort from the FRH (Palmer-Zwahlen, et al. 2004). One of the products of this analysis was an estimate of the rate at which fish released in the estuary return to the Feather River and to other streams (the stray rate). DFG staff estimated that of the estimated numbers of fall and spring FRH Chinook that returned to the Central Valley, about 90%

returned to the Feather River (including the FRH), and about 10% strayed outiside the FR basin. By comparison about 6% of the in-basin releases strayed to streams other than the Feather River. It is quite likely that the 1998 cohort analysis significantly underestimated the straying rate, mainly due to lack of consistent tag recovery efforts on the major Chinook salmon spawning streams. At this time we are unable to determine the extent of this underestimate.

The findings from the cohort analysis are in line with those from tag recoveries in Central Valley hatcheries and streams. Although tags from FRH fish were collected in most Central Valley streams sampled, about 96% of the 12,438 tags recovered during the 1997–2002 period were collected in the Feather River or at the hatchery. Compared to Bay releases, a lower percentage of in-basin releases survived to reenter the estuary as adults (0.3% vs. 0.9%), however these fish returned to the Feather River with greater fidelity (around 95% as compared to around 90% for Bay releases).

Although the straying rate from Bay releases is less than might be expected based on earlier studies, it is still higher than natural straying rates and higher than the 5% recommended as a maximum by NOAA Fisheries. One has to be careful interpreting the data. First, the cohort analysis was only for one broodyear. Second, and perhaps most importantly, tagging and tag recovery efforts on all Central Valley streams do not provide statistically robust data on the proportion of tagged fish in the spawning populations. Third, there is a significant inland sports fishery in most Central Valley salmon streams and in recent years sampling this fishery, and collecting tags, has been spotty. The Central Valley Project Improvement Act's Comprehensive Assessment and Monitoring Program (CAMP) sponsoring this valley wide fishery sampling effort for two years but the program was largely eliminated due to budget shortfalls.

Due to the lack of tags applied to most hatchery populations, and the relatively poor success at quantitatively estimating the numbers of tagged spawners, it was not possible to obtain reliable estimates of the percentages of salmon from other Central Valley hatcheries that stray into the Feather River drainage. Most of the non FRH strays observed came from either experimental releases (Merced Hatchery fall Chinook releases in Delta studies or Coleman late fall Chinook released, also in Delta studies) or from bay releases of fall Chinook from the Mokelumne Hatchery.

Genetics

There are several concerns about how hatcheries may affect naturally spawning salmonids including hybridization between runs on the same stream, spawning with salmonid from other streams, and changing in the genetic structure as a result of fish culture practices. The approach to this study element involved contracting with geneticists from the UC Davis Bodega Marine Laboratory and Oregon State University to examine the genetic structure of Central Valley and Feather River Chinook salmon population. The CALFED Bay Delta Authority funded similar analyses for steelhead. In both instance DFG collected, archived and distributed the tissue samples. A caveat on using these genetic data to examine hatchery impacts is that the sample collections began in the mid-1990s – we have no historical data on the baseline before hatcheries and dams changed the physical and biological landscape to such an extent. Also until recently many of the "spring" run samples from the Feather River may not have been from phenotypic spring run.

The results of the Central Valley Chinook salmon and steelhead genetic analyses show that:

- The winter Chinook are genetically distinct from the other three Central Valley runs.

- There are two distinct spring Chinook genotypes – one from Mill and Deer creeks and the second from Butte Creek. The genotypes exhibit some phenotype differences as well, with the Mill and Deer creek populations being more along the lines of "stream" type fish, and the Butte Creek population exhibiting more of a mix between stream (adult immigration and timing) and ocean type (juvenile emigration).

- The fall and late fall runs are genetically similar, although with a sufficient number of genetic markers, the two runs can be separated.

- Using the present set of microsatellite markers, all Central Valley fall Chinook are genetically identical. This result may have been caused by fish management and hatchery practices that caused increased straying of hatchery fish (off site releases) and extensive transfer of genetic material from stream to stream and hatchery to hatchery.

- There is still significant local genetic structure to Central Valley steelhead populations, although fish from the San Joaquin and Sacramento basins can not be distinguished genetically. Hatchery effects seem localized – for example Feather River and Feather River Hatchery steelhead are closely related as are American River and Nimbus Hatchery fish.

One of the key questions about Feather River Chinook salmon involves the genetic and phenotypic existence of a spring run, and the potential effects of the FRH on this run. The Feather River phenotypic spring run is currently part of the spring run ESU and is thus listed as threatened. The hatchery population, on the other hand, is not part of the ESU. The phenotypic spring and fall runs on the Feather are genetically similar and most closely related to Central Valley fall Chinook. There is, however, a significant phenotypic spring run that arrives in Feather River in April, May and June – the run numbered at least 3,700 in 2004. (That many salmon entered the FRH hatchery when the ladder to the hatchery was opened, were tagged with visible tags, and released back to the river.) On September 13, 2004 the ladder was opened again and 1100-1200 fish entered, 110 of which had the visible tags. By the first of October more than 800 of the tagged fish had entered the hatchery. These two data sets indicate that there was a substanttial spring run in the Feather River in 2004 and that it consisted of a mixture of fish that spawn in river and are spawned in the hatchery. All phenotypic and genetic evidence at this time points to a Feather River Chinook salmon run – some of which arrive early. There does not appear to be distinct stream and hatchery components to the run. The genetic evidence does not lead to a conclusion that there has been hybridization between the Mill/Deer/Butte creek genotypes with a Feather River fall or spring genotype.

Fraction of Chinook Salmon in Feather River Spawning Runs that are of Direct Hatchery Origin

Because of the low tagging rates of FRH salmon, it is not possible to obtain reliable estimates of the hatchery fraction of the Chinook salmon spawning run. Estimates in the report indicate that from 30 to 50 percent of the Chinook salmon runs in the Feather River consist of fish that were released from the FRH as juveniles. Smaller, but unquantifiable, fractions of fish from other Central Valley hatcheries are also part of the annual spawning runs.

Contribution of FRH Fall and Spring Run to the Ocean and Inland Recreational Fisheries

- The 1998 fall and spring FRH Chinook cohort contributed an estimated 137,300 fish to the ocean recreational and commercial fisheries during 2000-2003. Most of the contribution occurred when

the fish were three years old. At that age, FRH 98 broodyear fall and spring Chinook released in San Pablo Bay represented around 10% of the coast-wide recreational and commercial landings. . In-basin and experimental releases contributed much smaller fractions to the fisheries.

- The ocean harvest of the 1998 cohort occurred mainly off the coasts of California and Oregon with 76% and 21% of the tags recovered in these two areas respectively.

- An estimated 3,000 adult salmon from the 1998 fall Chinook FRH cohort were caught by recreational anglers in the Sacramento River sport fishery. In addition there is a sginficant recreational harvest in the Feather River.

Disease Transmission from FRH Naturally Spawning Fish

- As part of this study, DWR contracted with UCD and US Fish and Wildlife fish pathologists to examine the potential impacts of one fish pathogen – infectious hematopoietic necrosis virus (IHNV) – on Feather River and other Central Valley salmonids. The study was included in this element because, after several years of not seeing IHNV problems at the FRH, severe epizootics broke out in 1999 and 2000.

The study consisted of several elements including genetic typing of the virus, assessing its transmissibility and virulence to non-infected fish and the presence of IHNV in juvenile and adult Chinook salmon and steelhead in the Feather and Yuba River basins.

- The genetic typing showed that, in the Central Valley, the IHNV has evolved from the original strain to several different strains, with the Feather River the site of much of this evolutionary activity. The rapidly evolving strains do not seem to becoming more virulent. The Central Valley strains are (and have been) part of a separate clade (the L clade) that is genetically distinct from the U and M clades found in the Pacific Northwest and Alaska.

- Separate field surveys indicated that IHNV was not present in juvenile salmonids, or other non-salmonid resident fish, in either the Yuba or Feather River watersheds. Returning adults to both watersheds were found to be infected with IHNV – 27.8 and 18.1 percent, respectively, for the Yuba and Feather rivers. There were no clinical signs of disease in these fish.

- The hypothesis advanced by DFG pathologists for the cause of the recent IHNV epizootics at the FRH is that planting Chinook salmon in Oroville Reservoir (the hatchery water supply) resulted in amplifyng existing low levels of the virus, which then entered the hatchery. Hatchery conditions lead to stress and the infections rapidly escalate to clinical disease as evidenced by high mortality. After planting Chinook salmon in the reservoir was stopped in 2000, there have been no additional epizootics but only time will tell if this measure prevents future IHNV outbreaks at the FRH. This hypothesis is also supported by the finding that the viurs type in the reservoir fish was identical to that in samples of diseased fish from the hatchery.

- In streams IHNV can be transmitted laterally among adults, with IHNV being more prevalent later in the run.

Effects on FRH on Fitness of Central Valley Chinook salmon and steelhead populations.

- Based on straying, genetic, and other data, it appears that the FRH has had minimal impact on spring Chinook runs in Mill, Deer and Butte creeks and on winter and late fall runs that spawn in the mainstem Sacramento River. The FRH has probably affected the other fall run stocks through straying and active transfers of genetic material to and from the FRH.

- Although the FRH may have adversely affected the Central Valley fall run, its effects are difficult to distinguish from those of the mostly ad hoc hatchery Central Valley, fisheries and hatchery management system.

- It is not possible with the available data to determine if the hatchery system has reduced the fitness (overall surviveability) of Central Valley fall Chinook salmon and steelhead, however the literature suggests that such a reduction in fitness is highly likely.

What Next?

- In the past few years, DFG and the hatchery have made several improvements to hatchery operation that are intended to correct some of the problems noted in this report. Some of the improvements are:

  - Implementing the 1999 operational protocols which clearly lay out constraints on hatchery operations.

  - Taking gametes throughout the run and reducing inventory proportionally across the egg take, with the object of growing only those fish needed to meet hatchery production goals.

  - Eliminating the practice of planting excess fry production in many Valley streams.

  - Minimizing transfers of fish and eyed eggs among hatcheries.

  - Planting one-half the spring run production in the stream and the other half in the estuary. All hatchery spring run juveniles are being marked and tagged.

  - Working with NOAA Fisheries and DWR to experiment with early opening of the ladder to the hatchery with the goal of better understanding how hatchery operations can be modified to protect the spring Chinook run to the Feather River.

  Overall, DFG has been an effective participant in a team that is considering changes to the FRH's facilities and operations. The plan is for this partnership to continue into the next FERC licensing period.

- As part of the new FERC license we recommend that DWR and DFG commence an adaptive management process that continually updates management of the FRH and the Feather River based on a series of conceptual models, information collection and analysis and dissemination (feedback) of results among affected agencies and stakeholders.

- One of the key components of this effort will to review, revise and adjust hatchery production goals as necessary to meet DWR's mitigation needs in a biologically responsible manner. The group should consider the following when discussing new hatchery goals:

  - Should escapement goals be set and hatchery production goals be adjusted to meet them?
  - Should planting strategies be identified prior to setting escapement and production goals, - i.e. on site or off site releases, or both.
  - Should the group consider modifying the mitigation goals and not the enhancement goals?
  - Should the group consider recommending changes in river fishing regulations to further protect Feather River spring Chinook.

- Another recommended component is a marking and tagging program at the FRH that will involve adipose clips for all Chinook salmon, coded wire tags for all spring Chinook, a constant fractional marking program for fall Chinook, and otolith marks for all hatchery Chinook. To be most effective this marking program should be part of a Valley-wide marking and tag recovery effort.

Introduction

The California Department of Water Resources (DWR) constructed the Feather River Hatchery (FRH) in the mid 1960s to mitigate for Chinook salmon and steelhead spawning habitat made inaccessible due to construction of Oroville Dam on the Feather River near the City of Oroville. The Oroville Dam and Reservoir are key features of the State Water Project (SWP) and provide flood protection, water storage, hydropower production, recreation, and other benefits.

Under contract to DWR, the California Department of Fish and Game (DFG) has operated the FRH and produced and released tens of millions of spring and fall Chinook and steelhead. The released fish have helped support extensive ocean and inland fisheries and many of the fish have returned to the Feather River to spawn. Over the years DFG has modified its hatchery practices to help ensure maximum survival of the production releases. The overall goal has generally been to maintain the three salmonid runs in the Feather River at pre-project levels, while making excess fish available for harvest. The FRH has also provided millions of juvenile salmon for research purposes, both in the river and the estuary.

Since the FRH began operating in 1967 there has been relatively little effort allocated to examining the effects of the hatchery on the fisheries, escapement to the Feather River and to other Central Valley streams and to salmonid populations in the Feather River and other Central Valley streams. Dettman and Kelley (1987) and Cramer (1990) attempted to examine the FRH contribution to the fisheries and escapement (including straying to other Central Valley streams) but their analyses and conclusions were constrained by insufficient data – mainly by the lack of a consistent tagging and tag recovery program at the Feather River and other Central Valley streams and hatcheries. Their results did indicate that the FRH made a significant contribution to the ocean fisheries and that a high proportion of adult Chinook salmon returning to the Feather River each year were of direct FRH origin. The data also indicated a significant degree of straying to other Central Valley streams.

In this paper we take a comprehensive look at the FRH, its operations, contributions and potential effects on naturally spawning Chinook salmon and steelhead populations in California's Central Valley. This examination is one component of the package of analyses being completed by DWR as part of the its application for a license from the Federal Energy Regulatory Commission to operate the Oroville Complex – an integral part of the SWP. The FRH is part of the Oroville complex. The paper is an

outgrowth of a hatchery evaluation study plan (see Approach below and in Attachment 1) developed through extensive discussion with staff from the resource agencies (DFG, NOAA Fisheries and the US Fish and Wildlife Service) and DWR staff.

In these analyses we not only examine the individual effects of the FRH, but also look at the integrated impacts of the overall system of Central Valley anadromous salmonid hatcheries and salmon and steelhead management. The broader look is necessary because the FRH operates as part of a complex salmon management framework that was originally designed to provide salmon and steelhead for harvest, with sufficient numbers left over to allow for sufficient escapement to perpetuate the runs – at least on those streams with hatcheries. The Central Valley salmon hatcheries have also provided large numbers of tagged Chinook salmon for experimental purposes – with the experimental fish being released in several streams and in the San Francisco Estuary.

In addition to looking at the overall system of salmon and steelhead and hatchery management, we examine hatchery impacts as part of an ever changing environment – not only in the sense of the biological and physical environment, but also in the institutional environment that has affected salmonid populations and the role of production hatcheries in maintaining and restoring salmonid runs. In the Central Valley, a major institutional change occurred in 1992 with the first biological opinion affecting operations of the SWP and the federal Central Valley Project (CVP). The opinion resulted from the federal and State listing of Central Valley winter Chinook as threatened (now endangered) and was designed to prevent the water projects from jeopardizing the continued existence of this unique salmon race. The listing and subsequent biological opinions affected the ability of the water projects to deliver water to their agricultural and urban contractors. Since an estimated twenty million Californians receive some of their water supply from the two projects, the listing and biological opinions caused agencies and stakeholders to renew their efforts to upgrade salmon habitat with the goal of restoring Chinook salmon populations. One result of this listing (and the subsequent listing of spring Chinook and steelhead) has been allocation of significant amounts of money and water to salmonid protection and recovery. These allocations, along with changes in operation of water projects in the Sacramento-San Joaquin Delta, may have impacted the environment downstream of the FRH to such an extent that hatchery staff can rethink release strategies.

Along with the environmental and institutional changes occurring over the past few decades, fish managers have become more aware of the potential environmental impacts of mitigation/production hatcheries on naturally spawning salmonid populations. Although the literature on hatchery impacts is quite extensive, the following two publications demonstrate the issues quite well. (Note that references to the more extensive literature are included in subsequent chapters as we examine the issues associated with the impacts of the Feather River and other hatcheries.)

- Nehlsen et al. (1991) identified 214 anadromous salmonid populations in Oregon, Washington, Idaho and California in danger of going extinct and 100 populations in the same area that had recently gone extinct. This seminal paper stimulated thinking and research to better understand the status of these populations and the reasons for observed declines. The paper also resulted in extensive efforts to stabilize and enhance threatened populations.

- The National Research Council (1996) surveyed the literature regarding salmon and society in the Pacific Northwest and hypothesized variety of possible explanations for observed declines of wild salmonid populations, including the effects of production hatcheries. They listed the following as potential adverse hatchery effects.

Demographic Risk, mostly due to the indirect effect that large numbers of hatchery fish in fisheries can exert on weaker natural stocks. The hypothesis is that the fisheries are based on the abundant hatchery fish and harvest rates that are acceptable for hatchery stocks may result in over-harvest of naturally spawning stocks and could drive these stocks to extinction.

Genetic and Evolutionary Risks can show up in four main areas (as identified by Busack and Currens 1995 and cited in NRC 1996):

- Inbreeding depression
- Loss of between-population genetic variation.
- Loss of within-population genetic variation.
- Domestication in which the fish become genetically adapted to the hatchery environment, with an accompanying loss of overall fitness. (Fitness can be described as the ability to survive to a reproductive age and leave viable offspring, Hallerman 2003.)

Behavior Risks are associated with the differences between the behavior of wild and hatchery stocks. The behavior traits of hatchery fish may result in loss of fitness, for example, reduced predator avoidance by hatchery fish (Berejikian 1995) or adverse affects on the natural populations into which the hatchery fish are released: for example, increased aggressive behavior by hatchery as compared to their wild cousins (Peery and Bjorn 1996).

Fish Health and Disease, both in the released hatchery fish and in the interactions between hatchery and naturally spawning populations.

The Physiological State of Hatchery Fish is often sub-optimal, due perhaps to hatchery conditions, handling, and transportation.

Ecological Problems that may be associated with competiton between planted hatchery fish and the progeny of naturally spawning fish for available carrying capacity in streams, estuaries and the ocean between hatchery and naturally spawning stocks.

To this list of hatchery effects, we would add the false sense of environmental security engendered by large numbers of returning hatchery fish. If tens of thousands of Chinook salmon spawn in Central Valley streams and the commercial and recreational fisheries are harvesting large numbers of salmon, managers and the general public may believe that everything is going well for salmon. In reality, many natural stocks are in trouble and in need of drastic action to prevent their extinction.

Two recent documents directly related to Central Valley salmonids and hatchery operations are also important in the sense that they are among the first local documents to look at hatchery operations and production from a biological standpoint. The first is the biological assessment of artificial propagation at the federal Coleman National Fish Hatchery and Livingston Stone National Fish Hatchery as related to the take of the listed Chinook salmon races and steelhead trout (USFWS 2001). The assessment includes a complete description of the programs at the two hatcheries and an evaluation of the impacts of hatchery operation on salmon populations. This assessment represents the first serious examination of the effects of a major Central Valley hatchery program – albeit after about 60 years of operation. (The BA also served

as a Hatchery and Genetic Management Plan – HGMP – for Coleman National Fish Hatchery.) Overall the BA concluded that operation of the two hatcheries has had no or minimal effects on all four Central Valley Chinook salmon races and steelhead (theirTable 2-4).

The second report summarizes the results of a joint DFG/NOAA Fisheries review of California's anadromous salmonid hatcheries (DFG and NOAA Fisheries 2001). To our knowledge this is the first such comprehensive review of California's salmon and steelhead hatchery system. Although DFG and NOAA Fisheries biologists participating in this review were hampered by a lack of data, their overall recommendations, listed below, helped shape our efforts to evaluate the FRH.

1. Feather River spring Chinook should be released "in-river" and not be trucked to distant downstream sites.

2. The production of fall run Chinook salmon at Feather River and Nimbus hatcheries should be considered for "in-river" releases instead of being trucked downstream.

3. Hatchery "in-river" releases and water management practices (including water exports from the Sacramento-San Joaquin Delta) should be coordinated so that emigration survival is maximized.

4. A formal process should be identified for the periodic review and assessment (e.g. every 6 to 9 years or 2 to 3 broodyears) of hatchery production levels.

5. All agencies should pursue efforts to establish a constant fractional marking program at all hatcheries.

6. All agencies should pursue efforts to develop adequate sampling programs to recovered marked and tagged fish in the Central Valley.

7. Hatchery and Genetics Management Plans should be adopted for each hatchery.

In summary, many conditions have changed since the FRH commenced operating in 1967. The environment itself has changed, mainly due to natural and anthropogenic factors such as ocean conditions and climate and water development and flood control, respectively. The regulatory environment has changed, mainly due to efforts to protect the three listed Central Valley salmonid stocks. Finally, the role of hatcheries is being reexamined in view of increasing evidence that production salmon hatcheries may have significant adverse effects on naturally spawning salmonid populations. One of the objects of this review is to provide recommendations about how the FRH should be operated in view of the evolving institutional, physical and biological setting. Particular attention is placed on hatchery production goals and release strategies.

The Approach

As described in the study plan (Attachment 1), the approach to examining the effects of the Feather River Hatchery on naturally spawning populations included several facets of the problem. Among the important facets are:

- Describe Central Valley, ocean environmental and institutional conditions, and in particular, how these conditions have changed in the past three decades. The goal of this effort is to determine if conditions have changed to the extent that the FRH should modify its goals and specific operations. For example, increased protection for emigrating salmon may obviate the need for, or reduce the benefits of, trucking hatchery production for release in the San Francisco Estuary.

- Describe the FRH and its operations over the past three decades including such key components as production goals, founding stocks, breeding protocols, disease control, and release strategies. This description is based mainly on annual reports prepared by hatchery staff.

- Describe the FRH in the context of other Central Valley salmon hatcheries. We use annual reports from the hatcheries as well as other relevant publications that describe key hatchery functions and features. The rationale for including the other hatcheries is based on the extensive exchange of biological material among the hatcheries, in part due to direct actions by hatchery staff and agency managers and in part on subsequent straying of adults from juvenile fish planted at various locations in the system. One of the goals is to suggest ways in which better coordination among Central Valley fish and hatchery managers can be achieved.

- Examine specific effects and benefits of hatchery operations by analyzing the results of the following studies conducted by DWR: (Note that the studies themselves are described in more detail as the results are presented.)

  - Studies of the Feather River below the hatchery fish ladder. DWR began intensive studies of the Feather River in 1992. These studies included such key components as emigration patterns, a modified Instream Flow Incremental Methodology examination of flow needs of Feather River fall Chinook, distribution and abundance of spawning salmon (and recovery of coded wire tags), and use of the stream by juvenile salmonids with particular reference to steelhead.

  - A comprehensive examination of the genetic structure of Central Valley Chinook salmon by researchers at the UC Davis, Bodega Marine Laboratory. This study began in 1995 and originally focused on distinguishing winter Chinook from the other three Central Valley races. The study was modified to include more Feather River samples of phenotypic spring and fall Chinook. It should be noted that the CALFED Bay-Delta Program subsequently funded additional studies to examine the genetics of Central Valley Chinook salmon and steelhead. These latter studies play an important role in helping understand the genetic structure of these fish and the potential impacts of hatchery operations on this structure.

  - In 1994 DWR began an extensive program to coded wire tag several hundred thousand FRH fish each year. Some of the tagged fish were released in the river to estimate their survival through the Sacramento-San Joaquin Delta and to the ocean fisheries. Other tagged fish were released with the production fish in the San Francisco Estuary. We used recovery of the tags in the fisheries, in the streams and in the hatcheries to examine ocean distribution of FRH fish, returns to the hatchery and strays to other streams. The release and recovery data are also used to reconstruct the fate of the 1998 FRH cohort. In a related study, in the late 1990s, DWR began tagging and releasing the progeny of naturally spawning Chinook salmon. Recoveries of these tagged fish can provide an idea of their migration through the Delta and the contribution of the naturally spawners to ocean catch and escapement.

- An extensive review of the literature related to the impacts of hatcheries on naturally spawning salmon. References from this review are included in the discussion of individual components of this analysis as well as in the overall discussion.

The study plan included the following tasks and objectives:

1. Confirm and clearly define the mitigation goals and objectives of the FRH.

2. Characterize the non-genetic attributes of salmonid resources of the Feather River and other Central Valley streams, including run size, emigration, and historical abundance and distribution.

3. Characterize the Central Valley salmonid management context in which the FRH operates including other hatcheries, inter-basin transfers of genetic materials, escapement goals and commercial and recreational fisheries management.

4. Provide a comprehensive description of the physical facilities and operations of the FRH from 1967 to 2003.

5. Characterize the genetic composition of Chinook salmon and steelhead spawning in the Feather River and entering the FRH.

6. Characterize the genetic composition of Chinook salmon and steelhead spawning in other Central Valley streams.

7. Estimate the hatchery contribution to Feather River in-river and hatchery populations of Chinook salmon and steelhead.

8. Estimate the numbers and rate of FRH Chinook straying to other Central Valley streams and hatcheries.

9. Estimate the numbers of Chinook salmon that stray from other Central Valley hatcheries to the Feather River.

10. Estimate the contribution of FRH production to the commercial and recreational fisheries.

11. Assess the ongoing and future impacts of the FRH mitigation program on naturally spawning Central Valley salmonids.

12. Assess the likelihood of transmission of disease from hatchery to wild fish with special reference to Infectious Hemopoietic Necrosis Virus (INNV)

13. Construct conceptual models of the role and impacts of FRH operations on Chinook salmon and steelhead in the Feather River and other Central Valley streams.

14. Assess the role of the FRH in public education and research.

15. Assess the role of the FRH in California's economy.

16. Develop recommendations for potential additional protection, mitigation and enhancement measures for operation of the FRH.

We also draw on other reports that are being submitted as part of DWR's application to FERC, specifically:

- SP - F2: Effects of Project Operations on Fish Disease
- SP - F10: Evaluation of project effects on anadromous salmonids and their habitat.
- SP - W1: Project effects on water quality designated beneficial uses for surface waters.
- SP - W6: Project effects on water temperatures.

Using data from the various sources, we reach tentative conclusions about the effects of the FRH on naturally spawning Chinook salmon and steelhead. These conclusions are couched in terms of the physical, biological and institutional environment in which the hatchery has operated over the past 37 years. We also provide information on the positive effects the hatchery may have had. We also offer some suggestions on how hatchery goals and operations could be modified to reduce any observed impacts. In many cases, modification of hatchery operations may reduce adverse impacts but may also reduce perceived benefits. For example, it may be that planting all hatchery production in the Feather River will reduce straying and its associated genetic problems. On the other hand, planting all fish in river may reduce the numbers of salmon caught in the recreational and commercial fisheries and escaping to the Feather River to spawn.

After the introductory material, we describe the results of individual tasks described in the study plan. Note that in some cases we could not fully accomplish the task due to lack of data.

Environmental and Institutional Background

The impacts of the FRH on naturally spawning salmonids can only be considered in the context of the system in which the hatchery operates. A science panel, convened to look at the role of the Coleman National Fish Hatchery (CNFH) on restoration of Battle Creek concluded, among other things, that biologists and managers must look beyond the stream mouth and use a life cycle approach to evaluate the feasibility of restoring Battle Creek and the role of the CHFH on the stream's restoration potential (Lichatowich et al. 2004).

The institutional and environmental context is of particular importance in California's Central Valley with its complex of streams with naturally spawning Chinook and steelhead runs, multiple mitigation and supplementation hatcheries, water development projects (and associated facilities and operations), a myriad of studies that use marked juvenile salmon to investigate water project impacts, and intense inland fisheries on both salmon and steelhead. This system also includes the ocean and its fisheries and changing environmental conditions. All of these elements can affect the numbers of salmon that return to FRH, or stray to other streams, and hence the effects of the hatchery on naturally spawning salmonids.

In the following pages we describe some of the physical and institutional conditions that can affect the fate of hatchery releases and naturally spawning salmonids. Whenever possible we summarize the results of published reports and provide the references for those readers interested in more detail.

Physical Setting

This section is included to highlight some of the more important features of the Central Valley as they affect salmon production and survival. Most of the features and streams described in this section will appear later in the report in connection with straying, sources of mortality, hatcheries operations, etc. The section is not intended to be a complete description of the Central Valley, including the San Francisco Estuary. However references are provided for those readers interested in more detail. The entire Central Valley is included since many Central Valley (CV) streams have anadromous salmon and steelhead runs and fish released at the Feather River Hatchery may stray into these streams.

Figure 1 provides an overall view of the Valley floor and shows the major tributaries and the locations of the major dams.

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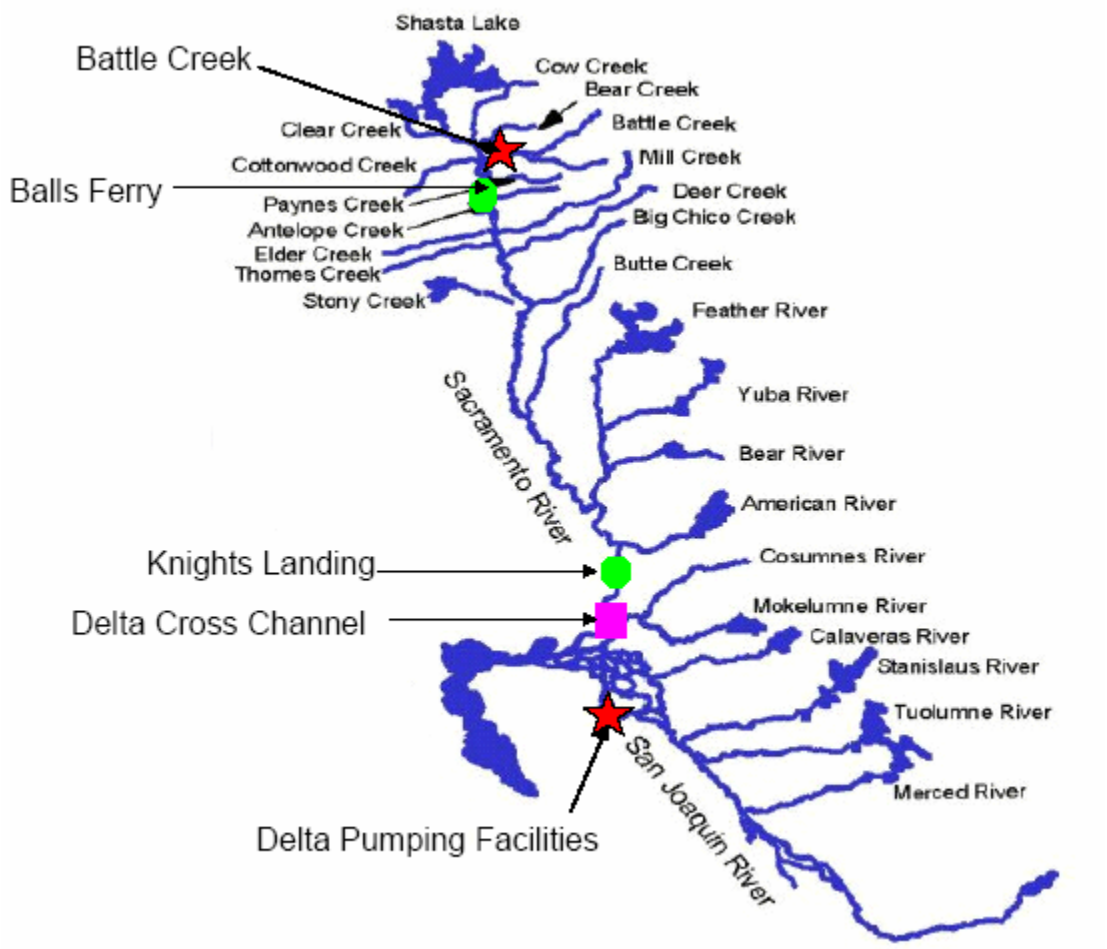

Figure 1. Major features of the Central Valley, California

From north to south, some important features are:

The Mainstem Sacramento River

Keswick Dam, a relatively small water regulation dam constructed in the 1940s, blocks the mainstem Sacramento River at river mile 302. Shasta Dam is about 12 miles above Keswick Dam can store more than 4.5 million acre feet (maf) of water and, during most years, has a significant amount of cold water which can be released to the river by means of a structure that draws on hypolimnetic water without causing loss in power production. The Red Bluff Diversion Dam (RBDD) is located about 35 miles south of Keswick on the mainstem. The stretch of the river between Keswick and the RBDD is of particular importance to the Feather River studies in that this stretch provides valuable spawning habitat for all four races of Chinook salmon and steelhead. An earlier report (Cramer 1990) indicated that significant numbers of returning FRH adults strayed to this section of the river.

Battle Creek

Battle Creek enters the Sacramento River from the east at river mile 271.5. A barrier weir and ladder complex, part of the CNFH, is located about 3 miles upstream of the mouth and limits access to the upper Battle Creek watershed. Presently all four races of Chinook salmon and steelhead spawn in Battle Creek, although the fall run is by far numerically dominant (USFWS 2001). Battle Creek, which drains a spring fed watershed and can provide a cool and stable water supply, is the site of a proposed major effort to restore winter and spring Chinook and steelhead (Brown and Kimmerer 2004). Tagged FRH adults have been recovered in Battle Creek and the CNFH.

Mill, Deer and Butte Creeks

These three eastside tributaries enter the Sacramento River below Red Bluff. Salmon entering Mill and Deer creeks are able to access the upper watersheds and the streams support runs of spring Chinook and steelhead in the upper reaches and fall Chinook in the lower reaches. Although salmon can not access the upper Butte Creek watershed, cool summer water from a hydropower project (constructed in the 1870s) provides adequate temperature in most years to support a spring run (M.Meinz, DFG, personal communication). These streams, and Butte Creek in particular, are of interest to the FRH evaluation in that one of the concerns is that returns from FRH releases may stray to these streams and compromise the genetic integrity of what appear to be the only remaining significant and genetically distinct spring Chinook runs in the Central Valley. Also, in the past DFG staff made several attempts to supplement the Butte Creek spring run by planting FRH spring Chinook in Butte Creek.

The Feather River

A detailed description of the Feather River below the fish barrier dam can be found in a variety of publications including Brown and Greene (1993), Sommer et al. (2001) and Seesholtz et al. (2004). The Feather River in the vicinity of the hatchery is also described in more detail elsewhere in this report. The barrier dam stops all upstream migration and a gated fish ladder at the dam allows adult salmon to enter the FRH. The Feather River supports runs of spring and fall Chinook and steelhead. The Feather River also supports a diverse fish community consisting of more than 30 species of native and introduced fish (Seesholtz et al. 2004). Of the non-salmonid native species, green sturgeon and splittail are species of special concern.

The Yuba River

The Yuba River enters the Feather River near Yuba City, 39 miles downstream of the fish barrier dam. The Yuba River supports runs of fall Chinook and steelhead. Although not confirmed by genetic analysis, the Yuba River may support remnant runs of spring Chinook (D. Massa, DFG, personal communication). Fish migration is blocked at Englebright Dam.

The American River

The American River enters the Sacramento River at Sacramento. Access to the upper watershed has been blocked at mile 23 by Nimbus Dam, a regulating dam below Folsom Reservoir. The Nimbus/Folsom complex, constructed in the 1950s by the US Bureau of Reclamation, is operated for water supply, flood control, recreational and other benefits. (For a more complete description of the Lower American River system, including anadromous fish see Williams 2001.) DFG produces fall Chinook and steelhead in a mitigation hatchery located near the base of Nimbus Dam. Earlier studies (Hallock and Reisenbichler 1979; Dettman and Kelley 1987; Cramer 1990) indicated that significant numbers of FRH Chinook salmon strayed into the American River.

The Sacramento-San Joaquin Delta (Delta)

Historically the confluence of the Sacramento and San Joaquin rivers consisted of a vast system of seasonally flooded tule marshes and channels (Fox et al. 1990). The Delta provided a migratory corridor for adults and juveniles of all four Chinook salmon races and steelhead and probably important juvenile rearing habitat as well.

Today's Delta little resembles the area prior to the influx of Gold Rush miners and their supporting agriculture and other industries (State Lands Commission 1991). The Delta is now a complex of channels and semi-permanent islands – tracts of land surrounded by levees, with the land surface often several feet below the water level (Figure 2). More than 90 percent of the former marshes have been lost (State Lands Commission 1991), thus the value of the Delta as salmonid rearing habitat has likely been severely diminished. In addition to the changes in landform, the Delta is the hub of California's water supply system with an estimated 20 million Californians receiving at least a portion of their water supply from the Delta. Much of this water is diverted from the southern Delta by State and federal water project pumps – pumps with a combined capacity of more than 15,000 cfs. Water project pumping from the Delta is often considered to be one of the major causes of observed declines in all salmon runs and is the principal reason why salmon produced from the Feather River and Nimbus hatcheries are now trucked to San Pablo for release.

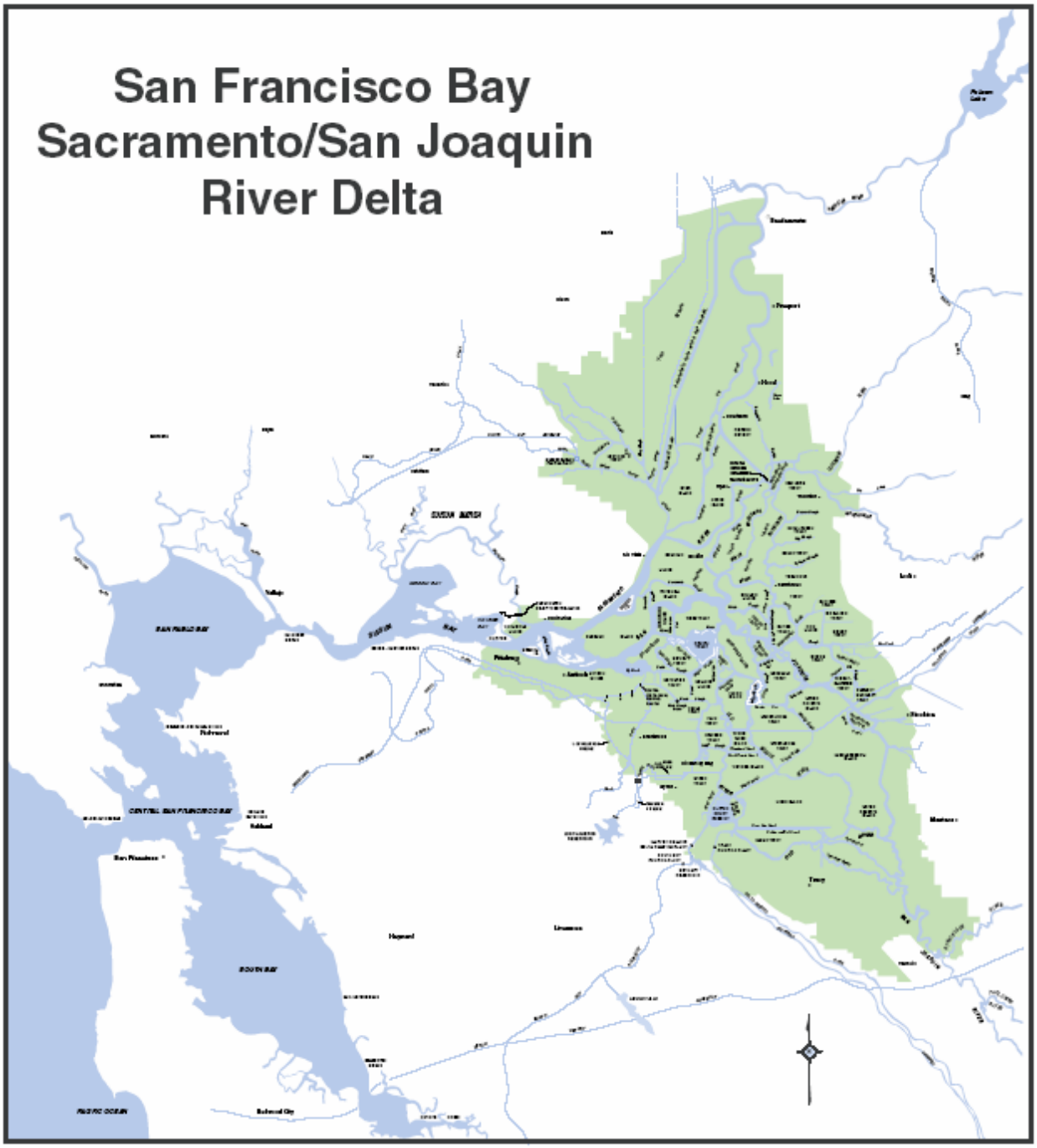

Figure 2. The San Francisco Estuary, including the Sacramento – San Joaquin Delta

It is beyond the scope of this document to go into detail about the Delta but there are several facilities, features and locations that are mentioned at various times in the text thus brief descriptions are needed. (More exhaustive treatments of the Delta and salmon can be found in Brown et al. 1996; Brown and Kimmerer 2001; and Brandes and McClain 2001.

- Miller Park – An above Delta location where tagged juvenile hatchery fish (often from the FRH) are released to help evaluate the effects of water project operation on the survival of juvenile Chinook salmon emigrating through the Delta.

- Clarksburg – An interior Delta site where tagged hatchery fish are released specifically to evaluate the effects of the Delta Cross Channel gates (see below) on survival of juvenile Chinook salmon emigrating from the Sacramento River system.

- The Delta Cross Channel – A feature of the Central Valley Project constructed in the 1950s to help move Sacramento River to the federal pumps in the south Delta. The Cross Channel is gated, with the gates closed when river flows exceed about 25,000 cfs. To help protect emigrating juvenile winter Chinook and other salmon, the gates now remain closed from February 1 through about May 20 each year and the fish agencies may ask that they be closed for up to 45 days during the October 1 – January 31 period (Brown and Kimmerer 2001).

- Georgiana Slough – The upstream end of this natural, ungated slough is located just downstream of the Delta Cross Channel and debouches into the San Joaquin River. Georgiana Slough thus is natural conduit for water to move from the Sacramento River to the interior Delta and the export pumps and is part of the juvenile salmon migratory corridor. In recent years, the Interagency Ecological Program (IEP) has conducted studies to examine the survival of juvenile salmon through Georgiana Slough – studies which have required the release of tagged late fall Chinook from the CNFH. These studies have indicated that fish entering Georgiana Slough have a lower chance of surviving to Chipps Island than those remaining in the Sacramento River (Brandes, preliminary data as cited in Brown and Kimmerer 2003), and that there may be predator "hot spots" in Georgiana Slough (Vogel 2001).

- Ryde – A site below the Delta Cross Channel where tagged juvenile salmon are released as a "below the Cross Channel" control location for survival studies.

- Chipps Island – A site at the western edge of the Delta where IEP operates a near year round mid-water trawling operation (see Brandes and McClain 2001) to capture tagged salmon released at upstream locations. The recapture data are used to develop survival indices from the release location to Chipps Island. The trawl data also allow the IEP to estimate the annual numbers of Chinook salmon emigrating from the Sacramento and San Joaquin systems. We use information from this site to index survival of groups released in the Feather River and other locations above the Delta.

The San Francisco Bay Complex

Although the Bay and Delta are often considered as the San Francisco Estuary, they are treated as separate entities in the report – mainly because Feather River and Nimbus hatcheries release their production in San Pablo Bay. A few important sites in this area are:

- Benicia – An IEP release site used to index survival of fish not experiencing problems associated with traversing the Delta. Since the release site is below Chipps Island, survival from these releases (and from other San Pablo Bay sites) is indexed from catches of tagged fish in the ocean fisheries.

- Carquinez Strait – A constriction in the estuary and another below the Delta release site.

- San Pablo Bay – For the past three decades most of the production fish from the Feather River and Nimbus hatcheries have been released at various locations in San Pablo Bay. In recent years the "enhancement" production from the Mokelumne River Hatchery has also been released in San Pablo. (Enhancement production is considered above and beyond the hatchery's mitigation responsibilities and is the result of a commercial fisheries supported initiative.) In recent years the principal release site has been net pens in San Pablo Bay. (Fish placed in floating net pens are towed towards the center of the Bay and released. This is in contrast to the former practice of releasing fish directly from trucks into the Bay.)

The San Joaquin System

The mainstem San Joaquin River has been blocked by Friant Dam since the 1940s and the river bed is normally dry from a few miles below the Dam to the confluence with the Merced River. Although the San Joaquin formerly supported a large run of spring Chinook, Friant Dam eliminated access to the upper watershed and the run was eliminated in the 1940s (Yoshiyama et al. 2001). The San Joaquin system is of particular interest to this analysis as both a source of tagged fish that may stray to other Central Valley streams and streams where fish released from the FRH may stray.

- The Merced River. The Crocker-Huffman Dam below New Exchequer Dam blocks salmon migration several miles above the mouth of the Merced River. The CDFG operates the Merced Fish Hatchery (MFH) a few miles below the dam. Most of the MFH production is coded wire tagged and released in San Joaquin River tributaries, the mainstem and in the Delta for experimental purposes. Only fall Chinook are currently found in the Merced River.

- Tuolumne River. La Grange Dam blocks salmon migration at about river mile 50 on the Tuolumne River. (New Don Pedro Dam, the major storage reservoir on the Tuolumne River is about 15 miles above La Grange.) Only fall Chinook spawn in the Tuolumne and there is no hatchery on this stream. Readers can refer to Ford and Brown (2001) for more information on salmon in this important river system. Of particular interest to this study, Ford and Brown (2001) reported that the percentage of coded wire tags in spawning salmon increased from about 2% before 1987 to an average of about 20% during 1992-1997, with most of the tagged fish originating from MFH fall Chinook released on the Tuolumne and strays from Delta study releases.

- Stanislaus River. Goodwin Dam blocks access to the upper Stanislaus River, but there is salmonind spawning areas in the lower reach. Fall Chinook and steelhead are found in this river. There is no salmonid hatchery on the Stanislaus.

- The Mokelumne River. The Mokelumne River joins the San Joaquin River in the Delta, a few miles above the confluence of the Sacramento and San Joaquin rivers. Woodbridge Dam seasonally blocks salmon migration, although a pool and weir fish ladder provides upstream passage all times (Miyamoto and Hartwell 2001). Camanche Dam, at about river mile 30, blocks access to the upper watershed, which has several additional dams. A DFG operated hatchery raises mitigation fall Chinook and steelhead. A separate fall Chinook enhancement program is funded by the commercial fishing community. The FRH has provided juvenile fall Chinook and eyed eggs and juvenile steelhead to supplement production at the Mokelumne River Hatchery.

Institutional Setting

The fate of Chinook salmon and steelhead released from the Feather River and other Central Valley hatcheries is affected by a variety of environmental conditions and institutional activities and constraints. The institutional background has evolved over the life of the Feather River Hatchery and will continue to evolve as the hatchery continues salmon production through the life of the next FERC license. The following are brief descriptions of some of the institutions that have affected environmental conditions, and salmon survival, from the Feather River through the near shore ocean environment. The descriptions generally include direct references to how the institutions have and will affect such variables as location at which hatchery fish can be planted to maximize societal benefits.

Water Projects

Water projects in the Central Valley have resulted in the construction of more than 11 major dams (storage of 500,000 acre feet or more) with a combined storage capacity of more than 20 million acre feet. The dams have blocked salmon migration (Yoshiyama et al. 2001), have changed the amount of flow and flow patterns below streams below the dams and these changed flows have made the migratory pathway to the ocean (including the Delta) less hospitable. Although somewhat speculative, the dams on major salmon spawning streams has likely changed the overall Chinook salmon run dominance from spring and winter Chinook to mostly fall Chinook. In addition, the fall runs on those streams with hatcheries (e.g. Battle Creek and the Feather River) have a high proportion of hatchery fish (USFWS 2001, Cramer 1990). Steelhead have suffered a similar fate, with access to the upper reaches of many of their historic spawning streams cut off and most of the steelhead now being of hatchery origin (McEwan 2001).

The five Central Valley fall Chinook/steelhead hatcheries are the direct result of the construction and operation of water projects in the Central Valley. The hatcheries have been quite successful in providing salmon for commercial and recreational anglers and, when constructed in the 1940s, 50s and 60s, were considered by many fish biologists and managers to be acceptable mitigation for lost habitat and less than optimum stream flows.

Hydropower Development

Although the water projects mentioned above included hydropower development, in many watersheds, there was already extensive hydropower development above the reservoirs. For example in the Feather River, by the time Oroville Dam was constructed in the 1960s there had already been several decades of hydroelectric development in the watershed, espcecially in the North Fork. Fish migration was already blocked to the extent that there may have been intermingling of spring and fall runs (M. Meinz, DFG, personal communication).

The Interagency Ecological Program (IEP)

The IEP consists of 9 state and federal agencies that are charged with studying the effects of the SWP and CVP on environmental resources, mainly in the San Francisco Estuary. (See http://iep.water.ca.gov/ for more details.) Since the 1970s the IEP has used marked juvenile Chinook salmon to evaluate the direct and indirect effects of water project pumping on the survival of emigrating Chinook salmon. The early studies focused on the fall Chinook emigration period (April through June), however during the past decade the studies have also included the winter/early spring period when late fall, winter and spring Chinook are moving through the estuary. Originally most of the Chinook salmon for these studies were FRH falls, but in recent years researchers have also used late fall Chinook from the Coleman National Fish Hatchery (CNFH).

Four Pumps Mitigation Agreement (Also Known as the Two Agency Fish Agreement)

In 1986 DWR and DFG signed an agreement to mitigate for the direct impacts of losses of salmon, steelhead and striped bass caused by SWP diversions from the Sacramento-San Joaquin Delta. The agreement contains two components: a lump sum payment ($15 million) for uncalculated past losses and an annual charge based on the calculated numbers of the three species lost during the diversion and fish salvage process. The funds from this innovative program have been used to improve salmonid habitat, expand and improve the Merced Fish Hatchery and fund rearing of steelhead at Nimbus and Feather River hatcheries. The contributions from these and other projects have been estimated (in smolt equivalents) and used to offset calculated direct losses at the pumps. This mitigation agreement has not only resulted in improved salmon habitat but also in fish being reared in hatcheries and released to mitigate DWR's impacts in the Delta.

The Resource Agencies

In this context, we refer to the fish and wildlife agencies that are charged with protecting and managing California's fish resources. They are:

- NOAA Fisheries (formerly the National Marine Fisheries Service). NOAA Fisheries has the following main responsibilities that bear on this analysis:

  The agency receives and evaluates petitions to list anadromous fish species such as salmon and trout. If the petition is warranted, the agency may list the species as threatened or endangered pursuant to the federal Endangered Species Act (ESA). If a species is listed, NOAA Fisheries will issue biological opinions on specific project and the opinion may include reasonable and prudent alternatives that result in a non-jeopardy opinion for the species.

  NOAA Fisheries works with the Pacific Fishery Management Council and the State and federal agencies and stakeholders to establish commercial fishing regulations for ocean fisheries, including salmon. As part of this process, NOAA may act as lead agency on the environmental process associated with adopting fishing regulations (e.g. NOAA Fisheries 2004) and may issue biological opinions to lessen the impacts of the fisheries to listed species. NOAA Fisheries is a member of the IEP and, as such, approves research programs including salmon survival studies using tagged hatchery fish.

  NOAA Fisheries participates in the Federal Energy Regulatory Commission's hydropower relicensing process and may require the project to modify operations and facilities to protect listed species.

  NOAA Fisheries is a member agency of the CALFED Bay-Delta Program described below.

- US Fish and Wildlife Service (USFWS). In the Central Valley, the USFWS has several functions that relate to hatcheries and their impacts, including:

  The USFWS is a member of the IEP and is responsible for developing, conducting, and analyzing the results of the Delta salmon survival studies.

  The USFWS administers the anadromous fisheries and other environmental aspects of the federal Central Valley Project Improvement Act described below.

The USFWS operates two major Central Valley salmonid hatcheries: the Coleman National Fish Hatchery (CNFH) and the Livingston Stone National Fish Hatchery (LSNFH). The CNFH is a mitigation hatchery, whereas the LSNFH is a supplementation hatchery.

The USFWS is a member agency of the CALFED Bay-Delta Program.

The USFWS is an integral part of the FERC hydropower relicensing process.

- The California Department of Fish and Game (DFG). As related to this project, DFG has the following functions:

  DFG is a member of the IEP.

  DFG operates four Central Valley salmonid hatcheries: the Feather River Hatchery, the Nimbus Fish Hatchery, the Mokelumne River Hatchery, and the Merced River Hatchery.

  DFG conducts escapement surveys and other scientific studies to document fish abundance trends and factors that may be influencing these trends.

  DFG is a member of the CALFED Bay-Delta Program.

  DFG is an integral part of the FERC hydropower relicensing process.

  DFG works with the Pacific Fishery Management Council to establish ocean harvest seasons and goals.

- The California Fish and Game Commission. As one of its responsibilities the Fish and Game Commission receives petitions to list species that may require protection under the State Endangered Species Act. DFG will prepare a status report for the petitioned species. If found warranted, the Commission may list the species as threatened or endangered, or may include the species on the list of species of special concern. The Commission is also involved in setting fishing regulations.

The State Water Resources Control Board (SWRCB)

One of the functions of the SWRCB is to balance the allocation of water supplies among often competing beneficial uses, with one of the beneficial uses being protection of coldwater fish. Diversion of water from the Delta by the CVP and SWP is subject to water rights permits issued by the SWRCB. The Board periodically holds comprehensive hearings and triennial reviews to receive evidence of the impacts of the CVP and SWP on beneficial uses of the water supply and could modify permit conditions to more evenly allocate the water supply. Water rights decisions from the early hearings (D-1369 and D-1485, for example) focused on protecting juvenile striped bass with the idea that striped bass protection (Delta pumping limits and flow standards) would protect other species such as Chinook salmon and steelhead. For example striped bass protection in D-1485 issued in 1978 called for pumping curtailments during May and June, the period when most juvenile fall Chinook were emigrating through the Delta. The most recent decision, D-1641, was released in 1995 and contains salmon protection measures.

In spite of SWRCB diversion restrictions and water quality standards placed on the water projects in the 1970s, DFG remained concerned that through-Delta losses of their hatchery fish would be

unacceptable and continued to release FRH spring and fall Chinook and Nimbus fall Chinook in San Pablo Bay.

The Endangered Species Act (ESA) and California Endangered Species Act (CESA)

In 1989 the federal government listed winter Chinook as threatened under ESA. In 1994 the listing was changed to endangered. California also lists winter Chinook as endangered pursuant to CESA. Although winter Chinook are not reared at the FRH, the listing indirectly affected the survival of juvenile Feather River Chinook emigrating through the Delta. The change in survival resulted from the need to ensure that CVP and SWP operations in the Delta would not jeopardize the continued existence of the race. Through a 1992 section 7 consultation, NOAA Fisheries (then known as the National Marine Fisheries Service) imposed the first ESA-related reasonable and prudent measures that would protect winter Chinook, and presumably the other three races and steelhead. This initial consultation has been followed by similar consultations for spring Chinook and steelhead, with the most significant Delta protection measures being: (A new biological opinion on SWP and CVP operations was released on October 27, 2004).

- Limits to the number of winter Chinook juveniles that can be taken (killed) at the intakes to the CVP and SWP.

- Closing the Delta Cross Gates from February 1 to about the end of May each year to increase smolt survival through the Delta, (The fish agencies can request up to an additional 45 days of closure during the October 1 through January 31 period.)

- Limiting the amount of water that can be exported as a fraction of the inflow.

Although the goal of these and other actions was to make the Delta more friendly for all races of juvenile salmon, the Feather River and Nimbus hatcheries continued to release their production below the Delta.

The Central Valley Project Improvement Act (CVPIA)

Congress passed the CVPIA in 1992, with the purpose of adding fish and wildlife protection as specific features of the US Bureau of Reclamation's Central Valley Project. Two components of the CVPIA are of particular interest in this evaluation, namely the Anadromous Fish Restoration Program (AFRP) and the Anadromous Fish Screen Program (AFSP).

- AFRP. One of the AFRP goals is to double the naturally spawning populations of five anadromous fish species, including all Central Valley races of Chinook salmon and steelhead (USFWS 1997a). As part of the AFRP, the USFWS described the runs of anadromous fish in the Central Valley, their status and factors that may have caused observed declines and which may be bottlenecks towards recovery. The AFRP also included annual funding for research and monitoring (see, for example USFWS and USBR 1999) and for restoration of salmon habitat. These actions are designed to help achieve the goal of doubling naturally spawning populations and to acquire the data necessary to know when the goal had been achieved. With respect to the impact of hatcheries, the AFRP specifically developed an analysis of a constant fractional marking program intended to help determine the proportion of hatchery fish in spawning Chinook populations (USFWS 2000). The AFRP has proposed certain environmental conditions (e.g., flow) of many Central Valley streams, including the Feather River, that may help achieve the doubling goal.

- AFSP. The AFSP provided funding to improve and screen water intakes in the Sacramento and San Joaquin valleys that may entrain juvenile Chinook salmon and steelhead. To the extent that the more than 700 significant diversions along the Sacramento and San Joaquin rivers (Herren and Kawasaki 2001) are entraining juvenile Chinook salmon and steelhead, and these losses have population level impacts, screening the diversions should benefit naturally spawning salmonid populations. It should be noted that in recent years, the AFRP and AFSP elements of the CVPIA have been brought together with other restoration efforts (e.g. CALFED and 4-Pumps projects) under the "single blueprint" concept to evaluate and fund projects that have the maximum chance of improving conditions for salmonids.

The Delta Accord

In 1994 many of the environmental and water interests joined with the water and fisheries agencies to sign the "historic" Delta Accord. The basic intent of the Accord was to establish interim protection for listed species, including winter and spring Chinook salmon, steelhead and delta smelt. (DFG and USFWS listed the delta smelt as threatened in 1993.) The interim protection was to be followed by long-term measures that would not only result in more favorable conditions for listed fish species (with eventual delisting) but would also help achieve water supply reliability. With respect to the fate of emigrating Chinook salmon and steelhead, there were three important outcomes of the Accord:

- A SWRCB 1995 Water Quality Control Plan that codified the fish protection measures.

- The California Bay-Delta Program (Now called the California Bay-Delta Authority). This important entity is discussed in more detail below.

- The Vernalis Adaptive Management Plan (VAMP). VAMP is a series of experiments over a 12-year period designed to evaluate the effects of San Joaquin River flow and water project pumping on survival of fall Chinook emigrating from the San Joaquin system. The experiments began officially in 2000 but pilot studies were conducted in 1988 and 1999. From a Feather River Hatchery perspective, VAMP is particularly important in that the study protocol calls for combined SWP and CVP pumping to be held to a range of 1,500 to 3,000 cfs from April 15 through May 15 each spring, depending on the exact protocol for each year. In reality the VAMP period pumping reduction is often extended to June 1st each spring to provide additional protection for San Joaquin basin Chinook salmon and delta smelt, the so-called "shoulders on VAMP". Since many Sacramento Valley fall Chinook emigrate during this period, reduced pumping should increase the survival of salmon smolts through the Delta. The VAMP also annually releases tens of thousands of tagged study fall Chinook in the Delta. These fish are from the Merced Fish Hatchery and tend to stray to other streams when they return as adults.

The California Bay-Delta Authority (CALFED)

CALFED is a comprehensive, multi-agency, long-term effort with the goal of restoring ecological systems in the Central Valley and the San Francisco Estuary, while maintaining the reliability of water supplies. The four major CALFED program areas are ecosystem restoration, levee system integrity (along the rivers and in the Sacramento-San Joaquin Delta), water quality and water supply reliability. Information on this complex, proposed multi-billion dollar program can be found at http://calwater.ca.gov/.

Several CALFED efforts not only affect the quality of the Delta as salmonid habitat and a migratory pathway, but also the overall quality of salmonid habitat in the Central Valley. The results of CALFED

programs will influence future decisions on where hatchery production should be released and the overall role of hatcheries in Central Valley salmon restoration and management. A few key CALFED programs affecting salmon distribution and abundance and recovery are:

- The Ecosystem Restoration Program (ERP). Over the past five years, the ERP has awarded more than 450 million dollars in contracts to restore ecosystem functions, screen irrigation and other water intakes, improve fish ladders, and fund research and monitoring needed to understand the effects of these efforts. One of the overall ERP goals is to restore essential fish habitat to promote recovery of naturally spawning salmonid populations. As mentioned earlier, the ERP works in conjunction with the Central Valley Project Improvement Act staff and DWR staff implementing the 4-pumps mitigation program to cooperatively fund those projects that have maximum ecosystem values, i.e. the "single blueprint" concept. Restoration of Butte Creek, one of three Central Valley streams with significant natural spring Chinook runs, provides an excellent example of how such restoration actions (e.g. removing barriers) can improve a stream's ability to support a listed salmon run. As shown in Figure 5 (plate C), recent spring Chinook salmon runs to Butte Creek have increased but it is not clear how much of the recovery is due to good ocean conditions, restoration measures on Butte Creek or better conditions in the Delta.

- The Environmental Water Account (EWA). The CALFED Record of Decision included the EWA, a new concept in fish protection in the Delta. Basically the EWA acquires water, mostly from willing sellers above the Delta, and stores the water until needed for fish protection. Through an integrated process of data collection, posting, and evaluation, biologists from the fish agencies keep track of fish abundance and distribution, hydrology, and water project operations. When it appears that water project operations, mainly pumping in the Delta, may impact Chinook salmon, steelhead or delta smelt, the fish biologists can recommend that Delta pumping be curtailed for one to several days. Any water costs to project customers are made up from the EWA water in storage, thus promoting the CALFED goals of fish protection and improving water supply reliability. A more complete description of the EWA and salmon can be found in Brown and Kimmerer (2002, 2003). The EWA can be expected benefit Sacramento and San Joaquin Valley emigrating salmon and steelhead by reducing entrainment.

- The South Delta Fish Facilities Forum (Forum). The Forum is to help CALFED, member agencies and stakeholders sort out the issues associated with fish protection at the screened south Delta intakes to the State and federal water projects. The fish protective facilities in the south Delta are based on designs from the 1950s and should be upgraded. At both facilities, fish salvaged during the screening process are held in collecting tanks and periodically trucked several miles for release. There is considerable mortality at several steps in the screening, collection and hauling process. The Forum is charged with finding ways to reduce fish losses, and in turn, to make the Delta less stressful to migrating salmon and other fish. A less stressful Delta would affect decisions on whether or not to release Feather River production in the river,

Ocean and Inland Harvest

Mitigation hatcheries are not only intended to produce salmon to offset losses of habitat lost due to dam construction or other projects, they are to produce adult salmon for harvest. In the case of the Central Valley Chinook salmon, the fish may be harvested in the ocean commercial and recreational fisheries and in the inland recreational fisheries. Harvest of Central Valley steelhead is restricted to an inland sports fishery and, after release from the hatchery, steelhead may be caught at the yearling through adult life stages. It is important to understand the fisheries and their harvest because: 1) harvest contributes a socio-

economic benefit to society; 2) harvest of abundant hatchery fish may lead to incidental harvest of naturally spawning stocks; and 3) trends in harvest, including effort, should be considered when setting or adjusting hatchery production goals.

Two organizations are of particular importance in following harvest and setting regulations to allocate harvest in a manner that protects the overall fisheries resources and, in particular, salmon stocks and species that are at risk.

- Pacific Fishery Management Council (PFMC). The PFMC is one of eight regional fishery management councils established by the Magnuson Fishery Conservation and Management Act of 1976 for the purpose of managing fisheries 3 to 200 miles offshore of the US coastline. The Pacific Council is responsible for salmon and other fisheries off the coasts of California, Oregon, and Washington.

The Council's Salmon Fishery Management Plan describes the goals and methods for salmon management. Management tools such as season length, quotas, and bag limits vary depending on how many salmon are present. There are two central parts of the Plan: an annual goal for the number of spawners of the major salmon stocks ("spawner escapement goals" of 122,000 to 180,000 fall Chinook spawners in the Central Valley), and allocation of the harvest among different groups of fishers (commercial, recreational, tribal, various ports, ocean, and inland). The Council must also comply with laws such as the Endangered Species Act. In recent years the PFMC has adjusted the ocean fisheries to help ensure that Klamath River escapement goals have met. ESA and fishery season, gear and location-related adjustments to protect specific stocks have affected the numbers of salmon that escape to the Feather River and other Central Valley streams.

- The California Fish and Game Commission. The Commission has the general regulatory function to set seasons, bag limits and methods of take for game animals and sport fish. In adopting hunting (biennially, even-numbered years) and sport fishing regulations (biennially, odd-numbered years), the Commission, in each case, holds a series of open public meetings (three for hunting and four for sport fishing) located in various parts of the state, so that individual and group input can be received and considered prior to adoption of new or changed regulations. The Commission can decide to increase the catch of hatchery salmon by increasing the bag limit and season for adipose clipped Chinook, for example in the Feather River sport fishery, and to limit the take of listed species, such as early returning spring Chinook on the Feather River.

Institutional Setting: Overall Effects on Operation of Feather River Hatchery

The institutional setting in the 1950s and 1960s mainly associated with water development and operations, led to a concern about the numbers of Chinook salmon that would be available for harvest and to return to the streams. One outcome of this concern was to encourage hatchery production and to release many of the hatchery fish in the estuary below the Delta. In recent years, extensive efforts have been taken, and are underway, to improve salmonid habitat in the Central Valley and make the Delta less threatening to emigrating salmon and steelhead. This analysis of the effects of the FRH, and other Central Valley anadromous hatcheries, will examine the role of hatcheries in providing salmon to be harvested and if hatchery operations should be modified in light of new information on environmental and institutional conditions in the Valley, the estuary and the ocean. A hypothesis is that the suite of actions taken in the past decade has improved environmental conditions in the streams and the estuary to the extent that hatchery production could be released on site, while realizing acceptable levels of ocean harvest and escapement.

Use of Marked Hatchery Juvenile Salmon and Steelhead in Research

As described earlier, essentially all of the major Central Valley streams have been dammed for flood control and water supply. Stream flow below the dams is generally regulated, with the overall flow patters much different than under pre-dam conditions (see for example, Sommer et al. 2001a for the Feather River). Flood bypasses have been constructed to help protect agricultural and urban areas and these bypasses may provide important salmon rearing habitat (Sommer et al. 2001b). The CVP and SWP pumps in the South Delta divert large quantities of water and entrain large numbers of fish, including salmon and steelhead (Brown et al. 1996). For more than three decades, State and federal biologists have been using marked hatchery fish (fall and late fall Chinook) to help assess the impacts of the Delta facilities on emigrating salmon and to develop recommendations for operational and physical means of minimizing or eliminating any adverse impacts. The large numbers of hatchery fish released off-site for study purposes may stray and lead to the genetic homogenization of the Central Valley fall Chinook as recently reported by Williamson and May (2003).

The following are some of the more important studies that have used marked hatchery fish to better understand movement and fate of juvenile salmon through the system, including the Delta and ocean. These studies do not include releases designed primarily to evaluate the direct effects of hatchery operation, such as size at release, release location, and manner of release (i.e. net pens versus direct release from transport trucks).

IEP Studies of the Effects of the Delta Water Project Pumping and Related Facilities on Juvenile Chinook Survival: the Sacramento System

The IEP studies have been underway since the 1970s and the results have been documented in a series of papers (Kjelson et al. 1982, 1981; Kjelson and Brandes 1989; Brandes and McClain 2001) and annual progress reports (for example, USFWS 1997b). The study managers have often released several groups of 50,000 or more fish at various locations above, in and below the Delta to evaluate the effects of Delta water project pumping and facilities on survival of juvenile salmon migrating through the Delta. USFWS biologists developed a survival index from the release site to Chipps Island – at the western edge of the Delta – and to the ocean fishery (Brandes and McClain 2001).

The information collected from these studies has been used to help develop the present operating restrictions for the SWP pumps and the Delta Cross Channel. (See Brown and Kimmerer 2001 for a summary of the current restrictions,) Newman and Rice (1997) and Newman (2003) have used the survival indices to evaluate statistically the effects of flow, temperature, pumping and other variables on salmon survival.

Early on many of the juvenile fish used in the Delta survival studies originated at the FRH. Since the fish were needed as early as late March/early April for Delta releases, and had to be at smolt size, these test fish were the progeny of early spawners. This selection may have resulted in mixing of some nominal Feather River springs into the release group. In recent years, there has been less dependence on FRH juveniles, with the CNFH late fall juveniles being used in late fall/early winter period to better simulate the size and timing of winter Chinook migration through the Delta. For example in the fall/winter of 2003 about 270,000 Coleman late fall Chinook were released in the Delta for study purposes. (E. Chappell, DWR, unpublished data.)

Studies of the Fate and Survival of Fall Chinook from San Joaquin Tributaries

All major San Joaquin River tributaries (Merced, Tuolumne, and Stanislaus rivers) are dammed. Over the years, many studies have been conducted to determine if the flows below the dams are adequate for salmon production. These studies have generally used juvenile fall Chinook tagged at the Merced River Hatchery. If these fish return to the release streams rather than to the hatchery, they can potentially reduce fitness of stream specific runs.

Vernalis Adaptive Management Plan (VAMP)

VAMP incorporates a series of studies to be conducted over a projected 12-year period that is designed to assess the relative roles of San Joaquin River spring flows and CVP and SWP pumping on the survival of fall Chinook salmon emigrating from the San Joaquin River system. The long timelime is required to capture the combination of river flows and pumping rates called for in the study plan. VAMP is an integral component of the State Water Resources Control Board's Water Quality Control Plan for the San Joaquin Basin.

Although there are several components of VAMP that are important when evaluating the effects of the FRH on naturally spawning salmonids, two stand out.

- The study design is based on the release and recovery of large numbers of coded wire tagged juvenile salmon. As in the Sacramento River survival studies, a key experimental variables in VAMP is the calculated survival index from the point of release to Chipps Island. In 2003, VAMP studies resulted in the release of about 300,000 MFH fall Chinook smolts in the lower San Joaquin River, just above and in the Delta (San Joaquin River Group Authority 2004).

- The VAMP studies focus on the peak period of juvenile emigration from the San Joaquin system; i.e., April 15 through May 15. During this period water project pumping is kept low as part of the study design. These annual periods of low pumping must be considered when examining survival of salmon smolts emigrating from the mainstem Sacramento River, its tributaries and hatcheries. For example, CNFH fall Chinook releases are timed to reach the Delta during this window of reduced pumping. (S.Hamelberg, USFWS, personal communication.) Recent releases of tagged FRH smolts in the Feather River also have been timed to bracket the period of reduced pumping – and thus evaluate its benefit to through Delta survival – with a USFWS calculated Chipps Island survival index being the independent experimental variable.

Yolo Bypass Studies

The entrance to the Yolo Bypass (the Fremont Weir) is located on the Sacramento River, just upstream of Sacramento. When Sacramento River flows exceed about 100,000 cfs, the weir overflows and water spills into the Bypass and reenters the estuary upstream of Chipps Island. Since the weir is not screened, juvenile salmon enter the Yolo Bypass, where they may rear and leave the Yolo Bypass at the lower end, or be trapped in isolated ponds as the water recedes. To evaluate relative survival and growth of Chinook salmon, for the past several years, DWR biologists, as part of the IEP, have released tagged groups of FRH fall Chinook in the Bypass and just downstream of the weir in the Sacramento River. Although the numbers of fish released are relatively small (200,000 annually) the Yolo Bypass is an example of studies that results in the release of hatchery fish off site. The study objectives, results and conclusions can be found in several papers including, Sommer et al. 2001b.

Summary of Experimental Releases

In total more than a million marked and tagged juvenile Chinook hatchery salmon are released annually off site for experimental purposes. In essentially all cases the rationale for these studies is compelling and the results of interest to salmon managers and biologists. Later on in this report we examine the fate of the adults returning from experimental releases and discuss the effects of off-site experimental releases on the gene pool and fitness of Central Valley Chinook salmon.

Results of Specific Tasks Identified in the FRH Study Plan

We now go through the individual tasks outlined in the original study plan (Attachment 1). We also indicate where these tasks have been modified.

TASK 1. Conduct and Document a Comprehensive Survey of the Literature Regarding the Impacts of Salmonid Hatcheries on Naturally Spawning Salmonid Populations.

This task was completed and the resulting document is found in Attachment 2. The results of this review are included as part of various tasks in this report.

TASK 2. Describe the Goals and Objectives (1967 through the period of the existing license) of the Mitigation Aspects of the Feather River Hatchery.

The general goals and objectives of the Feather River Hatchery were to mitigate for Chinook spawning and rearing habitat lost due to the construction of Oroville Dam for spring and fall Chinook and steelhead,. These goals have not quantified all that well in terms of the numbers of fish that the hatchery was expected to return to he river. The following provides some background information.

In a 1960 memo from DFG to DWR, the chief of the Marine Resource Branch estimated that about 9,000 Chinook salmon would need to be handled at the yet to be built hatchery. These numbers were based on the largest run seen during the 1954-1959 period and considered that some fall run historically spawned below the proposed dam site. The memo also indicated the hatchery should be operated to maintain a run of 2000 steelhead. The steelhead numbers were not based on an actual count but on the observation that steelhead used the Feather River above Oroville. The Chinook salmon and steelhead egg take was expected to be about 18,000,000 and 3,500,000 respectively.

Spring run counts during the 1953-1962 pre-project period averaged 1,700 fish as compared to 1,362 during the 1963-1966 period (also pre-project, as cited in Painter et al. 1977). For the period 1953 to 1967, the total fall run to the Feather River range from 10,000 to 86,000 spawners, with an average of about 39,000 (Menchen 1969). By the time Oroville Dam was constructed only the Middle Fork was fully accessible to spring Chinook and steelhead.

Although there was some attention to the numbers of spawners that existed prior to the construction of Oroville Dam, including the numbers of salmon and steelhead that spawned and reared above the Dam, FRH has production goals centered around the numbers of eggs to be taken and numbers of juveniles released to the stream and estuary. While this strategy is reasonable from a hatchery management perspective, it may be time to take a life cycle approach to setting production goals, an approach that considers changing environmental and regulatory coniditions, mitigation responsibility and societal values.

TASK 3. Characterize the Non-Genetic Aspects of Feather River and Other Central Valley Salmonid Populations and Runs.

Central Valley Chinook Salmon and Steelhead

Chinook salmon (*Oncorhynchus tshawytscha*) populations are found from the Central Valley, California at least through the Kotzebue Sound in Alaska in North America in northern Japan and several streams in Russia north of the Amur River (McPhail and Lindsey 1970, as cited in Healey 1991). Healey (1991) provides a comprehensive review of the distribution and life history of the species and cites references indicating there may be more than 1000 Chinook salmon spawning populations along the West Coast of North America, (e.g. Atkinson et al. 1967). As described by Yoshiyama et al. (2001) most Central Valley streams originating in the Sierra Nevada or the Cascades once supported one or more races of Chinook salmon. The four Central Valley Chinook salmon races are identified by the time the adults enter freshwater: winter, spring, fall and late fall.

Steelhead (*O. mykiss irideus*) is generally considered to be the anadromous form of the rainbow trout, *O. mykiss*. As discussed by Moyle (2002), this is an oversimplification of a complex taxonomy in that the species may or may not be anadromous depending on environmental and other factors. For example, dam construction and temporary barrier formation (natural closing of sandbars across stream mouths) may temporarily or permanently limit anadromy. Steelhead were historically distributed along the Pacific Coast of North America from southern California through Alaska and in Asia on the Kamchatka Peninsula and scattered streams on the Russian mainland (Burgner et al. 1992 as cited in McEwan 2001). Although there are two steelhead races or runs – summer and winter – only the winter run is now found in the Central Valley. The winter run is characterized by arriving on the spawning grounds with mature or nearly mature gonads. McEwan (2001) provides a summary of the present status of Central steelhead and Yoshiyama et al. (2001) describe its historical distribution in Valley streams.

The Feather River Hatchery cultures and releases spring and fall Chinook and steelhead. The other two races, winter and late fall, in the Central Valley must also be considered when evaluating the effects of the FRH on naturally spawning salmonids although there is no reliable evidence that historically there were runs of these two races in the Feather River basin. FRH effects on other salmonids can result from competition, predation, genetic issues associated with straying and from the potential indirect impacts associated with harvesting hatchery fish in the ocean, e.g. over-harvest of natural spawning stocks. The FRH also raises the winter race of steelhead.

The following sections provide brief summaries of the four Central Valley Chinook salmon races and steelhead and references where additional information can be found.

Winter Chinook

Winter Chinook salmon are unique to California's Central Valley in that pre-spawning adults enter the San Francisco Estuary and immediately move upstream where they hold until spawning in the May through early August period. The run originally spawned in streams (e.g., the McCloud and Pit river systems) on the slopes of Mt. Lassen where springs kept summer stream temperatures suitable for spawning and early rearing (Yoshiyama et al. 2001). Although access to this habitat was blocked by the construction of Shasta Dam in the early 1940s, cold hypolimnetic water from Shasta Reservoir has allowed the run to survive in the Sacramento River between Keswick Dam and the City of Red Bluff. Juvenile winter Chinook begin to work their way downstream soon after emergence in the early fall and

by the end of October of most years, essentially all have passed by the Red Bluff Diversion Dam (Gaines et al. 2003). The juveniles continue their downstream movement and most have left the Delta by the end of March at an average size of 100 to 150 mm (Figure 3).

OBSERVED CHINOOK SALVAGE AT THE SWP & CVP
DELTA FISH FACILITIES 8/1/95 THROUGH 3/19/01

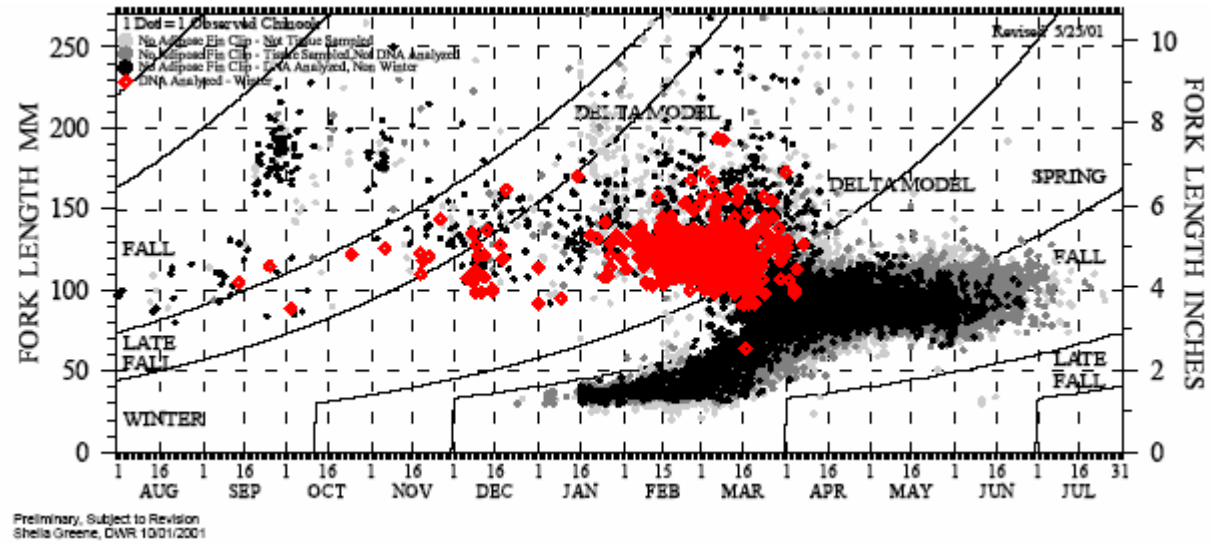

Figure 3. Size and timing of juvenile Chinook salmon salvaged at SWP and CVP – 1995 – 2001. (Each dot or symbol may represent more than one fish.) Courtesy of S. Greene, DWR.

Figure 3 is particularly important to understanding the emigration of juvenile Chinook salmon through the Delta. The symbols represent the day fish were salvaged at the State and federal water project intakes in the South Delta. By looking at the figure, one can obtain an idea of when salmon of various sizes move through the system. The lines demarcating the runs were developed by estimating fish size based on time of spawning and growth rates (Fisher 1992). The fish themselves are captured in the salvage (see Brown et al. 1996 for a description of the salvage process) and measured before being released back to the Delta at a site several miles from the intakes. Basically, the plot is of fork length over time with the hypothesized boundaries of the various runs superimposed on the plots. This run timing information is important when considering the effects of hatcheries on naturally spawning fish, especially if hatchery fish are be released on site and may be moving through the Delta with the progeny of naturally spawning fish.

Some observations about the data in Figure 3:

- There are fish of various sizes moving through the Delta during all months of the year, although the numbers are much lower in July and August. This finding indicates that considerable diversity remains among Central Valley runs and populations.

- There are some very large early emigrants (170 to 200 mm), perhaps yearling spring, fall or late fall run. To date, routine genetic techniques are not adequate to separate individual fish in these three runs with any degree of accuracy. These data also demonstrate the continued presence of

different life history strategies among the runs in spite of over 150 years of water development, hatcheries, and other perturbations.

- The red diamonds represent genetically confirmed winter Chinook juveniles, with the chances of error less than one in one hundred. The data indicate that winter run has a prolonged through-Delta emigration period – from September through March – but the bulk of the emigrating winter Chinook move through the Delta from January through March.

- The fall/spring run emigration seems to occur in two phases:

  - Fry movement to the Delta in the January - March period. It isn't clear if this movement is due to flows or displacement but it does coincide with the period when small fish move from their natal streams (Seesholtz et al. 2004, Williams 2001).

  - Smolt movement during the March through June period. The smolt period includes movement of unmarked smolts from the Coleman National Fish Hatchery through the Delta.

- It must be kept in mind that:

  - These are salvage data from a particular location in the system, the South Delta. Only a small percentage (0.25% to 3%) of juvenile salmon from the Sacramento River system reach the water project intakes (E. Chappell, DWR, unpublished data as shown in Brown and Kimmerer 2003).

  - Some of the larger fish may have entered the Delta at a smaller size and were taken in the salvage process when they reached the size to migrate to the ocean.

The bottom line is that there appears to be considerable life history diversity remaining in Central Valley Chinook. In the impacts section we examine more historic run timing data to determine if there has been any loss of life history diversity over the past four decades.

Some winter Chinook return to spawn at 2 or 4 years of age but more than 90% spawn as 3-year-old fish (Viele as cited in Brown et al. 2003).

Installation of fish ladders at the RBDD in 1967 allowed, for the first time, the resource agencies to estimate winter Chinook escapement (Figure 4) As shown in the upper plate, winter Chinook escapement declined precipitously immediately after RBDD was installed – from a peak of over 100,000 spawners in the late 1960s to less than 200 in 1989. In the lower plate, where number of spawners is plotted on a log scale, indicates there has been some recovery, with recent escapements exceeding 5,000 adults. (Note that recent restrictions on operation of the RBDD have resulted in the fish ladders not being operational during much of the winter Chinook adult migration and carcass surveys are now being used to estimate escapement.) The RBDD also impacted upstream and downstream migration of winter Chinook and may have contributed to the decline of the run (Upper Sacramento River Task Force 1978).

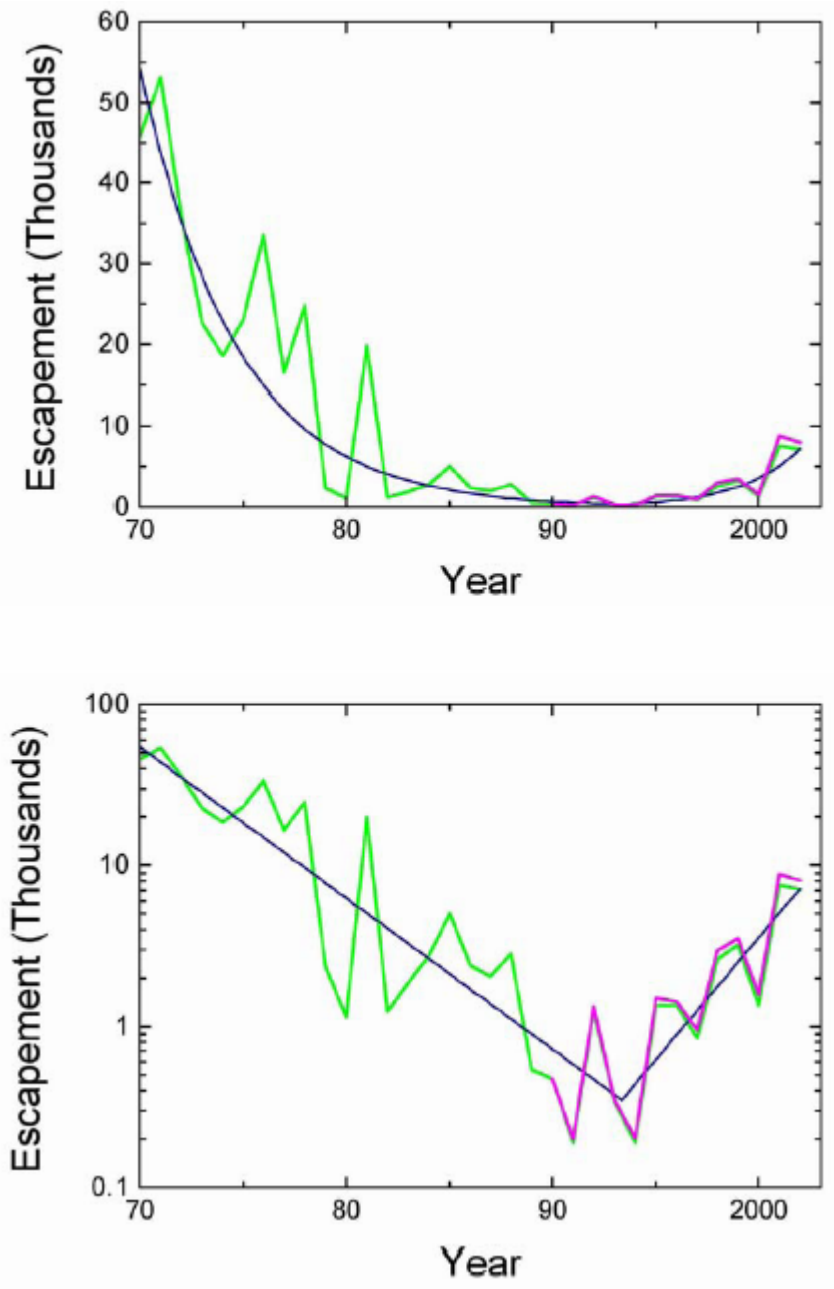

Figure 4. Escapement of winter chinook slamon to the upper Sacramento River. Top Plate: Data plotted on arithmetic scale. Bottom Plate: data plotted on log scale. Plots courtesy of W. Kimmerer, SFSU.

The winter Chinook was first listed as threatened both under CESA and ESA in 1989. The animal is currently listed as endangered pursuant to both federal and state endangered species acts. Listing of winter Chinook is of particular importance in our later consideration of changing modifying operation of the FRH in such areas as release strategy and production goals. The 1992 biological assessment on effects of CVP and SWP operations (Brown and Greene 1992) and the resulting NOAA biological opinion

dramatically changed water management in the Delta, and along with the 1993 listing of delta smelt, led to 1994 Delta Accord and the 1995 start of the CALFED Bay-Delta Program.

Finally, winter Chinook are cultured at the Livingston Stone National Fish Hatchery. This program is an integral part of the winter Chinook restoration program and broodstock collection and production are limited to protect the genetic integrity of this endangered races (see for example Niemela as cited in Brown and Kimmerer 2004 and USFWS 2001). Note that winter Chinook was first cultured at CNFH but production was shifted to LSNFH when biologists confirmed that cultured winter Chinook were returning to Battle Creek to spawn – not the mainstem Sacramento as desired – and that there was evidence of winter/spring Chinook hybridization at the CNFH.

Spring Chinook

Historically spring Chinook was probably one of, if not the, most abundant of the Central Valley salmon runs (Yoshiyama et al. 2001). Spring Chinook spawned in the higher reaches of many eastside Central Valley streams including the San Joaquin, American, Feather, Yuba and Sacramento rivers. Dams constructed over the past century have blocked access to most of the high-altitude holding, spawning, and rearing areas and genetic spring run are now restricted mainly to Deer, Mill and Butte creeks. In some years, spring Chinook spawn in small east side streams such as Antelope, Big Chico and Battle creeks. Spring Chinook may still spawn in the Sacramento River between Keswick and the Red Bluff Diversion Dam, although there is concern that these fish may interbreeding with fall Chinook. A discussion of a spring Chinook run in the Feather River is included in the subsequent section on Chinook salmon genetics. For now it is sufficient to note that there is a run of Chinook salmon to the Feather River that arrives in April, May, and June as bright (immature) fish. Since the barrier dam blocks the run from moving upstream to historical spawning habitat, this FR spring Chinook run now spawns in the same geographic location as the more numerous fall Chinook.

Spring Chinook life history is more complicated than winter Chinook. In the spawning phase, Central Valley spring Chinook are included in the stream type category (Healey 1991) in that they arrive on the spawning ground in an immature state and hold for a few months before spawning. The juvenile emigration phase includes both stream and ocean type characteristics – i.e. some juveniles leave the stream shortly after emerging while others may remain in the stream for several months and leave as yearlings. (Harvey-Arrison, as cited in Brown and Kimmerer 2003) The proportion leaving as yearlings may vary annually and between streams. On the Feather River almost all Chinook salmon have left the stream by March 1, although there is some smolt migration later in the spring (Seesholtz et al. 2004). Little yearling emigration has been detected in the Feather River, although the data are less reliable than for fry – the fish are larger (and harder to catch) and are less numerous (Seesholtz et al. 2004). Summer snorkel surveys have not detected large numbers of juvenile Chinook salmon in the Feather River – but have seen juvenile steelhead (FERC Report SP-F10, 3A, 2004).

Recent spring Chinook abundance estimates for Mill, Deer and Butte creeks are shown in Figure 5, plates 1–3 (Note different scales on y-axis). In the past few years the Butte Creek run has been relatively abundant, with the numbers of spawners exceeding several thousand. In Figure 6 we have plotted the numbers of spring Chinook taken into the FRH. Although this information is not the same as from typical spawning surveys, the data do provide some idea of the population trends on the only other Central Valley stream with a significant run of spring Chinook. It is also important to note that what has been called the Feather River Hatchery spring run may actually be a mixture of fall and spring runs.

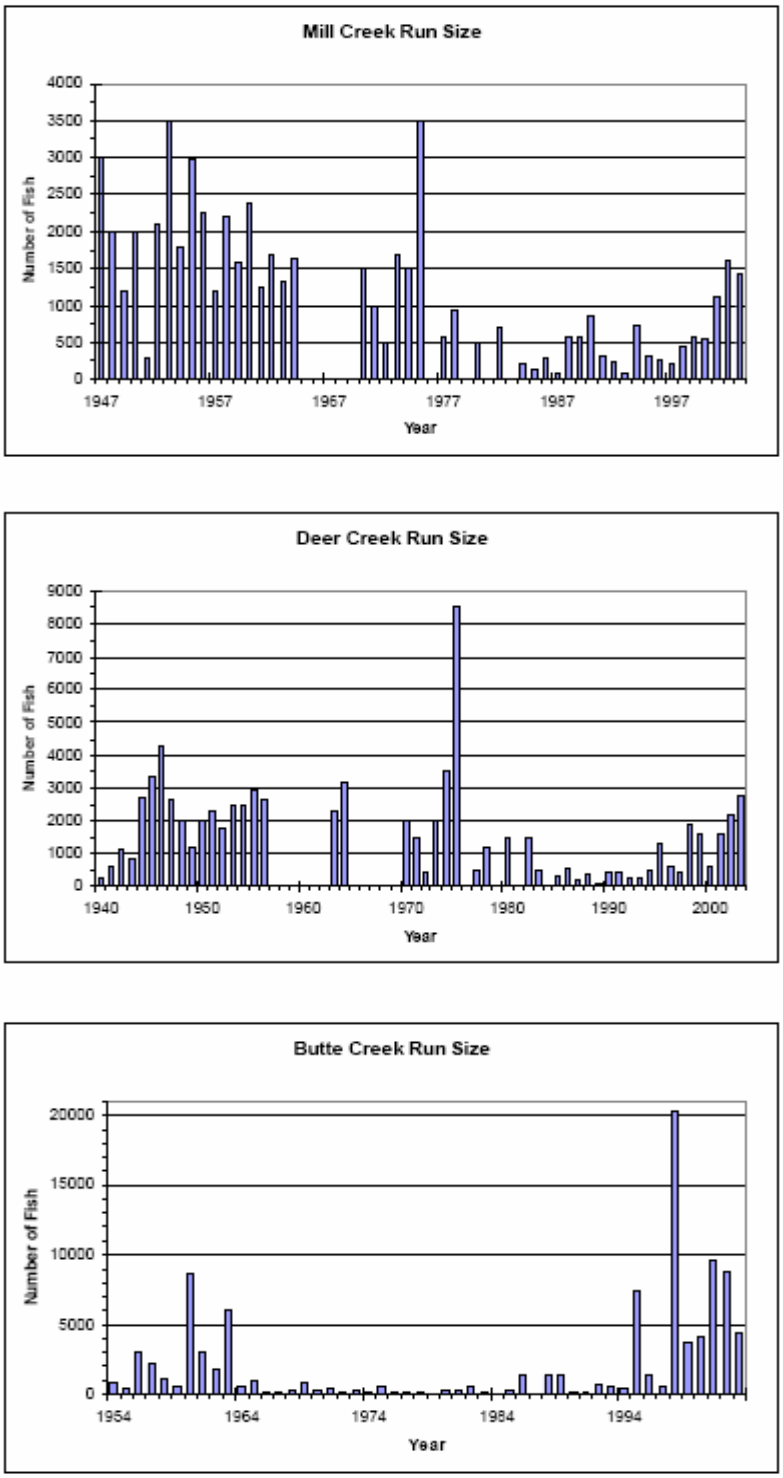

Figure 5. Recent estimated spring run escapement to Mill, Deer and Butte creeks.

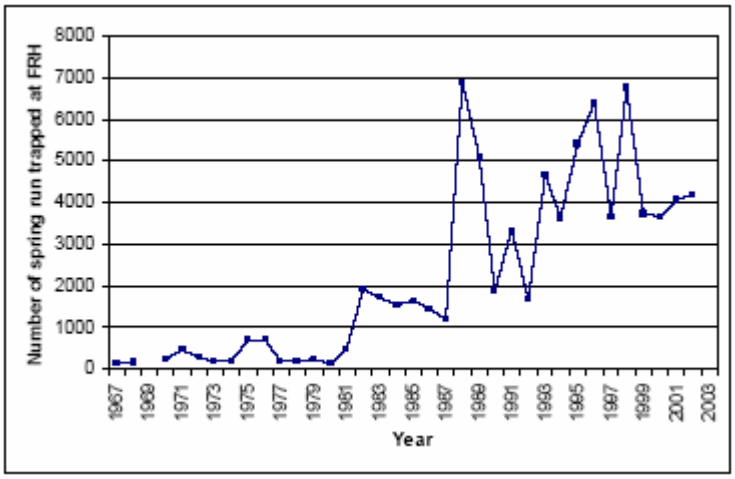

Figure 6. Number of spring Chinook taken into the Feather River Hatchery. Date from December 2003. Note that run designations is based on time on entry into hatchery and may not be indicative of actual numbers of spring Chinook.

Since 1999, spring Chinook has been listed as threatened pursuant to both the state and federal endangered species acts. Information used to support the listing, and more life history and historical information can be found in the DFG (1998) and NOAA Fisheries status reviews (NOAA Fisheries 1998 and 2003).

Nominal spring Chinook have been cultured at the FRH since operations began in 1967. (Note that nominal is used because subsequent marking studies indicated that the FRH spring Chinook contained a likely admixture of fall and spring runs.) As is shown later, on several occasions, juvenile spring Chinook were taken from the FRH and planted in Butte Creek and other Central Valley locations. For several reasons (which include deliberate planting in other basins, the potential effects of straying of nominal FRH spring Chinook to other basins, and hatchery spawning practices that may have resulted in hybridization between spring and fall Chinook), the effects of the FRH on spring Chinook is of particular importance in this analysis.

Late Fall Chinook

As implied by the name, the late fall run enters freshwater in the late fall and proceeds directly to the upper river where they hold for 1 to 3 months before spawning (Moyle 2002). The late fall Chinook is generally the largest (in size) of the four Central Valley runs, in part because its life history patterns make the mature adults less vulnerable to the ocean and inland fisheries.

Using the Healey (1991) model, the late fall run can be considered mostly a stream type Chinook salmon. The adults hold for a short period on the spawning grounds and the juveniles leave freshwater as sub-yearlings during the late fall through winter period. Based on collections of coded wire tagged fish from the Delta, the juvenile late fall Chinook are relatively large; the typical size range for recaptured late fall juveniles is 100 to 170 mm. (Note that we are unable to routinely genetically identify the progeny of naturally spawning late fall Chinook in Delta thus the use of hatchery surrogates.)

Because late fall Chinook move upstream during the period when Red Bluff Diversion Dam gates were generally raised and during the period of high, and turbid, river flows it has proven difficult to estimate the natural spawning population. The numbers of late fall entering the CNFH are shown in Figure 7.

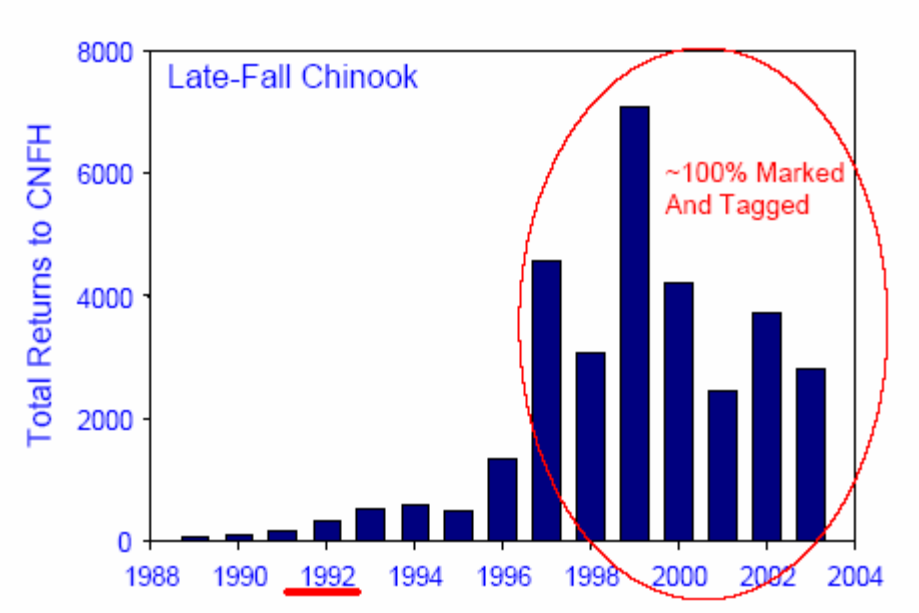

Figure 7. Number of late fall adults entering Coleman National Fish hatchery. Data from S. Hamelberg, USFWS.

Late fall Chinook is listed as a candidate species pursuant to the federal ESA and is not listed by the State of California.

The USFWS cultures late fall Chinook at the CNFH, with the annual production goal of about 1 million post smolts to be released in the upper Sacramento River near the mouth of Battle Creek. Since 1992 all late fall production has been marked with an adipose fin clip and a CWT inserted in the snout. During the past several years, marked late fall Chinook have also been released in the Delta as part of IEP and other studies to evaluate the effects of pumping and other water project operations on juvenile survival salmon (Brandes, as cited in Brown and Kimmerer 2002). These off-site releases can result in straying and adult CNFH late fall are returning to many Central Valley streams and hatcheries.

Late fall Chinook are important to this analysis because CWT tag recovery data for 1992-2003 may help shed light on salmon survival down the Sacramento River and through the estuary. In addition, tagged CVPIA late fall fish are now showing up in the Feather River and could compromise the genetic integrity of Feather River salmon runs or establish a new run on the Feather River.

Fall Chinook

The fall run is now the dominant Chinook salmon runs in the Central Valley with runs to most eastside tributaries and some west side Sacramento Valley streams. The fall run provides the backbone of extensive ocean and inland fisheries (Moyle 2002).

Central Valley fall Chinook fit the Healey (1991) ocean classification more consistently than the other three races (Moyle 2002). The adults enter freshwater mostly during the fall and proceed directly to the spawning grounds, arriving there mature and ready to spawn. Juveniles leave their natal streams soon after emergence with most of them gone by the first of March (Williams 2001, Seesholtz et al. 2004). There does appear to be some variation in the emigration strategy in that what appear to be fall Chinook have been captured emigrating as post smolts from the San Joaquin River and other systems (S.Cramer, SP Cramer and Associates, personal communication).

Since fall Chinook are so ubiquitous in the Central Valley, plates 1 through 4 in Figure 8 are used to show recent abundance in several streams (Due to differences in run sizes, not all figures have same scale on the y-axis). As with other runs, abundance has been quite high in recent years, perhaps in part due to favorable ocean conditions. A caveat regarding these data (and all salmon escapement data for that matter), particularly during large runs, is lack of precision and accuracy. The data should be used only to examine gross trends in abundance. Note that San Joaquin basin runs have not responded to the same extent as those in the Sacramento basin.

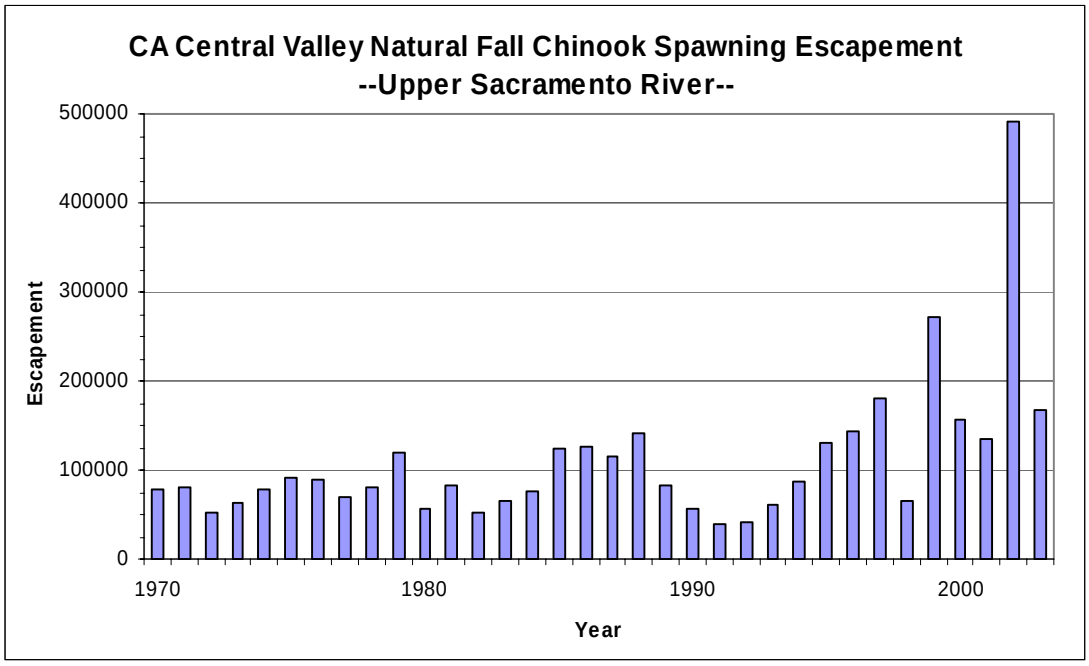

Plate 1

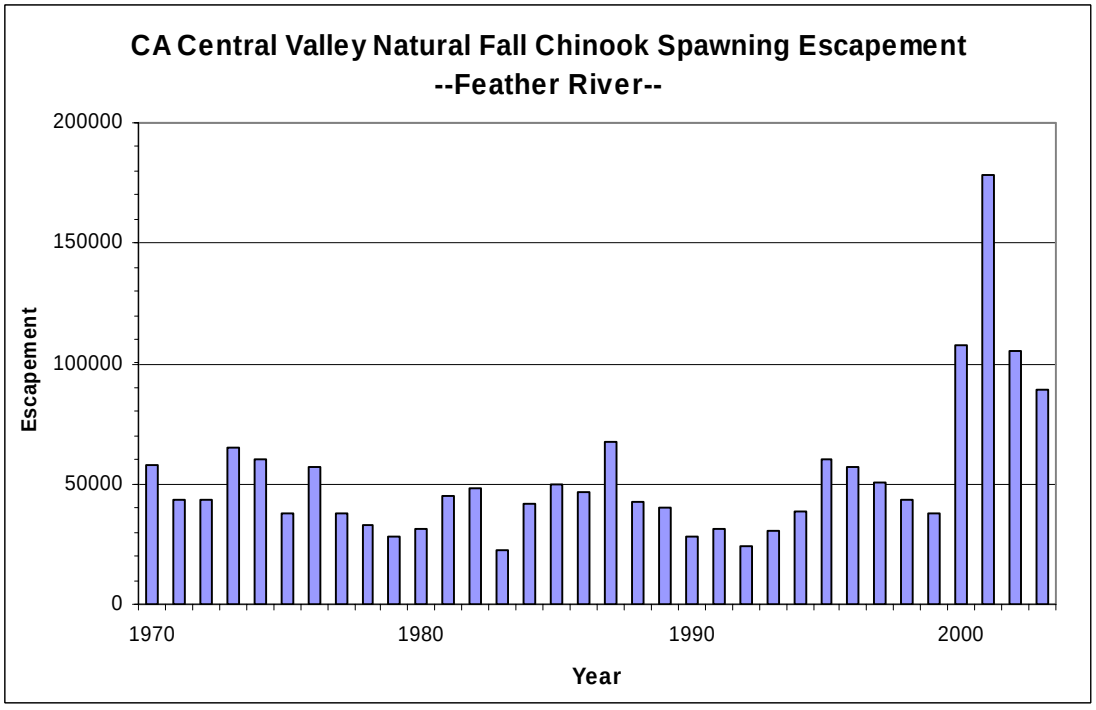

Plate 2

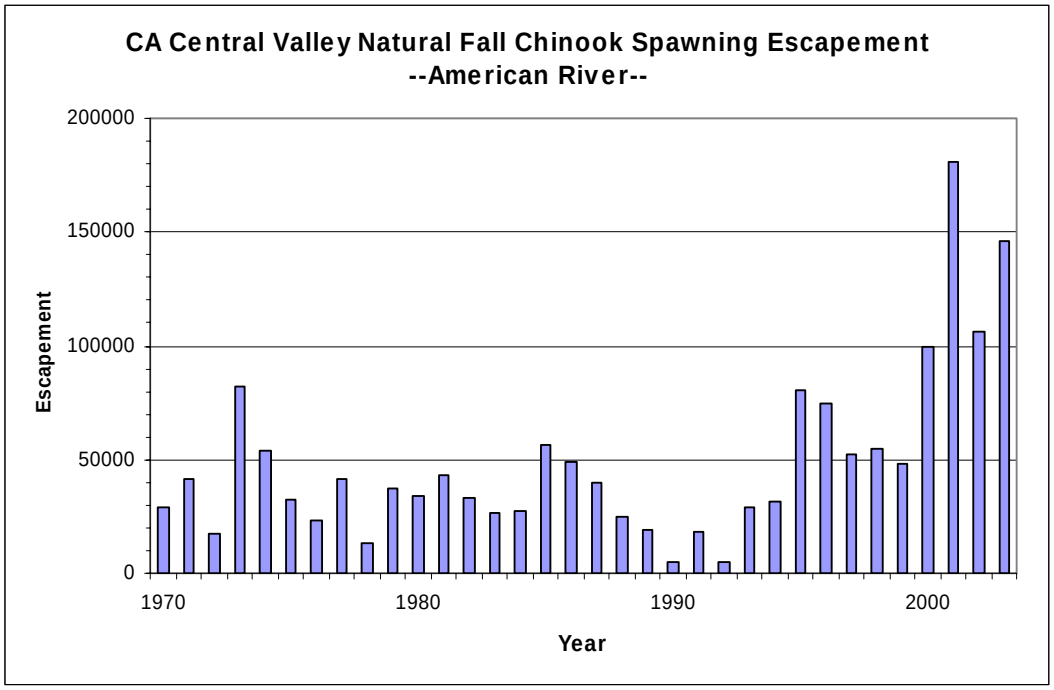

Plate 3

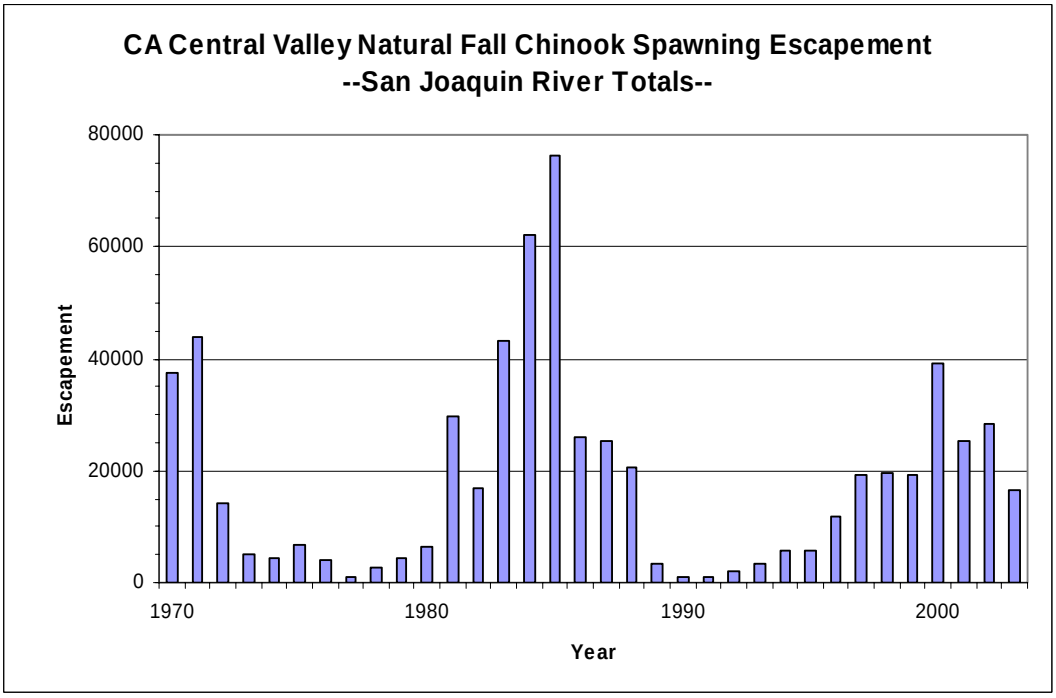

Plate 4

Figure 8. Fall run escapements to the American, Feather and upper Sacramento River and to the San Joaquin Basin.

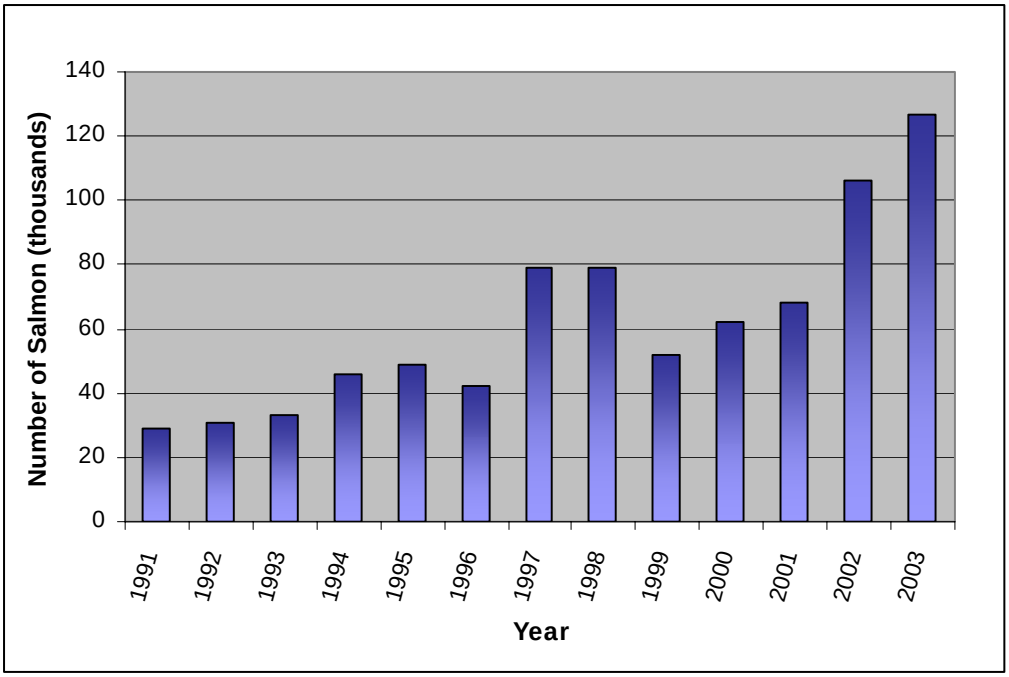

Figure 9. Number of fall Chinook salmon entering Central Valley Hatcheries during period 1991 through 2003.

A presumably large, but un-quantified, portion of the annual fall Chinook escapement is a result of hatchery production. Figure 9 shows the annual numbers of adult fall Chinook taken into Central Valley hatcheries for the past two decades. Note that these numbers only reflect the adult salmon entering the hatchery. In many cases, hatchery operations are designed to limit the numbers of fish entering the hatching and that are held, sorted and spawned. The Coleman National Fish Hatchery is the exception in that in recent years large numbers of fall Chinook have been taken into the hatchery to reduce crowding on the Battle Creek spawning grounds. (Fish in excess of the hatchery's needs are killed.) These fish taken into CNFH are the main reason for the large increases in numbers of fall Chinook entering the hatcheries in recent years – i.e., hatchery broodstock needs have remained relatively stable over time.)

Central Valley fall Chinook is listed as a candidate species under the federal ESA and is not listed under CESA.

As is shown later, fall Chinook are cultured at five of the six Central Valley anadromous salmonid hatcheries. The total number of smolts released each year varies somewhat but the combined production target exceeds 30 million. The release strategies vary among hatcheries. For example, all fall Chinook reared at CNFH are released on site. At the other extreme, all Nimbus Hatchery and FRH fall production Chinook are released in the estuary. The Mokelumne River Hatchery releases its mitigation fish near the hatchery, but its enhancement fish are released in the estuary. The Merced River Hatchery does not release production fish in the estuary, but large numbers are used for experimental purposes, with marked fish being released in other San Joaquin tributaries, in the San Joaquin River above the Delta, and in the Delta itself.

Chinook Salmon Summary

Figure 10 provides an overall summary of migratory timing of juvenile and adult Central Valley Chinook salmon. Although this information is shown for all races in the vicinity of the Red Bluff Diversion Dam, information about fall and spring Chinook generally applies to other areas in the Central Valley. The important message from these data is that juvenile and adult Chinook salmon are moving or holding in Central Valley streams during essentially all months of the year. This information must be considered when evaluating hatchery impacts and suggesting alternative hatchery management strategies.

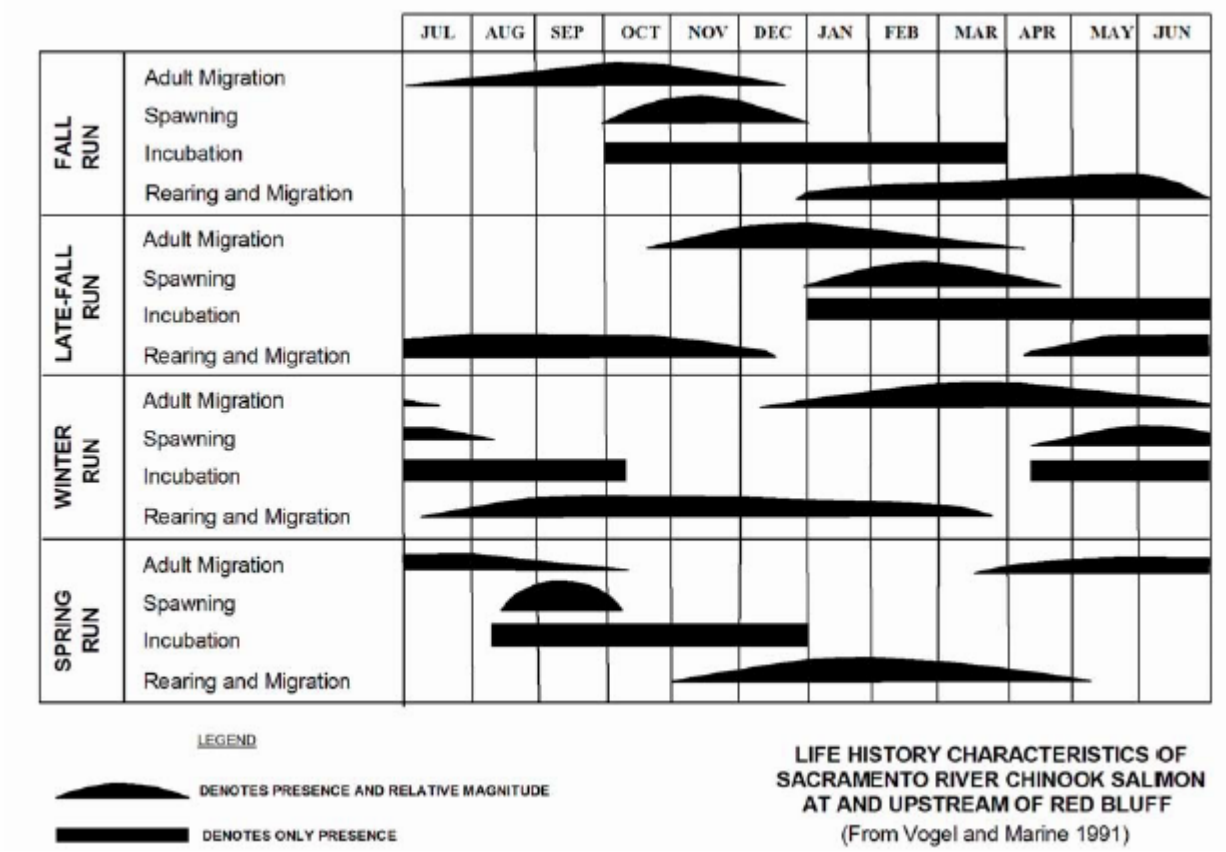

Figure 10. Life history characteristics of Sacramento River Chinook salmon at and upstream of Red Bluff (From Vogel and Marine 1991)

Steelhead

The following is a brief summary of steelhead life history and recent distribution and abundance trends. Interested readers should review McEwan (2001), McEwan and Jackson (1996), Moyle (2002) and DWR and USBR (2000) for additional information. We should point out that steelhead are much more difficult to sample than Chinook salmon due to the timing of their spawning (winter), the location of spawning (formerly in the highest passable stream reaches), and their relatively large size at emigration. The sparseness of steelhead data is also in large part is due in part to the lack of a commercial steelhead fishery, thus the species has received less attention than has Chinook salmon.

Life History

Central Valley steelhead now all belong to the winter run, thus arriving on the spawning ground nearing spawning condition. In many tributaries, peak adult steelhead immigration to the spawning grounds now occurs during the winter, whereas they formerly moved upstream mostly in the fall (Hallock et al. 1961). In the mainstem Sacramento above the Red Bluff Diversion Dam, adult steelhead still exhibit the fall immigration pattern (see Figure 2 in McEwan 2001). The general life history patterns are illustrated in Figure 11.

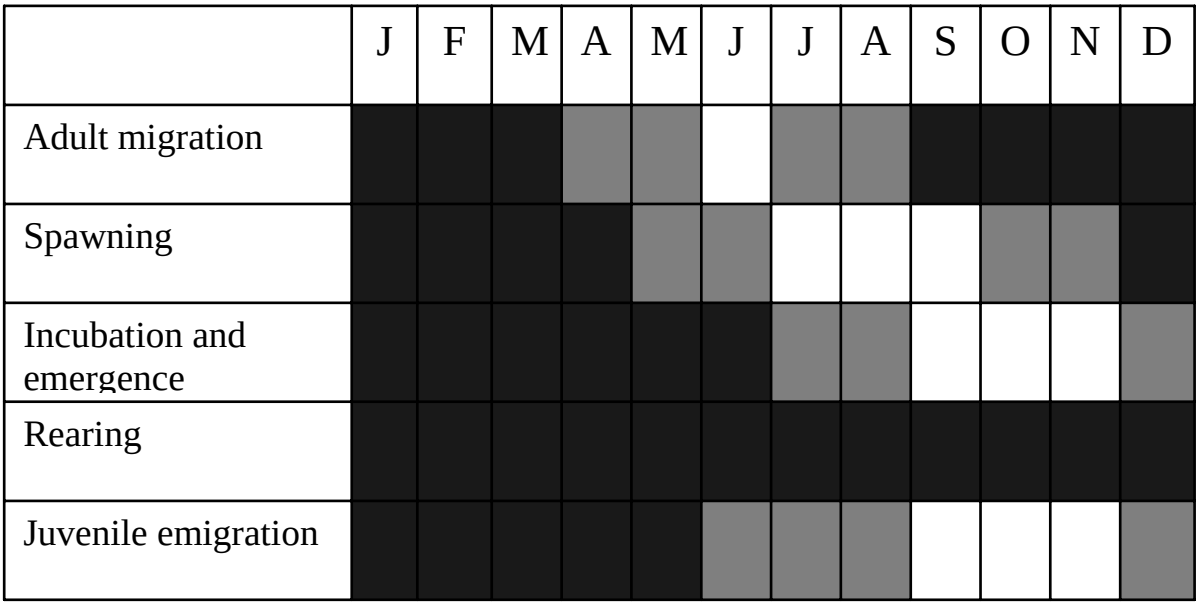

Figure 11. Steelhead life history (From McEwan 2001)

After emerging from the gravel, juvenile steelhead may spend one. or most often, two years in the streams before migrating to the ocean. Steelhead emigrate most of the months of the year, but peak migration seems to be in the winter-spring period. For example, unpublished USFWS data from annual trawl survey shows peak emigration during March and April of 1998 and 1999, although the overall emigration period extended from October through the following June. During 1976-1977 average fork length of steelhead leaving the Delta is almost always in excess of 200 mm, with many fish over 250 mm (unpublished USFWS Chipps Island trawl data as plotted in Figure 2-3; DWR and USBR 2000).

Central Valley steelhead typically spend one or two years in the ocean before returning to freshwater to spawn. Because steelhead are not commercially fished, not much is known about the animal's ocean distribution.

We must emphasize that the above life history is a generalization of a complex and variable life cycle. Titus (2000) used genetic evidence from three recently spawned rainbow trout from the Calaveras River to determine that:

- One female steelhead appeared to be the progeny of a female steelhead.
- One non-anadromous male steelhead was the apparent progeny of a female steelhead.
- One non-anadromous male was the progeny of non-anadromous rainbow trout.

Geographic Distribution

If one assumes that steelhead occupied about the same habitat as spring Chinook, historically they were distributed in most east side Central Valley streams (McEwan 2001 and Yoshiyama et al. 2001). Impassable dams have blocked access to the headwaters of most streams, and runs on many of the streams below the dams are mainly supported by hatchery production. Figure 12 illustrates the present system in which natural and hatchery steelhead runs can occur.

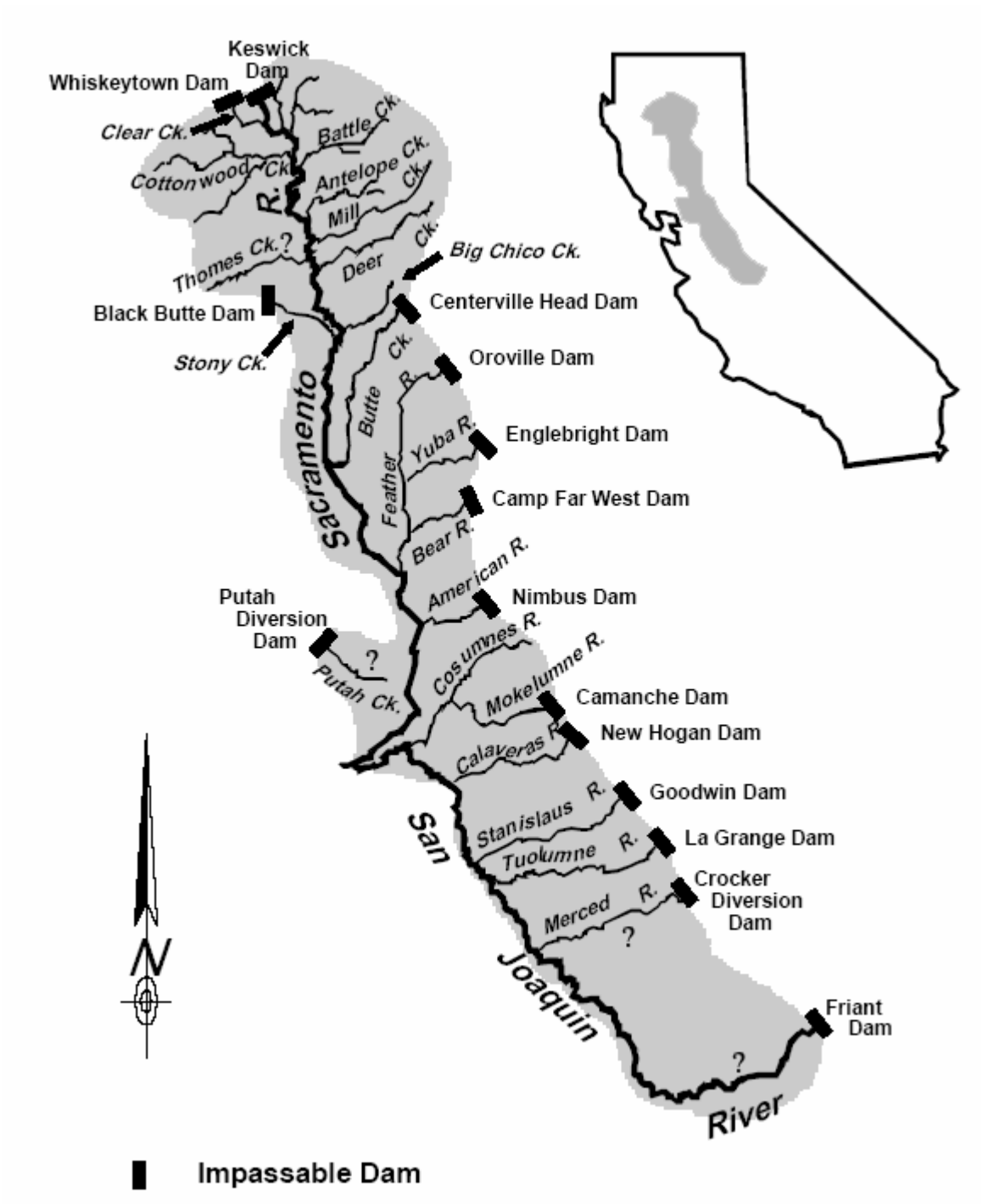

Figure 12. Central Valley stream habitat (shaded areas) now available to steelhead. The impassable dams have blocked access to about 90% of historic habitat. (? = uncertain about runs.) From McEwan 2001.

Abundance Trends

Since steelhead formerly spawned in the headwaters of Central Valley streams, and access to most of these streams has been blocked by dams, present steelhead abundance is undoubtedly much less than it was historically. Hallock et al. (1961) estimated that the runs above the mouth of the Feather River were on the order of 20,000 adults in the 1950s, and for the 1990s, McEwan and Jackson (1996) estimated the total natural run size for the entire Central Valley was no greater than 10,000 adult fish

The numbers of steelhead entering the FRH each year are shown in Figure 13. The run seems to have increased over the past several years, however more than 99% of these fish are of direct hatchery origin, presumably mostly from the FRH.

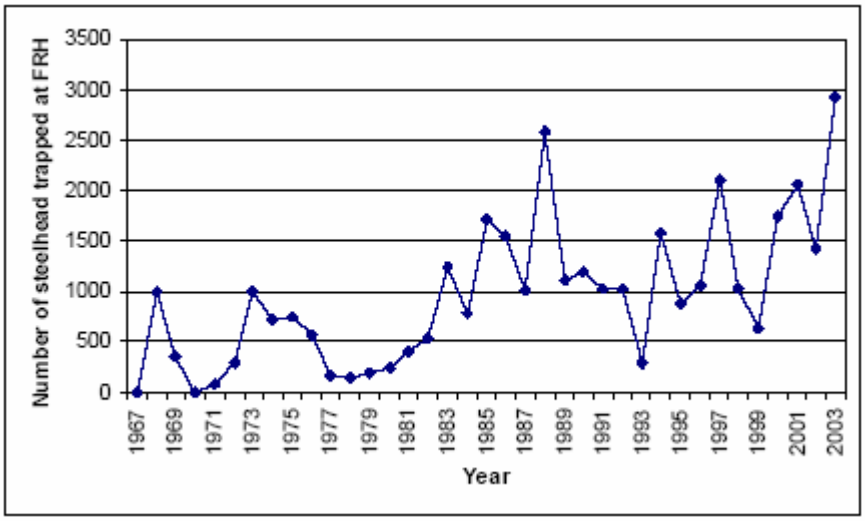

Figure 13. Number of steelhead entering the Feather River Hatchery, 1967-2003

Diseases of Central Valley Salmonids

Interested readers are referred to another Oroville FERC relicensing related report, *Evaluation of Project Effects on Fish Disease* (MWH 2003), for more information of fish disease as they may relate to the overall project.

Several viruses, bacteria, external and internal parasites can cause clinical infections in hatchery and naturally spawning Chinook salmonid populations in the Central Valley. Many of the disease vectors are routinely present in hatcheries and enter via surface water supplies, in the adult fish coming into hatcheries, or are transmitted by birds and other vectors. There are two major concerns about hatcheries and disease: first that disease problems will affect the hatchery's ability to meet production goals; and second, that diseases present in hatchery fish will be transmitted to wild and naturally spawning species. In this analysis of the impacts of the FRH, we are most concerned about the second impact. FRH staff must be concerned about limiting disease outbreaks that affect production, however we consider effects of disease on the quality of the hatchery product.

The following brief description of diseases of Central Valley salmonids is extracted from material on disease in Lichatowich et al. (2004) and personal communication from Tresa Veek, DFG.

- **Virus**. Although three viruses have been detected in Central Valley hatchery salmonid populations (the cutthroat virus, the salmonid herpes virus type 1, and the infectious hematopoietic necrosis virus or (IHNV), only IHNV has caused large scale Chinook salmon losses Other viruses have not caused disease/mortality. IHNV is discussed in more detail following the general descriptions of diseases.

- **Bacteria**. The following bacterial pathogens have been found in California salmonids (Foott and True 1998):

  - *Flavobacterium psychrophilum* (cold water disease) and *F. columnare (*columnaris*)*
  - *Aeromonas hydrophila/salmonicida*
  - *Pseudomonas*
  - *Yersinia ruckeri*
  - *Renibacterium salmoninarum* (bacterial kidney disease, or BKD)

- **Fungi**. *Saprolegnia* and other water molds are often present on fish and eggs of Central Valley salmonids.

- **Protozoans**. The following flagellated and ciliated protozoans are often found on wild and hatchery fish:

  - *Ichthyobodo*
  - *Hexamita*
  - *Ichthyophthirius multifilis* (commonly called Ich)
  - *Tricodina*
  - *Ambiphrya*
  - *Epistylis*
  - *Chilodonella*
  - *Trichophyra*

- **Metazoans**. The following metazoans can be external and internals parasites on Central Valley salmonids:

  - *Gyrodactylus*
  - *Nanophyetes salmonicola*

- **Myxozoans**

  - *Ceratomyxya shasta*
  - *Parvacapsula*
  - *Chloromyxum*

- **Parasitic copepods**
  - *Lernaea*
  - *Salmonicola*

In this evaluation, we focus on IHNV. The impetus for this focus came from discussions with fish agency representatives during development of the hatchery study plan and recent experience at the FRH with severe IHNV outbreaks and mortality in hatchery Chinook salmon. (And the conclusion that other diseases were not causing major problems with FRH fish.) As a result of these discussions DWR, with financial support from the USBR, contracted with fish disease specialists at the University of California Davis and the USFWS's Northern California Fish Health Laboratory to investigate IHNV concerns at the FRH and the likelihood that IHNV could be spread from hatchery to naturally spawning fish. The results of these studies are discussed in Task 12 of this report. Note that in the FRH, IHN has been a more serious problem for Chinook salmon, with steelhead not appearing to be as susceptible.

IHNV has been found in salmonid populations from the west coast of North America, Europe, Japan, China, Taiwan, and Korea. The virus causing the disease is taxonomically in the family Rhabdoviridae and the genus *Novirhabdovirus*. Three distinct groups of INHV have been recognized in North America:

- U clade – northern parts of Pacific Northwest
- M clade – portion of Idaho
- L clade – California

The California clade contains several internal groupings and there is evidence of recent evolution of the genotypes (R. Hedrick, UCD, personal communication.)

As implied by its name, IHNV causes severe necropsis of hematopoeitic (blood forming) tissues, especially in the anterior kidney, spleen and pancreas. The virus has been most troublesome in hatchery situations where culture conditions may increase stress, transmission, and move rapidly from infection to clinical disease. Culture operations that have been affected by IHNV outbreaks include net pen Atlantic salmon growing facilities in the Pacific Northwest and commercial rainbow trout operations in Idaho to Coleman National Fish Hatchery and the Feather River Hatchery in the Central Valley. During serious outbreaks, mortalities of juvenile salmon can reach 70% to 80% in infected raceways. Virus sensitivity generally varies inversely with fish size, thus juvenile Chinook salmon are most vulnerable between the yolk sac fry stage to about two months of age. IHNV is spread mostly through the water with two most likely routes: (1) in the water itself, or (2) horizontal transmission from fish to fish. The virus may also be transmitted vertically from parents to progeny through gametes (Noga 2000).

Although there appear to be Central Valley reservoirs of IHNV that can infect hatchery populations, it isn't clear how they function. For example resident rainbow trout may carry the virus and provide a source of infection to those hatcheries receiving a surface water supply. Another potential source of contamination comes from returning adult Chinook salmon. Early spawners may be IHNV free but later spawners may essentially all be carriers, implying a local source for this rapid spread of the virus (Scott Foott, as cited in Brown and Kimmerer 2004). Two local examples may shed light on the importance of virus in the water source to infection and outbreaks in the hatchery:

1. The CNFH, which allows some adult passage into upper Battle Creek, suffered severe INHV outbreaks in the mid 1990s. No additional outbreaks have occurred since the hatchery installed an ozone sterilization system on the hatchery water supply intake.

2. There had been no IHNV problems at the FRH since the late 1980s when DFG began to routinely use iodophore for egg disenfection and before DFG began planting Chinook salmon in Oroville Reservoir, i.e. in the water supply immediately above the hatchery. There have been no outbreaks since 2002 after planting of Chinook salmon was stopped in 2000.

Although the examples do not demonstrate direct cause and effect (and the period of record is quite limited) there is ample evidence that the spread of virus in the water supply must be considered.

There is no effective treatment for IHNV, although moving the fish to water >59 degrees F after detection may control the outbreak (R. Hedrick, UCD, personal communication). Iodine treatment of incubating eggs may limit vertical transmission of IHNV.

TASK 4. Characterize the Central Valley Fish Management Context in which the FRH Operates, Including Other Hatcheries, Interbasin Transfer of Genetic Material, Escapement Goals, and Commercial and Recreational Fisheries Management.

California has a long salmonid culture history. In 1872 the federal Fish Commission funded Livingston Stone to build and operate the first salmon hatchery in California, and indeed on the west coast. Stone built the hatchery on the McCloud River, a tributary to the upper Sacramento River. Although the hatchery was originally operated to provide eggs for east coast restoration efforts, one of its early goals was to augment Central Valley salmon fisheries. A second hatchery was constructed on Battle Creek, which enters the Sacramento River near Red Bluff. The premise underlying hatchery production was that hatcheries increase survival from the egg to early juvenile stages, as compared to that in the wild, and that survival would translate into larger numbers of adults that could be harvested and still allow for sufficient spawners to repeat the cycle. Until recent years that premise has remained intact.

The Central Valley now has six federal and state hatcheries that culture one or more races of Chinook salmon or steelhead. Collectively these hatcheries release tens of millions of juvenile salmon and steelhead. In all but two cases, the hatcheries are intended to mitigate for habitat lost due to dam construction. (These hatcheries are often referred to as production hatcheries.) One non-mitigation hatchery is specifically operated to supplement the numbers of the endangered winter Chinook. The second is to supplement fall Chinook production on the Merced River system.

The four Central Valley mitigation hatcheries, operated by the State (3) and federal governments (1), not only provide fish for production releases but all but also for experimental purposes. In some instances, hatchery produced fish have been planted in out-of-basin streams. Although not operated as an integrated system, the effects of individual hatcheries can not be evaluated without considering their collective effects. We reached this conclusion because:

- There has been extensive direct exchange of genetic material among the hatcheries.

- The adults returning from production releases by individual hatcheries often stray to other streams.

- The adults returning from experimental releases by individual hatcheries often stray to other streams.

- Collectively the hatcheries contribute large numbers of cultured fish to the ocean and recreational fisheries and thus exacerbate demographic problems associated with mixed stock fisheries. The large runs returning to hatchery streams may also lead to a false sense of complacency by the public and administrators.

Below we describe key features of the other five Central Valley salmonid hatcheries. The FRH is described in more detail in Task 5.

Coleman National Fish Hatchery (CNFH)

The USFWS operates CNFH, located on Battle Creek, as partial mitigation for the Central Valley Project's construction and operation of Shasta and Keswick dams. (A complete description of the facilities and operations can be found in USFWS 2001.) From 1996 through, the steelhead component of the hatchery operation has included a supplementation program for Battle Creek above the fish barrier dam. After a review of the program by a panel of fish biologists and geneticists, the supplmentation program was terminated in 2004, pending additional evaluation. For purposes of these analyses, the following are some key features of CNFH.

- **Year hatchery began operation**. 1942

- **Races and species propagated**. CNFH rears and releases fall and late fall Chinook and steelhead. Until 1997 they reared winter Chinook. In 1998 winter Chinook production was moved to Livingston Stone National Fish Hatchery (see below). Several unsuccessful attempts were made to hold and/or rear spring Chinook (Black 2001).

- **Production targets and stage to be released.**

  12,000,000 fall Chinook smolts

  1 million late fall subyearlings

  500,000 steelhead yearlings

- **Release location and timing**

  Fall Chinook – In Battle Creek with fish mostly released in April.

  Late fall Chinook – production fish are released in Battle Creek. Production releases are typically in January. In addition to production releases, there are several experimental releases of fish from December through February at locations such as Battle Creek, in the Sacramento River near Sacramento and below the Delta Cross Channel, and in Georgiana Slough.

  Steelhead – All are released in the upper Sacramento River near the mouth of Battle Creek.

- **Marking of hatchery fish**

  Fall Chinook – Until 2002 some fall Chinook had adipose clips and coded wire tags. Since then none have been marked.

  Late fall Chinook – Since 1992 all late fall Chinook have been marked and tagged. These tags allow production and experimental releases to be distinguished and to distinguish between Coleman late fall run and winter run fish in the same size range.

  Steelhead – All steelhead have adipose fin clips.

- **Relevance to FRH hatchery evaluation**

  CNFH fish may stray to the Feather River and vice versa.

  CNFH strays, especially steelhead, provided some of the founding broodstock for the FRH.

  There has been direct exchange of genetic material between the two hatcheries.

  The CNFH contributes to the overall harvest and escapement of Central Valley salmon, information that can bear on individual hatchery goals.

  Most CHFH fish are released near or on-site thus providing a control against which straying rates from estuary releases can be evaluated.

Livingston Stone National Fish Hatchery (LSNFH)

The LSNFH is operated by the USFWS as a winter Chinook supplementation facility. The need for a supplementation hatchery was identified as winter Chinook escapement plummeted in the 1980s. The supplementation program was located at CHFH until concerns about interbreeding between spring and winter Chinook and homing fidelity to Battle Creek (and not the mainstem Sacramento River) resulting in it being moved to a new facility on the Sacramento River near the base of Shasta Dam. Some important feature of the LSNFH culture program are:

- **Year hatchery began operation**. 1998

- **Race cultured.** Winter Chinook.

- **Production goal and stage to be released.** To protect the genetic integrity of the wild winter Chinook (effective population size), LSNFH is limited to taking no more than 15 percent of estimated winter Chinook escapement, with a maximum of 120 spawners. The spawning population levels experienced in the past few years results in production of more than 200,000 advanced smolts.

- **Release location and timing.** The production fish are typically released in late January in the Sacramento River near Redding.

- **Marking of hatchery fish.** All released winter Chinook are marked and tagged.

- **Relevance to FRH evaluation.** In general the LSNFH program has no direct relation to the FRH evaluation. The release and other hatchery related information does provide useful background for evaluating hatchery operations.

Nimbus Fish Hatchery (NFH)

The US Bureau of Reclamation funds DFG to operate the NFH as mitigation for construction and operation of Nimbus and Folsom dams - both integral components of the Central Valley Project. The hatchery is located just downstream of Nimbus Dam on the lower American River. Williams (2001) describes the lower American River and includes some information on the hatchery. Dettman and Kelley (1986) also describe the hatchery and its role in maintaining lower American River salmon runs. The following summarizes some important points about the NFH.

- **Year hatchery began operation.** 1955.

- **Races and species propagated.** DFG spawns and rears fall Chinook and steelhead at the NFH. Although spring Chinook runs were native to the American River drainage, this race has never been propagated at Nimbus. Early on, hatchery managers used different steelhead strains in attempts to establish summer and winter steelhead runs on the American River. Eventually the winter run was established using a strain from California's Eel River. This run is considered an out-of-basin strain and is not included in the Central Valley steelhead ESU.

- **Production targets and stage to be released.**

  Fall Chinook – The target is to release 4 million smolts. Note that the 1999 DFG protocols for operation of NFH provide for taking up to 4 million eggs to be used to supplement production at the Mokelumne River Hatchery. In 2004, DFG managers agreed that escapement and egg production at the Mokelumne operation were such that these transfers were not needed.

  Steelhead – The target is to release 430,000 steelhead yearlings. Note that the 1999 protocols for operation of the NFH specified that up to 250,000 steelhead eggs could be taken for transfer to the Mokelumne Fish Hatchery. For the past several years, these eggs have been taken at the FRH and the progeny released in the Feather River. This egg take is for mitigation of DWR pumping related impacts in the Delta.

- **Release location and timing.**

  Fall Chinook – All fall Chinook are currently released during the April-June period in the estuary. This release strategy evolved in the late 1960s when studies demonstrated that recruitment to the fishery and escapement was significantly improved when juvenile Chinook were released in the estuary rather than in the American River.

  Steelhead – All steelhead are currently released in January in the Sacramento River.

- **Marking of hatchery fish.**

  Fall Chinook – With the exception of some fin clips in the late 1960s, relatively few NFH fall Chinook have been marked. In 2001 and 2002, as part of a CALFED funded program to test an

automated tagging machine, several hundred thousand NFH fall Chinook were coded wire tagged, adipose fin clipped and released in the lower estuary.

Steelhead – All released steelhead have adipose fin clips.

- **Relevance to the FRH evaluation.**

Many of the founding steelhead broodstock at the FRH resulted from NFH strays to the Feather River.

Previous studies (e.g. Reisenbichler et al. 1982; Dettman and Kelley 1987) demonstrated that significant numbers of FRH released juvenile Chinook salmon strayed to the American River when returning as adults.

There have been numerous transfers of genetic material between the Feather River and Nimbus hatcheries.

The NFH is an integral component of the hatchery-fish management system that has contributed to the present state of the Central Valley anadromous salmonid populations.

Mokelumne River Fish Hatchery (MRFH)

The East Bay Municipal Utility District (EBMUD) contracts with DFG to operate the MRFH, located on the lower reaches of the Mokelumne River just below Camanche Dam. The hatchery is used to mitigate for upstream spawning and rearing habitat lost due to construction and operation of Camanche Dam. Miyamoto and Hartwell (2001) include references to the hatchery in their description of the lower Mokelumne River salmon program.

- **Year hatchery began operation.** 1964. EBMUD funded an extensive renovation of the hatchery in the late 1990s.

- **Races and species propagated.** Fall Chinook and steelhead.

- **Production targets and stage to be released.**

Fall Chinook – As with the FRH, the MRFH has two fall Chinook components - mitigation and ocean enhancement. These components have individual production goals and release strategies.

- Mitigation – 3.25 million smolts and up to 1.5 million yearlings (current capacity to rear yearlings is limited to 500,000).

- Ocean Enhancement – 2 million post smolts. Note that for several years the ocean enhancement salmon production was derived from eyed salmon eggs originating from the FRH. In recent years escapement to the Mokelumne River has been sufficient to provide the egg take needed for the Ocean Enhancement program.

Steelhead - 100,000 steelhead yearlings.

- **Release location and timing.**

Fall Chinook –

- Mitigation – smolts to be released in May through July and yearlings released in September through November. Both groups are to be released on the Mokelumne River. Note that some experimental releases may be made in the Delta.

- Ocean Enhancement – Released during the May-June period in the estuary.

- Steelhead –Released in January in the lower Mokelumne River.

- **Marking of hatchery fish.**

  Fall Chinook – All fall Chinook are coded wire tagged and adipose fin clipped.

  Steelhead – All steelhead have adipose fin clips.

- **Relevance to the FRH evaluation.**

  The MRFH fall Chinook founding population originated mostly from the Feather River stocks (Miyamoto and Hartwell 2001).

  There has been extensive movement of genetic material from the Feather River Hatchery to the MRFH.

  There has been extensive straying of Ocean Enhancement salmon that were resulted from eyed FRH eggs and juveniles transferred to the MRFH for rearing and released in the lower estuary (Smith et al. in draft).

Merced Fish Hatchery (MFH)

DFG operates the Merced Fish Hatchery, located below Crocker-Huffman Dam on the Merced River (a tributary to the San Joaquin River) to supplement fall Chinook production on the Merced River. The MRH also provides tagged juvenile Chinook salmon for numerous studies in the San Joaquin River tributaries, the mainstem San Joaquin River and in the Delta.

- **Year hatchery began operations.** 1970. (Using funds from DWR's Four-pumps mitigation program, the hatchery underwent extensive renovation in the 1990s.) Annual funding is from a combination of DFG internal funds and from the 4-pumps mitigation program.

- **Races and species propagated.** The MFH only propagates fall Chinook, although steelhead and spring Chinook are likely to have occurred in the watershed before dam construction eliminated access to the upper watershed (Yoshiyama et al.).

- **Production targets and stage to be released.** The hatchery goal is to produce and release 960,000 smolts. In years of poor river conditions or low escapement, up to 330,000 fish may be kept over for release as yearling. Each year, 30,000 smolts are released as part of DWR's obligation to mitigate for salmon losses at its Delta pumps.

- **Release location and timing.** Although the plan is to release all fish on site, in reality, the experimental releases result in a significant portion of the production being released off-site. Smolt production releases are typically scheduled for the April through June period and yearling releases from October through December.

- **Marking of hatchery fish.** All hatchery fish are coded wire tagged and marked.

- **Relevance to FRH evaluation.**

  The Merced River fall Chinook population is the southernmost population in the Central Valley and such may provide useful information on Chinook salmon at the southern end of its range and how the fish handles changing environmental conditions.

  Comparing recoveries from off-site and on-site releases provides information on straying impacts of these release strategies.

  Until the late 1990s, many FRH juvenile salmon were used for experiments on the San Joaquin system. In almost all instances MRH fish have replaced the FRH experimental releases on the San Joaquin. The change was made due to concerns about use of out-of-basin fish in the experiments.

Summary of Central Valley Hatchery Salmonid Production Goals

As shown in Table 1, the goals of the five Central Valley salmonid hatcheries are to produce about 33 million Chinook salmon (all races) and 1.5 million steelhead for release each year in the streams and in the San Francisco Estuary. The FRH is the only source of hatchery spring Chinook, the CNFH the only source of late fall Chinook and LSNFH the only source of winter Chinook. The FRH releases about 25% of the hatchery fall Chinook production. A variable but significant percent of hatchery produced salmon is used for experimental purposes. All steelhead are released in the watershed relatively close to the hatcheries.

Table 1. Overall summary of production goals for Central Valley Chinook salmon and steelhead hatcheries

	Production goals by race (x million)				
Hatchery	*Winter*[1]	*Spring*	*Late fall*	*Fall (m)*	*Steelhead*
CNFH	---	---	1(y[2])	12(s[3])	0.6(y)
LSNFH	0.25(as[4])	---	---	---	---
FRH	---	5	---	8(s)	0.4(y)
NFH	---	---	---	4(s)	0.43(y)
MRFH	---	---	---	6.75(s&y)	0.1(y)
MRH	---	---	---	0.96(s)	---

The figures in Table 1 are production goals. For fall and late fall Chinook, the goals are generally achieved. In recent years winter Chinook production has reached or exceeded 200,000 advanced smolts. Spring Chinook production at the FRH has never reached the goal - for example in the 2001 and 2002 broodyears, the actual releases amounted to less than one-half of the target. Failure to meet spring run production goals has been due to a combination of lack of adutls and inability to process to process a sufficient number of adults (A. Kastner, DFG, personal communication.)

TASK 5. Describe Feather River Hatchery Facilities and Operations for the Period 1967-2003.

Feather River Hatchery (FRH)

In describing the FRH we loosely follow the NOAA template for a Hatchery and Genetic Management Plan (HGMP) (NOAA Fisheries 2002.). The sections we omit most often deal with impacts of hatchery operations on ESA species - impacts that are assessed following the hatchery descriptions. Much of this information can be used to prepare a HGMP for the Feather River Hatchery. General information on the FRH can be found at http://www.dfg.ca.gov/lands/fh/feather/feather_index.htm

General Program Description

1. Name of Hatchery or Program:

1Note that winter Chinook production is based on an allowable percentage of the natural run that can be used for brookstock and has varied considerably from year to year.
2y = yearlings
3s = smolts
4as = advanced smolts

This facility is referred to as the Feather River Hatchery and includes the Thermalito Annex.

2. The hatchery propagates:

   a. Spring Chinook salmon (*Oncorhynchus tshawytscha*). Federal and state threatened species.

   b. Fall Chinook salmon. Federal candidate species.

   c. Steelhead rainbow trout (*Oncorhynchus mykiss*) Federal threatened species.

3. Responsible Organizations and Individuals:

   a. Anna Kastner, Manager

   b. California Department of Fish and Game

   c. Address: 5 Table Mountain Blvd., Oroville, CA 95965

   d. Phone number: (530) 538-2222

   e. Cooperator - California Department of Water Resource (DWR)

4. Funding Source and Staffing Level:

   a. DWR funded construction and operation of the Feather River Hatchery

   b. The FRH is staffed by 12.5 full time employees and 4 seasonal workers.

   c. Annual operational costs are approximately $1,000,000 (2002-2003 fiscal year).

   d. Construction of the Thermalito Annex was funded by a DFG salmon stamp program. Operation of the Annex is covered in the annual DWR-DFG contract for operation of the FRH.

5. Location of Hatchery and Associated Facilities

The FRH is located on the Feather River in the town of Oroville, California. The Thermalito Annex is located about 10 miles from the FRH along the Thermalito Afterbay. Figure 14 provides a general map of the area.

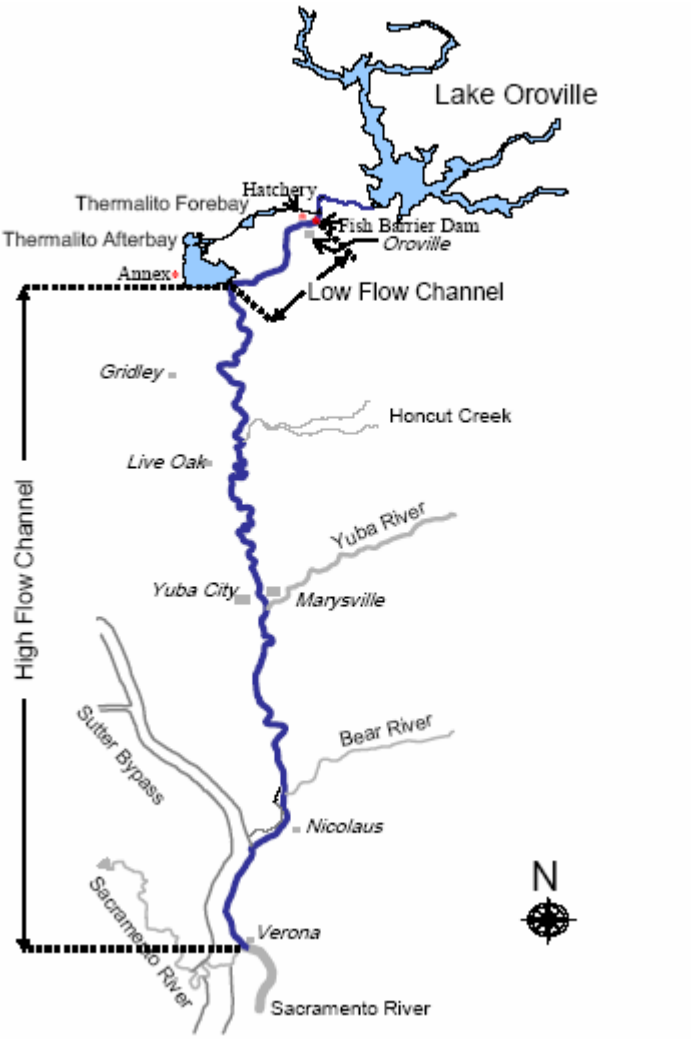

Figure 14

Figure 14. Feather River and Feather River Hatchery

6. Purpose (Goal) of Program

The FRH is operated to partially mitigate for lost salmon and steelhead production that occurred in the Feather River watershed in the years immediately prior to construction of Oroville Dam. In the 1980s, DFG used funds from the ocean trollers to construct additional salmon culture facilities on a separate site about 10 miles from the FRH, called the Thermalito Annex. The new facility was designed to enhance the numbers of fall Chinook salmon available in the ocean fisheries. Although not formally connected to the mitigation hatchery, all broodstock for the enhancement program is collected at the Feather River barrier dam/ladder complex, spawning and incubation are carried out at the FRH and the fish are released with mitigation fish in San Pablo Bay. In addition, in the past production fish were often moved between the two facilities to enhance growth, reduce density at the main hatchery, or for disease control. The Annex, and "enhancement" production is included in this analysis - mainly because it is impossible to cleanly separate their impacts.

The annual broodstock collection levels for the mitigation program are geared to produce the following numbers of eggs and juveniles, by race and species (Table 2).

Table 2. FRH production goals

Race/Species	*Number of Eggs*	*Release Goals*
Spring Chinook	up to 7,000,000	5,000,000 smolts
Fall Chinook	up to 12,000,000	6,000,000 smolts
Steelhead	up to 1,000,000	400,000 yearlings

The 12 million fall Chinook egg take provides sufficient eggs to produce two million enhancement smolts at the Thermalito Annex and two million smolts at the Mokelumne River Hatchery. In 2000, DFG stopped transferring eyed eggs to the Mokelumne River Hatchery for the salmon enhancement program. (Recent escapements to the Mokelumne River have been adequate to meet their egg needs.) Steelhead eggs are still being transferred to the Mokelumne River Hatchery (MRH)as part of a mitigation program for Delta pumping impacts. For example, in 2003 more than 300, 000 eyed eggs were transferred from the FRH to the Mokelumne with the goal of producing about 100,000 yearling steelhead at the MRH.

7. ESA Coverage for Operations of the Feather River Hatchery

DFG has an ESA section 4-d permit for experimental operation of the fish ladder during the spring and summer. Hatchery operation is covered under a biological opinion issued as part of the OCAP on operation of the CVP and SWP.

8. Relationship of FRH Program to Other Management Objectives

As mentioned earlier, the FRH is one of six Central Valley hatcheries that produce and release Chinook salmon and steelhead. There is no integrated plan or agreement linking the hatcheries. Three state-operated hatcheries (Feather, Nimbus, and Mokelumne) operate under production goals and constraints developed by the Department of Fish and Game (DFG et al. 1999 and Attachment 3). The fourth state-operated hatchery, the Merced Hatchery, has less formal production goals based on a combination of desired in-river releases and needs for experimental fish. The production protocols define such hatchery related procedures as source of broodstock, distribution of egg allotment, production goals, spawning protocols, disposition of trapped salmon and steelhead, etc. The two federally operated hatcheries (Coleman and Livingston Stone) have similar operating procedures as described by the USFWS (2001).

Although there are no direct relationships of hatchery operations to harvest objectives, the Pacific Fishery Management Council's framework management plan contains a Sacramento River fall Chinook escapement goal of 122,000 to 180,000 fish (PFMC 2004). Since it is likely that a significant fraction of returning adult fall Chinook are of direct hatchery origin, the hatcheries have a major role in meeting this objective. Before 1989, the PFMC and its member agencies based their projections of the Central Valley Index (CVI, an index of the combined Central Valley Chinook salmon stocks) on recent CVI levels, hatchery releases and previous year two-year old returns. Since 1991 the PFMC's Salmon Technical Team has used a linear regression of the CVI on the Central Valley's jack (two-year old mostly male

salmon) return to forecast the upcoming CVI - i.e. hatchery production is no longer included in the predictive equation (PFMC 2004).

The ocean fisheries benefiting from FRH production are mainly the commercial and recreational ocean fisheries off California and, to a much lesser extent those fisheries off Oregon and Washington. Central Valley recreational anglers also harvest large numbers of Chinook salmon originating in the Feather River and other Central Valley hatcheries. The contribution of the FRH to these fisheries is discussed later in this paper.

9. Water Sources

   a. The FRH draws up to 74 cfs of water from the Feather River at the Thermalito Diversion Dam. Additional water is used for the fish ladder.

   b. The Thermalito Annex, near the Thermalito Afterbay, uses about 12 cfs of well water that have percolated through Thermalito Afterbay soils. In both cases, the water supply comes from sources that do not involve ESA issues. (The Thermalito Diversion Dam is above the fish barrier dam thus no listed species are in the intake water.)

10. Facilities

We briefly describe the FRH facilities and, as appropriate, those in the Annex. Note that all fish for both facilities are collected, spawned and incubated at the FRH. The Annex is basically a grow-out operation. Overall facility schematics are found in Figures 15 and 16.

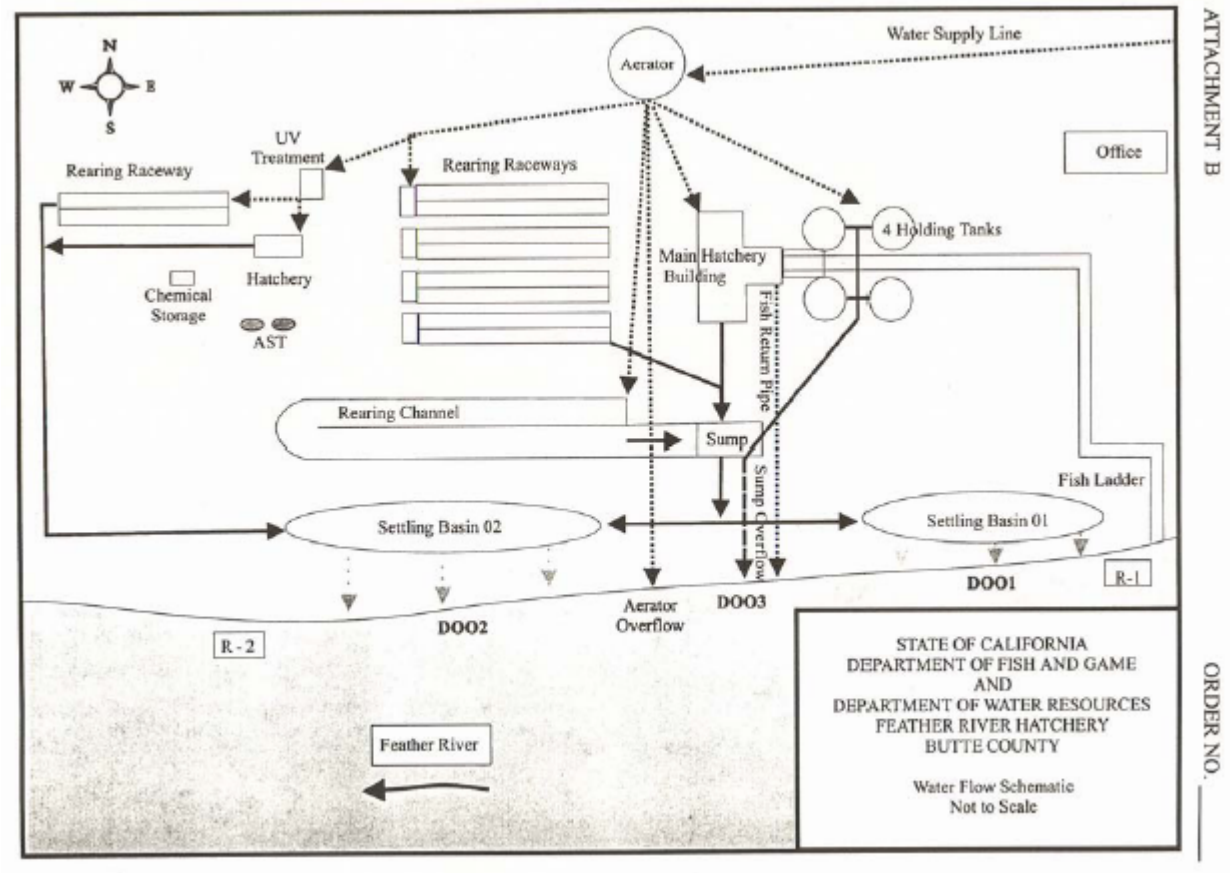

Figure 15

Figure 15. Schematic of Feather River Hatchery

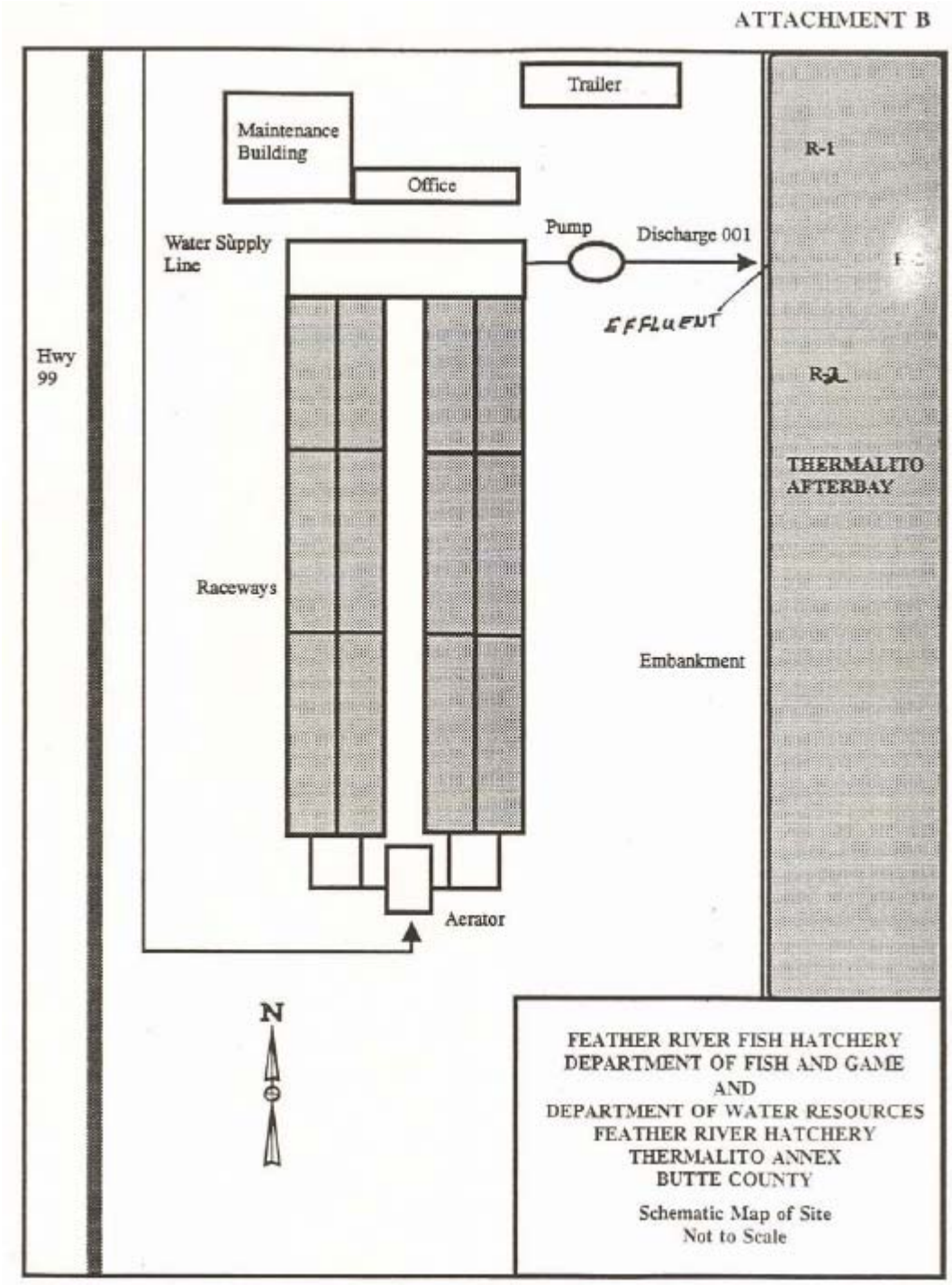

Figure 16

Figure 16. Schematic of Thermalito Annex to FRH

- **Broodstock collection facilities.** All upstream migrating Chinook salmon and steelhead are stopped at the Fish Barrier Dam (Figure 14). A one-half mile long gated fish ladder at the base of

the dam allows fish to move up to the hatchery. The ladder gates are generally open from about September 1 through the following March to ensure that spring and fall Chinook and steelhead have an opportunity to enter the hatchery. Four circular concrete tanks in the hatchery hold the adults until hatchery staff determines they are ready to be spawned.

- **Spawning.** Mature fish are moved to a separate building for spawning and egg fertilization.

- **Incubation.** Hatchery staff transfers the fertilized eggs to an incubation building where they are held until the button-up stage. In the past eyed eggs were also transferred to other hatcheries - notably to the Mokelumne River Hatchery - for both their mitigation and enhancement programs. After 1999 these transfers no longer occur. Note that in 2000 DWR completed an addition to the incubation facilities that allowed for better separation (and disease control) for Chinook salmon that were destined for planting in Lake Oroville in an effort to provide an in-reservoir cold-water fishery. (Some of these fish were also planted in other Central Valley reservoirs.) Due to disease concerns (mainly IHNV), in 2000 DFG stopped planting juvenile Chinook in Oroville Rreservoir. The new incubation facility is now being used to incubate inland salmon plants (coho, for example) or steelhead eggs if no inland fish are available.

- **Rearing.** Salmon and steelhead fry are transferred to a series of concrete lined raceways. The raceways are covered with a wire mesh enclosure to limit avian depredation. Nominal flow and water velocity are 5 cfs and 0.1 fps respectively in each raceway. The raceways can be blocked at various intervals to provide holding space for special studies or for holding individual groups of marked and tagged fish. Fish destined for the enhancement program are transported to the Thermalito Annex for rearing in additional concrete raceways. Due to temperature differences in the water supplies for the hatchery and the Annex (the Annex water is generally warmer during the rearing season) in the past fish were occasionally moved to the Annex for faster growth or to control diseases (IHNV in particular). After growth had been achieved, or disease problems eliminated, the fish could be returned to the main hatchery. As of 1993, this practice of moving fish back and forth had been mostly discontinued and the Annex is being used almost exclusively for enhancement fish, although some mitigation fish may be reared there. (A. Kastner, DFG, personal communication).

- **Transportation.** DFG currently uses five tanker trucks - one, 600-gallon, one, 1,200 gallon, and three, 2,800 gallon capacity - to move the juvenile salmonids from the hatchery to release locations in the Feather River, the Sacramento River, the Sacramento-San Joaquin Delta and San Pablo Bay. Internal baffles minimize damage to fish during transport and the haulers may use chilled water and salt in the water to minimize stress during transport. For this analysis of hatchery impacts, it is important to note that the 2800 gallon tanks have only been used since 1987-1991 (first large tanker acquired in 1987, third in 1991). Before then, the hatchery used one 600 gallon, one 1200 gallon and one 2500 gallon tankers to move the fish. With the smaller tankers, it often took most of the summer to move the entire production to the release sites. Now FRH Chinook salmon production releases are always completed by mid July, and generally earlier. This change in release timing may be ecologically important in that release timing may be more in line with the fish's physiological state (e.g. smoltification), thus less stressful.

11. Broodstock Origin and Identity

DWR began construction of Oroville Dam in the early 1960s. As part of the construction process, the contractor diverted the Feather River past the site through a tunnel. DWR funded DFG to construct and operate a fish trap near the downstream end of the tunnel where DFG staff collected adult Chinook salmon and steelhead and transported them by truck to the river above the construction site (DFG 1964). The October 1963 through June 1967 data provide some of the best information available on the abundance and timing of Feather River salmonid runs immediately before the dam was closed in 1967. Since the FRH staff began collecting fish from the river in 1967, the data also provide an idea of the abundance of the founding stocks.

The fish trap data are plotted in Figures 17 and 18. The total numbers of fish trapped for the three years of complete data are shown below in Table 3.

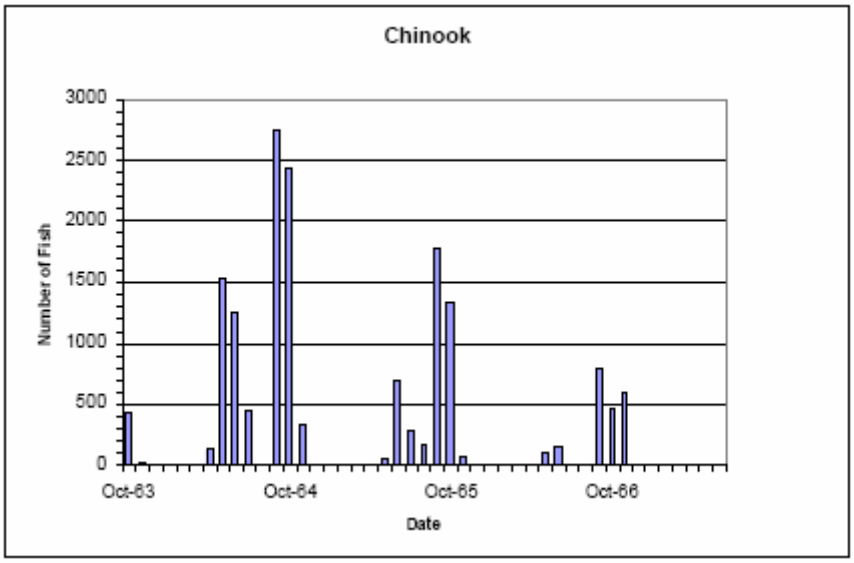

Figure 17. Numbers of adult Chinook salmon captured at mouth of construction tunnel bypassing Oroville Dam site – 1963 - 1965

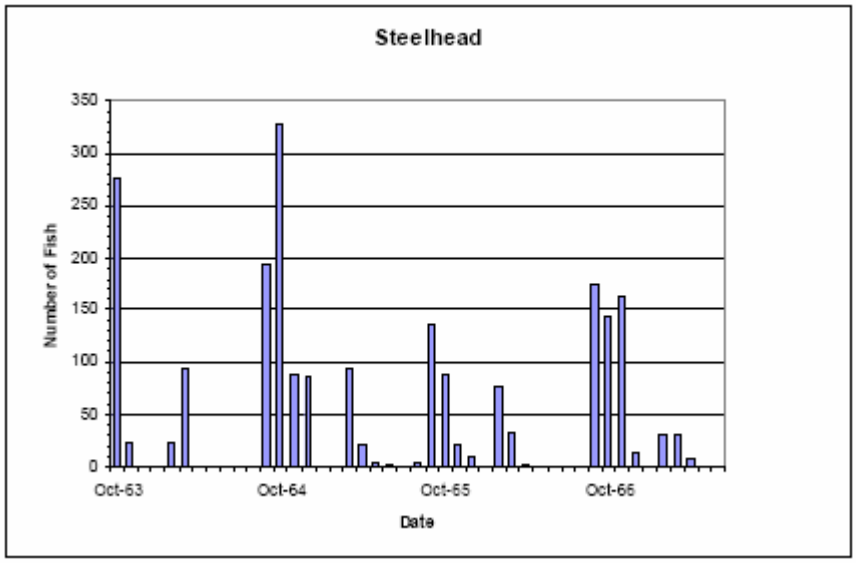

Figure 18. Numbers of adult steelhead captured at mouth of construction tunnel bypassing Oroville Dam site – 1963 - 1965

Table 3. Total numbers of Chinook salmon and steelhead trapped at (Data from Rice 1964, Rice and Pollitt 196, Rice 1967)

Species or Race	*1964*	*1965*	*1966*
Steelhead	813	383	607
Spring Chinook	3377	1015	304
Fall Chinook	5531	3355	1893

The data in Figures 17 and 18, and in the above table, lead to a few observations about the runs, and possible FRH founding stocks:

- Steelhead runs to the Feather River were relatively small during the three years before the dam was closed, and most of the fish (average of 78%) showed up at the trap during the fall months.

- Spring Chinook run sizes were variable with an average of around 1600 fish. Most of the fish arrived at the trap during the April through early July period, with an apparent peak in May and June. (Note that we included July fish in the spring run category.)

- Fall Chinook were numerically dominant with an average run size of around 3600 fish with most of the fall run arriving at the trap in September and October. (Note that the trap was above much of the fall Chinook spawning grounds and thus the data underestimate total run size.)

For spring and fall Chinook, the fish trap data are about the best we have on run size and timing for the runs that might have been taken into the hatchery beginning in the fall of 1967. When the FRH began

operating, there were already three Central Valley hatcheries producing steelhead - Coleman, Nimbus and Mokelumne River. These hatcheries marked (fin clips) and released some of their production at various locations in the Delta. As shown in Table 4, fish from these releases made up a varying proportion of the steelhead being taken into the FRH during the 1971-72 through 1974-75 seasons.

Table 4. Numbers and origin of marked steelhead recovered at the FRH - 1971-1975. (Data from Schlicting 1972, 1975, 1978a, 1978b)

Source	*1971-72*	*1972-73*	*1973-1974*	*1974-1975*
FRH	---	163	75	166
CNFH	37	20	5	---
NFH	11	6	23	12
NFH/MFH[5]	NA[6]	39	NA	---
MRH/FRH[a]	8	22	3	---
MRH/NFH/FRH[a]	6	NA	NA	---
Unknown	34	6	8	---
Yearly totals	96	258	117	178

Strays from other Central Valley hatcheries appear to have contributed to the Feather River founding stock. As was discussed earlier, fish from the Nimbus Hatchery were originally derived from coastal stocks. As hatchery managers moved away from releasing steelhead in the estuary, the numbers of strays to the Feather River decreased.

In addition to strays contributing to the founding FRH stocks, in the early years some eyed eggs and juvenile salmon and steelhead were brought into the hatchery to augment production that was being limited by the number of spawners or losses to such diseases as *Ceratomyxa shasta* and Sacramento River Chinook Disease (now known as infectious hematopoietic necrosis virus, or IHNV). A few examples of these transfers of genetic material into the hatchery are:

- 1967 broodyear: 185, 000 eyed steelhead eggs brought in from Nimbus
- 1969 broodyear: 650,000 yearling steelhead brought in from Nimbus
- 1970 broodyear: 2.3 million eyed steelhead eggs brought in from Nimbus
- 1970 broodyear: 150,000 yearling steelhead brought in from Nimbus
- 1971 broodyear: 2.9 million eyed fall Chinook eggs brought in from Nimbus.

5Same mark at these hatcheries thus could not determine origin.
6Mark combination not applicable.

Early on there was an attempt to establish the summer steelhead run on the Feather but the run did not take. As disease problems were brought under control and the Feather River runs increased, direct transfers of genetic material into the hatchery decreased.

To compensate for expected low natural adult steelhead returns during the first years of hatchery operation, and to combat the effects of *Ceratomyxa* and other diseases, DFG staff began a domesticated broodstock program for steelhead. From each of the initial broodyears, DFG held juveniles at the hatchery until they were ready to spawn. To all appearances the program was moderately successful but seems to have been terminated after spawning 79 females from the 1975 broodyear. DFG returned surplus adult broodstock to the river. There was no marking program to determine the fate and contribution of juveniles released as part of the domesticated steelhead component of FRH initial operations. As was shown in Table 4, the domesticated steelhead likely included strays from other Central Valley hatcheries and thus probably did not represent a true Feather River strain.

A final complication to the steelhead founding stock involves periodic attempts to establish non-native (or at least not present when Oroville Dam was constructed) steelhead runs on the Feather River. For three years in the late 70s early 80s, DFG brought Washougal (Washington) strain steelhead to the FRH and planted them in-river to establish a summer run, with the goal of prolonging the angling season. Fish from the Mad River strain were also planted in the Feather River. In the case of the Washougal strain, the fish were marked and the lack of recoveries indicated that the strain did not do well in the Feather River. The strain was no longer planted after the 3-year experiment.

In the case of the spring Chinook, diseases and handling and holding losses compromised the hatchery's early efforts to effectively use the native spring Chinook to support the mitigation program. Hatchery staff attempted to hold adult spring Chinook in the hatchery for the first three years with varying levels of success. External pathogens (bacteria and Ich) were the major problems associated with holding adult fish. In year 3 of the hatchery operation, DFG decided to leave the adults in the river until they opened the ladder around the first of September. Table 5 summarizes the numbers of spring Chinook adults captured and spawned during the first 5 broodyears and the numbers of juveniles released.

Table 5. Spring run statistics from first five broodyears at the Feather River Hatchery

			Numbers Released	
Broodyear	*Adults Collected*	*Females Spawned*	*Fingerlings*	*Yearlings*
1967	146	29	---	71,000
1968	171	60	---	25,000
1969	351	121	106,000	71,000
1970	235	65	26,500	233,000
1971	484	211	32,000	157,000

The data indicate that the spring run persisted in low numbers during the first years of hatchery operation but that production was low. Although production was low, the cohort replacement rates for the 1967 and 1968 cohorts were encouraging, 2.4 and 2.8, respectively. Since cohort replacement rates are affected by a variety of conditions, not much should be read into this other than during the early years of operation a spring run persisted on the Feather River in spite of disease and other problems at the hatchery.

12. Broodstock Collection

The following is based on the 1999 DFG et al. document, *Feather River Hatchery - Production Goals and Constraints* (Attachment 3). All broodstock is currently collected from the Feather River via the fish trap and ladder at the base of the fish barrier dam (Figure 14). The assumption is that salmon and steelhead entering the hatchery of their own volition are representative of the runs spawning in-river. To capture both races of Chinook salmon and steelhead the fish ladder is typically opened on or about September 1 each year and closed around the end of the following March.

Hatchery staff uses time of volitional entry into the ladder and hatchery to separate spring from fall Chinook. Based on previous data and life history characteristics, the earliest salmon entering after the gates open are assumed to be spring run. In a typical year the gates are opened on September 1 and all Chinook entering through September 15 are considered spring run. (This short window has been one of the reasons the FRH has been unable to meet spring run production goals.) Salmon entering the hatchery after September 15 are considered fall Chinook. (It should be noted that there has been minor year-to-year variation in the date of ladder opening and the cutoff date.) Although many fish returning to, or straying to, the FRH are marked with an adipose clip, the presence or absence of a clip is not considered in whether a fish should be spawned.

The number of broodstock collected is keyed to the following production goals:

- Mitigation spring Chinook: 5,000,000 fish, at least 60/pound and preferably larger.
- Mitigation fall Chinook: 6,000,000 fish at least 60/pound and preferably larger.
- Enhancement fall Chinook: 2,000,000 fish 30/pound.
- Fall Chinook for the Mokelumne River Hatchery. Until 1999 sufficient fall Chinook eggs were taken to provide up to 4 million eyed eggs to the Mokelumne River Hatchery.
- Fall Chinook for inland planting. Until 2000 there was a goal to take up to 2 million eyed eggs from the earliest spawning fall Chinook for release in inland reservoirs. If certified disease free by the DFG pathologist, these fish were reared for planting in Lake Oroville as part of the FERC mandated program to maintain a coldwater fishery in Lake Oroville. (Some of the inland Chinook were also planted in other California reservoirs.) This program was discontinued in 2000 due to concerns that planting Chinook salmon in the watershed above the hatchery had caused serious outbreaks of IHNV in the hatchery. (BY 1999 fry being reared for the inland fishery program were destroyed in May 2000 and no Feather River Chinook eggs have been collected for the inland program since then.)
- Oroville Dam mitigation steelhead. The goal is to produce and release 400,000 yearling steelhead.

- Delta pumps mitigation steelhead. The goal is produce and release 50,000 yearling steelhead.

Table 6 lists the numbers of salmon and steelhead broodstock collected at the FRH for the past 37 years. The adults are held in circular tanks until they are ready to be spawned. When necessary the ladder is closed to prevent the tanks from being overcrowded. Unneeded fish are returned to the Feather River. A DFG pathologist periodically examines the collected adults for diseases.

Table 6. Trapping record at Feather River Hatchery

Year	*Spring Chinook*	*Fall Chinook*	*Steelhead*
1967	146	1,856	no info
1968	171	5,446	1,005
1969	no data	no info	361
1970	235	3,346	no info
1971	484	3,539	78
1972	256	3,635	288
1973	205	8,477	1,000
1974	198	5,428	715
1975	691	5,025	758
1976	713	5,198	573
1977	194	8,787	163
1978	202	4,759	153
1979	250	4,090	189
1980	122	3,690	238
1981	469	8,282	414
1982	1,910	7,778	537
1983	1,710	7,699	1,238
1984	1,562	9,288	783
1985	1,632	5,811	1,721
1986	1,433	8,628	1,553
1987	1,213	10,108	1,018
1988	6,883	6,480	2,587
1989	5,078	7,578	1,106

1990	1,893	6,126	1,193
1991	3,338	7,830	1,025
1992	1,670	16,636	1,028
1993	4,672	11,985	297
1994	3,641	15,202	1,594
1995	5,414	12,149	877
1996	6,381	8,107	1,058
1997	7,017	15,128	2,113
1998	6,746	18,889	1,220
1999	4,534	12,927	642
2000	3,972	18,146	1,742
2001	4,078	24,870	2,161
2002	4,189	20,507	1,444
2003			2,929

Chinook salmon carcasses are disposed of in the following manner:

- The heads of all adipose clipped salmon are removed from the carcasses, recorded, and stored for coded-wire tag processing. The heads are periodically transferred to the DFG tag recovery/decoding laboratory in Santa Rosa.

- Carcasses with food value are donated to nonprofit organizations. The hatchery manager has the authority to determine the suitability of the carcasses for donation.

- Carcasses not donated to nonprofit organizations are disposed of at a rendering plant or other appropriate refuse disposal site. Since 1996, no FRH salmon carcasses have been returned to the Feather River

  Steelhead are spawned live and all fish surviving the spawning process are returned directly to the Feather River.

13. Mating

In 1997 hatchery staff began taking eggs from all fall Chinook entering the hatchery. DFG arrived at the number of eggs needed from each female by plotting the average spawning run timing and numbers over the past 10 years (a bell shaped curve, Figure 19) and assuming that ounce of eggs contained about 90 eggs. Using these calculations, the desired egg take per female was found to be 33 ounces. (Due to the larger than average runs in recent years the egg take per female has been reduced to 25 ounces.) With this egg take the hatchery could reach its goal of taking 12 million eggs. The hatchery now uses a fertilization procedure in which eggs from three females are mixed with sperm from three males. Based

on a recommendation from NOAA Fisheries, hatchery staff includes up to 5% 2-year-old males (jacks) in the spawning population. There is no policy about limiting the numbers of adipose clipped (mostly hatchery origin) fish in the spawning population and the presence of an adipose fin has no bearing on whether the fish will be spawned in the hatchery.

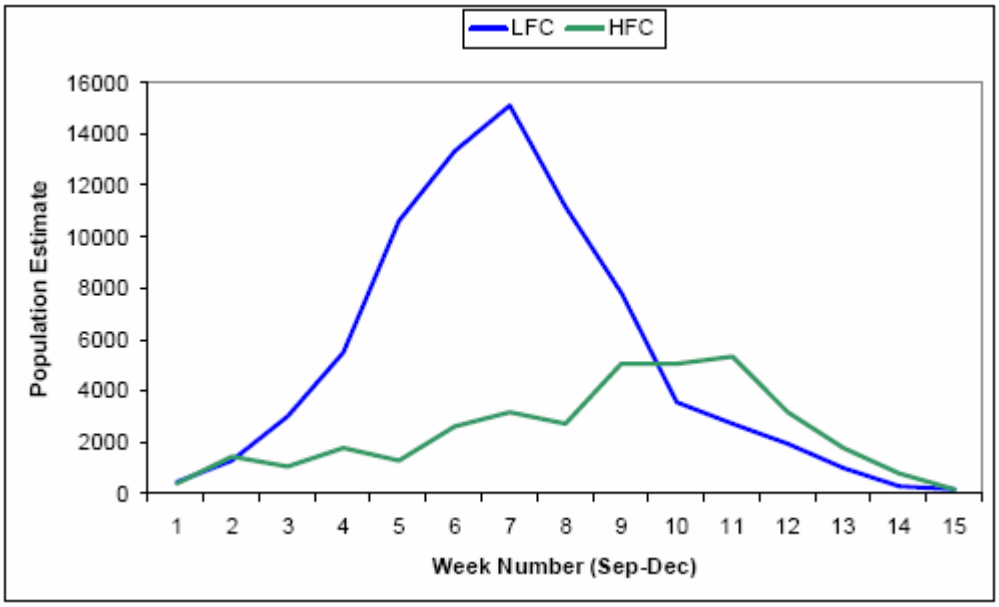

Figure 19. Estimated spawning populations of Chinook salmon in the Feather River's low (LFC) and high flow (HFC) channels

By the time the first lot of eggs is eyed, about half way through the spawning season, staff can reduce the number of eyed eggs to meet the egg take goal. The reduction is based on total number of eggs taken in relation to the goal and is taken from all egg lots across the season.

Since the numbers of spring Chinook and steelhead returning to the hatchery are relatively low, eggs are collected from all females and there are generally no subsequent reductions at the eyed stage. (Reductions in steelhead embryos may be required in those years when eggs are not needed for the Mokelumne River Hatchery program.)

The hatchery now has some late fall Chinook entering the hatchery in late December. These fish are from the Coleman National Fish Hatchery and have been released off site to evaluate emigrant survival through the Sacramento San-Joaquin Delta. The late fish are not incorporated in the spawning population. Adipose clipped fish are sacrificed and the heads sent to DFG's Santa Rosa laboratory for tag extraction and decoding.

In summary the mating protocols now in place are designed to incorporate all components of the Feather River runs into the genetic makeup of the hatchery-produced Chinook salmon and steelhead. Before 1997, hatchery staff used considerably different procedures for fall Chinook. All the eggs the

hatchery staff could incubate were kept (up to 32 million each year) and resulting fry were ponded from lots scattered through the year. The remaining (excess) fry were released into the Feather and other rivers at the swim-up stage. The eggs from two females were fertilized by placing them into a tub with a mix of the sperm from three or more males. A male would be used in successive tubs until milt could no longer be expressed.

14. Incubation and Rearing

The fertilized salmon eggs are incubated in 128 vertical flow incubators. For steelhead, hatchery staff may use either the vertical flow incubators or hatching jars. The only treatment is iodine for disinfection. The eggs are not checked or disturbed any way until at the eyed stage. After that the eyed eggs are checked daily and dead eggs removed at least every third day.

Once the fry reach the button-up stage (all the yolk sack absorbed) they are moved to the raceways. (Hatchery staff also keeps track of daily temperature units with about 1500 daily temperature units needed before the fish are ready to move outside. Depending on water temperature, reaching the button up stage takes from 75 to 90 days.) Initial stocking density in the raceways is around 1.5 million fish per raceway. (As part of the Ocean Enhancement Program, up to three million fry are transferred to the Annex for rearing.) As the fry grow, stocking density per raceway is around 800,000 to 900,000 fish. When the fry reach about 300/pound, some of the fish are moved the channel. During this period tagging operations, and the need to confine relatively small lots of tagged fish in sections of the raceways, can limit rearing capacity in the raceways.

The Chinook salmon are fed Skretting (formerly known as Moore Clark) with a conversion efficiency goal of 1.06%. Steelhead are initially fed Skretting and subsequently switched to extruded feed, either Silvercup or Rangen.

If no disease problems are reported by the hatchery manager, DFG pathologists may perform routine health assessments. DFG uses a modification of the organosomatic analysis system (Goede et al. 1987 as modified by Foott 1990) to check and report on the condition of the fish. The DFG pathologists typically examine 20 juveniles randomly selected from the middle of the pond before the fish are to be planted in the estuary. DFG policy is not to plant diseased fish. As William Cox, DFG pathologist, emphasized in a recent workshop on Battle Creek, there is a distinction between infected and diseased fish, Figure 20 (B. Cox, DFG as cited in Brown and Kimmerer 2004). Many fish are infected but do not show clinical signs of disease.

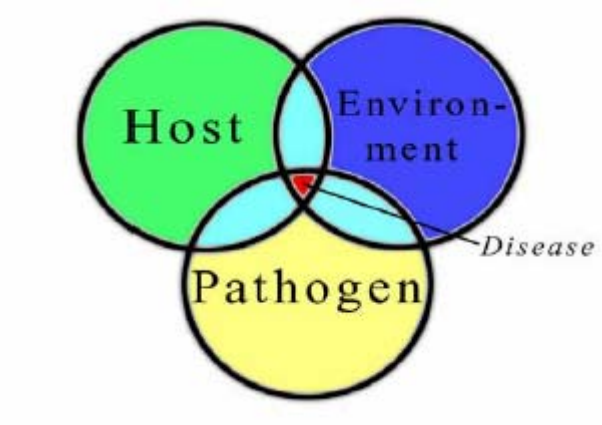

Figure 20. Relation between host, environment, and pathogen that results in disease. From W. Cox, DFG.

If the hatchery manager notices excessive mortality in the incubators, tanks or the raceways the pathologist is called in to determine if mortalities are pathogen related. If clinical signs of specific diseases are detected, the pathologist may recommend treatment or, in rare cases, disposal and release of the diseased fish. A decision to release clinically diseased fish is based on the understanding that the chances of the disease spreading to wild fish are minimal, such as the case of freshwater parasites that do not survive after the fish are released in the lower estuary. In the case of recent outbreaks of IHNV at the FRH, some clinically diseased fish were transferred to the Thermalito Annex, where warmer water suppressed clinical manifestation of the disease.

Overall detection and treatment of diseases in hatchery fish is complicated by staff reductions in DFG's pathology section and limitations on the chemicals that may be used to treat disease outbreaks.

15. Release

In the past, fish were generally released when they reached 90/pound. In the mid-80s this size criterion was changed to 60/pound. The 60/pound is the current target with a subset of the fish subjected to a salt water challenge (30 parts per thousand for 24 hours) to verify their readiness for release in the estuary.

Release strategies can be divided into three separate categories - production releases, experimental releases and releases of surplus fry. All releases strategies have evolved over the past thirty seven years and continue to evolve. The following briefly describes each category of releases.

- Production Releases

During the first few years, FRH production of fall and spring Chinook was released in the Feather River. Subsequent studies demonstrated that early survival, and return to the fisheries and to escapement, could be increased dramatically if the salmon were released in the estuary. Although studies also showed that fish released off site showed increased straying, it became DFG policy to release all FRH production in the estuary. (DFG has always released steelhead in-river.) After some experimentation, DFG concluded that fall and spring Chinook should be released as smolts. Two significant changes in release practices have occurred over the years,

- Moving to larger tanker trucks. Until 1987, DFG used 3 tanker trucks with a total capacity of 3,700 gallons. With this limited hauling capacity, it took several months to move the production fish to the estuary - with accompanying feeding costs and possible stress associated with over summering the fish in Oroville. By 1991DFG had acquired 3 large tanker trucks and can now plant all production salmon by July 1 in essentially all years.

- In 1994 DFG, with financial support from the Fishery Foundation and DWR's Four Pumps Mitigation Agreement, began a multi-year evaluation of the use of floating net pens to release fish in to the estuary. The typical (control) release practice was to dump the fish directly in the estuary through a short pipe attached to the tanker truck. The experimental practice was to place the fish in a floating net pen, close the pen and tow the juvenile salmon and pen a few hundred yards to a few miles from shore and then release the fish. The hypothesis being tested was that a few hours in the net pen would allow the fish to better acclimate to the receiving water. Also built into the hypothesis was off-shore releases would avoid significant predation by striped bass and birds at the release site. All released fish were marked with an ad clip and had coded wire tags inserted in their snouts to identify the test groups The experiments were conducted in June and July of all years.

The results of the ocean recoveries for the three-year study are summarized in Table 7.

Table 7. Comparison of recoveries of tagged juvenile Chinook salmon released from net pens and transport trucks, 1994-1996

	Numbers Released		*Ocean Recoveries*[7]	
Release Year[8]	*Control*	*Experimental*	*Control*	*Experimental*
1994	149,554	149,002	1057	2565
1995	139,443	147,816	716	1878
1996	149,440	150,089	1077	2595

The overall result is that net pen released salmon were caught in the ocean at a rate of roughly 2.5 times (range of 2.4 to 2.6) that of fish released directly from the trucks to the estuary. This effect was confirmed in freshwater where the ratio of recoveries was also 2.5. Interestingly, more than 95% of the fish escaping the fisheries returned to the Feather River or the Feather River Hatchery - with a few straying to the Nimbus and Mokelumne River facilities.

Such promising results led DFG to adopt the net pens as its standard release practice in the estuary. From 1995 to 2002, essentially all production was released with the net pen technology. In 2003, use of the net pens was discontinued due to the deteriorating condition of the nets and the boat used to tow the nets offshore. DFG is rebuilding the nets and will replace the boats to allow resumption of net pen releases as funding allows.

Table 8 summarizes the production releases for spring and fall Chinook and steelhead for the period 1967 through 1987. Note that these figures were taken from the annual DFG FRH reports and in some cases we had to guess at the meaning of some of the numbers. (The numbers have been reviewed by the current hatchery manager and we agreed they are about the best we can do.)

Table 8. FRH production releases, 1967 through 1987

Report Year	*# Fish Planted*
67-68	-424,000 fall fingerling
	-124,000 SH fingerling
	-11,250 SH yearling
68-69	Artificially Spawned
	-437,200 fall fingerling
	-338,475 fall yearling

7Recoveries through year 4 of the cohorts in ocean fisheries off CA, OR and WA.
8Adapted from DFG memo to Randall Brown dated 2/14/00.

	Spawning Channel
	-90,640 fall fingerling
69-70	1968 Brood Year
	-1,790,000 fall fingerling
	1969 Brood Year
	-1,170,500 fall fingerling
	1967 & 1968 Brood Year
	-1,000 SH yearling
70-71	1969 Brood Year
	-535,500 fall fingerling
	-157,800 fall yearling
	1970 Brood Year
	-5,599,670 fall fingerling
	-562,000 SH FRH domestic fing.
	-208,000 SH FRH domestic year.
	-75,000 SH FRH wild fing.
	-48,000 SH FRH wild year.
	-147,500 SH NFH yearling
	-1,000 SH FRH domestic yearling (67-69 brood year)
	-631,250 fall NH year. (69 BY)
	-2,276,020 fall NH fing. (70 BY)
	-912,200 fall CNFH yrl. (69 BY)
71-72	1970 Brood Year
	-1,715,790 fall yearling
	1971 Brood Year
	-2,802,750 fall fingerling
	-84,700 wild SH yearling
	-500,000 domestic SH fingerling
	-473,050 domestic SH yearling
72-73	1967-68 Brood Year
	-95 domestic SH yearling

	1971 Brood Year
	-548,355 fall fingerling
	-682,988 fall yearling
	-960 domestic SH yearling
	1972 Brood Year
	-956,315 fall fingerling
	-3,837,575 NH fall fingerling
	-595,700 domestic SH fingerling
	-181,735 domestic SH yearling
	-63,350 wild SH yearling
73-74	1972 Brood Year
	-253,100 fall fingerling
	-765,269 fall yearling
	-326,200 NFH fall fingerling
	-2,631 NFH fall yearling
	1973 Brood Year
	-4,658,551 fall fingerling
	-681,565 wild SH fingerling
	-122,600 wild SH yearling
	-285,664 domestic SH fingerling
	-88,300 domestic SH yearling
74-75	1973 Brood Year
	-2,050,900 fall fingerling
	-680,210 fall yearling
	1974 Brood Year
	-9,449,019 fall fingerling
	-204,000 wild SH fingerling
	-101,510 wild SH yearling
	-42,710 domestic SH yearling
	-426 domestic SH yearling (assorted years)
75-76	1974 Brood Year

	-837,595 fall yearling
	1975 Brood Year
	-3,271,750 fall fingerling
	-751,600 SH fingerling
	-241,375 SH yearling
76-77	1975 Brood Year
	-809,140 fall yearling
	1976 Brood Year
	-2,207,350 fall fingerling
	-419,760 SH fingerling
	-176,840 SH yearling
	-22,200 SH yearling
77-78	1976 Brood Year
	-655,271 fall yearling
	1977 Brood Year
	-5,839,700 fall fingerling
	-537,938 fall fingerling
	-99,320 summer SH yearling
	-122,380 SH yearling
78-79	1977 Brood Year
	-305,500 fall fingerling
	-733,700 fall yearling
	-704,540 fall yearling
	1978 Brood Year
	-2,821,399 fall fingerling
	-108,230 SH yearling
	-96,230 SH yearling
79-80	1978 Brood Year
	-829,490 fall fingerling
	-1,935,162 fall yearling
	1979 Brood Year

	-2,552,607 fall fingerling
	-83,915 SH (early) yearling
	-122,617 SH (late) yearling
	-126,230 SH summer Washougal yearling
80-81	1979 Brood Year
	-679,036 fall fingerling
	-1,806,612 fall fingerling
	1980 Brood Year
	-2,672,681 fall fingerling
	-6,267,200 NH fall fingerling
	-64,995 SH (early) yearling
	-148,830 SH (late) yearling
	-91,350 NH SH fingerling
	-51,010 NH SH yearling
	-101,250 Washougal SH yearling
	-28,500 Klamath SH yearling
81-82	1980 Brood Year
	-1,262,850 fall fingerling
	-1,821,635 fall yearling
	1981 Brood Year
	-8,007,360 fall fingerling
	-30,024 SH (late) fingerling
	-131,960 SH (late) yearling
	-77,945 SH (early) yearling
	-73,100 NH SH fingerling
	1982 Brood Year
	-69,870 SH (early) fingerling
	-629,800 SH (late) fingerling
	-200,912 NH SH fingerling
82-83	1981 Brood Year
	-1,569,539 fall yearling

	1982 Brood Year
	-6,575,983 fall fingerling
	-180,076 SH (early) yearling
	1983 Brood Year
	-535,966 SH fingerling
83-84	1982 Brood Year
	-869,100 fall fingerling
	-1,312,116 fall fingerling
	1983 Brood Year
	-2,870,035 fall fingerling
	-119,253 SH fingerling
	-326,245 SH yearling
	1984 Brood Year
	-266,633 SH fingerling
84-85	1983 Brood Year
	-1,915,925 fall fingerling
	-576,850 fall yearling
	1984 Brood Year
	-5,927,961 fall fingerling
	-413,870 SH yearling
	1985 Brood Year
	-389,600 SH fingerling
85-86	1984 Brood Year
	-6,495,655 fall fingerling
	-112,800 fall yearling
	1985 Brood Year
	-5,020,625 fall fingerling
	-440,562 SH yearling
	1986 Brood Year
	-938,240 SH fingerling
86-87	1985 Brood Year

-3,756,595 fall fingerling

-1,451,450 fall yearling

1986 Brood Year

-9,528,167 fall fingerling

-452,455 SH yearling

1987 Brood Year

-788,010 SH fingerling

One final point about the release strategy for FRH production fish relates to the special case of spring Chinook. Partly in response to a recommendation in the 2001 DFG/NOAA Fisheries hatchery review report that spring Chinook production be released in river, in 2003, DFG began releasing one-half of the annual production in river and the other half in the estuary. Both release groups were marked (adipose clipped) and coded wire tagged to identify them in the downstream sampling stations, in the ocean fishery and upon their return to freshwater. The rationale is to continue this release strategy for at least three years and examine ocean catches, survival through the Delta and escapement to help identify the release strategy that offers the most biological and social benefits.

- Experimental Releases

  As described earlier, there has been considerable demand for juvenile salmon to be used in experiments in the Delta, as well as the Sacramento and San Joaquin rivers and their bypasses. Hatchery managers have attempted to meet the needs of the researchers and, as a result, several million experimental fish have been marked, tagged and released off site. Minimal consideration was given to the biological consequences of straying that might be associated with these release groups.

  Table 17 contains a tabulation of the numbers and release location of the experimental releases during the period 1980 through 2003. The data in Table 17 do not provide a complete picture of the use of experimental releases. In the past decade there has been an increasing awareness of the possible biological impacts of off-site releases. Feather River origin fish are no longer used in experiments in the San Joaquin River and use in the Southern Delta is now limited. In some cases, the researchers are using fish that more resemble the animals for which they are surrogates - i.e. use late fall CNFH juveniles as surrogates for winter Chinook, The rationale is that the late fall are about the same size emigrating winter Chinook and move through the Delta about the time of year. Although this new strategy, makes sense, fish from the hatcheries, in this case the Merced and CNFH, continue to be released off site and may stray at a higher rate that if they had been released near the hatchery.

Table 9. Release of "excess" production to Central Valley streams

Report Year	*Number of Release Locations of "Excess Production"*	
85-86	-24,000 fall (0.9 g ave.) at Coon Creek	-79,200 fall (0.9 g ave.) at Bear River
	-24,000 fall (0.9 g ave.) at Doty Ravine	
	-24,000 fall (0.9 g ave.) at Auburn Ravine	
	-84,000 fall (0.9 g ave.) at Dry Creek	
	-24,000 fall (0.9 g ave.) at Secret Ravine	
86-87	-50,400 fall (0.44 g ave.) at Dry Creek	-24,640 fall (0.44 g ave.) at Dry Creek
	-50,400 fall (0.44 g ave.) at Auburn Ravine	
	-100,000 fall (0.44 g ave.) at Secret Ravine	
	-49,280 fall (0.44 g ave.) at Doty Ravine	
	-24,640 fall (0.44 g ave.) at Coon Creek	
	-101,376 fall (0.44 g ave.) at Bear River	
87-88	----------	----------
88-89	-502,000 fall (0.4 g ave.) at Chico Creek	-100,678 fall (0.41 g ave.) at Secret Ravine
	-114,704 fall (0.41 g ave.) at Colusa Drain	-100,678 fall (0.41 g ave.) at Miners Ravine
	-194,072 fall (0.41 g ave.) at Dry Creek	-485,616 fall (0.41 g ave.) at Colusa Drain
	-100,678 fall (0.41 g ave.) at Coon Creek	-100,678 fall (0.41 g ave.) at Auburn Ravine
	-100,678 fall (0.41 g ave.) at Bear Creek	

- Releases of Fry in Excess of Production Needs

  Until 1996, FRH managers typically raised fall Chinook in excess of production needs. In late winter mortality had stabilized and some fish then deemed excess. Instead of killing the excess, they were often loaded in tanker trucks and planted at various Central Valley locations. Table 9 lists some of these excess fish plants made during the 1980s.

  In all cases the fish were discharged to the streams with no study protocol nor any distinctive marks to determine if the plants resulted in returning adults. In most cases anecdotal evidence suggests the plants were not successful. In any event, in 1996 DFG discontinued planting "excess

production" and the 1999 FRH operational protocol prohibits such plants. The present culling process at the eyed egg stage results in a close match between the numbers of organisms being reared and the production goals.

16. Research

There are several lines of research underway at the FRH and in the Feather River downstream of the hatchery. These research activities are designed to increase our understanding of the effects of the hatchery and the Oroville Dam complex on fish and other resources of the Feather River and the Central Valley. Much of this research started in the early to mid 1990s and is expected to continue for the next several years. The following briefly describes the major study elements and, where applicable includes research activities that use FRH and Feather River fish in their sampling protocol.

1. Assessing the genetic composition of the salmonid runs using the Feather River and other Central Valley streams.

   For Chinook salmon this work is a continuation of the research began in 1995 at the UC Davis's Bodega Marine Laboratory (Banks et al. 2000, Hedgecock et al. 2002). The continuation, began in 2002, is being conducted by Dr. Michael Banks of Oregon State University's Hatfield Laboratory, and is to examine the relation between fall and spring Chinook more closely. Dr. Banks will use a combination of additional microsatellite markers and genes that may determine run timing ("circadian rhythm" or "clock" genes) to make this determination. In addition, Dr. Carlos Garza, with the NOAA Fisheries laboratory in Santa Cruz, is collecting tissue samples from the Feather River and other Central Valley streams and using a variety of microsatellite genetic markers to characterize the genetic baseline for Central Valley Chinook populations.

   For steelhead, DFG collected more than 1,500 tissues from Central Valley and coastal steelhead, including the Feather River and the FRH. Dr. Jennifer Nielsen of the US Geological Survey used microsatellite markers to characterize Central Valley steelhead runs (Nielsen et al. 2003).

2. Assessing the contribution of FRH and naturally spawning Feather River fish to the ocean and inland fisheries, escapement and straying.

   DWR is continuing to coded wire tag several hundred thousand FRH production Chinook salmon and up to 200,000 Chinook fry/fingerlings that resulted from naturally spawning Chinook salmon. The tagging program, which began in 1995, was modified in 2002, to focus on spring Chinook. Beginning with the 2002 broodyear, one-half the spring Chinook production will be released in-river and the remainder in San Pablo Bay. Significant numbers of fall Chinook will be still be tagged to examine the fate of this race once it is released from the hatchery - including in-river releases of smolts and pre-smolts. DWR contributes funding to programs in the Delta and in the ocean designed to recover tagged fish and send the heads to a DFG laboratory in Santa Rosa for tag extraction and decoding.

3. Assessing the strain types, virulence and transmission of Infectious hematopoietic necrosis virus (IHNV) among Central Valley salmonid populations.

   In 2003 DWR contracted with Dr. Ronald Hedrick (UC Davis) and Scott Foott (US Fish and Wildlife Service, Red Bluff) to examine incidence and transmission of IHNV among Central

Valley salmonid stocks. The impetus for this contract arose from the high incidence of IHNV in FRH production Chinook salmon observed in 1998, and 2000 through 2002. There was also evidence that the IHN virus was evolving in the Valley and concern that the more recent strains were becoming more virulent (Ron Hedrick, UC Davis, personal communication.) NOAA Fisheries staff also expressed concern about transmission of IHNV from infected to wild fish.

4. Assessing the timing and numbers of steelhead and spring Chinook salmon that may be arriving in the Feather River during the April through June period.

   The gates to the ladder leading to the FRH are generally closed each year around March 31 and not opened again till around September 1. During this period late arriving adult steelhead and early arriving spring Chinook may be moving into the Feather River below the fish barrier dam. In an attempt to better understand run timing and numbers DFG, in cooperation with DWR, obtained a 4-d permit from NOAA Fisheries to open the gate April 1 and close it again as late as July 15. The permit is valid through 2008. In 2003, the first year of extended ladder operation, several hundred Chinook salmon entered the hatchery on Memorial Day weekend. About 100 of these fish were held in the hatchery and the remainder returned to the river. Tissue samples from 100 fish were collected and sent to the OSU and Santa Cruz laboratories for genetic analysis. In addition some of the fish retained in the hatchery had adipose clips. When the tagged fish were artificially spawned in September the heads of the adipose clipped salmon were sent to Santa Rosa for tag extraction and decoding. In 2004, almost 3,700 bright Chinook salmon entered the hatchery.

5. Using juvenile Chinook in experimental studies to evaluate various factors affecting the distribution, movement and abundance of naturally emigrating Chinook salmon.

   As is shown in Table 17, juvenile Chinook salmon from the FRH continue to be used in several research projects. Specifically in 2004 (2003 by), the following numbers of juvenile Chinook salmon were tagged for out of basin research projects (Table 10). Staying of these fish may pose risks to Central Valley salmonid populations.

Table 10. 2004 Feather River Hatchery tagging/marking plan version 09/26/03

Release	*How Many?*	*Released When?*	*Released Where?*
Yolo Bypass	50,000	Early Feb	Yolo Bypass
	50,000	Early Feb	Elkhorn Boat Ramp
	50,000	Late Feb	Yolo Bypass
	50,000	Late Feb	Elkhorn Boat Ramp
USFWS Release - Smolts	50,000	15-Apr	West Sacramento
	50,000	30-apr	West Sacramento
	50,000	3-May	Port Chicago
	50,000	14-May	West Sacramento

USFWS Release - Fry	50,000	Mid Feb	Lighthouse
	50,000	Mid Feb	Isleton
	50,000	Late Feb	Lighthouse
	50,000	Late Feb	Isleton

TASK 6. Characterize the Genetic Composition of Chinook Salmon and Steelhead Spawning in the Feather River.

The overall objective of this task is to provide the background information necessary to determine if operation of the Feather River Hatchery, including the fish barrier dam, has changed the genetic identity of fall and spring Chinook and steelhead that were present in the Feather River before Oroville Dam was completed in the mid-1960s. It should be made clear that we have no pre-Oroville genetic data that provide the genetic baseline against which data collected in the 1990s can be compared. We do have information on broodstock source and selection, mating protocols, straying and other factors that may have affected the genetic integrity of the original salmonid populations. We also have information about transfers of eggs, juveniles and adults among Central Valley, and other, hatcheries that may have influenced the Feather River and other Central Valley genotypes. Finally, we have good genetic data on Feather River Chinook salmon and steelhead, as part of larger efforts to collect similar data from other Central Valley runs. We do not have adequate information to determine if the present genotypes are more or less fit than those that existed before the Department of Water Resources built Oroville Dam and funded operation of the mitigation hatchery at Oroville.

Our general approach to this task is to separate the discussion of Chinook salmon from that of steelhead and to examine the question of genetic effects of hatchery operation on genetics of Feather River salmonids under this task, rather than in task 13, as called for in the original study plan.

The examination of genetic effects includes a look at the historic run timing to determine if there have been significant changes in timing since the hatchery began in operation in 1967. We then examine practices at the Feather River and other Central Valley hatcheries to assess their potential effects on genetic structure of Feather River salmonids. Data on overall survival rates are used to evaluate the relative fitness of Feather River Hatchery Chinook salmon to that of other hatcheries and wild fish. (Note that this is not possible to calculate survival rates for steelhead reared at the FRH.) Finally we look at the existing genetic structure of Feather River salmonids, as compared to that of other Central Valley salmonids, to help determine if operation of the Oroville Facilities has affected the genetic integrity of FR Chinook salmon and steelhead.

There were four subtasks in Task 6 - three that involved working with salmon geneticists from UCD, NOAA Fisheries, USGS, and Oregon State to better understand Central salmonid genetics. Interactions among the geneticists and DWR staff continued during the hatchery study but the independent report called for in the report was not prepared - in part due to contracting problems and in part due to lack of time on the part of potential report writers. As part of subtask 1, we continued to look for old scale collections that might shed light on the historic genetic structure of Central Valley Chinook salmon and steelhead. A collection of several thousand scales has been located in the DFG Arcata office but the collection has not been cataloged. CALFED, UCD and DFG are working to determine if a cataloging process can be developed and funded - including testing a random sample of the scales to determine if DNA can be extracted.

Chinook Salmon

The most important Chinook salmon genetic question on the Feather River involves the genetic integrity of the nominal spring Chinook run. The Feather River spring Chinook population was included in the Central Valley spring Chinook ESU and is listed as threatened pursuant to the federal endangered species acts (64 FR 50394, September 16, 1999). The hatchery population is not included in the ESU. In a recent review of listing status of 27 ESUs of West Coast salmonids, NOAA Fisheries recommended that Central Valley spring Chinook runs to Mill, Deer and Butte creeks retain their threatened status (69 FR 33102, June 14, 2004). The latest status review noted that FRH spring Chinook were genetically similar to fall Chinook but failed to note that the phenotypic in-river run is also more similar to fall Chinook than spring Chinook runs on Mill, Deer and Butte Creeks. The question comes down to: *Is there a genetically distinct spring run to the Feather River or is the Feather River spring run a mixture of fish that spawn in the river and in the hatchery?* The following information addresses the question.

Run Timing

The conventional conceptual model of spring Chinook stream-type life history has the adults arriving on the stream green. They then hold over until spawning in the late-September/October period. With this model, most of the juveniles oversummer in the streams and emigrate as yearlings.

Adult Immigration. There is general consensus that there was one or more genetically distinct spring Chinook runs to the Feather River system (see for example, Lindley et al. 2004 and Yoshiyama et al. 2001). The data in Figure 17 demonstrate that immediately before Oroville Dam was closed, there was a remnant spring run with typical stream type stream arrival timing - i.e. the fish entered the Feather system during the April through June period.

Until 2003 we had relatively flittle reliable data on the timing of the nominal spring Chinook to the Feather River system, although there has long been a summer recreational fishery on the Feather for bright Chinook salmon. The data base became much better in 2003 when, as part of an experiment to look at immigration timing of both Chinook salmon and steelhead, hatchery staff opened the fish ladder on April 1. On May 26, more than 1000 bright Chinook salmon entered the hatchery. Most of these fish were tagged and returned to the river and the ladder closed. About 100 adults were kept in the hatchery until they were successfully spawned in October. Twelve of the fish had adipose clips and coded wire tags, indicating they were from the FRH. (Note that only a fraction of the hatchery production is tagged each year thus the number of tags does not indicate how many of the fish were of direct hatchery origin.) Of the 12 tagged adults, 10 were the progeny of what the hatchery had called spring Chinook during the broodyear. These data indicate:

- There is a run of salmon to the Feather River that maintains the typical spring Chinook adult immigration pattern.
- The run contains a significant fraction of fish that originated in the FRH.
- For this group of fish, the hatchery system of selecting between spring and fall Chinook for spawning worked reasonably well.

Tissue samples were collected from the 100 fish that were kept in the hatchery. Geneticists from the NOAA Fisheries Laboratory at Santa Cruz and from Oregon State University's Hatfield Marine Science

Center analyzed the samples at part of their current research into the genetic structure of Central Valley Chinook salmon. (See figure 23 for the results.)

In 2004, the ladders were again kept open during the spring months to examine run timing. The phenotypic spring Chinook again entered the hatchery, but over an extended period of time (Table 11). All the fish were tagged with visible external tags and returned to the river. The goal was to mark the spring Chinook so they could be distinguished from fall Chinook when they reentered the hatchery later on in the summer and spawned separately. There were 30 observed mortalities during the tagging and handling process.

Table 11. Numbers and dates of Chinook salmon entering the Feather River Hatchery - spring of 2004. (All fish were tagged with visible external tags and released back to the river.)

Date[9]	*Number of Fish Tagged*	*Number of Recaptures*
5/17	101	-
5/18	320	-
5/20	44	-
5/24	486	7
5/27	322	8
5/28	56	-
6/1	643	19
6/2	342	23
6/3	82	8
6/7	580	56
6/8	288	68
6/10	278	53
6/14	114	37
6/17[10]	2	5
Totals	3656	279

The more complete 2004 ladder counts demonstrate:

- The existence of a Chinook salmon run to the Feather River that has the typical stream-type arrival timing on the spawning grounds.

9The date the fish traps were sampled, not necessarily when they entered the hatchery.
10The ladder to hatchery was closed.

- The inclination for these early arrivals to enter the Feather River Hatchery. (We do not have any data on what proportion of the total population entered the hatchery.) This inclination supports the hypothesis that the spring Chinook population on the Feather River is likely a mix of river spawned and hatchery spawned fish. The data could also support the alternate hypothesis that these fish were still heading upstream and sought the ladder's attraction flows as a route to that goal.

- That the nominal spring Chinook run to the Feather River is significant and probably larger than what was present in the years immediately before Oroville Dam (see Table 3).

Juvenile Emigration. The conceptual spring Chinook life history model has the juveniles emigrating mostly as yearlings. On the Feather River, rotary screw trap data show that most Chinook salmon emigrate by March 1, i.e. before smolting (Seesholtz et al. 2004). The apparent failure of the Feather River springs to follow the "typical" spring Chinook emigration pattern may not have much bearing on whether a true spring run exists on the Feather River because: the conceptual model of a spring run life history and emigration strategy is not without its variations. Although the model may work well for the Columbia River system, it appears that Central Valley spring Chinook have much more variable emigration patterns. On Mill, Deer and Butte creeks, creeks with the remaining significant and genetically distinct spring Chinook runs, juveniles may leave the streams as fry, smolts or yearlings (Colleen Arvey-Harrison, DFG, personal communication). Emigration timing may vary annually in response to hydrology, and can vary among streams. In general it appears that Deer and Mill creek springs more closely follow the stream type model, whereas those from Butte Creek more closely resemble the expected ocean type model.

Segregation on the Spawning Grounds

Historically spring and fall Chinook were isolated in time and space - i.e. the spring Chinook spawned higher in the watershed and earlier than fall Chinook. Construction of the Oroville Dam complex forced the spring run to spawn below the dam, perhaps with early maturing fall Chinook. Although we have no reliable data on in-river spawning, and the chances of spring and fall hybridization, a temporal look at spawning distribution (Figure 19) does not show a bi-modal peak that would be expected if there is a distinct spawning segregation by time. The data do indicate, however, that there are opportunities for spring and fall Chinook spawning together, thus hybridization is a distinct possibility.

Hatchery Practices

In this section we focus on the hatchery's ability to distinguish accurately between spring and fall Chinook when artificially spawning them in the hatchery. In a perfect world hatchery, staff would be able to sort the adult salmon by race and there would be no hybridization. Since 1995, DWR has tagged significant numbers of nominal fall and spring Chinook juveniles from the FRH. The returns of these tagged fish can be used to evaluate the accuracy of run designation by hatchery staff - i.e. did a juvenile tagged as the progeny of a spring Chinook mating return to the hatchery as a spring run?

The 1997-2002 data from this analysis are summarized in Table 12. For this period we examined a total of about 11,000 tagged Chinook that returned to the FRH and were spawned as either fall or spring Chinook. In September, the first month of spawning, hatchery staff correclty assigned the run to that of its parents about 51 percent of the time. In September about one third of the total numbers spawned had been released as fall run and the returning progeny spawned as spring run. About 18% of the nominal spring Chinook were subsequently spawned as fall Chinook. By October, most of the salmon spawned

were fall run and correctly identified as such, although about 10% were not correctly identified. By November spawning had tapered off and all spawners were correctly assigned to the fall run.

Although the data in Table 13 are from recent years, Frank Fisher (DFG, as described in Brown and Greene 1994) found a similar problem with earlier run designation at the hatchery.

Table 13. Numbers and percentages of spring and fall run Chinook correctly identified at the Feather River, by month for the period 1997-2002. Run identification is from coded wire tag recoveries at the hatchery and is based on the run designation of the original spawners as compared to the run designation of the returning adults.

	Month			
Run Designation of Parents/ Run designation of progeny	*September*	*October*	*November*	
Fall/Fall	418 (21%)	7023 (83%)	611 (100%)	
Fall/Spring	629 (31%)	457 (5%)	0	
Spring/Spring	621 (31%)	429 (5%)	0	
Spring/Fall	355 (18%)	537 (6%)	0	
Totals by month	2,023	8,446	611	GT 11,080

The bottom line is that there has been considerable mixing of genetic from nominal spring and fall Chinook in the FRH. This potential hybridization makes it less likely that there is a genetically distinct spring Chinook run on the Feather River.

Genetic Information about Feather River Spring and Fall Chinook

Since 1995 there have been extensive studies of the genetics of Central Valley Chinook salmon that have included samples from the nominal Feather River spring and fall runs. These studies help shed light on the any genetic separation of the two runs. Since they do not include any samples before Oroville was constructed, they do not help determine if any recently observed differences in genetic structure between the runs has been caused by the Oroville Facilities.

For this examination of Feather River salmon genetics we rely mainly on the work of Dennis Hedgecock and Michael Banks conducted at the UC Davis Bodega Marine Laboratory. (Michael Banks is now with Oregon State University's Hatfield Marine Science Center, Newport, Oregon.) Briefly these genetic efforts began in 1995 with the goal of determining the genetic structure of Central Valley Chinook salmon. Although the original study focused on winter Chinook, the study design called for an examination of several Central Valley Chinook salmon populations to determine if winter Chinook could be readily separated from the other three races through use of genetic techniques. DWR funded this study, along with accompanying efforts by DFG to collect, archive, and distribute tissue samples from Central Valley Chinook runs. Microsatellite markers were selected as the method used to determine if the runs could be genetically sorted.

Banks et al. (2000) and Hedgecock et al. (2001) describe the procedures and present many of the results from these studies. For purposes of this evaluation we are particularly interested in the neighbor - joining tree that resulted from this work (Figure 21 from Banks et al. 2000).

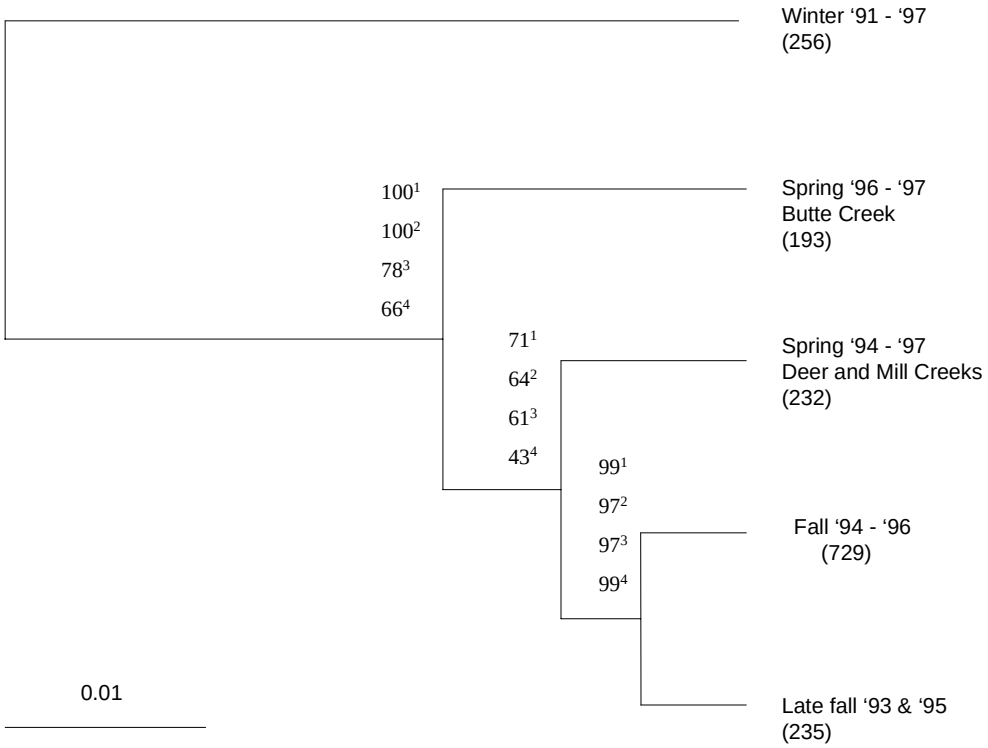

Figure 21. UPGMA phenogram derived from the Cavalli-Sforza (1967) chord measure using adjusted data from ten microsatellite loci. From Banks et al. 2000.

In this genetic tree, runs on the same limb are the most similar. Some important points from these data relative to the Feather River spring/fall issue are:

- There are two major branches on the tree - one that contains winter Chinook and one that contains the other three races. This separation supports that the hypothesis that the winter run was long isolated from the other three races. Historically winter Chinook spawned during the summer in the spring-fed streams on the slopes of Mt. Lassen.

- There are genetically distinct spring Chinook runs on Butte Creek (on its own limb) and on Mill and Deer creeks (on a common limb).

- All Central Valley fall Chinook populations are on one limb - i.e the microsatellite markers used in this study could not distinguish among fall run stocks in the Sacramento and San Joaquin drainages or in individual streams within these drainages.

- Genetic data from tissues collected from nominal Feather River spring samples are on the fall run limb, thus indicating that these fish were most closely related to fall run, but there was a slight difference. These nominal spring Chinook samples were collected for this study were collected mostly in the late 1990s and came from a variety of sources including fish captured in river by anglers and early arrivals to the FRH.

At the request of DWR Hedgecock (2002) expanded the earlier work on genetic separation of Feather River Chinook by increasing the number of microsatellite markers used (from 7-8 loci to 12 in these samples) to examine the samples shown in Table 14. Note that these samples were provided by DFG. The 1994 samples are of particular importance in that DFG opened the hatchery ladder in June 1994 and the samples are from 25 fish that ascended the ladder - i.e. fish that exhibit the spring run adult run timing characteristic. The unknowns likely include nominal spring Chinook and fall Chinook (e.g. 1999 FRH adults tissue collected from 9/23 to 10/4. Many of these samples could be more properly described as Feather River "early".

Table 14. Samples of adult, potential spring Chinook provided to Bodega Marine Laboratory for genetic analysis.

Year	*Race*	*Location*	*Date*	*Life Stage*	*N*
1994	Spring	FRH	6/6/94	Adult, spawning	25
1995	Unk.	FRH	10/2/95	Adult, spawning	95
1996	Unk.	FR*	6/3-21/96	Adult	17
1996	Unk.	FR	10/3-9/96	Adult, carcass	78
1996	Unk.	FRH	9/30/96	Adult, spawning	95
1999	Unk.	FRH	9/23-10/4/96	Adult, spawning	115
2000	Unk.	FR*	5/6-6/12/00	Adult	50

* Fish tissue collected directly from anglers.

Based on the 12 microsatellite loci used, the samples analyzed formed a cohesive set of genetically similar populations that is somewhat different, but still most closely related to, from Central Valley fall populations. There was some indication of genetically distinct sub-populations in the Feather River, as well as indications that all the samples may not have contained genetically homogenous fish - e.g. in 1999 the 9/23 fish seemed genetically distinct from the latter two sets of fish samples collected during the September/early October period.

As shown in Figure 22 the data from this study again confirmed that phenotypic Feather River early fish are distinct from Butte, Mill and Deer creek springs and most similar to Central Valley fall Chinook. The data did indicate that there may be subpopulations of Chinook on the Feather River - populations that are relatively close genetically but still distinguishable.

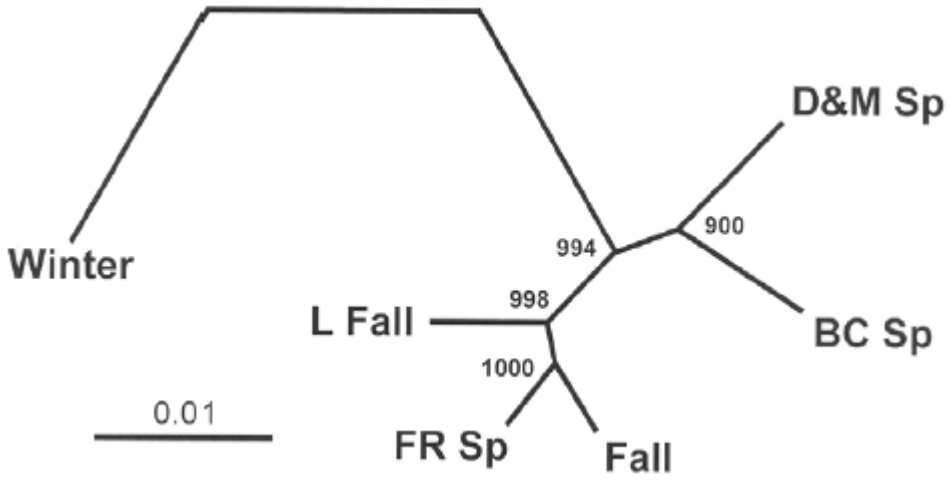

Figure 22. Genetic distance among Central Valley Chinook runs. L Fall = late fall, D&M Sp = Deer and Mill Creek springs, BC Sp = Butte Creek springs, FR Sp = Feather River Springs. From Hedgecock et. al 2002.

The last results to be included in this report involve the results of analyzing about 100 tissue samples collected on Memorial Day weekend in 2003. These samples were sent to Michael Banks at Oregon State for analysis. The genetic tree in Figure 23 shows that the samples follow the previous pattern - i.e. the Feather River spring run is genetically closer to Central Valley fall Chinook than spring runs on Deer and Mill Creeks. Carlos Garza (NOAA Fisheries, personal communication) also examined about 70 of these samples and concluded that Feather River springs were most similar to Central Valley falls but that there may be variants within the Feather River Chinook population that segregate by run timing.

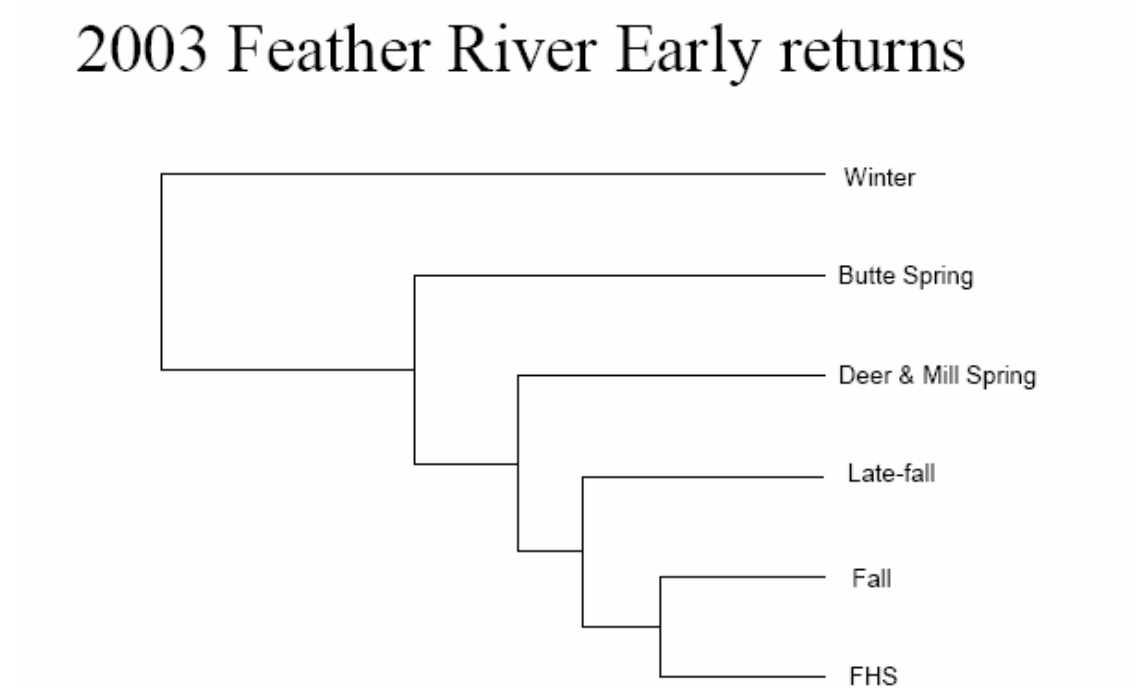

Figure 23. Genetic tree for Central Valley Chinook salmon. The FHS are samples from fish that enter the hatchery on Memorial Day, 2003. Preliminary date from M. Banks, OSU.

TASK 6. Summary and Conclusions.

We use information from this section to address the following questions:

1. Was there a historic spring run on the Feather River?

2. Is there now a genetically or phenotypically distinct spring run on the Feather River?

3. If the answers to 1 and 2 are yes, has the Oroville Facilities, including hatchery operation, adversely affected the spring run on the Feather River?

4. If the answer to 2 is yes, does the existing spring run meet the requirements necessary to place it in the Central Valley spring Chinook ESU? A subset of that question is "Is the in-river spring run genetically and otherwise distinct from the hatchery spring Chinook population?

Question 1. Was There a Historic Spring Run on the Feather River?

There is no doubt that historically there was a spring run on the Feather River. Although estimates of historic run size would be sheer speculation, we do know by the time DWR constructed Oroville Dam in the 1960s, the annual run numbered from a few hundred to a few thousand spawners. We do not know the genetic identity of the historic Feather River spring run, however it appears that it did not resemble current day spring runs on Mill, Deer and Butte creeks. This latter conclusion arises from the genetic distance between the runs and low probability that the present genetic structure in the Feather River could not have arisen from hybridization between a Mill/Butte/Deer genotype and a Feather River spring genotype (Hedgecock 2002).

Question 2. Is There Now a Genetically or Phenotypically Distinct Spring Run on the Feather River?

There is some genetic evidence of that the early returns (i.e. fish that enter the river in May and June) can be separated from the later returning fish. There is clear evidence that there is a phenotypically distinct run of Chinook salmon that enters the river in May and June and presumably spawns in September and October. Not only is the run distinct, in 2004 it may have been in the range of 8,000 to 12,000 individuals. (Estimate based on the assumption that only 1/3 to 1/2 of the spawners entered the hatchery. Almost 4,000 fish enterered the hatchery in April, May and June.) The nominal Feather River spring run's closest genetic relative is the fall run. This may indicate genetic similarity that has always been present in the system. An alternative hypothesis is that the nominal Feather River spring run has evolved in recent times. As cited in Nielsen et al. (1997) experience with transplanting Central Valley Chinook salmon to New Zealand has shown that the species is genotypically and phenotypically plastic.

There is no evidence at this time that mating spring Chinook with spring Chinook will result in progeny that return to the river during the May/June period. The definitive experiment has not been conducted. Matings of clearly phenotypic spring Chinook in 2004 may help resolve this issue. Almost 1.2 million marked and tagged fish will be released in the spring of 2005, with the tagged fish returning mostly in 2007.

Question 3. If the Answers to Questions 1 and 2 are Yes, has the Oroville Facilities, Including Hatchery Operation, Adversely Affected the Spring Run on the Feather River?

The first order answer to this question is yes. The barrier dam has caused spring run and fall run to commingle on the spawning grounds with likely inter-run spawning. There is anecdotal evidence (A. Quinones, DFG, personal commuication) that even with the dam, there was a one-week window between the end of spring run spawning and the beginning of fall run spawning. Over the years this window in the FRHhas eroded, with the spawning timing now overlapping. The data in Table 13 above show conclusively that hatchery staff has extensively mixed (hybridized) nominal fall and spring Chinook for at least the past several years, and probably since the hatchery began operation in 1967. Combining the answers to questions 2 and 3 results in somewhat of a paradox. We have a run on the Feather River that maintains some aspects of a spring (stream type) life history in spite of the barrier dam and hatchery practices that should be working against maintaining a distinct spring run. Perhaps what we have is a genotype that has considerable variation in the phenotype, with some fish returning early each year.

Question 4. If the Answer to Question 2 is Yes, Does the Existing Spring Run Meet the Requirements Necessary to Place it in the Central Valley Spring Chinook ESU?

A subset of that question is "Is the in-river spring run genetically and otherwise distinct from the hatchery spring Chinook population? The answer to question 2 was an equivocal yes, thus the answer to

the first part of question 4 is at best a maybe. The phenotypic spring run on the Feather River is genetically closer to fall run than spring runs on the Mill, Deer and Butte creeks. The population is most certainly not an isolated interbreeding population - nominal fall Chinook genes are routinely mixed into the run's genetic structure, either through interbreeding on the spawning grounds or in the hatchery. There are no data either way to show that spring run timing on the Feather River is an inheritable trait and the loss of the this phenotype would adversely affect the recovery of the Central Valley spring run ESU. On the other hand, the run does exhibit some spring run characteristics and should receive attention from hatchery managers, if not through endangered species act protection.

If the answer to the first part of question 4 is maybe, the answer to the second part (i.e. are the hatchery and river runs of phenotypic spring Chinook on the Feather River separable) is definitely no. The current genetic and other evidence shows that the two runs are thoroughly mixed. The genetic data from Hedgecock (2002) show that the hatchery and river phenotypic spring Chinook have the same genetic profile. When the hatchery ladder is open in April, May and June, spring Chinook holding in the river readily enter the hatchery. If spring Chinook from the Feather River are part of the Central Valley spring Chinook ESU, the available data indicate that the hatchery population should also be included in the ESU - similar to steelhead on the Feather River where both river and hatchery populations are part of the Central Valley steelhead ESU. We must point out that the available microsatellite markers may not be up to the task of sorting out genotypes that are so similar.

Regardless of the listing status of spring Chinook on the Feather River, DWR and DFG management should continue measures to better understand the run (continued data collection) and to protect it from the effects of continued hatchery operation. The study in 2004 may be a good first step in that direction. In this study, about 3700 phenotypic spring Chinook were tagged with visible external tags and released back to the Feather River. When these fish returned to the hatchery, they were mated exclusively with similarly tagged fish. Their progeny will be coded wire tagged with the goal of determining if early run timing is genetically controlled. The hatchery managers and scientific support staff will also complete the on-going three year study to assess survival and straying. The study involves tagging all juvenile hatchery spring Chinook and releasing roughly half of these in river and the remainder in the lower estuary.

The 2004 spring run study may provide some answers to the spring run questions on the Feather River. DFG opened the fish ladder on 9/13, ten days later than normal, and nearly 2,800 fish entered the hatchery. Of these more than 800 had the floy tags that were used in the sprng to identify those fish entering the hatchery and released back to the river. Of these 800 tagged fish 750 were ripe and were spawned. All fish with floy tags and those fish that entered the hatchery on 9/13 will be called early spring run and kept separate. All untagged fish arriving after 9/15 will be considered fall run. CWT will be used to identify the separate groups and track their subsequent contribution to the fisheries and to escapement. Floy tag returns from anglers and the spawning surveys may help identify the extent and sources of mortality to the over-summering fish. Indications are that it is extensive. Also the data may help estimate the numbers of spring run in the river during the summer of 2004.

Steelhead

We follow the same general outline as with Chinook salmon by looking at the original and current run timing, the barrier dam, hatchery practices and the existing Central Valley genetic structure to evaluate the effects of the Oroville complex on the Feather River steelhead run.

Run Timing

Before Oroville Dam, steelhead moved past Oroville during the fall period (Figure 18), presumably to spawn during the winter months in headwater streams. Although the hatchery ladder is now open during the fall months to take in spring and fall Chinook, adult steelhead do not enter the hatchery at this time. Steelhead begin entering the hatchery in December and the run peaks during January through February. Ripe steelhead may continue entering the hatchery through March. Although data are sparse, it appears that historical (early 60s) and recent run timing is similar to today's timing.

Spawning Location

The fish barrier dam now restricts spawning to the lower reaches of the Feather River and forces wild (naturally spawning) and hatchery steelhead to spawn in the same general location. This co-location presumably results in a homogenization of the Feather River steelhead genetic structure. An important point: steelhead continue to spawn naturally in the Feather River. (There are currently no data to show if these river spawners are of direct hatchery origin or the progeny of a previous natural spawning.) The progeny of the river spawners survive to emigrate below the low flow channel, thus helping maintain a natural component to the run.

Juvenile Residence and Emigration

There are no historical data on the use of the Feather River system by juvenile steelhead. Before Oroville and other blockages on the Feather system, juvenile steelhead probably spent one or two years in the upper reaches before emigrating to the ocean.

Studies during the past few years have shown that juvenile steelhead (from naturally spawning adults) reside in the low flow channel and exhibit good growth - especially in the lower reaches of the low flow channel (DWR 2004)). Some steelhead oversummer in the low flow channel but it is unclear if the section offers the habitat complexity needed to support a naturally spawning steelhead population. Relatively large numbers steelhead fry are caught in the Feather River rotary screw traps. Since these fish are too small to smolify and enter the ocean, their fate and contribution to the wild steelhead population is unclear.

Titus et al. (2004) have collected field data at Knights Landing and elsewhere and show that:

- At Knights Landing hatchery steelhead appear to emigrate about 2 months earlier than wild steelhead.

- At Knights Landing, on average hatchery steelhead were smaller at emigration than wild steelhead. This is due mostly to hatchery fish emigrating at age 1, while wild steelhead emigrate at age 2, with some 1s and 3s. Size - not age - seems to be dominant factor in determining emigration timing.

Hatchery Practices

We restrict this discussion to three aspects of steelhead production at the FRH - founding stock, spawner selection and mating, and transfers of steelhead among hatcheries. We do not have data on the domestication effects of the hatchery on FR steelhead genetic structure.

- **Founding Stock**. As was shown in Table 4 the original founding stock for the FRH came from a variety of sources, including probable Feather River stocks. During the initial years of operation, the hatchery maintained a broodstock consisting of many of these lineages. The combination of the original broodstock selection and the captive broodstock program undoubtedly affected the genetic composition of this run.

- **Spawner Selection and Mating**. Due to the relatively low numbers of steelhead that enter the Feather River Hatchery, meeting hatchery egg production goals results in almost all fish being spawned. There is little mixing of the hatchery and wild gene pool in the hatchery in recent years - essentially all adult steelhead entering the hatchery are of direct hatchery origin. (Note that adipose clips show the fish were from hatcheries but not which hatchery they were from. The presumption is that all marked steelhead entering the FRH are from the FRH.) Spawned steelhead are released back to the river. There are no data to determine how many of these fish survive to spawn again.

Transfers of Genetic Material from Other Sources to the FRH

Over the years, genetic material (eggs and juvenile fish, and even a few adult fish) have been brought to (and shipped from) the FRH (see Table 18). These transfers have probably contributed to the present genetic structure of the Feather River "wild" and hatchery runs.

Genetic Structure of Central Valley Steelhead, Including the Feather River Component

The CALFED Bay-Delta Authority recently supported an extensive examination of the genetic structure of Central Valley rainbow trout and steelhead populations. Jennifer Nielsen (USGS) conducted the study and the methods and results are described in Nielsen et al. (2003).

For purposes of this evaluation, the location of Feather River and hatchery steelhead on the genetic neighbor-joining tree (Figure 24 from Nielsen et al. 2003) is most relevant to this discussion. (The overall Central Valley steelhead genetic structure is discussed in Task 7 as it relates to the effects of FRH operation on Central Valley steelhead populations.)

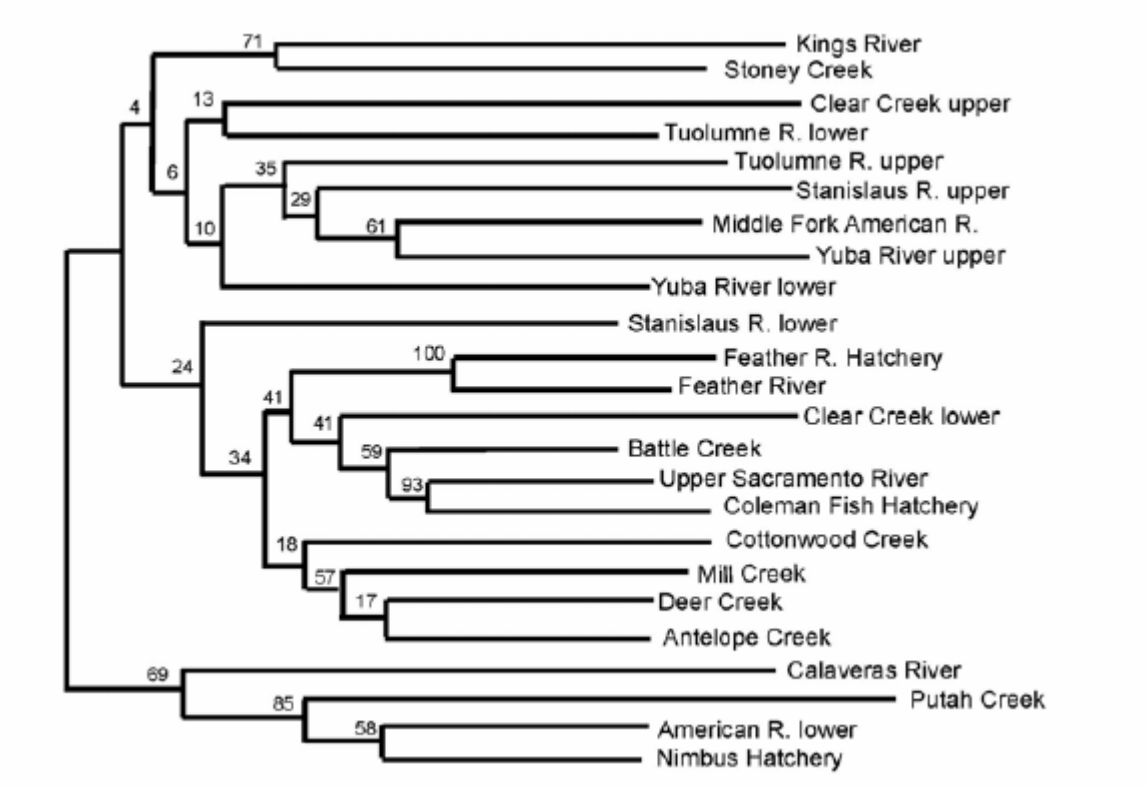

Figure 24. Neighbor-joining tree based on Cavalli-Sforza and Edwards chord distance for Central Valley steelhead populations. From Nielson et al. 2003.

The genetic tree leads to several conclusions that are important to the issue of hatchery effects on steelhead.

- The Feather River populations are branches on a limb that contains populations from Clear Creek, Battle Creek, Upper Sacramento River, Coleman National Fish Hatchery and Cottonwood, Mill, Deer, and Antelope creeks – i.e. streams that are in the same general geographic location.

- The Feather Rivers populations are not closely linked to Nimbus and American River populations - the source of many transfers of genetic material to the FRH.

- The Feather River population's closest relative is the Feather River Hatchery population.

Summary: Effects of the Oroville Complex, Including the FRH, on Feather River Steelhead

Since we do not have any pre-project genetic data it is not possible to determine if the Oroville complex, including the hatchery has affected the genetic structure of Feather River steelhead. The genetic data in Figure 24 show that the Feather River and FRH steelhead populations are distinct from other Central Valley populations, indicating that some of the original genetic attributes of the run may remain.

The lack of data should not lead to the conclusion that there have been no effects on the Feather River steelhead run. The run is now dominated by the hatchery component. Including the Feather River and FRH runs in the Central Valley steelhead ESU seems appropriate. DWR and DFG should look into the results of the NATURES studies being conducted at the CNFH to determine if rearing practices for steelhead at the FRH should be modified to produce fish for release that are more fit than typical hatchery production. The observations that essentially no unmarked steelhead enter the FRH and that there are naturally spawning populations does raise the question about the two components being indistinguishable.

TASK 7. Characterize the Genetic Composition of Chinook Salmon and Steelhead From Central Valley Streams Other Than the Feather River.

The overall objective of this task is to provide the background data that can be used to determine if operation of the Feather River Hatchery has affected the genetic structure of salmonids in streams other than the Feather River. Our general approach to this task is to separate the discussion of Chinook salmon from that of steelhead and to examine the question of genetic effects of hatchery operation on genetics of Central Valley salmonids under this task, rather than in Task 13, as called for in the original study plan.

We first look at the genetic structure of Central Valley salmon and steelhead then at transfers of genetic material among Central Valley hatcheries, and finally at straying of FRH releases to streams other than the Feather River. We then reach tentative conclusions about the effects of hatchery operations. This analysis includes the effects of releases of experimental fish at various locations in the Central Valley and the San Francisco Estuary. Researchers used these study fish to examine a variety of questions and were not tied directly to hatchery operations. As will be shown, these releases may have had significant effects on Central Valley fall Chinook. We also examine straying from other Central Valley hatcheries to assess the relative importance of FRH straying to the overall problem role of genetic transfer among individual salmon runs.

Chinook Salmon

We chose the latest genetic information that had been published (Hedgecock et al. 2001) as the Central Chinook salmon genetic baseline (Figure 25). We have shown similar microsatellite derived data previously, with the important points in terms of this task being:

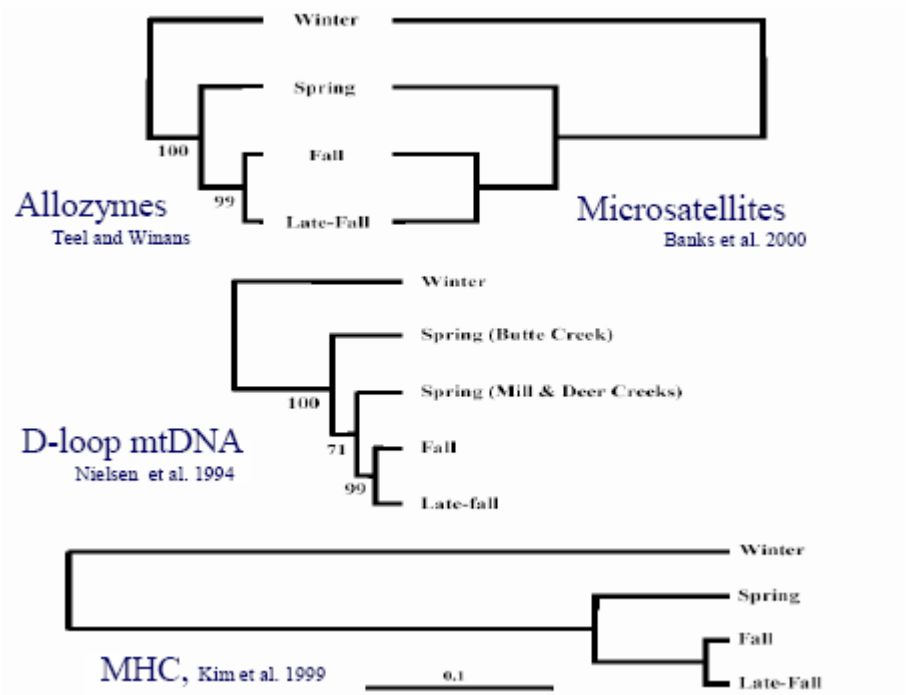

Figure 25. Genetic baseline for Central Valley Chinook salmon as characterized by allozymes, microsatellites, D-loop mtDNA, and MHC. From Hedgecock et al. 2001.

- There are genetically distinct spring runs on Mill, Deer and Butte creeks.

- The winter run is clearly genetically distinct from the other three Central Valley Chinook runs. The winter Chinook run is confined to the mainstem Sacramento River and the Livingston Stone National Fish Hatchery, although a few adult winter run enter Battle Creek.

- Late fall and fall runs are genetically similar. Use of additional microsatellite markers has been able to separate these two runs (Figure 26). (M. Banks, OSU, personal communication.) Although there may have historically been significant late fall runs in other streams, the wild late fall run is now largely spawns only in the Sacramento River between Keswick Dam and Red Bluff.

- The fall Chinook run is genetically homogenous throughout the Valley. This conclusion was supported by Williamson and May (2002) using a more extensive set of samples and a different set of microsatellite markers.)

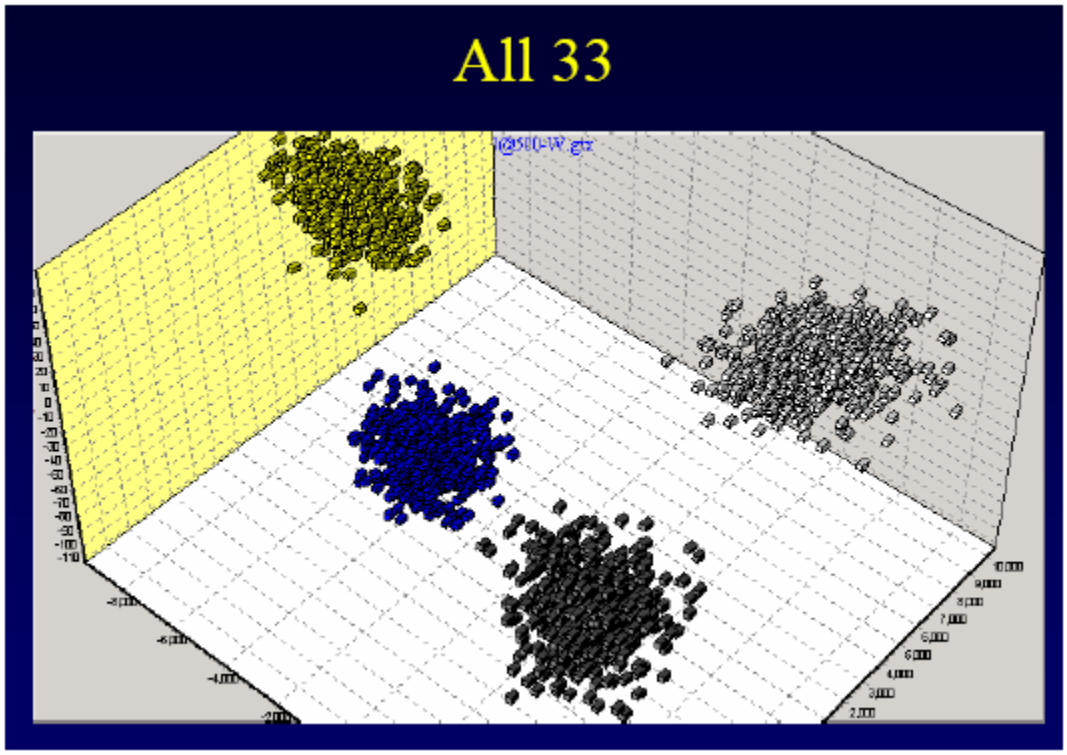

Figure 26. Representation of genetic distances among Central Valley fall, late fall, Deer and Mill creek and Butte Creek spring salmon population using 33 microsatellite markers. Preliminary data from M. Banks, OSU.

The FRH practices that could have the most significant effect on Central Valley salmon genetics are transfers of genetic material among streams and hatcheries and straying of hatchery releases to non-natal streams. A subset of the straying issue comes from the extensive use of FRH juveniles as test fish. In these tests fish have been released off site to examine entrainment in fish screens, the importance of flood bypasses as salmon rearing habitat, and the effects of Delta water project operations on the survival of juvenile salmon emigrating through the Sacramento-San Joaquin Delta. We examine each of the factors below.

Transfers of Chinook Salmon Genetic Material Among Hatcheries and Intentional Releases of FRH in Streams Other Than Those in the Feather River Basin

Over the years there has been considerable transfer of eggs and juvenile Chinook salmon among Central Valley hatcheries. These transfers were to supplement hatchery production to meet goals during years when the numbers of adults returning to the hatchery were not sufficient to meet hatchery goals. Conversely, in many years the hatchery more juveniles than needed to meet goals and many fish were released as part of a so-called "inventory reduction" production. In some instances Chinook salmon from

the FRH were intentionally released in out of basin streams to enhance natural production. All of these practices had the potential to affect the genetics of Central Valley Chinook salmon.

Transfers of Chinook salmon genetic material within Central Valley hatcheries. Table 15 is a partial listing of the transfers of genetic material to and from the FRH.

Table 15. A partial list of transfers of genetic Chinook salmon material to and from the FRH. (Data compiled from the FRH annual reports prepared by DFG. Numbers have been rounded.)

	Number of fall Chinook eggs or juveniles shipped - in millions	
Year	*To FRH and source*	*From FRH and destination*
69-70	1.1 - fry from NFH[11]	
	1 - eyed eggs from CNFH[12]	
70-71	3.3 - eyed eggs from CNFH	
	0.65 - yearlings from NFH	
71-72	2.4 - eyed eggs from NFH	
72-73	5.3 - eyed eggs from NFH	
	9.9 - eyed eggs from TRH[13]	
73-74		5.1 - eyed eggs to CNFH
		1 - fry to TCSC[14]
77-78		0.5 - fry to MRH[15]
		303 - fry to CNFH
80-81	7.1 fall eggs - NFH	
81-82		2.6 - eyed eggs to NFH
83-84		2.4 - eyed eggs to NFH & CNFH
84-85		3.0 - fingerlings to MRH
85-86		3.2 - fingerlings to MRH
88-89		1.8 - fingerlings to MRH

11Nimbus Fish Hatchery
12Coleman National Fish Hatchery
13Trinity River Hatchery
14Tehama-Colusa Spawning Channel - located near the Red Bluff Diversion Dam.
15Mokelumne River Hatchery

		1.5 - eyed eggs to MRH
		0.9 - eyed eggs to NFH
89-90		1.1 - fingerlings to MRH
		0.3 - eyed eggs to MRH
90-91		2.5 - fingerlings to MRH
91-92		1.5 - fingerlings to MRH
		1.5 - eyed eggs to MRH
92-93		0.2 - fingerlings to MRH
		O.4 - fingerlings to DFG, Reg. 2
		11 - eyed eggs to MRH
93-94 and later	No transfers into FRH and only material shipped was to MRH and to Yountville quarantine facility for subsequent planting in DFG's inland Chinook salmon planting program.	

The data in Table 15 illustrate that transfers of genetic material to and from the FRH has been fairly extensive, with one transfer to the hatchery coming from the Trinity River. Transfers of eyed eggs and juveniles to other hatcheries, and their subsequent planting, can even further disrupt the salmon's homing abilities and result in considerable straying. We should point out that these transfers were part of an overall hatchery strategy (largely ad hoc) of moving material among federal and state hatcheries according to the supply and demand. Transfers of material to the Mokelumne River Hatchery were part of a program to enhance the numbers of salmon available to for the ocean fisheries.

Planting "excess production" in Central Valley streams. After the hatchery began to routinely produce more fall Chinook salmon than were needed to meet hatchery mitigation goals, DFG fish managers often planted the excess as fry in several locations in the Valley (see Table 10). (In a few instances these fish were planted as far away as the coast.) The fish were generally fry and in no case were the fish marked so that an evaluation could be made of their fate and ultimate contribution to the stream or Central Valley Chinook population. The objectives were to enhance salmon production in streams receiving the fry. Some of the Central Valley locations where these fry were planted in the late 1980s were:

- Bear River
- Coon Creek
- Doty Ravine
- Auburn Ravine
- Dry Creek

- Secret Ravine
- Chico Creek
- Miners Ravine
- Colusa Drain
- Cache Creek

Cumulatively several million fry were planted in these and other Central Valley streams with most of them going to the Sacramento Valley. This practice is no longer permitted under DFG's hatchery protocols.

Straying of Returning Adults from Feather River Hatchery Production Releases to other Central Valley Streams

The FRH practice of releasing most of its production in San Pablo Bay increases the chances that many of these fish will return to spawn in other Central Valley streams. Thus straying has the potential to transfer genetic material from one segment of the population to another. While some exchange of genetic material is natural and desirable, in general excessive transfers, especially between hatchery and naturally spawning salmonids, are viewed as adverse hatchery impacts (Busack and Currens 1995).

To examine the straying question we first compiled the numbers of FRH production releases that were found in stream spawning surveys or taken in to other Central Valley hatcheries. The FRH fish were identified by reading a coded wire tag implanted a few to several weeks before the juveniles were planted. Since extensive tagging of FRH Chinook salmon did not occur before 1995, we restricted our search for tagged fish to the period 1997 through 2003.

Table 16 contains the numbers of tags recovered in several Central Valley streams, including the Feather River.

Table 16. Raw numbers of coded wire tags recovered in several streams and Central Valley hatcheries during the period 1997-2002.

	Hatchery Source				
Recovery Stream	*FRH*[16]	*MRH*[17]	*MFF*[18]	*NFH*[19]	*CNFH*[20]
Yuba River	29	16	4	1	---
American River	168	1062	117	239	358
Mokelumne River	63	2499	155	18	56
Stanislaus River	31	---	34	---	---
Tuolumne River	19	3	103	---	1
Merced River	15	36	1032	---	5
Butte Creek	12	10	23		---
Mill Creek	4	2			12
Battle Creek	123	---	---	---	---
Feather River	12,097	208	383	1	153

A few caveats are necessary when considering the data in this table.

- The table shows the raw number of tags collected. They are not expanded for sampling effort in the streams nor by the number (and percentage) of tags applied at the Feather River and other hatcheries. For example, the low number of tagged fish from the Nimbus Fish Hatchery is due to the lack of tagging at the hatchery. The few Nimbus fish that were recovered were jacks from the 2001 broodyear.

- The stream data for Battle Creek, Feather River, American River, Mokelumne River and Merced River include both stream and hatchery recoveries. In all these cases, by far the majority of the tags were recovered at the hatchery. On the American River, for example, tag recovery efforts were not very effective before 2003. All stream tag recovery programs, which are part of escapement surveys, do not provide statiscally robust estimates of the numbers of tags present in the spawning population.

- The FRH tag release groups were a combination of experimental and production releases, but more than 95% of the releases were made off site - mostly in the Sacramento-San Joaquin Delta and San Pablo Bay.

*16*Feather River Hatchery
*17*Mokelumne River Hatchery
*18*Merced Fish Facility
*19*Nimbus Fish Hatchery
*20*Coleman National Fish Hatchery

The data provide some expected and unexpected results regarding the fate of tagged fish released from Central Valley Chinook salmon hatcheries.

- As expected we found FRH origin hatchery fish widely distributed in Central Valley streams - in fact they were found in every stream sampled.

- Perhaps not expected was the finding that about 97% of the FRH tags were recovered in the Feather River and the FRH. This observation is contrary to the idea that FRH production fish planted off site stray at an extremely high rate. (A stray rate as high as 80% was included in the 2001 DFG/NOAA hatchery evaluation report.)

- The sources of the fish from the Mokelumne River and Coleman National Fish Hatcheries are of interest to the straying question. Most of the MFH fish that strayed from the Mokelumne are those fish that were part of the ocean fisheries enhancement program - i.e. they originated from eyed eggs or juveniles that were transferred from the FRH to Mokelumne for rearing. These fish were eventually released in San Pablo Bay. The CNFH returns are all late fall run fish that were released in the Delta as part of a long-running series of studies on the effects of water project pumping on juvenile salmon survival. No CNFH fall Chinook - released on station - were recovered during the surveys. This is probably mostly due to the lack of adequate numbers of tags applied during the period but also due to the lower straying rate from on-station releases.

- The low numbers of FRH Chinook salmon straying into the nearby Yuba River is encouraging but the data should be viewed with some caution in that the tag recovery efforts may not have been adequate.

Experimental Releases

As mentioned earlier, the FRH has been the source of large numbers of marked and tagged test fish. As shown in Table 17, about 16 million juvenile fall Chinook have been tagged and released at 32 locations, mostly in the Sacramento-San Joaquin Delta. Fish in these off-station releases are likely to stray at about the same rate as fish in San Pablo Bay production releases. The FRH test releases are not the only releases that may be having high stray rates. Most of the Merced Fish Facility strays were from Delta releases that are part of the long-term Vernalis Adaptive Management study. The Coleman late falls used in IEP studies are also showing high stray rates.

Table 17. Numbers and locations of releases of experimental fish from the Feather River Hatchery - 1980-2003

	FRH Experimental Release Summary (1980-2003)		
	Release Location	*Releases per Location*	*Number Released*
1	Benicia	35	2,149,073
2	Buckley Cove Marina	4	199,161
3	Clifton Court Forebay	1	25,899
4	Courtland	24	1,266,112

5	Crockett	22	1,139,964
6	Discovery Park	6	470,186
7	Dos Reis Road	18	816,987
8	Elkhorn Boat Ramp	19	249,858
9	Empire Tract	2	95,602
10	Fremont Weir	2	51,543
11	Georgiana Slough	22	735,407
12	Gridley	3	184,373
13	Isleton	15	536,403
14	Jersey Pt., San Joaquin R.	17	654,720
15	Lighthouse Marina	14	350,325
16	Live Oak	32	1,813,625
17	Mokelumne R., Mouth	10	334,217
18	Mokelumne River	1	83,435
19	Mossdale	4	76,487
20	North Fork Mokelumne	3	262,993
21	Old River	3	185,757
22	Palm Tract	7	474,064
23	Rio Vista	4	97,811
24	San Joaquin R., Below Old R.	3	148,126
25	South Fork Mokelumne	4	259,638
26	Steamboat Slough	4	200,564
27	Stewart Road	34	1,703,968
28	Sutter Slough	2	99,086
29	Thornton	2	95,000
30	Verona	8	487,169
31	Vierra’s Resort	4	101,702
32	West Sacramento	24	597,734
	Totals	353	15,946,989

Stray Rates Estimated from Reconstructing the 1998 FRH Fall and Spring Chinook Cohort

Based on Central Valley tag recovery data, DFG (2004) estimated that about 90% of the fall and spring FRH Chinook that survived the ocean fisheries and entered Golden Gate returned to the Feather River or to the FRH. The straying estimate is reasonably consistent with the numbers of tags collected from different streams. By comparison, the straying rate for the in-basin releases was around 6%, although the relatively low number of returns makes this estimate less defensible. The overall return rate (harvest plus escapement) of in-basin releases was about one-third that experienced by bay releases. The lack of good tag recovery and escapement data on several Central Valley streams likely results in the estimated straying rate being less than the actual rate.

Summary: Effects of FRH Operation on the Genetic Structure of Central Valley Chinook Salmon

The following is a qualitative summary of the expected effects of FRH operation on Central Valley Chinook salmon. The summary, by run, is based on the observed genetic structure, the life history of individual races and by FRH operations themselves. The general approach is to look at the possibilities of inter-breeding of FRH fish and those from the other runs. A low probability indicates a low chance of adverse impacts.

- **Winter Chinook**. Operation of the FRH has not affected (and is not expected to affect) the winter Chinook genome. This conclusion is based on the winter run's unique May through July spawning timing and the location of spawning in the Sacramento River between Keswick Dam and Redding. Any spring run strays from the FRH hatchery would not arrive on the spawning grounds mature enough to participate in winter Chinook spawning. The location of the winter Chinook on a separate branch of the Central Valley genetic tree supports the conclusion that the race continues to be isolated from the other three races.

- **Late Fall Chinook**. It is unlikely that operation of the FRH has effected the genetic structure of late fall Chinook. This conclusion is based on this run's spawning time and location - late fall/early winter in the Sacramento River between Keswick Dam and Red Bluff. In recent years, several late fall Chinook from the CNFH have returned to the Feather River (and other streams): however they arrive past the fall Chinook spawning period and are not included in the FRH spawning population. There is some possibility the run could be established in Feather River and hatchery operations could affect it.

- **Spring Chinook**. There is more of a possibility that FRH operations have affected the genetic structure of this run. The FR spring Chinook propagated at the FRH are released off site and thus stray more than wild population - albeit at rates that appear to be significantly lower than expected. A few nominal FRH spring Chinook have been collected on spring Chinook tributaries and in Battle Creek and the CNFH. (Battle Creek is the site of an extensive restoration program, one of the goals of which is to provide habitat necessary to establish a spring Chinook run.) The FRH spring run fish have only been recovered in the lower, fall run spawning sections of Deer, Mill, and Butte creeks, perhaps in part due to low total numbers in the higher reaches and sampling problems in these areas. The genetic structure of spring Chinook runs to Mill, Deer and Butte creeks indicates that to date, FRH operations have not affected this run - i.e. the structures are genetically quite different from that of the FRH and FR spring runs.

- **Fall Chinook**. Although there are no pre-project data, it is almost certain that operations of the FRH have contributed to the homogenization of the Central Valley fall Chinook genome. That

being said, it is almost certain that operation of the FRH has been only one of a wide variety of factors that has caused the lack of genetic diversity in this race - assuming it was there in the first place. Most of the factors deal with the lack of biological concern about moving hatchery fish from place to place (and releases strategies) and an overall production oriented mindset of hatchery and fishery managers over the past 35 or more years. The past 5 or so years have seen a gradual change in this mindset (partly the result of the DFG/NOAA 2001 Hatchery Review.)

Steelhead

The Central Valley steelhead genetic data were summarized in the neighbor-joining tree in Figure 24. As is usually the case with steelhead, we have considerably less information for this species than with Chinook salmon. We look at the effects of hatchery operation on the genetics of Central Valley steelhead we are limited to information on the transfer of genetic material to and from the FRH. Because all Central Valley steelhead are marked only with an adipose clip, there is no direct way to determine if the adults are straying from their hatchery streams.

Transfer of steelhead genetic material to and from the FRH. The extensive transfers of genetic material are tabulated in Table 18.

Table 18. Transfers of steelhead genetic material to and from the Feather River Hatchery during the period 1967-2002. (Data from DFG FRH annual reports.)

	Number of Steelhead Life Stage and Source or Destination Transferred x 100,000	
Year	*Number Transferred to the FRH*	*Number Transferred from the FRH*
70-71	1.5 - fingerlings from NFH	
75-76	0.4 - summer run eggs from NFH	
76-77	0.4 - summer run eggs from NFH	
77-78	2.6 - eyed eggs from Mad River H	
78-79	2.1 - summer run fry from NFH	
79-80	1.5 - summer run fry from NFH	
	0.3 - eyed eggs from Iron Gate H	
80-81	2.0 - “late” run eyed eggs from NFH	
	0.5 - Klamath R. fry from DFG Reg. 1	
81-82	2.7 - “late” run eyed eggs from NFH	
87-88	1.1 - yearlings from NFH	
88-89		3.0 - fingerlings to MRH
90-91		1.0 - fingerlings to MRH
97-98		1.4 - fingerlings to MRH
02-03		3.0 - eyed eggs to MRH

The data indicate that during the early years, the transfers were mainly into the hatchery to help establish one or more steelhead runs on the Feather River. From a biological standpoint it may be fortunate that these efforts seemed to have failed and the run that was present immediately before Oroville Dam was completed remained the only Feather River run. Since many of the early transfers came from

the Nimbus Fish Hatchery, whose founding stock originated from the Eel River system, it is fortunate that this stock did not seem to dominate the Feather River run. The later transfers to the Mokelumne River were part of an attempt to establish a steelhead run.

Summary of the Effects of FRH Operation on the Genetic Structure of Central Valley Steelhead Runs

The genetic information shown in Figure 24 indicates that considerable genetic diversity exists within Central Valley steelhead populations and that the effects of the hatcheries that rear steelhead seem to restricted to the populations on the hatchery streams - i.e. Battle Creek, Feather River and the American River - indicating high level of gene flow between hatchery and stream populations. The lack of distinction between San Joaquin and Sacramento populations (less than 1% of allelic variance was partitioned between the two populations, Nielsen et al. 2003) leads to the conclusion that there has been genetic exchange between the basins, either by straying or direct exchanges of genetic material such as shown in Table 18.

It must be emphasized that this study, although it included 1570 samples and used 11 microsatellite loci, is limited and the results should be viewed with some caution. The genetic differences observed among some of the adjoining neighbors (e.g. Stanislaus, Middle Fork American, and the Yuba River) are difficult to explain.

TASK 8. Estimate the FRH Contribution to the In-River and Hatchery Population of Fall and Spring Chinook and Steelhead Returning to the Feather River.

Estimates of hatchery contribution to the fisheries and escapement help fish managers determine if in-river actions are likely to affect run size – i.e. the runs are not dominated by direct hatchery returns. Obtaining accurate estimates of the proportion of hatchery fish in a spawning populations is difficult at best and near impossible in most circumstances. Nevertheless, we agreed to make an attempt.

All attempts to estimate the numbers of hatchery fish in a spawning run depend on the presence of a unique and identifiable external or internal mark on the hatchery fish and, in the most common circumstance of having much less than 100% of the hatchery fish marked (closer to 10-15% in this case), a quantitative sampling method to extrapolate from the number of marked fish in the population to the total numbers of hatchery fish. In the case of the FRH, there has always been less than 100% marking and recovering the marked fish on the spawning grounds almost never meets the standards of statistical reliability. Most salmon tag recovery efforts are combined with escapement surveys. If large numbers of tags have been applied and lead to large numbers of tags recovered in the field, the tendency is for the field crews to under-recover the tags, especially during the peak of the spawning migration. In the case of the Feather River and other hatchery streams, the hatchery itself provides a backup estimate of the number of tags in the spawning population - i.e. the assumption is that all tags are recovered during the spawning operations.

The following discussion applies only to Chinook salmon. There is no unique mark for steelhead nor can the winter spawners be sampled effectively. The fact that more than 99% of the steelhead entering the Feather River Hatchery have clipped adipose fins (the hatchery mark) indicates that a very high proportion of the Feather River steelhead run is of direct hatchery origin.

We have 4 individual estimates of the in-river FRH contribution to the Feather River spawning population and will work from the most recent to the oldest. In the most recent, DFG (2004) reconstructed

the 1998 FRH fall and spring run cohort and included estimates of the in-river hatchery contribution. The estimates for the 2000 - 2003 period are that FRH fall and spring Chinook contribution to the spawning run was about 39%. (Note that this estimate is based on reconstructing the 1998 cohort and involves numerous assumptions.) The age structure (based on actual coded wire recoveries at the FRH) shows interesting annual variation - especially the fraction of 2-year-olds in the spawning run. In most years, 3-year-olds dominate but in some years, 4s make up a significant fraction. The percentage of 5-year-olds is consistently low.

One of us (Cavallo) used the 2002 tag recovery data to estimate that at least 44% of the 2002 escapement consisted of hatchery origin returns (Figure 27). Jones applied the Cavallo calculation process to the 2004 run and estimated that at least 43% of the spawners were of hatchery origin. As shown below, the distribution of tag recovery by stream area indicated that hatchery fish may be returning prefentially to the vicinity of hatchery:

Estimated percentage of hatchery origin by area in Feather River system.

In the hatchery – 44% FRH tagged returns

In the low flow channel – 51% FRH tagged returns

In the hight flow channel – 24% FRH returns

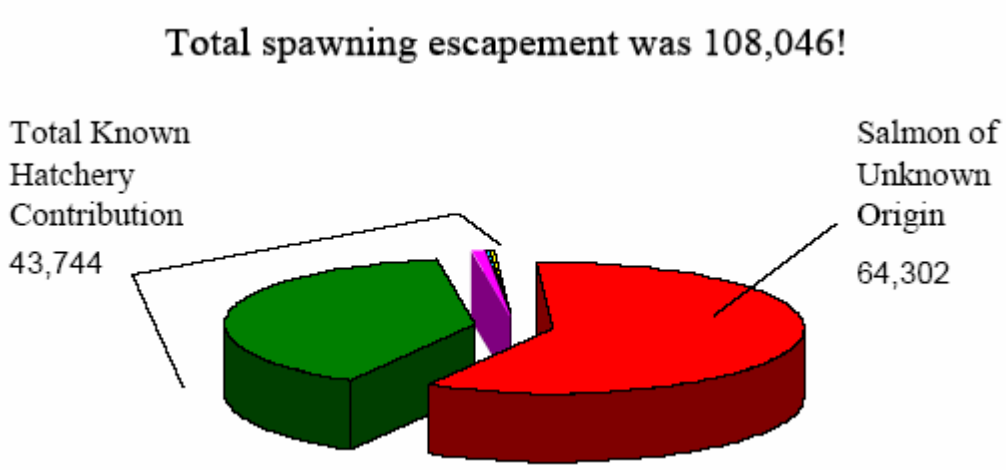

Figure 27. Estimated percentage of hatchery origin returns in 2002 fall Chinook salmon run to the Feather River. (Green = FRH returns). B. Cavallo, preliminary data.

Cramer (1990) used a much more limited tag recovery data base to estimate that, during the period 1975-1988, the hatchery contribution to the Feather River Chinook salmon spawning run ranged from 9 to 62%, with an average of about 26%. Dettman and Kelley (1987) used even less coded wire tag data to

estimate that during period 1978-1984, about 78% of the salmon spawning in the Feather River were hatchery fish - with about 76% of these hatchery fish from the FRH and the remainder from Nimbus Hatchery.

The data in Table 16 indicate that the FRH is by far the most significant hatchery contributor to the Feather River Chinook salmon run, although some salmon from Mokelumne and Merced hatcheries do stray into the Feather system.

In summary, about all we can say about the fraction of FRH in the Feather River spawning populations is that it is significant, probably varies annually, and likely is in the range of 40-75%.

There were several subtasks associated with Task 8. The following provides the information that is currently available This information is also useful for Task 9 and 10.

Subtask 1. Collect tag release and recovery information in an electronic data base

We used the Pacific States Marine Fisheries Commission Regional Monitoring Information System (RMIS) data base. DWR hired a technician to work with DFG and the PSMFC to error check and update the files, in particular the inland recoveries. The most serious problem found has been with inland recoveries from the San Joaquin system. DFG staff have been unable to allocate the time needed to verify the numbers and factors for expanding tags recovered to tags estimated to be in the population. In addition DFG and PSMFC staff assigned to the cohort project often had trouble reconciling information from the DFG annual reports and the PSMFC data base.

Subtask 2. Use tag release and recovery data to reconstruct the FRH fall Chinook population

For a variety of reasons, DWR decided to change contractors to conduct the cohort analysis. DFG reconstructed the 1998 cohort.

Subtask 3. Submit the draft cohort report for peer review

The draft report was sent to three scientists (NOAA Fisheries, Humboldt State University, and DWR) for review. Comments were due August 1, 2004 and two of the reviewers responded.

Subtask 4. Expand cohort analysis to include spring Chinook

Attempts to reconstruct the 1998 FRH spring cohort have been put on hold due to problems in the hatchery in distinguishing the runs. DFG is considering combining the runs and doing an overall cohort reconstruction on FRH Chinook.

Subtask 5. Use the data bases to estimate travel time from the hatchery to Chipps Island and estimated survival

The task was not completed in time for this report.

Subtask 6. In the fall of 2002, improve escapement and tag recovery sampling on the Feather River

A new tag sampling protocol has been in place since 2002. .The new protocols separates the recovery and escapement sampling processes and appears to be vey effective in providing statistically reliable results.

Subtask 7. Review Bailey and Munroe (2000) to determine if their analyses contribute to the issues in Task 8

This task was completed but the information in the report did not appear to be that useful for this report.

Subtask 8. Repeat cohort analysis in the spring of 2003

Due to the change in contractors, the initial cohort analysis was not completed until the summer of 2004. This analysis does include information on the contribution of FRH releases to ocean fisheries.

Subtask 9. Use the recovery data to estimate the overall survival of FRH releases

This information is available for the 1998 cohort and is included in Task 13.

TASK 9. Estimate the Numbers and Percentage of FRH Chinook Salmon Found in Other Central Valley Streams.

It is not possible to complete this task at this time - or in the foreseeable future. The tag recovery and escapement estimating processes are not sufficiently quantitative to allow reliable estimates of the numbers of adult FRH Chinook on any Central Valley stream, including the Feather River itself. Howevr the available data suggestthat the numbers of FRH Chinook salmon that stray in other Central Valley streams appears to be relatively low.

This task has several subtasks associated with straying of FRH fish. These subtasks were completed to the extent practicable and the result shown in Task 7 as part of the evaluation on the effects of the FRH on the genetic structure of Central Valley salmonids.

TASK 10. Estimate the Numbers of Chinook Salmon from Other Central Valley Hatcheries that Stray into the Feather River and Other Central Valley Streams.

Table 16 contains information on the numbers of Chinook salmon from Central Valley hatcheries that have been found in the Feather River and other Central Valley streams. At this time this we can go no further with this analysis. Some hatcheries (for example Nimbus and Coleman) do not routinely tag their fall Chinook population. Tag collection efforts on most streams are not adequate to extrapolate from the numbers of tags found to the numbers in the spawning population. DFG concluded the data were not sufficient to include these estimates in its reconstruction of the 1998 cohort.

TASK 11. Estimate the Contribution of Feather River, and Other Central Valley Hatcheries to the Ocean and Inland Fisheries.

Due to lack of tags applied at the other hatcheries, the lack of a statistically valid survey of the inland fisheries, and lack of an effective inland tag recovery program, the contribution of the FRH could only be estimated for the ocean fisheries, and even then only for the 1998 cohort.

An estimated 137,300 1998 broodyear FRH Chinook salmon were harvested in the ocean fisheries during 2000-2003. About 76% of the harvested fish were 3-year olds and about 71,000 and 29,400 of these fish were taken in the commercial and recreatonal fisheries, respecitvely. Fish trucked to San Pablo Bay had the highest contribution rate at all ages. The highest contribution for the sports fishery were at Monterey, northern Oregon port area, and San Francisco. The commercial contribution was also highest in these three areas. Trucked fall run contributed about 75% of the harvested FRH fish and the spring run contributed about 18%. The remaindere were from in-basin and experimental releases.

TASK 12. Assess the Likelihood of Disease Transmission from Hatchery to Naturally Spawning Salmonids (Fish Releases Below Hatchery) and to Hatchery Fish (Fish Releases Above Hatchery) and the Effects of Hatchery Operation on Water Temperatures in the Feather River.

The disease and water temperature effects are addressed in reports SP-F2 and SP-W1, respectively Copies of these reports can be found at http://orovillerelicensing.water.ca.gov. During discussions of the hatchery effects study plan, it became apparent that additional work was needed to address specific questions related to one disease, infections hematopoietic necrosis virus (IHNV), that had caused recent epizootics at the Feather River Hatchery. With financial support from the DWR and the USBR, fish pathologists from UC Davis and the US Fish and Wildlife Service's California-Nevada Fish Health Center conducted studies to determine:

a.) the different strains of IHNV found in California watersheds (UCD);

b.) differences among the genotype, serotype and virulence of the virus for Chinook salmon and steelhead (UCD);

c.) if the virus could be transmitted to sexually mature adult Chinook salmon (UCD);

d.) if the virus could be transmitted from infected hatchery fish to wild Chinook salmon and steelhead (UCD), and;

e.) the distribution of the pathogen in the Feather River and Yuba River watersheds (USFWS).

The results of the IHNV work are summarized here. The complete UCD study results (Hedrick et al. 2004) are found in Attachment 4. The USFWS results (True 2004) can be found in Attachment 5. The subtask of assessing the effects of releases of FRH Chinook salmon in the watershed above the hatchery was not addressed by specific studies, but by discussions with DFG's fish pathologist, William Cox. The general approach is to provide a brief history of IHNV epizootics in California anadromous salmonid hatcheries followed by results of specific study elements listed above. Finally, we address the original broad questions of the potential effects of FRH operation on IHNV infection in the Central Valley. We also address a NOAA Fisheries concern about the potential problems associated with transfer of local (Feather River strains) to salmonid populations along the West coast.

IHNV in Central Valley Anadromous Salmonid Hatcheries.

IHNV is ubiquitous in salmonid streams and it is not surprising that the virus has infected, and affected, hatchery operations in the Central Valley. The following brief narrative is based on 2004 personal communications with Bill Wingfield (retired DFG fish virologist) and Bill Cox (DFG Statewide Fish Health Coordinator)

Epizootics of IHNV were noted when Coleman National Fish Hatchery began operation in the 1940s. The early days of FRH and Nimbus Hatchery operations also saw IHNV outbreaks, with juvenile mortalities exceeding 90% in some cases. Such hatchery practices as feeding Alaskan sockeye salmon (*O. nerka*) viscera (possibly carrying IHNV) and Coleman's rearing and planting an infected strain of rainbow trout (Kamloops) in Shasta Reservoir may have contributed to the IHNV problem in the Valley. Movement of infected juveniles from place to place may have led to spread of different strains of the virus. For example, almost one million infected juvenile Chinook were moved from CNFH to the Mad River Hatchery, where they were reared and then hauled back to the Sacramento River system for eventual release. There have also been some anomalous situations that puzzled fish pathologists - i.e. IHNV was a problem in the Trinity River but not at the Iron Gate Hatchery on the Klamath.

In recent years IHNV has been less of a problem in Central Valley hatcheries. Although Coleman had epizootics in the mid 1990s, installation of an ozone treatment system on the water intake has apparently eliminated the problem at this facility. For several years before 1998, IHNV had not been a significant problem at the FRH. Epizootics in juvenile hatchery Chinook salmon then occurred in 1998, 2000 and 2001, and 2002 with significant fish losses. In 2002 steelhead mortality due to IHNV occurred at the FRH.

IHNV has typically been a problem for Chinook salmon production, although there have been instances when the virus affected steelhead production. Although the virus had been detected in stream

salmonids, there have been no reported epizootics of IHNV in Central Valley stream populations - i.e. the virus was detected but the fish themselves were asymptomatic of the disease.

The following summarizes the information collected in the recent IHNV studies by objective listed above.

Objective A. Determine the Different Strains of IHNV Found in California Watersheds (UCD)

UC Davis researchers used gene sequences to type 81 isolates from FRH salmonids collected over the past 18 years and 138 isolates from the following locations:

- Yuba River
- Coleman National Fish Hatchery
- Battle Creek
- Clear Creek
- Trinity River Hatchery
- Hoopa Fish Rearing Facility
- Lake Oroville
- Nimbus Hatchery
- Merced River Hatchery
- Mokelumne River Hatchery
- Mad River Hatchery
- Rowdy Creek Fish Hatchery
- Klamath River

In addition, isolates were obtained from 3 Oregon locations: Elk River Hatchery, Sixes River, and Rogue River. Data from the northwest and Alaska were also included in the analysis to show the coast-wide distribution of the viral isolates.

The details of the analyses can be found in Attachment 4. Figure 28 (from Hedrick et al. 2004) shows a phylogenetic tree constructed using the gene sequence data.

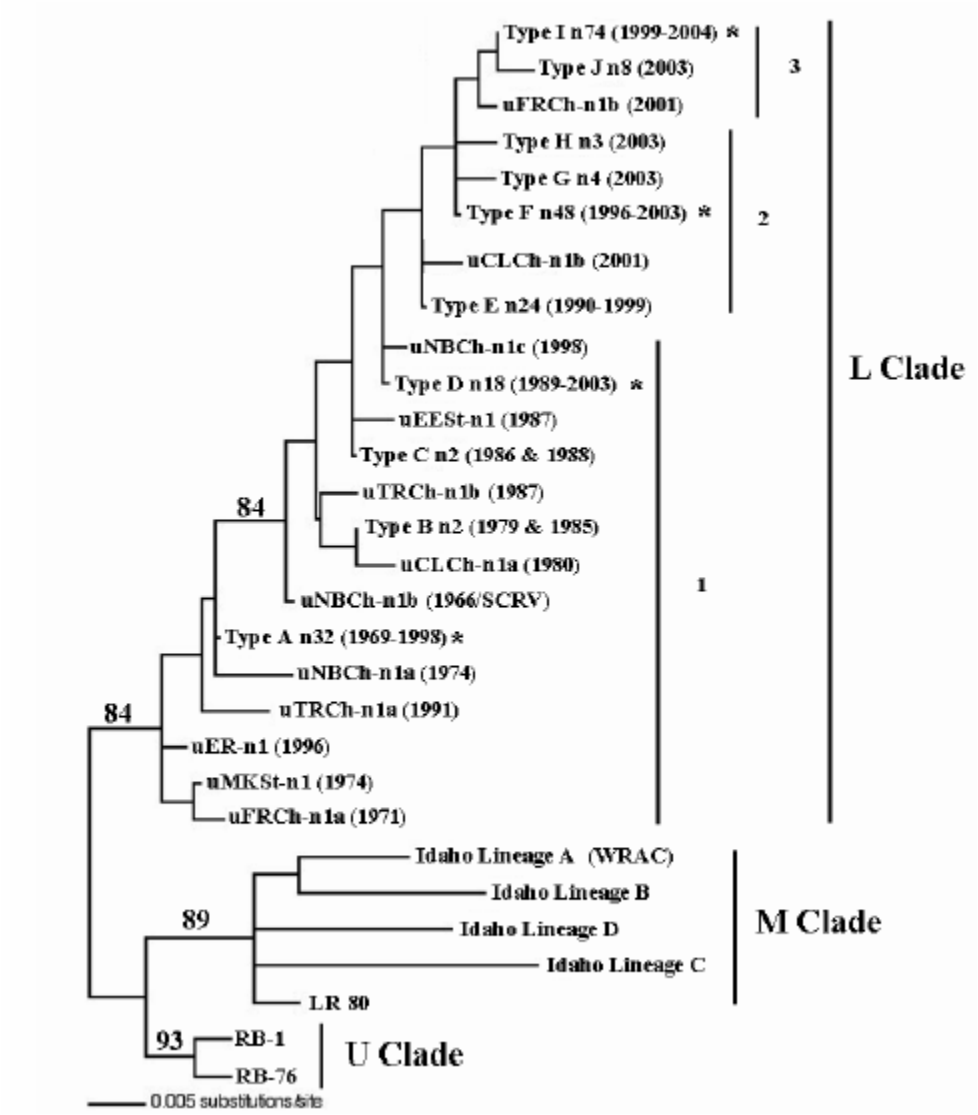

Figure 28. A rooted phylogenetic tree constructed using the mid-G sequence (303 nt) representing relationships among L, M and U Clades. (from Hedrick et al. 2004)

Branch lengths correspond to genetic distance and the limbs and branches can be used to evaluate association between the various clades and types within the three IHNV clades. A few comments may help better understand the tree itself:

- The individual limbs are coded to denote when the isolates were collected, source and number of samples for the individual isolates. For example, Type E, n24 (1990-1999) reads: this is classified as a Type E sequence containing 24 samples collected during the period 1998-1999. Appendix Table 1 shows that the 24 fish in Type E came from the FRH, Nimbus Hatchery, Merced Hatchery, Coleman Hatchery, Mokelumne Hatchery and Battle Creek.

- The asterisks indicate the sequence types that were present in epizootics.

- The numbers #1, 2 and 3 to the right of the tree are the three serotypes found in L clade isolates and indicate the approximate chronological evolution of the IHNV types in California. Limbs with a "u" indicate a unique isolate.

The following tentative conclusions can be drawn from the data shown in Figure 28 and Appendix Table 1.

1. The California isolates of IHNV belong to a different clade than those from the Northwest and Alaska. There is some overlap in southern Oregon where the L clade is also found. This geographic separation has existed for a considerable time.

2. In the Central Valley, the IHN virus has undergone, and is apparently still undergoing, considerable genetic evolution. There are several major sequences (A through J) that we have seen or are now seeing. It now appears that one of the original Central Valley types, Type A, is no longer found in the Valley. As seen in Figure 28, the evolutionary process appears to be proceeding at much faster pace in the Central Valley than in coastal isolates.

3. Although the latter types, e.g. Type I, have been found in several Valley locations, more than seventy-five percent were found in the Feather and Yuba River drainages. Type J has only been found in the Feather River. On the other hand, Type F has been found is samples from throughout the Valley. For whatever reason, it appears that IHNV is evolving rapidly in the Feather/Yuba systems.

4. Although most of the isolates are from Chinook salmon samples, the virus was detected in steelhead samples as well.

5. Although not specifically shown in the data in the tree and table, other data on mutation rates suggest that a host jump occurred in the 60s - perhaps from sockeye salmon to Chinook resulting from the use of ground sockeye viscera as salmon food in Central Valley hatcheries.

Objective B. Determine if There are Differences Among the Genotype, Serotype and Virulence of the Virus for Chinook Salmon and Steelhead

UCD researchers tested eight L clade strains of IHNV for their virulence to juvenile Chinook salmon (Nimbus Hatchery) and juvenile rainbow trout (Trout Lodge Hatchery, Sumner WA). In both cases the fish averaged a little more than 0.5 grams. The viral genotypes were collected from the Feather, Merced, Nimbus, Mokelumne, and Coleman hatcheries and consisted of types A through F, I and two unique genotypes.

The results showed the virulence for all isolates of IHNV tested for juvenile Chinook salmon were nearly the same, regardless of genotype or serotype. The exception was an isolate from Nimbus steelhead trout that was more virulent for Chinook salmon. The same isolate had a lesser virulence to rainbow trout. Overall, most isolates of IHNV tested were less virulent for rainbow trout than Chinook salmon. In general the L clade IHNV appears to be adapted more the Chinook salmon than other salmonids (LaPatra 1998.) M clade viruses found in Idaho and the Columbia River system may be highly virulent for rainbow trout Troyer et al. 2000).

Objective C. Determine if the Virus Could Be Transmitted to Sexually Mature Adult Chinook Salmon

UCD researchers at the Bodega Marine Laboratory exposed adult winter Chinook from a captive broodstock program to 350,000 plaque forming units of IHNV per milliliter (pfu/ml). The test fish had no prior exposure to IHNV. The exposures were water borne. At several days post exposure, the investigators examined the kidney and spleen, ovarian fluid, gills and plasma for presence and concentration of the virus. Controls were held in identical laboratory conditions but without exposure to the IHNV. The experiment was terminated at 14 days.

The results clearly demonstrated that IHNV can be transmitted to adult Chinook salmon via water borne exposure. By as early as day 4, the virus was detected in all tissues examined and by day 14, all tissues in the exposed fish had measurable levels of the virus. No virus was found in the unexposed fish. In spite of viral concentrations as high as 1.78×10^7, there was no detectable symptomatic evidence of the disease (the presence of microscopic lesions) in exposed as compared to control fish. Other experiments at the Bodega laboratory had demonstrated that green (pre-spawning) adult salmon were not susceptible to the disease until about 14 days before spawning (Ronald Hedrick, UCD, personal communication).

Objective D. Determine if the Virus Could Be Transmitted from Infected Hatchery Fish to Wild Chinook Salmon and Steelhead

In these studies, UCD researchers used three approaches to examine the concern about transmission of IHNV from hatchery to wild fish:

- Expose 4 gram Iron Gate hatchery fall Chinook to a single exposure of IHNV at a concentration of 70,000 pfu/ml for one hour.
- Expose 0.5 gram Nimbus fall Chinook to 30 minute doses of IHNV for 5 consecutive days.
- In the second group, 20, 0.5 gram steelhead were added to each group of 30 exposed juvenile Chinook salmon. Cohabitation occurred for 18 days.
- Controls – no exposure – were also maintained and examined for virus during the 100 day study. Examination consists of looking for clinical signs of the disease, mortality, and presence of the virus on gills, skin and kidney/spleen of the test fish.

The results showed that juvenile Chinook salmon exposed to a range of IHNV concentrations, either singly or in multiple doses, resulted in viral infections but no clinical signs of disease. Virus was consistently found up to 39 days post exposure, with the gill and skin appearing to be the sites of residence and replication. Although the virus was residing at the external sites, the shedding rates were not sufficient to infect juvenile rainbow trout living with the infected Chinook salmon. After 79 days culture, no virus was found in previously infected salmon. No virus induced mortalities were detected during the studies.

Objective E. Determine the Distribution of the Pathogen in the Feather River and Yuba River Watershed

This study (True 2004, Attachment 5) looked for the presence of several fish pathogens in the Yuba and Feather rivers. Clear Creek was sampled for pathogens in returning adults, as a non-hatchery out-of-basin control. Finally, the researchers sampled adult Chinook salmon in Battle Creek (below CNFH) as

part of an existing program. Although the study collected information on a variety of pathogens, we only include data on IHNV in this report.

During the 2002-2003 study the team collected fish and fish tissue samples from rotary screw traps on the Feather and Yuba rivers (juveniles), by electrofishing and beach seines on the Yuba River (juveniles), and from fall carcass surveys on both streams (adults). Although the study focused on Chinook salmon and steelhead, other fishes were examined including hardhead (*Mylopharodon conocephalus*), smallmouth bass (*Micropterus dolmieu*), bluegill (*Lepomis microchirus*), Sacramento sucker (*Catostomus occidentalis*) and golden shiner (*Notemigonus crysoleucas*). Typically kidney/spleen samples were collected for IHNV examination, however in small fish visceral samples were examined.

IHNV was not detected in any of the more than 1,500 juvenile fish examined in the Yuba and Feather rivers. The majority of the fish examined were fall Chinook, with lesser numbers of steelhead (or rainbow trout) and common non-salmonid species. The returning adults showed the following incidence of IHNV infection:

- Yuba River – average of 27.8% from three reaches (23%, 29% and 40%) with the highest incidence in the lowest reach.

- Feather River – 18.1% in 83 individual fish collected on one date in October, 2003 below the fish barrier dam.

- Clear Creek – 45.6% in 46 individuals collected on one date in October 2003.

- Battle Creek – average of 11% in 114 fish sampled over three periods. On Battle Creek the average incidence of IHNV infection in returning adults has ranged from 11% (2003) to 83%, with an average of 55.5%.

These data should be used with caution due to the relatively small sample size, the lack of multiple sampling dates and the short study duration.

Tentative Conclusions from the IHNV Studies

Although the UCD and USFWS studies were relatively limited in both time and scope, the results do lead to the some preliminary conclusions about the effects of FRH operation on naturally spawning salmonids. Results from other IHNV studies and literature are included where appropriate. Note that although these conclusions have been reviewed by fish pathologists, they are personal conclusions based on our interpretation of the data.

- Sacramento Valley strains of IHNV have continued to evolve, with particular activity in the Feather River and the FRH.

- The continuing evolution of the virus does not seem to be resulting in strains that are more virulent than early ones. This does not mean to imply that future strains will not increase in virulence.

- In recent years IHNV has caused epizootics in the CNFH and the FRH. In the case of Coleman IHNV has been a recurring problem over the years. In the Feather River system, IHNV was a

problem early on but, until 1998, had not caused epizootics. The potential effect of IHNV on naturally spawning salmonids is a legitimate concern.

- There is a general pool of the IHNV in the Central Valley that appears to be affecting returning adults. There is some possibility that the pool is maintained in part by the presence of adults in the system during all seasons of the year.

- The laboratory infection studies demonstrate that adults can be infected horizontally by exposure through the water. This helps explain the observation that the degree of infection is generally higher later in the run as compared to earlier (e.g. Wingfield and Chan 1970). This transmissibility could lead to the different strains being carried from stream to stream as fish enter one or more streams before moving on to their spawning stream. This concern may be alleviated somewhat by the observation that green (immature) fish do not seem as susceptible to infection.

- Infected juveniles can be released from the hatchery without affecting juveniles from naturally spawning salmonids. This conclusion is based on laboratory studies of fish with relatively low IHNV titers. Information on the effects of clinically diseased fish on naturally occurring salmonids is not know. Free and Foott (1998) did show that infected juveniles released from CNFH were still infected when collected about 180 miles below the hatchery. Foott and Williamson (1998), with another study of CNFH juvenile released showed that infected juveniles could survive to for several days - in fact the release group with the highest infection rate, had the highest survival to the Sacramento-San Joaquin Delta. (They were also the largest fish.) The point is that infected fish do survive after release and the potential for disease transmission is still there.

- We still do not know what combination of conditions in the hatcheries cause the disease to move from infection to epizootic. Free and Foott (1998) suggest that if 7-day mortality exceeds 0.5%, the hatchery managers should be concerned that the infection rates may exceed 10% and are cause for concern.

- The absence of IHNV in juvenile salmonids in the Yuba and Feather rivers suggests that transmission from the hatchery to stream fish, including salmonids, may not be a major concern. It must be kept in mind that these data are limited in both time and space.

- There are effective measures for controlling IHNV - iodophor treatment for eyed eggs and ultraviolet or ozone sterilization for the water supply. Idophor is now routinely used. Ozone treatment, or similar sterilizing process, is expensive (and a high energy use process) and the cost and environmental impacts of the process itself must be carefully weighed against the benefits.

Returning to the original questions about the effect of FRH hatchery operation on naturally spawning salmonids, the tentative answers are:

1. Does IHNV transmission associated with FRH juveniles planted below the hatchery appear to be adversely affecting salmonids in either the Feather River or other California streams? The guarded answer is no. No adverse effects have been shown nor do the data support the conclusion that there are significant effects.

2. A subset of this question is: Does IHNV transmission associated with the release of FRH juvenile salmonids appear to be affecting salmonids in other salmonid supporting streams along the west

coast of North America? Again the data do not support such an effect. There are very few Feather River salmon that stray into northwest streams. The long term evidence indicates that the U and M clades are distinct from the Central Valley's L clade.

TASK 13. Assess the Ongoing and Future Impacts of the FRH on Naturally Spawning Chinook Salmon in the Feather River and Other Central Valley Streams.

This task is the essence of the F9 analysis but unfortunately most of the data needed to make the assessment has not been collected in this system or in most systems where hatchery and naturally spawning Chinook salmon. Where possible we use data from the Feather River Hatchery and other Central Valley hatcheries and streams in analyzing the impacts. We draw on the literature to supplement these data. The following discussion is in the order presented in the F9 study plan.

Straying rate. Determination of the straying rate requires that sufficient numbers of tags be applied to FRH fish and that stream recovery efforts be sufficient to recover the tags when the salmon return to spawn. Although DWR applied CWT to 10-15% for the FRH juvenile production from 1995, the number of tags was less than the minimum 30% tagging rate recommended by Newman et al. (2004). The lower than optimum tagging rate results in less precise straying estimates. Perhaps a more important limitation on the data collected is the limited tag recovery effort on most Central Valley streams. On most streams, the effort devoted to collecting tags, and estimating escapement is by the same crews and is not sufficient to collect a representative sample of the tags from the spent carcasses.

As agreed to in the F9 study proposal, DWR worked with DFG, the USBR, and the Water Forum to organize escapement and tag recovery surveys on the American River in the fall of 2003 and 2004 (DFG did not have funding) and supplemented the field crews with two technicians. DFG ran the surveys. DWR also provided an extra technician for the Yuba River surveys in 2003 and 2004. We considered these streams particularly important since earlier studies had shown that significant numbers of FRH adults strayed to the American River (Dettman and Kelley 1987) and the Yuba River is a tributary to the Feather River.

In spite of the data limitations, the tag recovery data for the 1998 fall run cohort indicated that the straying rate for hatchery juveniles released in the estuary was on the order of 10% and was about 5% for hatchery fish released in the basin. Tag recovery data for the 1997-2003 period also indicated that the straying rate was relatively low in that about 96% of the tags applied to FRH juvenile salmon were collected at the FRH or in the Feather River. Both estimates are probably biased significantly low since tag recovery efforts on many streams are not very good. Tag recovery data on the San Joaquin system are a particular problem in that it is not now possible to expand the number of tags recovered to estimates of the total numbers of tagged fish that were in the spawning runs. The data do indicate that although Feather River Hatchery fish do stray to the San Joaquin system, the stray rate appears to be relatively low.

The 2003 data from the American River and Nimbus Fish Hatchery confirm that appreciable numbers of tagged FRH spawners stray to the American River (Table 20), with 146 FRH tagged fish collected in the river or in Nimbus Hatchery. (For comparison, in 2003 1519 FRH tags were recovered on the Feather River or in the FRH – with about 80% if these tags recovered in the hatchery itself.) It is not possible to expand the tag recoveries to total number of tagged fish in the spawning populations either in the river or the hatchery without making several unverifiable assumptions. Using a simple expansion from the calculation that the 2003 spawning run to the American River was about 50% Nimbus Hatchery direct returns, it appears that the FRH straying rate would be higher than that calculated in for the 1998 cohort.

Table 20. Number and source of coded wire tags recovered from Chinook salmon in the American River and Nimbus Fish Hatchery in the fall of 2003.

Tag Source	*Recovery Location*	*Number of tags recovered*
Coleman	American River	8
Coleman	Nimbus Hatchery	82
FRH	American River	58
FRH	Nimbus Hatchery	88
Merced	American River	19
Merced	Nimbus Hatchery	33
Mokelumne	American River	70
Mokelumne	Nimbus Hatchery	166
Nimbus	American River	275
Nimbus	Nimbus Hatchery	856
Tiburon Net Pens	American River	6
Tiburon Net Pens	Nimbus Hatchery	2
Total recoveries		1663
Total recoveries in Nimbus Hatchery		1227
Total recoveries in the American River		436

The American River data demonstrate one of the problems with the tag recovery data. There were about 10 times as many fish in the river as entered the hatchery: however in almost every case more tags were recovered in the hatchery than in the river. Do hatchery fish return to the hatchery or the tag recovery crews are not very efficient at recovering tags – or both?

The Yuba River tag recovery data for 2003 also demonstrated that tagged Feather River Hatchery salmon stray into this tributary. The unexpanded recoveries were:

Source	Number of tags recovered
Coleman	1
FRH	47
Mokelumne	2
Nimbus	2
Tiburon net pens	1
Total recoveries	54

As expected, FRH fish were most common source of tags recovered on the Yuba River. As with the American River, it is not possible to estimate the total number of tagged Feather River Hatchery fish that spawned on the Yuba River in 2003. The relatively high tag recovery rate in the Yuba River in 2003, as compared to previous years, may have been due to the extra field person DWR supplied and an increased emphasis on tag recovery.

Effects on run timing. Although we are unable to determine if FRH salmon are affecting the run timing in other streams, they do stray and in the Feather River, fall run hatchery fish are spawning earlier than in-river spawners (B.Cavallo, unpublished data). Since spring and fall run have been hybridized at the FRH, this early run timing could be a manifestation of this interbreeding.

Effect of the FRH on the morphology of juvenile and adult Chinook salmon. The data were not adequate to determine if the hatchery has affected morphology. Abundant food normally ensures that juvenile hatchery fish are larger at a given early life stage than fish rearing naturally in the streams (see for example Reisenbichler and McIntyre 1977, Rhodes and Quinn 1999). The size at return as adults is dependent on the ocean environment and the fisheries, as well as any effects of domestication on hatchery fish. For example, the average size of Chinook salmon taken in the California troll fisheries has increased about two pounds in the last three years. The size increase may be due to better ocean conditions or a less intense ocean fishery that allows the fish to remain longer in the ocean. The hatchery records are not adequate to determine if the hatchery has affected the size or spawners taken into the hatchery. Taylor (1986) and Fleming et al. (1994) have shown that body shape for juvenile and adult salmonids from hatcheries populations were more similar than body shapes from genetically similar wild runs.

Outbreeding depression. In theory interbreeding between hatchery and wild salmon will result in reduced fitness – often called outbreeding depression. To minimize the effects of such interbreeding, interbreeding should be avoided by reducing straying and physically, or temporally segregating salmon races in the spawning streams. One of the possible effects of outbreeding depression is loss of adaptation to local conditions (Busack and Currens 1995).

It is clear that the Feather River and other Central Valley fall Chinook salmon hatcheries have resulted in extensive gene flow among hatchery and the then wild populations. It is also likely that this excessive gene flow has caused the resulting populations to be less fit. Certainly the resulting fall Chinook populations in the Central Valley have low genetic diversity as compared to Chinook salmon populations elsewhere (Banks et al. 2000, Williamson and May 2003). As stated in the study plan, we use straying rate as a surrogate parameter for evaluating outbreeding depression – i.e., high straying rate mean that outbreeding depression problems are increased. We know that hatchery release practices at the Feather River and other CV hatcheries have increased the straying rate over that experienced by wild or naturally spawning salmon.

Using straying rate as a surrogate for potential outbreeding depression, we can expect that the FRH has or has not affected the following races:

- Winter Chinook – This race is isolated in time and space from FRH fish thus, the hatchery stock has not interbred with winter Chinook.

- Spring Chinook – Tag return data and genetic structure of Mill, Deer and Butte creeks indicate there has been minimal interbreeding between FRH springs and the individual runs.

- Fall Chinook – The potential for outbreeding depression is quite high with this race.

- Late fall Chinook – Like winter Chinook, late falls are isolated in space and time and there has historically been little interaction between FRH salmon and naturally spawning late falls.

Reduced predator avoidance. Several investigators have concluded that hatchery reared fish have reduced predator avoidance (see for example, Moyle 1969 and Berejikian 1995). There are no specific data from the FRH that shed light on this question. Until recently all FRH production was released in San Pablo Bay thus in-river predator avoidance was not an issue. For the past two years, one-half of the spring run production has been released in river. The lack of exposure to predators in the hatchery will probably put these fish at risk and the returns from these fish may be less than that exhibited by the progeny of naturally spawned salmon.

Disease transmission to wild fish. The primary disease concern at the Feather River Hatchery has recently been IHNV, and the concern has been more focused on transfer of disease between hatchery fish released above the hatchery to fish in the hatchery. Although the data are limited, it doesn't appear that IHNV is readily transmitted from hatchery fish to salmon and other fish in the streams, estuary and the ocean. This concern may be increased as more hatchery production is released on-site, however, the released smolts move rapidly downstream, thus minimizing exposure and disease transmittal. IHNV is ubiquitous in the Central Valley watershed and there is no indication that FRH production has resulted in distributing the FR strain of the virus to other streams.

Selection for non-territorial behavior and reduced activity in pre-smolts. We have no data on the territorial behavior and activity of hatchery pre-smolts but it seems likely that the hatchery environment will lead to reduced territorial behavior and decreased activity.

Early maturation in smolts. In 2003 Tresa Veek (DFG) examined a random sample of 200 steelhead smolts and found no evidence of early maturation. Anna Kastner (DFG) has seen no indication of early maturation in Chinook salmon smolts.

Increased number of two-year olds in the spawning population. The number of two-year olds varies considerably from year to year in the hatchery, with no consistent trend (A. Kastner, DFG, personal communication).

Return of hatchery fish to hatchery instead of to suitable in-river spawning habitat. DWR field crews have observed that hatchery fish tend to return to the hatchery, at least in the Feather River. Fish arriving early to the low flow channel have the highest proportion of coded wire tags. Overall the low flow channel is much more heavily used than the high flow channel. The barrier dam and fish ladder confound the hatchery return question since the fish are stopped at the barrier dam and may not drop back below the low flow channel to spawn. When the gates to the ladder are open, the attraction flows may lead all fish into the hatchery, not just those of direct hatchery origin. In those streams with a hatchery, there is a higher proportion of tagged (hatchery) fish in the hatchery than in the stream. Whether this demonstrates that hatchery fish preferably return to hatcheries, or is a sampling problem with tag recovery in the streams can not be determined at this time. It is probably a combination of both.

Hybridization between runs. Hybridization between the Feather River fall and spring runs has occurred. It does not appear that hybridization between FRH fish and winter, spring and late fall runs on other streams has occurred, or if it has, it has not affected their genetic structure as described by

microsatellite markers. There has been extensive mixing of the CV fall run gene pool through operation of the Feather River Hatchery.

Inbreeding depression – loss of fitness due to domestication and other issues associated with hatchery operation. Inbreeding – the breeding of like individuals in a hatchery – can result in loss of genetic variability in that individuals with similar backgrounds are more likely to have the same alleles than ones from a more varied background. The loss of fitness should be assessed at the overall population level – not at a particular life stage. That is, do hatchery fish have an overall survival rate that is lower than their wild or naturally spawning relatives?

We could not answer that question or determine if in-breeding depression was causing loss of fitness in FRH fish. The survival of tagged wild (from naturally spawning parents) released in the Feather River was not measurable with the low number of tags applied. Survival indices from release locations to Chipps Island at the western Delta proved to be a poor indicator of the number of released fish that were ultimately harvested (a measure of survival) in the ocean fisheries (r square = 0.07) and could not be used in this analysis.

Superimposition of redds. As documented by Sommer et al. (2001), superimposition has become an increasing problem in the Feather River, especially in the upper three miles of the low flow channel. About 60% of the salmon spawn in the low flow channel and there is considerable re-digging the redds by later arriving females. Indications are that there is not adequate habitat in the low flow channel for all the spawning adults, but there is extensive under-used habitat below the low flow channel. Superimposition may be a particular problem for early arriving spring run, as their redds are disturbed by later arriving fall run. Other than a physical barrier, like a removable weir, no ready solution is available for the superimposition problem.

TASK 14. Evaluate the Effects of FRH Steelhead Planted in the Feather River on Naturally Spawning Steelhead in the Feather River.

All evidence points to the fact that the Feather River Hatchery and Feather River steelhead runs form an entity. Without the hatchery, there would likely only be a small steelhead run on the Feather River. With the hatchery the run is as large or larger than it was before Oroville Dam was constructed in the 1960s. The hatchery has almost certainly affected the fitness of the fish themselves, although they are fit enough to maintain a relatively stable run and provide angling opportunities on the Feather River. The hatchery does not seem to have affected spawning timing. It is not possible with the available data to determine if it has affected emigration timing and age at emigration.

The hatchery and Oroville Dam may have provided both the fish and the habitat needed to maintain a fish that is typically more at home it small tributaries in the upper watershed. Before Orovile was built much of this habitat had already been lost and the remaining run numbered in the hundreds of fish. Oroviille provided cool water and the river below the fish barrier dam provided a suitable, and retatively stable, envrironment for spawning and rearing.

That being said there are probably ways to make the area below the barrier dam even more suitable for steelhead, perhaps by increasing habitat complexity and extending the area with suitable water temperatures. The hatchery program could be modified to produce steelhead that are more like their wild (naturally spawned) cousins. These options should be evaluated as part of the adaptive process proposed to guide futute hatchery operations.

TASK 15. Conceptual Models of Chinook Salmon and Steelhead in the Feather River.

Conceptual models depict our understanding of a process or life history. As illustrated in Figure 28 these models are integral to the adaptive management process. The models are explicit and thus can be reviewed by others. This review can result in revised, and more useful, models. The models can also be used to assess the strength of the information in each of the model links, as well as the relative importance of the links themselves. Using this knowledge scientists and planners can determine the relative importance of acquiring new information (research) in certain areas or the likelihood that actions will result in the desired outcome. In a sense, conceptual models are transitory statements of our knowledge about a subject. They can only improve as we learn more.

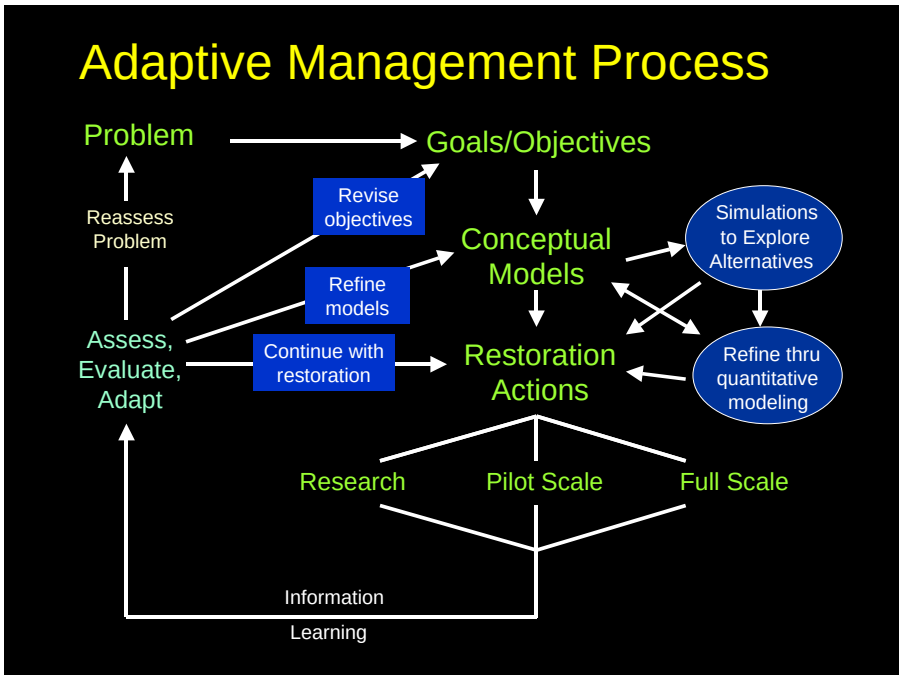

Figure 28. Conceptual models and the adaptive management process. (From Hymanson 2004 presentation to Suisun Marsh Workshop in Brown 2004 and based on M.Healey, 2000).

The following models of Chinook salmon and steelhead life histories in the Feather River as affected by the FRH and the Oroville Complex are offered in the spirit of encouraging discussion and helping point out where data are most needed to improve our understanding of the life histories.

Chinook salmon

We start with a statement of the background conditions followed by a more contemporary model of Chinook salmon on the Feather River, as affected by hatchery operation and blockage by the fish barrier dam.

Initial Conditions

Historically there were two runs of Chinook salmon in the Feather River – the fall run that spawned in the lower river near the current location of the City of Oroville and a spring run which spawned in the headwaters. We have no reliable data on the numbers of fish in each run but indications are they were substantial runs. By the time the Oroville Facilities came on line in the late 1960s, events in the upper watershed (mainly logging, dams and mining) had degraded salmonid spawning and rearing habitat to the extent that the spring run had been reduced to a few hundred to a couple thousand spawners. The fall run above spawning above the present Oroville Dam site was a few thousand adults, with the total FR fall run averaging 39,000 spawners. We have no information on the genetics of these runs but assume that they were genetically distinct – historically they were certainly segregated in both time and space. We do not know if the spring run exhibited the typical stream type behavior associated with this race. What data we have indicate that the spring run arrived on the spawning grounds in April, May and June and spawned mostly in September. The fall run began arriving in late August and spawning typically occurred from mid-September through mid-November with the peak in October.

Contemporary conditions

Run timing. There are two distinct phenotypic Chinook salmon runs to the Feather River – one arriving in April, May and June and the second arriving in August through October. This timing is similar to that observed before the Feather River Hatchery was constructed in the mid 1960s and exhibits the typical spring and fall run (stream and ocean types) life history characteristics. The spring run must find suitable cold water pools to hold until spawning commences.

Straying. We only have estimates of the stray rate for the 1998 fall run cohort. These estimates indicate about 10% of the off site production releases stray to other Central Valley streams, as compared to a 5% straying rate for fish released closer to the hatchery. Note that the in-river straying rate estimates do not include any fish released directly at the hatchery.) Although straying rates were not calculated, during the 1997-2003 period, about 96% of the recoveries of tagged FRH fish were from the Feather River or the Feather River hatchery. On the other hand, some tagged Feather River fish were recovered in almost every stream sampled, from the San Joaquin basin to the upper mainstem Sacramento River and Battle Creek. We must emphasize that the straying rate is likely to be biased low because of relatively poor tag recovery efforts in most CV streams.

Spawning. Instead of being segregated in time and space, for the past 35 years spring and fall run fish have spawned in the Feather River below the fish barrier dam or have been spawned in the hatchery. Although adult Chinook salmon return to the Feather River in two distinct groups, annual plots of in-river spawning over time is a smooth plot indicating that there is an overlap in spawning timing between the two runs and thus the likelihood that there is interbreeding. In the hatchery, an examination of tag returns from nominal spring and fall run fish shows conclusively that these two runs have been accidentally interbred in the hatchery. The bottom line is that for the past 35 years, the presence of the fish barrier dam and hatchery have resulted in the fall and spring run gene pools on the Feather River being intermixed.

Hatchery component of the spawners. We have estimates of the percent hatchery fish in the spawning run for the 2002 and 2003 runs. Although both indicate that about 50% of the returning fish are of direct hatchery origin, these estimates should be viewed as tentative. It is probably safe to say however, that at around one-half of the spawning run is of direct FRH origin. The spawning run also contains fish from other Central Valley hatcheries including Nimbus, Mokelumne and Merced. Those fish entering the hatchery are spawned with Feather River salmon, thus helping homogenize the CV fall Chinook population. Many of the fish from other hatcheries were from experimental or other off site releases.

Genetic identification and ESU considerations. Before going into the genetics of FR Chinook salmon, two caveats are in order. First, the genetic identification thus far has relied on a relatively small number of microsatellite markers – markers that are not specific to such characteristics as run timing. Second, sampling of the two runs to date has not been quantitative – ie tissue samples were collected from fish that may not have been representative of the individual runs. Only in 2003 and 2004 do we have adequate numbers of phenotypic spring run from the Feather River. We have preliminary results from the 2003 samples but none from 2004.

That being said, the conclusions from the data at hand show that the Feather River Chinook salmon runs:

- contain a mixture of hatchery and river runs with the admixture occurring in the river and in the hatchery – that is, there is no distinct river or hatchery population of either race;
- are not genetically distinguishable with the markers that have been used to date, and;
- are isolated from genetically distinct spring run populations on Deer, Mill and Butte creeks.

Based on these data a possible hypothesis is that the Feather River genotype expresses itself in two distinct phenotypes – spring and fall – and there is no run fidelity in the offspring of this genotype. Mating studies could be used to test this hypothesis, however they would have to be designed to ensure that return rates were sufficient to support statistically valid conclusions. Spawning of marked spring Chinook in the fall of 2004 should provide the data needed to test this hypothesis. With the correct sampling protocol, additional microsatellite, or other, markers may cause this hypothesis to be rejected.

In river survival of adult salmon. Since spring and fall Chinook arrive in the river at different times, their in-river survival rates should be expected to differ. Spring run arrive in April, May and June and are bright – i.e. are desirable sports fish. Although the data are not good, it appears that there is significant in-river mortality in the 2-3 months adult spring Chinook hold in the Feather River before spawning. The hypothesis is that much of this mortality is to due to an intense recreational fishery. Fall run arrive in the river about ready to spawn, have already began to color up and thus are probably subject to a lower harvest rate. The zero keep limit for salmon after October 1 also acts to reduce fall Chinook harvest rates. There are no data to determine if there is a substantial non-fishing mortality in the river.

Emigration timing- from the upper Feather River. Screw trap and snorkel survey demonstrate that the majority of juvenile Chinook salmon leaves the upper Feather River by around March 1 of each year. Although this observation is not consistent with the typical model of a stream type emigration pattern, it is consistent with data from Butte Creek which has a genetically distinct spring population. A hypothesis arising from this observation is that the quality over-summer habitat in the Feather River for the first few

miles below the fish barrier dam is not an important factor in determining survival of phenotypic spring Chinook in the Feather River.

Emigration timing from the lower river and the Sacramento-San Joaquin Delta. There are few data to determine where juvenile fish rear between the time they leave the lower river and they leave the Delta by the end of June. We also have no data to determine if spring Chinook behave differently than fall Chinook during the juvenile rearing period. A preliminary hypothesis would be that both races use the lower river habitat in a similar fashion.

Survival from the time the juveniles leave the upper river and the time they exit the Delta. There are no data to estimate the freshwater survival of juveniles that originated from natural spawning. We do know that not many of the tagged progeny of naturally spawned salmon are captured at downstream sampling sites nor are they caught in the ocean fisheries or return to the Feather River. It must be kept in mind that the sample sizes are relatively small thus the lack of downstream recaptures is not unexpected.

The cohort reconstruction does allow some estimates of suvvival from time of release to 2-year-olds in the ocean. Of the 9.8 million smolts that were released at various locations, estimated survival to two years was:

- Trucked spring run released in San Pablo Bay – 5.8%
- Trucked fall run released in San Pablo Bay – 2.1%
- In-basin releases – 1.3%
- Experimental releases – 0.4%

Ocean survival. We do not have data in which to estimate the numbers of progeny of naturally spawning FR Chinook salmon reaching the ocean it is not possible to determine their survival in the ocean. The information presented in Task 17 does indicate that there may be a decreasing trend in the ocean fisheries, thus fishing mortality should be decreasing. Anecdotal evidence indicates that ocean conditions have been favorable the past few years, which should also have increased survival. The combined effect of this increased survival may be partly responsible for strong spawning escapements seen in recent years.

FR spring Chinook should have a higher ocean survival rate than falls since they typically leave the ocean early thus their exploitation rate is lower. Unfortunately the mixing the races in the FRH has prevented us from using tag returns to estimate ocean mortality by race.

Overall survival from juveniles to adults. The results of the 1998 cohort estimated that survival from off-site releases to the ocean fishery and escapement (both to the Feather River and to other CV streams) was 0.91%. Survival from in-basin releases was estimated to be about 0.31%. We do not have any reliable data on survival of progeny of natural spawners: however since the spawning runs consist of about 50% non-hatchery fish, some fraction of naturally emigrating fish survives to adulthood. Since run size and hatchery production and release practices have been relatively constant over the past decade or so, it does not appear that there is a downward trend in overall survival of hatchery and natural spawning populations.

The cohort reconstruction and the results of mark-recapture studies indicate that releasing FRH production in the river, as compared to the estuary, will result in 2/3 fewer fish returning to the Feather River and taken in the ocean fisheries. It thus appears that salmon protection efforts in the river and Delta have not substantially increased survival through the lower rivers and Delta.

Steelhead

Since we have much fewer data on steelhead, the conceptual model is much simpler. A simpler model does not mean the life cycle or the hatchery effects are less complex – it just means we do not have sufficient data to develop a more complicated model.

Initial conditions

Steelhead spawned above the present Oroville Dam, with numbers in the order of a few hundred fish. Conditions in the watershed had been degraded by mining, dam construction, logging etc. to the extent that the historic run numbers had been diminished considerably. We do have not have data to determine when these fish spawned but they moved past Oroville during the fall months.

Contemporary conditions

Spawning timing. The hatchery spawns steelhead mostly during the January-February period – probably about the time the original run spawned. Stream conditions are such that is not possible to determine when steelhead now spawn naturally in the Feather River.

Genetic identification of FR steelhead. Steelhead in the Feather River form one genetic unit with in-river and hatchery fish having the same genetic makeup. Essentially all steelhead entering the hatchery are marked (hatchery origin). We do not have information on the hatchery composition of those fish spawning in river, but the assumption is that most of them are of hatchery origin as well.

In-river mortality. There is a significant in-river fishery for steelhead on the Feather River. All hatchery steelhead are marked and anglers can keep one marked fish. Although all unmarked fish must be released, there will be hooking mortality.

Emigration timing. Many young of the year steelhead leave the Feather River in the late winter: however, snorkel surveys show that significant numbers do hold over in summer and may leave as yearlings in the fall or winter. Habitat complexity and the extent of summer temperatures in the high flow channel may be limiting steelhead production on the Feather River.

Survival from juvenile to adult stage. We have no information on survival of the progeny of naturally spawning steelhead or hatchery produced steelhead. The recent population levels have been relatively stable at numbers that are roughly 4-5 times those present before Oroville Dam was constructed.

TASK 16. Assess the Contribution of the FRH to Public Education and Outreach.

Since the FRH opened in 1967, numerous school groups and individuals have visited the hatchery to learn more about the mysterious salmon and steelhead. They see the fish as juveniles and adults and learn how the fish survive the rigors of 2 or more years in the ocean before they return to freshwater to spawn, and in the case of salmon, to die.

In 1996 the informal education and outreach element took a major step destined to bring the hatchery and the fish even more into the foreground - the Feather River Salmon festival began as a modest event in

Oroville Municipal Auditorium. By the third year attendance had grown from a few hundred to around two thousand people.

The Feather River Salmon Festival is now looking forward to its 8th consecutive year and will be held this fall in a local Pow Wow. In recent years attendance has ranged from 6,000 to 8,000 mostly local attendees. The hatchery provides environmental education (mostly to children), exhibits of the Chinook salmon spawning process, hatchery tours. Like similar festivals at Battle Creek and the Nimbus Fish Hatchery, the Feather River Salmon Festival has become a significant event on the local calendar.

TASK 17. Assess the Economic Contribution of the FRH to the California Economy.

This task is a very limited analysis of the economic impacts of the FRH. The resources were not available to conduct a full-scale economic analysis. Such an analysis mayt be warranted as hatchery operation continues into the next license period and the trends in ocean harvest continue.

In this discussion we focus attention on the ocean commercial and recreational fisheries – mainly because that is where the information is. The FRH has economic impacts on the local economy through its labor force and expenditures for supplies and other expenses associated with running the hatchery. The recreational fishery in the Feather River also has economic benefits that have not been quantified. Over the years the in-river fishery has intensified in response to the availability of spring and fall Chinook and steelhead in the river. For Chinook, it appears that 20 – 30 percent of the escapement is harvested each year by the in-river angling community. The fishery, and its impacts, has not been well documented and an evaluation of the fishery should be considered in future studies of the Feather River and the hatchery.

In the ocean fisheries the data are somewhat better. We base the economic analysis on catch, effort and economic information provided in the Pacific Fishery Management Council's report on the 2003 ocean salmon fisheries (PFMC 2004). Before going into the economics, it may be useful to look at the ocean fisheries, and trends in effort and harvest over the past few decades. This can provide an idea of whether the economic contribution will remain stable over the next few years. This information can also help assess the need to adjust production levels if trends in effort and catch indicate that the fisheries are becoming more or less intense.

Over the past several years the numbers of commercial trollers and recreational charter boats has decreased significantly (Figures 29 and 30) Comparing 2003 with 2002, the commercial fleet decreased by 18% and the number of recreational angling trips (both charter boat and trips in private skiffs – with about 40% percent of the trips on the charter boats) decreased by over 30%. The effects of these reductions in effort, combined with recent high escapements to Central Valley streams, have resulted in a significant decrease in the fraction of Central Valley fall Chinook salmon harvested in the ocean, Figure 31.

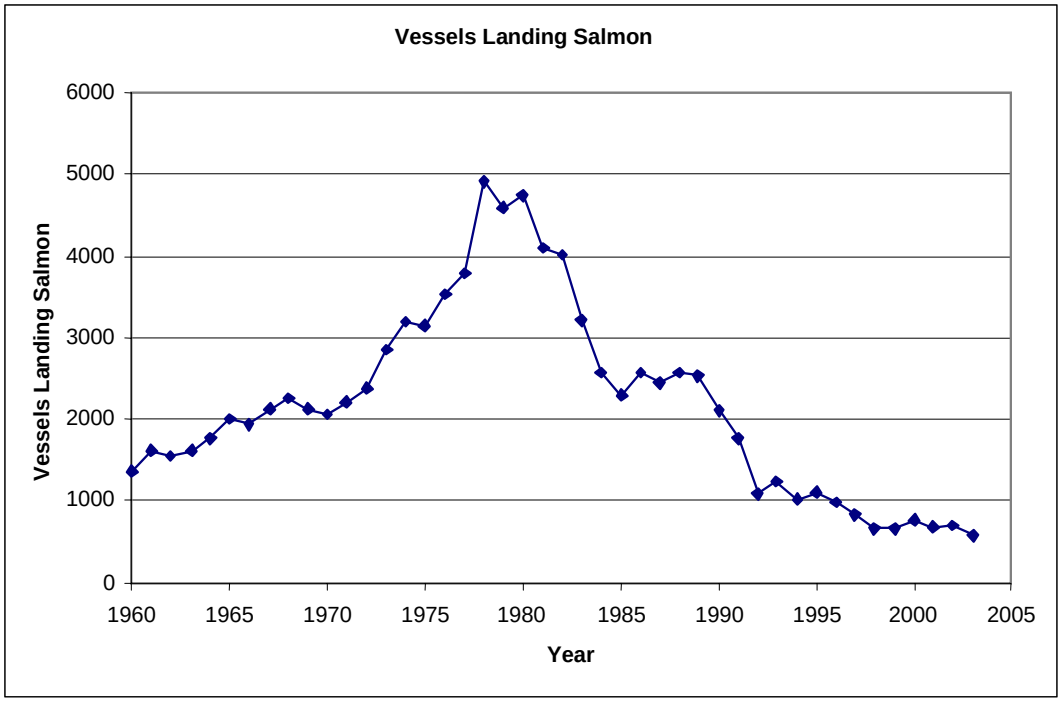

Figure 29. Number of commercial trollers registered in California, 1960-2003. (Adapted from data in PMFC 2004)

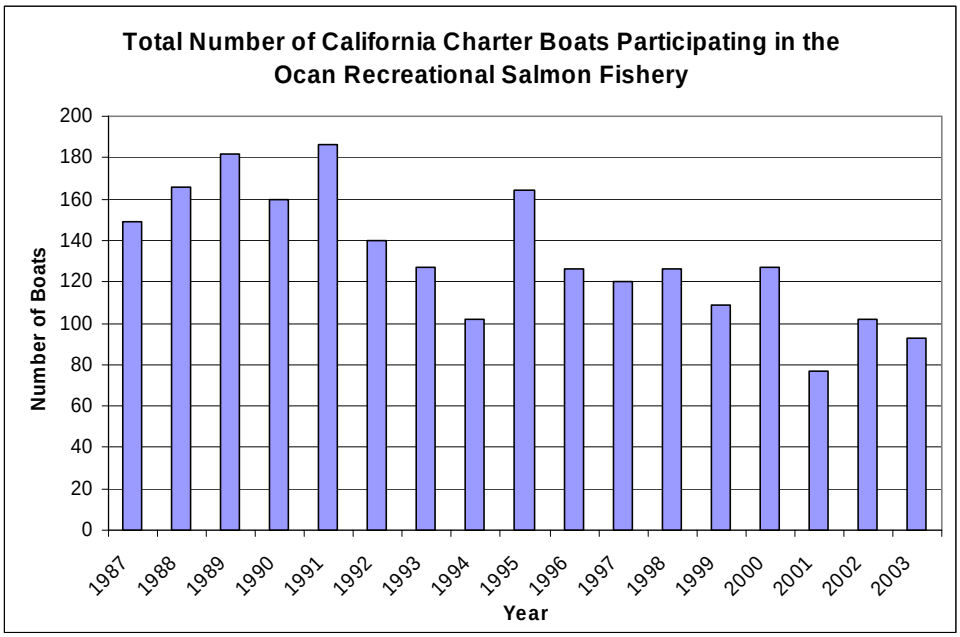

Figure 30. Total number of California charter boats participating in the ocean recreational salmon fishery – 1987-2003. (Data from PMFC 2004)

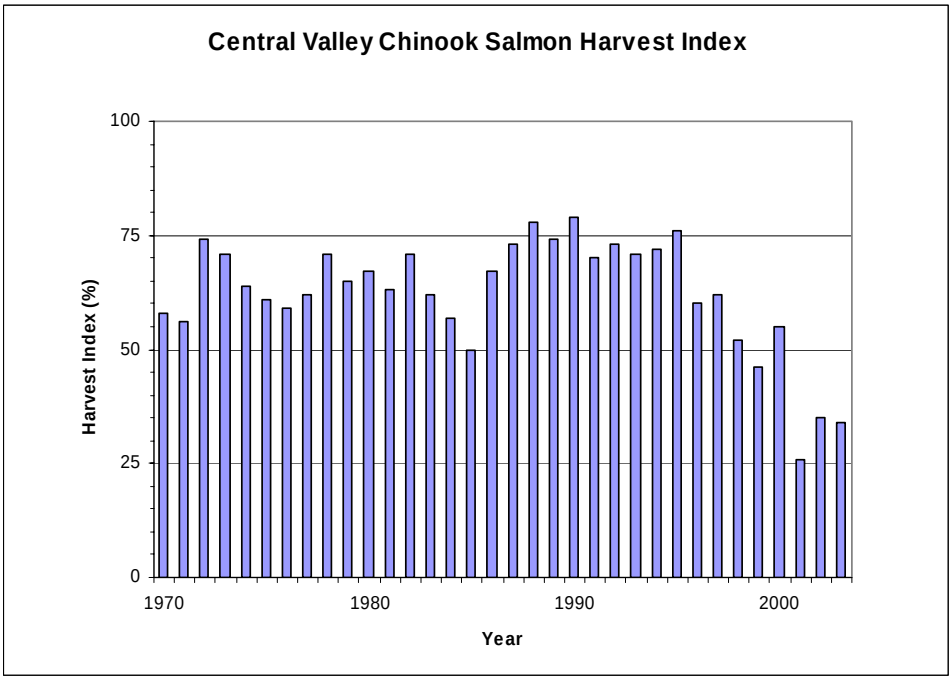

Figure 31. Central Valley Chinook salmon harvest fraction, 1970-2003. (Data from PMFC 2004)

In 2003 the average ex-vessel price for west coast Chinook salmon was $1.87/pound and may have been slightly higher in California after post season price adjustments were added in. The total ex-vessel value of Chinook salmon in California was slightly more than 12 million dollars, 53% more than in 2002 but 33% below the 1976-2001 average. California trollers landed 30% of the total west coast Chinook harvest, down considerably from 43% in 2002 and 72 % in 2001.

The estimated total state economic contribution from the California ocean commercial and recreational fisheries in 2003 was about $44 million, with more than $30 million from the troll fisheries and the remainder from the charter and skiff recreational fisheries. The $44 million was more than half of the estimated $81 million for the west coast salmon fisheries. (Note that in some years, the FRH contributes fair numbers of salmon to Oregon fisheries and this benefit is not included in these results.) The total west coast contribution was about 10% more than in 2002 but 36% below the 1976-2002 average in real (adjusted) dollars.

We only have data for the FRH ocean fishery contribution from the 1998 cohort. The commercial and recreational harvest information was not broken out for California (significant numbers salmon were landed in southern Oregon ports) but conservatively we assume that 10-15% percent of the total ocean catch originated from the FRH. If we assume 10%, the economic value of the FRH contribution to the ocean fisheries would be at least $4-5 million dollars.

These data indicate that the FRH makes a measurable contribution to California, especially if local impacts of hatchery operation and the in-river salmon and steelhead fisheries are included. These beneficial impacts have to be assessed against any detrimental impacts caused by hatchery operations on other Central Valley salmonid populations.

TASK 18. Develop Information to be Used in Identifying and Assessing the Feasibility of New Protection, Mitigation, and Enhancement Measures.

In the past five years, DFG managers have been proactive in modifying operations to make them more biologically friendly. Among the changes made in this relatively short period are:

- Implementing the 1999 operational protocols which clearly lay out constraints on hatchery operations.
- Taking gametes throughout the run and reducing inventory proportionally across the egg take, with the object of growing only those fish needed to meet hatchery production goals.
- Eliminating the practice of planting excess fry production in many Valley streams.
- Minimizing transfers of fish and eyed eggs among hatcheries.
- Planting one-half the spring run in the stream and the other half in the estuary. All spring run are being marked and tagged.
- Working with NOAA Fisheries and DWR to experiment with early opening of the ladder to the hatchery with the goal of better understanding how hatchery operations can be modified to protect the spring Chinook run to the Feather River.

Overall, DFG has been an effective participant in a team that is considering changes to the FRH's facilities and operations. The plan is for this partnership to continue into the next FERC licensing period.

In the early 1990s DWR began the present series of in-stream and hatchery studies to obtain a better picture of the ecology of the Feather River fish community and the how the hatchery may be affecting this community. As documented in this report, we have learned quite a bit. As also pointed out in numerous places in this report, we have a long ways to go in many areas. In particular we need better answers to questions dealing specifically with spring run and steelhead on the Feather, in hatchery and in the stream, for example:

- Are there distinct stream and hatchery populations of spring Chinook in the Feather River?
- Why don't more juvenile Chinook salmon and steelhead over-summer in the Feather River below the barrier even when stream temperature and flow conditions appear adequate?

The information from the studies has led to tentative recommendations for changes in hatchery operation and the need to continue our examination of the effects of the hatchery on naturally spawning salmonid populations in the Feather River and other Central Valley streams. The studies have led us to conclude that it is not possible to separate the Feather River Hatchery effects from the effects of the other fall Chinook and steelhead hatcheries in the Central Valley and the effects of fish and fishery

management practices in the Central Valley and the ocean. Finally, preparing this report has led us to the conclusion that DWR and DFG should revisit the Feather River Hatchery goals. It is not enough to cast the goals in terms of numbers of fish to be produced - hatchery goals should be consistent with consensus ecosystem, fishery, and societal goals.

Before listing specific (and general) recommendations, we think it important to recognize that this report was prepared with the assistence of a FRH Technical Team established during the FERC relicensing process for the expressed purpose of implementing SP-F9. The opinions, finings, and conclusions expressed in this report are those of the authors or other FRH Techinical Team members. This report does not express the official position of DWR unless specifically approved by the Director or his designee.

The entire process outlined before is couched in adaptive management terms. Without going into the complexities and nuances of adaptive management (see for example Walters 1986), we use the term to mean that:

- We establish goals.
- We construct conceptual models needed to explain the system well enough to see what actions are needed to achieve the goals.
- To the extent possible we establish a hypothesis driven data collection program to examine the effect of our actions, and other factors on achieving our original goals.
- In an iterative process, we analyze the data, revise the conceptual models as necessary and re-examined the goals - i.e. the adaptive management process involves a series of feedback loops.

The key components in this adaptive process are: defining the “we”, establishing tentative goals, conceptual models, and hypotheses and making sure the feedback loops are in place and working. We should point out that this is not active adaptive management in the traditional sense in that our ability to conduct experiments is limited by the large number of uncontrollable variables that affect our actions - i.e. seasonal and annual climate induced changes, changes in water project operations, and ocean conditions, including the fisheries.

The first step in this process is to define the group that will make this all happen - the “we” in the above model. (It must be emphasized at this point, that implementing the following recommendations will require that a lot more attention be devoted to the hatchery than has been allocated in the past.) We propose the following structure be established.

- **The Analytical Unit**. This would be a permanent team housed in DWR, with analysts located in Sacramento and a field crew stationed in Oroville. Although staffing would depend on available funding and positions, it would appear that 2-3 full time staff, in addition to the existing Feather River crew, would be adequate to keep track of the hatchery. This approach will result in 1 or 2 technicians added to the hatchery staff. The unit staff, working with instream staff, would:
  - Design and implement hatchery and stream studies, construct conceptual models, propose and test hypotheses, conduct periodic annual cohort analyses using DFG software, and document

the results of these efforts in presentations, periodic study reports and in published papers as appropriate.

- Provide information and participate in the FRH Agency Oversight Group described below.

- Make recommendations as to allocation of tagged fish for research and hatchery evaluation purposes.

- **The Hatchery Staff**. The staff would remain abou as now but augmented by one or two technicians or scientific aids to handle the additional data needs as defined by the analytical unit and the oversight team. A biologist from the analytical unit would be available to the hatchery staff as needed.

- **The FRH Agency Oversight Group**. The Oversight Group would consist of representative of DFG, USFWS, NOAA Fisheries, DWR (including operations staff) and other agencies that have an active interest in hatchery management and its effects on salmon and steelhead. The group would resemble the FRH Technical Team established during the FERC process but would take on a more active role in making recommendations about changes in hatchery operations and practices. A similar group is proposed in the draft NOAA Fisheries Biological Opinion on operations of the CVP and SWP – The Feather River Technical Team.

The DFG representatives should include the hatchery manager, the supervisor for Feather, Nimbus and Mokelumne hatcheries, the regional fish biologist, and someone from the Ocean Salmon Project. This group would meet periodically during the year and annually with the Hatchery Review panel described below. The group would review draft goals, conceptual models, data and analytical reports and recommendations made by the analytical unit and would have decision making authority on some of the non-operational recommendations such as allocation of FRH tagged fish to special studies.

The Agency Oversight Group could also include ex officio representatives of such stakeholder organizations such as the Pacific Coast Federation of Fishermen's Associations and the State Water Contractors.

- **The Hatchery Review Panel**. This is a new group to be established by DWR, with input from the oversight group, to provide outside review of hatchery practices and impacts. Ideally the group would be charged with looking at the entire Central Valley hatchery system but would be valuable if its role were restricted to the three DFG - operated mitigation hatcheries - i.e. Feather, Nimbus, Mokelumne - or even restricted to the FRH The panel would consist of recognized scientists in the following disciplines - we have included some names for illustrative purposes only – no one has been contacted to determine their willingness to be part of such a group nor has funding been committed.

  - Hatchery management:

  - Salmon genetics:

  - Salmonid health and disease:

  - Stream ecology:

- Wild/hatchery fish interactions:

- Population dynamics:

If the above concepts seem appropriate, formation of the groups should begin immediately and not be tied to completion of the FERC approval process. The rationale for this recommendation is that at the end of the FERC review process, the newly licensed Oroville Facilities will almost certainly include the FRH. Thus, we should not wait 2-3 years before moving forward with actions that will result in increased ability to assess hatchery effects and change operations as needed. We recommend that the proposal for the Agency Oversight Group and the Hatchery Review panel be discussed at upcoming meetings of the current FRH Technical Input Team and the Environmental Work Group. The agencies and stakeholders should agree on representation and charge to the Oversight Group. Candidates for the Review Panel should be considered and contacted for their interest in participating and funds established to bring the Panel on board with the first annual meeting to be held during the summer of 2005 - after the hatcheries have finished planting their fish. Agency representatives should discuss the envisioned FRH process with the DFG/NOAA Fisheries Hatchery Coordination Team and representatives of CNFH, the Battle Creek Restoration Program and CALFED who are discussing similar needs.

Although the team leader and the Agency Oversight Group should be part of the discussion on any final plans for studies and changes in hatchery operations, below we include some thoughts on studies and operations.

Hatchery Related Studies

We recommend the following studies be considered, mostly as continuation of existing efforts.

- Continue the comparison of in-river and in-bay releases of phenotypic spring Chinook salmon. This study involves tagging all FRH juvenile spring Chinook and releasing half in river and the other half in San Pablo Bay. The original study was planned to include 3 consecutive years of tagging and should be completed. The data should then be evaluated making a decision on whether all nominal FRH spring Chinook should be released on site. The Agency Oversight Team should develop a recommendation as to the length of the evaluation period - i.e. how many year classes need to return before making a decision.

- Continue genetic studies of spring and fall Chinook on the Feather River with the express objective of determining if there are distinct stream and hatchery runs of the two races. A study plan is needed by April 2005 and should be developed by a small subcommittee of the oversight group with assistance from a geneticist. A similar study plan should be developed for FR steelhead, but in this case the study should be Valley-wide, with samples, and funding, from other hatcheries and streams. In particular these efforts should be coordinated with steelhead genetic work on Battle Creek and CNFH.

- Continue the existing mark-recapture efforts to evaluate the contribution of FRH fall Chinook to the fisheries and escapement and their straying rate. This effort has at least four components:

  - <u>The number, and size of the tags to be applied.</u> How many tags are needed at the FRH to obtain sufficient (statistically useful) recoveries in the fisheries and in the rivers? Are half tags being returned at a rate comparable to full tags? Consider implementing the 30%

minimum marking rate recommended by Newman et al. (2004). Also consider marking all FRH Chinook with adipose clips and/or otolith marks.

- Ocean tag recoveries. Existing ocean tag recovery efforts, being coordinated by DFG's Ocean Salmon Project, are probably adequate and should be continued. The Agency Oversight Team should work with other hatchery managers and the Interagency Ecological Program to determine an equitable distribution of costs for this mark recovery program.

- Inland tag recoveries. Existing inland tag recovery efforts are inadequate to obtain reliable estimates of the number of FRH origin fish that spawn in Central Valley streams. In most instances, the existing program appears to underestimate the numbers of tagged fish in the spawning population. We recommend that DWR and the oversight team meet with other agency biologists and representatives of the CALFED Bay-Delta Authority to work towards a field and analytical program that will lead to more useful spawning escapement and tag recovery estimates - probably as part of the existing IEP salmonid escapement team. We further recommend that the initial efforts focus on the Feather, American, and Yuba rivers. These streams have been proposed because they have relatively large spawning escapements and significant numbers of tagged hatchery fish. It appears that for effective tag recovery, this element should be separated from estimating escapement (B.Cavallo, DWR, personal communication) i.e. separate field crews. DWR, DFG, and the USBR will conduct a pilot modified tag recovery/escapement program on the American River during the fall of 2004.

- The recreational fishery. More attention should be devoted to the recreational fishery on the Feather River and other Central Valley salmonid streams. The fishery takes a large number of spring and fall run on the Feather River, although it is not possible at this time to determne the exact impacts. To be effective the fishery evaluation should include all aspects of the system from the estuary to the streams. The Feather River would be one component of the system. Special considerations should be given to the potential harvest impacts on FR Springs.

- Other Central Valley hatcheries. It has long been recognized that all Central Valley hatcheries need to include a mark-recovery program as a routine part of hatchery operations. Currently Coleman and Nimbus hatcheries produce significant numbers of fall Chinook but are not marking any of them. Merced and Mokelumne hatcheries now mark most of their fall Chinook production. The agencies should continue to look into the use of otolith marks in place of, or in addition to coded wire tags. The oversight team and DWR should ask Dave Hankin to present the results of his efforts to determine what it might entail to have a constant fractional marking program at Central Valley fall Chinook hatcheries. (Marking winter and late fall Chinook is presently more than adequate.)

- Work with DWR stream biologists to further define the early life history of the Chinook salmon and steelhead in the Feather River, with the objective of determining the importance of the upper reaches pre-emigration juveniles.

- Work with DWR stream biologists and hatchery staff to determine if there are distinct runs of spring Chinook and steelhead to the hatchery and to the Feather River - i.e. these runs can be distinguished in their respective ESUs. A study plan will be needed to ensure that results from this effort will accepted by the scientific community.

Hatchery Practices

The following are some thoughts about hatchery operations and procedures. As with the study ideas listed above, these are suggestions are intended to stimulate discussion among the analytical unit, the oversight group and hatchery managers. In reality, the studies and hatchery practices are closely inter-related, and the separation is somewhat arbitrary.

- **Hatchery Goals**. After about 37 years of operations, it is time for a thorough review of the FRH goals. This should be one of the first items to be discussed by the oversight team, with objective of including a revised set of goals in the submittal to FERC in early 2005. Once consensus goals are established, or the existing goals are confirmed, hatchery operations and production can be tailored to meet those goals. It does not appear that the existing production goals are biologically useful - i.e. hatchery goals should encompass the fish's entire life history and explicitly consider freshwater mortality as well as harvest in the ocean and inland fisheries. The goals should also consider DWR's mitigation responsibilities with respect to the Oroville Facilities, but perhaps in light of what we now know about the ability of hatcheries to truly mitigate for loss of spawning and rearing habitat.

  The team should consider the following when discussing changing FRH goals:

  - Should escapement goals be set and hatchery production goals be adjusted to meet them?
  - Planting strategies should be identified prior to setting and escapement and production goals, - i.e on site or off site releases, or both.
  - Does the group consider modifying the mitigation goals and not the enhancement goals?
  - The group should consider recommending changes in river fishing regulations to further protect Feather River spring Chinook.

- **Hatchery and Genetics Management Plan**.Once the goals have been established or confirmed, work should begin on the HGMP. This document, including the goals, will help define hatchery operation practices and their effects and should lead to modifications that will help ensure the FRH has minimal impacts on Central Valley salmonid populations. In the meantime, DFG staff should look at the current version of the FRH SOP to see if any modifications are needed to right away to minimize the impacts of hatchery operations - e.g. consideration of a ban on transfers of genetic material among hatcheries and a policy on the use of hatchery fish for experimental - out of basin - studies. The HGMP should be completed by October 2005.

- There are some specific hatchery related actions that should be considered.

  Continue discussions with Dave Hankin (HSU) and Carlos Garza (NOAA Fisheries) regarding their concept of using the FRH as a research hatchery. The discussion can not be serious until they submit an actual proposal that clearly defines how a research hatchery would affect hatchery operations and how the study results can be used to better understand how hatchery operations affect naturally spawning salmonids.

  Work with UC Davis and the Fish Health laboratory to determine if, and which, additional studies are needed to understand IHNV and its effects on salmonid and steelhead being reared at the FRH

and other Central Valley salmon hatcheries. The work to date has shown that the Central Valley IHNV continues to be in a distinct clade (as compared to the Northwest) but is has been rapidly evolving. Although the new isolates don't seem to be increasing in virulence, continued monitoring may be needed follow the virus' evolution and virulence. A new study plan will be needed before any additional work is initiated. To limit the possibility of additional IHNV epizootics at the FRH, DFG should continue to ban planting Chinook salmon in Lake Oroville.

Make the annual hatchery report more useful and timely. The report provides the historical record for what happens at the hatchery each year. A review of past reports has shown that the record is incomplete or inconsistent. The reports don't seem to be a priority within DFG and many recent reports remain in draft. DWR will provide DFG will a more detailed list of our observations made while trying to summarize the information from the past 30 plus years of hatchery operations. The same comments apply to similar annual reports from other hatcheries DFG operates in the Central Valley.

After the 2004 spawning season, review the spring Chinook studies that involve phenotypic nominal spring Chinook to enter the hatchery in May and June, tagging them, and then releasing them back to the river. Among the questions to be addressed in this review are:

- Do these fish re-enter the hatchery in the fall to spawn?
- Should spring Chinook spawning in the hatchery be restricted to these fish?
- Does the operation appear to cause significant mortality to fish going through the process?
- Are there significant numbers of salmon in the river during April, May and June that do not enter the hatchery?

Significant progress has been made in the fall of 2004 to answer this and other questions and the work needs to be continued.

- The goal will be to have a policy in place by the spring of 2005 as to the spring/summer operation of the hatchery ladder.
- Other actions that the group should consider are:
  - Continue to investigate the feasibility and usefulness of installing a weir in the Feather River below the low flow channel. The weir could be used to get a better handle on the numbers of adult steelhead and salmon entering the spawning grounds, and with the right configuration, could be used to physically isolate spring and fall Chinook on the spawning grounds.
  - Consider instituting a system of data collection that will enable biologists and the hatchery manager to evaluate the fitness of smolts and yearlings being produced at the Feather River Hatchery. Ideally this system would become part of the SOP at all Central Valley hatcheries. The number and type of metrics to be included in this system would be developed through discussions with DFG and USFWS pathologists, UCD fish physiologists, and others who have experience assessing fitness of hatchery and naturally produced salmonids.

- Evaluate the results of the pilot otolith marking program undertaken at the FRH with the 2003 by Chinook. The initial results look promising and we recommend that all FRH Chinook be thermally marked.

- Use the cohort analyses, genetic and other data to assess the biological, economic, and societal impacts of San Pablo Bay versus on-site releases of production fish. DWR should acquire the model from DFG and plan to make the analysis in the future.

- Meet with USFWS staff and others to evaluate the costs and benefits of NATURES type programs with the goal of determining if the FRH should be modified to incorporate some features designed to make the hatchery environment less artificial. This could be started by holding a 1-day workshop in early 2005 to discuss USFWS results at CNFH, plus inviting experts from the Pacific Northwest to share their experiences.

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Appendix Table 1. A listing of IHNV isolates from California for which sequence information in the Mid G range was obtained. The isolates were then grouped into genotypes – U for unique or type A through L.

• *Sequence Type, n#*	• *Isolation Site*	• *Host*	• *River Drainage*	• *Year*
Unique sequences				
uER-n1	Elk River, Oregon	unknown	Elk	1976
uFRCh-n1a	Feather River H.	Ch	Sacramento	1971
uMKSt-n1	Mokelumne River H.	St	San Joaquin	1971
uNBCh-n1a	Nimbus H.	Ch	Sacramento	1974
uTRCh-n1a	Trinity River H.	Ch	Klamath	1991
California sequence type A (n = 32; 1969-1998)				
aFRCh-n3	Feather River H.	Ch yearling	Sacramento	1969
aFRCh-n3	Feather River H.	Ch Spring fry	Sacramento	1976
aFRCh-n3	Feather River H.	Ch Fall	Sacramento	1977
aTRCh-n18	Trinity River H.	Ch	Klamath	1979
aRCCh-n1	Rowdy Creek H.	Ch subyearling	Smith	1981
aHOCh-n1	Hoopa Fish Rearing Facility	Ch Fall	Klamath	1987
aHOCh-n1	Hoopa Fish Rearing Facility	Ch Fall	Klamath	1987
aMCCh-n1	Merced River H.	Ch	San Joaquin	1987
aCCCh-n1	Klamath River, CA	Ch	Klamath	1987
aTRCh-n18	Trinity River H.	Ch	Klamath	1987
aTRCh-n18	Trinity River H.	Ch yearling	Klamath	1988
aTRCh-n18	Trinity River H.	Ch	Klamath	1988
aTRCh-n18	Trinity River H.	Ch Fall	Klamath	1988
aTRCh-n18	Trinity River H.	Ch fry	Klamath	1989
aTRCh-n18	Trinity River H.	Ch	Klamath	1989
aTRCh-n18	Trinity River H.	Ch	Klamath	1989
aTRCh-n18	Trinity River H.	Ch yearling	Klamath	1989
aTRCh-n18	Trinity River H.	Ch Spring	Klamath	1989
aTRSt-n3	Trinity River H.	St	Klamath	1989

aTRCh-n18	Trinity River H.	Ch Fall	Klamath	1990
aTRSt-n3	Trinity River H.	St	Klamath	1990
aTRSt-n3	Trinity River H.	St	Klamath	1990
aTRCh-n18	Trinity River H.	Ch Spring	Klamath	1991
aTRCh-n18	Trinity River H.	Ch	Klamath	1991
aTRCh-n18	Trinity River H.	Ch Spring	Klamath	1991
aTRCh-n18	Trinity River H.	Ch Fall	Klamath	1991
aTRCoho-n2	Trinity River H.	Coho	Klamath	1991
aTRCoho-n2	Trinity River H.	Coho	Klamath	1991
aTRCh-n18	Trinity River H.	Ch	Klamath	1993
aTRCh-n18	Trinity River H.	Ch	Klamath	1993
aERCh-n1	Elk River, Oregon	Ch	Elk	1994
aRRCh-n1	Rogue River, Oregon	Chfall	Rogue	1998
Unique sequences				
uNBCh-n1b (SRCV)	SRCV	Ch	Sacramento	1966
uTRCh-n1b	Trinity River H.	Ch	Klamath	1987
California sequence type B (n=2; 1979&1985)				
bMACh-n1	Mad River H.	Ch	Mad	1979
bCLSt-n1 (CL 85)	Coleman H.	St	Sacramento	1985
Unique sequence				
uCLCh-n1a (CL 80)	Coleman H.	Ch	Sacramento	1980
Califonrnia sequence type C (n=2; 1986&1988)				
cSXCh-n1	Sixes River, Oregon	Ch Fall	Sixes	1986
cMCCh-n1	Merced River H.	Ch	San Joaquin	1988
Unique sequence				
uEESt-n1	Eel River	St	Eel	1987
California sequence type D (n=18; 1989-2003)				
dCLCh-n3	Coleman H.	Ch	Sacramento	1989
dFRCh-n1	Feather River H.	Ch Fall	Sacramento	1991
dFRSt-n2	Feather River H.	St	Sacramento	1992
dFRSt-n2	Feather River H.	St	Sacramento	1992

dCLCh-n3	Coleman H.	Ch Fall	Sacramento	1997
dCLCh-n3	Coleman H.	Ch Fall juvenile	Sacramento	1999
dCLSt-n1	Coleman H.	St	Sacramento	1999
dNBCh-n7	Nimbus H.	Ch	Sacramento	1999
dMCCh-n1	Merced River H.	Ch	San Joaquin	2000
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBSt-n2	Nimbus H.	St	Sacramento	2001
dNBSt-n2	Nimbus H.	St	Sacramento	2001
dBCCh-n1	Battle Creek, CA	Ch male	Sacramento	2003
Unique sequences				
uNBCh-n1c	Nimbus H.	Ch	Sacramento	1998
uCLCh-n1b	Coleman H.	Ch	Sacramento	2001
California sequence type E (n=23; 1990-1999)				
eFRCh-n4	Feather River H.	Ch	Sacramento	1990
eFRCh-n4	Feather River H.	Ch	Sacramento	1992
eNBCh-n4	Nimbus H.	Ch	Sacramento	1992
eNBCh-n4	Nimbus H.	Ch	Sacramento	1992
eMCCh-n1	Merced River H.	Ch	San Joaquin	1992
eCLCh-n10	Coleman H.	Ch	Sacramento	1992
eCLCh-n10	Coleman H.	Ch	Sacramento	1993
eCLCh-n10	Coleman H.	Ch Fall	Sacramento	1993
eCLCh-n10	Coleman H.	Ch Fall	Sacramento	1993
eCLCh-n10	Coleman H.	Ch	Sacramento	1993
eCLCh-n10	Coleman H.	Ch	Sacramento	1993
eFRCh-n4	Feather River H.	Ch	Sacramento	1993
eNBCh-n4	Nimbus H.	Ch	Sacramento	1993

eNBCh-n4	Nimbus H.	Ch	Sacramento	1993
eMKCh-n2	Mokelumne River H.	Ch	San Joaquin	1993
eMKCh-n2	Mokelumne River H.	Ch	San Joaquin	1993
eCLSt-n2	Coleman H.	St	Sacramento	1994
eCLCh-n10	Coleman H.	Ch Late Fall	Sacramento	1994
eFRCh-n4	Feather River H.	Ch	Sacramento	1995
eCLSt-n2	Coleman H.	St	Sacramento	1997
eCLCh-n10	Battle Creek, CA	Ch	Sacramento	1997
eCLCh-n10	Coleman H.	Ch Fall	Sacramento	1997
eCLCh-n10	Coleman H.	Ch Fall	Sacramento	1999
California sequence type F (n=49; 1996-2003)				
fNBCh-n14	Nimbus H.	Ch	Sacramento	1996
fCLCh-n6	Coleman H.	Ch Fall juvenile	Sacramento	1997
fFRCh-n11	Feather River H.	Ch	Sacramento	1997
fFRCh-n11	Feather River H.	Ch Fall	Sacramento	1997
fFRCh-n11	Feather River H.	Ch Fall	Sacramento	1997
fMKCh-n2	Mokelumne River H.	Ch	San Joaquin	1997
fMKCh-n2	Mokelumne River H.	Ch	San Joaquin	1997
fNBCh-n14	Nimbus H.	Ch	Sacramento	1997
fFRCh-n11	Feather River H.	Ch fry	Sacramento	1998
fFRCh-n11	Feather River H.	Ch	Sacramento	1998
fNBSt-n9	Nimbus H.	St	Sacramento	1998
fNBCh-n14	Nimbus H.	Ch	Sacramento	1999
fCLCh-n6	Coleman H.	Ch female	Sacramento	2000
fFRCh-n11	Feather River H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000

fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBSt-n9	Nimbus H.	St	Sacramento	2000
fFRCh-n11	Feather River H.	Ch Spring	Sacramento	2001
fFRSt-n1	Feather River H.	St	Sacramento	2001
fNBCh-n14	Nimbus H.	Ch	Sacramento	2001
fNBSt-n9	Nimbus H.	St	Sacramento	2001
fNBSt-n9	Nimbus H.	St	Sacramento	2001
fNBSt-n9	Nimbus H.	St	Sacramento	2001
fCLCh-n6	Coleman H.	Ch	Sacramento	2002
fCLCh-n6	Coleman H.	Ch Fall	Sacramento	2002
fCLCh-n6	Coleman H.	Ch Fall	Sacramento	2002
fCLCh-n6	Coleman H.	Ch Fall	Sacramento	2002
fFRCh-n11	Feather River H.	Ch Fall	Sacramento	2002
fFRCh-n11	Feather River H.	Ch Fall	Sacramento	2002
fFRCh-n11	Feather River H.	Ch Fall	Sacramento	2002
fFRCh-n11	Feather River H.	Ch	Sacramento	2002
fNBCh-n14	Nimbus H.	Ch	Sacramento	2002
fNBSt-n9	Nimbus H.	St	Sacramento	2002
fNBSt-n9	Nimbus H.	St	Sacramento	2002
fNBSt-n9	Nimbus H.	St	Sacramento	2003
fNBSt-n9	Nimbus H.	St	Sacramento	2003
fBCCh-n2	Battle Creek, CA	Ch female	Sacramento	2003
fBCCh-n2	Battle Creek, CA	Ch female	Sacramento	2003
fCKCh-n3	Clear Creek, CA	Ch	Sacramento	2003
fCKCh-n3	Clear Creek, CA	Ch	Sacramento	2003
fCKCh-n3	Clear Creek, CA	Ch	Sacramento	2003
fMKCh-n1	Mokelumne River H.	Ch	Sacramento	2003
Unique sequence				
uFRCh-n1b	Feather River H.	Ch	Sacramento	2001
California sequence type G (n=4; 2003)				
gBCCh-n2	Battle Creek, CA	Ch female	Sacramento	2003

gBCCh-n2	Battle Creek, CA	Ch male	Sacramento	2003
gCKCh-n2	Clear Creek, CA	Ch	Sacramento	2003
gCKCh-n2	Clear Creek, CA	Ch	Sacramento	2003
California sequence type H (n=3; 2003)				
hCKCh-n2	Clear Creek, CA	Ch	Sacramento	2003
hCKCh-n2	Clear Creek, CA	Ch	Sacramento	2003
hBCCh-n1	Battle Creek, CA	Ch female	Sacramento	2003
California sequence type I (n=74; 1999-2002)				
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	1999
iFRCh-n44	Feather River H.	Ch	Sacramento	1999
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	1999
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	1999
iFRCh-n44	Feather River H.	Ch	Sacramento	1999
iNBCh-n1	Nimbus H.	Ch	Sacramento	1999
iNBSt-n2	Nimbus H.	St	Sacramento	1999
iFRCh-n44	Feather River H.	Ch fry	Sacramento	2000
iFRCh-n44	Feather River H.	Ch fry	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRSt-n5	Feather River H.	St	Sacramento	2000
iORRb-n1	Lake Oroville	RBT	Sacramento	2000
iORCh-n7	Lake Oroville	Ch fry	Sacramento	2000
iORCh-n7	Lake Oroville	Ch male	Sacramento	2000
iORCh-n7	Lake Oroville	Ch female	Sacramento	2000
iORCh-n7	Lake Oroville	Ch male	Sacramento	2000
iORCh-n7	Lake Oroville	Ch female	Sacramento	2000
iORCh-n7	Lake Oroville	Ch female	Sacramento	2000
iORCh-n7	Lake Oroville	Ch male	Sacramento	2000

iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2001
iFRSt-n5	Feather River H.	St	Sacramento	2001
iFRSt-n5	Feather River H.	St fingerling	Sacramento	2001
iFRSt-n5	Feather River H.	St	Sacramento	2001
iMCCh-n1	Merced River H.	Ch	San Joaquin	2001
iNBSt-n2	Nimbus H.	St	Sacramento	2001
iFRCh-n44	Feather River H.	Ch	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRSt-n5	Feather River H.	St	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003

iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch	Sacramento	2003
iYMCh-n3	Yuba River (middle)	Ch	Sacramento	2003
iYMCh-n3	Yuba River (middle)	Ch	Sacramento	2003
iYMCh-n3	Yuba River (middle)	Ch	Sacramento	2003
iYLCh-n1	Yuba River (middle)	Ch	Sacramento	2003
iYLCh-n2	Yuba River (middle)	Ch	Sacramento	2003
iMKCh-n2	Mokelumne River H.	Ch fingerlings	Sacramento	2004
iMKCh-n2	Mokelumne River H.	Ch fingerlings	Sacramento	2004

California sequence type J (n=8; 2003)				
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jYLCh-n2	Yuba River (lower)	Ch	Sacramento	2003
jYLCh-n2	Yuba River (lower)	Ch	Sacramento	2003

ATTACHMENT 1

F9 STUDY PLAN

SP-F9. Evaluation of the Feather River Hatchery Effects on Naturally Spawning Salmonids

February 28, 2002

1.0 Introduction/Background

The California Department of Water Resources (DWR) constructed the Feather River Hatchery (FRH) to mitigate for the loss of salmonid spawning habitat lost when Oroville Dam was closed in 1967. Since the late 1960s, the FRH, operated by the California Department of Fish and Game (CDFG), has released millions of spring and fall chinook salmon fry, fingerlings, smolts and yearlings, and yearling steelhead to fulfill DWR's Oroville Federal Energy Regulatory Commission (FERC) license mitigation responsibility. The FRH releases provide significant contributions to ocean commercial and recreational fisheries (chinook salmon) and inland recreational fishery (chinook salmon and steelhead) (Dettman and Kelley 1987 and Cramer 1992). Spawning escapement data (Reynolds et al. 1993) indicate that the FRH has apparently met its implicit mitigation responsibility in that runs of fall and spring chinook and steelhead to the Feather River have been numerically greater, on average, than runs seen in the years immediately before construction of Oroville Dam.

As defined in this study plan the Feather River Hatchery includes the fish diversion dam below Oroville Dam, the fish ladder, holding tanks, hatchery buildings and raceways. A separate fish rearing facility, the Salmon Stamp funded Thermalito complex, is also included in this evaluation because chinook salmon reared in this enhancement program are derived from gametes taken at the main hatchery and production is mixed with that from the main hatchery for release in San Pablo Bay. Hatchery activities included in this study plan include spawner selection, egg take and fertilization, rearing practices (including disease control) and release strategies, including release site.

The FRH is one of five major Central Valley hatcheries producing and releasing fall chinook, one of three producing and releasing steelhead rainbow trout and the only hatchery producing and releasing spring chinook. An examination of the effects of FRH operations and facilities must consider any impacts in the context of the past and present practices of the entire Central Valley complex of hatcheries. Although there may be late fall chinook in the Feather River (B.Cavallo, DWR, personal communication) this study focuses on fall and spring chinook and steelhead.

The study plan will focus on several potential impacts of hatchery operation on naturally spawning salmonids. These potential impacts include (adapted from NRC, 1966):

- Effects on harvest – both commercial and recreational for chinook salmon and recreational for steelhead. A concern is that production from the FRH and other hatcheries has lead to the mixed stock fisheries that can overfish depleted natural stocks.
- Genetic effects – Hatchery operations can potentially cause problems with interbreeding depression and loss of genetic diversity within and among stocks.
- Domestication – Hatchery practices can lead to genetic adaptation to the hatchery, an adaptation that can reduce overall population fitness.

The plan will also identify the positive aspects of hatchery operation such contributions to commercial and recreational harvest and resulting economic contributions to society.

The general approach to the study involves completing several tasks involving: 1) an examination of past and present hatchery practices and other Central Valley hatcheries; 2), documenting the results of genetic analyses of chinook salmon and steelhead from the FRH and other Central Valley streams and hatcheries; 3), compiling the results of extensive tagging studies to estimate the contribution of FRH fall chinook production to ocean and recreational fisheries, escapement and to straying, and, 4) for steelhead, evaluate in-stream rearing, and possible competition, between hatchery produced and naturally produced fish. In addition, the study will examine potential changes in hatchery practices, such as releasing production spring run juveniles directly in the Feather River. The information derived from these, and from other study elements in the FERC process will be organized into a final comprehensive evaluation of the benefits and concerns about hatchery operations.

Hatchery evaluations as part of the FERC process will be coordinated with take and other issues associated with hatchery operations as part of DWR and CDFG obligations pursuant to provisions of the federal Endangered Species Act.

The following paragraphs provide a brief background on the mitigation goals of the FRH and some of the complications expected to be addressed in the hatchery evaluation process.

The actual mitigation goals for the FRH are defined in terms of the numbers of eggs taken each year for rearing and the numbers to be released as smolts or yearlings. CDFG (1999) has the following goals by race or species:

For Mitigation

Race or species	number of eggs to be taken	number and stage at release
Spring chinook	up to 7,000,000	5,000,000 smolts
Fall chinook	up to 12,000,000	6,000,000 smolts
Steelhead	up to 1,000,000	400,000 yearlings

For Ocean Enhancement – Salmon Stamp facilities at Oroville

Fall chinook	from egg take above	2,000,000 smolts

For Ocean Enhancement – Salmon Stamp facilities on the Mokelumne River

Fall chinook	up to 4,000,000 eggs from above fall chinook egg take

chinook salmon and steelhead eggs, adults, and juveniles from the FRH have been used at other hatcheries (Nimbus Hatchery on the American River and the Mokelumne River Fish Facility) when spawning escapement to the hatcheries, or other conditions, limited their production. In addition, for more than three decades researchers have used tagged and externally marked juveniles from the FRH to help address such important questions as (1) the rate at which juvenile salmon enter water diversions; (2) the importance of the Yolo Bypass to salmon production and; (3) the survival of juvenile chinook salmon through the Sacramento-San Joaquin Delta. These uses of eggs and juveniles complicate the hatchery evaluation by adding additional release points (with increased straying potential) for FRH produced fish.

Evaluation of the FRH as a DWR mitigation facility is also complicated somewhat by some non-mitigation aspects of the take and rearing of eggs from Feather River chinook salmon spawners. With support from

California's Salmon Stamp Program, chinook salmon embryos from the FRH are used at the Thermalito Annex to rear and release juveniles beyond DWR's mitigation responsibilities (so-called "enhancement production"). Eyed eggs from the FRH have been taken to CDFG's Mokelumne Fish hatchery for rearing in a similar Salmon Stamp supported ehancement program. (In recent years escapement to the Mokelumne River has been adequate to satisfy mitigation and enhancement needs and there have been no egg transfers from the FRH.) Juvenile chinook salmon from the Feather River have also been used to stock inland reservoirs (including Lake Orvoville and Lake Almanor above the hatchery) to provide cold-water sports fishing opportunities.

For purposes of the FERC process, the hatchery evaluation is limited to the mitigation aspects of the FRH. In reality, the evaluation must include all aspects of the hatchery operation and the mitigation portions subsequently sorted out. For example, mitigation and enhancement juveniles are routinely moved between the FRH to the Thermalito facilities for disease control and other purposes and the enhancement and mitigation production are mixed for transport to San Pablo Bay. Some juvenile chinook salmon planted in Oroville Reservoir may leave the reservoir during flood periods, move to the ocean and possibly return to spawn.

A final complication in analyzing the impacts of the hatchery involves changing hatchery practices over the past three plus decades. For example into the nineties, planting surplus fry in many Central Valley streams was a common hatchery practice. The 1999 hatchery operations plan (CDFG 1999) stipulates that this practice will no longer occur. At various times FRH chinook salmon have been planted in the Feather River as fry, fingerlings, smolts and yearlings. Since the mid 80s most of the production has been planted in San Pablo Bay. Also the length of time it takes to plant production chinook has changed from April through September to April through July – mainly due to the use of larger capacity transport vehicles. There are some indications that changes in release timing may have changed the straying rates (S Cramer, personal communication).

The early 1960s, when CDFG and DWR agreed to construct and operate the FRH, was a period when hatcheries were deemed appropriate mitigation for habitat loss. In recent years salmon biologists have come to recognize that hatcheries can affect natural salmonid runs (for example, Reisenbichler 1997), especially when operated without taking into account potential effects of hatchery releases on wild fish. For example, successful efforts by FRH hatchery staff to reduce instream and Delta mortality by trucking production to San Pablo Bay has resulted in some adults returning to other streams (a behavior called straying). Straying into other streams, in particular to those streams containing threatened wild spring run, can result in interbreeding that may reduce the genetic fitness of wild spring run. Effects on spring run, which formerly spawned high in the watershed, may be compounded further by the presence of Oroville Dam, forcing spring run to spawn in the same area as fall run. When combined with hatchery practices that potentially result in interbreeding of spring and fall run straying may pose a hazard to the genetic fitness of wild spring run and naturally spawning fall run. Using microsatellite markers, Hedgecock et al. 2001 found only one genotype in naturally spawning and hatchery chinook in the Feather River and that genotype was distinct from spring chinook on Deer, Mill and Butte creeks – looking more like fall chinook. If spring and fall chinook were genetically distinct, one would expect at least two genotypes, and perhaps even distinct natural and hatchery genotypes.

In a recent draft report, the National Marine Fisheries Service (NMFS) and CDFG (NMFS and CDFG 2001) reviewed practices in Central Valley hatcheries operated by CDFG, including the FRH. The report identified three principal hazards of hatchery operations to listed winter and spring chinook and steelhead:

- Genetic hazards caused by reducing genetic diversity in depressed natural populations;
- Ecological hazards to natural populations caused by straying, including competition for spawning sites and disease transmission; and
- Management hazards caused by the inability to differentiate hatchery from wild stocks. (This inability may be masking declining productivity of natural populations.)

The report further cautioned that managers should be concerned about management and genetic hazards because they have high risks of occurrence. The hazards are particularly troublesome because they include the risk of extirpation of natural stocks. Several times in the main report and in an appendix (Appendix 1 "Off-site Release and Straying Subcommittee Report") the authors referred to straying as a "significant problem" and mentioned the present practice of releasing production in San Pablo Bay as a particular concern. The report included a recommendation to tag (and fin clip) and release all FRH spring production in the Feather River and consider the same release strategy for fall run production.

NMFS and CDFG recommended that all Central Valley hatcheries prepare Hatchery and Genetics Management Plans (HGMPs) to minimize the risks to threatened and endangered salmonids. NMFS developed a detailed format for the HGMP, intended to provide a single comprehensive source of hatchery information for planning and satisfy permitting requirements under the federal Endangered Species Act (ESA). In a recent evaluation of the Coleman National Fish Hatchery (CNFH) and the Livingston Stone National Fish Hatchery (LSNFH), the U.S. Fish and Wildlife Service (USFWS) used the HGMP template for their biological assessment (USFWS 2001).

Steelhead present somewhat of a special case with respect to the effects of hatchery operations on naturally spawning salmonids. This special case is because:

- Relative to chinook salmon, the FRH produces few juvenile steelhead.
- All juvenile steelhead are released as yearlings in the Feather River.
- For the past few years all juvenile steelhead produced in Central Valley hatcheries must have external marks (adipose fin clips) to distinguish from wild fish. In addition FRH production is coded wire tagged.
- Juvenile steelhead may spend one or two years in freshwater before migrating to the ocean, and in some cases may not migrate at all. Outmigrants are relatively large compared to emigrating chinook salmon – 150 - 200 mm total length for steelhead compared to 40 – 120 mm for chinook salmon.
- In contrast to chinook salmon some steelhead survive spawning and may return to the ocean, spawning again in subsequent years.
- There is no commercial fishery for steelhead and the freshwater anglers are only allowed to keep hatchery (adipose clipped) fish. In addition, it appears that significant numbers of immature fish ("half pounders") are taken in freshwater – many in the Feather River.

As summarized by McEwan (2001) the complex life history (including sampling difficulty) and the lack of commercial importance have resulted in less relatively little information about this Central Valley steelhead. The documentation leading to listing the Central Valley steelhead Evolutionary Significant Unit (NMFS 1996 and 1997, and Busby and others 1996) resulted in the compilation of much of the available information on west coast steelhead – compilations that will form the basis of this evaluation. For example, Busby and others used allozyme analyses to demonstrate that the genetic structure of steelhead from the Coleman National Fish Hatchery, the FRH and wild fish from Mill and Deer creeks and the Stanislaus River was similar and did not

resemble the genetic structure of coastal populations. On the other hand, the genetic structure of steelhead from the Nimbus Hatchery and the American River resembled that of their founding stock from the Eel River.

2.0 Study Objectives

The objectives of this study plan are to:

- determine the ongoing and future impact of the FRH's Oroville mitigation activities; and
- develop information to be used in identifying and assessing the feasibility of potential protection, mitigation and enhancement measures.

To achieve these objectives , the plan will:

- Determine if operations at the FRH impact the genetic composition of spring and fall chinook and steelhead runs in the Feather River.
- Determine if operations of the FRH impact the genetic composition of spring and fall chinook and steelhead runs to other Central Valley streams;
- Estimate the contribution of Feather River chinook salmon production to ocean and inland fisheries and to escapement to the Feather River and other Central Valley streams;
- Evaluate the effects of FRH steelhead plants in the Feather River on naturally spawning steelhead in the Feather River.
- Determine how hatchery operations might be modified in light of findings presented in this and interrelated studies.

3.0 Relationship to Relicensing/Need for Study

The FRH is an integral component of the Oroville complex, and its operation has the potential to adversely affect naturally spawning salmonid runs. As mentioned previously a 2001 draft report by CDFG and NMFS suggests that the FRH practice of planting hatchery production in San Pablo Bay (instead of in-river) may have caused increased straying. This increased straying may have impacted chinook salmon and steelhead runs in other streams, in particular those with wild spring run (for example Mill, Deer and Butte creeks). The report also suggested that hatchery practices have co-mingled spring and fall chinook in the hatchery and impacted the threatened spring run.

On the positive side, the FRH has released millions of juvenile salmon in the past 30 plus years and there are more steelhead, and chinook salmon returning to the Feather River each than prior to construction of the Oroville Dam. These fish appear have made significant contributions to the ocean and inland commercial and recreational fisheries and escapement to the Feather River. After almost 30 years of operation, and with new thinking on the roles of hatcheries, it is time to evaluate the hatchery, its mitigation responsibility and operational practices.

Identification and quantification of project effects on fish and fish habitat has been recognized as an issue by relicensing stakeholders including stakeholders with mandatory conditioning authority and is a FERC requirement. Evaluation of project effects on wildlife resources is also required for CEQA/NEPA compliance.

Listings of the spring run as threatened pursuant to the federal and state endangered species acts and steelhead as threatened under the federal Endangered Species Act require that the State obtain take authorization in order to operate the hatchery. Although the fall run is not listed (but is a candidate species) under the federal ESA, there is considerable concern about the effects of hatcheries on naturally spawning fall chinook runs in the Feather River and other Central Valley streams. As mentioned previously, NMFS may require that hatcheries affecting listed species, such as the FRH, prepare hatcheries genetic management plans. Information collected and reported in this evaluation can form the basis for such a plan for the FRH.

These and other issues about hatchery operation must be addressed in the FERC relicensing process and, in light of the results of this study and analyses, the new FERC license may stipulate changes in hatchery practices.

Section 4.51(f)(3) of 18 CFR requires reporting certain types of information in the FERC application for license of major hydropower projects, including a discussion of fish, wildlife and botanical resources in the vicinity of the project. The discussion needs to identify the potential impacts of the project on these environmental resources, including a description of any anticipated continuing impact for any on-going and future operation. This study fulfills these requirements by evaluating potential project effects on anadromous salmonids and their habitat in Feather River below the Fish Barrier Dam.

4.0 Study Area

This study plan is designed to evaluate the impact, if any of FRH released salmonids on natural spawning salmonids in the Feather River and other Central Valley streams. In addition this study will evaluate whether the FRH has satisfied DWR's mitigation requirements, including supplementing chinook salmon harvest in the ocean commercial and recreational fisheries. The study area thus includes:

- the hatchery site (including the fish barrier dam and ladder);
- the Thermalito facilities
- the Feather River from the fish barrier dam to its confluence with the Sacramento River;
- the Sacramento River to its confluence with the San Joaquin River;
- the Sacramento-San Joaquin Delta;
- the San Francisco Bay;
- and the coastal ocean from southern California to British Columbia (the area where juvenile chinook salmon released from the FHR may be harvested in commercial and recreational fisheries.

Study plans approved by the Environmental Work Group define the limits of the study area. If initial study results indicate that the study area should be expanded or contracted, the Environmental Work Group will discuss the basis for change and revise the study area as appropriate.

5.0 General Approach

Evaluation of the FRH impacts will be based on review and synthesis of the vast amounts of information collected about the hatchery, the Feather River and other locations in the Central Valley and the Pacific Ocean. Of particular importance is the review of the recent biological assessment of the effects of the CNFH on

salmonids (USFWS 2001) and the NMFS guidelines for a Hatchery Genetics Management Plan (HGMP, see USFWS 2001 for components of HGMP.

In addition to compilation and analysis of existing data and literature, the hatchery evaluation will include additional field data collection and analysis. Much of this evaluation will be based on a hatchery marking study began in 1994. In each year of the study from 1 to 1.5 million production fish have been marked with adipose fin clips and magnetic coded wire tags implanted. Most of these tagged fish were released in San Pablo Bay but each year control groups, consisting of 200,000 tagged fingerlings and 100,000 tagged yearlings were released in the Feather River below the Thermalito outlet. The allocation of tags between putative hatchery spring and fall runs varied each year. Some of the tagged fish were subsequently recovered and the tags decoded in sampling at the Delta pumps, in midwater trawls at Sacramento and Chipps Island, in the ocean fisheries, in the inland fishery, during spawning ground surveys and at the FRH and other Central Valley hatcheries.

As mentioned previously, all juvenile steelhead produced at the FRH are tagged and externally marked. Although all steelhead produced at other Central Valley hatcheries have the external marks, almost none of them are tagged. (The exception is that a few experimental fish from the Coleman National Fish Hatchery have been tagged. Jim Smith, personal communication.) The IEP has provided portable tag detectors to crews at the hatcheries and other field locations. If a marked fish has a tag, the fish is to be sacrificed and the tag decoded. This information can provide an idea of movement, including straying of Feather River steelhead. A caveat is that the relatively small number of releases (the production is 400,000 yearlings) and the difficulty in capturing steelhead may not produce sufficient tag returns to provide a statistically useful sample size.

In addition to tagging the production fish, through other funding a three-year study used coded wire tags to compare the survival of juvenile chinook salmon released in San Pablo Bay directly from transport trucks versus placed in floating net pens and towed towards mid Bay for release. Since net pen releases are now a standard operational practice, the comparison will provide an examination of the effects of this release strategy on ocean contribution and escapement.

The fishery contribution rates and straying are being estimated by use of cohort analysis (Cramer 1992). Ocean and recovery data are now available through 2000 and inland recoveries through 1997. The cohort analysis will be updated as additional marked fish are recovered in the ocean and inland fisheries, on the spawning grounds and in the hatcheries. Preliminary analyses indicate that field sampling for marked fish on the spawning grounds is not adequate, thus additional recovery efforts will be designed, funded and conducted in the fall of 2002. Some additional tissues may be needed to verify the genetic identity of Central Valley salmonids, in particular fall run on the Mill and Deer creeks and adult chinook returning to the Feather River in the spring/early summer.

The conceptual foundation for the evaluation is found in the attached conceptual model. In summary, the model is as follows.

- The FRH rears steelhead and chinook salmon to mitigate for the loss of salmonid spawning and rearing habitat lost when Oroville Dam was constructed.
- Releases of the juvenile steelhead and salmon in the river, in other streams and in San Pablo can result in straying to other streams and interbreeding of wild and hatchery fish.

- This interbreeding can depress the fitness of wild chinook and steelhead.
- Hatchery practices that select for certain traits (time of arrival at the hatchery, size, fecundity, etc.) as well as the general hatchery rearing conditions (feeding methods and diseases) may reduce the overall fitness of chinook salmon and steelhead and this reduced fitness may be transferred from generation to generation.
- In the past few years a combination of a successful hatchery, an in-Bay release strategy, reduced ocean harvest, good ocean conditions, and spawners being drawn to the river channel immediately below the barrier dam has resulted in spawning runs that exceed the available spawning area. The large number of spawners competing for a relatively small area results in redd superimposition and may be affecting productivity of natural spawners.
- Central Valley chinook salmon, including those in the Feather River, suffer from a variety of diseases. The occurrence and intensity of disease outbreaks can be intensified by intensive culture practices used in hatcheries and the diseases, in turn, may affect natural populations.
- Drawing water from Oroville Reservoir to meet temperature requirements for hatchery operation may result in river temperatures that differ from historic conditions. The changed water temperature regime may affect naturally spawning and rearing salmonids.

It must be kept in mind that this is an abbreviated conceptual model and that conceptual models are used to make hypotheses and assumptions explicit. The analyses being conducted are to help validate or refute the model with the goal of having a better model when the evaluation is complete.

If initial study results indicate that the methods and tasks should be modified, the Environmental Work Group will discuss the basis for change and revise the study plans as appropriate.

Detailed Methodology and Analysis

Task 1 – Evaluate the Genetic Effects of FRH Practices on In-river Populations of Spring-run and Fall-run chinook Salmon and Steelhead

The gates to the fish ladder leads to FRH are generally open from about September 1 through the end of March. The early entries are ready for spawning in October. Through the mid-nineties fish entering the hatchery after October 1 were generally classified as fall-run. There is concern that this hatchery practice may have genetic effects on the in-river populations of chinook salmon and steelhead (see for example Hedgecock et al. 2001). In addition, spring and fall chinook now spawn in the same general time period in the area just downstream of the fish barrier dam. This co-mingling of spawners also increases the chances that spring and fall chinook are interbreeding. In 1999 DFG developed a hatchery operations plans (CDFG 1999) which modified and standardized processes to minimize chances of interbreeding spring and fall chinook. The new procedures specify only those fish entering the hatchery between September 1 and September 15 will be considered spring run. chinook salmon entering the hatchery after September 15 will be considered fall run. In addition, no eggs will be taken for spring run production after October 7, even if the fish had entered the hatchery before September 15.

DWR began studies in 1994 and 1995 to help address genetic issues. The 1994 tagging studies, described previously, involved tagging both nominal spring and fall chinook in the hatchery. The time of tagging (and race as defined by hatchery staff) will be compared to the time the tagged adults return to the hatchery 2 or 3 years later. Previous studies (Brown and Greene 1994) have shown that fish called one race in the hatchery

may return as another. (For example, the progeny of a spring run female spawned on October 1 may return and be spawned in early November and would be called a fall run.) The 1995 studies were part of a major effort by UC Davis scientists to determine the genetic diversity of Central Valley chinook salmon populations. Small tissue samples were collected from adult chinook salmon from major spawning streams and hatcheries and analyzed through use of a series of micro-satellite markers. (See Banks et al 2000 for a complete description of the methods used.)

Completing this task will require the following activities:

- Review and synthesize information related to the use of micro satellite markers and allozymes to determine the genetic composition of the three anadromous salmonid runs in the Feather River; collect and analyze additional tissue as needed.
- Review and synthesize past, present and projected hatchery practices to determine the founding broodstock for each run and how broodstock selection procedures may be impacting genetic integrity of the three runs.
- Compile available information on production and outplanting of chinook salmon at the FRH.
- Compile and synthesize information about hatchery practices geared to increase production of FRH including predator control, food and feeding, movement of fish between Thermalito and the main hatchery and egg take and early incubation.
- Review and synthesize run timing and spawning location data to determine if the Feather River fall and spring runs are segregated in time or space.
- Review coded wire tag data to determine the fidelity of putative FRH spring and fall run production when they return to the hatchery two to four years after release.

Task 2 – Evaluate the Effects of FRH Production on the Genetic Integrity of Spring-run and Fall-run chinook Salmon of Naturally Spawning chinook Runs in Other Streams

This task, based upon a literature review on genetic effects of salmon straying, available tag recovery data and modeling, attempts to address the question of what are the effects, if any, of FRH production on the genetic integrity of the spring and fall runs of Central-Valley chinook salmon. Elements of this review will include:

- Reviewing literature on straying and genetic effects from other areas and in particular from Central Valley streams;
- Review and synthesize physiological and morphometric information collected by NMFS and USFWS staff on FRH smolts with the goal of assessing any apparent reduction in fitness associated with hatchery rearing;
- Examine genetic data developed in Task 1 to help determine if Feather River Hatchery produced fish are altering the genetic structure of runs to other Central Valley streams, and in particular to spring chinook in Mill, Deer and Butte creeks;
- Use cohort analyses of tag recovery data to estimate the straying rates of production releases to other Central Valley streams (see Cramer (1992) for details;)
- Use simple statistics to show the numbers of tagged FRH releases that have been recovered in other streams;
- To correct a significant undersampling of tagged chinook and steelhead, conduct a “tag collection blitz” in the fall of 2002 and perhaps in 2003 to recover the maximum numbers of tags from Central Valley streams with particular attention to the Mill, Deer and Butte creeks and the mainstem Sacramento River between

Red Bluff and Keswick Dam. This subtask would be contingent on securing funding from the Interagency Ecological Program, CALFED, and/or the Andromous Fish Restoration Program.

Task 3 – Evaluate the Contribution of FRH chinook Salmon Production to the Ocean and Inland Harvest and Escapement to the Feather River

The tagging studies and cohort analysis described earlier will also provide estimates of contribution of Feather River Hatchery produced fish to the fisheries and escapement. For the past several years, DWR through the Interagency Ecological Program has supplemented CDFG's ocean tag recovery efforts so that the agency samplers would be looking at about 20% of the fish being landed in the ocean fisheries off California. In a separate effort, the US Department of Interior's Comprehensive Analysis and Monitoring Program has funded DFG to estimate the numbers of chinook salmon harvested in the inland recreational fishery. The inland samplers have also been recovering some tags and the tags sent to CDFG's Healdberg laboratory for decoding.

This task will include:

- Use the cohort analysis to estimate contribution rates;
- Review and synthesize information about ocean and inland harvest rates to determine if there are trends in these fisheries;
- Estimate and contrast the contributions of FRH salmonid production and of naturally produced salmonids to harvest by the ocean and inland sport and commercial fisheries;
- Review available data to determine changes in contribution rates due to changes in hatchery practices such as: release location (in-river, the Delta, San Pablo Bay); size at release (fingerling, smolt or subyearlings); and release method (directly from transport trucks, from net pens); and
- As data permit, compare individual survival estimates for fish traveling from the Feather River to Chipps Island collected over the past two decades to determine if there are any trends. This analysis will be supplemented by in-river survival information from Battle Creek releases of tagged fish from the Coleman National Fish Hatchery. The objective is to determine if in-river has changed over the past two decades and if this change would affect hatchery production release strategies.

Task 4 – Evaluate the effects of FRH steelhead planted in the Feather River on naturally spawning steelhead in the Feather River.

The significant differences in the biology and life history of chinook salmon and steelhead dictate that many aspects of the steelhead evaluation be handled in a separate task. Completing this task will require coordination between the in-river ecological project and integration of the results of these two components in the final synthesis report. Specific elements of this task include:

- Review applicable literature on the effects of steelhead conservation and production hatcheries.
- Summarize hatchery spawning and production for the period of record.
- Compile and assemble information collected in the Feather River pertaining to rearing and outmigration of juvenile steelhead. These data will include habitat use, food habits, catches of steelhead in rotary screw traps and other sampling methods.
- Examine tag return data to determine if they are adequate to describe the movement of FRH juvenile steelhead.

- Summarize information from DFG's recreational angler surveys to estimate harvest rate on hatchery steelhead.

Task 5 – Evaluate the potential benefits and impacts of planting a significant portion, if not all of the spring run production in the Feather River.

In their 2001 draft report, NMFS and DFG proposed to consider planting all of the spring run production directly in the Feather River. If implemented, this proposal could affect the stream's ability to support naturally reproducing salmonid populations. A basic premise of Task 6 is that planting spring chinook in the Feather River should only occur after a thorough review of what we know and, if implemented, should employ an adaptive management approach – i.e. a graduated release schedule accompanied by extensive data collection and analysis. Elements of this task include:

- Through SP F10 and other efforts assemble the available information on habitat use, condition factor, food use, food electivity and food composition in the Feather River from the barrier dam to the confluence with the Sacramento River.
- Work with DFG and NMFS biologists to determine the numbers, size and locations of possible spring run releases into the Feather River. These discussions would be based in part on emigration patterns of natural spawning and estimated survival of hatchery spring chinook to Chipps Island and the ocean fishery.
- As a special study in the springs of 2002 and 2003, increase releases of tagged hatchery spring chinook in the Feather River to help assure a statistically valid sampling size is available from recaptures at Chipps Island, the ocean fishery and on the spawning ground. In 2002 there will be three releases of 100,000 each. After reviewing these results DFG/NMFS/DWR would recommend the sample size and release timing for 2003.
- Consider adding a rotary screw trap, or other juvenile salmonid sampling device, nearer to the mouth of the Feather River. This sampling could provide additional information regarding emigration of juveniles from the Feather River.

Task 6– Prepare final report synthesizing the information from the above tasks in combination with information from other elements of the Oroville Project evaluation.

All the information related to this study plan will be compiled into a narrative report, with the report organized along the general format of a Hatchery Genetics Management Plan. Using this approach presents the information in a format readily used by DFG and NMFS in preparing the HGMP for the FRH. Specific FERC-related study elements expected to provide information for the final hatchery evaluation report are:

- SP-W1, Water quality, specifically with regard to the effects of hatchery produced fish on nutrients and dissolved oxygen in the river.
- SP-W6. Water quality, specifically the effects of the hatchery operation on stream temperature.
- SP-F10, In-river fish ecological assessments
- SP-F2, Disease studies

6.0 Results and Products/Deliverables

The information compiled in the above tasks will be assembled into a series of task specific reports. Where possible and informative, data will be organized and analyzed and presented in a series of figures and tables –

the tables and figures forming the basis of many of the tasks reports. The ultimate deliverable will be the synthesis report that evaluates the overall effects of the hatchery on naturally spawning salmonids. The synthesis report will based on a combination of data directly related to the FRH and information gleaned from similar analyses of the effects of other hatcheries.

Review will be a key element of the reporting process. The authors of the task reports will submit drafts to appropriate technical and policy reviewers. Any comment will be addressed before the reports are made final.

7.0 Study Plan Coordination

Coordination With Other Resource Areas/Studies

Coordination with other FERC relicensing studies, including those addressing fish disease (SP-F2), salmoids in the Feather River (SP-F10), water quality (SP-W1 & SP-W6), and interbreeding of salmon stocks (SP-E5).

<u>Evaluate the Likelihood Transmission of Disease from Hatchery to Wild Fish</u>

- SP-F2 – Effects of Project Operations on Fish Diseases:

SP-F2 will provide information crucial to the evaluation of stocking practices and artificial production as it pertains to management of fish resources at Oroville facilities.

Many bacteria, virus and protozoa are known to cause various diseases to both wild and hatchery Pacific salmonids (e.g., the bacterium *Renibacterium salmoninarium* that cause bacterial kidney disease (BKD), the rhabdovirus causing infectious haematopoietic necrosis (IHN), the myxosporean parasite *Ceratomyxa shasta* that is lethal to most strains of rainbow trout). It is a current concern to catalogue and assess the incidence of diseases at FRH and evaluate the probability of spreading them to wild fish populations. Activities included in this task are detailed below.

- Review report by Scott Foote 2000 on similar concern about release of chinook from the Coleman National Fish Hatchery (CNFH);
- Review incidence of diseases at the FRH and CNFH to determine their similarities and if the conclusions from the Foote report can be applied to the Feather River; and
- Work with DWR's fish disease consultant to synthesize data.

<u>Evaluate the Effect of Hatchery Produced Fish on Naturally Spawned Salmoids</u>

- SP-F10 Evaluation of Project Effects on Anadromous Salmoids and their Habitat

<u>Evaluate the Effects of the FRH on Water Quality in the Feather River</u>

- SP-W1 Project Effects on Water Quality Designated Beneficial Uses for Surface Waters

Review the existing and newly acquired data to estimate the water quality effects of the decomposition of spawned salmon of hatchery origin that have returned to the Feather River.

Evaluate the Effect of Hatchery on Water Temperatures

- SP-W6 Project Effect on Water Temperatures

Issues, Concerns, Comments, Tracking and or Regulatory Compliance Requirements

This study would address the project-related effects of the Feather River Hatchery on naturally spawning salmonids. The following specific issues will be addressed: (The list identifies if the issues are directly or indirectly addressed in the study plan. Some of the more complex issues are in both categories. The underlined sentence or clause is the one that is best identified with each category);

Direct

Issue	Description
FE31	Several fish hatchery issues need resolution, such as the relationship between the hatchery and restoration of a natural ecosystem, straying and genetic impacts, harvest rates, and disease;
FE87	Introgression occurring between various runs of chinook salmon and between hatchery and wild salmon and steelhead. This includes direct, indirect and cumulative impacts from hatchery practices, project facilities and operations, lack of adequate spawning habitat and impassable migration barriers that exclude access to historic spawning habitats;
FE88	Impact of hatchery facilities and/or operations on anadromous salmonids. This includes the direct, indirect and cumulative impacts of hatchery product on anadromous salmonids and the direct, indirect and cumulative impacts of hatchery facilities and operations on salmonids and their habitats;
FE93	Introgression occurring between fall-run and spring-run chinook populations in the Feather River due to hatchery practices and impassable migration barriers;
FE99	The Feather River Hatchery was constructed to mitigate for losses of upstream habitat when the Oroville facilities were constructed. There is a body of evidence suggesting that improperly planned hatchery practices can adversely impact native and non-native species including anadromous species. The effects of hatchery practices on naturally reproducing/self-sustaining anadromous populations should be examined as part of the fishery investigations. These evaluations should examine alternative practices that would lead to increased naturally reproducing/self-sustaining anadromous populations. Improper hatchery practices can also lead to transmission of serious fish diseases, and impact overall susceptibility of naturally reproducing populations to diseases.
W13	Effects of existing and future hatchery operations on water quality and water temperatures in the Feather River and Afterbay;
WE33	Relationship between hatchery and water quality.

Indirect

Issue	Description
FE95	The lower Feather River provides habitat to support a variety of anadromous fish species including chinook salmon, steelhead, striped bass, American shad and sturgeon. Potential changes in license conditions could adversely impact habitat supporting these species. Habitat investigations should evaluate the existing quality and quantity of habitat and determine alternative improvements for the various life history needs of anadromous species including flow, water temperature, instream and riparian cover, substrate and spatial area;

FE87	Introgression occurring between various runs of chinook salmon and between hatchery and wild salmon and steelhead. This includes direct, indirect and cumulative impacts from hatchery practices, project facilities and operations, lack of adequate spawning habitat and impassable migration barriers that exclude access to historic spawning habitats;
FE96	The lower Feather River provides habitat to support a variety of resident native and resident introduced species including coldwater species such as rainbow, brook, and brown trout, and warm water species such as bass, catfish, bluegill, green sunfish, carp and others. Potential changes in license conditions could adversely impact habitat supporting these species or upset habitat conditions such that less desirable species are favored. Habitat investigations should evaluate the existing quality and quantity of habitat and determine alternative improvements for the various life history needs of these resident native and non-native species including flow, water temperature, instream and riparian cover, substrate and spatial area;

8.0 Study Schedule

The synthesis report will be completed by June 30, 2004. Individual tasks will be completed in time to meet the final report schedule but in most all cases, the task reports should be completed by March 1, 2003 to allow incorporation in the final report and sufficient opportunity for review. For some discrete components of the individual tasks, the deadlines are:

- Initial results of cohort analysis to estimate contribution and straying rates - April 1, 2002 – part of Tasks 2, 3 and 6;
- Results of mark recovery blitz – January 31, 2003 – part of Tasks 1, 2, 3 and 6.
- Second cohort analysis using additional tag recovery data – April 30, 3002 – part of Tasks 2, 3, and 6.
- Literature reviews – December 31, 2003. Part of all tasks.
- Complete chinook salmon modeling development – March 1, 2003 – Task 5.
- Analysis of effect of hatchery operation on stream temperature – August 31, 2003 – Task 4.

Complete additional analyses of genetic tissue – October 31, 2003 – part of Tasks 2 and 3.

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ATTACHMENT 2

F9 – LITERATURE REVIEW

State of California
The Resources Agency
Department of Water Resources

PHASE 1 INTERIM LITERATURE REVIEW FOR SP-F9 EVALUATION OF PROJECT EFFECTS ON NATURAL SALMONID POPULATIONS

Oroville Facilities Relicensing
FERC Project No. 2100

By
Randall Brown

NOVEMBER 12, 2002

INTRODUCTION

The first salmon hatchery (albeit for Atlantic salmon) was constructed in Maine in 1871 (Moring 2000). In 1872 the first egg collecting began on the lower McCloud River (Black 2001) in the Sacramento River drainage and the Battle Creek egg taking station began operation in 1885. The Coleman egg taking station on Battle Creek commenced operation in 1943 by collecting eggs from spring Chinook as part of mitigation package for the construction of Shasta Dam. The Feather River Hatchery began operation in 1967 as mitigation for construction of Oroville Dam. At the same time as hatcheries began operating in California, similar efforts were occurring in the Northwest. The first salmon hatchery in Washington State was built in the 1890s on the Kalama River and by 2001, Washington had about 140 tribal; State and federal hatcheries releasing an estimated 180 million salmon smolts per year along with six to seven million juvenile steelhead (Blankenship, 2002). Oregon and British Columbia also implemented significant salmonid hatchery efforts.

During most of the past 130 years that salmonid hatcheries have been in operation on the west coast, their goals have generally been to produce fish for the commercial, recreational and tribal fisheries or to mitigate for habitat lost due to dams and other perturbations. In actuality production and mitigation goals often overlap and hatcheries have generally been operated as a technological solution to the overall problem of habitat loss due to changes in the amount and timing of streamflows, logging in the watersheds (with its consequent effects on the aquatic system), overfishing, blockages caused by dams and other obstructions, water diversions and the effects of municipal, industrial and agricultural waste discharges to streams and estuaries In recent years, conservation and supplementation hatcheries have come into the salmonid culture lexicon - hatcheries that are designed to be more environmentally benign and may overcome some of the concerns about production and mitigation hatcheries.

During the past two decades in particular there has been increasing evidence that our salmon management programs are not working. The winter run of Chinook salmon in the Central Valley was listed in 1989 and Nehlson, et al. (1991) listed numerous stocks in California and the Pacific Northwest that had been extirpated, or were threatened with extirpation. At the same time we began to learn more about the conservation genetics and could distinguish between runs (see for example, Utter, et a. 1989). The role of hatcheries in fish and ecosystem became of increasing interest.

As DWR developed the study plan for evaluating the effects of the Feather River Hatchery on naturally spawning salmonids, I was requested to examine the available literature regarding hatchery impacts. The original focus of this examination was to determine if the literature could be used to suggest additional study elements/information needs that should be included in the study plan – elements that could be completed within the available time and which would add to our understanding of hatchery impacts. As the study plan evolved, it included a literature review as one of the study elements. One of the other purposes of the literature review was to acquire and read the literature that would be helpful in preparing the final project reports.

In this report I include some observations from a survey of more than 100 published papers as well as some reports not available in the open literature. I do not attempt to duplicate some excellent reviews of this topic that have been conducted in recent years. In fact, I draw heavily from several of these reviews – namely by Campton (1995), Busack and Currens (1995), National Research Council (1996), Grant (1997) Waples (1999) and Orr and Pinikett (2002). Jim Bakke of the Native Fish Society prepared an annotated bibliography on the interactions between hatchery and wild salmonids. This undated bibliography is also quite useful.

These are not all of the reviews on this topic but the ones I found to be most helpful , and the ones I had access to. Jim Lichatowich, Rick Williams and Phil Mundy are preparing a report describing new approaches to hatchery management and the report will contain an extensive literature review. The report, being prepared for Trout Unlimited, is due to be released in January, 2003, thus will be available for inclusion in the hatchery evaluation report.

As with all complex issues, there are advocates for all sides of the issue – ranging from strong hatchery proponents to those stressing the serious environmental consequences of the West coast salmonid hatchery operation. On one hand it appears that from one-half to three-fourths of the Chinook salmon caught in the ocean commercial, recreational and tribal fisheries off Washington , Oregon and California are from hatcheries (Blankenship 2002 and Cramer 1992). On the other hand, Meffe (1991) cited the following reasons why hatchery production of salmonids is ecologically a bad idea and will ultimately fail:

1. *"data demonstrate that hatcheries are not solving the problem – salmon continue to decline despite decades of production,*
2. *hatcheries are costly to run, and divert resources from other efforts, such as habitat restoration,*
3. *hatcheries are not sustainable in the long term, requiring continual input of money and energy,*
4. *hatcheries are a genetically unsound approach to management that can adversely affect wild populations,*
5. *hatchery production leads to increased harvest of wild populations of salmon, and*
6. *hatcheries conceal from the public the truth about the real reason for the salmon decline."*

Both sides of the argument make valid points. Waples (1999) put the controversy in perspective by describing some of the myths and misconceptions about the effects of hatchery production on salmonid populations. He concluded that:

1. *"Hatcheries are intrinsically neither good nor bad – their value can be determined only in the context of clearly defined goals;*
2. *genetic changes in cultured populations can be reduced but not eliminated entirely;*
3. *empirical evidence exists of many adverse effects of hatcheries, but some risks have been overstated;*
4. *monitoring and evaluation programs are important but should not be used as a substitute for developing risk-averse hatchery programs in the first place."*

Waples (1999) further recommended that we need more effort in the areas of goal identification, benefit:cost analysis, data collection and analysis and dealing with uncertainty.

Leading to the myths and misconceptions described by Waples (1999) is the relative paucity of site specific data and from fisheries management practices that make it difficult to sort out direct hatchery impacts from the effects of other factors. For example Hayes and Carmichael (2002) began tagging Chinook salmon destined for the Umatilla River in Oregon and were surprised that many of the returning adults strayed in the Snake River and mixed with threatened Snake River stocks – contributing up to 26% of the escapement. Given the facts that -

- Chinook salmon had been extirpated from the Umatilla River;
- the founding population for the new stock came from adults collected at Bonneville Dam and were of mixed genetic stock;
- the juveniles destined for return as adults to the Umatilla River were reared in different hatcheries with different water supplies – none of which was from the Umatilla River itself;
- and the juveniles were released off site at different locations –

it is not surprising that the fish strayed. In this case well-meaning managers from several agencies (including the Bonneville Power Administration, Oregon Department of Fish and Wildlife, Confederated Tribes of the Umatilla Indian Reservation, US Forest Service and the US Bureau of Reclamation) established a goal of 11,000 returning Chinook salmon with hatchery production used to realize the goal (Boyce 1986). The implementation plan, developed by the tribes and ODFW and extensively reviewed by fish biologists and managers did not include a marking program to establish risks to other salmonid populations associated with achieving the goal for the Umatilla River. This is an example of how fish managers even as late as the 1980s-1990s did not foresee the consequences of an action taken to provide societal benefits, nor did they initially undertake the monitoring needed to assess the risks.

My approach to this literature review is to summarize conclusions from the major reviews cited above. This interim report will be followed in about three months by an annotated bibliography of the technical papers I have collected. (Copies of these papers will be placed in the FERC archives.) It is important to note that the final F9 report will include specific literature references in the individual sections. For example, the extensive work of Quinn and his colleagues (for example Quinn, T. 1997) will be used to put observed straying by fish from the Feather River Hatchery (and other Central Valley hatcheries) in perspective. Finally, I include a short summary of some of the "take-home messages from literature as they apply to the evaluation of the impacts of Feather River Hatchery on naturally spawning salmonids.

From available reviews

Since I don't believe in reinventing wheels, I have based this summary largely on what others have pulled together. As is pointed out in most of the reviews, one has to be careful when applying the results of the literature to each particular situation being evaluated. As will be shown in the summary, however, there are several common themes in all the reviews. For those seriously interested in the issue of hatchery impacts, I recommend that you read the reviews and original literature yourselves. All summaries are abstracts of the original papers and the abstracter provides his or her slant on the topic, if only by selecting which parts of the paper to include.

Robin Waples -1999, *Dispelling some myths about hatcheries*. I found the 1999 review published in Fisheries (a monthly semi-technical journal of the American Fisheries Society) to be quite useful, perhaps because the Fisheries audience is diverse, containing a mix of strong opponents and proponents of hatcheries as well as those that believe properly operated hatcheries will continue to be an integral part of the fisheries managers' tool boxes. (The American Fisheries Society was originally organized around fish culturists.) Following are some of the main messages I took from Waples.

- **Fisheries management and fish hatcheries**. In this opening paragraphs, Waples stated "*because the key issues involve both fish culture and fisheries management, I emphasize hatchery programs rather than hatcheries <u>per se</u>.*" The take home message is that it is not productive to look at an individual hatchery without considering the fisheries management context in which was developed and operated.
- **Hatchery goals**. Hatchery goals need to be clearly identified and programs established to monitor progress towards realizing the goals. Setting goals is not enough, however – goal setting is an iterative process and the original goals need to continuously examined as new data about the effects and benefits of the hatchery program become available.
- **Genetic risks posed by hatcheries**. Genetic changes in hatcheries are associated, in part, with domestication and domestication selection – processes resulting from human efforts to control the environment in which the fish are cultured. Adding one Campton's (1995) factors identified as leading to genetic change, Waples listed the following.

a. Intentional or artificial selection for a desired trait.
b. Selection resulting from non-random broodstock collection procedures
c. Unintentional natural selection that happens in the hatchery environment but might not happen in the wild.
d. Temporary relaxation of selection of selection in the culture phase of selection processes that would occur outside the hatchery.

Hatchery programs may be able to eliminate the effects of the first factor but it will be impossible to completely avoid problems with the last three factors because;

- the hatchery environment is not the same as the wild environment
- hatchery programs dramatically change the mortality profiles of the species cultured – ie hatchery programs are geared to increase egg to smolt survival.

The resulting conclusion is that hatchery programs can reduce genetic risks but can not entirely avoid them. (See also Busack and Currens 1995). This domestication selection can occur in the absence of mortality during the culture phase, if family sizes are equalized or if the broodstock are selected through a random sampling protocol. Although natural selection will occur post release, can not be assumed to eliminate any genetic changes due to domestication selection.

Waples concluded that there is no universal axiom that can be used to develop methods to avoid genetic risks – each situation must be evaluated on a case-by-case basis.

- **Unintended effects of hatcheries on natural populations.** It is not appropriate to conclude, a priori, that hatcheries always have detrimental effects on natural populations. Again the conclusion will have to be based on the information from individual cases and the extent to which the hatchery and natural populstions are isolated will affect the conclusion. Waples identified two incidental risks to hatchery programs.
  a. Straying. Reviewing mostly the literature by Quinn (1993,1997) Waples concluded;
    - The extent to which hatchery and wild fish stray varies widely.
    - Whether hatchery fish stray more than wild is not clear – mainly because of lack to data.
    - The science behind our understanding of homing and straying is poorly understood.
    - Effects of straying on natural populations are a function of the percentages of strays in the affected population, not in the percentage rate at which hatchery fish stray.
  b. Disease transfer. Although several pathogens and diseases are widely present in west coast hatcheries and watersheds, and can cause severe problems to salmonid populations, there is little empirical evidence of

widespread transfer of disease and pathogens from hatchery to wild fish. However, there have been relatively few studies to determine if this is a serious problem.

- **Are objections to hatcheries based strictly on theory or do they have ecological basis?** Waples concluded that there is a solid body of empirical data to support most of the concerns about the impacts of hatchery fish on natural populations, but that our understanding is incomplete. Two quotes capture the situation quite well.
    a. As quoted in Waples from Busack and Currens (1995, p77) *"We are unaware of rigorous research designed to detect genetic impacts that has failed to find them."*
    b. From Waples 1999 " *What is lacking is consensus on what constitutes a reasonable approach to this issue given the substantial uncertainty and its potentially major consequences of whatever actions are (or are not) taken."*

- **Fisheries management and hatcheries**. Waples argued that we need to depersonalize the problem and work towards solutions, not assessing blame.

- **The role of monitoring in hatchery management**. Although monitoring and assessment are important components of well-run hatchery program, they are not panaceas. Monitoring data may be slow in coming in (e.g., tag returns from fisheries) and may not have the power to detect subtle, but important population effects.

- **Where to go from here?** My summary of where Waples recommended we go next.

    a. Work with the community of fisheries biologists, fish culturists, conservation biologists and managers to reach general agreement on the role of a hatchery or hatcheries in a basin.
    b. In reaching this agreement examine hatcheries in the traditional benefit:cost approach where benefits to society and population and to the ecosystem are compared to costs to the same components are evaluated to determine if there is a net benefit.
    c. Conduct more research to increase our understanding of hatchery impacts, perhaps with the focus of expanding existing hatchery facilities to expand these research efforts.
    d. Recognize uncertainty and deal with it.

Orr, Gallagher and Penikett, 2002. ***Hatcheries and the protection of wild salmon.*** The authors edited the proceedings of a workshop organized to explore the general topic of hatcheries and the protection of wild salmon. The workshop itself consisted of about 20 presentations on such topics as:

- The setting: Why hatcheries
- Evaluating some stated benefits of hatcheries
- Ecological Issues
- Genetic Issues
- Hatchery Reform: Goals, Data Gaps, Measures of Success

I have taken several points from the Convener's report of the workshop.

- A consensus emerged from the participants that:
    a. "*Hatcheries and other forms of artificial enhancement cannot readily replace damaged or lost freshwater habitat.*
    b. That we humans can never fully understand the complexities of natural ecological and genetic systems to maintain them artificially.
    c. That there can be no substitute for diligent maintenance of:
        - *High quality natural habitat,*
        - *Healthy freshwater and marine ecosytems,*
        - *Abundant and, naturally reproducing salmon populations with their genetic fitness and diversity intact."*

- There was also general agreement that hatcheries need to be viewed as components of complex ecological and genetic systems and that hatchery evaluations need to focus on the interactions between the hatchery and the systems – not strictly on the numbers of fish released or subsequent returns.
- The marine and freshwater environments have finite but varying carrying capacity, thus carrying capacity needs to be considered in hatchery planning and evaluation.
- The workshop participants identified the following information gaps:
    a. A comprehensive assessment of the role of hatcheries in fish management leading to more defensible hatchery goals.
    b. Use an adaptive management approach to evaluating the impacts of hatchery interventions in fish management.
    c. An examination of the effects of varying ocean survival on salmon populations.
    d. What are genetic impacts?

Sigurd Einum (2001) ***Implications of stocking: Ecological interactions between wild and introduced salmonids.*** Although Einums's article had been published in the Norwegian Journal of Freshwater Research, it was reprinted in the proceeding of the Orr, Gallagher and Penikitt (2002) workshop. Note that this review was based on literature surveys that included migratory populations of trout, charr and Pacific salmon – not just Pacific salmon. The author emphasized several points.

- Why to hatchery and wild fish differ?
    a. Salmonids exhibit high phenotypic plasticity and phenotypes may be changed significantly by the hatchery environment. The feeding regimes, density, substrate, exposure to predators and interactions with conspecifics

are examples of differences between hatchery and wild environments that can lead to changes in behavior.
    b. The intensity and direction of selection differs between the two environments. – perhaps most importantly in the differences in survival between eggs and smolts. One outcome of this difference is that less fit genotypes that might not survive in the wild may persist in the hatchery environment.
    c. In many of the early hatcheries non-native runs were used as the founding stocks.

- Which characters differ between hatchery and wild salmonids?
    a. In 5 of 9 studies reviewed by Einum, hatchery fish were more aggressive than their wild kin. A meta-analytical approach to the data supported the hypothesis that hatchery fish were generally more aggressive than wild fish.
    b. Hatchery fish exhibited a reduced response to predator risk.
    c. Hatchery fish may have different migratory patterns than wild fish – i.e., changes in migration timing and length of time spent in the ocean.
    d. After release hatchery fish may feed differently than wild fish, although they may adjust to new food sources relatively quickly.
    e. Hatchery fish may be morphologically different than wild fish and morphological traits may be important to breeding success.
- How successful are hatchery fish in the wild?
    a. Growth rates differ between hatchery and wild fish but the direction is not consistent.
    b. Hatchery fish consistently experienced lower overall survival than wild fish.

- How do naturally produced fish respond to hatchery releases?
    a. Since they are generally more aggressive, hatchery fish may replace wild fish. Agressiveness may be compensated by poorer survival of released fish. Initial displacement of wild fish followed by poor survival of hatchery fish could result in lower overall density of fish in the stream.
    b. Hatchery releases of fish ready to emigrate may attract wild fish to join in the movement.
    c. Hatchery releases may attract predators.
    d. Interbreeding may reduce population fitness.
- Conclusions
    a. Although the reports cited may be biased towards the negative effects of stocking, the potential for negative effects must be acknowledged.
    b. Any negative effects of hatcheries may be minimized by:
        - Better broodstock collection and mating protocols.
        - Creating more natural rearing conditions.
        - Employing fish friendly wild-fish release strategies
        - More focus on local broodstocks.

National Research Council (1996). ***Upstream – Salmon and Society in the Pacific Northwest***. In 1992, the NRC formed the Committee for Protection and Management of Pacific Northwest Anadromous Salmon, consisting of 15 scientists with a wide range of technical disciplines. The committee was formed to (in part):

"*The committee will review information concerning the seven species of the genus* Oncorhynchus *in the Pacific Northwest. The review will focus on the population status, habitat, and environmental requirements of the stocks. It will include analyses of information about their genetics, history, management and production by hatcheries, as well as federal, state, tribal and other management regimes."*

I have included the partial charge because it is very similar to the charge of the salmon-related FERC activities involved in studying the Feather River. For this report, I only reviewed the hatchery related chapter of the report (pp 302-323): however, the book is recommended reading for everyone working on anadromous salmonids in the Feather River studies.

The authors led off with some examples of the increasing importance of hatchery salmonids in Northwest salmon management. Below are a few of these examples, including the citation for the source of the information.

- *By 1987, hatchery-origin fish dominated adult returns to the Columbia River basin, compromising more than 90% of the coho, 70% of the spring Chinook, about 80% of the summer Chinook, more than 50% of the fall Chinook and about 70% of the steelhead (Columbia Basin Fish and Wildlife Authority 1990).*
- *In the Snake River basin, reliance on hatchery propagation of Chinook increased from 0.75 million juveniles released in 1964 to 14.9 million in 1989, but this did not prevent steep declines in numbers of adult returns to the basin (Chapman, et al. 1991).*
- *Hatchery fish make up about one-half of the overall abundance of steelhead trout found from Alaska to California but about 70% of steelhead from Coastal Oregon and Washington and the Columbia River basin (Light 1987).*

The NRC report identified the following areas of concern about the effects of hatchery production on wild fish.

- **Demographic effects**. Large releases of hatchery fish can result in overfishing of natural stocks in mixed stock fisheries. Wild populations can be driven to extinction if their escapement drops below replacement levels.
- **Genetic and evolutionary risks**. The discussion was mainly drawn from Busack and Currens 1995.
    a. Loss of population identity and within-population genetic variability. This risk is increased by collection of non-indigenous broodstock (which was a problem for early hatcheries but not as much now), straying, low effective population size in the hatchery and artificial selection of specific traits (e.g., selection for size and run timing) by hatchery managers.

b. Domestication can result in a decline in fitness to survive in the wild. Domestication can occur by two pathways – nonrandom selection of broodstock over the spawning period and the responses of fish growing in the non-natural hatchery environment.

- **Behavior**. As shown earlier, hatchery fish are often more aggressive that wild fish but have higher mortality levels. In one study cited (Nickelson et al. 1986) of releases of hatchery coho in a stream containing wild coho juveniles it was shown that:
    a. Larger and more aggressive hatchery releases displaced wild juveniles.
    b. The hatchery releases returned earlier than wild fish and contributed little to the population.
    c. The net result in subsequent years was that fewer juveniles were present in the stream than would have been present had there not been a hatchery intervention.
- **Fish Health** In spite of widespread occurrence of disease in hatcheries, there is little evidence of evidence of transmission of disease from infected wild fish (as reviewed by Steward and Bjorn 1990 – **note that I have not yet been able to obtain a copy of this report.**) The authors noted that there have not been many studies to address this complex problem. They also noted that loss of genetic diversity due to hatchery practices could result in loss of the genes that help salmonids fight infections (see for example Stet and Egbert 1991).
- **Physiology** Post release stresses caused by crowded rearing conditions and handling and transportation often results in high post release mortality and may reduce the fish's immune response. Incomplete smoltification in hatchery fish may result in the fish remaining in the river longer than desired and may compete with wild populations.
- **Ecological Problems** The authors raised the issues of limited carrying capacity, the ability of hatchery fish to survive and be integrated into natural populations and habitats without adversely affecting the natural populations and the loss of carcasses (and their nutrients) on streams.

W. Stewart Grant (1997) ***Genetic effects of straying of non-native hatchery fish into natural populations. Workshop proceedings.*** Several speakers in this 1995 NOAA sponsored workshop provided examples of straying and others addressed the general topic of the genetic effects of straying. NMFS representatives stated that the Agency goal was to limit the number of strays in a stream to less than 5% of the total number of fish present in the stream. On the second day of the session, the organizers assembled a panel to address several questions and reach some general conclusions regarding the effects of straying. Some of the questions (with the answers) and the conclusions are found below.

- **Questions**

1. **What are appropriate parameters to consider in evaluating the effects of straying?**

a. **Stray rate.** The key straying parameter is proportion of non-native fish successfully spawning in the population.
b. **Gene flow.** Gene flow only happens when the stray fish become integrated into the population. Stray rate provides an approximate upper limit of gene flow.
c. **Local population size.** The genetic consequences of straying depend on effective population size more than census size. For salmon, the average population size must be averaged over the entire return period.
d. **Random genetic drift** The effects of genetic drift are not predictable and can be consequential in small populations. Genetic drift may not be important when the effective population size is greater than 1,000 individuals.
e. **Inbreeding depression – loss of fitness due to mating of related individuals.** Most important in populations with a small effective size.
f. Outbreeding depression – loss of fitness due to mating of genetically divergent individuals. Outbreeding depression can occur due to loss of local adaptation or breakdown of favorable gene loci.

2. **What other parameters are important in determining the effects of straying?**
    a. Genetic and life history differences between hatchery and natural populations
    b. Magnitude straying and strength of selection.
    c. Duration of straying.
    d. Number of natural populations affected.
3. **Do short and long-term effects of straying differ?** The answer is yes, with short term effects having either negative or positive effects.
4. **Are the effects of staying likely to be permanent?** The answer is yes.
5. **Can hatchery straying be beneficial to natural populations?** Theoretically, yes by increasing genetic diversity. For well-adapted populations, this increased genetic diversity could be detrimental.
6. **Can the effects of hatchery straying be predicted with any certainty?** No.
7. **What will be the effect of straying at the 5% level?** Although this can not be predicted, the value of a 5% gene flow may be higher than generally occurring between natural populations.
8. **What research should be undertaken to help resolve uncertainties of hatchery straying?**
    a. The relationship between the rate of hatchery straying and the rate at which gene flow occurs.
    b. The nature and extent of outbreeding depression in natural salmon populations.
    c. Rates of straying and gene flow among natural populations.
    d. Selection intensities on whole traits.
    e. Genetic attributes of successful populations.

Craig Busack and Kenneth Currrens (1995). ***Genetic risks and hazards in hatchery operations: Fundamental Concepts and Issues*** Although not a typical review paper, I have included it because it contains one of the original references I found in the fisheries literature to the concepts of genetic risks and hazards in hatchery operations.

- Goal of paper is to acquaint fishery professionals with genetic concepts – concepts that may not be widely known by many professionals.
- Some definitions
    a. A hazard is a potentially adverse consequence of an event or activity. The most commonly cited genetic hazard is a loss of genetic diversity.
    b. A risk is the likelihood of the hazard occurring. Both terms are modified from Smith (1962).
    c. Genetic diversity is all the genetic differences contained with a population or groups of populations.
    d. A population is a group of interbreeding individuals.
- Genetic hazards we should be concerned with:
    a. Extinction, or the complete loss of genetic information. Extinction of a population reduces overall genetic diversity of a species. Until recently extinction has not been associated with hatcheries but broodstock selection, diseases, power failures and ecological interactions between hatchery and wild fish may result in the extinction of some populations.
    b. Loss of within-population variability due to reduction in quantity, variety and combinations of alleles in a population.
    c. Loss of among-population variability is a reduction in the genetic diversity among populations caused by such practices as transfer of genetic material between basins, stocking hatchery fish outside the natural distribution of the species or race and straying.
    d. Domestication is the changes in genetic diversity within the cultured populations or between the cultured population and the population in the wild. Domestication may occur due to intentional selection for some traits, biased sampling in some stage of culture, or unintentional selection during culture.
- In all hazards, theoretical considerations exceed empirical evidence – partly because it is difficult to separate hatchery effects from environmental effects and the lack of science that has been applied to the problem.
- We need more research into the areas of genetic risk including a rigorous treatment of outbreeding depression, domestication selection and the effects of reductions in effective population size.
- In summary they concluded:
    a. There are sound theoretical reasons to expect genetic impacts from hatcheries.
    b. Empirical evidence, albeit sketchy supports the theoretical considerations.
    c. Although more research will shed light on genetic risks, there are likely to real limits to our ability to predict these effects.

d. They recommend that we should begin managing based on the goal of maximizing genetic diversity – mainly because it stresses preservation of fitness.

Don Campton (1995***). Genetic effects of hatchery fish on wild populations of Pacific salmon and steelhead: What do we really know?*** Many of the concerns described in Campton's paper have been mentioned in the above papers. There are several comments from the conclusions that I believe bear considering when approaching an analysis of the effects of hatcheries on wild salmonid populations.

- Many of the perceived and potential genetic effects appear to attributable to fisheries management, either of the hatchery or wild fish.
- Much of problem in distinguishing between management causes and biologic causes is attributable to the relative differences in detecting effects of the two causes. Baseline genetic data prior to the introduction of hatchery fish are seldom available for use in assessing impacts of the hatchery.
- "*there has been a general blurring between fact and speculation, between data and interpretation and between science and values*." This blurring affects our ability to look at the problems objectively and scientifically.
- As proposed by Hilborn (1992), we may have to resolve questions regarding the use of hatcheries in salmonid management in terms of values, Campton also cited the following quote from Scarnecchia (1992) for the need to combine science and value when considering the role of hatcheries in salmon management.

  "*Salmon resources have been aided and harmed by technology, and managers must carefully assess how current and future technologies will be used to manage salmon. Effective managers must be knowledgeable of fishery science and human values. The science of fishery management is the objective, logical and systematic method of obtaining reliable knowledge about fishery resources. The art in fishery management involves our values, that is, what we judge to good, desirable, and important in the long run."*
- Campton suggested we use the following recommendations (from the International Symposium on Fish Gene Pools, Preservation of Wild Fish Stocks, as summarized by Hindar et al. 1991) when considering supplementing natural salmonid populations with hatchery fish:
  a. Identify genetic resources.
  b. Maintain natural ecosytems.
  c. Avoid selective harvest of natural populations.
  d. Release fish into natural environments with great care.
  e. Provide adequate funding for basic and applied research.
  f. Inform those responsible for management of existing knowledge.

  Campton added an final recommendation

  g. understand, scientifically, the biological consequences of management decisions. He suggested that one of the essential hatchery goals should be to " *integrate scientific research and management into a mutually*

beneficial relationship in order to learn as much as possible about the fish we are propagating and the effects of those fish on natural populations."

SUMMARY

My interpretation of what the some of published literature tells us about the effects of hatcheries on natural salmonid populations can be summarized by the following. (The order is not significant.)

Hatcheries and fisheries management. We can not consider one without the considering the other. Hatchery managers and their staff grow fish and fishery managers tell them what kind to grow, how many to grow, where to plant them and set harvest targets and regulations. Fish managers determine if the hatchery is to be used for mitigation, supplementation, production or a combination of these purposes.

Hatchery goals. Hatchery goals are generally stated in terms of production or escapement targets and may not be updated as new information comes along. Goals of older hatcheries (i.e., hatcheries older than 10 years) seldom include ecological goals.

Science and hatcheries. In many instances, the early hatchery programs did not include monitoring and research components to help assess genetic and other hatchery impacts. On the other hand hatcheries do provide much of the facilities and raw material needed to conduct large scale studies of the effects of hatchery operation on naturally spawning fish populations.

Hatchery benefits. The literature is not filled with papers lauding the benefits of hatcheries – or at least not the literature I could readily find. On the other hand, most of the Chinook salmon, coho salmon and steelhead rainbow trout caught along the west coast of North America come directly from hatcheries. Defining and maintaining "acceptable" levels of salmonids in these waters will require the collective efforts of fish and fisheries biologists, hatchery managers, economists, sociologists, engineers and restoration biologists. Hatcheries have a long term role in the process of fisheries management and ecosystem science but the role will not be the same as it has been in the past hundred years.

Fitness of hatchery fish. Due to crowded conditions, unnatural feeding regimes, lack of contact with predators and natural stream conditions, hatchery fish are less fit than naturally produced fish. When released they are often larger and more aggressive than wild fish and may displace wild fish and attract predators. In the long run, initial aggressive nature of hatchery fish and their overall lack of fitness can result in depleting natural fish populations. Methods to increase fitness are being explored – methods which in general work towards creating a more "natural" environment in the hatchery.

Empirical versus theoretical data. Given the complexity of the genetic and other issues, the relative newness of concerns in these areas, it is not surprising that many of the concerns are based mainly on theoretical data. The empirical data that are available

generally support conclusions from theory; thus fisheries and hatchery managers should take the concerns into consideration during hatchery operation.

Elimination of hatchery impacts. Hatchery impacts can not be completely eliminated but, through proper management, they can be minimized. Proper broodstock selection and mating protocols and release strategies can go a long ways to minimizing impacts

Straying. There appears to be enough natural variation in straying and homing that each hatchery should be evaluated separately through use of a marking program. Marking of hatchery fish should be accompanied by a similar program with wild (natural fish) to provide a comparison. The straying rate is not as important as the percentage of strays in the receiving population. The NMFS recommended maximum of 5% strays in population seems to be a useful goal.

Disease transmission. The relatively limited literature available on transmission of disease from hatchery to wild fish does not indicate that it is a significant problem. On the other hand, there are several diseases and parasites that affect hatchery fish and are found in natural fish as well. Diseases can be acquired by fish in laboratory studies. Clearly more work is needed in this area.

New information that we should be collecting for FERC related studies of the impacts of the FRH on naturally spawning salmonids. Nothing leaps out at this time. As we learn more about straying and genetics, it is clear that sound hatchery management in the future will require more involvement by geneticists.

Mixed stock fisheries. A mixed stock fishery could help isolate some of the impacts of harvest of hatchery fish at the expense of wild stocks. Such a fishery is now present for steelhead but many details need to be worked out for Chinook salmon. In general hatchery and fish managers should constantly aware of changes in fishery conditions and regulations and consider these changes when considering egg take and release numbers.

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ATTACHMENT 3

FRH OPERATIONS AND CONSTRAINTS

FEATHER RIVER HATCHERY
1999 DRAFT

PRODUCTION GOALS AND CONSTRAINTS[1]
(Operational Plans)

California Department of Fish and Game

California Department of Water Resources

Commercial Salmon Trollers Advisory Committee

Source of Hatchery Broodstock

For all species cultured, fish entering the hatchery volitionally shall be used as broodstock.

Distribution of Egg Allotment

The annual egg allotment for all species cultured shall be distributed throughout the length of the spawning run in proportion to historic temporal distribution of the runs. Maintaining genetic diversity by distributing the egg allotment throughout the spawning run shall take precedence over meeting numeric production goals.

Excess Eggs and Fry

No excess eggs or fry shall be stocked in anadromous waters.

CHINOOK

Trapping

The ladder and trap will be opened on or about September 1, of each year. Returning fish shall be allowed free access to the hatchery after that date, consistent with hatchery physical constraints and water quality. In the event conditions develop a potential for unacceptable fish loss, free access may be temporarily curtailed. The earliest spawning fish from salmon trapped between September 1, and September 15, will be considered "spring-run". The salmon designated as “Spring-run”, will be held and spawned as a discrete group, and the resultant eggs and juvenile fish will be treated as such. Chinook entering the hatchery after September 15, will be considered "fall-run".

Disposition of Trapped Salmon

All salmon adults or grilse entering the hatchery will be retained and utilized for egg taking or fertilization as stated in the section titled “Egg taking”, and the carcasses disposed of in the following manner:

[1] These goals and constraints are designed to meet the mandated mitigation features of the hatchery, California fish and Game Commission policies, and the California Fish and Game Code.

Continued next page:

1**.** The heads of all adipose clipped salmon shall be removed from the carcasses, recorded, and stored for coded-wire tag processing.

2. Carcasses shall be donated to nonprofit organizations. The hatchery manager shall have the authority to determine the allocation of the carcasses to be donated.

3. Carcasses not donated to nonprofit organizations shall be disposed of at a rendering plant or other appropriate refuse disposal site.

Egg taking - Spring run

Eggs will be taken from the earliest spawning salmon designated as Spring Run, up to a total of 7,000,000. No eggs will be taken for Spring Run production after October 7.

Mitigation Production - Spring run

The goal for spring-run production is 5,000,000 fish of at least 60/lb. and preferably larger. These fish will be hauled to the Carquinez Straits - San Pablo Bay area, May - July, for release at various sites, with the exception of any marked or tagged fish which will be released at the assigned locations and dates.

Egg taking - Fall run

Eggs will be taken from fish designated as, "fall-run", up to a total of 12,000,000. Eggs from fall-run fish will represent the full spectrum of the run. All trapped adult salmon that are alive and ripe, will contribute to the egg taking or fertilization of eggs. One half of early maturing males (jacks) trapped, up to approximately 5% of the total run, will be randomly selected and included in the egg fertilization. Some or all of each pooled lot of eggs will be retained according to a predetermined schedule of weekly egg taking needs.

If it becomes apparent by early November that the **Mokelumne River Hatchery** will not be able to take enough chinook eggs to reach production goals; up to 4,000,000 chinook eggs may be taken at Feather River Hatchery for **transfer to Mokelumne River Hatchery**. Eggs or fingerling chinook transferred to Mokelumne River Hatchery will be taken from all the available lots of eggs or fingerlings at Feather River Hatchery.

Mitigation Production - Fall run

6,000,000 fall-run fish will be reared to at least 60/lb. and preferably larger. and transported to release sites in the Carquinez Straits-San Pablo Bay area, May - July.

Ocean Enhancement (Salmon Stamp) Fish and Game Code Section 7861

2,000,000 fall-run fish will be reared to 30/lb and transported to release sites in the Carquinez Straits-San Pablo Bay area, May - July.

Inland Chinook

Up to 2,000,000 eyed eggs from the spawning of the earliest trapped chinook, may be specified, with the approval of the Fish Health Laboratory, for use in producing fish for the Inland Chinook Program. These eggs will be transferred to the Silverado Fisheries Operations Base, or incubated and hatched in isolation at Feather River Hatchery at the discretion of the Fish Health Laboratory.

Restoration

Fall-run chinook fingerlings may be produced and planted in appropriate tributary streams identified by Regional Fisheries Management and approved by the Chief, Central Valley Bay-Delta Branch.

STEELHEAD

Trapping

The ladder will be operated continuously through the fall and winter, as long as fish with viable eggs will ascend the hatchery ladder. Live steelhead that have contributed to the egg taking or fertilization will be returned to the Feather River. Also, steelhead that are not ready to spawn may be returned to the river.

Egg taking

Up to 1,000,000 eggs will be retained, representing the full spectrum of the run. Some or all of each pooled lot of eggs will be retained according to a predetermined schedule of weekly egg taking needs.

If it becomes apparent by late January that the **Mokelumne River Hatchery** will not be able to take enough steelhead eggs to reach mitigation goals; up to 250,000 steelhead eggs may be taken at Feather River Hatchery for **transfer to Mokelumne River Hatchery**. Eggs or fingerling steelhead transferred to Mokelumne River Hatchery will be taken from all the available lots of eggs or fingerlings at Feather River Hatchery.

Mitigation Production - DWR

400,000 steelhead will be raised to yearlings and released January - February for DWR mitigation. All steelhead to be released will be marked with an adipose fin clip or coded-wire tag as appropriate.

Mitigation - Delta Pumps Fish Protection Agreement (4-Pumps)

Up to 50,000 steelhead will be reared to yearlings and released January - February for 4-Pumps mitigation. All steelhead to be released will be marked with an adipose fin clip or coded-wire tag as appropriate.

Steelhead release location

Steelhead yearlings will be released at Gridley, or further downstream to avoid predation on naturally produced salmon fry, or competition with naturally produced steelhead.

Procedures for change

Any exception to or modification of this Department of Fish and Game program shall require joint written approval of the Regional Manager, Sacramento Valley - Central Sierra Region, and the Chief, Native Anadromous Fishes and Watershed Restoration Branch.

The goals and constraints for egg allotments, release numbers, size at release, release sites, and release timing for all species cultured at the hatchery are listed in the table below.

NIMBUS SALMON AND STEELHEAD HATCHERY

PRODUCTION GOALS AND CONSTRAINTS[1]
(Operational Plans)

California Department of Fish and Game
and
United States Bureau of Reclamation

Source of Hatchery Broodstock

For all species cultured, fish entering the hatchery volitionally shall be used as broodstock.

Distribution of Egg Allotment

The annual egg allotment for all species cultured shall be distributed throughout the length of the spawning run in proportion to historic temporal distribution of the runs. Maintaining genetic diversity by distributing the egg allotment throughout the spawning run shall take precedence over meeting numeric production goals.

Excess Eggs and Fry

No excess eggs or fry shall be stocked in anadromous waters.

CHINOOK

Trapping

The fish ladder will be opened in the fall when the water temperature in the American River decreases to a daily maximum of 60 degrees F.(generally late October - early November). Returning fish shall be allowed free access to the hatchery after that date, consistent with hatchery physical constraints and water quality. In the event conditions develop a potential for unacceptable fish loss, free access may be temporarily curtailed.

Disposition of Trapped Salmon

All adult salmon or grilse entering the hatchery will be retained and utilized for egg taking or fertilization as stated in the section titled “Egg taking”, and the carcasses disposed of in the following manner:

1. The heads of all adipose clipped salmon shall be removed from the carcasses, recorded, and stored for coded-wire tag processing.

1. These goals and constraints are designed to meet the mandated mitigation features of the hatchery, and California Fish and Game Commission policies.

Continued next page:
Nimbus Hatchery Goals & Constraints - page 2

2. Carcasses shall be donated to nonprofit organizations. The hatchery manager shall have the

authority to determine the allocation of the carcasses to be donated.

3. Carcasses not donated to nonprofit organizations shall be disposed of at a rendering plant or other appropriate refuse disposal site.

Egg taking

Up to 8,000,000 chinook eggs will be taken representing the full spectrum of the run. All trapped adult salmon that are alive and ripe, will contribute to the egg taking or fertilization of eggs. One half of early maturing males (jacks) trapped, up to approximately 5% of the total run, will be randomly selected and included in the egg fertilization. Some or all of each pooled lot of eggs will be retained according to a predetermined schedule of weekly egg taking needs.

If it becomes apparent by early November that the **Mokelumne River Hatchery** will not be able to take enough chinook eggs to reach production goals; up to 4,000,000 chinook eggs may be taken at Nimbus for **transfer to Mokelumne River Hatchery**. Eggs or fingerling chinook transferred to Mokelumne River Hatchery will be taken from all the available lots of eggs or fingerlings at Nimbus Hatchery.

Mitigation

4,000,000 smolts will be reared to at least 60/lb. These fish will be transported to the Carquinez Straits - San Pablo Bay area for release May-July.

Inland Chinook

Up to 500,000 eyed eggs from the spawnings of the earliest trapped chinook, may be specified, with the approval of the Fish Health Laboratory, for use in producing fish for the Inland Chinook Program. These eggs will be transferred to the Silverado Fisheries Operations Base.

Restoration

Fingerling chinook in addition to mitigation needs may be produced and planted in appropriate tributary streams identified by Regional Fisheries Management and approved by the Chief, Central Valley Bay-Delta Branch.

Steelhead

Trapping

The ladder will be operated continuously through the fall and winter, as long as fish with viable eggs will ascend the hatchery ladder. Live steelhead that have contributed to the egg taking or fertilization will be returned to the American River. Also, steelhead that are not ready to spawn may be returned to the river alive.

Egg taking

Up to 800,000 steelhead eggs will be taken representing the full spectrum of the run. Some or all of each pooled lot of eggs will be retained according to a predetermined schedule of weekly egg taking needs.

If it becomes apparent by late January that the **Mokelumne River Hatchery** will not be able to take enough steelhead eggs to reach mitigation goals; up to 250,000 steelhead eggs may be taken at Nimbus for **transfer to Mokelumne River Hatchery**. Eggs or fingerling steelhead transferred to Mokelumne River Hatchery will be taken from all the available lots of eggs or fingerlings at Nimbus Hatchery.

Mitigation

430,000 steelhead will be reared to yearlings and released Jan-Feb in the Sacramento River below Discovery Park. All steelhead to be released will be marked with an adipose fin clip or coded-wire tag, as appropriate.

Procedures for change

Any exception to or modification to this Department of Fish and Game program shall require the joint written approval of the Regional Manager, Sacramento Valley - Central Sierra Region, and the Chief, Native Anadromous Fishes and Watershed Restoration Branch.

The goals and constraints for egg allotments, release numbers, size at release, release sites, and release timing for all species cultured at the hatchery are listed in the table below.

MOKELUMNE RIVER HATCHERY
(Operational Plans)

Production Goals and Constraints[1]

California Department of Fish and Game

East Bay Municipal Utility District

Commercial Salmon Trollers Advisory Committee

Source of Hatchery Broodstock

For all species cultured, priority for brookstock will be fish entering the hatchery volitionally. In the event fish returns to the hatchery will not provide sufficient eggs to meet mitigation and ocean enhancement goals; chinook or steelhead eggs may be taken at Feather River Hatchery or Nimbus Salmon and Steelhead Hatchery and transferred to Mokelumne River Hatchery.

Distribution of Egg Allotment

The annual egg allotment for all species cultured shall be distributed throughout the length of the spawning run in proportion to historic temporal distribution of the runs. Maintaining genetic diversity by distributing the egg allotment throughout the spawning run shall take precedence over meeting numeric production goals.

Excess Eggs and Fry

No excess eggs or fry shall be stocked in anadromous waters.

CHINOOK

Trapping

The fish ladder will be operated continuously from October 1, or earlier if salmon are observed in the river, throughout the fall and winter. Returning adult fish shall be allowed free access to the hatchery, consistent with hatchery physical constraints and water quality. In the event conditions develop a potential for unacceptable fish loss, free access may be temporarily curtailed.

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[1] These goals and constraints are designed to meet the mandated mitigation features of the hatchery, California fish and Game Commission policies, and the California Fish and Game Code.

Continued next page:
Mokelumne River Hatchery Goals & Constraints - page 2

Disposition of Trapped Salmon

All salmon adults or grilse entering the Mokelumne River Hatchery will be retained and utilized for egg taking or fertilization as stated in the section titled "Egg Taking", and the carcasses disposed of in the following manner:

1**.** The heads of all adipose clipped salmon shall be removed from the carcasses, recorded, and stored for coded-wire tag processing.

2. Carcasses shall be donated to nonprofit organizations. The hatchery manager shall have the authority to determine the allocation of the carcasses to be donated.

3. Carcasses not donated to nonprofit organizations shall be disposed of at a rendering plant or other appropriate refuse disposal site.

Egg taking

Up to 9,000,000 chinook eggs will be taken representing the full spectrum of the run. All trapped adult salmon that are alive and ripe, will contribute to the egg taking or fertilization of eggs. One half of early maturing males (jacks) trapped, up to approximately 5% of the total run, will be randomly selected and included in the egg fertilization. All trapped salmon that are alive and ripe, (including grilse), will contribute to the egg taking or fertilization of eggs. Some or all of each pooled lot of eggs will be retained according to a predetermined schedule of weekly egg taking needs.

If it becomes apparent by early November that the Mokelumne River Hatchery will not be able to take enough chinook eggs to reach production goals; up to 4,000,000 chinook eggs may be taken at Nimbus Salmon and Steelhead Hatchery and /or Feather River Hatchery for transfer to Mokelumne River Hatchery.

Priority will be given to eggs taken from salmon returning to the Mokelumne River, for mitigation yearlings, mitigation smolts, and ocean enhancement, in that order.

Production - Mitigation

3,250,000 chinook will be reared to smolt size. Up to 1,667,000 will be released in May - June into the Lower Mokelumne River near Thornton. Enough chinook smolts will be reserved to rear to yearlings, at facility capacity, up to 1,500,000, (current capacity is 500,000), and released into the Lower Mokelumne River between Woodbridge Dam and the San Joaquin River, September - November. Groups of cwt-ad marked fish may be released at other locations in the Lower Mokelumne River, or the Sacramento/San Joaquin River Delta.

Production - Ocean Enhancement (Salmon Stamp)

2,000,000 chinook will be reared to 30/lb. post-smolts and released in selected locations in the Carquinez Straits-San Pablo Bay Area, May - June.

Steelhead

Trapping

The ladder will be operated continuously through the fall and winter, as long as fish with viable eggs will ascend the hatchery ladder. Live steelhead that have contributed to the egg taking or fertilization will be returned to the Mokelumne River.

Egg taking

Up to 250,000 steelhead eggs will be taken from adults representing the full spectrum of the run. All trapped steelhead that are alive and ripe, (including half-pounders), will contribute to the egg taking or fertilization. If insufficient adult Mokelumne River steelhead are trapped to achieve production goals, eggs or fry may be obtained from American River stock or Feather River stock.

Production - Mitigation

100,000 steelhead will be reared to yearlings and released in January into the Lower Mokelumne River. All steelhead to be released will be marked with an adipose fin clip or coded-wire tag, as appropriate.

Procedures for change

Any exception to or modification to this Department of Fish and Game program shall require the joint written approval of the Regional Manager, Sacramento Valley - Central Sierra Region, and the Chief, Native Anadromous Fishes and Watershed Restoration Branch.

The goals and constraints for egg allotments, release numbers, size at release, release sites, and release timing for all species cultured at the hatchery are listed in the table below.

GOALS AND CONSTRAINTS
(Operational Plans)

For the

SALMON AND STEELHEAD HATCHERIES

Operated by the

CALIFORNIA DEPARTMENT OF FISH AND GAME

SACRAMENTO VALLEY - CENTRAL SIERRA REGION

Feather River Hatchery

California Department of Fish and Game
California Department of Water Resources
Salmon Stamp Advisory Committee

Nimbus Salmon and Steelhead Hatchery

California Department of Fish and Game
U. S. Bureau of Reclamation

Mokelumne River Hatchery

California Department of Fish and Game
East Bay Municipal Utility District
Salmon Stamp Advisory Committee

Approved:_____ Date:____ Banky E. Curtis, Regional Manager
Sacramento Valley - Central Sierra Region

Approved:_____ Date:____ Perry Herrgesell, Chief,
Central Valley Bay-Delta Branch

ATTACHMENT 4

F9 – IHNV REPORT

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Davis, CA 95616
October 27, 2004

Executive Summary

A series of studies were conducted to examine the potential impacts and management of infectious hematopoietic necrosis virus (IHNV) as it occurs in salmon and trout in watersheds of northern and central California. Genotyping of 222 IHNV isolates from hatchery and wild salmonids demonstrated two major lineages of virus - one from coastal locations and the other from inland waters. A total of 23 unique sequence types of viruses were identified of which 8 (genogroups) represented the majority of viruses encountered. The genotyping database was used to demonstrate unique virus evolution patterns in the Feather River system, including the origin of successively different serotypes of the virus that have contributed to virus epidemics at the hatchery. Genotype data also suggested one potential reservoir for the virus in the system: that being Chinook salmon and or rainbow trout from Lake Oroville as isolates obtained from these in 2000 matched identically those found in the hatchery epidemic that year. Genotyping data also implicated movements of Chinook salmon for as a source for the virus appearing in a second anadromous fish hatchery (Mokelumne) and excluded the potential that the virus involved could have originated from farm-reared rainbow trout also planted in the lake above the Mokelmune River hatchery.

Laboratory challenge studies were conducted on viruses representing 6 of the 8 genogroups and 2 additional unique sequence types to evaluate their virulence (ability to induce mortality) for Chinook salmon and rainbow trout fry. All 8 viruses induced significant mortality among both salmonid species, with most isolates demonstrating equal virulence for Chinook salmon and rainbow trout. Three viruses were more virulent for Chinook salmon than for rainbow trout. Only one IHNV isolate originating from Chinook salmon at the Merced Hatchery in 1988 was more virulent for rainbow trout than for Chinook salmon.

Additional laboratory trials examined the effects of fish size and virus dose on severity of IHNV infection in Chinook salmon and the potential to infect rainbow trout cohabited with infected Chinook salmon. Transmission of IHNV was demonstrated with Chinook salmon fingerlings (4 g) by a single high dose bath exposure of 10^4 plague forming units (pfu) per ml of water (pfu is an indirect measure of virus particle numbers). Although these fish did not undergo

mortality, virus was found in high concentrations up to 10^6 pfu per gram in the gill, skin and internal tissues for up to 22 days post virus exposure. Repeated low doses of 10^2 or 10^3 pfu per ml of IHNV by bath exposures of smaller Chinook salmon (0.4 g) also did not result in mortality but transmitted the virus which was detected in the gill tissues up to 23 or 39 days post virus exposure.

Experimental waterborne exposures of adult Chinook salmon demonstrated their susceptibility to IHNV infections. Concentrations of virus in adult fish tissues exceeded 10^8 pfu per ml of ovarian fluid. Also most internal organs were shown to be infected with virus concentrations in excess of 10^5 pfu per gram of tissue. Subsequent adult salmon studies suggest that susceptibility, as measured by the ability to induce productive virus infections, occurs only during the last phases of life (2 – 3 weeks). These transmission trials confirm that most IHNV infections in Chinook salmon are not characterized by high mortality.

Factors such as high host densities must contribute to the epidemic mortality observed in hatchery outbreaks. Other environmental factors or stressors encountered by outmigrant Chinook salmon may be sufficient to cause young salmon to undergo virus-induced mortality but this is difficult to assess. In the laboratory, IHNV was not easily transmitted from infected Chinook salmon to cohabitant rainbow trout and similar results have been obtained in trials with Chinook to Chinook salmon fry by others. These results suggest that fish harboring IHNV infections as outmigrant juveniles, particularly when they are not clinically ill, may not represent a major source of virus that would infect other salmonids they might encounter in the river (e.g. resident salmonids such as steelhead or rainbow trout).

Infections among adult Chinook salmon in the hatchery or that spawn in the river may represent the major virus source in the system. Virus concentrations amplified in adult salmon may then serve as a source to infect a reservoir (e.g. resident salmonids) in the river system or other migrating adult salmon when such runs overlap (e.g. fall and late fall). That adult Chinook salmon might move viruses between watersheds is less likely than previously supposed if the window of susceptibility to IHNV infection is indeed narrowed to the last weeks of life of the fish.

Future Research

As expected, the research conducted in this study prompted additional research questions of concern to management of IHNV in the Feather River system. Perhaps the most important and liable to be of concern are those surrounding the potential movement of adult salmon to access spawning habitat above the hatchery. Determining the reservoirs of infection so that decisions on when and where adult salmon and steelhead become infected will be critical. This would include investigations both above and below Lake Oroville, the former of

importance to know even if uninfected adults could be successfully moved above.

Purpose of the Study

The purpose of this study is to assist the Department of Water Resources, Ecological Studies Program (DWR ESP) to better understand the recurrence of serious outbreaks of infectious hematopoietic necrosis (IHN) due to the rhabdovirus IHNV among Chinook salmon at the Feather River Hatchery. The principal objectives of the study were to determine the different strains or genotypes of the virus as found in California watersheds, including the Feather River, to determine if there were correlatives between the genotype, serotype and virulence of the virus for Chinook salmon and rainbow trout, to examine potential transmission of the virus to sexually mature adult Chinook salmon, and to investigate the potential for infected Chinook salmon from the hatchery to transmit the virus to resident or wild outmigrant salmon. The objectives were pursued by a combination of laboratory and field studies with assistance from both U.S. Fish and Wildlife Service and California Department of Fish and Game fish health specialists. This is the final report for this project.

Background

Infectious hematopoietic necrosis (IHN) due to the rhabdovirus IHNV is considered the most significant viral pathogen of salmonid fish in North America (Wolf 1988). The virus has spread from it origins in western regions of North America to Japan, Korea, China, Taiwan and continental Europe most likely through the shipment of salmon eggs that were not or improperly disinfected. Phylogeographic studies that have compared a short (303 nucleotide region) variable region of the glycoprotein gene of IHNV isolates from North American demonstrate the isolates are separable into 3 major groups or clades designated as U for upper, M for middle and L for lower to describe their relative geographic distribution (Kurath et al. 2003). U clade isolates are found in Oregon, Washington, Idaho and Alaska and British Columbia Canada. M clade represents viruses encountered in southern Idaho in the principal rainbow trout hatchery production areas. Lastly, the L clade represents a group of viruses found on the southern Oregon coast and the coastal and inland waters of northern California. The biological properties of viruses in each of the 3 clades demonstrate key differences, perhaps the most important being the host preferences for the viruses with U clade predominantly in sockeye (*Oncoryhnchus nerka*), the M clade in rainbow trout (*O. mykiss*) and the L clade in Chinook salmon (*O. tshawytscha*), although viruses in each clade are known to cross to other species within their geographic range (Kurath et al. 2003).

The historic origins of IHNV in California are unknown but mortality among Chinook salmon in hatcheries in the upper Sacramento River as early as 1941

were most likely due to the virus. The association between the disease and the virus was firmly established in 1957 (Ross et al. 1960). Since that time there have been periodic epidemics due to IHNV in California and in particular among Chinook salmon at the Feather River Hatchery and the Coleman National Fish Hatchery (CNFH). The outbreaks at the Feather River Hatchery (FHR) have emphasized the need for more adequate disease management..

Outbreaks in the FRH can be cited (whether proven or not) as major point sources for virus amplification in river systems that may subsequently negatively influence the health of released fish and resident trout populations.. The virus is also found in the Trinity, American and San Joaquin river systems in Chinook salmon and or steelhead trout with periodic outbreaks of IHN experienced in hatcheries on those streams.. Due to the widespread occurrence of the disease, information that may lead to improved control of IHNV is needed.

Identification of strain types of IHNV by molecular methods has proven to be an extremely useful management tool for control of IHNV in the Columbia River drainage and studies in river basins in California should have similar rewards. Detection and then strain typing of IHNV can be used to establish the prevalence, distribution and potential movements of virus within a basin. Furthermore, correlations between strain types and virulence of the virus for different salmonid hosts provides a quantitative risk evaluation of management procedures that might increase or decrease contact between the virus and potential salmonid hosts.

Establishing an initial baseline or profile for each affected basin is a first priority. In this report I, we describe the results of research that begins to establish this baseline. The strain typing is integrated with laboratory and field studies that aid in assessing the impacts of the virus on the salmonid hosts in a given system. While other disease agents are bound to be of importance in the river basins mentioned (e.g. *Ceratomyxa shasta*), IHNV and the current problems it poses to evaluations of hatchery impacts on aquatic ecosystems is a logical first candidate for study.

Tasks

Task 1: Strain Typing Baseline

Task 1a & 1b – UC Davis

Virus Isolates. A total of 222 IHNV isolates were obtained from hatchery-reared or wild Chinook salmon, steelhead and rainbow trout. The studies of Nichol et al. (1995) demonstrated that a variable portion of the glycoprotein or G-gene, one of five genes coded by the viral genome, had potential diagnostic significance. The G-gene of IHNV is a critical molecule on the surface of the virus controlling virus attachment and penetration of the host cell. The G-gene is also the principal viral

protein recognized by the fish immune response and antibodies produced to the protein are responsible for neutralization and immunity in salmonid fish (LaPatra et al. 1998). Sequencing of a 303 nucleotide region of the G-gene (mid-G) allowed us to type 71 isolates obtained from the Feather River Hatchery over the last 35 years. In addition, sequence typing was performed on 128 isolates obtained from the Yuba River, Coleman National Fish Hatchery, Battle Creek, Clear Creek, Trinity River Hatchery, Hoopa Fish Rearing Facility, Lake Oroville, Nimbus Hatchery, Merced River Hatchery, Mokelumne River Hatchery, Mad River Hatchery, Rowdy Creek Fish Hatchery, and the Klamath River. Isolates were also obtained from three Oregon locations - Elk River Hatchery, Sixes River, and the Rouge River. The results are presented with respect to the overall IHNV picture which included all of the 222 (199 new sequences and 23 previously published) isolates and a second analysis that included just those isolates from the Feather River system.

Mid-G sequence and phylogenetic analyses of all IHNV isolates. A listing of all of the 222 isolates and their genotypes and assignments to sequence groups is shown in Appendix 1. Identical isolates were grouped together (genogroups) and designated as major sequence types that are identified by the location and letters (e.g. A - J), the sample size (n), and year collected. Isolates identified by 'u' represent sequence types that are currently regarded as unique or the only isolate of this sequence type (n = 1). In addition, unique sequence types shown in the tree (Figure 1) are characterized by abbreviating the location and the species infected. Letters (a, b, c, etc.) following the sample size indicate unique sequence types found in the same location and host that are separated temporally.

Analyses of California Isolates. The sequence analyses showed a total of 23 different types that included 13 unique and 10 sequence types (A – J) that contained two or more identical isolates. There was no demonstration of a strict host specificity for any of the IHNV genogroups observed in this study but the majority of the isolates were obtained from spawning Chinook salmon (76%) and a smaller percentage were found among fry or fingerlings during epidemics (5%).

Phylogenetic analyses were conducted and trees created to visualize the relationships among the different IHNV sequence types. The trees were created by rooting with isolates from the U and M clades, and by retaining bootstrap group frequencies of >70% and >50% (Figures 1 and 2, respectively). The bootstrap values are an indication of the strength of a given branch, with the higher values indicating that the separations created by the branch do indeed indicate the two branches represent different groups of viruses. When we consider that the branch strength must be at least 70% the tree is more collapsed and shows fewer branches than at 50% (Figure 1). When this is done the L clade, the IHNV types known to be dominant in California, is divided into 2 larger groups designated lineage I and lineage II. Sequence types inside lineage I and II were present as single branches linked directly to the ancestral node for each

lineage, and bootstrap-supported by values of 84% and 83%, respectively. Lineage I contained 5 unique sequence types and 1 major sequence group identified as Type A. Lineage II contained 8 unique sequence types and 9 major sequence groups identified as Types B thru J. Interestingly, lineage I and II are dominated by coastal and inland isolates, respectively. When nodes were retained at >50% (Figure 2) the topology of the phylogram (tree) implied a trend toward greater divergence from the distant uER-n1 sequence type to more recent types (F thru J) found near the crown of the tree. This would suggest that the ancestral virus was of coastal origin (like the Elk River, OR) but then evolved into isolates that now are quite different but are dominant in inland waters, including the Sacramento system.

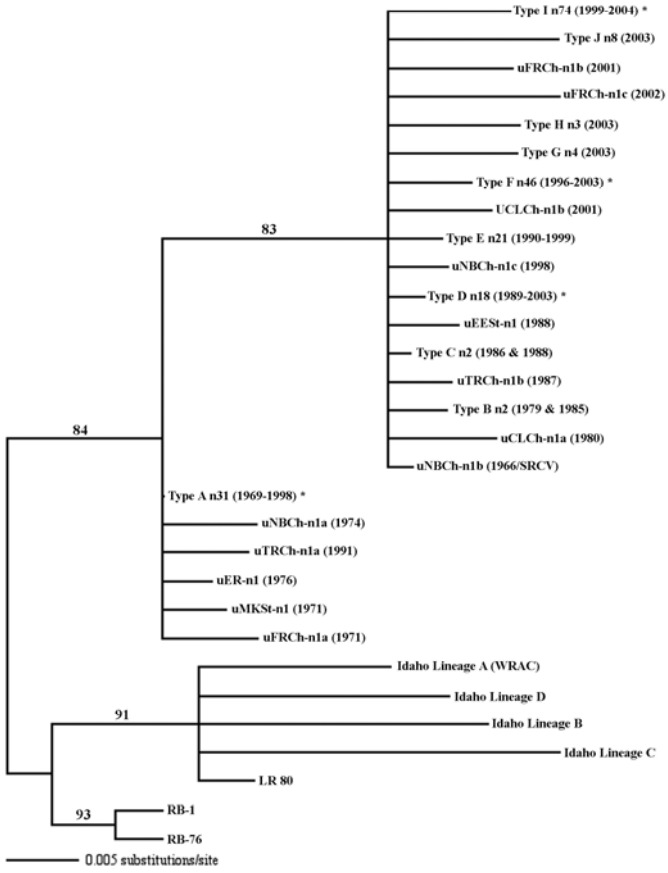


Figure 1. A rooted phylogenetic tree constructed using the mid-G gene sequence (303 nt) of infectious hematopoietic necrosis virus (IHNV) isolates from California (L Clade) and their relationships to IHNV isolates in the M and U Clades. The L Clade is composed of two lineages (I and II) representing isolates

from the central valley or those predominantly originating from coastal rivers. Branches retained at bootstrap group frequencies >70%. The names representing U and M Clades as previously described by Nichol et al. (1995), Troyer et al. (2000), Kurath et al. (2003) were retained. The U and M Clades were used as outgroups to root the phylogram. Individual isolates within each sequence type of the L Clade may be found in Appendix 1. Asterisks represent groups containing isolates associated with juvenile mortality.

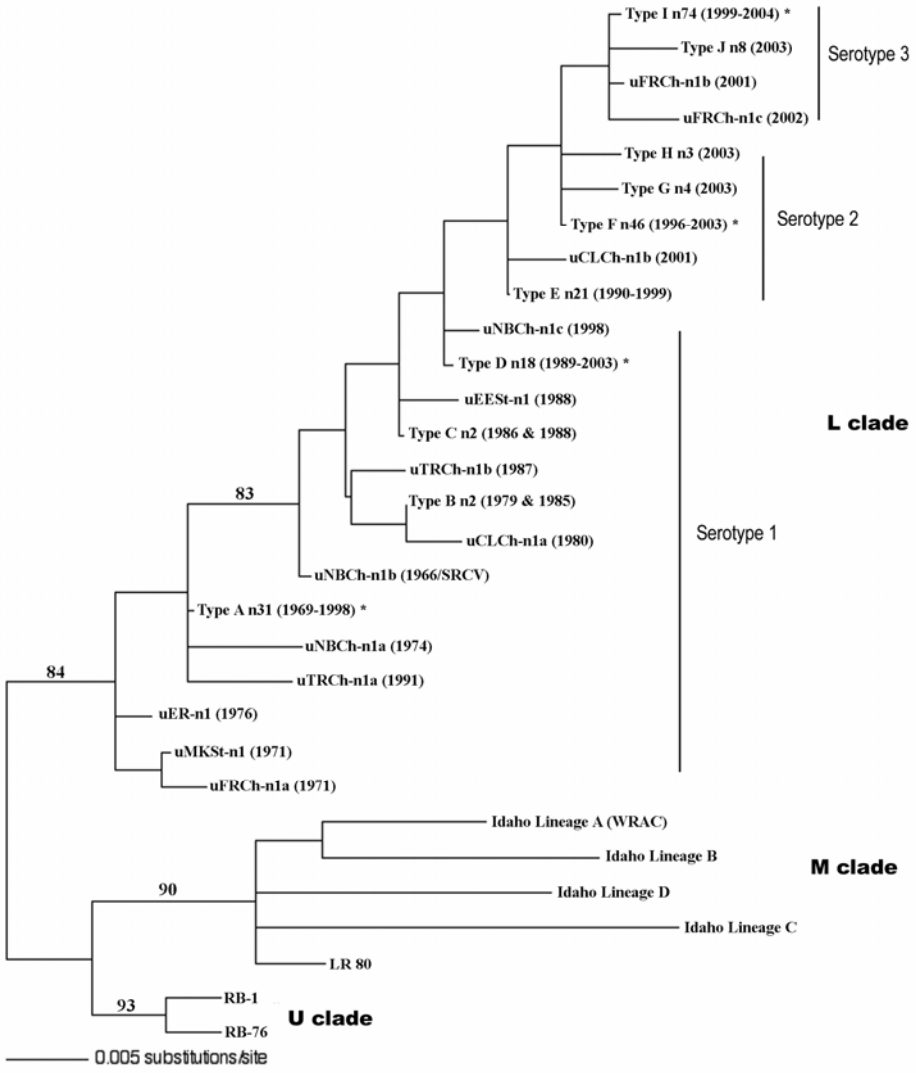


Figure 2. A rooted phylogenetic tree constructed to represent relationships among infectious hematopoietic necrosis virus (IHNV) from California (L Clade) with representative isolates from the M and U clades. Tree branches are retained at bootstrap group frequencies >50% and provide a greater tree

topology that suggests a trend of temporal divergence of IHNV isolates in the L Clade. Names for major sequence types A thru J and unique sequences are shown at terminal nodes. Asterisks indicate IHNV isolates associated with juvenile mortality. The bold vertical lines represent the serogroup distinctions found among the L Clade.

Phenetic comparisons of California IHNV isolates. A phenetic comparison of the 23 sequence types found an overall maximum pairwise nucleotide diversity of 4.0% (12 nucleotides different out of 303). This amount of diversity is similar to that of 3.5% observed by Kurath et al. (2003) with 23 isolates from the L Clade (California isolates). Kurath et al. (2003) also reported the presence of two subclades or lineages which our studies confirm with a much larger number of isolates. Thus the L Clade represents a group of viruses quite different from those found to the north and appears to have evolved independently from members of the U or M Clades. That salmonid migrations differ between populations to the north (the Cape Blanco effect) has been one suggestion for the lack of mixing of viruses in the U and M with those from salmonids in the south that harbor L clade viruses (Kurath et al. 2003).

An examination of the lineages within the L Clade indicates that most isolates in one lineage are from inland waters (Lineage II), while the second lineage (I) represents isolates from coastal salmonid populations. A different pattern of virus mutation was observed between these two L Clade lineages of IHNV. Among the inland isolates, the intra-population nucleotide diversity (π), a measure of the diversity among viruses in this group, was 0.017 ± 0.0001 (π ± standard deviation) and the ratio of nonsynonymous (would change the amino acid in the protein) to synonymous (no change in amino acid coding) mutations was 0.3461. This produced a rate of divergence of 0.7×10^{-3} mutations per nucleotide site per year (Figure 3) and a trend line with a positive slope significantly separated from zero ($P < 0.0001$). The positive slope demonstrates a correlation ($r^2 = 0.69$) between year of isolation and the number of mutations which have accumulated within each sequence type. This suggests an L clade mutation rate greater than that observed for U Clade viruses but less than that for M Clade viruses (Kurath et al. 2003).

In contrast to the inland isolates, the coastal isolates from California had a nucleotide diversity of 0.014 ± 0.0001 and a rate of divergence of -0.2×10^{-3} with a trend line not different than zero. Also, there was no correlation ($r^2 = 0.04$) with year of isolation and mutation rate for the coastal isolates (Figure 4). These data suggest that factors within inland waters create a selection pressure that has increased the mutation rate and in a particular direction with previous year isolates giving rise to viruses observed in subsequent years. This contrasts with U Clade viruses where there is no indication that viruses are changing over time (Kurath et al. 2003). Kurath et al. (2003) have suggested that viruses in the U Clade may have reached a level of fitness in balance with their environment and thus they are less susceptible to selection and mutational change.

In contrast, viruses in the L Clade (California) appear to be in a more dynamic mode of evolution, responding to a mild to moderate selection pressure. The factors driving this selection are uncertain. Possible explanations include reservoirs for the virus that harbor isolates that contribute to successive years of infections in returning anadromous salmonids. This could be resident populations of salmonids either above or below hatchery or nonhatchery runs of Chinook salmon. Viruses amplifying with the seasonal increases in susceptible fish biomass (e.g. Chinook adults) might then dominate in the system for that year and in the case of downstream reservoirs serve to expose populations of reservoir hosts potentially infecting those with no or insufficient immunity. In the case of Feather River, the potential reservoirs might exist both above (historically planted inland Chinook or rainbow in or above the lake) or below (steelhead or rainbow trout) the hatchery. A second potential reservoir would be sufficient overlap of Chinook salmon adults of different runs such that the virus is maintained in adult Chinook salmon.

Figure 3. Year of isolation of inland isolates (lineage II) of infectious hematopoietic necrosis virus (IHNV) plotted against the genetic difference (mutation/nucleotide) from the ancestral node of the genogroup.

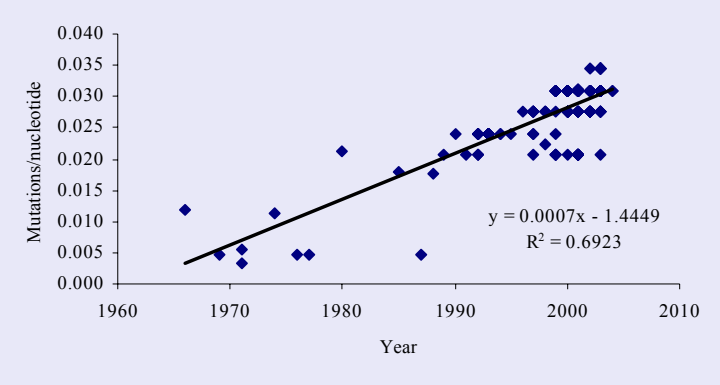
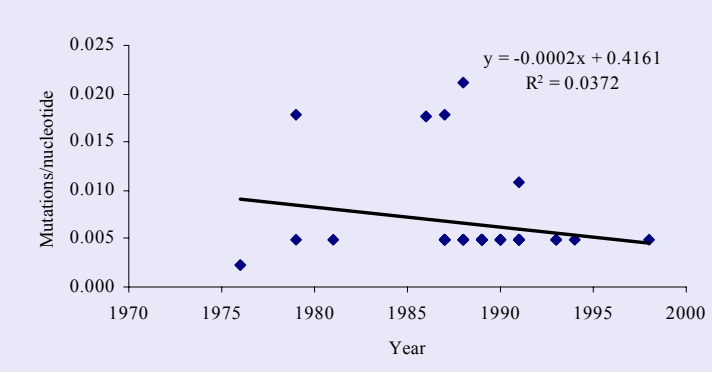


Figure 4. Year of isolation of coastal isolates (lineage I) of infectious hematopoietic necrosis virus (IHNV) plotted against the genetic difference (mutation/nucleotide) from the ancestral node of the genogroup.



Serum Neutralization Characteristics of California Isolates. Serum neutralization, is a technique that employs rabbit antibodies made to specific virus types, which then allows us to distinguish those virus types (serotypes) from other types. The technique starts with production of rabbit antibodies prepared by injecting rabbits with purified virus of a specific strain of IHNV. The immune response of the rabbit is quite finely tuned (just like in humans) and can distinguish quite small changes in proteins it recognizes as foreign (in this case a viral protein). The antibodies made by the rabbit when mixed with the virus to which they are made prevent the virus from replicating in cell culture and thus we refer to this as "neutralization". A single amino acid change in a viral protein may be sufficient to cause a virus to no longer be neutralized and thus the neutralization test is an excellent method to compare small changes occurring in viruses.

Changes in the G gene (glycoprotein) of IHNV (the gene for which we are sequencing for genetic analyses) are responsible for changes in the ability to neutralize the virus (Roberti et al. 1998). Serum neutralization analyses were conducted on nearly all of the IHNV isolates in our study and it demonstrated they fall into three groups (serotypes 1, 2, or 3). The pattern of emergence of these different serotypes of IHNV in California corresponded to sequence divergence as seen phylogenetically in the mid-G gene (Figure 2). Serotype 1 antibodies neutralized 55 isolates within 12 sequence types beginning with uER-n1 (1976) thru uNBCh-n1c (1998). Serotype 2 antibodies effectively neutralized 72 isolates that included uCLCh-n1b (2001), and California Types E (1990-1999), F (1996-2003), G (2003), and H (2003). Interestingly, isolates neutralized by serotype 2 antibodies possess a lysine (K) residue at position 252 in the mid-G gene. In contrast, viral isolates neutralized by serotype 1 antibodies contained glutamic acid (E) at the same position (data not shown). Finally, serotype 3 antibodies neutralized the remaining 64 isolates that included type uFRCh-n1b (2001), uFRCh-n1c and California Types I (1999-2004) and J (2003). Isolates grouped as serotype 3 contained a conserved E residue at position 282 while all other isolates had a K residue at this position (data not shown). Amino acid changes in this region of the protein have been shown to be important in neutralization of IHNV by the mapping studies of Huang et al. (1996).

The changes in amino acids at 252 and 282 would significantly affect the epitopes (antibody binding sites) in this region and thus are viewed as the mostly likely basis of the emergence of the different serotypes in the Feather River system. What factors or pressures are forcing this virus evolution are not clear but changes in neutralization suggest that pressures exerted by the immune response of either the Chinook salmon or perhaps a resident salmonid population may be involved in virus selection (Huang et al. 1996).

IHNV in the Feather River System

Genotypes. The mid-G gene sequences of 79 new IHNV isolates from Feather River and Lake Oroville were obtained and they were combined with 9 previously recognized isolates (Kurath et al. 2003) for analysis as a separate group (Appendix 2). The phylogenetic analyses revealed the presence of 9 unique sequence types. Of the 9 sequence types (genogroups) characterized in this study, 5 were identical to those previously described from California by Kurath et al. (2003). Three of the 4 genogroups not previously described were identified as unique sequences while the fourth sequence type or genogroup J represented the more recent isolates of IHNV from 2003. The isolates obtained were primarily from hatchery fish but included some naturally spawning fish and most isolates were from ovarian fluid of adult female Chinook salmon (Appendix 2). Some isolates were from kidney and spleen of sexually mature adult males or kidney, spleen, viscera or whole body from Chinook salmon less than one year of age. IHNV was also isolated on a few occasions from rainbow and steelhead trout.

All of the recent (1990-2003) Feather River and Lake Oroville isolates clustered within lineage II (inland) in the L clade. In the phylogenetic analyses of the Feather River isolates there was a trend toward greater divergence with time, i.e. older isolates in general tended to be positioned closer to the ancestral root of the Feather River watershed, while newer isolates tended to be located toward the tips of the tree (Figure 2). The maximum pairwise nucleotide diversity for the Feather River/Lake Oroville isolates was 3% (10 nt out of 303 nt) with a mean nucleotide diversity of 4.8±1.4. The intrapopulational nucleotide diversity (π) was 0.016 ± 0.00002 and the ratio of synonymous to nonsynonymous mutations was 0.4.

We estimated a rate of evolution for the mid-G sequence region of all Feather River IHNV isolates by plotting their genetic distance from the phylogenetically inferred ancestor of the L clade versus the year of virus isolation (Figure 5). The rate observed was 0.89×10^{-3} mutations per nucleotide site per year. This rate is in the middle of the range of evolutionary rates assumed for other RNA viruses (Domingo et al. 2001, Jenkins et al. 2002). The positive slope of the line is significantly different from zero ($p<0.001$) depicting a positive correlation between year of isolation and the number of mutations which have accumulated in each sequence type or isolate ($r^2 = 0.92$).

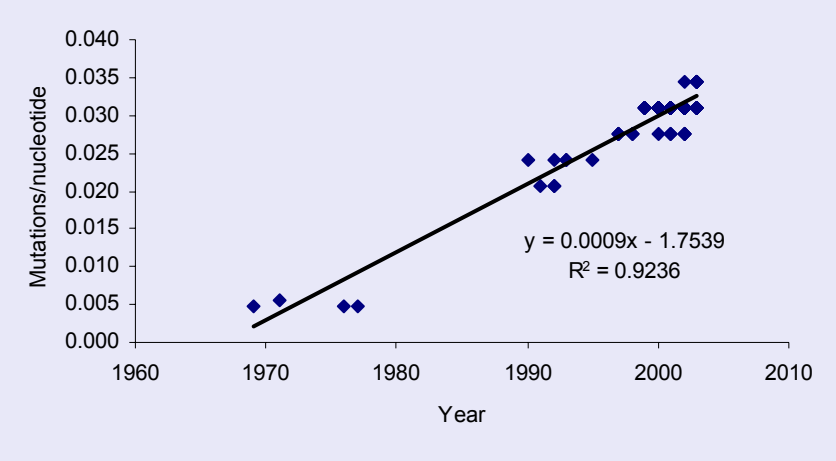


Figure 5. Year of isolation of isolates of infectious hematopoietic necrosis virus (IHNV) from the Feather River system plotted against the genetic difference (mutation/nucleotide) from the ancestral node of the genogroup.

Alignment of all Feather River watershed IHNV mid-G sequence types indicated that nucleotide substitutions were present throughout the mid-G region but that several hotspots existed. Those nucleotide positions in which greater than one-third of the sequence types contained a mutation included positions 722, 800, 851, and 890. The ratio of nonsynonymous mutations to synonymous mutations for all characterized IHNV in the Feather River watershed was examined to determine the extent of positive selection acting on the mid-G region of IHNV. A ratio of 0.4 was calculated, indicating an overall excess of synonymous mutation and thus a lack of evidence of positive selection (Nei & Gojobori 1986, Hughes & Hughes 1995, Seibert et al. 1995). However, specific codons may in fact be under positive selection despite an overall excess of synonymous mutations for the entire region.

Alignment of the amino acid sequences of all isolates in this study showed several hotspots for nonsynonymous mutation. In particular, glycoprotein amino acids 252, 269, and 282 for which greater than one-third of the sequence types contained a nonsynonymous mutation. The significance of these amino acid sites were discussed above. This may indicate that regions of the glycoprotein, which is known to be critical in host cell recognition and virus neutralization, are more apt to mutate, perhaps in response to antibodies or other immune factors encountered in their salmonid hosts. It would be of interest to determine if this differs between viruses that are predominantly maintained in Chinook salmon populations compared to those in rainbow or steelhead trout. This might assist in determining whether resident rainbow trout do play a role in maintaining the virus in watersheds intermittently inhabited by Chinook salmon.

Temporal distribution of IHNV Feather River isolates. The temporal distribution of the 79 IHNV isolates in this study and those of Kurath et al. (2003)

showed several gaps in the data, with no isolates in 1970, 1972 to 1975, 1978 to 1989, 1994, or in 1996. We chose to divide the isolates into 2 temporal groups (1969-1977, and 1990-2003) for the purpose of examining changes in the IHNV subclade distribution over time. The two earliest isolates analyzed, lot 118 and lot 121, differed by 3 nucleotides (1.0%). The 1976 (lot 129) and 1977 (lot 131) isolates were identical to the earliest isolate (lot 118). The four isolates from the early emergence of the virus within the watershed represented 2 different sequence types, one unique and the other type A (Appendix 2). Sequence type A disappeared in the proceeding years being replaced by a succession of 5 other types and two additional unique sequences. Presumably each new virus was more successful and out competed the earlier isolates. Sequence type D was isolated from 1991 to 1992, type E from 1990 to 1995, type F from 1997 to 2002, type I from 1999 to 2003 and type J from 2003. The unique sequence CDFG 01-8-19 and CDFG 02-13-1 were isolated in 2001 and 2002, respectively.

Plotting sequence type to date of isolation (as above but graph not shown) provided a line with positive slope for the Feather River from 1990 to 2003 which was significantly different from zero ($p<0.0001$) and serves to illustrate a general association between year of isolation and the number of mutations which have accumulated in each sequence ($r^2 = 0.72$). The positive slope prior to 1978 was not significantly different from zero ($p=0.61$) revealing no association between year of isolation and the number of mutations which have accumulated in each sequence ($r^2 = 0.15$). We are investigating whether there may be a logistical (?) explanation for why virus evolution became more directed after 1990 compared to before that date or whether this represents a sample size phenomenon since fewer isolates were available in the earlier dates.

Significance of Feather River IHNV Analyses. The results suggest that viruses present in the Feather River system are evolving in a somewhat linear fashion (at least since 1990) in response to some unknown factor(s). Thus the Feather River system appears not to be affected by incursions of new strains of the virus in a haphazard or random fashion nor is it in a stable mode as found for the U Clade viruses in the Pacific Northwest (Kurath et al. 2003). Thus, straying of fish with other sequence types from other parts of the Sacramento River drainage are not likely involved in the virus types encountered in the Feather River system. This suggests that a reservoir of the virus resides in this system that allows for this linear evolutionary pattern. One possible reservoir would be resident steelhead/rainbow trout that would encounter large amounts of virus each year in response to an ever building virus release from spawning Chinook salmon in the upper reaches of the river or as released from broodstock holding ponds from the hatchery. Although other suspected reservoirs have been pursued (e.g. leeches, insects, etc) none of these or the stability of the virus in sediments, seems able to explain the carry over of virus to each new year of adult salmon.

That once infected, adult salmon populations could become a major source of amplification of the virus in the environment, is shown later in this report on the susceptibility of adult Chinook salmon to waterborne exposures to IHNV. That study confirmed a prior hypothesis that the increasing prevalence of virus in adult salmon as the run progresses is a direct result of adult to adult transmission of the virus. While the involvement of resident rainbow trout in the life cycle of IHNV is an attractive theory, the means by which the virus would be transmitted to the adult Chinook salmon is less clear as presumably the peak releases from rainbow or steelhead trout would be at the time of spawning. Additional studies that characterize the potential release of virus from healthy appearing Chinook salmon and rainbow trout juveniles are needed.

We demonstrate with studies in this report that juvenile Chinook salmon can contract IHNV infections and show no signs of infection yet can harbor the virus for periods up to 39 days. Whether rainbow trout are capable of a similar virus-host relationship with viruses of the L clade (California types) has not been examined in detail. In general rainbow trout appear more resistant to viruses in the L compared to the U or M clades, the potential for cryptic infections, as seen in juvenile Chinook salmon in our studies should be investigated with rainbow trout. If such infections do occur, this might represent a reservoir for IHNV in the Feather River system.

Effects of Planting Juvenile Chinook salmon in Lake Oroville. Planting large numbers of Chinook salmon susceptible to IHNV in the lake (inland Chinook salmon recreational fishery program) has been cited as a possible reason for recent IHNV outbreaks in the Feather River Hatchery. Plants of Chinook salmon in the lake began in 1976 but the largest plants began in 1996 with yearly numbers increasing up to over 400,000 juveniles in 1998 and 1999 the last two years of stocking in the lake. That Chinook salmon in the lake may have contributed to epidemics of IHNV in the hatchery below are in part supported by the absence of epidemics since the planting program was discontinued in 2000. Epidemics among Chinook salmon at the Feather River Hatchery occurred in 1998, 2000 and 2001. Curiously there was no outbreak in 1999 - the year after the lake was stocked with Chinook salmon originating from Iron Gate Hatchery, a hatchery with no history of IHNV. In all other years the source of the fish was the Feather River Hatchery. This suggests somewhat indirectly that planting of fish free of IHNV does not allow for sufficient virus build up to infect fish in the hatchery in the subsequent year (must consider that we only have a n = 1). It also may suggest that “silent” infections in the juveniles (which we demonstrate occur later in this report) planted from Feather River Hatchery is a key source of virus that then shows up in the hatchery, rather than planted fish acting as a large IHNV susceptible population that could become infected.

An analysis of 8 IHNV isolates obtained from Chinook salmon and rainbow trout in the lake in 2000 showed all viruses matched identically the virus causing the

epidemic in the hatchery that same year (Appendix 2). Currently, sufficient time has passed for all of the Chinook salmon stocked into the lake to have died and thus this source of the virus should now be gone. Correspondingly, no new IHNV outbreaks have occurred at the hatchery.

We suspect the virus is still resident in waters above the lake but that the population of susceptible salmon that were needed to amplify the virus to sufficient levels to transmit to fish in the hatchery is no longer present. It is unknown whether the virus could be resident in rainbow trout, the same question we have for a potential reservoir for the virus below the dam. If the rainbow trout are functioning in this capacity, the re-introduction of large numbers of IHNV susceptible Chinook salmon (or other IHNV susceptible species e.g. kokanee) could serve to amplify IHNV concentrations in the lake sufficient to re-initiate IHNV outbreaks in the hatchery. Water treatments could significantly reduce but not eliminate this risk of outbreaks of IHNV if planting into the lake or moving of IHNV susceptible salmonids above the lake was resumed.

Conclusions

These studies are the first comprehensive analyses of IHNV in California, the southern most reach of the distribution of this rhabdoviral pathogen of salmonids. Our studies reveal that the virus has adapted particularly well to the inland water environments in California while much less so to coastal stream systems. This is shown by the failure of coastal types (Lineage I) to persist once introduced into inland waters (e.g. historic exchanges of infected fish between Mad River and Coleman NFH) and the infrequent occurrence of IHNV in the more coastal hatcheries.

The means by which IHNV survives and persists in the major Central Valley river systems is unknown and the presence of some reservoir of infection (resident salmonids) is suspected but unproven. The overlapping runs of adult Chinook salmon do provide a large susceptible population in which the virus is able to amplify each year and adult to adult transmission (even between runs) has been demonstrated (fall to late fall) or is suspected. The sequence type database provides a context to evaluate the type of IHNV that may be encountered in the future. The epidemiological information that can be obtained from the database has provided information of direct use to fisheries managers. This includes strong evidence that the types of IHNV found in hatchery outbreaks in the Feather River did originate above the hatchery and were associated with the presence of large numbers of Chinook salmon in the lake. Outbreaks of IHNV in juvenile Chinook salmon at the Mokelumne Hatchery were also most likely due to planting Chinook salmon from Feather River Hatchery into a reservoir above the hatchery rather than from farmed rainbow trout from a basin where the virus types would differ from that seen at Mokelumne Hatchery. There was no evidence to suggest the farmed trout were a source of IHNV as the farm has

historically been free of the virus but the strain typing data helped to eliminate this possibility.

Analyses of Feather River IHNV isolates also suggest that adults straying into one drainage, picking up a different IHNV strain and then moving this strain back to their natal drainage is not a frequent occurrence or likely sufficient to cause establishment of new strains in the system. The study (described later in this report) on infections of adult salmon susceptibility to IHNV may in part reveal why this is not a frequent event. In those studies, adult Chinook salmon poorly supported IHNV replication until they approached spawning. Therefore, most adult salmon are presumably infected only during the very last phases of their life, thus precluding contracting and moving viruses easily between watersheds.

Task 2: Laboratory and Field Studies

Task 2a. Adult Chinook Salmon IHNV Susceptibility – UC Davis

Adult Chinook salmon. Adult female winter-run Chinook salmon were obtained by permit as excess animals to the Winter Run Chinook Salmon Broodstock Program at the UCD Bodega Marine Laboratory. These adults were progeny of other captively reared adults that were not suitable for supplementation and thus could be used as experimental fish. As the fish began final maturation they were transferred to fresh water (12 ^{o}C) and monitored daily. In the first trial all adults were within 14 days of spawning and all fish died during the course of the study due to senility. In a series of later trials female salmon were obtained and groups (n = 10) exposed to virus at different time points prior to spawning. These later trials provided the first indications infections with IHNV are more apt to be supported in fish as they approach spawning.

Virus exposures. Adult Chinook salmon were exposed to IHNV (sequence type I) at the concentrations indicated by addition of virus to the tank water. All fish that died or were severely moribund were sampled for virus as present in various fluids and tissues. The quantity of virus in these tissues was estimated by plaque titration and concentrations of virus are expressed as plaque forming units (pfu) per ml of fluid or gram (g) of tissue.

Results

Sexually mature female winter-run Chinook salmon brood year 1998 – 1999 reared in captivity and with no prior history of exposures to infectious hematopoietic necrosis virus (IHNV) were susceptible to experimental infections induced by additions of virus to the water (Table 1). The resulting infections resembled those observed among naturally infected hatchery and wild populations of Chinook salmon. At water temperatures of 12^{o}C, virus was detected as early as 4 d post exposure and subsequently in all virus-exposed fish

that died or that were examined at 14 d when the study was terminated. The greatest concentrations of virus, up to 10^8 plaque forming units (pfu) ml^{-1}, were found in the ovarian fluid at 13 to 14 d post virus exposure but virus was also found in high concentrations in the gill, kidney/spleen and plasma. In contrast, virus was not recovered from unexposed control adult salmon that died or were sampled at the end of the study.

Despite detecting concentrations of IHNV in excess of 10^7 pfu g^{-1} of tissue, there were no specific microscopic lesions found in IHNV-exposed compared to control unexposed salmon. These initial studies suggest that virus found in the spawning environment, either from adult salmon or other sources, may contribute to a rapid spread of the virus among adult Chinook salmon, thereby considerably increasing the prevalence of IHNV infection as detected in wild and hatchery populations of adult Chinook salmon. Additional trials with less mature adult Chinook salmon demonstrated that fish do not become susceptible to IHNV infection until they approach the time of spawning (within approximately 2 weeks or less). Thus, contracting virus and then spreading it between adult Chinook salmon may be limited to a narrow window of time, perhaps much less time than initially expected.

Table 1. Concentrations (pfu g^{-1} or pfu ml^{-1}) of infectious hematopoietic necrosis virus (IHNV) in tissues of winter-run Chinook salmon following experimental water borne exposures ("Exp") to 3.5 x 10^5 pfu ml^{-1} or held under the same conditions without addition of virus to tank water ("C"). DPE indicates days post exposure. N/D indicates no virus detected.

Fish	DPE	Kidney & Spleen	Ovarian Fluid	Gill (Filtered)	Plasma
Exp-1*	4	5.00 x 10^2	1.58 x 10^3	5.00 x 10^5	---
Exp-2	8	1.58 x 10^3	1.58 x 10^3	1.58 x 10^5	---
Exp-3	13	8.25 x 10^4	4.88 x 10^6	1.78 x 10^7	3.00 x 10^4
Exp-4	13	4.00 x 10^5	3.65 x 10^8	4.50 x 10^4	2.13 x 10^5
Exp-5	14	4.68 x 10^5	2.50 x 10^8	8.75 x 10^4	1.25 x 10^4
Exp-6	14	1.50 x 10^4	2.35 x 10^6	1.25 x 10^4	4.75 x 10^4
C-1	8	N/D	N/D	N/D	N/D
C-2	13	N/D	N/D	N/D	N/D
C-3	13	N/D	N/D	N/D	N/D
C-4	14	N/D	N/D	N/D	N/D
C-5	14	N/D	N/D	N/D	N/D

Conclusions

These studies clearly demonstrated that adult Chinook salmon are susceptible to infections initiated by additions of IHNV to the water. This laboratory study provides an explanation for the increasing prevalence of IHNV with later returning Chinook salmon observed in hatcheries where the virus is present (Wingfield and Chan 1970). Although this method of virus transmission to adults was suspected, it could never be clearly separated from the other suspected explanation for adult infections, the recurrence or activation of virus carried through the life time of the fish following virus exposure as young fish (Amend 1975, Drolet et al. 1995).

Results from the second series of trials are still being analyzed but they suggest that adult Chinook salmon are not readily susceptible to IHNV infection until they approached spawning (2- 3 weeks). Thus, a rather narrow window of time may exist for these salmon to become infected. If this is true, there must be a significant temporal overlap between spawning runs of salmon to effectively perpetuate the virus in a river system. The transmission of virus from fall run to late fall run Chinook salmon at the Coleman NFH as shown by Dr. Scott Foott is perhaps the best example of this phenomenon. Studies that carefully follow IHNV infections in the skin and gills (not becoming systemic to involve internal organs) of adult salmon from the time they would enter freshwater until spawning are warranted and excess winter-run Chinook salmon should be available for this type of investigation.

Lastly, if infections with IHNV are obtained only near the final weeks of life of adult Chinook salmon, the threat of strays moving virus from one watershed to another is somewhat lessened.

Task 2b. Correlations Between Virus Type and Virulence for Salmon and Trout – UC Davis

Virus isolates. Eight isolates of IHNV were chosen to represent a number of the more dominant genogroups based upon sequences from the mid-G region of the viral genome and their virulence evaluated for both Chinook salmon and rainbow trout fry. The origins of the virus strains and the sequence type designations are given in Table 2.

Fish species. Chinook salmon used in these trials were from the Nimbus Hatchery (Rancho Cordova, CA) and were 295 degree days in age and weighed an average of 0.56 g. Rainbow trout were obtained as eggs from the Trout Lodge Hatchery (Sumner, WA) and were 339 degree days and weighed approximately 0.61 g.

Virus exposures. Duplicate groups of 30 fish per species were exposed for 1 h to concentrations of IHNV of either 10^3, 10^4 or 10^5 pfu ml^{-1} in 12°C water. Cumulative mortality was recorded over a 21-day period post exposure. The viscera of dead fish were removed and processed for detection of IHNV by virus isolation and in certain cases the concentrations of virus determined by plaque titration.

Results

Virus isolates representing several mid-G gene sequence types showed differences in their virulence for either Chinook salmon or rainbow trout. As many exposure trials resulted in cumulative mortality less than 50%, a lethal dose 25% (LD_{25}) was used as the standard for comparing the virulence for the different IHNV isolates. The lower the LD_{25}, the greater the virulence of a given IHNV isolate. The LD_{25} values for IHNV isolates in this study were quite similar and ranged from $10^{4.0}$ to $10^{4.9}$ pfu ml^{-1} for Chinook salmon (Table 2). A greater variation from $<10^{3.9}$ to $10^{5.5}$ pfu ml^{-1} was found for the virulence of these same IHNV isolates for rainbow trout. Four of the eight isolates examined demonstrated significant differences in virulence between the two fish species based on the LD_{25} values ($P < 0.01$). Three of these isolates (dNBst-n2, uFRCh-n1b, uCLCh-n1b) were more virulent for Chinook salmon than rainbow trout. The isolate with the greatest virulence for Chinook salmon ($10^{4.0}$ pfu ml^{-1}) was dNBSt-n2 a representative of the genogroup D but this same isolate was one of the lesser virulent isolates for rainbow trout ($10^{5.2}$pfu ml^{-1}). The cMCCh-n2 isolate, representing genogroup C, was the only isolate tested that was more virulent for rainbow trout ($<10^{3.9}$ pfu ml^{-1}) than for Chinook salmon.

Table 2. Virulence of IHNV isolates representing 8 sequence types from California for juvenile rainbow trout and Chinook salmon. Virulence is expressed at the lethal dose 25% or the dose of virus sufficient to kill 25% of the exposed fish. Dose of the virus is expressed in plaque forming units (pfu) for Chinook salmon ($LD25_{CHIN}$) or rainbow trout ($LD25_{RBT}$). The P values are for differences between the virulence of a single isolate for the two salmonid species.

IHNV Isolate	Sequence type	Serogroup	Source location	Source species	Date Isolated	$LD25_{CHIN}$	$LD25_{RBT}$	P value
aFRCh-n3	A	1	Feather	Chinook	1/69	$1 \times 10^{4.5}$	$1 \times 10^{4.2}$	0.2242
cMCCh-n1	C	1	Merced /Snelling	Chinook	3/88	$1 \times 10^{4.8}$	$<1 \times 10^{3.9}$	<0.0001
dNBSt-n2	D	1	Nimbus	Steelhead	12/01	$1 \times 10^{4.0}$	$1 \times 10^{5.2}$	<0.0001
eMKCh-n2	E	2	Mokelumne	Chinook	12/93	$1 \times 10^{4.9}$	$1 \times 10^{5.2}$	0.0823
fFRCh-n10	F	2	Feather	Chinook	11/98	$>1 \times 10^{4.9}$	$1 \times 10^{5.4}$	0.5606
iFRCh-n44	I	3	Feather	Chinook	10/02	$1 \times 10^{4.7}$	$1 \times 10^{4.4}$	0.1313
uFRCh-n1b	Unique	3	Feather	Chinook	1/01	$1 \times 10^{4.7}$	$1 \times 10^{5.3}$	0.0082
uCLCh-n1b	Unique	3	Coleman	Chinook	8/01	$1 \times 10^{4.4}$	$1 \times 10^{5.5}$	<0.00018

Conclusions

The virulence for nearly all isolates of IHNV tested for Chinook salmon juveniles, regardless of sequence type or serogroup, was relatively similar. The exception was the isolate from steelhead trout from the Nimbus hatchery in 2001 which was the most virulent for Chinook salmon. Curiously, this same isolate was one of the least virulent for rainbow trout. In general, most isolates of IHNV were of equal or lesser virulence for rainbow trout than Chinook salmon. The one exception was the cMCCh-n1 isolate from Merced/Snelling. This isolate obtained from adult Chinook salmon in 1988 was more virulent for rainbow trout than Chinook salmon in our trials. This isolate represents a rare sequence type (C) that appeared on the south coast of Oregon and the Merced Hatchery in the mid to late 1980s that has not been seen since. This isolate may represent a one time event and fortunately this virus was not able to establish itself in the San Joaquin system.

Although several isolates representing genogroup C and two unique types from Feather River and Coleman NFH were clearly more virulent for Chinook salmon than rainbow trout, four of the isolates tested had equal virulence for both Chinook salmon and rainbow trout in our trials. These four isolates represent genogroups A, E, F and I with the A and E isolates from both historic and recently encountered types at Feather River (aFRCh-n3 and iFRCh-n44). Epidemiological evidence from the Feather River Hatchery suggests that Chinook salmon are more likely to be impacted although the effects of IHNV on steelhead trout have been significant. Discrepancies between the field and laboratory observations may reflect differences in the age and size of each species at first contact with the virus in the hatchery and other environmental or genetic factors of the host all of which are known to influence the severity of IHNV infections (LaPatra et al. 1990, LaPatra 1998).

Our studies on cohabitation of IHNV (Type F) infected juvenile Chinook salmon with rainbow trout (Task 2c) would appear to support the hypothesis that most California types of IHNV are less virulent for rainbow trout than Chinook salmon as it was difficult to transmit the virus from Chinook salmon to cohabitant rainbow trout. However, even transmission under these laboratory conditions from Chinook salmon to Chinook salmon was difficult in trials described by Foott and Free (1998). In contrast to the L clade viruses examined in our studies, M clade viruses as found in Idaho and the Columbia River system (Troyer et al. 2000) are highly virulent for rainbow trout, even for older fish and can spread by among cohabitant rainbow trout, although much less efficiently that would be presumed (Ogut and Reno 2004).

Our results suggest that in general IHNV is not easily spread from fish to fish, regardless of the species (Chinook salmon or rainbow trout), unless certain conditions are met that were not present in our or others laboratory trials. One such factor may be high fish host densities that were considered as factors in

epidemics due to IHNV among wild populations of sockeye salmon in British Columbia, Canada and Alaska (reviewed in Traxler and Rankin 1998). Densities of Chinook salmon or steelhead trout on the order of those observed in sockeye in Canada and Alaska are unlikely to be encountered in California waters and thus it seems that other stressors (environmental?) would be more likely to cause epidemic losses if they were to occur in our waters. In the absence of active disease episodes, other questions arise. Are resident rainbow/steelhead trout able to carry the virus, although not being largely impacted by it, and transmit it to adult Chinook salmon? If yes, this may explain one important reservoir for the virus that shows up yearly in Chinook adults. Examinations of resident rainbow trout, particularly serological examinations of juvenile rainbow/steelhead trout to detect presence of anti-IHNV antibodies might provide insights into their potential role as reservoirs of the virus.

Task 2c. Transmission of IHNV from Hatchery Fish to Resident/Wild Outmigrant Salmon/Trout – UC Davis

Methods

In these studies the potential spread of IHNV between infected and uninfected Chinook salmon and steelhead/rainbow trout was examined in controlled laboratory trials with the objective of demonstrating whether hatchery releases of infected fish represent a risk of infecting wild salmonids.

Fish and virus exposures. In these initial trials, juvenile Chinook salmon were exposed to IHNV at high or low doses or with repeated low doses of virus. Mortality and presence of IHNV in the tissues of exposed fish was examined over time and the ability of virus to be shed from Chinook salmon and to infect rainbow trout placed in tanks with exposed Chinook salmon was investigated. Chinook salmon (Iron Gate Hatchery origin 4.0 g) held in 12^{o}C well water were exposed to IHNV (fCLChn-n6) at a concentration of 7.0 x 10^{4} pfu ml^{-1} for 1 h. After virus exposure, flow of well water to replicate aquaria was resumed. In a second set of trials, juvenile Chinook salmon (Nimbus Hatchery origin 0.47 g in weight) exposed to repeated low doses (3 doses chosen) of IHNV (30 min at each time on each of 5 consecutive days).

Virus detection and sampling. The presence of IHNV in tissues of healthy appearing or dead fish was evaluated by isolation in cell cultures. Concentrations of virus in selected tissues were estimated by titration on these cell cultures to establish the pfu per gram.

Cohabitation of rainbow trout with virus-exposed Chinook salmon. At 24 days post exposure of Chinook salmon to IHNV in the repeated low dose exposure trial, rainbow trout (0.56 g) were cohabited with Chinook salmon for a

period of 18 days. Rainbow trout were monitored for the presence of disease signs consistent with IHNV and at 18 days post cohabitation with Chinook salmon all rainbow trout were sacrificed and examined for presence of virus in the kidney/spleen by virus isolation methods.

Results

Single high dose virus exposure of juvenile Chinook salmon. Fish showed no signs of disease upon first sampling at 3 d post exposure (Table 3) but virus was present as detected in the gill, skin and a pool of the kidney and spleen tissues. Virus concentrations were approximately 10^3 pfu g^{-1}. Surprisingly, virus was then not detected among healthy appearing Chinook salmon on days 5 and 8, times at which from prior studies exposed younger Chinook salmon would be experiencing virus-induced mortality. Virus was again detected at 16 and 22 days post exposure with concentrations of virus reaching 10^6 pfu g^{-1}. At the final sampling at 79 days, no virus was detected. Although sample sizes were relatively low at each date, the data indicate that Chinook salmon of this age and size resist the virus-induced mortality seen with fish in the 0.5 – 2.0 g range. However, larger fish can become infected and virus production in these fish can be substantial in the absence of signs of disease. Whether a continuing pattern of presence and then absence of the virus can be expected following these types of exposures is unknown. Additional studies over a longer time with more fish might establish whether the virus has the potential to persist and undergo periodic cycles of replication. This study demonstrated that the gill and skin are sites of virus replication in juveniles that may show no signs of disease.

Table 3. Detection of infectious hematopoietic necrosis virus (IHNV) among juvenile Chinook salmon following exposures to a single high dose of the virus in the water.

			Presence of virus in tissues (pfu g^{-1})		
Day (dpe)	No. Fish +* / No. Fish		Gill	Skin	Kidney/spleen
3	2/3		2/3 (10^3)	2/3 (10^3)	2/3 (10^3)
5	0/3				
8	0/3				
16	1/3		1/3 (10^4)	1/3 (10^3)	1/3 (10^5)
22	1/3		1/3 (10^6)	1/3 (10^4)	1/3 (10^6)
79	0/3				
100	0/3				

*3 control fish sampled at each time point were negative for IHNV.

Repeated low dose virus exposures. Repeated low dose exposures resulted in IHNV infections only when concentrations of virus were 1.90 x 10^2 pfu ml^{-1} or greater at each of the 5 exposures (Table 4). There was no mortality

experienced by any of the virus-exposed Chinook salmon at any of the doses but virus was detected beginning at 11 days post virus exposure in the highest dose (1.9×10^3 pfu ml^{-1}) in the gill, skin and kidney/spleen with concentrations up to 10^5 pfu g^{-1}. Virus was again detected in fish examined at 23 days post exposure in both the 1.9×10^2 and the 1.9×10^3 pfu ml^{-1} doses with most virus (10^5 pfu g^{-1}) present in the gill compared to the other tissues sampled. Virus was detected in only one fish sampled at 39 days post exposure in the gill and skin tissues and only from the highest dose (1.9×10^2 pfu ml^{-1}) and the concentrations of the virus (10^3 pfu g^{-1}) were lower than at earlier time points. No infected fish were detected at sample times of 79 and 100 days post exposure.

Table 4. Detection of infectious hematopoietic necrosis virus (IHNV) among juvenile Chinook salmon following multiple low dose exposures to virus in the water.

Tissue: positive/ total sample

(Titer in pfu/g)

Days	**Dose**	**Fish + / Fish sampled**		**Gill**	**Skin**	**Kidney/spleen**
8	All doses	0/3				
11	1.9	0/3				
	1.9×10^1	0/3				
	1.9×10^2	0/3				
	1.9×10^3	2/3		1/3(10^4)	2/3 (10^5)	2/3 (10^4 & 10^5)
23	1.9	0/3				
	1.9×10^1	0/3				
	1.9×10^2	1/3		1/3 (10^5)	1/3 (10^4)	1/3 (10^4)
	1.9×10^3	2/3		2/3 (10^3)	0/3	0/3
39	1.9	0/3				
	1.9×10^1	0/3				
	1.9×10^2	0/3				
	1.9×10^3	1/3		1/3 (10^3)	1/3 (10^3)	0/3
79 & 100	All doses	0/3				

Cohabitation of rainbow trout with virus-exposed Chinook salmon. At 24 days post exposure of Chinook salmon to IHNV a total of 20 rainbow trout (0.56 g) were added to each replicate group of 30 Chinook salmon. Cohabitation continued for a total of 18 days at which time no rainbow trout had died. No evidence of IHNV was found in the tissues of rainbow trout cohabiting with either IHNV-exposed or control Chinook salmon upon examination at 18 day post initial contact with Chinook salmon. Based upon sampling of Chinook salmon on days 23 and 39 days post exposure, IHNV was present but apparently the concentrations released into the water were insufficient to induce systemic infections in cohabited rainbow trout.

Conclusions

These trials with Chinook salmon exposed to a range of doses of IHNV either by a single higher dose or repeated lower doses resulted in virus infections but with no signs of disease. Virus was found from 11 to 39 days post virus exposure and the gill and skin appear to be sites of viral replication and residence. Although virus is replicating at these external sites the concentrations released were lower than that needed to induce systemic infections in cohabited rainbow trout (we only examined kidney and spleen tissues).

From trials conducted in Task 2b, the concentrations of IHNV needed to induce mortality in rainbow trout should be approximately 10^4 pfu ml^{-1}. This suggests that if Chinook salmon released from the hatchery are not undergoing active disease episodes they would be less likely to be releasing sufficient virus to infect wild fish or other emigrating salmonids with which they may come into contact. Studies by Free and Foott (1998) have further shown that even when Chinook salmon with acute disease are cohabited with healthy Chinook salmon that the latter do not show a virus-induced mortality. Their results are consistent with our findings that rather high levels of virus are required to induce mortality (see Virulence Testing Results for Task 2b).

The infection trials beg the question “how do epidemics occur under hatchery conditions”? Ogut and Reno (2004) examined the kinetics of IHNV infections among rainbow trout of 2 months in age under laboratory conditions. They demonstrated that virus transmission occurs among recipient or naive rainbow trout exposed to 1 to 5 donor trout that were previously exposed to IHNV. Curiously, infection rates were generally low (less than 20%) and no mortality or further spread of the virus occurred among recipient fish.

Other studies, as those reported by Free and Foott (1998) with Chinook salmon, demonstrate that other predisposing factors are required for virus entry, establishment and replication sufficient to induce epidemic mortality in salmonids (LaPatra 1998). Factors such as high fish densities, damage to the epithelium of the gill or skin by various factors inherent in raceway rearing, or water quality may be involved.

The gill and skin may play a critical role in infections in older Chinook salmon juveniles (and perhaps adults?) as suggested by studies with older rainbow trout by Yamamoto et al. (1990) and Yamamoto and Clermont (1990) and LaPatra et al. (1989). In the laboratory trials by Yamamoto and colleagues they demonstrated an early involvement of gill and epidermal tissues following waterborne exposures of rainbow trout to IHNV. They concluded that virus may undergo some replication in these tissues as early as 1 day post exposure and then spread to internal organs which begin to show positive for the virus at 3 days and thereafter. In our studies, gill tissues were positive in fish up to 39

days, a time point well past the sampling dates in the studies by Yamamoto and colleagues. While the gills and skin were viewed as more initial and transient locations for virus replication in rainbow trout, we speculate that in Chinook salmon juveniles these tissues may remain infected for longer periods of time and perhaps support virus growth in the absence of an extended involvement of internal organs such as the kidney and spleen which are viewed as the key target organs for the virus (LaPatra 1998).

Based on the initial results from our study and those of Free and Foott (1998) it seems unlikely that virus present in healthy outmigrating hatchery fish is a key source of infections that would result in significant mortality among healthy wild fish they may encounter in the system. One unexpected finding of these trials was that older Chinook juveniles appear to experience and "eclipse period" or period where virus is not detected but later reappears. The basis of this observation is unknown but it indicates that virus infections may not be a steady or progressive event but episodic in nature. While samples sizes and time points after 39 d were few, further sampling of Chinook exposed in this manner may reveal the virus is retained for longer periods in essentially a silent mode. If infections in these Chinook juveniles can be activated, perhaps by stresses associated with out migration, then IHNV may exert population effects that would be difficult to easily observe.

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Appendix 1. A complete listing of infectious hematopoietic necrosis virus (IHNV) isolates most of which were from California and many which are from the Feather River. The isolates are grouped into either unique groups or "u" (unique sequences) or California sequence types designated by the letters A through I. Grouping was based upon the sequence of a 303 nucleotide region of the G or gylcoprotein gene of the virus.

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Sequence Type, n#	Isolation Site	Host	River Drainage	Year
	Unique sequences			
uER-n1	Elk River, Oregon	unknown	Elk	1976
uFRCh-n1a	Feather River H.	Ch	Sacramento	1971
uMKSt-n1	Mokelumne River H.	St	San Joaquin	1971
uNBCh-n1a	Nimbus H.	Ch	Sacramento	1974
uTRCh-n1a	Trinity River H.	Ch Spring	Klamath	1991
	California sequence type A (n = 31; 1969-1998)			
aFRCh-n3	Feather River H.	Ch yearling	Sacramento	1969
aFRCh-n3	Feather River H.	Ch Spring fry	Sacramento	1976
aFRCh-n3	Feather River H.	Ch Fall	Sacramento	1977
aTRCh-n16	Trinity River H.	Ch	Klamath	1979
aRCCh-n1	Rowdy Creek H.	Ch subyearling	Smith	1981
aHOCh-n1	Hoopa Fish Rearing Facility	Ch Fall	Klamath	1987
aHOCh-n1	Hoopa Fish Rearing Facility	Ch Fall	Klamath	1987
aMCCh-n1	Merced River H.	Ch	San Joaquin	1987
aCCCh-n1	Klamath River, CA	Ch	Klamath	1987
aTRCh-n16	Trinity River H.	Ch	Klamath	1987
aTRCh-n16	Trinity River H.	Ch yearling	Klamath	1988
aTRCh-n16	Trinity River H.	Ch	Klamath	1988
aTRCh-n16	Trinity River H.	Ch Fall	Klamath	1988
aTRCh-n16	Trinity River H.	Ch fry	Klamath	1989
aTRCh-n16	Trinity River H.	Ch	Klamath	1989
aTRCh-n16	Trinity River H.	Ch	Klamath	1989
aTRCh-n16	Trinity River H.	Ch yearling	Klamath	1989
aTRCh-n16	Trinity River H.	Ch Spring	Klamath	1989
aTRSt-n3	Trinity River H.	St	Klamath	1989
aTRCh-n16	Trinity River H.	Ch Fall	Klamath	1990
aTRSt-n3	Trinity River H.	St	Klamath	1990
aTRSt-n3	Trinity River H.	St	Klamath	1990
aTRCh-n16	Trinity River H.	Ch	Klamath	1991
aTRCh-n16	Trinity River H.	Ch Spring	Klamath	1991

aTRCh-n16	Trinity River H.	Ch Fall	Klamath	1991
aTRCoho-n2	Trinity River H.	Coho	Klamath	1991
aTRCoho-n2	Trinity River H.	Coho	Klamath	1991
aTRCh-n16	Trinity River H.	Ch	Klamath	1993
aTRCh-n16	Trinity River H.	Ch	Klamath	1993
aERCh-n1	Elk River, Oregon	Ch Fall	Elk	1994
aRRCh-n1	Rogue River, Oregon	Ch Fall	Rogue	1998
	Unique sequences			
uNBCh-n1b (SRCV)	SRCV	Ch	Sacramento	1966
uTRCh-n1b	Trinity River H.	Ch	Klamath	1987
	California sequence type B (n=2; 1979&1985)			
bMACh-n1	Mad River H.	Ch	Mad	1979
bCLSt-n1 (CL 85)	Coleman H.	St	Sacramento	1985
	Unique sequence			
uCLCh-n1a (CL 80)	Coleman H.	Ch	Sacramento	1980
	Califonrnia sequence type C (n=2; 1986&1988)			
cSXCh-n1	Sixes River, Oregon	Ch Fall	Sixes	1986
cMCCh-n1	Merced River H.	Ch	San Joaquin	1988
	Unique sequence			
uEESt-n1	Eel River	St	Eel	1988
	California sequence type D (n=18; 1989-2003)			
dCLCh-n3	Coleman H.	Ch	Sacramento	1989
dFRCh-n1	Feather River H.	Ch Fall	Sacramento	1991
dFRSt-n2	Feather River H.	St	Sacramento	1992
dFRSt-n2	Feather River H.	St	Sacramento	1992
dCLCh-n3	Coleman H.	Ch Fall	Sacramento	1997
dCLCh-n3	Coleman H.	Ch Fall juvenile	Sacramento	1999
dCLSt-n1	Coleman H.	St	Sacramento	1999
dNBCh-n7	Nimbus H.	Ch	Sacramento	1999
dMCCh-n1	Merced River H.	Ch	San Joaquin	2000
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBCh-n7	Nimbus H.	Ch	Sacramento	2001
dNBSt-n2	Nimbus H.	St	Sacramento	2001
dNBSt-n2	Nimbus H.	St	Sacramento	2001
dBCCh-n1	Battle Creek, CA	Ch male	Sacramento	2003

Unique sequences				
uNBCh-n1c	Nimbus H.	Ch	Sacramento	1998
uCLCh-n1b	Coleman H.	Ch Winter	Sacramento	2001
California sequence type E (n=21; 1990-1999)				
eFRCh-n5	Feather River H.	Ch	Sacramento	1990
eFRCh-n5	Feather River H.	Ch	Sacramento	1992
eNBCh-n4	Nimbus H.	Ch	Sacramento	1992
eNBCh-n4	Nimbus H.	Ch	Sacramento	1992
eMCCh-n1	Merced River H.	Ch	San Joaquin	1992
eCLCh-n7	Coleman H.	Ch	Sacramento	1992
eCLCh-n7	Coleman H.	Ch	Sacramento	1993
eCLCh-n7	Coleman H.	Ch Fall	Sacramento	1993
eCLCh-n7	Coleman H.	Ch Fall	Sacramento	1993
eFRCh-n5	Feather River H.	Ch	Sacramento	1993
eFRChn5	Feather River H.	Ch	Sacramento	1993
eNBCh-n4	Nimbus H.	Ch	Sacramento	1993
eNBCh-n4	Nimbus H.	Ch	Sacramento	1993
eMKCh-n2	Mokelumne River H.	Ch	San Joaquin	1993
eMKCh-n2	Mokelumne River H.	Ch	San Joaquin	1993
eCLSt-n2	Coleman H.	St	Sacramento	1994
eCLCh-n7	Coleman H.	Ch Late Fall	Sacramento	1994
eFRCh-n5	Feather River H.	Ch	Sacramento	1995
eCLSt-n2	Coleman H.	St	Sacramento	1997
eCLCh-n7	Coleman H.	Ch Fall	Sacramento	1997
eCLCh-n7	Coleman H.	Ch Fall	Sacramento	1999
California sequence type F (n=46; 1996-2003)				
fNBCh-n14	Nimbus H.	Ch	Sacramento	1996
fCLCh-n6	Coleman H.	Ch Fall juvenile	Sacramento	1997
fFRCh-n10	Feather River H.	Ch Fall	Sacramento	1997
fFRCh-n10	Feather River H.	Ch Fall	Sacramento	1997
fFRCh-n10	Feather River H.	Ch Fall	Sacramento	1997
fMKCh-n2	Mokelumne River H.	Ch	San Joaquin	1997
fMKCh-n2	Mokelumne River H.	Ch	San Joaquin	1997
fNBCh-n14	Nimbus H.	Ch	Sacramento	1997
fFRCh-n10	Feather River H.	Ch fry	Sacramento	1998
fFRCh-n10	Feather River H.	Ch	Sacramento	1998
fNBSt-n9	Nimbus H.	St	Sacramento	1998
fNBCh-n14	Nimbus H.	Ch	Sacramento	1999
fCLCh-n6	Coleman H.	Ch female Winter	Sacramento	2000

fFRCh-n10	Feather River H.	Ch Fall	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBCh-n14	Nimbus H.	Ch	Sacramento	2000
fNBSt-n9	Nimbus H.	St	Sacramento	2000
fFRCh-n10	Feather River H.	Ch Spring	Sacramento	2001
fFRSt-n1	Feather River H.	St	Sacramento	2001
fNBCh-n14	Nimbus H.	Ch	Sacramento	2001
fNBSt-n9	Nimbus H.	St	Sacramento	2001
fNBSt-n9	Nimbus H.	St	Sacramento	2001
fNBSt-n9	Nimbus H.	St	Sacramento	2001
fCLCh-n6	Coleman H.	Ch Winter	Sacramento	2002
fCLCh-n6	Coleman H.	Ch Fall	Sacramento	2002
fCLCh-n6	Coleman H.	Ch Fall	Sacramento	2002
fCLCh-n6	Coleman H.	Ch Fall	Sacramento	2002
fFRCh-n10	Feather River H.	Ch Fall	Sacramento	2002
fFRCh-n10	Feather River H.	Ch Fall	Sacramento	2002
fFRCh-n10	Feather River H.	Ch	Sacramento	2002
fNBCh-n14	Nimbus H.	Ch	Sacramento	2002
fNBSt-n9	Nimbus H.	St	Sacramento	2002
fNBSt-n9	Nimbus H.	St	Sacramento	2003
fNBSt-n9	Nimbus H.	St	Sacramento	2003
fNBSt-n9	Nimbus H.	St	Sacramento	2003
fBCCh-n2	Battle Creek, CA	Ch female	Sacramento	2003
fBCCh-n2	Battle Creek, CA	Ch female	Sacramento	2003
fCKCh-n1	Clear Creek, CA	Ch	Sacramento	2003
fMKSt-n1	Mokelumne River H.	St	Sacramento	2003
Unique sequence				
uFRCh-n1b	Feather River H.	Ch	Sacramento	2001
uFRCh-n1c	Feather River H.	Ch	Sacramento	2002
California sequence type G (n=4; 2003)				
gBCCh-n2	Battle Creek, CA	Ch female	Sacramento	2003
gBCCh-n2	Battle Creek, CA	Ch male	Sacramento	2003
gCKCh-n2	Clear Creek, CA	Ch	Sacramento	2003
gCKCh-n2	Clear Creek, CA	Ch	Sacramento	2003

California sequence type H (n=3; 2003)				
hCKCh-n2	Clear Creek, CA	Ch	Sacramento	2003
hCKCh-n2	Clear Creek, CA	Ch	Sacramento	2003
hBCCh-n1	Battle Creek, CA	Ch female	Sacramento	2003
California sequence type I (n=74; 1999-2002)				
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	1999
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	1999
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	1999
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	1999
iFRCh-n44	Feather River H.	Ch	Sacramento	1999
iNBCh-n1	Nimbus H.	Ch	Sacramento	1999
iNBSt-n2	Nimbus H.	St	Sacramento	1999
iFRCh-n44	Feather River H.	Ch fry	Sacramento	2000
iFRCh-n44	Feather River H.	Ch fry	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRCh-n44	Feather River H.	Ch	Sacramento	2000
iFRSt-n6	Feather River H.	St Yearling	Sacramento	2000
iORRb-n1	Lake Oroville	RBT	Sacramento	2000
iORCh-n7	Lake Oroville	Ch fry	Sacramento	2000
iORCh-n7	Lake Oroville	Ch male	Sacramento	2000
iORCh-n7	Lake Oroville	Ch male	Sacramento	2000
iORCh-n7	Lake Oroville	Ch male	Sacramento	2000
iORCh-n7	Lake Oroville	Ch female	Sacramento	2000
iORCh-n7	Lake Oroville	Ch female	Sacramento	2000
iORCh-n7	Lake Oroville	Ch male	Sacramento	2000
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2001
iFRSt-n6	Feather River H.	St	Sacramento	2001
iFRSt-n6	Feather River H.	St fingerling	Sacramento	2001
iFRSt-n6	Feather River H.	St Sub yearling	Sacramento	2001

iMCCh-n1	Merced River H.	Ch	San Joaquin	2001
iNBSt-n2	Nimbus H.	St	Sacramento	2001
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Spring	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2002
iFRSt-n6	Feather River H.	St	Sacramento	2002
iFRSt-n6	Feather River H.	St Yearling	Sacramento	2002
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iFRCh-n44	Feather River H.	Ch Fall	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch Fall	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch Fall	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch Fall	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch Fall	Sacramento	2003
iYUCh-n5	Yuba River (upper)	Ch Fall	Sacramento	2003
iYMCh-n3	Yuba River (middle)	Ch Fall	Sacramento	2003
iYMCh-n3	Yuba River (middle)	Ch Fall	Sacramento	2003
iYMCh-n3	Yuba River (middle)	Ch Fall	Sacramento	2003
iYLCh-n2	Yuba River (lower)	Ch Fall	Sacramento	2003
iYLCh-n2	Yuba River (lower)	Ch Fall	Sacramento	2003
iMKCh-n2	Mokelumne River H.	Ch fingerlings	Sacramento	2004
iMKCh-n2	Mokelumne River H.	Ch fingerlings	Sacramento	2004
California sequence type J (n=8; 2003)				
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003

jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jFRCh-n6	Feather River H.	Ch Fall	Sacramento	2003
jYLCh-n2	Yuba River (lower)	Ch Fall	Sacramento	2003
jYLCh-n2	Yuba River (lower)	Ch Fall	Sacramento	2003

Appendix 2. Isolates of infectious hematopoietic necrosis virus (IHNV) from the Feather Rivers system examined in this study. The sites of isolation are as follows FR: Feather River below dam, LO: Lake Oroville and the fish species are designated as CH-F: fall run Chinook, CH-S: spring run Chinook, STHD: steelhead trout, RBT: rainbow trout.

Isolate	Location	Sample Date	Type	Serum Neutralization	Host	Sample source[1]	Age[2]	Sex
Lot 118	FR	01/10/69	A	1	CH		Y	
Lot 121	FR	05/21/71	unique	1	CH			
Lot 129	FR	11/05/76	A	1	CH-S			
Lot 131 (C9*)	FR	01/04/77	A	1	CH-F			
CDFG 90-80	FR	11/13/90	E	2	CH-F	OF	A	F
CDFG 91-76	FR	10/31/91	D	1	CH-F	OF	A	F
CDFG 92-3 (C7*)	FR	01/13/92	D		STHD	OF	A	F
CDFG 92-11	FR	02/18/92	D	1	STHD	OF	A	F
CDFG92-61-16 (C4*)	FR	11/09/92	E	2	CH	OF	A	F
CDFG 93-83-7	FR	11/22/93	E	2	CH-F	OF	A	F
CDFG 93-83-20 (C10*)	FR	11/22/93	E	2	CH-F	OF	A	F
CDFG 95-99-5	FR	11/06/95	E	2	CH-F	OF	A	F
CDFG 97-29-4 (C11*)	FR	10/06/97	F	2	CH-F	OF	A	F
CDFG 97-29-8	FR	10/06/97	F	2	CH-F	OF	A	F
CDFG 97-33-20 (c group*)	FR	10/09/97	F	2	CH-F	OF	A	F
CDFG 98-19 (C12*)	FR	03/19/98	F	2	CH	K,S	FR	
CDFG 98-59-4	FR	11/30/98	F	2	CH	OF	A	F
CDFG 99-43-7	FR	10/07/99	I		CH-S	OF	A	F
CDFG 99-46-3 (C13*)	FR	10/13/99	I		CH-F	OF	A	F
CDFG 99-46-6	FR	10/13/99	I	3	CH-F	OF	A	F
CDFG 99-47	FR	10/18/99	I		CH-F	OF	A	F
CDFG 99-57-7	FR	11/02/99	I	3	CH	OF	A	F
CDFG 00-6 (C15*)	FR	01/20/00	I	3	CH	Whole	FR	
CDFG 00-19-2	FR	03/13/00	I	3	STHD	K,S	Y	
CDFG 00-31 (C16*)	FR	04/17/00	I	3	CH	K,S	FR	
CDFG 00-38	FR	05/12/00	I	3	CH	V, K	FI	
CDFG 00-59-7	FR	10/18/00	I	2	CH	OF	A	F
CDFG 00-64-3	FR	10/24/00	F	2	CH-F	OF	A	F
CDFG 00-67-2	FR	11/02/00	I	3	CH	OF	A	F
CDFG 00-75-1	LO	11/15/00	I	3	CH	K,S		

CDFG 00-80-5	FR	11/16/00	I	3	CH	OF	A	F
CDFG 00-85-1	LO	12/04/00	I	3	CH	K,S		M
CDFG 00-85-2	LO	12/04/00	I		CH	K,S,Milt		M
CDFG 00-85-3	LO	12/04/00	I	3	CH	K,S		M
CDFG 00-85-4	LO	12/04/00	I	3	CH	K,S,OF		F
CDFG 00-85-5	LO	12/04/00	I	3	CH	K,S,OF		F
CDFG 00-88-4	LO	12/07/00	I		CH			M
CDFG 00-88-5	LO	12/07/00	I	3	RBT			M
CDFG 01-2-1	FR	01/03/01	F	2	STHD	OF	A	F
CDFG 01-6-5	FR	01/10/01	I		STHD	OF	A	F
CDFG 01-8-19	FR	01/19/01	unique	3	CH	V	YOY	
CDFG 01-40-7	FR	05/03/01	I		STHD	V	FI	
CDFG 01-84-1	FR	10/01/01	F	2	CH-S	OF	A	F
CDFG 01-84-13	FR	10/01/01	I		STHD	K,S	SY	
CDFG 01-90-1	FR	10/18/01	I	3	CH-F	OF	A	F
CDFG 01-90-4	FR	10/18/01	I	3	CH-F	OF	A	F
CDFG 01-90-5	FR	10/18/01	I	3	CH-F	OF	A	F
CDFG 01-90-8	FR	10/18/01	I	3	CH-F	OF	A	F
CDFG 01-90-9	FR	10/18/01	I	3	CH-F	OF	A	F
CDFG 01-96-4	FR	10/25/01	I	3	CH-F	OF	A	F
CDFG 01-96-5	FR	10/25/01	I	3	CH-F	OF	A	F
CDFG 01-96-6	FR	10/25/01	I	3	CH-F	OF	A	F
CDFG 01-96-7	FR	10/25/01	I	3	CH-F	OF	A	F
CDFG 01-96-8	FR	10/25/01	I	3	CH-F	OF	A	F
CDFG 02-8-5	FR	01/14/02	I	3	STHD	OF	A	F
CDFG 02-13-1	FR	02/05/22	unique	3	CH	V,K	FI	
CDFG 02-13-3	FR	02/05/02	I		STHD	K,S	Y	
CDFG 02-25-4	FR	04/16/02	I		CH-S	M	FI	
CDFG 02-56	FR	09/23/02	I	3	CH-S	OF	A	F
CDFG 02-58-1	FR	10/07/02	I		CH-S	OF	A	F
CDFG 02-58-2	FR	10/07/02	I	3	CH-S	OF	A	F
CDFG 02-58-3	FR	10/07/02	I		CH-S	OF	A	F
CDFG 02-58-4	FR	10/07/02	I		CH-S	OF	A	F
CDFG 02-58-5	FR	10/07/02	I	3	CH-S	OF	A	F
CDFG 02-58-18	FR	10/07/02	I	3	CH-F	OF	A	F
CDFG 02-58-19	FR	10/07/02	I	3	CH-F	OF	A	F
CDFG 02-58-27	FR	10/07/02	I		CH-F	OF	A	F
CDFG 02-64-2	FR	10/23/02	I		CH-F	OF	A	F
CDFG 02-64-8	FR	10/23/02	I		CH-F	OF	A	F
CDFG 02-64-10	FR	10/23/02	I		CH-F	OF	A	F
CDFG 02-81-1	FR	11/12/02	I		CH-F	OF	A	F
CDFG 02-81-2	FR	11/12/02	F		CH-F	OF	A	F
CDFG 02-81-7	FR	11/12/02	F	2	CH-F	OF	A	F
CDFG 02-81-9	FR	11/12/02	I		CH-F	OF	A	F
CDFG 02-81-10	FR	11/12/02	I		CH-F	OF	A	F
CDFG 02-89-3 (Coleman Stray)	FR	11/25/02	F	2	CH	K,S	J	M
CDFG 03-151-4	FR	10/27/03	J	3	CH-F			
CDFG 03-151-7	FR	10/27/03	I	3	CH-F			
CDFG 03-151-17	FR	10/27/03	I		CH-F			

CDFG 03-151-18	FR	10/27/03	I		CH-F			
CDFG 03-151-28	FR	10/27/03	I		CH-F			
CDFG 03-151-31	FR	10/27/03	J		CH-F			
CDFG 03-151-32	FR	10/27/03	J		CH-F			
CDFG 03-151-39	FR	10/27/03	J		CH-F			
CDFG 03-151-41	FR	10/27/03	I	3	CH-F			
CDFG 03-151-42	FR	10/27/03	I	3	CH-F			
CDFG 03-151-56	FR	10/27/03	I		CH-F			
CDFG 03-151-68	FR	10/27/03	J	3	CH-F			
CDFG 03-151-79	FR	10/27/03	J	3	CH-F			

* Kurath et al. (2003)

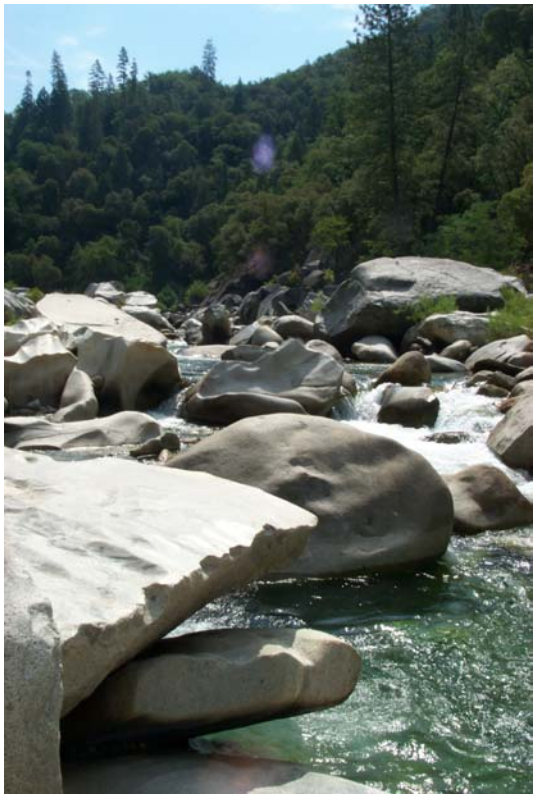
[1] OF: ovarian fluid, K: kidney, S: spleen, V: viscera, M: midsection

[2] A: adult, J: jack, YOY: young of the year, Y: yearling, SY: sub yearling, FI: fingerling, FR: fry

ATTACHMENT 5

FINAL YUBA RIVER REPORT – 2002-2003

DRAFT REPORT
Fish Health Monitoring of Fall Chinook and Steelhead in the Yuba and Feather Rivers (2002-2003)



Kimberly True
United States Fish and Wildlife Service
California-Nevada Fish Health Center

Oroville Facilities Relicensing Environmental Work Group
Project No. 2100
SP-F2. Evaluation of Project Effects on Fish Diseases

April 2004

CONSERVING AMERICA'S Fisheries

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ABSTRACT

The California- Nevada Fish Health Center, with the support of the California Department of Fish & Game (CDF&G) and the California Department of Water Resources (DWR), conducted fish health surveys in the Yuba and Feather Rivers to determine what major fish pathogens are present in the watershed and how they are distributed geographically and among different fish species.

Of particular interest is the presence or absence of the fish virus, Infectious Hematopoietic Necrosis Virus (IHNV), which is endemic to the Sacramento basin and a significant fish pathogen of cultured and wild chinook salmon (*Oncorhynchus tshawytscha*). Unique strains of IHNV, FR2 and FR3, have been identified in the Feather River State Fish Hatchery (FRSFH) production program in recent years (Pers.comm Dr. Bill Cox, CDFG 2003). These unique viral strains caused higher rates of mortality in hatchery-reared Steelhead (*Oncorhynchus mykiss*) and there is concern that virulent strains of IHNV could impact natural populations of steelhead and chinook in the Feather and Yuba Rivers.

Infectious Hematopoietic Necrosis virus was not detected in over 1,500 juvenile fish tested in the Feather and Yuba Rivers. Virology was performed primarily on fall chinook juveniles, a limited number of steelhead, and common non-salmonid fish species. Other fish pathogens including *Renibacterium salmoninarum, Yersinia ruckeri, Aeromonas hydrophila, Pseudomonad spp* and *Ichthyopthirius multifilis, and Lernaea* were detected in juvenile fish. *Pseudomonad* infections in hardhead (*Mylopharodon conocephalus*) in the Yuba River in 2003 and *Ichthyopthirius multifilis* detected in juvenile fall chinook in the Feather River in 2003 occurred at significant numbers of organisms, or high prevalence levels in fish populations, to pose a health risk for these species.

IHN viral testing was conducted on returning fall chinook adults sampled during carcass surveys on Feather River, Yuba River and Clear Creek from Oct-Nov 2003. IHNV was detected in fall chinook adults from the Feather River at an incidence of 45.6%, from the Yuba River at 27.8%; and in Clear Creek at 45.6%. Historical data for Coleman NFH (Battle Creek) is also reported as a mean incidence of IHNV of 55.5% from the sampling period of 1993-2003.

Dr. Ron Hedrick of the University of California, Davis (UCD) is in the process of strain typing the viral isolates obtained from adults tested in this study using polyclonal antibodies developed against the FR2 and FR3 IHNV strains. This work will determine if the endemic strain of IHNV or more virulent strains (FR2 and FR3) are present in the adult chinook populations. Antibody studies will be followed by sequence analysis of the G gene in a subset of the viral isolates.

STATUS OF FISH POPULATIONS

The Yuba and Feather Rivers are major tributaries to the Sacramento River and are essential watersheds in California for natural production of Chinook salmon and steelhead. CALFED, along with numerous stakeholders are in the process of evaluating the feasibility of removing dams that block adult salmon migration. Removal of existing dams could open up large amounts of natural habitat, thereby increasing natural production by chinook salmon and steelhead, and potentially aiding in the rate of recovery for these important species.

Declining chinook populations in the Central Valley have prompted intense restoration efforts in the Yuba River as Chinook salmon are a valuable resource and key element of the State's aquatic biodiversity. The lower Yuba River supports fall, late-fall, and spring-run (state and federally listed threatened) Chinook salmon and steelhead trout (state and federally listed threatened).

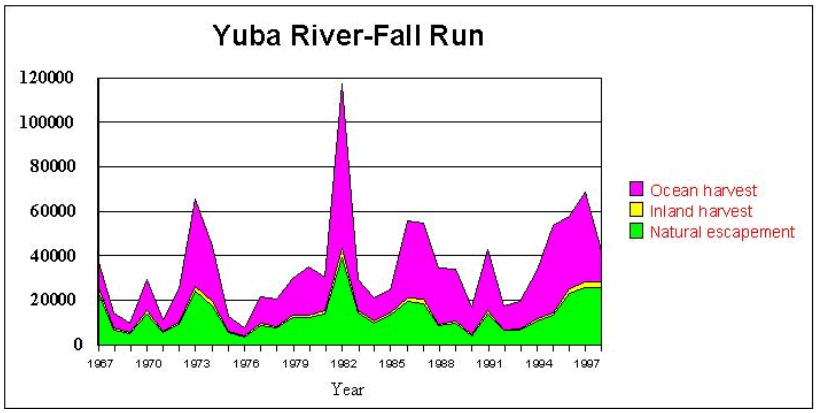
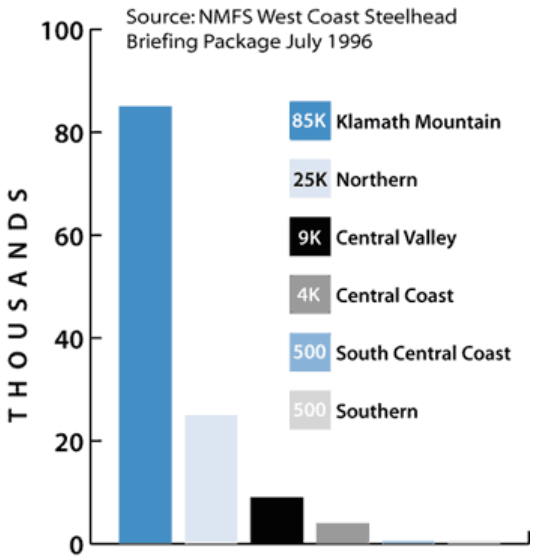


Figure 1. Fall Chinook natural production and escapement.
Source: Anadromous Fish Restoration Program (AFRP) website.

The Yuba River supports a self-sustaining population of steelhead and is essentially the only wild steelhead fishery remaining in the Central Valley (AFRP 2004). Statewide, numbers of steelhead have fallen to less than 50% of their populations of 30 years ago. Sacramento and San Joaquin River system populations are significantly reduced to fractions of their 1960's levels with dams blocking 90% of their spawning habitat. A 1996 briefing by National Marine Fisheries Service (NMFS), a division of the National Oceanic and Atmospheric Administration (NOAA), estimated the total run size of steelhead for the Central Valley Evolutionary Significant Unit (ESU) to be approximately 9000 (CalTrout 2004).



Wild stocks are mostly confined to upper Sacramento River tributaries such as Deer, Mill and Antelope Creeks and the Yuba River. The National Marine Fisheries Service has listed steelhead as Threatened or Endangered in nearly every river they inhabit within California. Steelhead are listed as Threatened in the Yuba River (ESU12 – Central Valley).

Figure 2. Estimated California Steelhead Populations by ESU
Source: Caltrout website.

Multi-year, comprehensive fish health assessments are needed in the Yuba and Feather Rivers to ascertain the distribution and effect of fish disease on anadromous and resident fish populations in these important watersheds. Health and fitness of juvenile salmon out-migrants are major determinates of their performance and ability to survive early ocean rearing. Infectious disease during the critical out-migrant period can exhaust energy reserves and impair immune function. Disease can influence survival directly (mortality) and indirectly by affecting fitness during early ocean rearing (predator avoidance, saltwater adaptation, etc.). It is also important to understand the health status of resident populations in the Yuba and Feather River. Resident trout and non-salmonid species can act as disease carriers or reservoirs of infection than can affect juvenile salmonids, as well as returning adults.

The information obtained from this study provides baseline data for fish health management by providing a better understanding of pathogen prevalence and physiological condition of Chinook and steelhead juveniles and adults in the Yuba and Feather River. This information can assist the CALFED Bay Delta program and stakeholders in determining the current risks associated with fish disease. The potential impacts to the health of anadromous fish populations under current conditions will provide a baseline for any future watershed restoration activities.

In addition to supporting CALFED's feasibility studies under the Upper Yuba River Science Program, this study builds on data collected from natural fish populations under the USFWS-National Wild Fish Health Survey (NWFHS). The NWFHS is a national fish health initiative to determine the prevalence and distribution of major fish pathogens in wild fish populations throughout the United States. Fish health data is maintained in a national database established in 1998 and maintained by Montana State University Environmental Statistics Group. Fish health data is accessible, via the internet, to researchers, resource managers, stakeholders, and the public to allow queries of fish health findings by geographical area (Hydrological Unit Code or HUC), species, or positive pathogen findings. The NWFHS website can be accessed at http://wildfishsurvey.fws.gov/

Study Objectives

The objectives of this study are:

1. Determine the presence and distribution of major fish pathogens in the Yuba and Father River in natural Fall Chinook, steelhead and non-salmonid fish populations (Table 1). Pathogens of interest include the major diseases of salmonid fish species and pathogens of regional interest (Table 2).

2. Compare pathogen distribution in natural fish populations in the Yuba and Feather River and assess risks associated with known pathogen epizootics at Feather River SFH.

3. Determine if a unique strain of IHNV (FR –Type 2) detected at Feather River State Fish Hatchery (FRSFH) in 1999 and 2000 is present in natural chinook and steelhead juvenile, and adult populations.

4. Determine the prevalence of IHNV in returning fall chinook adults in the Feather and Yuba Rivers.

5. Determine the prevalence of IHNV in fall chinook adults returning to Clear Creek and Battle Creek (from hatchery monitoring records) to compare IHNV prevalence in the upper Sacramento basin to the Yuba and Feather River watershed.

6. Assist with strain-typing analysis of all IHN viral isolates collected during the study. Submit viral isolates to Dr. Ron Hedrick of UCD to perform serological strain typing of viruses to determine distribution and movement of viral serotypes within the basin.

7. Include pathogen survey data from the Yuba and Feather River in the National Wild Fish Health Survey database to provide baseline fish health information about these important watersheds.

Table 1. Non-salmonid fish species examined in the Feather and Yuba River.

Fish Species	**Common Name**
Mylopharodon conocephalus	Hardhead
Micropterus dolomieu	Smallmouth bass
Lepomis macrochirus	Blue gill
Catostomus occidentalis	Sacramento sucker
Notemigonus crysoleucas	Golden shiner

Table 2. Major fish pathogens and diseases tested for under the National Wild Fish Health Survey (NWFHS).

Fish Pathogens	**Fish Disease Common Name or Abbreviation**
Infectious Hematopoietic Necrosis virus	IHN
Infectious Pancreatic Necrosis virus	IPN
Viral Hemorrhagic Septicemia virus	VHS
Oncorhynchus Masou virus[1]	OMV
Largemouth Bass virus[2]	LMBV
Renibacterium salmoninarum	Bacterial Kidney Disease (BKD)
Yersinia ruckeri	Enteric Red Mouth (ERM)
Aeromonas salmonicida	Furunculosis
Flavobacterium columnare[3]	Columnaris
Edwardsiella ictaluri[2]	Enteric Septicemia
Ceratomyxa shasta[3]	Salmonid Ceratomyxosis
Myxobolus cerebralis	Whirling Disease
Bothriocephalus acheilognathi	Asian Tapeworm
Other Parasites[4]	Parasitic infections
Numerous ectoparasites and internal parasites and associated diseases[4]: *Ambiphyra, Epistylis, Chilodonella, Ichthyobodo necatix (Costia) , Ichthyopthirius multifilis(ICH), Gyrodactylus, Lernaea (anchor worm), Nanophyetus (salmon poisoning fluke).*	

Note: **1. Not found in North America to date.**
2. Family or species-specific pathogen tested for if species are examined (Largemouth bass and catfish were not collected in this study).
3. Pathogen of Regional Interest (PRI) under the NWFHS.
4. External and internal parasites detected by microscopic examination and/or histology.

FISH PATHOGENS AND DISEASE TRANSMISSION

Disease is the culmination of various defects, abnormalities, deficiencies and injuries as they occur at the cellular and tissue level resulting in clinically apparent dysfunction. Cellular injury leads to changes in structure and function of tissues and organs. The changes in function are recognized as symptoms or clinical signs. The more subtle changes in structure at the cellular and tissue level are recognized as morphological lesions and histological changes. Disease can result from infectious agents, nutritional deficiencies, toxicants, environmental factors, or genetics (Plumb 1994).

Infection versus Disease

Infectious disease involves the reproduction and transmission of a causative organism (virus, bacteria, parasite, and fungi) from one host to another, resulting in an abnormal number of animals becoming infected. When effects and/or numbers of the organism result in impaired physiological function or performance, the infection has progressed to an epizootic disease. Endemism is the continued presence or persistence of a pathogen in a population or geographical area and may, or may not, be accompanied by clinical signs of disease. Infectious organisms are of two basic types: obligate and facultative. Obligate pathogens require a fish host to reproduce and survive for any length of time. Facultative organisms occur in the environment where they can survive and reproduce freely.

It is important to differentiate between infection – the presence of an infectious organism, and the conditions that manifest as disease. Fish may be infected, and carriers of an organism without being diseased. Many organisms are normally present in the aquatic environment, but do not cause disease. Under certain conditions, when an environmentally induced host-pathogen imbalance occurs, facultative organisms infect a normally resistant host and cause adverse pathology (Plumb 1994). Because disease is the interruption or dysfunction of normal physiological processes that are necessary for growth and survival, it generally involves major organs or primary physiological function (i.e. normal respiration by the gills, ion exchange in the kidney, etc).

Hatchery and Wild Fish Interactions

Hatchery and wild fish interactions can be controversial topics in fish health and natural resource management. While disease in the hatchery setting is often initiated by transmission of pathogens from wild fish (Oliver 2000,Wedemeyer 1996), hatchery dynamics can amplify disease and may contribute to increased numbers of pathogens in the natural environment. The specific mechanisms related to disease transmission between hatchery and wild fish are poorly understood.
It is important to study disease interactions between hatchery and wild fish in both controlled laboratory studies and in the natural environment in order to define the risks associated with hatchery diseases to natural fish populations.

Disease susceptibility to infectious organisms differs for wild fish in a natural environment compared to the artificial conditions that exist in a hatchery setting.
Stress is the most significant factor in the hatchery setting, and plays a major role in susceptibility to fish pathogens. Fish reared in hatchery settings are exposed to adverse environmental conditions including elevated temperatures, poor water quality, high density and frequent handling. These factors taken individually, and especially cumulatively, can cause significant strain on the defense mechanisms of the immune system. Many diseases of hatchery fish are associated with, or enhanced by, the stress associated with hatchery environment.

Wild fish are typically in equilibrium with endemic pathogens when environmental conditions are relatively normal, and natural outbreaks are rarely observed (Wedemeyer 2001). However,

environmental degradation and elevated water temperatures in natural settings pose many of the same stressors experienced by hatchery fish. It is equally important to our understanding of fish disease interactions to profile the health status of natural chinook and steelhead in order to understand what factors contribute to infection and disease progression. By understanding fish health in both hatchery and natural populations, we can determine what, if any, impacts hatchery fish may have on natural populations.

IHNV Transmission Studies

The U.S. Fish and Wildlife Service (USFWS) through the California-Nevada Fish Health Center (Ca-Nv FHC) has studied IHNV transmission at Coleman National Fish Hatchery (CNFH) for several years to determine the risks to natural fish populations below the hatchery in Battle Creek and in the Sacramento River. While experiments conducted on clinically infected Chinook indicated significant numbers of viral particles are shed from infected fish, disease transmission to healthy fish has been difficult to demonstrate (unpublished data, Foott and True 1996).

Surveys of 377 natural fall chinook fry in the upper Sacramento River in 1996 (Foott 1996) and 203 fall chinook sampled from the Red Bluff Diversion Dam RST in 1997 (True, unpublished data) did not detect IHNV, indicated this virus is not common in juvenile chinook.

Further studies to determine the minimum age that fish become infected with IHNV indicate that Chinook salmon become susceptible to infection by virus as yolk-fry. While young fish may be infected with low levels of viral agents, fry did not develop signs of clinical disease, nor progress in their infection levels over an 8 week period. This study also demonstrated that groups of fish subjected to stress mimicking hatchery handling did have increased titers of virus by approximately 10-fold compared to non-stressed groups. Even with higher viral titers, stressed fish failed to develop disease in two studies repeated over a 16 week period (unpublished data, True 1999).

More recent studies (Foott 2000) designed to mimic hatchery and wild fish interactions employed natural fish that were placed in co-habitation with fish artificially-infected with IHNV. Natural fish did not become infected or diseased despite a study design that included manipulations with the density of fish in individual units and the ratios of infected fish to natural fish per tank.

In summary, the Ca-Nv FHC has conducted several studies to determine the transmissibility of IHNV to natural chinook. Fall chinook have not demonstrated a high degree of susceptibility to infection with IHNV at the viral doses that would be expected in a river environment. Abstracts of these studies can be found in Appendix C, or on the Ca-Nv FHC website (http://www.r1.fws.gov/canvfhc/nwfhsman.htm).

Viral Strains and Genetic Analysis of Viral Traffic

Infections with IHNV have resulted in significant mortality at Feather River State Fish Hatchery (FRSFH) during early operation of the facility and up until the late 1970's (Pers. comm. Tresa Veck, CDFG 2004). IHNV epizootics have occurred more recently in 1998, 2000, 2001, causing significant losses of chinook salmon (DWR 2001). In 2000, a unique strain of IHNV, FR Type 2, was isolated from wild chinook exhibiting clinical signs below the FRSFH in snorkel surveys conducted by DWR. In 2002, FR Type 2 IHNV caused significant mortality in steelhead at FRSFH (Pers. comm. Dr.Bill Cox, CDFG 2002).

When unique or virulent strains of virus occur, genetic techniques tell much about the relatedness of a viral isolate to its predecessors in a watershed or larger geographical region. The literature contains several examples where genetic analysis is utilized to demonstrate the establishment of new viral strains or movement of existing strains in previously non infected chinook populations (Anderson 2000, Kurath 2003). Researchers at USGS-Western Fisheries Research Center in Seattle, Washington have also been successful in developing genetic techniques to analyze the phylogenetic relationship of viral isolates in the Columbia River basin (Kurath 1993). Previous work done by Dr. Kurath has shown dramatically different patterns of virus evolution under varying environmental conditions (Kurath 1999). This information can be analyzed from an epidemiological perspective to help identify viral sources following disease outbreaks, and demonstrate geographical movement of IHNV within a basin.

The close proximity of the Feather River to the Yuba watershed adds to the level of concern for potential impacts from IHNV, or other hatchery related diseases, to natural fish populations in this adjoining watershed. It is logical to hypothesize that IHNV can move both upstream and downstream in a watershed with migrating infected fish (Busch 1983, Groberg 1983). The primary concern is that this apparently virulent isolate could spread to other hatchery facilities and/or infect naturally produced steelhead in the Feather and Yuba Rivers. Therefore, for this study, it is important to fully characterize all IHNV isolates that are recovered from anadromous fish populations.

Dr. Ron Hedrick, University of California Davis (UCD) has been studying the FR Type 1 and 2 strains of IHNV to gain a better understanding of virulence factors and susceptibility of different salmonid hosts. Viral isolates obtained in this study will be submitted to UCD for strain typing analysis. Dr. Hedrick's laboratory will utilize polyclonal antibodies in serum neutralization assays, and has developed 3 antibodies against the IHNV type strain for the Sacramento River and the two unique FR strains. Sequence analysis of the mid G gene of the virus will also be preformed on a subset of the viral isolates. This strain typing work is an important step to understanding the prevalence, distribution and potential movements of IHNV within the basin.

Importance of Fish Health Monitoring

It is important to establish a baseline of the prevalence and distribution of IHNV and other significant fish pathogens in a watershed. Baseline information and continued monitoring is necessary to determine the changes that occur in prevalence and distribution of pathogens both spatially (geographical distribution and movement) and temporally (seasonality). Identification of strain types of IHNV by molecular methods can provide information about changes in the viral genome and virulence (LaPatra 1993a) . Molecular tools have been an extremely useful management tool in the Columbia River and similar work should be performed in the Sacramento basin.

For endemic pathogens such as *Infectious Hematopoietic Necrosis virus*, *Renibacterium salmoninarum* and *Ceratomyxa shasta*, the likelihood that these pathogens will persist is high now that they are established in the region. The severity of infection and distribution in the Yuba River is not well known (Pers.comm. Dr. Bill Cox, CDFG 2002). For facultative, or opportunistic organisms, environmental conditions can play a much larger role in the spatial and temporal changes that are observed. Comprehensive fish health monitoring can provide current data on fish diseases and help to elucidate the environmental conditions that lead to impaired fish health and disease susceptibility.

MAJOR FISH PATHOGENS

Specific pathogens that are vertically transmitted, difficult to control, or that become endemic in a fish population or watershed are of major concern. Significant diseases for salmonids include: Infectious Hematopoietic Necrosis (IHN) virus, *Renibacterium salmoninarum* (Bacterial Kidney Disease) and *Ceratomyxa shasta*. These pathogens are endemic to the Sacramento basin and have been routinely isolated from juvenile and adult chinook salmon at federal and state fish hatcheries including Coleman National Fish Hatchery (CNFH) on Battle Creek and the Feather River State Fish Hatchery (FRSFH) in Oroville.

Infectious Hematopoietic Necrosis Virus (IHNV)

Infectious hematopoietic necrosis virus (IHNV) is a significant viral pathogen of both cultured and wild salmon and trout throughout western North America (Williams and Amend, 1976; Groberg and Fryer, 1983; Meyers et al., 1998). IHNV is the type species of the newly recognized aquatic rhabdovirus genus *Novirhabdovirus* (Walker 2000) and causes acute disease in cultured and wild fish salmonids in both freshwater (Groberg and Fryer 1983, Williams and Amend 1976) and saltwater (Kent et al, 1988). IHNV is virtually endemic to all watersheds (Wolf 1988) in North America that support salmonid populations, and is endemic to chinook populations in several major rivers in Northern California (Sacramento, San Joaquin, and Feather River). IHNV is routinely isolated from adult stocks returning to state and federal hatcheries of the Sacramento basin and is routinely recovered from wild spawning salmonids with no clinical signs of IHNV(Mulcahy et al 1983, 1987. LaPatra et al. 1991a; Meyers1998). The virus is transmitted horizontally through the water column and vertically via egg surfaces. Epizootics in hatchery populations of Fall and Late-fall chinook cause significant losses. Steelhead juveniles are generally considered non-susceptible to the specific strain of IHNV (type IV) found in California, as compared to strains found elsewhere in the Pacific Northwest, with the exceptions noted for the FR-2 strain.

***Renibacterium salmoninarum* - Bacterial Kidney Disease (BKD)**

Another significant fish disease, termed Bacterial Kidney Disease (BKD), is caused by the gram-positive bacteria *Renibacterium salmoninarum* and is vertically transmitted, within the ova, from the female adult to progeny. *Renibacterium salmoninarum* causes Bacterial Kidney Disease (BKD) in both hatchery and natural salmonid stocks (Fryer, 1981 and Bullock, 1988) and is a chronic infection which can be systemic but primarily impairs normal kidney function. The most significant impairment caused by this bacterium is the inability of infected smolts to osmoregulate properly as they transition to salt water, resulting in smolt mortality and/or poor early ocean survival.

Ceratomyxa shasta - Ceratomyxosis

The parasite *Ceratomyxa shasta* is included in the taxonomic class *Myxosporea* (Hoffman 1999) and causes the disease referred to as Ceratomyxosis in salmonids. The parasite causes acute inflammation of the intestine and visceral organs leading to death (Bartholomew 1989). *C.shasta* has a complicated life cycle with two life stages, which includes development of an actinosporean in the aquatic worm *Manayunkia speciosa* and a myxosporean stage that develops in salmonids. The distribution of the polycheate likely defines the geographical distribution of this pathogen (Bartholomew 2001).

OTHER PATHOGENS

A parasite of concern is another myxosporidean *Myxobolus cerebralis* which causes Whirling Disease (Markiw 1992b). This parasite has two life stages involving a polycheate worm (Tubifex tubifex) and salmonids. The parasite infects the epithelium of young fish, and then migrates

through neural tissue and the spinal column where it infects soft cartilage in the brain prior to bone ossification. The parasite undergoes asexual mitosis in the cartilage and forms myxosporean spores (Moeller 2001). While Whirling Disease has garnered much concern and study in the Rocky Mountain states, the effects of the disease have been less severe in California salmonid populations (Modin 1998).

YUBA RIVER

The Yuba River watershed is a major tributary to the Sacramento River system and essential water resource in Northern California. From it's headwaters in the Sierra Nevada, the river is comprised of three forks; the North, the Middle, and the South.

The forks flow west through rugged canyons toward their confluence in California's northern Central Valley. The North Fork flows first into New Bullards Bar Reservoir, then is joined by the Middle Fork 5 miles below the New Bullards Bar Dam. The South Fork is born from run off out of Lake Angela at Donner Pass in the Sierra Nevada, and runs 64 miles before joining the other two forks at Englebright Reservoir. In total, the watershed drains over 1,300 square miles before flowing into the Feather River at Marysville, CA. The Feather River then joins the Sacramento River as it heads toward the San Francisco Bay and the Pacific Ocean.

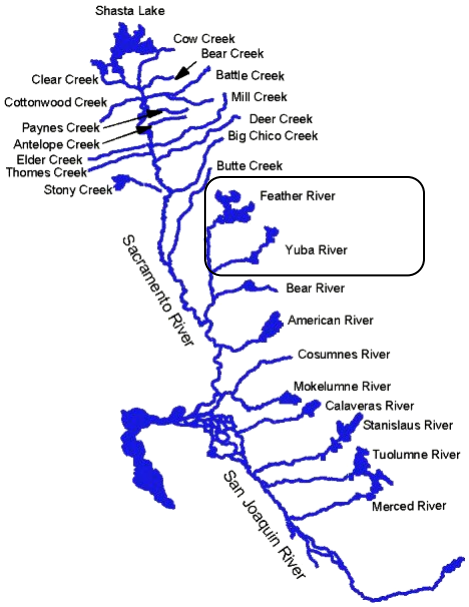


Figure 3. Map of Feather and Yuba Rivers in Sacramento River basin.

The Yuba watershed is a vital resource for wild chinook and steelhead fisheries, drinking and irrigation water for many municipalities, hydroelectric power, and recreational use in a 39-mile stretch of the South Yuba designated as Wild and Scenic in 1999.

Ecological Impacts to the Yuba Watershed

Hydraulic Mining

Historically, the Yuba was the most heavily mined basin in the Sierra Nevada. Mining was halted, due to severe environmental degradation, in the mid 1900's. The changes to normal hydrological function that occurred in the Yuba River as a result of the late 1800s hydraulic mining was one of the most dramatic environmental events in California history. Thousands of acre-feet of sediment entered the river channel, causing the Yuba River channel near Yuba City to rise 90 feet, which led to repeated flooding for decades (Mount 1954).

Effects of mining are still seen today in perturbed hydrology, heavy sedimentation and the accumulation of arsenic and mercury contaminants in certain tailings in the Yuba. Several of the dams on the Yuba were built to contain sediment or control flooding that resulted from hydraulic mining operations.

Dams

The Yuba River system has become one of the most dammed and diverted water systems in the Sierra Nevada. Twenty significant dams have been built throughout the watershed. The largest are the New Bullards Bar Dam, and Englebright Dam which forms the Englebright Reservoir.

The North Yuba begins below Yuba Pass near State Highway 49 at an elevation of 6701 feet. It runs near the state highway as far down the valley as Downieville, where it heads westward to New Bullards Bar Reservoir.

The Middle Yuba originates from snow runoff gathered at Jackson Meadows Reservoir in Sierra County. It flows through steep, narrow canyons to the 75 ft. Our House Dam, just south of Camptonville. There it is diverted into a 3.8 mile-long tunnel that conveys the water to Oregon Creek, as described in two agreements with the Federal Regulatory Commission (FERC) and California Department of Fish and Game(CDFG). Middle Yuba and Oregon Creek water is diverted into a second 1.2 mile-long tunnel that flows into New Bullards Bar reservoir.

Bullards Bar Reservoir is the 11th largest reservoir in California, holding nearly 1 million acre-feet of water from Upper Yuba, Middle Yuba and Oregon Creek. In the 16 mile-long reservoir, water from the North Yuba and Middle Yuba are combined and utilized for hydropower generation at New Colgate Powerhouse at Bullards Bar Dam, operated by the Yuba County Water Agency (YCWA). Bullard Bar Dam was built in 1969 primarily for flood control. Major flooding occurred in the valley near Marysville and Yuba City in 1950, 1955, 1964, 1986, and 1997.

South Yuba flows through Placer and Nevada counties as it is joined by numerous small and large creeks on its way to Bridgeport. There it reaches it's confluence with the Middle Yuba, and is joined by the North Yuba (out of New Bullards Bar Reservoir). The Yuba flows into Englebright Reservoir, which was created by the 180-foot Englebright Dam built by the U.S. Army Corps of Engineers (USACE) in 1941. The original purpose of the Englebright dam was to trap gold mining debris to keep them out of the lower river. However, it also completely blocks 39 miles of suitable fish habitat on the South Yuba and 16 miles on the North and Middle Yuba Rivers. Englebright Dam was retrofitted after its construction for hydropower generation. Water is moved through two tunnels through turbines at the Narrows 1 Powerhouse owned and operated by PG&E, and Narrows 2 Powerhouse which is owned and operated by Yuba County Water Agency.

The three rivers are combined as they flow through the Yuba Goldfields and reach the Daguerra Point Dam (built by USACE in 1906) 12.3 miles below Englebright Dam. Neither Englebright nor Daguerra Dam provide flood control: both dams were built as debris dams, however Daguerra Dam now serves as a diversion site for irrigation canals.

Non-Native Fish Species

Biologically, the Yuba River system, including the associated reservoirs, holds a number of cold and warm water fish species, many of which have been introduced and are popular for recreational fishing. Hydraulic mining in the Yuba watershed has greatly impacted the diversity and number of fish species present. Habitat was transformed from shady, pool and riffle streams into long, exposed runs. The South Yuba presently contains only remnant populations of pikeminnow (*Ptychocheilus grandis*), hardhead (*Mylopharodon conocephalus*) and suckers (*Catostomus sp.*) (Moyle 2002). Other native species are missing altogether (Gard 1994).
Englebright Lake and the upper river support brown trout (*Salvelinus fontinalis*), resident rainbow trout (*Oncorhynchus mykiss*), largemouth (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieu*) , channel catfish (*Ictaluris punctatus*) and pikeminnow.

Water quality

Water quality in the Yuba River watershed has improved since the heavy sedimentation and contamination that occurred during the mining era. Efforts are under way to protect aquatic species

and humans from exposure to contaminants including actions such as listing by the Environmental Protection Agency (EPA) of the Lava Cap Mine Site as a Superfund National Priority Site.

In 2001, elevated levels of fecal coliform (*Enterococcus* bacteria) were identified in the South Fork of the Yuba, at Edward's Crossing. Public access and swimming were closed for a period of time, and the cause of the coliform contamination remains unknown (Pers. Comm. Janet Cohen, South Yuba River Citizens League-SYRCL 2002).

Other concerns about water quality in the Yuba system include fluctuating water levels and temperatures as related to migratory salmonids. To encourage the populations of these native species, certain minimum flow and maximum temperature requirements are needed to keep their spawning and rearing grounds available and adequate.

Fish Health in Natural Populations

The major concerns for this watershed involve hatchery and wild fish interactions in terms of disease transmission. These issues are being addressed by this study and in the current FERC re-licensing studies.

Despite the above listed issues of contamination, habitat degradation, and water quality, fish health in the Yuba river system appears to be relatively good. Major disease outbreaks in natural adult or juvenile fish populations have not been reported. It should be noted, however, that natural disease outbreaks are seldom observed and comprehensive fish health monitoring will be needed to ascertain the health status of fish populations in the Yuba River.

Adult pre spawn mortality of fall Chinook in the Yuba river and Feather River needs further study as well. In recent years, pre-spawn mortality has been observed in returning adults, during carcass surveys. Water quality at those times (primarily defined by temperature and dissolved oxygen) was relatively good compared to previous years (Pers. comm. Stephanie Theis, Jones and Stokes 2004). Fish health assessments of returning adults can determine if pre-spawn mortality is related to infectious processes or contaminants as determined by histological exams.

FEATHER RIVER

The lower Feather River is located within the Central Valley of California and drains the western slope of the Sierra Nevada. The reach of river below Oroville Dam to the confluence with the Sacramento River is low gradient and consists of several structures. These include the Thermalito Forebay, Afterbay, and the Fish Barrier Dam (rm 67) at the Feather River State Fish Hatchery (FRSFH). The state hatchery in Oroville which was constructed by Department of Water Resources to mitigate for habitat loss in the upper Feather River.

Lake Oroville was created with the completion of the Oroville Dam in 1967, and has a capacity of approximately 3.5 million acre feet. The reservoir is multi-use providing flood control, municipal water supply, hydropower, and recreation.

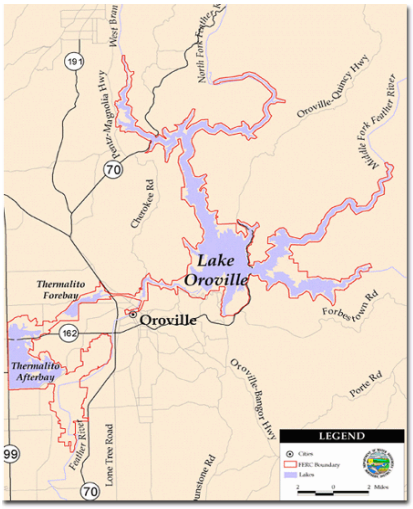


Figure 4. Upper Feather River drainage (Source: DWR–Oroville Facilities re-licensing website.

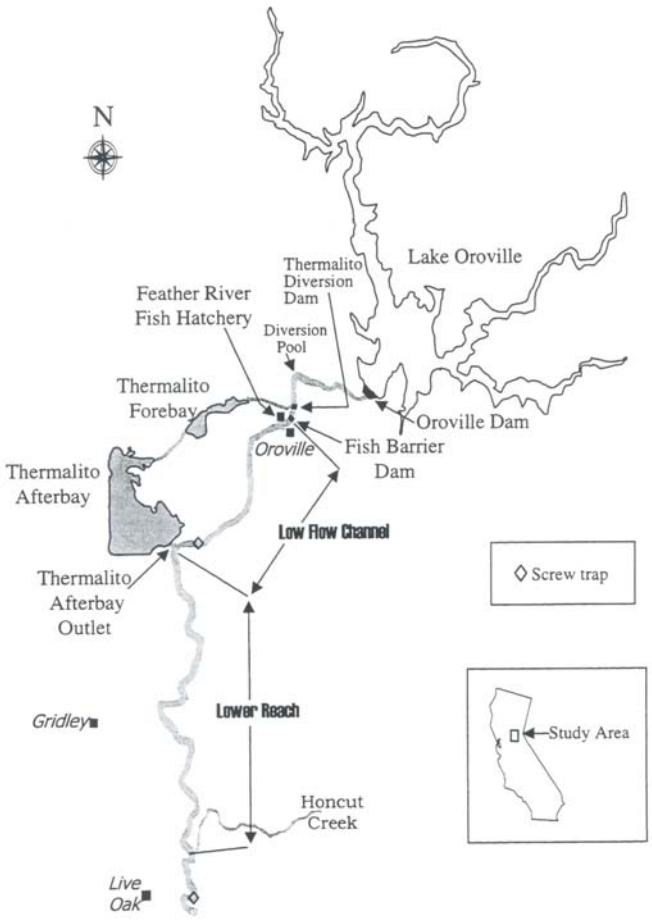


Figure 5. Feather River study site.
Source: DWR –Feather River Study 1997-1998.

The majority of water released from Lake Oroville is diverted at Thermalito Diversion Dam into the Power Canal and Thermalito Forebay.

Hydropower is produced as water flows from the Forebay to the Afterbay and then is returned to the Feather River via the Thermalito Afterbay Outlet. The remainder of flow, approximately 500 cubic feet per second (cfs) is released into the historic river channel termed the Low Flow Channel where natural production of chinook salmon occurs. The Fish Barrier Dam is the upper limit for upstream migrating fish.

Rotary screw traps are operated by DWR just above the Thermalito Afterbay outlet (Thermalito RST- approximately rm60) and just upstream of the Gridley boat launch (Gridley RST – approximately rm 50). The majority of juvenile salmon collected by these traps are parr, and averaged from 27-115mm, indicating that most of the fall chinook emigrate below the low flow channel well before smoltification.

The California-Nevada Fish Health Center (CaNv FHC) assessed fish health and tested for major fish pathogens in natural juvenile fall chinook (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) in the Yuba River. Fish were collected by Rotary Screw Trap (RSTR), operated by CDFG, from February through July in 2002.

Non-salmonids, limited to Hardhead (*Mylopharodon conocephalus*), were collected from the SF Yuba near Purdon Crossing in July 2002.

Fish health assessments continued in the Yuba River in 2003. Fall Chinook, steelhead and non-salmonids were collected by beach seine and electro-fishing on the main stem (Hwy 20 bridge), the SF (Hwy49 bridge) and the MF Yuba (Hwy 49 bridge) from April through July.

Adult fall Chinook were collected in cooperation with carcass surveys conducted on the Yuba by Jones & Stokes from October through November in 2003. Thirty kidneys were collected from carcasses in three reaches:Parks Bar, Rose Bar and Daguerra Dam. A total of ninety fish were sampled to assess the prevalence and distribution of IHNV in returning adults.

Juvenile fall chinook were collected by rotary screw trap in the Feather River, operated by DWR, from February through March in 2002.

Adult fall Chinook were collected in cooperation with carcass surveys conducted on the Feather River by DWR on October 27, 2003. Eighty-seven kidney tissues were collected from carcasses located below Feather River SFH

Additional adult fall Chinook were collected from Clear Creek, near Redding on October 29, 2003. 46 kidneys were collected from chinook carcasses and tested to assess the prevalence and distribution of IHNV in returning adults.

The methods used to collect, process, and test fish tissues are standardized throughout the country for the National Wild Fish Health Survey (NWFHS). The detailed procedures and laboratory protocols can be found in The National Wild Fish Health Survey Procedures Manual (True 2000) at the following websites:

NWFHS	http://fisheries.fws.gov/FHC/FHCNational.htm.
CaNv Fish Health Center	http://www.r1.fws.gov/canvfhc/nwfhsman.htm

Organosomatic Indices

A subset of twenty individual fish were weighed (0.1 g) and measured (total length, mm) to determine condition factor (KTL = W/L^3x10,000).

Parasitology

Fish were then examined externally and internally for clinical signs of disease and any organ abnormalities. Mucus samples (skin scrape) and gill tissues were examined for parasites and general morphology with light microscopy at 40-450x magnification.

Bacteriology

A sample of kidney tissue from fish of appropriate size was streaked onto 100 mm petri plates, or 20 x 125 mm test tube slants, of Brain Heart Infusion Agar (BHIA) and incubated at room temperature for 72 hours. If growth appeared on the BHIA media, isolated colonies were subcultured onto new BHIA plates to supply bacteria for phenotypic characterization and presumptive identification. Subcultured isolates were screened for bacterial fish pathogens by standard microscopy (Gram characteristics, morphology and motility) and appropriate biochemical tests. Bacterial isolates that were ubiquitous in freshwater and without associated clinical signs were identified to a general group, while those that were potential fish pathogens such as *Aeromonas salmonicida*, or *Yersinia ruckeri* were examined to a presumptive identity. Corroborative testing of positive bacterial isolates was done by Fluorescent Antibody Testing (FAT).

Renibacterium salmoninarum by ELISA

Kidney tissue from fish of appropriate size was removed and diluted 1:8 with Phosphate Buffer Saline (PBS) with Tween 20, homogenized, and separated by centrifugation. The samples were then loaded onto 96-well plates assayed by Enzyme Linked Immunosorbent Assay (ELISA) for the presence of *Renibacterium salmoninarum* antigen (Pascho 1987) . The ELISA was run in replicate when the quantity of kidney tissue from individual fish was sufficient. The absorbency values, measured as optical density(OD), were averaged for replicate wells. Individual fish with ELISA OD values greater than 2 standard deviations above the negative reference control OD, and up to 0.200, were defined as low level infections, 0.201-.999 moderate level, and values of 1.00 or higher were considered high infection levels. Corroborative testing of positive ELISA samples was done by Polymerase Chain Reaction (PCR).

Polymerase Chain Reaction (confirmation testing for *R.salmoninarum*)

Kidney samples are tested using Quantitative PCR, which detects and quantifies the specific P57 DNA sequences from *Renibacterium salmoninarum* (Chase 1998, Maniatis 1982). When Rs DNA is present, the quantity of DNA is increased with each amplification cycle of the assay and exceeds

normal background levels of fluorescence. The cycle number when this occurs provides relative quantification of DNA present in the original kidney tissue.

Positive Controls used in the assay are cultured *R.salmonarum* cells (ATCC 33206) diluted 1:5 in PBS and extracted in the same manner as kidney sample sets.

Virology

Samples of kidney and spleen, or visceral tissue in the case of smaller fish, were removed from each fish to assay for the prevalence of Infectious Hematopoietic Necrosis Virus (IHNV), Viral Hemorrhagic Septicemia Virus (VHSV), and Infectious Pancreatic Necrosis Virus (IPNV) using accepted cell culture techniques (True 2000, AFS Blue Book 2003). Kidney and spleen tissues from 3 fish were pooled into one sample, but occasionally 4-5 fish were pooled when the total number of fish was not a multiple of three. For cell culture assay, tissue samples were weighed and diluted to 1:10 in Hank's Balanced Salt Solution (HBSS) and homogenized with a Stomacher 80 Lab Blender®. Samples were centrifuged at 5000 x g for 15 m and then 1.0 mL of the supernatant was combined with 1mL of HBSS supplemented with antibiotics and antimycotic (200 IU mL-1 penicillin G, 200 IU mL-1 streptomycin, 0.5 µg mL-1 amphotericin B and 40 µg mL-1 gentamycin). Final sample dilutions of 1:20 and 1:100 were inoculated onto confluent Chinook Salmon Embryo 214 (CHSE-214), Epithelioma Papillosum Cyprinid (EPC), and Fat Head Minnow (FHM) cell lines in replicate wells of 48-well plates. Samples were incubated on a platform rocker for 30-60 m at 15°C and then 0.5 mL Minimum Essential Media (MEM) with 5% Fetal Bovine Serum (FBS) was added to each well. Plates were incubated at 15°C for 21 d and were examined bi-weekly for evidence of cytopathic effects (CPE). Corroborative testing of positive viral results utilized Immunohistochemistry techniques (Drolet 1993) using a Diagxotics (Wilton, CT) universal antibody (14D) against IHNV and a Vectastain Laboratories® (Burlingame, CA) Horseradish Peroxidase Kit.

Myxobolus cerebralis (Whirling Disease)

Screening for *Myxobolus cerebralis*, the causative agent of Whirling Disease, was done by Pepsin-Trypsin Digest (PTD) of cranial elements consisting of bone and cartilage. Sampled salmonids were decapitated and the heads grouped into pools of 5 fish, then frozen until laboratory analysis could be performed. The heads were heated in a 60°C water bath for 60 m, so that the cranial elements could be removed from the soft flesh. The cranial elements were then ground in a blender and placed in a pepsin solution of 20 mL g-1 of tissue, and incubated at 37°C for 40 m. The samples were centrifuged, supernatant removed, and digested in a solution of trypsin at 20 mL g-1 of tissue. Samples were incubated at room temperature on a rocker plate for 30 m. The larger remaining particles were filtered through cheesecloth and the samples were centrifuged a final time, prior to discarding the supernatant. A small amount of water was added to the pelleted preparation to provide adequate solution volume in which samples could be examined by phase contrast microscopy at 200-400x. If tissues were positive for myxosporean parasites, corroborative testing was done by PCR.

Histology

During field dissection, target organs were rapidly removed from the fish, or whole fish were fixed in Davidson's Fixative or Prefer Fixative (Anatech, Battle Creek, MI) for 24-48 hours. Tissues were processed for 5 m paraffin sections and stained with hematoxylin and eosin (Humason 1979). All tissues for a given fish were placed on one slide and identified by a unique code number. Each slide was examined at both low (40X) and high magnification (400X) for internal and intracellular

parasites, and tissue changes associated with disease. Presence or absence of the metacercarial stage of *Nanophyetus salmonicola* (presumptive) in the posterior kidney was noted. If typical *C. shasta* trophozoites were observed in the intestine the infections were rated as light or heavy based on the number of parasites observed (>10 parasites in section = heavy).

2002 Yuba River – Juvenile Monitoring on the Main stem (RST) and SF Yuba at Purdon Crossing

Fall Chinook and steelhead were sampled at the main stem Yuba RST, RM 6 near Marysville (N39.10.55.92; W121.30.23.22) on Feb 12, Mar 21, and May 14. During the March period, the RST was capturing approximately 500-1000 fall Chinook per day, and 100-200 fish/day on May 14.
Few Steelhead were collected by RST on Mar 21 (n=3) and May 14 (n=6). Two Bluegill were collected by RST on Mar21 and examined for viruses and bacteria and found negative. Hardhead were the only species of fish collected by beach seine and electrofishing at Purdon Crossing on the south fork the Yuba on July 11.

Figure 6. Rotary screw trap on Yuba River, near Marysville. Photo: K.True (USFWS)

Fall Chinook

Juveniles collected at the Marysville RST appeared normal and growing well between February and May 2002. With the exception of some skin abrasions and scale loss, fish were in good conditions and very few abnormalities were noted (see organosomatic datasheet – Appendix A).

Fish had normal fat scores indicative of natural fish, and grew an average of 13mm in the period from Feb 12 to Mar 21. Condition factor (TL-KTL) also increased from 0.559 to .636 during this period, indicating that fish were gaining weight as well as length.

Only 1 fish was observed with anemia on Mar 21. Anemia is a common clinical sign of viral infection, however virus was not detected in the kidney and spleen tissues.

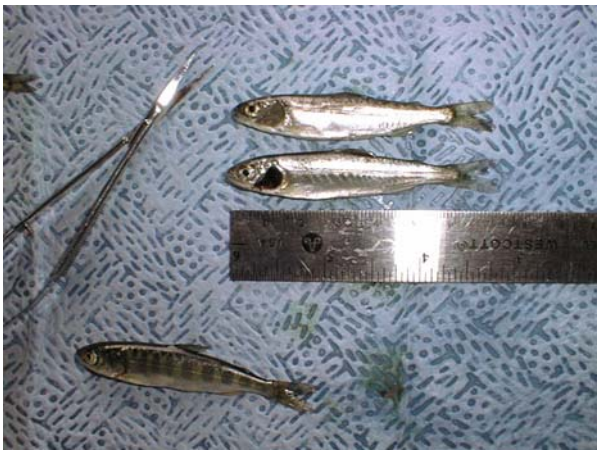


Figure 7. Fall Chinook with anemic gills (top) and normal gills (bottom). Photo: K.True (USFWS)

Other abnormalities included coagulated yolk syndrome in a few fish sampled Feb 12. Coagulated yolk is generally caused by trauma to alevins during a sensitive period prior to complete absorption of the yolk sac. High flows that occurred in the Yuba the week prior, may have mechanically traumatized fish within redds, or displaced sac-fry into the river earlier than they would have normally emerged.

Parasitology exams were conducted on the larger fish collected Mar 21 by standard skin and gill scrapes and microscopic examination at 200-600x using phase contrast. Internal organs and the intestinal tracts were also examined for helminths and spores of *Ceratomyxa shasta*. No parasites were observed on the skin, gill, abdominal cavity or in the intestine.

Histology was performed on 4 fish and no inflammatory response or lesions associated with the coagulation yolk were noted. No internal parasites were observed histologically (see pathology reports, Appendix B).

Figure 8. Fall chinook smolts from Yuba RST (May 14 2002) Photo: K.True (USFWS)

Fish collected on May 14, 2003 were well developed smolts and appeared in excellent condition. Forklengths ranged from 61-89mm, with an average length of 70.8mm. Twenty fish were examined by organosomatic index and no abnormalities were noted.
Laboratory testing was negative for all major fish pathogens (Table 3)

Table 3. Summary of Sample Location and Assays Performed for fall chinook in the Yuba River in 2002

Sample Date	Location	No. Fish Examined	Assays Performed	Test Results	Remarks
Feb 12	Main stem RST (Marysville)	20	Organosomatic Index	Normal	Coag yolk observed 2/20 Darkened peduncle 1/20 Some scale loss/fin erosion 2/20 Fat scores normal (natural fish)
		415	Virology	Negative	
		4	Histology	Normal	No internal parasites
		30	Pepsin-Trypsin Digest (Whirling disease)	Negative	
Mar 21	Main stem RST (Marysville)	30	Organosomatic Index	Normal	Severe anemia 1/30
		245	Virology	Negative	
		10	Parasitology	Negative	No externals or *C.shasta*
May 14	Main stem RST (Marysville)	20	Organosomatic Index	Normal	
		40	Virology	Negative	
		30	Bacteriology	Negative	
		30	Pepsin-Trypsin Digest (Whirling disease)	Negative	
Total No. Fish Examined per Assay:					
			Organosomatic Index	**70**	
			Virology	**700**	
			Histology	**4**	
			Bacteriology	**30**	
			Digest – Whirling Disease	**60**	

Steelhead

Sample numbers of steelhead were very low due to inefficiency of RSTs to capture this species. A total of 3 fish were examined on Mar 21 ranging in size from 75-99mm. Six fish were examined on May 14, with size ranges of 81-122mm. Fish appeared normal on both collection dates with the exception of some pectoral fin erosion in one fish. Fish were large enough to sample blood for hematocrits (percent of whole blood that is comprised of red blood cells). Values were within normal ranges of 35-45% packed red blood cells. The mean hematocrit value increased from 36% on Mar 21 to 44% on May 14, however with the small sample sizes of fish collected, it cannot be determined if this increase was a significant change in percentage of red blood cells.

Figure 9. Steelhead collected from Yuba River RST Mar 2002 Photo: K.True (USFWS)

ELISA testing showed elevated OD values indicative of the presence of soluble P57 protein of *Renibacterium salmoninarum* in the 9 fish sampled. Polymerase Chain Reaction using primers specific to *R.salmoninarum* confirmed the presence of DNA in the steelhead. Soluble protein alone can indicate prior exposure, but not necessarily active infection with *R.salmoninarum*. However, the confirmation of bacterial DNA of *R.salmoninarum* indicates that fish are actively infected with this bacteria. However, the infection level was very low and does not pose a significant health risk.

Other bacteria, *Aeromonas hydrophila* (1/6 fish) and *Micrococcus spp*. (1/6 fish) were cultured from steelhead sampled on May 14. *Aeromonas hydrophila* is generally considered an opportunistic bacteria that infects fish when they are handled and stressed, such as in a hatchery setting, or when environmental conditions are degraded. Steelhead had been held in the trap for an extended period of time (over 24 hours) to provide samples for the fish health assessments. Holding these steelhead for this period may have compromised the immune system sufficiently to permit opportunistic bacterial infections, or the fish may have harbored these bacteria prior to capture. No clinical signs of bacteremia (swollen kidney or internal hemorrhaging) were observed in the fish on field exam, and despite isolation of bacteria in 15% of the fish tested, these fish did not appear clinically diseased.

Noteworthy for the May 14 collection of steelhead is the observation that all fish examined, size range of 81-122 TLNG(mm) were females with clearly discernable ova. This indicates the initiation of the reproductive cycle for these presumed steelhead yearlings collected in the main stem Yuba.

Table 4. Summary of Sample Location and Assays Performed for steelhead in the Yuba River in 2002

Sample Date	Location	No. Fish Examined	Assays Performed	Test Results	Remarks
Mar 21	Main stem RST (Marysville)	3	Organosomatic Index	Normal	Hct range: 32-42 (mean=36)
		3	Virology	Negative	
		3	Bacteriology (culturable)	Negative	
		3	Bacteriology/ELISA (Bacterial Kidney Disease)	Negative	
		3	Parasitology	Negative	No externals or *C.shasta*
		3	Pepsin-Trypsin Digest (Whirling disease)	Negative	
May 14	Main stem RST (Marysville)	6	Organosomatic Index	Normal	Hct range: 32-55 (mean=44) Moderate gill hyperplasia 1/3 All females with developing gonads
		6	Virology	Negative	
		6	Bacteriology (culturable)	+1/6 +1/6	*Aeromonas hydrophila* *Micrococcus spp.*
		6	Bacteriology/ELISA (Bacterial Kidney Disease)	+1/6	*Renibacterium salmoninarum* (Confirmed by PCR)
		6	Parasitology	Negative	
		6	Pepsin-Trypsin Digest (Whirling disease)	Negative	
Total No. Fish Examined per Assay:					
			Organosomatic Index	**9**	
			Virology	**9**	
			Bacteriology (cultured)	**9**	
			Bacteriology/ELISA	**9**	
			Parasitology	**9**	
			Digest – Whirling Disease	**9**	

Hardhead – South Fork Yuba at Purdon Crossing

Thirty-five Hardheads (*Mylopharodon conocephalus*) were collected at Purdon Crossing in July 2002 by beach seine, cast net, and electrofishing. The site had very little cover in the month of July, some deep pools but primarily slow, shallow reaches where water temperatures reached 75.8F (ambient air temperatures were >100F). Hardhead were the only species observed with the exception of a few unidentified larval fish. This site was selected due to the presence of fecal coliforms in 2001 (*Enterococcus spp*) which closed the area to public use. While we would not normally expect to isolate coliforms (enteric bacteria of warm blooded mammals) from poikilothermic fish, the elevated summer water temperatures could possibly support these bacteria in the water column for limited periods of time.

Figure 10. Purdon Crossing – South Fork Yuba
Photo: K.True (USFWS)

Virology was negative for the 35 fish tested. *Pseudomonad spp*. bacteria were cultured from 10/35 (29%) indicating systemic infection by this opportunistic bacterium which is most likely due to the environmental stress associated with the elevated water temperature.

Yuba 2003 – Juvenile Monitoring on the Main stem and Upper Tributaries

Main stem Yuba

Fall Chinook were sampling on the main stem Yuba at the highway 20 bridge on Apr 1 and June 11, 2003. Non-salmonids were sampled from the upper tributaries on Jul 23 at the highway 49 bridge on the SF and on the MF of the Yuba river.

Fall Chinook Juveniles

Juveniles were collected by beach seine at the Hwy 20 bridge on the main stem on Apr 1 (N39.13.205' W121.19.949'). Large numbers of juveniles were holding in back eddy areas within remnant side channels which provided decreased flows and some woody debris cover.

Over 290 fish were sampled for virus and 60 fish were tested for bacteria. Twenty fish were examined by organosomatic index. Fish were healthy and averaged 45.5mm in fork length. Fat scores were low, but within expected range for natural fish. Histology was performed on 10 fish and no significant health problems or parasite infections were detected, including *C.shasta* (organosomatic index and pathology report - Appendix A and B).

Figure 11. Beach seining main stem Yuba near Hwy 20 bridge Photo:K.True (USFWS)

Fish were sampled again on Jun 11 at this site, and 205 fish were tested for virus, 30 for bacteria and a 20 fish for organosomatic index. Virology was negative, however the bacterium *Yersinia ruckeri* was isolated from 1/30 fish tested.

Steelhead Juveniles

Sixty steelhead juveniles were collected by beach seine at the Hwy 20 bridge on the main stem on Jun 11. Twenty fish were examined for organosomatic index, and 60 fish for virology. Fish were too small (mean forklength 44.5mm) to perform bacteriology, ELISA, or test for *Myxobolus cerebralis* (Whirling Disease).

Non-salmonids

Sacramento sucker (*Catostomus occidentitalis*) were also collected by beach seine on Jun 11, 2003. Twelve fish were tested and found negative for viral and bacterial pathogens.

Figure 12. Field exams of rainbow trout collected from the Yuba RST
Photo: K.True (USFWS)

Table 5. Summary of Sample Location and Assays Performed for all fish species in the main stem Yuba River in 2003

Sample Date	Location	Spp and No. Fish	Assays Performed	Test Results	Remarks
Apr 1	Main stem (Hwy 20 bridge)	**Chinook** 20	Organosomatic Index	Normal	
		291	Virology	Negative	
		30	Bacteriology	Negative	
		10	Histology	Normal	No internal parasites
Jun 11	Main stem (Hwy 20 bridge)	**Chinook** 20	Organosomatic Index	Normal	
		205	Virology	Negative	
		30	Bacteriology	+1/30	*Yersinia ruckeri*
Total No. Fall Chinook Examined per Assay:					
			Organosomatic Index	**40**	
			Virology	**496**	
			Histology	**10**	
			Bacteriology	**60**	
Jun 11	Main stem (Hwy 20 bridge)	**Steelhead** 20	Organosomatic Index	Normal	
		60	Virology	Negative	
Jun 11	Main stem (Hwy 20 bridge)	**Sucker** 12	Virology	Negative	
		12	Bacteriology	Negative	

Upper Tributaries – SF and MF Yuba River

Rainbow trout and Non-salmonids

Fish were sampled by electrofishing on the South Fork of the Yuba near Hwy 49 bridge on Jul 23. Limited numbers of rainbow trout (*Oncorhynchus mykiss*), small mouth bass (*Micropterus dolomieui*) and hardhead were collected at two sites approximately ½ mile and 1 mile upstream of the Hwy 49 bridge. No clinical signs of disease were present in any of the fish sampled, and all laboratory tests were negative (Table 6).

Non-salmonid fish species were also collected by electrofishing on the Middle Fork of the Yuba at the intersection of Hwy 49, near the town of North San Juan. Sacramento sucker, small mouth bass and hardheads were sampled and found negative for fish viruses. The Sacramento suckers had *Aeromonas hydrophila* and *Pseudomonad spp.* bacteria cultured from kidney tissue from individual fish. With the small sample size per fish species and lack of clinical signs of disease upon field examination, the finding of these common bacteria is probably not significant to the health status of the non-salmonid fish populations in the upper tributaries.

Figure 13. SF Yuba near Hwy 49.

Table 6. Summary of Sample Location and Assays Performed for all fish species in the upper Yuba tributaries in 2003

Sample Date	Location	Spp and No. Fish Examined	Assays Performed	Test Results	Remarks
Jul 23	South Fork (Hwy 49 bridge)	**Rainbow** 1	Virology	Negative	
		1	Bacteriology	Negative	
		1	Pepsin-Trypsin Digest (Whirling Disease)	Negative	
		Hardhead 21	Virology	Negative	
		21	Bacteriology	Negative	
Jun 23	Middle Fork (Hwy 20 bridge)	**Sucker** 12	Virology	Negative	
		12	Bacteriology	+1/12 +1/12	*Aeromonas hydrophila* *Pseudomonas spp.*
		Hardhead 16	Virology	Negative	
		16	Bacteriology	Negative	
		Small mouth bass 5	Virology	Negative	
		5	Bacteriology	Negative	
Total No. Fish Sampled by Species:			**Rainbow trout**	1	
			Hardhead	**37**	
			Sacramento Sucker	**12**	
			Small mouth bass	**5**	

Feather River 2003 – Juvenile Monitoring (RST) of Fall Chinook salmon in the Low Flow Channel (LFC) above Thermalito Afterbay

Juvenile fall Chinook salmon were collected at the RST, operated by Department of Water Resources (DWR) in the low flow channel just upstream of the Thermalito Afterbay (TAB) on Feb 19, Mar 11 and Mar 27 and from the Gridley Boat Launch (GBL) on Mar 27.

Fish were just buttoning-up (sac fry) on Feb 19 when the trap was averaging 5000 fish per day. Juveniles appeared normal and growing well between February and late March 2003 with an average forklength of 37.8 and 47.9mm, and condition factor of 0.82 and 0.83, respectively.

By Mar 27, only 8 fall Chinook were captured in the RST and 2/8 of these fish had clinical signs of white spot disease caused by the ciliate *Ichthyopthirius multifilis,* commonly referred to as Ich. Parasite loads of this ciliate were moderate to heavy on the two fish infected. Because of the low sample numbers at the TAB RST, additional fish were collected from the next site downstream, the Gridley Boat Launch (rm 42), where traps were still collected ~200/day. The sample size needed to detect fish pathogens at a 5% prevalence is 60 fish (Ossiander 1973).

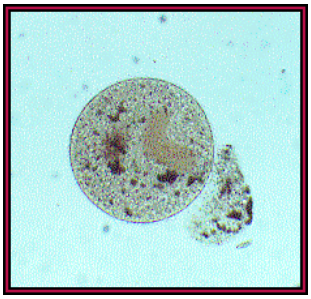


Figure 14. ***Ichthyopthirius multifilus*** **protozoan parasite of the skin and gills.**

Fish at the Gridley site appeared normal, and were comparable in size and condition factor to fish sampled at the low flow channel above TAB.
Ich was not observed on fish from this site.
Viral samples were collected from 153 fish and 30 fish were tested for culturable bacteria. Fish were too small to test for *Renibacterium salmoninarum* by ELISA (Bacterial Kidney Disease).
See summary of test results - Table 7.

Histology was performed on 10 fish from the TAB RST on Feb19 and ten fish from the GBL RST on Mar 27. Ich was also seen in histological sections of fish collected Mar 27 . No other significant abnormalities or lesions were observed in the fish sampled. *Ceratomyxa shasta* was not observed in either sample set (Appendix B – Pathology Reports).

Table 7. Summary of Sample Location and Assays Performed for fall chinook in the Feather River in 2003

Sample Date	Location	No. Fish Examined	Assays Performed	Test Results	Remarks
Feb 19	Thermalito RST (above TAB)	20	Organosomatic Index	Normal	
		153	Virology	Negative	
		10	Histology	Normal	No internal abnormalities or parasites
Mar 11	Thermalito RST	150	Virology only	Negative	Samples were collected and shipped by DWR RST crew
Mar 27	Thermalito RST	8	Virology	Normal	
		8	Parasitology exam	+2/8 +3/8	*Ichthyopthirius multifilus* *Lernaea (parasitic copepod)*
Mar 27	Gridley Boat Launch RST	20	Organosomatic Index	Normal (as noted)	1 fish - hemorrhaged mandible 1 fish with anemia)
		60	Virology	Negative	
		30	Bacteriology	Negative	
Total No. Fish Examined per Assay:					
			Organosomatic Index	**40**	
			Virology	**371**	
			Histology	**10**	
			Bacteriology	**30**	

IHNV Surveys of Returning Adult Chinook salmon in the Yuba, Feather and Clear Creek

To ascertain the incidence of IHNV in natural fall Chinook adults, kidney samples were collected from carcasses during the fall of 2003 and assayed for this virus from the Yuba River, Feather River and from Clear Creek, near Redding. Tissues were tested for all common fish viral pathogens.

Returning fall Chinook adults were sampled during carcass surveys on the main stem Yuba River conducted by Jones and Stokes on Oct 28, Nov 5 and Nov 6. Fish were collected from the upper reach, middle and lower reach from the Narrows near Englebright Dam to the confluence with the Feather River.

Adult chinook were collected from Clear Creek by Ca-Nv FHC staff. Clear Creek data, as well as historical data from Feather River SFH and Coleman NFH is included in this report to provide a comparison of IHNV incidence in the major tributaries of the upper Sacramento basin.

Yuba River

Fish were collected on the Yuba River in the three reaches (Rose Bar, Parks Bar, and Daguerra Point Dam) that comprise the main stem below Englebright Dam. Thirty fish were collected from each reach from Oct 27 through Nov 6. Kidney tissue was placed in an antibiotic solution to eliminate bacterial and fungal organisms and then assayed on cell culture for typical cytopathic effects (CPE) of fish viruses. Samples that were positive for CPE were confirmed with immunohistochemistry to identify IHNV using a universal antibody against all strains of IHNV.

Viral isolates were amplified by passage on EPC cell lines and stored at -70C. A sub-set of viral isolates was submitted to Dr. R. Hedrick at University of California, Davis (UCD) for strain typing analysis.

Adult escapement data for 2003 was provided by Stephanie Theis of Jones and Stokes. See Appendix D for spawning escapement and CWT recoveries for the Yuba River in 2002.

Table 8. Fall Chinook Adult Escapement by Reach – Yuba River 2003

Reach Description	Total Adult Escapement	No. Adult: No. Grilse
Rose Bar: Narrows to Hwy 20 bridge	9,193	8811/ 382
Parks Bar: Hwy 20 bridge to Daguerra Point Dam	11,731	11,072/ 659
Daguerra Point Dam: DPD to Simpson Lane	7,973	7,735/ 238
Totals:	**28,897**	**27,618/ 1279 (4.4%)**

Table 9. Summary of IHNV isolated from Yuba River adult Fall Chinook.

Collection Date (Lab Case No.)	Site Description (Lat/Long - DMS)	No Positive (Tissue Culture)/ No. Sampled	Percent Positive for viral CPE	No. Confirmed with IHC (% Positive by IHC)
10/28/2003 03-152	Rose Bar (upper reach) 391309N; 1211755W	7/30	23.3	7/10 (70)
11/05/2003 03-155	Parks Bar (middle reach) 391316N; 1211949W	6/30	20	6/6 (100)
11/06/2003 03-156	Daguerra Pt Dam (lower reach) 391051N;1213044W	12/30	40.0	12/13 (92)
	Totals:	**25/90**	**27.8**	**25/29 (86.2)**

Feather River

Adult Chinook were sampled from the Feather River in the low flow channel just below Feather River SFH on Oct 27. Eighty-seven fish were sampled in the same manner as described above and viral isolates were submitted to UCD for strain serotyping.

Table 10. Summary of IHNV isolated from Feather River adult Fall Chinook.

Collection Date (Lab Case No.)	Site Description (Lat/Long - DMS)	No Positive (Tissue Culture)/ No. Sampled	Percent Positive for viral CPE	No. Confirmed with IHC (% Positive by IHC)
10/27/2003 03-151	Feather River (below FRSFH) 393059N;1213313W	15/83	18.1	15/16 (93)
	Totals:	**15/83**	**18.1**	**15/16 (93.8)**

Clear Creek

Adult Chinook were sampled from Clear Creek in reach 5 and 6 on Oct 29, 2003. Forty-six fish were sampled in the same manner as previously described and viral isolates were submitted to UCD for strain serotyping.

Table 11. Summary of IHNV isolated from Clear Creek adult Fall Chinook.

Collection Date (Lab Case No.)	Site Description (Lat/Long - DMS)	No Positive (Tissue Culture)/ No. Sampled	Percent Positive for viral CPE	No. Confirmed with IHC (% Positive by IHC)
10/29/2003 03-150	Clear Creek (reach 5 and 6) 402952N;1222928W	21/46	45.6	21/21 (100)
	Totals:	**21/46**	**45.6**	**21/21 (100)**

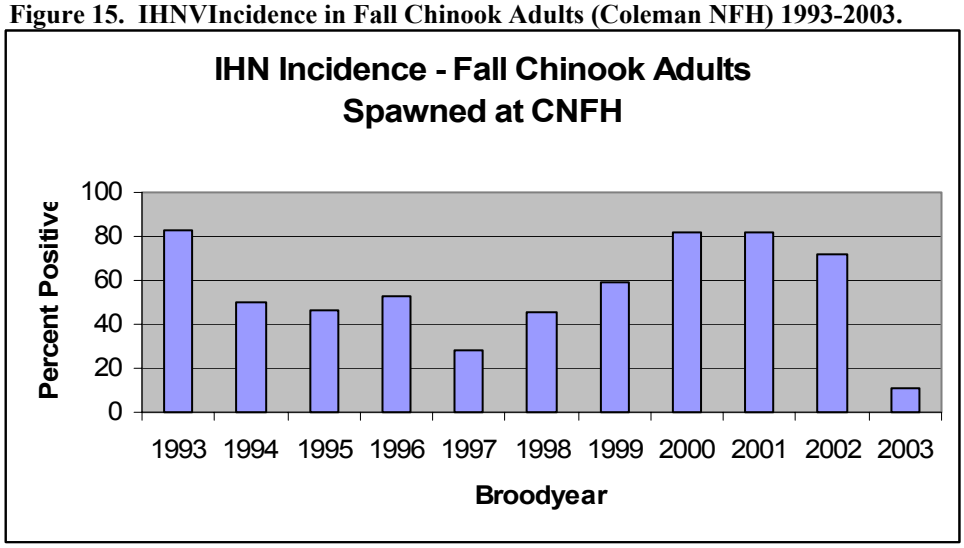
A total of 61 IHN viral isolates were submitted to Ron Hedrick at UCD (Yuba River 25, Feather River 15, and Clear Creek 21). Dr. Hedrick is using antibodies against the mid-glycoprotein (G) gene of IHNV to determine the relatedness of viral isolates and to determine if the IHN viral strains isolated from chinook adults in this study are similar to the FR-2 strain which has caused mortality in steelhead reared at FRSFH. Results of the Dr. Hedrick's strain evaluation work are pending at the time of this report.

Historical data from CNFH spawning operations indicates that the incidence of IHNV in fall chinook adults returning to the hatchery averaged 55 % over the past 11 years. The incidence has ranged from 11.4% in October-November 2003 to 82.6% in 1993.

Table 12. IHNV Incidence in Fall Chinook Adults Spawned at Coleman NFH

Brood Year	% Pos Males	% Pos Females	Total No. Fish Sampled (Pool size)	IHNV Incidence
2003	3	33	114 (3-pool)	11
2002	70	73	180 (3-pool)	72
2001	70	93	180 (3-pool)	82
2000	80	83	180 (3-pool)	82
1999	50	67	180 (3-pool)	59
1998	40	50	90 (3-pool)	45
1997	25	32	120 (1-pool)	28
1996	53	53	60 (1-pool)	53
1995	48	44	78 (1-pool)	46
1994	33	59	125 (1-pool)	50
1993	92	80	208 (1-pool)	83

Figure 15. IHNVIncidence in Fall Chinook Adults (Coleman NFH) 1993-2003.



Historical data from FRNFH spawning operations indicates that the incidence of pre-spawn mortality in fall chinook adults received at the hatchery averaged 17.7% in the period of 1993-2003. Pre-spawn mortality ranged from 3 to 36% in male fish and 4 to 38% in females.

Table 13. Pre-spawn Mortality (PSM) in Fall Chinook Adults returned to FRSFH, 1993-2003.

Brood Year	% PSM Males	% PMS Females	Total PSM
2003	11.8	17.6	14.6
2002	20.8	24.9	22.6
2001	19.7	26.0	22.4
2000	22.3	22.6	22.4
1999	14.9	13.3	14.1
1998	35.6	38.0	36.7
1997	10.8	15.5	12.9
1996	18.4	14.3	16.2
1995	14.6	27.4	21.4
1994	2.7	4.1	3.3
1993	9.6	8.4	8.9

DISCUSSION

VIRUSES

Major fish viruses, including IHNV, IPNV, VHSV, and OMV were not detected in juvenile fall chinook, steelhead or non-salmonid fish species during a two-year fish health monitoring study (2002-2003) of the Yuba and Feather rivers.

Yuba River - Juvenile Fall Chinook, Steelhead and Non-salmonids

In the Yuba River, IHNV was not detected in over 700 fall chinook juvenile salmon tested in 2002, and 490 fish tested in 2003 for a total of 1196 fish sampled. Virus was not detected in 69 steelhead and 47 non-salmonids fish species (hardhead, small mouth bass, Sacramento sucker) tested during the study. The sample sets for virology included large numbers of fall chinook, often over 200 fish per sample date. At this level of testing, there is a 95% confidence interval that IHNVwould be detected if it occurred at a prevalence of infection (POI) level of 2% in this population. Testing at a POI of 2% will generally detect IHNV in carrier fish; animals without clinical signs of disease. The large sample sets and repeated sample dates from Feb-May 2002 and Apr-Jun 2003 provide a high level of confidence that IHNV is not present in natural fall chinook juveniles in the Yuba River. Sample sets of steelhead and non-salmonids were small compared to the chinook sample sets and therefore cannot provide the same level of testing sensitivity.

Feather River - Juvenile Fall Chinook

In the Feather River, fall chinook were sampled from Feb 19-Mar 27, in 2003. Over 370 fish were tested for IHNV. Only two chinook throughout the study period exhibited general clinical signs (anemia and hemorrhaging) that may have been indicative of viral infection, however these fish tested negative for viral infection. These clinical signs are general and can be attributable to other pathological or physiological conditions. All virology testing, with the exception of Mar 27, consisted of sample sets large enough to provide detection of virus if it were present in the population at 2% POI.

BACTERIA

Yuba River - Juvenile Fall Chinook, Steelhead and Non-salmonids

Other bacterial fish pathogens were detected in the Yuba River. In 2002, 10 of 35 hardheads collected from Purdon Crossing on the SF of the Yuba tested positive for *Pseudomonad spp.* infections. While the fish lacked clinical signs of bacteremia and appeared normal on field exam, 29% of the fish had culturable bacteria in the kidney, a fairly high prevalence of infection. This level of *Pseudomonad* infection in the Hardhead population would most likely lead to disease as water temperatures (75.8F in July 2002) continued to increase, throughout the mid and late summer period.

Enterococcus bacteria, or other fecal coliforms, were not detected in SF Yuba in Hardhead. Bacterial fecal coliforms (fecal bacteria from warm blooded mammals) would not normally be expected to infect warm or cool water fish species, however previous detection of *Enterococcus* in water samples were detected in 2002 and these findings generated public health concerns. Ruling out this bacteria in resident fish populations is important in light of the highly elevated water temperatures and the recreational use of this area in the SF of the Yuba River by the public.

In 2003, 1 of 6 steelhead tested positive for *Renibacterium salmoninarum*, the bacterium responsible for Bacterial Kidney Disease. The OD value by ELISA indicated a low level of *R. salmoninarum* antigen present in the kidney tissue and further testing by Polymerase Chain Reaction confirmed the presence of specific *R.salmoninarum* DNA. Other bacteria isolated from steelhead include *Micrococcus spp* and *Aeromonas hydrophila*. None of the fish examined exhibited clinical signs of disease and these bacterial organisms can be opportunistic fish pathogens.
One fall chinook salmon collected in May from the main stem site near Hwy 20 tested positive for *Yersinia ruckeri,* the bacteria responsible for Enteric Redmouth disease in cultured fish.

No fish pathogens were detected in the other non-salmonid species tested during this study, including hardhead (n=16) and Sacramento sucker (n=12) collected in the main stem Yuba in 2003, and small mouth bass (n=5) collected from the middle fork in 2003.

Feather River - Juvenile Fall Chinook
No bacterial pathogens were detected in the Feather River in juvenile chinook sampled in 2002.

PARASITES
Yuba River - Juvenile Fall Chinook, and Steelhead
Significant parasites, including *Ceratamyxa shasta* and *Myxobolus cerebralis* were not detected in 84 chinook juveniles tested in 2002 and 2003. Sample size for microscopic or histological examination was relatively small for chinook (n=24) and steelhead (n=9), however no internal parasites or abnormalities were observed. Whirling Disease spores (*Myxobolus cerebralis*) were not observed in 60 fall chinook and 9 steelhead heads processed by Pepsin-Trypsin Digest and examined microscopically. While the sample size for steelhead was small, past surveys conducted in Battle Creek using the Pepsin-Trypsin Digest method detected *M.cerebralis* spores in small sample sets when the parasite was present in low to moderate numbers (True 1999).

Feather River - Juvenile Fall Chinook
Fall chinook collected from the TAB-RST on Mar 27 2003 had significant numbers of the parasite *Ichthyopthirius multifilis* (Ich) observed microscopically on the skin and gill of 2/8 fish examined. Histological examination also detected trophozoites, presumed also to be *Ichthyopthirius multifilis,*on the skin and gill. Water temperature was relatively low (57F/13C) at this sampling site in March. Ich is a temperature dependant pathogen, with an optimum temperature range for the infective stage of approximately 13-24C (Lom 1992). This parasite could be debilitating on juvenile chinook in the Feather River if the levels observed on gill tissue continued to rise with increasing water temperatures throughout late spring.

ADULT CARCASS SURVEYS – IHNV

Returning adult chinook salmon were tested from the Yuba River, Feather River, and Clear Creek in the Fall of 2003. Historical data from Coleman National Fish Hatchery has been included to provide information, and a relative reference of IHNV incidence in a hatchery populations compared to the natural populations in the Yuba River and Clear Creek.

Yuba River – Adult Chinook

The incidence of IHNV detected in returning adult chinook to the Yuba River averaged 27.8% in individual female fish collected in carcass surveys conducted between Oct 28-Nov 6, 2003. Fish were sampled from 3 reaches of the main stem below Englebright Dam. Viral prevalence was similar in the 30 fish collected from Rose Bar at 23% compared to 30 fish collected from the middle reach at Parks Bar at 20%. Viral incidence was highest in the lowest reach, Daguerra Point Dam, at 40%.

Viral incidence generally increases with density of congregating adult fish, migration distance in large river systems, and temporal distribution related to spawn timing (higher incidence in the later period of the run). While fish densities were not significantly different for the 3 reaches tested, IHNV prevalence was higher in the lowest reach at 40%, despite the lower density of adults observed in this reach of the river. Rose Bar (upper reach) was sampled October 28, and Parks Bar (middle reach) and Daguerra Point Dam (lower reach) were sampled approximately one week later (Nov 5 and 6), so temporal differences in viral incidence would not be expected to be significant. Migration distance would not be expected to be a significant factor in viral incidence in the Yuba as the distance from the lower reach to the upper reach is relatively small and less than 20 river miles. Total escapement was 9,193 for Rose Bar, 11,731 for Parks Bar, and 7,973 for the lowest reach from Daguerra Point Dam to Simpson Lane (Table 14).

Table 14. Viral Incidence and Total Escapement of Fall Chinook in the Yuba River 2003

Reach Description	Total Adult Escapement	Percent Pos IHNV
Rose Bar: Narrows to Hwy 20 bridge	9,193	23
Parks Bar: Hwy 20 bridge to Daguerra Point Dam	11,731	20
Daguerra Point Dam: DPD to Simpson Lane	7,973	40
	Total Adults: 28,897	**Mean Percent Positive: 27.8%**

Feather River – Adult Chinook

Incidence of IHNV in Feather River adult chinook was 18.1% in 83 individual fish, of approximately equal sex ratios, collected on Oct 27 from just below the hatchery ladder near FRSFH.

Clear Creek – Adult Chinook

The incidence of IHNV in adult chinook returning to Clear Creek was 45.6% in 46 individual fish, of approximately equal sex ratios, collected Oct 29 from reach 5 and 6.

Coleman National Fish Hatchery – Historical Data for Adult Chinook

Routine testing of adults returning to CNFH on Battle Creek over the entire run period detected IHNV in 11% of the 114 fish tested in 3-fish sample pools. Viral incidence at CNFH has ranged from the this low incidence in 2003, to as high as 83% of returning adults. Historically, CNFH IHNV incidence averaged 55.5% in the period from 1993-2003.

This data from carcass surveys conducted in 2003 suggests that incidence of IHNV is actually higher in the upper Sacramento tributaries in both hatchery and natural populations (CNFH and Clear Creek) compared to the Yuba and Feather rivers. Data from Yuba River and Clear Creek comprises a single year of adult testing and more monitoring would be needed to determine if this observation is representative of the overall geographical distribution of IHNV in the Sacramento basin tributaries. It should also be noted that routine testing at CNFH consists of viral testing of 3-fish pools after 1997 (see Table 12). Pooled samples can skew the percent positive towards a higher incidence for this population when compared to single sample testing.

It is interesting to note that data collected in carcass surveys for 2003, indicate that both the hatchery stock at CNFH and the presumed "hatchery origin" stock in the Feather River have lower viral incidences at 11% and 18% than the natural adults returning to the Yuba at 28% and Clear Creek at 46%. Again, in light of historical IHNV incidence at CNFH which averages 56%, further monitoring would be needed to determine if this trend holds over time.

RISK OF DISEASE TRANSMISSION TO NATURAL POPULATIONS

In terms of IHNV transmission to natural fish from hatchery fish straying into the Yuba River, the escapement data and viral incidence in returning adults does not suggest a significant risk to natural populations. FRSFH fall chinook have been identified by coded wire tag (CWT) recovery in carcass surveys on the Yuba river, as well as fish from Mokulumne, Merced and Nimbus SFH. In 2002, 56 CWT were recovered and 25 were determined to be of FRSFH origin (Pers. comm. Stephanie Theis, Jones and Stokes 2003). In 2003, a total of 60 CWT fish were recovered from a total escapement estimate of over 28,000. If viral incidence in straying FRSFH adult Chinook is similar to the incidence of adults returning to the FRSFH hatchery at 18%, then the number of infected adults in the Yuba would comprise a relatively small proportion of the spawning population.

IHN VIRAL STRAIN TYPING

Viral strain typing work will be completed by the Dr. Ron Hedrick of UCD. Using antibody serotyping and genetic sequencing, all viral isolates detected in this study will be tested to determine what strain types of IHNV exist in natural and hatchery populations in the Sacramento River tributaries. The majority of viral isolates detected in this study were confirmed as IHNV by the California-Nevada Fish Health Center, using immunohistochemistry techniques and a universal antibody (14D) from DiagXotics Laboratories. One isolate from the Feather River and 4 isolates from the Yuba River did not confirm using this universal antibody, which may indicate that these isolates have slightly different or altered epitopes than the wild type strain. Similar results have been observed in past testing of IHNV isolates from CNFH fall chinook adults when the 14D antibody is used in the immunoblot technique, a similar immunological confirmation method. In those studies, approximately 30% of CNFH IHNV isolates were not recognized by the Diagxotics 14D universal antibody (unpublished data, True 1994).

The California strain of IHNV is less virulent than geographic serotypes found in the Columbia River, Alaska, or the Hagerman Valley in Idaho. It has not been determined whether unconfirmed IHNV isolates represent unique strains of IHNV, or whether the universal antibody simply does not recognize all variants of the IHNV found in California. Dr. Hedrick's work will help determine whether these "unusual isolates" are significant in terms of the virulence factors and geographic distribution.

PRE-SPAWN MORTALITY

Pre-spawn mortality was estimated to be less than 1% in Yuba River adults, in 2003. However, in past years, pre-spawn mortality has been more significant. During these periods, fish appeared healthy and water quality conditions were relatively normal for the Yuba River system (Pers. comm. Stephanie Theis, Jones and Stokes 2004). Adult mortality prior to spawning has not been investigated from a fish health perspective and further study is needed to determine if the cause is infectious or environmental in nature.

Table 15. Pre-spawn Mortality Observations in Yuba River adults 1999-2003 (S.Theis, Jones & Stokes)

Year	Number of Pre-spawn Mortalities	Number of Fresh Females	Percent of Fresh Females Observed
1999	153	799	19.1
2000	52	760	6.8
2001	18	1001	1.8
2002	38	770	4.9
2003	34	1036	3.5

The Feather River SFH has also experienced significant pre-spawn mortality in the low flow channel and FRSFH holding units. Many of these mortality events can be attributed to increased densities and elevated water temperatures in specific years (Pers. comm. Tresa Veck, CDFG 2004).

SUMMARY

The risk of IHNV transmission to natural fish populations in the Yuba and Feather River from operation of the Feather River State Fish Hatchery appears to be moderate. Marked Feather River adults have been captured in Yuba carcass surveys, IHNV is present in Yuba River adults at a mean prevalence of 27.8%, and viral transmission may be occurring between these two watersheds.

IHN virus was not been detected in juvenile fish populations in the Yuba and Feather Rivers in this two-year study. A total of 1567 Chinook, steelhead or non-salmonid species have been tested. IHNV was not present in large sample sets of fall Chinook in the Yuba River: 700 tested in 2002 and 496 in 2003. Similar findings were observed in the Feather River, where testing at a prevalence of infection level of 2% did not detect IHNV. At this level of testing, it is reasonable to conclude that juvenile chinook are not infected, nor carriers, of IHNV in the Yuba and Feather Rivers. If the virus is present, it is at extremely low prevalence levels and does not pose a significant risk to natural juvenile chinook populations.

Viral incidence in natural adult populations is not significantly different from natural populations in the upper Sacramento tributaries, such as Clear Creek. Viral incidence in Yuba River natural adults is actually higher than adult Chinook returning to CNFH and FRSFH based on the data obtained in the 2003 carcass survey. Relatively few FRSFH chinook CWT adults are recovered in the Yuba carcass surveys, indicating the likelihood of viral transmission between these stocks, or to subsequent progeny of natural spawners, is quite low.

Parasitic infections with *Ichthyopthirius multifilis* and *Lernaea* pose some risk to Feather River fall Chinook juveniles as water temperatures increase throughout summer. Other bacteria, including *Yersinia ruckeri*, and opportunistic *Pseudomonad* infections could also pose risks of epizootics

under unfavorable environmental conditions. *Renibacterium salmoninarum* was detected in one steelhead, but at very low levels, and does not pose a significant health risk.

No other significant fish pathogens were present in juvenile or adult Chinook, steelhead, or non-salmonid fish species.

FURTHER STUDIES

1. Fish health assessments of resident fish populations in Englebright and New Bullards Bar Reservoirs are needed to determine if significant fish pathogens occur in these bodies of water and pose fish health risks to Chinook populations in the lower Yuba River.

2. Determine cause of significant pre-spawn mortality events in the Yuba river and determine if pre-spawn mortality is associated with individual stocks in each tributary (Yuba and Feather Rivers) or attributable to basin wide conditions for returning adult Chinook salmon.

3. Continue monitoring chinook and steelhead under the National Wild Fish Health Survey to build upon the baseline data provided in this study and expand our knowledge of changes in the fish health status of important natural fish populations in the Sacramento basin. Understanding the relationship between disease pathogens and wild fish populations provides a biological basis for management decisions regarding restoration efforts, fish passage above barriers, stocking programs of native and non-native fish species, and other fisheries activities in these two watersheds.

4. Continue to monitor incidence of IHNV in natural adult Chinook populations in the upper Sacramento River basin through carcass surveys. Extend surveys sites for adult chinook and continue strain typing studies to determine the prevalence and movement of this pathogen within the Sacramento basin

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DATE	**02/19/2003**	***SPECIES***	**FCS - naturals**
LOCATION	Feather River (Thermalito AB)	***STOCK***	
REPORT#	**03-033**	***UNIT(S)***	
H2OTEMP		***LOT/MARK***	
DO		***AGE***	outmigrant smolts / juveniles
Saturation (%)		***FISH/LBS***	
DENS.IND		***INVESTIG.***	KT, RS
FLOWIND.			
REMARKS	Fish collected in DWR rotary screw trap		
	Fish are normal		

Organosomatic Form No. 6 FL/HSI/Lct

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.10	0.30

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	%SILVER<1
MEAN	40.16	0.42	0.7280	ND	ND	ND	ND	37.75	0.82	70	0
STD	4.30	0.10	0.5290					4.04	0.31		
CV	10.70	23.99	72.67					10.69	38.44		

WEIGHT FACTORS:			1	2	2	3	1	1	0	2	2	3	2	0	2	0	2						
SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	HSI	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT
1	38	0.41	0	0	0	2	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.7472	2	6	35	0.9563
2	46	0.75	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7705	0	0	43	0.9433
3	40	0.40	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6250	0	0	38	0.7290
4	42	0.45	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6074	0	0	39	0.7586
5	39	0.37	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.6237	0	0	36	0.7930
6	39	0.39	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6575	0	0	37	0.7699
7	44	0.54	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.6339	0	0	42	0.7289
8	37	0.30	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.5923	0	0	35	0.6997
9	40	0.43	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.6719	0	0	38	0.7836
10	40	0.38	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5938	0	0	38	0.6925
11	42	0.50	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6749	0	0	40	0.7813
12	40	0.36	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5625	0	0	37	0.7107
13	40	0.42	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.6563	0	0	38	0.7654
14	40	0.39	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6094	0	0	37	0.7699
15	39	0.31	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5226	0	0	37	0.6120
16	25	0.26	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.4383	0	0	23	2.1369
17	45	0.47	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	3.0080	0	0	42	0.6344
18	44	0.50	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5487	0	0	41	0.7255
19	43	0.47	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5517	0	0	40	0.7344
20	41	0.37	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.4654	0	0	39	0.6237
% NORMAL			100	100	100	95	100	100	0	100	100	100	100	70									
									%SILVER<1					%FAT>0									

DATE **05/14/2002** ***SPECIES*** **STT**

LOCATION Yuba River RST (Marysville) ***STOCK***

REPORT# **02-061** ***UNIT(S)***

H2OTEMP ***LOT/MARK***

FEED ***AGE*** Juvenile

%BW/D ***FISH/LBS***

DENS.IND ***INVESTIG.*** KT

FLOWIND.

REMARKS Fish collected in CDFG rotary screw trap
Fish in excellent condition except for frayed dorsal fins
All fish were females with developing gonads
No 1 Skin score given for darkened head and dorsal area
Hematocrits done

Organosomatic Form No. 6 FL/HSI/Lct

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.67	0.00

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	SILVER<1
MEAN	106.83	10.31	0.8186	ND	44.83	ND	ND	101.333	0.9569	0	17
STD	14.94	3.51	0.0860		8.03			13.8	0.0932		
CV	13.98	34.04	10.51		17.91			13.60	9.74		

WEIGHT FACTORS: 1 2 2 3 1 1 0 2 2 3 2 0 2 0 2

SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT
STT 1	93	7.170	1	1	0	0	0	0	3	0	0	0	0	0	47	ND	ND	0.8914	2	0	89	1.0171
STT 2	81	4.740	1	0	0	0	0	0	3	0	0	0	0	0	55	ND	ND	0.8919	1	0	77	1.0383
STT 3	122	14.650	0	0	0	0	0	0	0	0	0	0	0	0	53	ND	ND	0.8068	0	0	115	0.9633
STT 4	120	13.780	0	0	0	0	0	0	1	0	0	0	0	0	44	ND	ND	0.7975	0	0	113	0.9550
STT 5	115	9.830	0	0	0	0	0	0	2	0	0	0	0	0	32	ND	ND	0.6463	0	0	109	0.7591
STT 6	110	11.680	1	0	0	0	0	0	2	0	0	0	0	0	38	ND	ND	0.8775	1	0	105	1.0090

% NORMAL 50 83.333 100 100 100 100 17 100 100 100 100 0

%SILVER<1 %FAT>0

DATE **05/14/2002** ***SPECIES*** **FCS-naturals** Organosomatic Form No. 6 FL/HSI/Lct

LOCATION Yuba River RST (Marysville) ***STOCK***

REPORT# **02-061** ***UNIT(S)***

H2OTEMP ***LOT/MARK***

FEED ***AGE*** Juvenile

%BW/D ***FISH/LBS***

DENS.IND ***INVESTIG.*** KT

FLOWIND.

REMARKS Fish collected in CDFG rotary screw trap
Fish in excellent condition

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.00	0.00

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	SILVER<1
MEAN	75.67	3.90	0.8615	ND	ND	ND	ND	70.8333	1.0522	65	100
STD	8.46	1.60	0.0525					8.4	0.0625		
CV	11.18	41.00	6.09					11.85	5.94		

WEIGHT FACTORS:			1	2	2	3	1	1	0	2	2	3	2	0	2	0	2					
SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT
1	72	3.360	0	0	0	0	0	0	0	0	0	0	0	1	ND	ND	ND	0.9002	0	0	68	1.0686
2	74	3.270	0	0	0	0	0	0	0	0	0	0	0	1	ND	ND	ND	0.8070	0	0	69	0.9954
3	69	2.780	0	0	0	0	0	0	1	0	0	0	0	2	ND	ND	ND	0.8462	0	0	64	1.0605
4	70	3.200	0	0	0	0	0	0	1	0	0	0	0	1	ND	ND	ND	0.9329	0	0	65	1.1652
5	94	7.440	0	0	0	0	0	0	0	0	0	0	0	2	ND	ND	ND	0.8958	0	0	89	1.0554
6	75	3.320	0	0	0	0	0	0	1	0	0	0	0	2	ND	ND	ND	0.7870	0	0	70	0.9679
7	80	4.160	0	0	0	0	0	0	0	0	0	0	0	2	ND	ND	ND	0.8125	0	0	75	0.986074
8	67	2.390	0	0	0	0	0	0	1	0	0	0	0	1	ND	ND	ND	0.7946	0	0	61	1.052952
9	78	4.040	0	0	0	0	0	0	0	0	0	0	0	1	ND	ND	ND	0.8513	0	0	72	1.08239
10	69	2.480	0	0	0	0	0	0	1	0	0	0	0	1	ND	ND	ND	0.7549	0	0	63	0.991814
11	72	3.000	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	0.8038	0	0	66	1.043493
12	87	5.430	0	0	0	0	0	0	1	0	0	0	0	2	ND	ND	ND	0.8246	0	0	82	0.984823
13	87	5.870	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	0.8914	0	0	81	1.104544
14	80	4.230	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	0.8262	0	0	75	1.002667
15	72	2.750	0	0	0	0	0	0	0	0	0	0	0	1	ND	ND	ND	0.7368	0	0	68	0.874593
16	71	2.910	0	0	0	0	0	0	0	0	0	0	0	2	ND	ND	ND	0.8131	0	0	65	1.059627
17	79	3.880	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	0.7870	0	0	73	0.997386
18	90	5.740	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	0.7874	0	0	84	0.968443
19	76	3.480	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	0.7928	0	0	71	0.972309
20	78	3.410	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	0.7186	0	0	72	0.913602
% NORMAL			100	100	100	100	100	100	100	100	100	100	100	65								
									%SILVER<1					%FAT>0								

DATE	**03/21/2002**	***SPECIES***	**FCS - naturals**	Organosomatic Form No. 6 FL/HSI/Lct
LOCATION	Yuba	***STOCK***		
REPORT#	**02-025**	***UNIT(S)***		
H2OTEMP		***LOT/MARK***		
DO		***AGE***	outmigrant smolts / juveniles	
%Saturation		***FISH/LBS***		
DENS.IND		***INVESTIG.***	KT, BMc	
FLOWIND.				
REMARKS	Fish collected in CDFG rotary screw trap			
	30 Fish Organo: Severe gill anemia (1 fish)			
	Parasitology exam of 10 larger FCS: No paras on skin, gill, or internally (GI)			

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.60	1.15

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	%SILVER<1
MEAN	52.77	1.16	0.6360	ND	ND	ND	ND	49.2	0.7841	40	40
STD	12.62	0.82	0.0860	ND	ND	ND	ND	11.6	0.1222		
CV	23.92	70.46	13.53	ND	ND	ND	ND	23.50	15.59		

WEIGHT FACTORS:			1	2	2	3	1	1	0	2	2	3	2	0	2	0	2						
SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	HSI	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT
1	60	1.45	1	1	0	1	0	0	2	1	0	1	0	0	ND	ND	ND	ND	0.6713	5	11	57	0.7830
2	70	2.38	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.6939	0	0	65	0.8666
3	62	1.82	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.7637	0	0	56	1.0364
4	72	2.67	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.7153	0	0	66	0.9287
5	68	2.35	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.7474	0	0	63	0.9398
6	73	2.83	0	0	0	0	1	0	2	0	0	0	0	1	ND	ND	ND	ND	0.7275	1	1	68	0.9000
7	69	1.88	0	0	0	0	0	0	2	0	0	0	0	1	ND	ND	ND	ND	0.5723	0	0	65	0.6846
8	59	1.51	1	0	0	0	0	0	2	0	0	0	1	0	ND	ND	ND	ND	0.7352	2	3	55	0.9076
9	69	2.09	0	0	0	0	0	0	2	0	0	0	0	2	ND	ND	ND	ND	0.6362	0	0	65	0.7610
10	56	1.37	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.7801	0	0	52	0.9743
11	62	1.47	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	ND	0.6168	0	0	58	0.7534
12	53	1.02	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	ND	0.6851	0	0	49	0.8670
13	57	1.14	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.6156	0	0	53	0.7657
14	39	0.312	1	1	0	1	0	0	2	1	0	0	0	0	ND	ND	ND	ND	0.5260	4	8	36	0.6687
15	43	0.481	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	ND	0.6050	0	0	40	0.7516
16	39	0.317	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.5344	0	0	37	0.6258
17	51	0.967	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	ND	0.7290	0	0	48	0.8744
18	64	1.85	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.7057	0	0	60	0.8565
19	40	0.361	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.5641	0	0	38	0.6579
20	40	0.365	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	ND	0.5703	0	0	38	0.6652
21	35	0.214	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.4991	0	0	33	0.5955
22	39	0.288	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.4855	0	0	35	0.6717
23	47	0.734	0	0	0	0	0	0	1	0	0	0	0	0	ND	ND	ND	ND	0.7070	0	0	45	0.8055
24	39	0.364	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.6136	0	8	37	0.7186
25	39	0.321	0	0	0	0	0	0	2	0	0	0	0	1	ND	ND	ND	ND	0.5411	0	0	37	0.6337
26	67	2.080	0	0	0	0	0	0	1	0	0	0	0	1	ND	ND	ND	ND	0.6916	0	0	61	0.9164
27	38	0.286	0	0	0	0	0	0	2	0	0	0	0	1	ND	ND	ND	ND	0.5212	0	0	36	0.6130
28	55	1.170	1	1	0	0	0	0	1	0	0	0	0	1	ND	ND	ND	ND	0.7032	2	0	50	0.9360
29	38	0.324	0	0	0	0	0	0	2	0	0	0	0	1	ND	ND	ND	ND	0.5905	0	0	36	0.6944
30	40	0.340	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.5313	0	0	37	0.6712
% NORMAL			86.667	90	100	93.333	96.667	100	40 %SILVER<1	93.333	100	96.6667	96.66667	40 %FAT>0									

DATE	**02/12/2002**	***SPECIES***	**FCS - naturals**
LOCATION	Yuba River RST (Marysville)	***STOCK***	
REPORT#	**02-014**	***UNIT(S)***	
H2OTEMP	9.5C / 49.1F	***LOT/MARK***	
DO	14.48	***AGE***	outmigrant smolts / juveniles
Saturation (%)	126	***FISH/LBS***	
DENS.IND		***INVESTIG.***	KT, BMc
FLOWIND.			
REMARKS	Fish collected in CDFG rotary screw trap		
	Fish are normal: some scale loss/skin abrasion; FAT scores indicative of natural smolts		

Organosomatic Form No. 6 FL/HSI/Lct

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.20	0.50

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	%SILVER<1
MEAN	39.70	0.35	0.5592	ND	ND	ND	ND	36.90	0.70	90	0
STD	1.82	0.06	0.0841					1.55	0.10		
CV	4.58	16.24	15.05					4.19	13.80		

WEIGHT FACTORS:			1	2	2	3	1	1	0	2	2	3	2	0	2	0	2					
SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	HSI	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT
1	39	0.30	0	1	0	2	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5057	3	8	35	0.6997
2	39	0.28	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.4720	0	0	37	0.5528
3	41	0.39	0	0	0	0	0	0	3	0	0	0	0	2	ND	ND	ND	ND	0.5659	0	0	38	0.7107
4	35	0.27	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.6297	0	0	33	0.7513
5	40	0.31	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.4844	0	0	38	0.5650
6	39	0.32	0	1	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5395	1	2	36	0.6859
7	40	0.36	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.5625	0	0	37	0.7107
8	39	0.37	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6237	0	0	37	0.7305
9	37	0.44	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.8687	0	0	35	1.0262
10	39	0.30	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5057	0	0	36	0.6430
11	40	0.36	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5625	0	0	37	0.7107
12	43	0.45	0	0	0	0	0	0	3	0	0	0	0	2	ND	ND	ND	ND	0.5660	0	0	40	0.7031
13	41	0.37	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5368	0	0	38	0.6743
14	37	0.26	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5133	0	0	35	0.6064
15	40	0.31	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.4844	0	0	37	0.6120
16	41	0.35	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5078	0	0	38	0.6378
17	42	0.46	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6209	0	0	39	0.7755
18	42	0.40	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5399	0	0	38	0.7290
19	40	0.33	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5156	0	0	37	0.6515
20	40	0.37	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5781	0	0	37	0.7305
% NORMAL			100	90	100	95	100	100	0	100	100	100	100	90									
									%SILVER<1					%FAT>0									

DATE	**06/11/2003**	***SPECIES***	**STT-naturals**
LOCATION	Yuba River Hwy 20 Bridge	***STOCK***	
REPORT#	**03-079**	***UNIT(S)***	
H2OTEMP	56.4F/13.6C	***LOT/MARK***	
DO		***AGE***	juveniles
Saturation (%)		***FISH/LBS***	
DENS.IND		***INVESTIG.***	KT, JR, LA
FLOWIND.			
REMARKS	Fish collected by beach seine Fish are normal		

Organosomatic Form No. 6 FL/HSI/Lct

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.15	0.46

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	%SILVER<1
MEAN	46.85	0.81	0.7536	ND	ND	ND	ND	44.46	0.88	92	0
STD	4.93	0.26	0.1017					4.70	0.12		
CV	10.52	32.84	13.50					10.57	13.90		

WEIGHT FACTORS: 1 2 2 3 1 1 0 2 2 3 2 0 2 0 2

SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	HSI	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT
1	38	0.30	0	0	0	2	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.5467	2	6	36	0.6430
2	43	0.77	0	0	0	0	0	0	3	0	0	0	0	2	ND	ND	ND	ND	0.9685	0	0	41	1.1172
3	44	0.71	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.8335	0	0	41	1.0302
4	40	0.39	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6094	0	0	38	0.7107
5	49	0.82	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6970	0	0	47	0.7898
6	47	0.80	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7705	0	0	45	0.8779
7	50	1.02	0	0	0	0	0	0	2	0	0	0	0	2	ND	ND	ND	ND	0.8160	0	0	48	0.9223
8	57	1.28	0	0	0	0	0	0	2	0	0	0	0	1	ND	ND	ND	ND	0.6912	0	0	54	0.8129
9	53	1.23	0	0	0	0	0	0	2	0	0	0	0	2	ND	ND	ND	ND	0.8262	0	0	50	0.9840
10	48	0.83	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7505	0	0	45	0.9108
11	48	0.85	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7686	0	0	45	0.9328
12	48	0.81	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7324	0	0	46	0.8322
13	44	0.67	0	0	0	0	0	0	3	0	0	0	0	2	ND	ND	ND	ND	0.7865	0	0	42	0.9043

% NORMAL 153.85 153.85 153.85 146.15 153.85 153.85 0 153.8 153.85 153.846 153.8462 92

%SILVER<1 %FAT>0

DATE	**06/11/2003**	***SPECIES***	**FCS - naturals**
LOCATION	Yuba River Hwy 20 Bridge	***STOCK***	
REPORT#	**03-079**	***UNIT(S)***	
H2OTEMP	56.4F/13.6C	***LOT/MARK***	
DO		***AGE***	juveniles
Saturation (%)		***FISH/LBS***	
DENS.IND		***INVESTIG.***	KT, JR, LA
FLOWIND.			
REMARKS	Fish collected by beach seine Fish are normal		

Organosomatic Form No. 6 FL/HSI/Lct

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.10	0.30

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	%SILVER<1
MEAN	61.11	2.36	1.0275	ND	ND	ND	ND	58.20	1.19	85	0
STD	4.05	0.48	0.1851					4.11	0.08		
CV	6.63	20.51	18.01					7.06	7.12		

WEIGHT FACTORS:			1	2	2	3	1	1	0	2	2	3	2	0	2	0	2					
SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	HSI	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT
1	58	2.10	0	0	0	2	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.0763	2	6	55	1.2622
2	57	1.80	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.9720	0	0	54	1.1431
3	62	2.50	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.0490	0	0	59	1.2173
4	69	3.30	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.0045	0	0	67	1.0972
5	67	2.90	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.9642	0	0	64	1.1063
6	64	2.50	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.9537	0	0	62	1.0490
7	59	2.10	0	0	0	0	0	0	3	0	0	0	0	2	ND	ND	ND	ND	1.0225	0	0	56	1.1958
8	59	2.20	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.0712	0	0	56	1.2527
9	64	2.70	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.0300	0	0	61	1.1895
10	59	1.90	0	0	0	0	0	0	3	0	0	0	0	2	ND	ND	ND	ND	0.9251	0	0	57	1.0260
11	60	2.10	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.9722	0	0	57	1.1340
12	67	3.60	0	0	0	0	0	0	3	0	0	0	0	3	ND	ND	ND	ND	1.1970	0	0	64	1.3733
13	60	2.30	0	0	0	0	0	0	3	0	0	0	0	3	ND	ND	ND	ND	1.0648	0	0	57	1.2419
14	60	2.20	0	0	0	0	0	0	3	0	0	0	0	3	ND	ND	ND	ND	1.0185	0	0	57	1.1879
15	65	2.70	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.9832	0	0	62	1.1329
16	55	1.80	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6554	0	0	52	1.2802
17	62	2.40	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.4425	0	0	59	1.1686
18	61	2.30	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.9651	0	0	59	1.1199
19	53	1.60	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.7049	0	0	50	1.2800
20	59	2.20	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.4777	0	0	56	1.2527
% NORMAL			100	100	100	95	100	100	0	100	100	100	100	85									
									%SILVER<1					%FAT>0									

DATE	**04/01/2003**	***SPECIES***	**FCS - naturals**
LOCATION	Yuba River Hwy 20 Bridge	***STOCK***	
REPORT#	**03-044**	***UNIT(S)***	
H2OTEMP	56.4F/13.6C	***LOT/MARK***	
DO		***AGE***	juveniles
Saturation (%)		***FISH/LBS***	
DENS.IND		***INVESTIG.***	KT, RS, SF
FLOWIND.			
REMARKS	Fish collected by beach seine Fish are normal		

Organosomatic Form No. 6 FL/HSI/Lct

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.10	0.30

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	%SILVER<1
MEAN	45.47	0.67	0.7196	ND	ND	ND	ND	41.75	0.89	70	0
STD	4.78	0.24	0.2474					4.52	0.15		
CV	10.52	36.28	34.39					10.81	17.23		

WEIGHT FACTORS:			1	2	2	3	1	1	0	2	2	3	2	0	2	0	2				
SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	HSI	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT
1	40	0.50	0	0	0	2	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7813	2	6	37	0.9871
2	47	0.70	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6742	0	0	42	0.9448
3	38	0.30	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.5467	0	0	36	0.6430
4	41	0.50	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.7255	0	0	38	0.9112
5	50	0.80	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6400	0	0	47	0.7705
6	50	0.80	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6400	0	0	46	0.8219
7	40	0.50	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7813	0	0	36	1.0717
8	54	1.10	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6986	0	0	50	0.8800
9	48	0.90	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.8138	0	0	44	1.0565
10	50	0.90	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7200	0	0	46	0.9246
11	50	1.00	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.8000	0	0	47	0.9632
12	41	0.30	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.4353	0	0	38	0.5467
13	44	0.50	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.5870	0	0	40	0.7813
14	48	0.80	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.7234	0	0	44	0.9391
15	40	0.40	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.6250	0	0	37	0.7897
16	43	0.40	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6250	0	0	40	0.6250
17	50	0.90	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.1320	0	0	47	0.8669
18	40	0.50	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.4000	0	0	36	1.0717
19	50	1.00	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	1.5625	0	0	46	1.0274
20	42	0.60	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.4800	0	0	38	1.0935
% NORMAL			100	100	100	95	100	100	0	100	100	100	100	70									
									%SILVER<1					%FAT>0									

DATE	**03/27/2003**	***SPECIES***	**FCS - naturals**
LOCATION	Feather River (Gridley BL)	***STOCK***	
REPORT#	**03-042**	***UNIT(S)***	
H2OTEMP	57F/13.8C	***LOT/MARK***	
DO		***AGE***	outmigrant smolts / juveniles
Saturation (%)		***FISH/LBS***	
DENS.IND		***INVESTIG.***	KT, RS
FLOWIND.			
REMARKS	Fish collected in DWR rotary screw trap near Gridley Boat Launch		
	Fish are normal except #8 & 11 - clinical signs (hemmorrhaging and anemia)		

Organosomatic Form No. 6 FL/HSI/Lct

CUMULATIVE ABNORMALITY	WEIGHTED ABNORMALITY
0.30	0.70

	TLNGTH	WEIGHT	TL-KTL	HSI	HCT	LCT	PL.PRO.	FLNGTH	FL-KTL	%FAT>0	%SILVER<1
MEAN	51.11	1.12	0.7048	ND	ND	ND	ND	47.85	0.83	80	20
STD	11.56	0.85	0.1359					11.23	0.14		
CV	22.62	75.48	19.28					23.46	16.72		

WEIGHT FACTORS:			1	2	2	3	1	1	0	2	2	3	2	0	2	0	2						
SAMPLE	TLNG(mm)	WGHT(g)	FIN	SKIN	EYE	GILL	PSBR	THY	S-IDX	LIV	SPL	KID	GI-TRC	FAT	HCT	LCT	P-PRO	HSI	KTL	CUMFIT	WTFIT	FL(mm)	FLKFACT	
1	70	2.60	0	0	0	2	0	0	1	0	0	0	0	1	ND	ND	ND	ND	0.7580	2	6	67	0.8645	
2	52	1.20	0	0	0	0	0	0	2	0	0	0	0	0	ND	ND	ND	ND	0.8534	0	0	50	0.9600	
3	55	1.30	0	0	0	0	0	0	2	0	0	0	0	1	ND	ND	ND	ND	0.7814	0	0	52	0.9246	
4	57	1.10	0	0	0	0	0	0	2	0	0	0	0	1	ND	ND	ND	ND	0.5940	0	0	54	0.6986	
5	41	0.50	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.7255	0	0	39	0.8429	
6	38	0.20	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.3645	0	0	36	0.4287	
7	70	2.70	0	0	0	0	0	0	1	0	0	0	0	1	ND	ND	ND	ND	0.7872	0	0	66	0.9391	
8	65	2.30	0	2	0	0	0	0	1	0	0	0	0	1	ND	ND	ND	ND	0.8375	2	4	62	0.9651	hemm jaw
9	70	2.80	0	0	0	0	0	0	1	0	0	0	0	1	ND	ND	ND	ND	0.8163	0	0	67	0.9310	
10	54	1.30	0	0	0	0	0	0	2	0	0	0	0	1	ND	ND	ND	ND	0.8256	0	0	51	0.9800	
11	60	1.60	0	0	0	0	0	0	2	2	0	0	0	1	ND	ND	ND	ND	0.7407	2	4	57	0.8640	anemic
12	52	1.20	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.8534	0	0	49	1.0200	
13	52	0.90	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6401	0	0	50	0.7200	
14	38	0.30	0	0	0	0	0	0	3	0	0	0	0	0	ND	ND	ND	ND	0.5467	0	0	35	0.6997	
15	39	0.40	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6743	0	0	36	0.8573	
16	38	0.40	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6743	0	0	36	0.8573	
17	41	0.50	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.9112	0	0	39	0.8429	
18	40	0.40	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5804	0	0	38	0.7290	
19	39	0.40	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.6250	0	0	37	0.7897	
20	39	0.30	0	0	0	0	0	0	3	0	0	0	0	1	ND	ND	ND	ND	0.5057	0	0	36	0.6430	
% NORMAL			100	95	100	95	100	100	20	95	100	100	100	80										
									%SILVER<1					%FAT>0										

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.**:** **2002-014 Feb12 2002** Submittal date**:**
Sample Collector**:** Sample Site(s): **Yuba River RST (Mryvl)**
Histological specimen examiner**: J. Scott Foott**
Species: **Chinook** Age: **fry**
Tissues: **sagittal sections of 7 fry**

Fixative: Davidson (X) , PREFER-ETOH ( ), 10%BF ( ), ZFIX ( ), Bouins ( )
Stains: Hematoxylin & eosin (X), PAS ( ), Iron ( )
Block No. 4275 -4279 Block / slide deposition: FHC

Blood Smear (Number): ND Bloodsmear Stain: Lieshman-Giemsa ( ), DiffQuick( )
Clinical chemistry: ND

Summary

Liver, gill, intestine, and kidney are normal in all 7 fish. No parasites were seen. While yolk was observed in the peritoneal cavity, no inflammation response or yolk composition difference suggestive of coagulated yolk was observed in 4 fish.

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.**: 2003-33 Feb 19 2003** Submittal date**:**
Sample Collector**:** Sample Site(s): **Feather River RST (TAB)**
Histological specimen examiner**: J. Scott Foott**
Species: **Chinook** Age: **fry**
Tissues: **sagittal sections with multiple tissues, not all organs found in every section**

Fixative: Davidson (X) , PREFER-ETOH ( ), 10%BF ( ), ZFIX ( ), Bouins ( )
Stains: Hematoxylin & eosin (X), PAS ( ), Iron ( )
Block No. 4275 -4279 Block / slide deposition: FHC

Blood Smear (Number): ND Bloodsmear Stain: Lieshman-Giemsa ( ), DiffQuick( )
Clinical chemistry: ND

Summary

Sagittal sections of 10 fish examined (2/block) revealed no significant lesions or abnormalities. A large ciliate parasite (Ich?) with macronucleus was observed on the gill of 1 salmon but was not associated with gill damage. Another fish had mild inflammation of the visceral adipose tissue. No *C. shasta* was observed in any intestinal section (0 of 9).

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.**: 2003-44 April 01 2003** Submittal date**:**
Sample Collector**:** Sample Site(s): **Yuba River**
Histological specimen examiner**: J. Scott Foott**
Species: **Chinook** Age: **fry**
Tissues: **sagittal sections with multiple tissues, not all organs found in every sec tion**

Fixative: Davidson (X) , PREFER-ETOH ( ), 10%BF ( ), ZFIX ( ), Bouins ( )
Stains: Hematoxylin & eosin (X), PAS ( ), Iron ( )
Block No. 4280 -4284 Block / slide deposition: FHC

Blood Smear (Number): ND Bloodsmear Stain: Lieshman-Giemsa ( ), DiffQuick( )
Clinical chemistry: ND

Summary

Sagittal sections of 10 fish examined (2/block) revealed no significant lesions, parasitic infection or abnormalities. Two fish had mild inflammation of the visceral adipose tissue with 1 animal showing lipofuscin pigment associated with the inflammation. This clinical picture is reminiscent of higher water temperature smolt migration in the Delta and Klamath R. No *C. shasta* was observed in any intestinal section (0 of 10).

APPENDIX C – Abstracts of Transmission Studies conducted at Ca-Nv FHC

1996 Investigative Report (Foott)
Survey of natural fall-run chinook alevin and swim-up fry from Battle creek and the Upper Sacramento River for Infectious Hematopoietic Necrosis Virus (IHNV). December 1995-January 1996. U.S. Fish and Wildlife Service, Anderson, CA.

Abstract - Over 377 Fall-run Chinook (FCS) alevins or 30-35mm fork length "swim-up" fry were collected by beach seine from 6 sites over a 28 day period (07DEC95-05JAN96). Virological assays of 2-5 fish pooled tissue samples from these fish did not demonstrate replicating virus (including IHNV) during 14-18 day incubation periods on epithelioma papulosium cyprinid cell cultures (EPC) held at 15C. FCS adults returning to Coleman NFH in 1995 had a 46% incidence of IHNV infection and the redd area surveyed in Battle creek had numerous FCS adult carcasses. This data suggests that IHNV infection was quite rare (if present) among this age group of natural Fall-run chinook in spite of the probability of horizontal transmission from the carcasses of IHNV+ parents.

Note: Under the National Wild Fish Health Survey, an additional 203 fall chinook were sampled from Mar-Apr in 1997 in the upper Sacramento River from rotary screw traps operated by Red Bluff Fish and Wildlife Office. IHNV was not detected in this sample of natural out migrating fall chinook juveniles.

1996 unpublished data (Foott and True)
Shedding Study of *Infectious Hematopoietic Necrosis Virus* (IHNV) from clinical moribund Fall Chinook, during an epizootic at Coleman NFH.

Moribund fall chinook were collected from Coleman NFH during an IHNV epizootic. Fish with clinical signs of IHNV (showing exophthalmia, darkened, riding high in water column), were placed in individual 100 mL beakers of sterile water. At 1, 10, and 30 minutes, a 10 ml water sample was taken and tested by tissue culture for number of plaque forming units (PFU). After 30 minutes, a mucus scraping and kidney sample were collected from each fish and tittered for IHNV. Virus was shed rapidly, within 1 minute, into the water and increased in quantity (1000-2000 PFU / mL) over the 30 minute period. Mucous sampled at 30 minutes contained high concentrations of virus at (10^4 - 10^5 PFU /ml), which is approximately 100 times higher than the quantity of virus shed directly into the water. Viral titers of the kidney were higher than mucous levels (10^6 - 10^7 PFU /ml).
It is unknown if short contact between fish infected with this level of virus with non-infected fish is sufficient to transmit virus and produce an infection. The high virus titer of the mucus could be a significant "inoculum" if fish make direct contact (nip or exhibit piscivory) with moribund fish.

1999 unpublished data (True)
Minimum dose of *Infectious Hematopoietic Necrosis Virus* (IHNV), and minimum age of Fall Chinook salmon to induce clinical signs of viral infection.

Summary - Transmission studies were conducted from January through April 1999 to determine the viral dose and incubation period required for fall Chinook fry to become infected with IHNV. The study challenged young fall Chinook (1200 and 600 fish/pound) with viral doses on 10^1-10^4 plaque-forming units per milliliter (PFU/ml) by 1-minute bath immersion. Following challenge, fish were subjected to stress 3 times per week by de-watering rearing units for 30 seconds. Prevalence of IHNV was monitored in all subsequent mortality and in sub-sets of each group (subclinical fish) at 3 and 7 weeks post challenge. The study demonstrated that IHNV caused low-level mortality (.02-.07%) within 2 weeks at higher doses (10^3 and 10^4 pfu/ml) in both stressed and non-stressed groups. However, fish did not develop clinical signs of disease despite high levels of infection in the subsampling testing conducted at weeks 3 and 7. Prevalence of IHNV in the 10^3 and 10^4 groups (both stressed and non-stressed) ranged from 28-71% at week 3, and 13-67% at week 7. Overall, the cumulative percent mortality during the study due to IHNV, was higher at 16.7% in the 10^4 stressed group when compared to 12.5% in the non-stressed group. Stress fish also had higher titers (an increase of 1 log or 10x) of virus in the kidney tissue compared to non-stressed fish at the same challenge dose.

2000 Investigational Report (Foott, Nichols and Harmon)
Lack of experimental evidence for IHNV transmission from infected hatchery salmon to natural Chinook salmon in the Sacramento River. U.S. Fish and Wildlife Service, Anderson, CA.

Abstract - Coleman National Fish Hatchery (CNFH) has a long history of infectious hematopoietic necrosis (IHN) disease in its juvenile chinook salmon (Oncorhynchus tshawytscha) that can result in high fish mortality and the subsequent release of large numbers of IHNV exposed juveniles. The transmission of IHNV to wild or natural chinook populations in the Sacramento River system from infected hatchery fish is a concern for resource managers. In this study, natural chinook juveniles were cohabitated with experimentally IHNV-infected hatchery chinook at ratios of 1:1, 1:10, and 1:20 for either 5 minutes or 24 hours. Additional natural chinook salmon were held in cages within the exposure tanks. During the 7 d post-exposure rearing period, a portion of each natural group was stressed daily. These exposures were designed to simulate brief and "worst case" natural fish contacts with a massive hatchery release of infected fish. Virus was not detected by tissue culture assays from any natural chinook in the 3 experiments. The inability to detect virus in the tissues of exposed natural fish, regardless of their duration of exposure, ability to directly interact with infected fish, or post-exposure stress indicates a low ecological risk to natural populations if infected hatchery fish are released into the Sacramento River. Unique characteristics of the host – pathogen relationship should be evaluated for each situation when developing risk assessments.

APPENDIX D – Yuba River 2002 Spawning Escapement Survey CWT Recoveries

Head Tag	Location	Sex	Recovery Date	CWT Code	Run	Brood Year	Hatchery	Release Site	Stock Name	Date Released	Tagged	Untagged	Agency
36122	Rose Bar	F	10/1/02	0501020713	Fall	1998	Feather R Hatchery	Georgianna Slough	Feather River	3/30/99	26248	0	CDWR
36123	Rose Bar	F	10/1/02	0601060902	Spring	1998	Feather R Hatchery	Crockett	Feather River	5/24/99	50473	0	CDWR
36124	Rose Bar	F	10/1/02	0601060904	Spring	1998	Feather R Hatchery	Crockett	Feather River	6/4/99	50713	0	CDWR
36137	Rose Bar	M	10/1/02	062631	Fall	1998	Feather R Hatchery	Crockett	Feather River	6/11/99	50877	0	CDWR
36138	Rose Bar	F	10/1/02	0601060904	Spring	1998	Feather R Hatchery	Crockett	Feather River	6/4/99	50713	0	CDWR
36139	Rose Bar	F	10/1/02	0601060902	Spring	1998	Feather R Hatchery	Crockett	Feather River	5/24/99	50473	0	CDWR
36140	Rose Bar		10/1/02	062682	Spring	2000	Feather R Hatchery	Rodeo Minor Port	Feather River	4/26/01	47742	2832	CDWR
36115	Parks Bar	F	10/2/02	062670	Fall	2000	Feather R Hatchery	Rodeo Minor Port	Feather River	5/22/01	31384	2146	CDWR
36125	Parks Bar	M	10/2/02	062631	Fall	1998	Feather R Hatchery	Crockett	Feather River	6/11/99	50877	0	CDWR
36130	Parks Bar	M	10/2/02	0601060906	Spring	1998	Feather R Hatchery	Crockett	Feather River	6/4/99	53958	0	CDWR
36136	Parks Bar	M	10/2/02	062664	Fall	2000	Feather R Hatchery	Wickland Oil Net Pen	Feather River	4/30/01	202096	718675	CDFG
36131	Rose Bar		10/3/02	062664	Fall	2000	Feather R Hatchery	Wickland Oil Net Pen	Feather River	4/30/01	202096	718675	CDFG
36132	Rose Bar	M	10/8/02	060215	Fall	1998	Mokelumne R Fish Ins	Crockett	Mokelumne River	7/2/99	95203	775696	EBMD
36141	Rose Bar	F	10/8/02	062655	Fall	1999	Feather R Hatchery	West Sacramento	Feather River	4/10/00	25005	0	FWS
36162	Rose Bar	F	10/8/02	100000		2000					0	0	
36163	Rose Bar	F	10/8/02	062653	Fall	1999	Feather R Hatchery	West Sacramento	Feather River	5/1/00	20926	0	FWS
36121	Rose Bar	F	10/9/02	062681	Spring	2000	Feather R Hatchery	Rodeo Minor Port	Feather River	4/23/01	47742	2832	CDWR
36142	Parks Bar		10/9/02	062673	Fall	2000	Feather R Hatchery	Rodeo Minor Port	Feather River	4/23/01	46642	3189	CDWR

Head Tag	Location	Sex	Recovery Date	CWT Code	Run	Brood Year	Hatchery	Release Site	Stock Name	Date Released	Tagged	Untagged	Agency
36159	Parks Bar		10/9/02	062680	Spring	2000	Feather R Hatchery	Rodeo Minor Port	Feather River	4/26/01	47742	2832	CDWR
36126	Daguerre	F	10/10/02	0601060905	Spring	1998	Feather R Hatchery	Crockett	Feather River	6/4/99	51333	0	CDWR
36135	Rose Bar	F	10/15/02	062663	Fall	1999	Mokelumne R Fish Ins	Mokelumne R, Mouth	Mokelumne River	4/21/00	24250	0	SJRG
36168	Rose Bar	F	10/15/02	062631	Fall	1998	Feather R Hatchery	Crockett	Feather River	6/11/99	50877	0	CDWR
36134	Rose Bar	F	10/16/02	062631	Fall	1998	Feather R Hatchery	Crockett	Feather River	6/11/99	50877	0	CDWR
36171	Parks Bar	M	10/16/02	062633	Fall	1998	Feather R Hatchery	Crockett	Feather River	6/11/99	51964	0	CDWR
36172	Parks Bar	F	10/16/02	062634	Fall	1998	Feather R Hatchery	Crockett	Feather River	6/11/99	50928	0	CDWR
36127	Daguerre	F	10/17/02	0601060906	Spring	1998	Feather R Hatchery	Crockett	Feather River	6/4/99	53958	0	CDWR
36170	Rose Bar	F	10/17/02	100000		2000					0	0	
36173	Parks Bar	F	10/17/02	062632	Fall	1998	Feather R Hatchery	Crockett	Feather River	6/11/99	50893	0	CDWR
36167	Daguerre	F	10/21/02	062665	Fall	2000	Feather R Hatchery	Wickland Oil Net Pen	Feather River	5/31/01	142204	718675	CDFG
36116	Rose Bar	F	10/22/02	062638	Fall	1998	Feather R Hatchery	Crockett	Feather River	6/11/99	50827	0	CDWR
36120	Rose Bar	F	10/22/02	100000		2000					0	0	
36128	Rose Bar	F	10/22/02	100000		2000					0	0	
36129	Rose Bar	F	10/22/02	060215	Fall	1998	Mokelumne R Fish Ins	Crockett	Mokelumne River	7/2/99	95203	775696	EBMD
36169	Rose Bar	F	10/22/02	062940	Fall	1999	Tiburon Net Pens	Tiburon Net Pens	Feather River	8/26/00	28888	0	TYEE
36174	Rose Bar		10/22/02	062671	Fall	2000	Feather R Hatchery	Rodeo Minor Port	Feather River	5/22/01	31575	2159	CDWR
36117	Parks Bar	M	10/23/02	064404	Fall	1999	Merced R Fish Facil.	Jersey Pt, San Joaquin R	Merced River	4/20/00	25824	0	CDFG
36118	Parks Bar	M	10/23/02	062673	Fall	2000	Feather R Hatchery	Rodeo Minor Port	Feather River	4/23/01	46642	3189	CDWR
34342	Parks Bar	F	10/30/02	064916	Fall	1998	Mokelumne R Fish Ins	New Hope Landing	Mokelumne River	5/28/99	51042	1208854	EBMD
36199	Daguerre	M	11/1/02	100000		2000					0	0	

Head Tag	Location	Sex	Recovery Date	CWT Code	Run	Brood Year	Hatchery	Release Site	Stock Name	Date Released	Tagged	Untagged	Agency
36198	Rose Bar	M	11/5/02	062675	Fall	2000	Feather R Hatchery	Rodeo Minor Port	Feather River	4/26/01	42704	2920	CDWR
36200	Rose Bar		11/5/02	062941	Fall	2000	Tiburon Net Pens	Tiburon Net Pens	Feather River	8/25/01	41819	12	TYEE
36119	Daguerre	M	11/7/02	060247	Fall	1998	Mokelumne R Fish Ins	Sherman Isl Op Jersy	Mokelumne River	5/21/99	51366	0	EBMD
36143	Rose Bar	F	11/12/02	100000		2000					0	0	
36177	Rose Bar		11/12/02	100000		2000					0	0	
36176	Parks Bar	F	11/13/02	064921	Fall	1998	Mokelumne R Fish Ins	Sherman Isl Op Jersy	Mokelumne River	5/21/99	25200	0	EBMD
36165	Rose Bar	M	11/19/02	0601061002	Fall	1999	Merced R Fish Facil.	Jersey Pt, San Joaquin R	Merced River	5/1/00	24661	0	CDFG
36166	Rose Bar	F	11/19/02	064920	Fall	1998	Mokelumne R Fish Ins	Sherman Isl Op Jersy	Mokelumne River	5/21/99	25162	0	EBMD
36175	Rose Bar	M	11/19/02	064921	Fall	1998	Mokelumne R Fish Ins	Sherman Isl Op Jersy	Mokelumne River	5/21/99	25200	0	EBMD
36194	Rose Bar		11/19/02	062716	Fall	2000	Mokelumne R Fish Ins	West Sacramento	Mokelumne River	4/26/01	25384	128	CDFG
43201	Daguerre	M	11/21/02	062663	Fall	1999	Mokelumne R Fish Ins	Mokelumne R, Mouth	Mokelumne River	4/21/00	24250	0	SJRG
36164	Daguerre	M	11/24/02	064920	Fall	1998	Mokelumne R Fish Ins	Sherman Isl Op Jersy	Mokelumne River	5/21/99	25162	0	EBMD
43203	Rose Bar	F	11/25/02	064918	Fall	1998	Mokelumne R Fish Ins	New Hope Landing	Mokelumne River	5/13/99	49804	0	EBMD
43204	Parks Bar	F	11/26/02	060257	Fall	1999	Mokelumne R Fish Ins	New Hope Landing	Mokelumne River	9/26/00	51076	185329	EBMD
43202	Parks Bar	M	11/29/02	064921	Fall	1998	Mokelumne R Fish Ins	Sherman Isl Op Jersy	Mokelumne River	5/21/99	25200	0	EBMD
43205	Rose Bar	M	12/3/02	060248	Fall	1998	Mokelumne R Fish Ins	Sherman Isl Op Jersy	Mokelumne River	5/21/99	49740	0	EBMD
36144	Parks Bar	F	12/4/02	065457	Fall	2000	Nimbus Fish Hatchery	Wickland Oil Net Pen	American River	6/15/01	99102	285185	CDFG