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U.S. BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT

GUIDE TO
UPPER SACRAMENTO RIVER
CHINOOK SALMON LIFE HISTORY

July 1991

CH2M HILL

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INTRODUCTION

PURPOSE OF DOCUMENT

This document has been prepared to serve as a "working reference" to the complex and overlapping life cycles of Sacramento River chinook salmon runs. As a working reference, this document will serve to enhance communication and coordination among the federal, state, and local government agencies with responsibilities for fisheries and water resources management in the upper reach of the Sacramento River (i.e., from about the city of Red Bluff upstream to Keswick Dam). The intent of this working reference is to supplement, not supplant, the coordination process. This document does not address the effects of Red Bluff Diversion Dam (RBDD) on Sacramento River chinook salmon as this is well discussed in widely available agency reports. As a working reference, this document is intended to evolve, incorporating newly developing biological information on Sacramento River chinook salmon runs and modifications of operations of the Central Valley Project (CVP) that might affect salmon habitat at regular update intervals. It is recommended that the update/review interval be no longer than every 3 to 5 years in light of the recent rate of development of new biological information on salmon from the Sacramento River basin.

This document is not intended as an exhaustive review of information pertaining to Sacramento River chinook salmon life history and habitat requirements, but rather a compendium of the working knowledge of the range of life history attributes most affected by operations of the CVP in the upper portion of the Sacramento River.

GENERAL LIFE HISTORY OF THE CHINOOK SALMON

The chinook salmon, or king salmon as it is commonly referred to in California, has the broadest geographic range of any of the Pacific salmon species. Runs of chinook salmon are found throughout the northern Pacific Ocean and tributary drainages around the Pacific Rim from northern Japan to southern California. In spite of its wide distribution, the chinook salmon is the least abundant of all the Pacific salmon species. The chinook salmon as a species is distinguished by its highly variable life history, and many rivers have more than one distinct stock identifiable by their unique life history patterns.

The life span of chinook salmon may range from 2 to 7 years. Chinook salmon will spend from 1-1/2 to 5 years feeding and roaming in the ocean before maturing and returning to their natal streams to spawn. Both life span and the timing of spawning migrations are primarily genetically controlled. All chinook salmon die upon completion of spawning.

The eggs are laid in nests, referred to as redds, excavated by the female in uncompacted gravels. Appropriate gravel beds selected by female chinook salmon consist mainly of gravel ranging in size from 1 to 6 inches in diameter. Optimal survival of eggs and pre-emergent fry occurs when the largest fraction of the redd is composed of the smaller-sized gravels. The female will seek out gravel beds with water depths and velocities sufficient for spawning activities and egg incubation. Depths where chinook salmon redds may be located range from shallow riffle areas (0.5 to 2 feet deep) to deep runs or glides (5 to over 20 feet deep). Spawning depth is a function of physiological requirements, available habitat, and specific preferential differences between stocks of salmon, probably under genetic influence. For instance, some winter-run chinook salmon have been observed to spawn on gravels in deeper water than the other three Sacramento River salmon runs. Preferred spawning velocities are generally in the range of 1.5 to 2.5 feet per second just above the surface of the gravel bed.

As the female lays the eggs in the redd, one or more male salmon fertilize the eggs. The female subsequently buries the eggs in the redd by displacing gravels upstream of the redd onto the eggs.

Eggs hatch after a variable incubation period dependent on water temperature, but is generally about 40 to 60 days. Maximum survival of incubating eggs and pre-emergent fry occurs at water temperatures between 40°F and 56°F. The newly hatched larvae, or pre-emergent fry, will remain in the redd and absorb the yolk stored in their yolk-sac to grow into fry. This period of larval incubation will last approximately 2 to 4 weeks depending on water temperatures. The fry then wiggle their way out of the redds, up into the water above. The fry will seek out shallow nearshore areas with slow current and vegetative and/or boulder cover nearby where they begin to feed on insects and crustaceans drifting in the current. As they grow, the juvenile salmon (approximately 50 to 75 mm in length) move out into deeper, swifter water for rearing, but continue to remain near boulders, fallen trees, and other such cover to reduce chances of being preyed upon and minimize energy expenditure. Juvenile salmon may emigrate downstream toward the estuary at any time from immediately after they emerge from the redd to after spending over one year in freshwater. The length of juvenile residence time in freshwater and estuaries varies between salmon runs and depends on a variety of factors including season of emergence, riverflow, turbidity, water temperature, and interactions with other species.

LIFE HISTORY STRATEGIES DISTINGUISHING THE FOUR RUNS OF SACRAMENTO RIVER CHINOOK SALMON

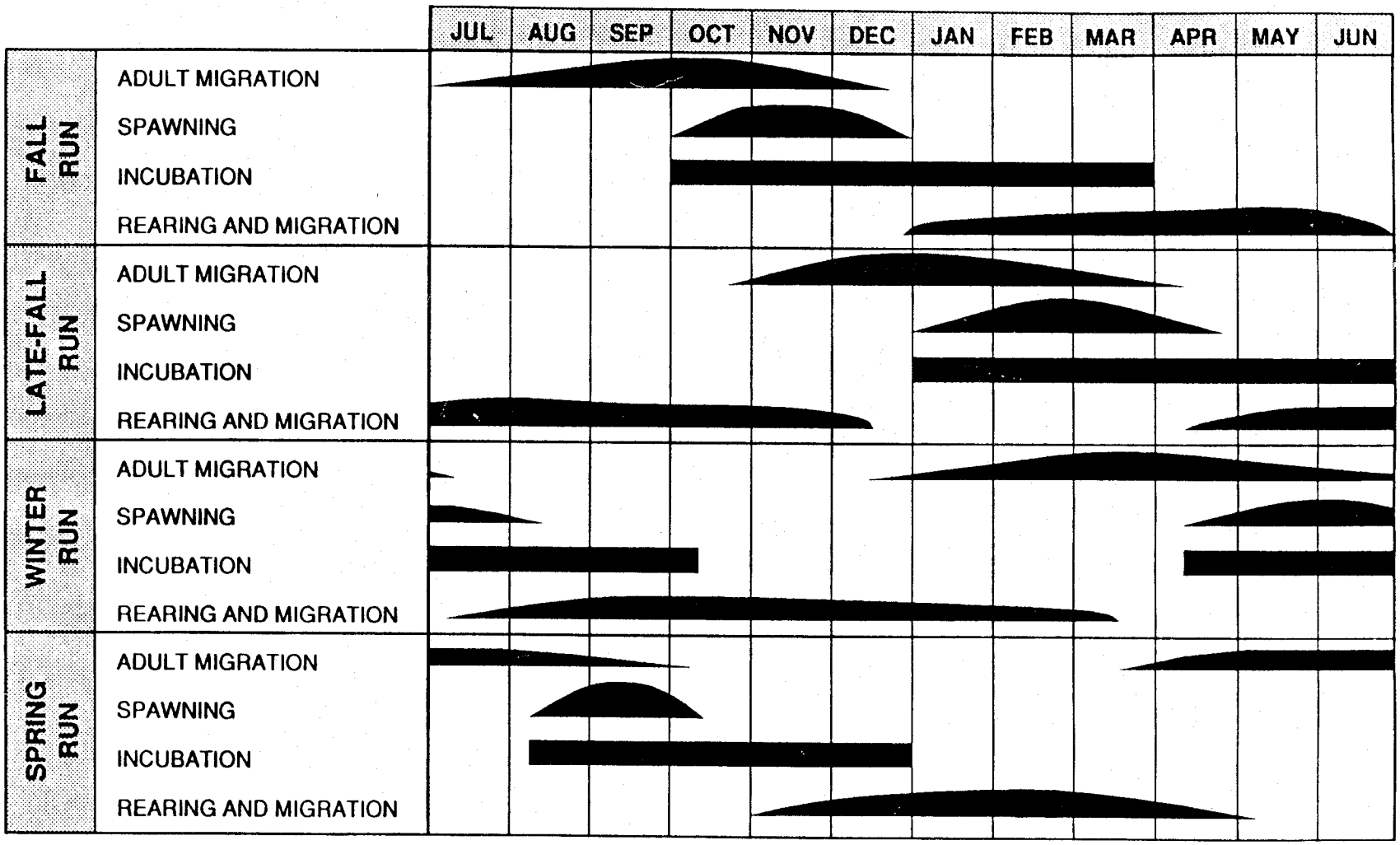
The Sacramento River is unique among Pacific coast streams and rivers in that it possesses four chinook runs (fall, late-fall, winter, and spring), and spawning occurs virtually year-round. Each of the freshwater life stages (i.e., spawning adult, egg and larva, fry and juvenile) may be found in the upper river every month of the year. This is due to a variety of factors including the remarkable adaptability of the chinook

salmon, the historically diverse river habitat available in the Sacramento River basin which includes spring-fed streams that remain cool all summer, and the moderate climate of California which provides for nearly year-round ice-free stream conditions throughout many drainages. Figure 1 illustrates the general timing of each run of Sacramento River chinook salmon at and upstream of Red Bluff for the respective freshwater life stages during the course of a year. The actual timing of each of the life stage events varies somewhat from year to year and is primarily a function of weather, riverflows, and water temperature. For example, the onset and peak of spawning for each run can vary by 2 to 3 weeks from year to year (Richard Painter, California Department of Fish and Game, personal communication).

Sacramento River chinook salmon runs are designated by the season during which they enter the river to begin their upstream spawning migrations. While migrating and spawning adults from adjacent runs may be found in the river at the same time, each run has a fairly discrete period of spawning (although some overlap of spawning activity does occur, particularly between the fall and spring runs). There is a general consensus among fishery scientists that a "genetically pure" mainstem spawning population of Sacramento River spring-run salmon no longer exists due to the broad overlap in spawning periods of the fall and spring runs: The fall run and spring run have likely crossbred to become one protracted late-summer through fall spawning run in the mainstem. The only remaining genetically-pure spring-run stocks in the upper Sacramento River basin are believed to be those utilizing the tributary spawning habitats (e.g., Mill Creek and Deer Creek). Such a phenomenon has not been observed between any other runs spawning in the mainstem.

The timing of spawning activity for each of the runs is fairly well established, and incubation periods can be reasonably calculated from knowledge of egg development in hatcheries. However, the timing and dynamics of the rearing and downstream migration periods of juveniles of each run are not as well understood. This latter circumstance is due to the paucity and limitations on data regarding juveniles, as well as the year-to-year variability affected by weather, riverflow, and the biological interactions of food availability, predation, and competition with other runs' juveniles rearing in the river at the same time. However, it is thought that some juveniles remain to rear in the mainstem Sacramento River to the yearling stage (generally considered <5 percent of the population). Results on ongoing and future studies on habitat utilization, downstream migration timing, predation and competition, and environmental tolerances should be eventually incorporated into this document.

Section 2 of this document describes the variation in salmon life history activities on a monthly basis during the course of a representative wet year (1983) and a representative dry year (1985). Comparison of life stage activities between these two contrasting years demonstrates the range in timing of the life history stages for each run.



LEGEND

DENOTES PRESENCE AND RELATIVE MAGNITUDE

DENOTES ONLY PRESENCE

FIGURE 1

LIFE HISTORY CHARACTERISTICS OF SACRAMENTO RIVER CHINOOK SALMON AT AND UPSTREAM OF RED BLUFF

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WATER QUALITY AND PHYSICAL HABITAT CRITERIA FOR SACRAMENTO RIVER CHINOOK SALMON

Although some general information is available, specific chinook salmon habitat criteria and riverflow/salmon habitat relationships have not yet been fully developed for the Sacramento River. Results of ongoing and future studies on salmon habitat utilization and requirements in the upper river should be incorporated into this document to improve its utility. For the present version of this document, effects of changes in riverflow on salmon habitat and behavior will be described in a qualitative rather than quantitative manner.

It is generally recognized by fishery managers that the best quality salmon spawning and fry and juvenile rearing habitat in the mainstem Sacramento River occurs in the reach from about the city of Red Bluff upstream to Keswick Dam (Figure 2). Spawning densities for each of the four runs are generally highest in this reach. This same reach is presently designated as critical habitat for winter-run chinook salmon under emergency rules of the Endangered Species Act. (The extent of critical habitat may change on November 5, 1991, following an economic impact analysis by the National Marine Fisheries Service.) It is also in this reach where operations of the Shasta/Keswick and Trinity Divisions of the CVP have the most significant effects on salmon spawning and rearing habitat in the mainstream Sacramento River. Rapid flow fluctuations can dewater edge and backwater habitat and strand fry and juvenile salmon. Redds can also be dewatered as a result of flow fluctuations. It is important to note that significant numbers of salmon still spawn downstream of Red Bluff. Approximately 15 to 30 percent of the total number of fall and late-fall chinook spawn downstream of Red Bluff when water quality is good.

Other habitat/water quality factors important to chinook salmon that could be affected by CVP operations to varying extents include water temperature, water turbidity, and dissolved oxygen. In this document, only the effects of elevated water temperatures on the survival of the freshwater life stages of chinook salmon will be directly addressed as it is the most common water quality problem affected by CVP operations. Effects of CVP operations on water turbidity and dissolved oxygen are less problematic with respect to chinook salmon habitat at the present time, but are under the direct and indirect influence of the CVP and deserve further investigation and future inclusion in this working reference.

The sensitivity and specific effects of elevated water temperatures vary with life stage for chinook salmon; Figure 3 generally depicts these relative changes in temperature sensitivity. This information has been derived from a number of different salmon stocks and thus represents a composite description for chinook salmon. For numerical values depicted in Figure 3, the reader should refer to the original source documents listed in Appendix A. It is known that considerable variation in environmental tolerances and habitat preferences exists between different stocks, and it is expected that there is some variation in temperature tolerances between different stocks as well.

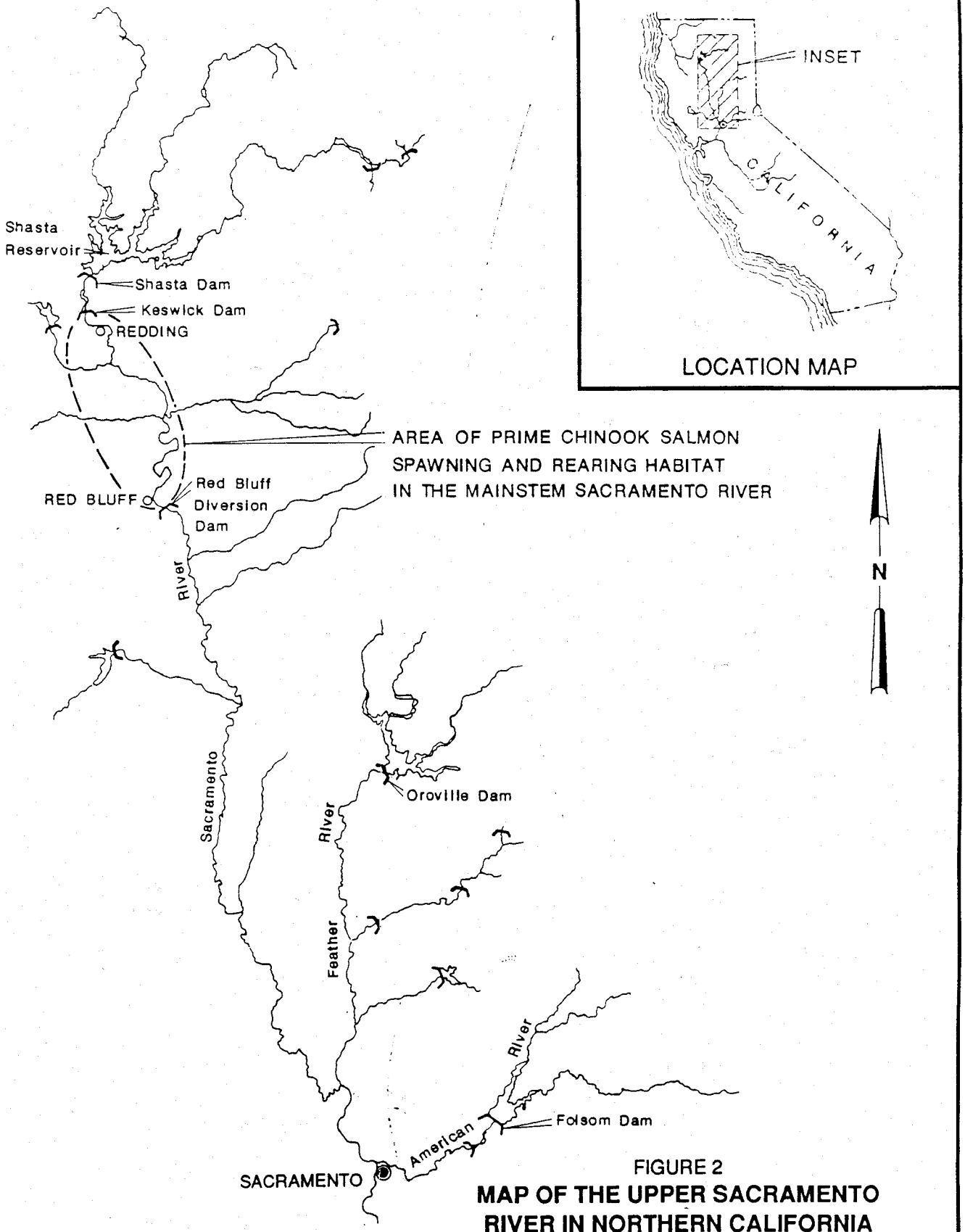

FIGURE 2

MAP OF THE UPPER SACRAMENTO RIVER IN NORTHERN CALIFORNIA INDICATING HIGH QUALITY SALMON SPAWNING AND REARING HABITAT

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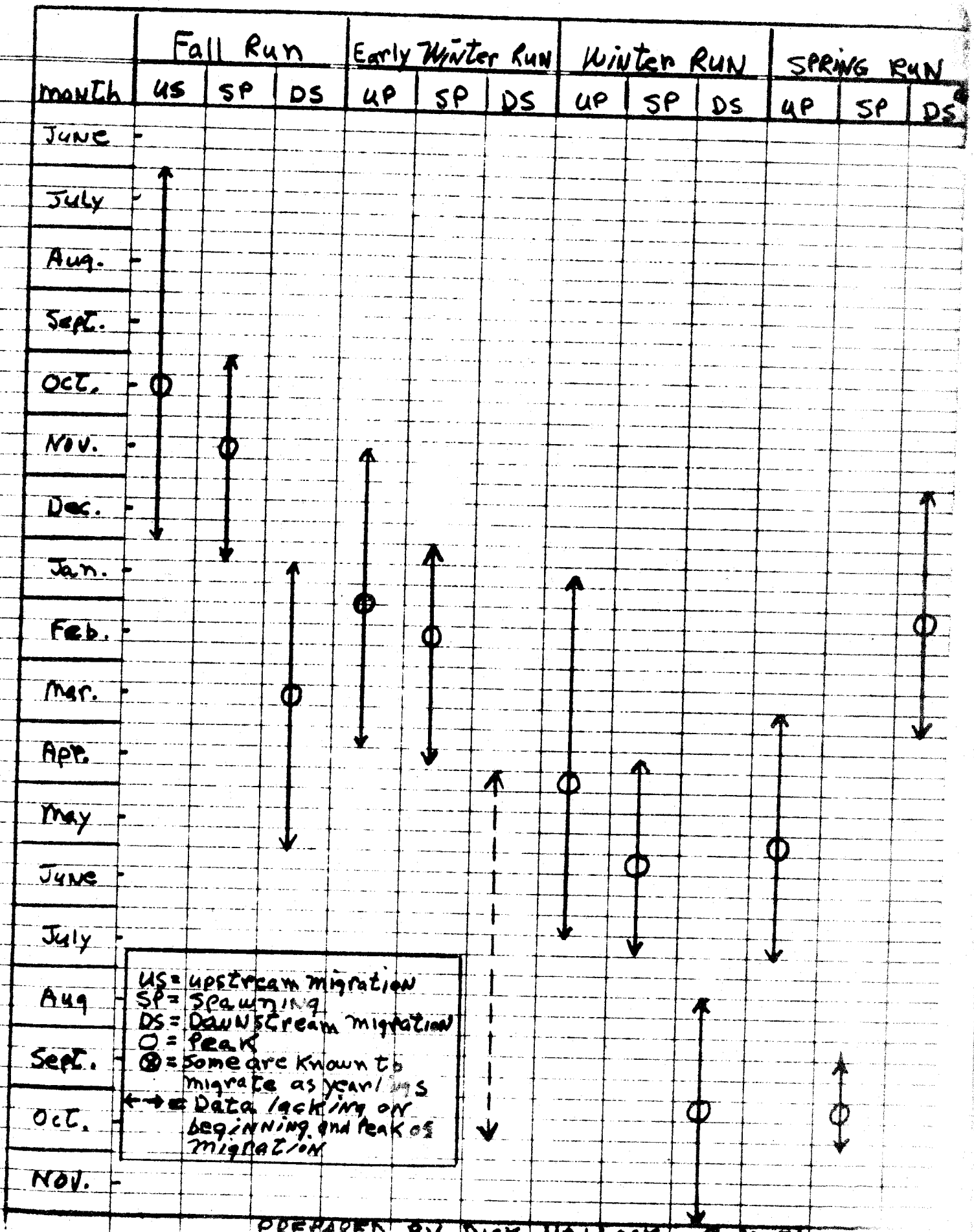
SACRAMENTO RIVER KING SALMON LIFE HISTORY PATTERNS NEAR RED BLUFF



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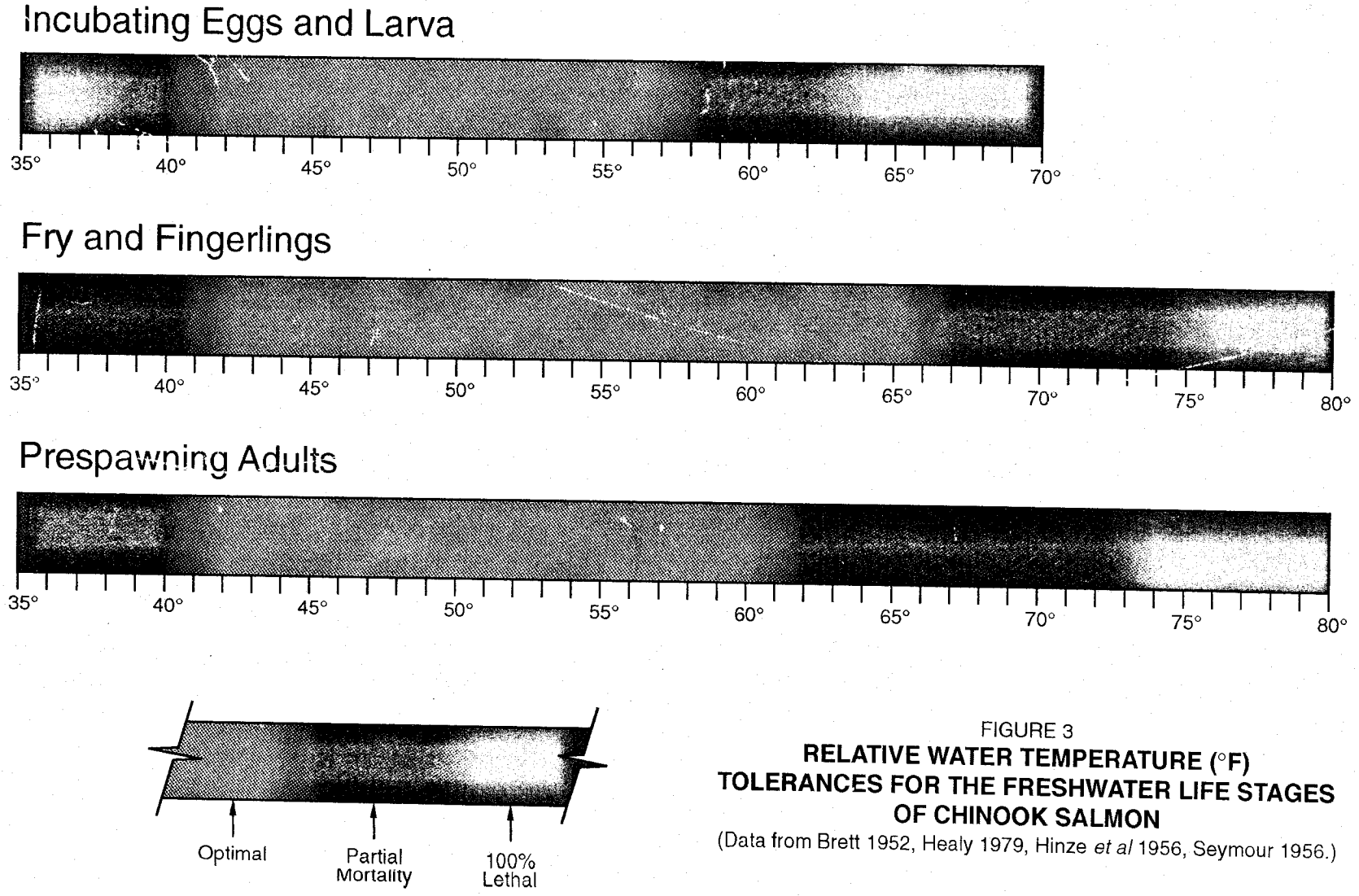

FIGURE 3

RELATIVE WATER TEMPERATURE (°F) TOLERANCES FOR THE FRESHWATER LIFE STAGES OF CHINOOK SALMON

(Data from Brett 1952, Healy 1979, Hinze *et al* 1956, Seymour 1956.)

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There are ongoing and planned assessments of egg and fry tolerances to elevated water temperatures for runs of chinook salmon in California. Results of these studies will be very useful for future inclusion in this reference document. Section 2 addresses the range of responses of egg and larval incubation and fry to temperature conditions during representative wet and dry years.

Section 2
MONTHLY SNAPSHOTS OF SALMON ACTIVITIES IN THE UPPER SACRAMENTO RIVER

JANUARY

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During January[a]				
Life Stage	Run			
	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

JANUARY

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of January[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month			65	85	<5	5		
Cumulative percent having spawned by mid-month			10	10				
Relative percent of year's brood as incubating eggs and larvae	50	60	10	10			0	--[b]
Relative percent of year's brood having reached fry life stage	50	40					95	--[b]
Relative percent of year's brood having reached juvenile life stage	0	0			100	100	5	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month	40-50	5-10			75-95	60-90	75-95	

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

JANUARY

ADULT UPSTREAM MIGRATION AND SPAWNING

- Late-fall-run upstream migration is at its peak.
- Spawning generally begins for late-fall-run salmon, but may vary by 2 to 3 weeks from year to year due to riverflows, water temperatures, and delays in passage at RBDD.
- Winter-run salmon continue to migrate to and hold in deep pools of upper river reaches.

EGG AND LARVAL INCUBATION

- Fall-run incubation is approximately half complete with mostly larvae in the redds. A small proportion of late-fall-run eggs have been laid in the river gravel.
- Fall-run fry are emerging from the redds by tens of thousands each day.
- Salmon redds on shallow riffles and side channels can be susceptible to dewatering if riverflows decrease significantly during the month; this can desiccate eggs still in the gravel and strand larvae and fry.

FRY AND JUVENILE REARING

- Fall-run fry are at peak of emergence by the end of January.
- Fall-run fry and spring-run fry and juveniles are at near peak abundances inhabiting nearshore rearing habitats.
- Fall-run fry are susceptible to stranding in shallow water habitats and increased vulnerability to predation by birds during rapid declines of riverflow that may occur during dry years or highly fluctuating flows in wet years.
- Large-sized winter-run juveniles remaining in the upper river are rearing in deeper water habitats associated with cover (e.g., fallen trees, root wads, boulders, and deep pools).

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- Emigration of newly emerged fall-run fry and spring-run fry and juveniles from the upper river can be very high, particularly during wet years with high riverflows.
- Limited emigration of fall-run fry occurs during January in dry years; short-term pulses of increased runoff and high turbidity may stimulate some downstream migration.
- Large-sized winter-run juveniles continue to emigrate throughout January, especially during storm events resulting in increased riverflows.

FEBRUARY

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During February[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

FEBRUARY

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of February[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month			90	95	15	20		
Cumulative percent having spawned by mid-month			65	65				
Relative percent of year's brood as incubating eggs and larvae	10	15	65	65				
Relative percent of year's brood having reached fry life stage	90	85					50	--[b]
Relative percent of year's brood having reached juvenile life stage	0	0			100	100	50	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month	65-80	15-30			80-100	75-95	80-100	--[b]

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

FEBRUARY

ADULT UPSTREAM MIGRATION AND SPAWNING

- The late-fall-run upstream migration will subside rapidly during this month.
- Late-fall-run spawning generally peaks during February, with spawning occurring predominantly in the upper river on riffles, point bars, and in shallow side channels.
- Winter-run salmon continue to migrate to and hold in deep pools of upper river reaches.

EGG AND LARVAL INCUBATION

- Fall-run fry continue to emerge from the redds by the tens of thousands daily. Only a small proportion of eggs have yet to hatch, and a small proportion larvae are still in the redds.
- Over half of the late-fall-run's eggs will be in redds by month's end.
- Salmon redds on shallow riffles and side channels can be susceptible to dewatering if riverflows decrease significantly during the month; this can desiccate eggs still in the gravel and strand larvae and fry.

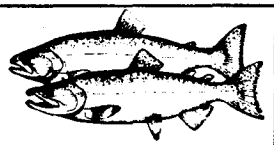
FRY AND JUVENILE REARING

- Most fall-run fry have emerged from the redds by month's end and are at peak abundances inhabiting shallow, nearshore rearing habitats.
- Spring-run fry continue to grow and are difficult to distinguish from fall-run fry.
- Winter-run juveniles continue to rear in deeper water habitats, more so during the drier winters with persistant low riverflows.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- Fall-run and spring-run fry will continue to emigrate from the upper river at high rates during wet years with high riverflows and turbidity.
- During most dry years, emigration of fall-run fry is low with most fry remaining in the upper river to rear throughout February; short-term pulses of increased runoff and high turbidity may stimulate substantial downstream migration.
- Most remaining winter-run juveniles have emigrated from the upper river during February of both wet and dry years.

MARCH

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During March[a]				
	Run			
Life Stage	**Fall**	**Late Fall**	**Winter**	**Spring**
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

MARCH

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of March[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month			100	<95	50	60	<5	<5
Cumulative percent having spawned by mid-month			95	95				
Relative percent of year's brood as incubating eggs and larvae	0	0	95	95				
Relative percent of year's brood having reached fry life stage	95	90					0	--[b]
Relative percent of year's brood having reached juvenile life stage	5	10			100	100	100	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month	70-90	20-40			100	100	90-100	--[b]

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

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MARCH

ADULT UPSTREAM MIGRATION AND SPAWNING

- Late-fall-run migration and spawning generally subsides to very low levels by the end of March.

- Winter-run migration is at its peak during March, but this can vary by 2 to 3 weeks, depending on run timing, riverflows, and operations at RBDD.

- The first spring-run salmon generally arrive in the upper river during this month.

EGG AND LARVAL INCUBATION

- Virtually all fall-run salmon fry will have emerged from the redds during most years, regardless of climate variation, by the end of March.

- Late-fall-run eggs predominate in the gravel during March; some laid in January will begin to hatch.

- Salmon redds on shallow riffles and side channels can be susceptible to dewatering if riverflows decrease significantly during the month; this can desiccate eggs still in the gravel and strand larvae and fry.

FRY AND JUVENILE REARING

- Fall-run fry remain near peak abundance, inhabiting the nearshore rearing habitat, especially during dry years.

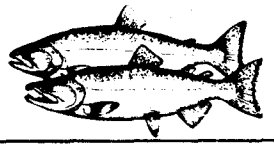
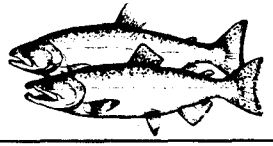
- During dry years, with low riverflows in March, increased heating during the lengthening days results in somewhat warmer water temperatures and fry growth rate increases compared to wet years with high riverflow.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- During wet years, most of the fall run will have emigrated from the upper river as fry by the end of March. During dry years, the majority of fall-run fry remain to rear in the upper river during March; short-term pulses of increased runoff and high turbidity may stimulate substantial downstream migration.

- Virtually all remaining winter-run and spring-run juveniles have emigrated by the end of March.

APRIL

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During April[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

APRIL

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of April[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month			100	100	75	85	<5	<5
Cumulative percent having spawned by mid-month			100	100	<5	<5		
Relative percent of year's brood as incubating eggs and larvae			100	80	<5	<5		
Relative percent of year's brood having reached fry life stage	<5	<5	0	20				
Relative percent of year's brood having reached juvenile life stage	>95	>95	0	0			100	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month	80-95	40-55	0	<10			95-100	--[b]

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

APRIL

ADULT UPSTREAM MIGRATION AND SPAWNING

- Late-fall-run migration ceases by mid-April and spawning is complete by the end of April.

- Winter-run migration is declining but can still be substantial during April in many years. During dry years, a greater proportion of the entire population has arrived in the upper river as compared to wet years. A small proportion of the spawning activity may begin as early as mid-April.

EGG AND LARVAL INCUBATION

- Most late-fall-run eggs will begin hatching by the end of April.

- During dry years, when warming begins early in the spring season, late-fall-run fry may begin emerging from redds by mid-month.

- In most years, the first winter-run eggs will be in redds by the end of April.

FRY AND JUVENILE REARING

- During dry years, fall-run juveniles will remain abundant and begin moving to deeper water habitat such as undercut banks, mid-channel areas with cover, and deep pools.

- During dry, warm years, early emerging late-fall-run fry will be found rearing in nearshore habitats.

- During wet years, few fall-run and spring-run fry and juveniles will remain in the upper river.

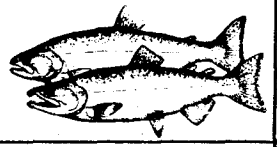
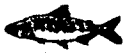
- Juvenile salmon growth rate increases dramatically during the month.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- During wet years, the few remaining fall-run and spring-run juveniles will continue to emigrate at low rates during April. During dry years, the major emigration of fall-run juveniles begins about mid-April.

- During dry, warm years, small numbers of late-fall-run fry disperse to areas downstream of RBDD.

MAY

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During May[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

MAY

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of May[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month					85	95	<5	10
Cumulative percent having spawned by mid-month					15	15		
Relative percent of year's brood as incubating eggs and larvae			40	10	15	15		
Relative percent of year's brood having reached fry life stage			60	90				
Relative percent of year's brood having reached juvenile life stage	100	100	0	0			100	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month	90-100	75-90	20-50	10-30			95-100	--[b]

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

MAY

ADULT UPSTREAM MIGRATION AND SPAWNING

- Arrival of winter run in the upper river subsides substantially during May. Spawning activity begins to increase. Winter-run chinook salmon are somewhat unique in that they utilize spawning gravels located both on shallow riffles and in deeper runs.

- The winter run's upstream migration progress appears to be influenced by increasing water temperature.

EGG AND LARVAL INCUBATION

- Virtually all late-fall-run eggs will have hatched by mid-May during all years, regardless of climatic variation.

- Late-fall-run fry emergence from the redds is at its peak during May. During dry years, fry emergence will be complete by the end of month; during wet years, it will extend into June.

- Increasing numbers of winter-run eggs are in the gravels.

FRY AND JUVENILE REARING

- Late-fall-run fry move to shallow, nearshore rearing habitat throughout the month in increasing numbers.

- Most remaining fall-run juveniles undergo smoltification during the month.

- Few fall-run and spring-run juveniles remain to rear in the upper river by the end of the month.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- During dry years, fall-run juvenile emigration generally peaks during early to mid-May.

- Late-fall-run fry disperse in large numbers from the upper river to areas downstream of RBDD, particularly during wet spring years, and in smaller numbers during dry spring years.

JUNE

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During June[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

JUNE

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of June[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month					95	99	10	25
Cumulative percent having spawned by mid-month					80	80		
Relative percent of year's brood as incubating eggs and larvae			<5	0	80	75		
Relative percent of year's brood having reached fry life stage			95	95	0	<5		
Relative percent of year's brood having reached juvenile life stage	100	100	0	5	0	0	100	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month	95-100	90-100	25-80	20-50		<5	95-100	--[b]

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

JUNE

ADULT UPSTREAM MIGRATION AND SPAWNING

- The winter-run migration continues during June and spawning is generally at its peak, but the actual peak time may vary by 2 to 3 weeks from year to year, depending on run timing, riverflows, and water temperature.

EGG AND LARVAL INCUBATION

- Late fall incubation is virtually complete in all but the coolest, wettest years by early June, and most fry have emerged from redds and are rearing in shallow, nearshore habitats. It is suspected that late-fall-run juveniles rear for a longer period than other runs. The summer months when they rear are very productive and contribute good growth conditions.

- Winter run are at peak of spawning with the majority of eggs incubating by month's end.

- During dry years, with warm spring season water temperatures, some of the earliest spawned winter-run eggs will hatch by mid-June.

FRY AND JUVENILE REARING

- Virtually all late-fall fry will be rearing in shallow, nearshore habitat by the end of June. Growth of fry is quite rapid during June due to long day length and abundant food.

- During dry years with warm spring seasons and low reservoir storage, some of the earliest spawned winter-run fry will emerge from the gravel and move to rear in shallow, nearshore habitat by the end of June. However, excessive water temperatures (>58°F) can result in significant winter-run egg and fry mortality during June.

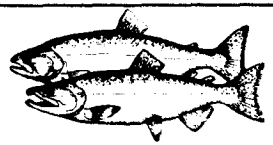
DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- During dry years, emigration of fall-run juveniles may continue through mid-June, tapering off by month's end.

- Emigration of late-fall-run fry occurs at moderate rates during most years during the month of June.

- Some early emerging winter-run fry may be found emigrating in June as well.

JULY

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During July[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

JULY

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of July[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month	<5	<5			>95	>99	25	40
Cumulative percent having spawned by mid-month					95	95		
Relative percent of year's brood as incubating eggs and larvae					75	70		
Relative percent of year's brood having reached fry life stage			25	<10	25	30		
Relative percent of year's brood having reached juvenile life stage	100	100	75	90	0	0		
Estimated cumulative percent of year's brood emigrating from upper river by mid-month	100	95-100	30-85	25-55	<5	0	100	--[b]

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

JULY

ADULT UPSTREAM MIGRATION AND SPAWNING

- In many years, early arrival of some fall-run adults to the upper river is observed by early July, but the time of first arrival can vary by as much as a month.

- Spring-run migration continues during July with the adults to be found holding in deep pool habitats until they begin spawning in September.

- Very low numbers of winter run continue to appear at RBDD.

- Winter-run spawning is almost completed by the end of July. When upstream reservoir storage is at low levels, summer water temperatures may exceed 56°F in the lower river spawning reaches. The area of good spawning success is determined by the length of river reach affected by cool water (<56°F). In most years, this area is located upstream of RBDD.

EGG AND LARVAL INCUBATION

- Only winter-run eggs are present during July; most are in redds by the end of the month. Most eggs spawned by early June will hatch by the end of July. Dry years with warm water temperatures (>56°F) will cause a certain level of mortality before fry emergence.

FRY AND JUVENILE REARING

- Winter-run fry are emerging from redds during July and move to shallow, nearshore habitats to rear.

- Late-fall-run fry continue to grow rapidly during July. Larger sized juveniles begin moving to the deeper rearing habitats.

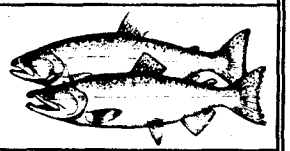
DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- Most fall-run and spring-run juveniles have emigrated from the upper river by the end of July. A few may remain upstream to rear to a yearling life stage.

- Late-fall-run fry and juveniles continue to emigrate at low rates throughout July.

- Some winter-run fry disperse to areas downstream of RBDD during July shortly after emerging from the redds, but the majority of fry remain to rear in the upper river throughout July.

AUGUST

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During August[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

AUGUST

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of August[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month	5	20			100	100	40	75
Cumulative percent having spawned by mid-month					100	100	<5	<5
Relative percent of year's brood as incubating eggs and larvae					25	5	<5	<5
Relative percent of year's brood having reach fry life stage					75	95		
Relative percent of year's brood having reached juvenile life stage			100	100	0	0		
Estimated cumulative percent of year's brood emigrating from upper river by mid-month			50-90	40-60	5-10	<5		

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.

AUGUST

ADULT UPSTREAM MIGRATION AND SPAWNING

- Fall-run upstream migrants begin arriving in greater numbers during August.
- Arrival of spring run in the upper river generally peaks in mid-August, but may vary from year to year by about 2 weeks.
- Spring run can begin spawning about mid-August. The onset and peak of spawning varies by 2 to 3 weeks from year to year.
- Winter-run upstream migration and spawning are completed.
- Both fall-run and spring-run adults are susceptible to pre-spawning mortality if water temperatures exceed 60 to 65°F during the pre-spawning period occurring in August.

EGG AND LARVAL INCUBATION

- During dry years with low reservoir storage, warm water temperature (>56°F) in the upper river will result in some mortality to winter-run eggs and larvae remaining in the redds. By month's end most surviving fry will have emerged from redds.
- Early spawning spring-run eggs will also be susceptible to mortality if water temperatures exceed 56°F.
- During wet years with cooler water temperatures, a significant portion of the winter-run larvae and some eggs will remain in redds by month's end.

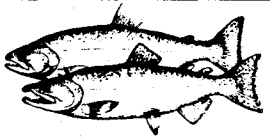
FRY AND JUVENILE REARING

- Most winter-run fry will have emerged from the gravel by month's end and will be found rearing in nearshore habitats, especially during dry years. Newly emerged fry grow rapidly at temperatures ≤58°F during late August and will be found at near-peak abundances.
- Late fall juveniles will be found rearing near cover in the deeper water habitats and will remain at near peak abundance in the upper river in late August.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- Late fall juveniles continue to emigrate at low rates during August.
- Some winter-run fry dispersal to areas downstream of RBDD occurs during August. Higher August flows may result in higher rates of emigration.

SEPTEMBER

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During September[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

SEPTEMBER

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of September[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month	35	55					80	90
Cumulative percent having spawned by mid-month							95	95
Relative percent of year's brood as incubating eggs and larvae					<5	0	95	95[b]
Relative percent of year's brood having reached fry life stage					>95	80		
Relative percent of year's brood having reached juvenile life stage			100	100	0	20		
Estimated cumulative percent of year's brood emigrating from upper river by mid-month			60-95	50-70	10-50	5-10		

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's egg brood.

SEPTEMBER

ADULT UPSTREAM MIGRATION AND SPAWNING

- Fall-run salmon migration to the upper river nears its peak around month's end. This peak may vary by several weeks depending on run timing, riverflows, and delays in passage by RBDD.

- Fall-run adults are susceptible to pre-spawning mortality and decreased egg viability caused by excessive water temperature (>60-65°F) during dry years when upstream reservoir storage is low.

- Spring-run spawning is nearly complete by late September, but completion of spawning may vary by 2 to 3 weeks from year to year.

EGG AND LARVAL INCUBATION

- Winter-run fry continue to emerge from the gravel through September.

- Spring-run eggs are very susceptible to excessive water temperatures (>56°F) during dry years. In most dry years, spring-run eggs may not survive to hatch due to excessive temperatures during September.

FRY AND JUVENILE REARING

- Winter-run fry are rearing in shallow, nearshore habitats at peak abundance by the end of September. They are susceptible to mortality caused by rapid declines of riverflow especially during dry years.

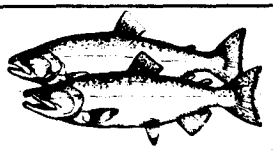
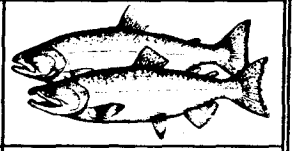
- Large-sized late fall juveniles remain, rearing in the deeper water habitats through September in most years.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- Late fall juvenile emigration generally continues at low levels during September. But early fall storms resulting in increased riverflow may stimulate increased emigration.

- Winter-run fry dispersal to areas downstream of RBDD generally peaks during September.

OCTOBER

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During October[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

OCTOBER

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of October[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month	80	90	15	25			100	100
Cumulative percent having spawned by mid-month	30	30					100	100
Relative percent of year's brood as incubating eggs and larvae	30	30					100	80[b]
Relative percent of year's brood having reached fry life stage					70	20	0	--[b]
Relative percent of year's brood having reached juvenile life stage			100	100	30	80	0	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month			65-90	55-70	20-75	10-20		

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

OCTOBER

ADULT UPSTREAM MIGRATION AND SPAWNING

- Fall-run migration generally peaks during October, and spawning begins.
- Late-fall-run salmon begin arriving in the upper river by late October. But this may vary by 2 to 3 weeks from year to year.

EGG AND LARVAL INCUBATION

- Fall-run and spring-run eggs are incubating during October. During dry years, excessive water temperatures (>56°F) during early October can cause significant egg mortality. During dry years, complete mortality of spring-run eggs can occur by late October.
- Salmon redds on shallow riffles and side channels can be susceptible to dewatering if riverflows decrease significantly during the month; this can desiccate eggs still in the gravel and strand larvae and fry.

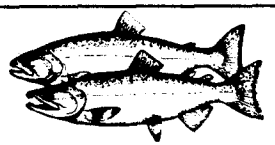
FRY AND JUVENILE REARING

- Winter-run fry are rearing in shallow, nearshore habitat and growing rapidly. Some larger winter-run juveniles move to deeper water habitat by late October.
- Rapid declines of riverflow during October can cause mortality to winter-run fry.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- Late-fall-run juveniles continue to emigrate during October. October storms resulting in increased riverflows will stimulate increased emigration.
- Emigration of winter-run fry and juveniles may be similarly stimulated by October storms, otherwise it generally remains at moderate rates through October.

NOVEMBER

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During November[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

NOVEMBER

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of November[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month	>95	>95	30	45				
Cumulative percent having spawned by mid-month	80	80						
Relative percent of year's brood as incubating eggs and larvae	>75	80					10	--[b]
Relative percent of year's brood having reached fry life stage	<5	0					90	--[b]
Relative percent of year's brood having reached juvenile life stage			100	100	100	100	0	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month			80-100	70-90	50-75	30-40	10-25	

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

NOVEMBER

ADULT UPSTREAM MIGRATION AND SPAWNING

- Arrival of fall-run salmon in the upper river tapers off through November with the peak of spawning occurring about mid-November. The majority of spawning is completed by month's end.

- The late-fall-run upstream migration increases significantly during November.

EGG AND LARVAL INCUBATION

- Decreasing daily air temperatures during November can lead to rapid declines in water temperature, especially during dry years with low riverflows. This decrease in water temperature will contribute to longer fall-run egg incubation periods during dry years compared with that of wet years. Some fall-run fry may emerge by late November during years with warm fall seasons.

- Salmon redds on shallow riffles and side channels can be susceptible to dewatering if riverflows decrease significantly during the month; this can desiccate eggs still in the gravel and strand larvae and fry.

- Few spring-run larvae remain in the gravel during wet years, having emerged by month's end.

- More than two-thirds of the fall-run's eggs will be in redds by month's end.

FRY AND JUVENILE REARING

- Spring-run fry may be present in shallow, nearshore rearing habitat during November in those years when they survive the incubation period. They may begin emigration as fry if storms result in increased riverflows and turbidity.

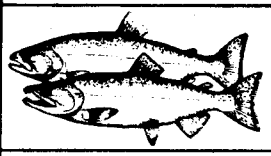
- Winter-run juveniles will be rearing primarily in the deeper water habitats with cover available.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- Remaining late-fall-run juveniles will emigrate during November storms that result in increased riverflows. If November is dry, their emigration will continue but at low rates.

- Similarly, large numbers of winter-run juveniles will emigrate *en masse* during November storms and increased riverflows. If November is dry, their emigration will continue at much lower rates.

DECEMBER

Freshwater Life Stages Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During December[a]				
	Run			
Life Stage	Fall	Late Fall	Winter	Spring
Upstream Spawning Migration				
Spawning				
Incubation				
Fry				
Juvenile				
Downstream Migration				

[a]Only those life stages which generally equal or exceed 5% of annual total population present by the end of the month are shown.

DECEMBER

Relative Proportions of Each Life Stage Present in Upper Sacramento River for Each Run of Sacramento River Chinook Salmon During a Representative Wet Year (1983) and a Dry Year (1985) for the Month of December[a]

	Run							
	Fall		Late Fall		Winter		Spring	
	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)	Wet (1983)	Dry (1985)
Cumulative percent of spawning migration passing RBDD by mid-month	100	100	50	65				
Cumulative percent having spawned by mid-month	100	100						
Relative percent of year's brood as incubating eggs and larvae	85	95					<5	--[b]
Relative percent of year's brood having reached fry life stage	15	5					>95	--[b]
Relative percent of year's brood having reached juvenile life stage			100	100	100	100	0	--[b]
Estimated cumulative percent of year's brood emigrating from upper river by mid-month			100	90-100	60-90	50-75	40-50	

[a]Hydrologic and water temperature data for 1983 and 1985 are presented in Appendix B Figures 1 and 2.
[b]Indicates high mortality of year's brood.

DECEMBER

ADULT UPSTREAM MIGRATION AND SPAWNING

- Fall-run migration and spawning is complete by mid- to late December.
- The late-fall-run upstream migration generally peaks near the end of December but can vary by 2 to 3 weeks from year to year.
- The first winter-run upstream migrants are beginning to arrive in the upper river.

EGG AND LARVAL INCUBATION

- Generally fall-run eggs begin hatching by mid- to late December, and the larvae remain in the gravel. The timing of egg hatching and fry emergence may be later in dry years as compared to wet years. This is caused by an increased cooling rate of lower river flows occurring in dry years, which causes slower egg and larval development.
- Salmon redds on shallow riffles and side channels can be susceptible to dewatering if riverflows decrease significantly during the month; this can desiccate eggs still in the gravel and strand larvae and fry.
- For those years when the spring run survive to emerge as fry, emergence will be nearly complete by the end of December.

FRY AND JUVENILE REARING

- The earliest emerging fall-run fry will move into shallow, nearshore rearing habitat. Both newly emerged fall-run and spring-run fry are vulnerable to rapid declines of riverflow that can result in their being stranded in these shallow nearshore areas during December.

DOWNSTREAM EMIGRATION OF FRY, JUVENILES, AND SMOLTS

- Late fall juveniles generally complete emigration by late December. Storms that result in increased riverflows will stimulate more complete emigration.
- Winter-run juveniles will continue to emigrate during December at low to moderate rates. Storms resulting in increased riverflows will stimulate greater emigration of winter-run juveniles during December.

Appendix A
SOURCES OF INFORMATION AND METHODS OF COMPILATION

Appendix A
SOURCES OF INFORMATION AND METHODS OF COMPILATION

The following table lists the primary sources of information on Sacramento River chinook salmon stocks and pertinent hydrologic data used to compile this document:

Table A-1
Information Sources

Data/Information	Source
Weekly run timing	Unpublished data. R. Painter and F. Fisher. California Dept. of Fish and Game, Inland Fisheries Branch, Red Bluff, CA
Weekly timing and spatial distribution of spawning	Unpublished data. R. Painter and F. Fisher. California Dept. of Fish and Game, Inland Fisheries Branch, Red Bluff, CA
Downstream migration timing	Unpublished data. R. Painter and F. Fisher. California Dept. of Fish and Game, Inland Fisheries Branch, Red Bluff, CA
	Vogel, D. A., K. R. Marine, and J. G. Smith. 1988. Fish Passage Action Program for Red Bluff Diversion Dam: Final Report. U.S. Fish and Wildlife Service Report No. FRI/FAO-88-19, 77 pp., plus appendices.
Growth of juveniles	Unpublished data. U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resources Office, Red Bluff, CA
CVP Hydrologic data	U.S. Geological Survey Database 1983-1986. EarthInfo, Inc., Boulder, CO
Sacramento River temperature data	California Dept. of Water Resources. 1990. Historic Sacramento River Temperature Data, Keswick to Butte City. 268 pp.
General chinook salmon life history characteristics	Scott, W. B. and E. J. Crossman. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada Bulletin 184. 866 pp.
	Moyle, P. B. 1976. Inland Fishes of California. University of California Press. 405 pp.
Salmon temperature tolerance	Brett, J. R. 1952. Temperature Tolerance in Young Pacific Salmon, Genus *Oncorhynchus*. Journal of the Fisheries Research Board Canada 9: 265-325.

Table A-1 Information Sources (continued)	
Data/Information	**Source**
Salmon temperature tolerance (continued)	Healy, T. P. 1979. The Effect of High Temperature on the Survival of Sacramento River Chinook Salmon, *Oncorhynchus tshawytscha*, Eggs, and Fry. California Dept. of Fish and Game, Anadromous Fisheries Administrative Report 79-10.
	Hinze, J. A., A. N. Culver, and G. U. Rice. 1956. Annual Report, Nimbus salmon and steelhead hatchery, fiscal year 1955-56. California Dept. of Fish and Game, Inland Fisheries Administrative Report 59-4.
	Seymour, A. H. 1956. Effects of Temperature upon Young Chinook Salmon. Ph.D. thesis. University of Washington, Seattle, WA.

WET AND DRY YEAR COMPARISONS

The variations in life cycle timing and life stage activities for each run of Sacramento River chinook salmon are highly correlated with hydrologic conditions during any given year. To illustrate this variation for the purposes of this document, we selected to display the life cycle timing for each run during representative "wet" and "dry" years using hydrologic conditions of 1983 and 1985, respectively. These years were selected on the basis of completeness of the hydrologic and water temperature data sets, fish counts at RBDD, and downstream migrant salmon indices, as well as for the extremes in salmon habitat conditions that occurred during those years. It is important to note that reservoir carryover storage greatly influences riverine conditions for salmon; future updates of this working reference should quantitatively describe effects on the salmon's life cycle as additional data become available. The most recent drought years (1987-1990) were not used primarily because of incomplete hydrologic records and partial salmon run counts and downstream migration indices due to the raising of RBDD gates during the nonirrigation season of those years. The use of 1983 and 1985 is not intended to statistically represent all wet and dry years, but the hydrologic contrasts provided by the years of 1983 and 1985 sufficiently depict a general range of effects that typical "wet" and "dry" years have on salmon life history traits. Hydrologic and water temperature data were used, and are presented, on calendar year rather than water year schedules to better correspond with salmon run life cycles (Figures B-1 and B-2). These years are not considered as continuous with adjoining water years but as representative of the conditions occurring throughout a wet or dry year period affecting the salmon's life cycle. We selected temperature and riverflow data for the USGS Bend Bridge gaging station as representative of the main spawning and rearing reach of the upper river due to the Bend Bridge station's location within this reach, Red Bluff to

Keswick Dam. These data were used in calculations to estimate duration of egg and larval incubation and timing of fry emergence.

RUN TIMING

Run timing data displayed in Section 2 tables are based on weekly salmon counts conducted at RBDD during salmon brood years 1983 and 1985. RBDD is known to delay salmon run timing, but the historical fish counts at the dam currently represent the best information available on migratory patterns of salmon entering the upper Sacramento River. Weekly cumulative proportions of each run passing by RBDD for 1983 and 1985 are compared to overall average run timing for each run in Figure B-3.

TIME OF SPAWNING

The timing of spawning activity for each run of Sacramento River chinook salmon is estimated based on aerial surveys of the spawning grounds conducted by the California Department of Fish and Game. Most of these surveys have been conducted since 1980 for the fall run and since 1985 for the late-fall and winter runs. Time of spawning for the spring run is estimated from historic spawning records of the Baird Hatchery on the McCloud River. All time of spawning data presented in Section 2 tables are based on the most recently available spawning data used by the California Department of Fish and Game. Figures B-4 to B-7 present data for the cumulative proportions of each run spawning by week relative to other life stage events. Time of spawning is assumed to be the same for 1983 and 1985 for purposes of this analysis as data for individual years are not available. However, time of spawning has been observed to vary by about 2 to 3 weeks from year to year (Richard Painter, California Dept. Fish and Game, Red Bluff, CA).

DURATION OF INCUBATION AND FRY EMERGENCE

The relative proportional differences in the duration of egg and larval incubation and the timing of fry emergence between "wet" and "dry" years (Figures B-4 to B-7) were estimated from data on time of spawning and average weekly water temperatures for representative years 1983 and 1985, respectively. It was assumed that development from fertilized egg to hatching requires 750 (°F) temperature units (TUs), and an additional 750 TUs from hatching to the emergent fry stage (1,500 TUs in total). One temperature unit is accumulated for each degree Fahrenheit above 32°F that water temperature averages for the period of a day. Average weekly TUs were calculated from average weekly water temperatures and summed to estimate the time of hatching and fry emergence for eggs laid each week during the spawning period for each run. The total proportion of eggs hatching and fry emerging were adjusted for temperature-induced mortality when average weekly water temperatures exceeded 56°F, using the

temperature-mortality schedule developed jointly by the California Department of Fish and Game and U.S. Fish and Wildlife Service in 1990.

JUVENILE LIFE STAGE AND DOWNSTREAM MIGRATION

Overall estimates of the relative growth of fry and juvenile salmon from each of the four runs in the upper Sacramento River were determined from monthly length-frequency data provided by the U.S. Fish and Wildlife Service's beach seining program (Figure B-8). These data were compiled and summarized by CH2M HILL to provide an indication of the presence of the early life phases for each of the runs during any particular month of the year. Over 14,000 fish were collected by USFWS personnel by beach seining at various locations from Redding to Red Bluff, measured, and released. This data base, as a whole, is useful to demonstrate general growth rates for young chinook over the seasons within a year. Although the beach seine samples are likely biased toward smaller-sized fish, and some year-to-year variation in fish growth rates does occur due to different water temperatures and food availability, some assumptions can be made by comparing the pooled growth rates over time to demonstrate the presence of the early life phases of any particular run in a given month. No attempt was made to differentiate runs where overlap of length frequencies was likely to occur. Fry emergence for a particular run was based on the spawning timing for that run.

The relative monthly proportions of each run emigrating from the upper river (Section 2 tables) were estimated using data from California Department of Fish and Game's downstream migrant trap at RBDD (Figure B-9). Data from U.S. Fish and Wildlife Service's juvenile entrainment netting at the headworks of the Tehama-Colusa Canal were used to adjust for differential timing of emigration between "wet" and "dry" years (Figure B-10). Both sources of information have limitations on their application for describing downstream migration and must be used with caution. But together they are the best available data on the downstream migration of Sacramento River chinook salmon. The emigration timing reflected in this report is only indicative of young fish migrating past RBDD to downstream reaches. Dispersal of fry from the upper river to areas downstream of RBDD is known to occur every month of the year; it is unknown when these fish emigrate to the ocean. Because of the limitations on downstream migrant data, there is a degree of uncertainty and disagreement among fishery biologists regarding timing of downstream migration for some runs, especially winter run. Therefore, ranges of values based on the data and discussions with California Department of Fish and Game biologists were developed and are presented in Section 2 tables.

Appendix B
FIGURES