3.2 Chinook Salmon Populations

3.2.1 Introduction

The restoration of chinook salmon populations in the mainstem San Joaquin River is the single-most important goal for each of the restoration strategies. To achieve the vision of a restored chinook population in the San Joaquin River, a number of objectives will need to be realized. Objectives for a restored population include:

- ***Self-sustaining populations***. Restored populations of chinook salmon will be self-sustaining, meaning that viable populations will be supported through natural spawning in the mainstem San Joaquin River and will not require artificial supplementation after they are successfully established. Natural habitats will be expected to provide for adult upstream migration, holding, spawning, egg incubation and alevin development, fry and juvenile rearing, and smolt outmigration.
- ***Minimum population size***. Escapement of restored populations will be large enough to maintain a self-sustaining population in the face of ongoing mortality factors operating outside of the planning area (e.g., entrainment or predation in the Delta, ocean harvest).
- ***Variable escapement***. Restored populations will exhibit variability in escapement, as is natural for wild chinook salmon populations. Escapement is expected to be high in years when ocean and freshwater habitat conditions are conducive to survival of the various life-history stages, and lower in years when environmental conditions–whether cyclical changes in ocean conditions, regional climatic effects, or other stochastic events–result in reduced survival of one or more salmon life-history stages.
- ***Genetic characteristics***. Restored populations will exhibit a genetic makeup as similar as possible to stocks that occurred in the San Joaquin River under historical conditions. Genetic variability and integrity will be maintained through minimizing the use of hatchery stocks and providing for natural selection within riverine habitats for each life stage.
- ***Life history characteristics***. Restored populations will exhibit life history characteristics within the range expected under historical conditions, but will not be expected to display the full range of life-history variability due to ongoing human uses of the San Joaquin River and basin.
- ***Support recreational fishing***. Restored populations may eventually be large enough to support a recreational fishery in the mainstem San Joaquin River.

The mainstem San Joaquin River once supported one of the largest runs of spring chinook salmon on the Pacific Coast until 1950, when the construction of Friant Dam (which blocked access to upstream spawning habitat) and the diversion of increasing amounts of water into canals initiated a population decline. Fall chinook salmon also occurred in the mainstem San Joaquin River, but in smaller numbers; the fall run was nearly eliminated by the 1920s due to reduced flows during the fall upstream migration. Although self-sustaining fall chinook salmon populations have successfully persisted in major San Joaquin River tributaries downstream of the project area, populations of spring chinook salmon have been extirpated from the San Joaquin basin. Because of this, it might be assumed that it would be more difficult to reestablish spring chinook salmon in the mainstem San Joaquin River than it would be to reestablish fall chinook salmon. Upon closer examination of the life history strategies employed by the two runs, however, it appears that it may actually be more realistic to reestablish spring chinook salmon populations in the mainstem San Joaquin River.

The restoration vision for chinook salmon includes both spring and fall runs, although we believe that restoring spring chinook has a greater likelihood of success. Spring chinook outmigrate at a larger size than fall chinook, and thus experience higher smolt and ocean survival. As a result, spring chinook could have lower escapement rates and nonetheless maintain a sustainable population.

The following sections address important assumptions and issues governing chinook salmon restoration in the mainstem San Joaquin River. These issues fall into three main categories: (1) the population dynamics of spring and fall chinook salmon, (2) the potential sources of parent stock for spring and fall run chinook salmon, and (3) the differences between the life histories of the two runs and the implications for restoring chinook salmon populations in the mainstem San Joaquin River.

3.2.2 Approach

Simulation population models were used to develop restoration strategies that attempted to meet the objectives for restoring chinook populations. The simulation models were used in an iterative process, using the following general procedures. Gaming was conducted with the population models to determine combinations of restoration measures (e.g., flow releases from Friant Dam) sufficient to meet basic sustainability targets. Next, the models were run with a long time-series of environmental inputs derived from historical data (appropriately modified to reflect basic restoration and likely operating scenarios), to determine the long-term average population levels that would be expected to result from these restoration measures. This process allowed us to evaluate the effect of various restoration strategies on the population abundance, or survival, at specific life stages. The population models were based on data from the Merced, Tuolumne, and Stanislaus rivers, and used life-stage parameter values based on the literature, as discussed in sections 3.2.3 to 3.2.6 below.

3.2.3 Sources of parent stock

Ideally, parent stock for restoring salmon populations originates from the river being restored. However, mainstem San Joaquin River chinook stocks have long since been extirpated. When selecting a stock from outside the basin, other considerations become crucial, including:

- life history timing (e.g., timing of adult migration, spawning, and smolt outmigration),
- habitat requirements (e.g., temperature tolerances),
- migration distance,
- genetic integrity of stock, and
- population size of stock.

Selection of a parent stock assumes that inherent genetic qualities of the parent stock will apply to the upper San Joaquin River stock after introduction. In truth, it is not known to what degree genetics versus environment dictate life history timing and habitat requirements of individual stocks. Determining the life history traits of introduced populations will be a key element of an adaptive management strategy, with potential consequences affecting all aspects of the life history and habitat requirements considerations discussed below.

3.2.3.1 Spring-run chinook salmon

The main concern in selecting a spring chinook stock is that the run timing be early, to avoid temperature increases in the lower river, and that the spawn timing be early, to avoid interbreeding with fall chinook. Since spring chinook hold during the summer, temperature tolerances have to be relatively high. Based on these considerations, Sacramento River tributaries are the primary candidates for stock (Table 3.2-1). In the Sacramento River, there are several tributaries that support relatively major spring chinook runs, including Deer, Mill and Butte creeks, and the Feather River. Based on the need for early upstream migration and spawning and relatively warm temperature tolerances, the best candidate for a parent stock is from Butte Creek. Butte Creek spring-run are genetically distinct from Feather River hatchery and Deer and Mill creek spring-run chinook (NMFS 1999) and their populations are relatively robust. Spring chinook return to Butte Creek early in the year (February and March), and are capable of withstanding relatively warm temperatures during adult holding (see Stillwater Sciences 2003). The Butte Creek stock migrates upstream earlier in the winter than other stocks, when water depths and temperatures in the San Joaquin River are likely to be more suitable than later in the season. In addition, the Butte Creek chinook typically spawn in September, early enough to avoid interbreeding with November-spawning fall chinook. Migration distances for Butte Creek spring chinook are about 200 mi (320 km), very similar to the 200-mi (320-km) distance expected for San Joaquin River, and therefore straying and stress related to migration distance are not likely to be a concern. Central Valley spring-run chinook are listed as threatened under the federal Endangered Species Act; therefore, developing an approach to jump-starting spring-run in the San Joaquin will require coordination with the regulatory agencies.

Table 3.2-1. Run Timing of Spring Chinook in Sacramento River Tributaries.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Upstream Migration													Sacramento River Ascend rivers in May and June (Rutter 1908). Which rivers, and source of data not stated. Upstream migration has been observed to be bi-modal in the Sacramento River (Fisher, pers. comm., as cited in Marcotte 1984) with a portion of the run migrating to or near spawning areas while the remaining fish hold downstream (where in the river was not stated) and move up in the summer.
Upstream Migration													Deer and Mill Creeks Migrate up Deer and Mill Creeks from March through June (Vogel 1987a and b, as cited in Moyle et al. 1995). Source of data not stated In 1941 adults were trapped at a weir in Deer Creek from April to July 6 (Parker and Hanson 1944). Migration peaks in late May in Mill Creek. Migration into rivers earlier in southern tributaries and later in northern tributaries (Colleen Harvey, CFG, pers. comm.. 2002). Data based on personal observations in Mill Creek.
Upstream Migration													Butte Creek Entered Butte Creek in February through April (Yoshiyma et al. 1996). Source of data not stated.
Upstream Migration													Feather River Enter Feather River in May or June (Yoshiyma et al. 1996). Hatchery influenced population. Source of data not stated.

	Span of Life History Activity
	Peak of Life History Activity

The adaptive management of spring chinook must focus in part on monitoring the life history traits of the population, with particular attention to determining if the run timing observed in Butte Creek is replicated in a restored San Joaquin River.

3.2.3.2 Fall-run chinook salmon

The main concern in selecting a fall chinook stock is the need for a run that migrates and spawns relatively early in the fall so that fry develop, emerge, and outmigrate before lethal temperatures set in during the spring. Also, spawning timing after October will minimize the risk of interbreeding with spring chinook. The spawning period needs to be compressed, since late spawners and late-emerging fry from fall chinook have a relatively low chance of survival. However, temperatures are high in the fall, so tolerance to high temperatures during migration is necessary. Tributaries to the San Joaquin River (Stanislaus, Tuolumne, and Merced rivers) were obvious candidates for fall chinook stocks, as they would likely provide phenotypes adapted to environments that resemble conditions in a restored San Joaquin River.

Of the fall chinook salmon stocks considered, Tuolumne River stocks appear to be best suited for use in restoring a fall run to the San Joaquin River. The Tuolumne River fall-run chinook migrate upstream in October and have compressed spawning period in November, which are ideally suited to temperature conditions in the San Joaquin River, and will minimize the risk of interbreeding with spring chinook. Tuolumne River fall-run chinook salmon are less influenced by hatchery introductions than stocks in other rivers, and are some of the most intensely studied salmon stocks in the Central Valley. The abundance of available data is a key advantage, as this information provides a detailed understanding of their specific life history and habitat requirements, and allows restoration planning efforts to incorporate these needs into restoration strategies. Fall-run chinook salmon stocks of the Stanislaus and Merced rivers are less well known; the lack of information on these stocks makes them less desirable.

The use of Tuolumne River fall-run chinook stock offers other advantages. Of the three tributaries considered, the Tuolumne River typically generates the largest escapements of naturally spawned fall-run chinook salmon (Figure 3.2-1), with relatively minor hatchery influence. This high level of production would minimize the impacts of an egg-harvesting operation on the Tuolumne River population, while allowing for a relatively high number of eggs to be collected for planting in the San Joaquin River. In addition, the genetic integrity (i.e., lack of hatchery influence) of the eggs planted would be relatively high.

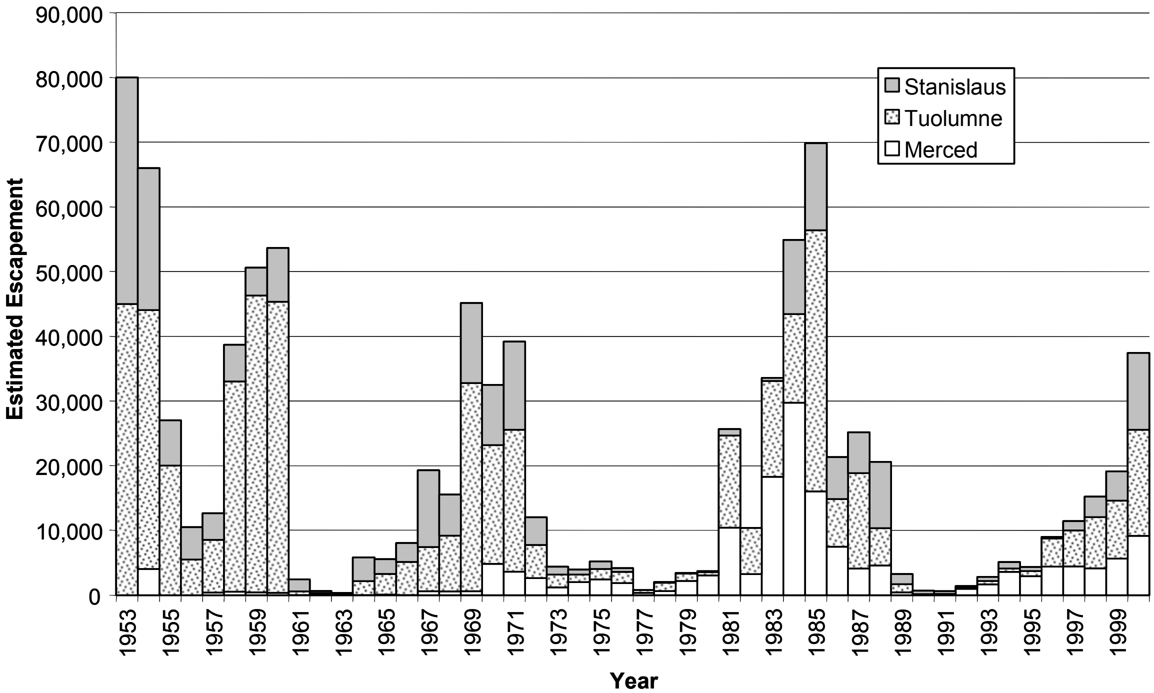

Figure 3.2-1. Cyclical escapement patterns of fall-run chinook salmon in San Joaquin tributaries. The cyclical nature of salmon populations is largely tied to environmental conditions, and is often a function of flow fluctuations. It is anticipated that restored San Joaquin River chinook populations that are based on Tuolumne River chinook parent stock will also exhibit cyclical population dynamics, however the restoration strategy will maximize population peaks to prevent population crashes.

The adaptive management of fall chinook will have to focus in part on monitoring the life history traits of the population, with particular attention paid to determining if the run timing observed in the Tuolumne River is replicated in a restored San Joaquin River. Because the migration distance for fall chinook in the San Joaquin River is much longer (200 mi [320 km]) than the migration distance in the Tuolumne River (about 80 mi [130 km]), there is a chance that the energy reserves, and thus health of the stock, could be a concern. Straying may also be a concern given the longer migration distance and the tributaries that may attract upstream migrants on their way upstream to spawning areas below Friant Dam.

3.2.3.3 Comparison of spring-run chinook salmon and fall-run chinook salmon

Selecting a parent stock for both runs focuses on the same principle factors, as described above. The Butte Creek spring chinook stock is well-suited for the San Joaquin River, although ideally the stock would come from within the basin. Even though a fall chinook stock from the Tuolumne River would migrate farther in the San Joaquin than in the Tuolumne River, this stock has the advantage of being from the same basin. There is more uncertainty associated with using the Butte Creek spring chinook stock than in using the Tuolumne River fall chinook stock. The Tuolumne stock originates from the San Joaquin River basin, and so does not present the uncertainties in transferring a stock to a new basin that the Butte Creek selection presents. In addition, a large amount of research has been conducted on the Tuolumne River, so the characteristics of the stock are relatively well known.

3.2.3.4 Introducing parent stock

Once parent stocks are selected, a program to "jump-start" populations is required. There are many different approaches that have had success in other rivers, including planting eggs, releasing hatchery-raised fry, releasing hatchery-raised smolts, releasing mature adults, and allowing adults to stray and recolonize the river. Fall-run chinook are likely to stray from existing tributaries, which could decrease the need to augment their populations in the San Joaquin River. Each of these methods has advantages and disadvantages. It is likely that a jump-start program will use several of these methods in attempts to establish populations. Major considerations in establishing the population include:

- imprinting smolts on the San Joaquin River,
- maximizing survival of early life stages,
- cost, and
- establishing populations in an experimental approach within an adaptive management program.

3.2.4 Chinook salmon life histories and habitat considerations

3.2.4.1 Upstream migration

Adult salmon migrating upstream to natal spawning grounds can be blocked or delayed in migration by physical barriers, lack of water depth, and inadequate water quality (e.g., temperature and dissolved oxygen). When conditions are poor, even fish that successfully migrate upstream may be too stressed to maximize their spawning effort, or may die from disease or other stress-related factors prior to spawning. Physical barriers to upstream migration of anadromous salmonids are discussed in Section 7.7.4 of the Background Report. Physical barriers mainly consist of flow control structures, such as the Bifurcation Structure, Sand Slough Control Structure, Sack Dam, and gates on Mariposa and Eastside bypasses. At these locations, structures may need to be removed and/or facilities added to achieve passage. Passage at some barriers, such as the Mendota Dam, is possible under certain flow conditions, but more modern facilities are warranted to allow passage under a wider range of flows.

Adequate water depths are necessary to facilitate safe passage to upstream holding and spawning areas. Instream flows of 100 cfs in the San Joaquin River upstream of the Merced River were observed to result in difficult passage routes that abraded the ventral areas of fall chinook salmon. Adult chinook salmon require depths of at least 0.8 ft (24 cm) for successful upstream migration (Thompson 1972, as cited in Bjornn and Reiser 1991). A minimum water depth of 1 ft (31 cm) needs to be maintained across at least 25% of the channel to provide for upstream migration. The restoration strategies will ensure that these minimum requirements are exceeded.

In addition to providing adequate water depth, increased flows are required to ensure suitable water quality for migration. Restoration strategies must provide sufficient volumes of cool water during upstream migration to ensure safe passage to cooler upstream holding and spawning areas, after which temperatures in downstream reaches can be allowed to warm without endangering the majority of the run. Providing sufficient flows to allow adequate passage past barriers is not expected to be a constraint, but providing sufficient flows to lower water temperatures in the lower river will be a challenge. Although the expectation is to increase discharges from Friant Dam to provide suitable water temperatures, initial analysis suggests that it is not certain that increased flows from Friant Dam will lower water temperatures in the lower reaches of the San Joaquin River. Other water quality conditions that may impede upstream migration of salmon include high salinity and low dissolved oxygen, as discussed in the Background Report.

Spring chinook salmon

The migration temperature target for spring chinook salmon is <65ºF (<18˚C), but spring chinook are commonly observed holding in water temperatures exceeding 70ºF (21°C) (Moyle 1976). Under historical conditions, spring chinook salmon in the mainstem San Joaquin River passed the Merced River between mid-April and mid-June; peak passage occurred in early May, and arrival at Mendota Pool in early June (Hallock and Van Woert 1959). Under current conditions, maintaining suitable water temperatures (<65ºF [18˚C]) during this time of year is a challenge. However, spring chinook salmon in Butte Creek (the proposed stock for a restored San Joaquin River population) migrate upstream from February through April, peaking in March (Yoshiyama et al. 1996). A restored spring run chinook population will need to migrate upstream during the period when temperatures remain suitable to reduce the need for substantial releases of water for this life stage. This will be accomplished by using early-run Butte Creek stock as parent stock and by ensuring that instream flows are sufficient to maintain suitable temperatures throughout the mainstem San Joaquin River. The later part of the run is likely to arrive in the mid-San Joaquin River in April or May, when flows are typically higher than in the winter. Although the flows are higher later in the spring, temperatures during this time are increasing from increased solar radiation, and thus later returning spring chinook will be at risk of exposure to elevated temperatures (Figure 3.2-2).

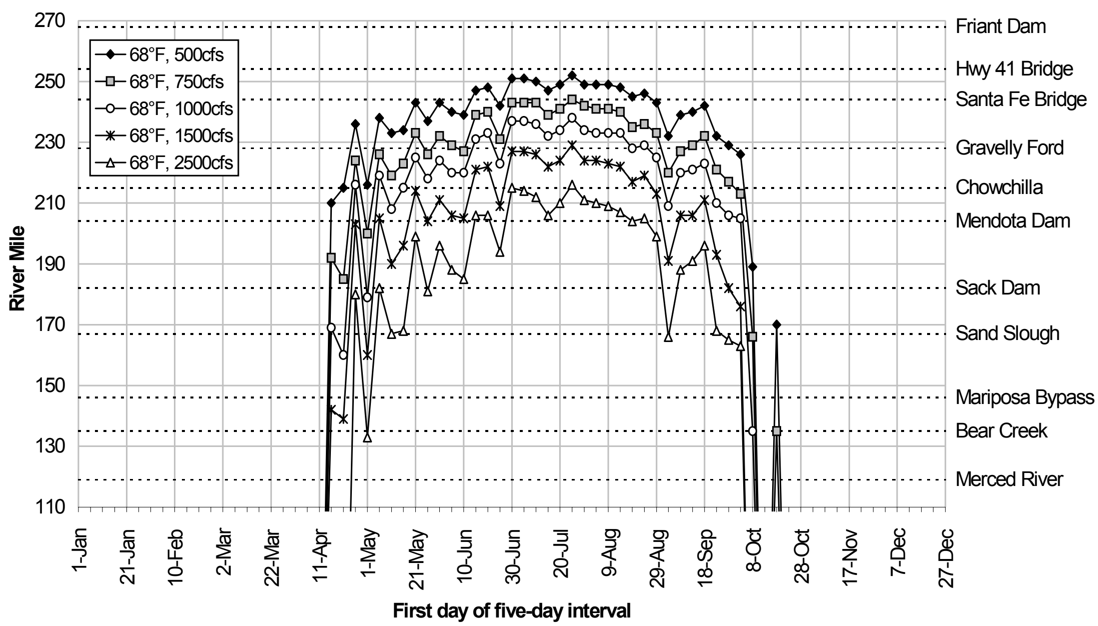

Figure 3.2-2. Last river mile for which 5-day average temperature is below threshold. San Joaquin River Temperature Model, average meteorology modeled temperatures from JSA, 26 April 2002.

Fall chinook salmon

Obtaining suitable water temperatures for fall chinook adult migration will be a challenge. Under current conditions, the lower San Joaquin River drastically exceeds the temperature objective of <65ºF (18˚C) for adult fall chinook migration. The San Joaquin River is inherently warm in its lower reaches, and even under historical conditions, fall chinook migrated upstream when average monthly temperatures often exceeded 70ºF (21°C) (Yoshiyama et al. 1996). If the

Tuolumne River stock is selected, adult upstream migration is likely to occur in October. It will likely be difficult to provide the high flows needed to obtain preferred migration water temperatures in the lower San Joaquin River, particularly in dry years. It will be possible to increase flows enough to provide adequate depths and velocities for migration, but migrants may encounter temperatures greater than 65ºF (18°C) for the initial part of the run. Temperatures will decrease in an upstream direction, from both decreasing solar radiation and increased cool-water flow releases at Friant Dam, so as migrants swim upstream their exposure to elevated temperatures will decrease. Although sublethal effects, such as susceptibility to disease, and decreased egg viability may result from exposure to high water temperatures in the lower river, most of the run could be expected to migrate successfully in most years. It is possible that the latter part of the fall chinook run may be stranded when flows drop, selecting for the early part of the run over time. The early part of the fall chinook run has a much higher chance of survival, since the young will emerge earlier and be able to outmigrate before water temperatures become unsuitable in the spring.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Historically, spring chinook likely encountered favorable conditions in their upstream migration. High spring snowmelt flows likely ensured relatively cool water, and reduced risk of encountering barriers. Fall chinook, however, migrated upstream during the low-flow period at the end of the summer. The susceptibility of fall chinook to poor water quality and potential low-flow barriers may have prevented them from historically having the run strength of fall chinook in other parts of the basin, or of spring chinook in the mainstem San Joaquin River.

Model parameterization

The population model uses a rate of upstream migration of 10 mi/day (16km/day) and has three statistical distributions representing the distribution of arrival dates of spawners of each age (age 2, age 3, and age 4). Temperature effects on upstream migration and other potential obstacles to migration are not included in the model, although these factors can be built into the model in the future.

3.2.4.2 Adult holding

Fall chinook do not require holding habitat during their upstream migration, whereas for spring chinook, holding habitat is a principle habitat requirement. Holding habitat for spring chinook must provide conditions that allow them to conserve energy and avoid predation while they mature, including cool temperatures of sufficient duration and deep water with slow velocities.

Spring chinook salmon

Spring chinook may hold for months after migration and prior to spawning. Spring chinook migrate upstream and hold in deep, cool pools over summer while they mature and then spawn in late summer/early fall. Historically, spring chinook probably held in pools above Friant Dam, and after Friant Dam was constructed, Clark (1942) observed an estimated 5,000 adult spring chinook holding in two large pools directly downstream of Friant Dam in July. The restoration vision for spring chinook adult holding is to provide holding habitat through the summer months in the same large bedrock pool below Friant Dam where Clark (1942) observed fish holding. This large pool is the best candidate for holding habitat because it is a bedrock pool that remains cool all summer and has complex structure, such as overhanging bedrock to provide cover.

Holding temperatures for spring chinook are reportedly optimal when <60.8ºF (<16.0°C), and lethal when >80.6ºF (<27.0°C). However, spring-run chinook in the Sacramento River basin typically hold in pools that have temperatures between 69.8 and 77ºF (21.0 and 25.0°C) (Moyle et al. 1995). In Butte Creek, average daily temperatures have been collected from 1996 to 2001 throughout a reach known to support spring chinook salmon holding and spawning (from Centerville Head Dam downstream to Parrott-Phelan Dam), which suggest that spring chinook salmon in this system can tolerate exposure to daily maximum temperatures in July of 59.7 to 74.7°F (15.4 to 21.2°C) and daily mean temperatures of 57.6 to 71.2°F (14.2 to 21.8°C) (Figure 3.2-3) (Williams et al. 2002). Release temperatures from Friant Dam range from 48 to 52°F (9 to 11°C), which would provide suitable holding temperatures in the existing pool below Friant Dam.

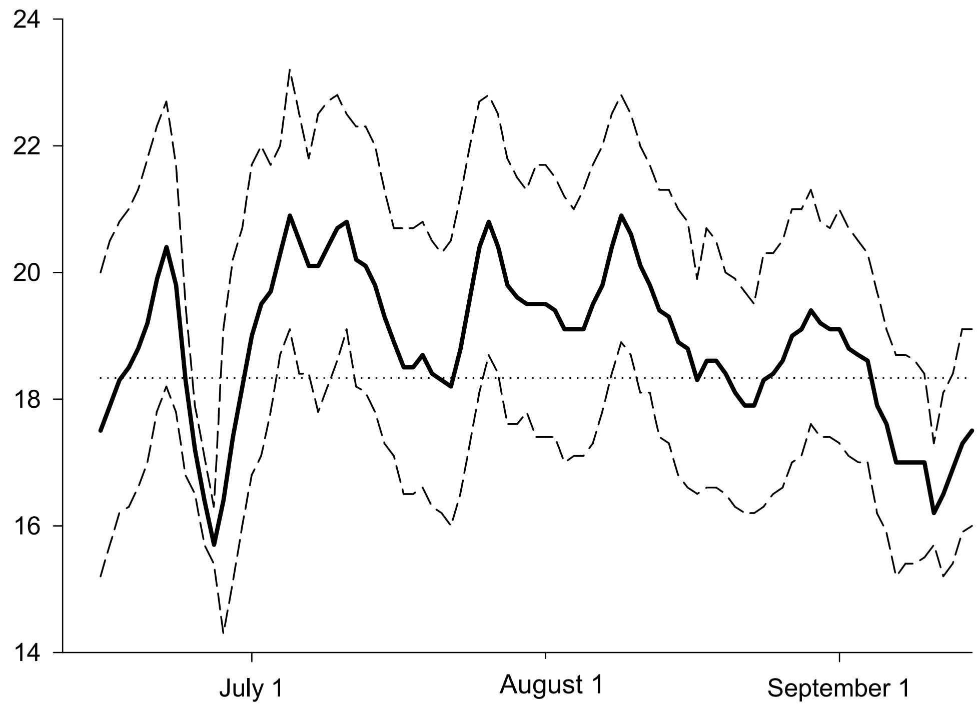

Figure 3.2-3. Daily maximum, average, and minimum water temperatures in a spring chinook holding pool in Butte Creek, summer 2001. Source: Williams et al. 2002.

The targeted pool for adult spring chinook holding has a maximum depth of 25 ft (8m) with an average depth of 11 ft (3m), with an approximate area of average depth of 93,000 ft^2 (8,600m^2) (Appendix B, Figure B-1). Chinook generally do not feed while they hold; therefore, they can hold at very high densities. Based on examination of photographs of spring chinook holding in Butte Creek, it was our professional judgment that spring chinook can hold at densities ranging from 0.5 fish/m^2 to 1.5 fish/m^2 (Appendix B, Figure B-2) Based on this assumption, the pool below Friant Dam can conservatively support 4,300 to 12,900 spring chinook. Other pools with residual depths of over 8 ft (2m) and a high potential to provide suitable habitat have been identified downstream of Friant Dam in Reach 1 (Appendix B, Figure B-3). There is potential to increase the overall holding habitat in Reach 1 by providing higher flows to maintain suitable holding temperatures in these downstream pools.

Poaching of holding salmon remains a concern, as fish are vulnerable for several months in a confined location at high densities. The banks of the pool below Friant Dam are fenced off, thus minimizing access for poachers. However, the North Fork Road bridge downstream of the dam has a boat launch that provides access to the river where poachers could gain access to the pool. To minimize poaching, a game warden or community organization may be required to police the holding pool during the summer. Adaptive management of spring chinook holding habitat should focus on assessing holding densities, egg viability, disease, and levels of poaching.

Fall chinook salmon

Fall chinook are not known to hold during their migration prior to spawning.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Conventional wisdom has held that a lack of adequate holding habitat limits the potential success of restoring spring chinook populations in the San Joaquin River. However, holding habitat is available for spring chinook in the San Joaquin below Friant Dam, and providing adequate conditions will not be as difficult as other challenges to restoration (e.g., providing suitable temperatures in lower reaches for upstream and downstream migration of fall chinook). It should be noted that Clark (1942) observed thousands of spring chinook holding in the mainstem San Joaquin River *after* the construction of Friant Dam, even after fall chinook had disappeared from the mainstem.

3.2.4.3 Spawning

Planning for spring and fall-run chinook spawning must take into account that these runs will likely share common spawning areas in the San Joaquin River below Friant Dam in Reach 1. Limitations on spawning gravels can result in redd superimposition, whereby later-arriving females build redds on top of existing redds, potentially destroying previously deposited eggs (McNeil 1964, Hayes 1987). Females do not distribute themselves equally, and may even select areas that have been previously dug, so even if spawning habitat is not limiting, superimposition is a potential concern (EA Engineering 1992). Spring chinook will be the primary run affected by superimposition, since they spawn earlier in the season than fall chinook.

Chinook are capable of spawning within a wide range of water depths and velocities, provided that intragravel flow is adequate (Healey 1991). Depths most often recorded over chinook redds range from 3.9 to 78 in (9.9 to 198 cm) and velocities from 0.5 to 3.3 ft/s (0.15 to 1.0 m/s), although criteria may vary between races and stream basins. Fall chinook salmon, for instance, are able to spawn in deeper water with higher velocities, because of their larger size (Healey 1991); spring chinook tend to dig smaller redds and use finer gravels than fall chinook (Burner 1951). The vision for restoring both spring and fall runs of chinook salmon includes using their microhabitat requirements regarding temperature, depth, and velocity to create spatial, temporal, lateral, and longitudinal segregation of spawning areas, and by appropriate stock selection and flow management. Habitat segregation is desired to increase the amount of spawning habitat, decrease redd superimposition, and maintain the genetic integrity of the runs. After spring chinook spawn in the early fall, flows will be increased. As flows are increased, preferred water depths and velocities will shift from the center of the channel (where spring chinook spawn) to the lateral portions of the channel, creating lateral separation of the runs. Since temperatures will also be decreasing, and since fall chinook are larger than spring chinook, they will be able to spawn further downstream, creating longitudinal separation. The total area of spawning habitat will also be increased by augmenting current spawning areas with suitable gravel.

There is conflicting information on the location of historical spawning areas that were the most suitable and frequently used, but in general, Clark (1942) and Hatton (1940, as cited in

Yoshiyama et al. 1996) both report that highly suitable gravels occured in the 10-mi (16-km) reach from Lanes Bridge to the current site of the Friant Dam. Currently, potential spawning gravels for chinook exist throughout Reach 1A and upper Reach 1B (Appendix B, Figures B-4a through B-4c), but downstream of Reach 1B, the river becomes sand-bedded and unsuitable for spawning habitat.

Spring-run chinook salmon

In order to focus spawning of spring-run chinook in September to minimize risk of hybridization with the later-spawning fall-run chinook, Butte Creek spring chinook is proposed as the parent stock for restoring San Joaquin populations, since it appears that they spawn earlier than other spring-run chinook in the Central Valley (Table 3.2-2), and earlier than Tuolumne River fall chinook. Spring chinook in upper Reach 1A will disperse from holding areas to spawning areas in the center of the channel, where preferred flow velocities and depths will be provided by late summer base flows. It is expected that an increase in flows will mimic a fall freshet and provide a cue for spawning. A fall freshet may serve as a spawning cue, given the absence of a temperature cue in the San Joaquin River; however, the magnitude and duration of the flow cue is uncertain. The effectiveness of providing a cue for spawning will need to be assessed as part of the Adaptive Management Plan.

The water temperature target for suitable spawning conditions is <56ºF (<13°C). Suitable spawning temperatures will be maintained downstream of Friant Dam from fall flow releases, providing usable spawning habitat in Reach 1A. During spring chinook spawning, temperatures will likely approach or exceed 56ºF (13°C) in lower Reach 1A and in Reach 1B, while such temperatures may not prevent some spring chinook from spawning there, survival of eggs to emergence in lower Reach 1A will likely be low due to exposure to increased temperatures. It is possible to increase the acreage of spawning habitat by increasing flow; however, by concentrating spring chinook spawning in the upper portion of Reach 1A, there can be longitudinal segregation with fall-run chinook.

Table 3.2-2. Spawning Timing of Spring Chinook in Sacramento River Tributaries.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Spawning													Deer and Mill Creeks Spawning in Deer and Mill Creeks is in late August to mid-October (Moyle et al. 1995). Source of data not stated. Spawning in Deer Creek is usually completed by the end of September (Moyle, pers. obs., as cited in Moyle et al. 1995). Source of data not stated.
Spawning													Sacramento River Spawning in Sacramento River basin from late August to October, with a peak in mid-September (Fisher 1994). Source of data not stated. Spawning in the Sacramento River basin in August (Rutter 1908). Source of data not stated.
Spawning													Deer Creek Intensive spawning observed in 1941 from the first week September through the end of October (Parker and Hanson 1944).

	Span of Life History Activity
	Peak of Life History Activity

Fall-run chinook salmon

In order to focus spawning of fall-run chinook in November to minimize risk of hybridization with earlier-spawning spring-run chinook and to facilitate earlier juvenile outmigration in the spring before water temperatures in the lower reaches become stressful or lethal, Tuolumne River fall chinook are proposed as the parent stock for restoring San Joaquin River populations. Fall chinook that spawn after November will produce juveniles that are not likely to survive their downstream migration, due to warming downstream temperatures. Water temperatures suitable for spawning will be maintained in November downstream of Friant Dam by increasing winter base flows. Increasing flows in November should shift preferred spawning habitat depth and velocity conditions out of the center of the channel to the channel margins, and farther downstream from Friant Dam (both by lowering temperature and increasing flow), thereby providing lateral and longitudinal segregation with spring-run spawning, and decreasing the risk of redd superimposition with established spring-run redds. Adult fall chinook are expected to migrate and immediately spawn, and should not require additional triggers to initiate spawning.

Comparison of spring-run chinook salmon and fall-run chinook salmon

The restoration vision provides for spawning in September for spring-run chinook salmon, with spawning redds located in the center of the channel and high upstream in Reach 1A. There is a risk of redd superimposition with fall-run chinook if lateral segregation is not as extensive as anticipated. Superimposition is mostly a risk for spring chinook redds, since they spawn prior to fall chinook. In addition, when fall-run spawn, flows will be higher and temperatures lower, so they will have a broader area of habitat to utilize for spawning. Monitoring and adaptive management will be necessary to address the effectiveness of using flows to provide habitat segregation. The genetic integrity of selected stock is also important to maintain temporal segregation between runs. Early spawning by spring-run chinook should also minimize the potential for redd scour, as high flows that could cause scour are not likely to occur until the spring, which is after emergence of fry. High fall migration flows designed to ensure safe passage for fall chinook are not expected to scour spring chinook redds (Section 3.1), although this uncertainty should be addressed through adaptive management. Spawning is expected to be concentrated in Reach 1A (see above), and thus gravel augmentation may be warranted in this reach as a component of an adaptive management approach to increase suitable habitat there. It is expected that gravel augmentations will increase permeability by increasing the amount of clean, suitable substrate

Model parameterization

The population model spatially distributes spawners over the reaches where temperature is suitable for spawning. It uses temperature data provided by outputs of a temperature model that predicts water temperature for varying flows and river miles. A scheduler is used to assign actual spawning dates and times, and to keep track of delayed or foregone spawning due to limitations in undefended spawning habitat and losses of embryos due to superimposition. The model assumes that spring and fall chinook have the same fecundity at a given age, the same ratio of females at a given age, and the same spawning age structure. 50% of the spawning run are considered to be 3-year-old fish, the remainder split between 2-year-old and 4-year-old spawners. The percentage of females (based on Merced River Hatchery data) was 20% of 2- year-old fish, 50% of 3-year-old fish, and 55% of 4-year-olds. Fecundity increases with age of spawning female: 2-year-old females spawn 2,217 eggs, 3-year-old females spawn 4,458 eggs, and 4-year-old females spawn 5,552 eggs/female (TID/MID 1992).

3.2.4.4 Incubation

Chinook eggs require cool temperatures (daily maximum <58ºF [14°C]) and high intragravel flow for successful incubation. Incubation temperatures influence the rate of embryo development, with warmer temperatures decreasing time to emergence. Water released from Friant Dam during egg incubation will meet temperature objectives for both fall and spring chinook egg incubation.

Intragravel flow delivers dissolved oxygen to incubating eggs and removes metabolic waste. Survival to emergence is a function of permeability, which in turn is influenced by substrate size, intragravel fines, and hydraulic head. Increases in permeability directly increase survival to emergence, which can have population-level effects. Permeability measurements indicate that intragravel flow conditions in Reach 1A are adequate (Appendix B, Figure B-5), though in many riffles spawning substrates compose only a thin (<12 in [<30 cm]) layer over bedrock. Permeability in lower Reach 1A and 1B is higher, though it begins to decline as the component of sand in the substrate increases in mid- to lower Reach 1B (Appendix B, Figure B-6). Spawning is expected to be concentrated in Reach 1A (see above), and thus gravel augmentation may be warranted in this reach as a component of an adaptive management approach to increase suitable habitat there. It is expected that gravel augmentations will increase permeability by increasing the amount of clean, suitable substrate.

Spring-run chinook salmon

Target incubation temperatures for spring chinook salmon are daily maximums of less than 58ºF (14°C). Water released from the Friant Dam when spring chinook are spawning (late September) will be lower than this target, and will decrease during their spawning period due to decreased solar radiation.

Fall-run chinook salmon

When fall chinook initiate spawning in November, daily maximum water temperatures released from Friant Dam will be less than 58ºF (14°C). The farther fall chinook spawn downstream from the dam, the warmer the water is likely to be. Fall chinook emergence and rate of development may be an important factor if juveniles outmigrate too late in the spring when lower river temperatures are likely to be stressful or lethal. A shorter time to emergence and faster growth can improve the likelihood that outmigration occurs before temperatures become too warm in the lower river. As water from Friant Dam warms downstream, it may increase the rate of embryo development and result in earlier emergence in redds located in lower Reach 1A or 1B.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Spring chinook eggs will develop faster than fall Chinook because spawning occurs when the water is warmer. However, fall chinook that utilize the higher flows and cooler temperatures during November may spawn farther downstream in Reach 1, and thus be exposed to warmer water temperatures, and shorter development times. The fall chinook redds in proximity of spring Chinook redds (in upper reach 1A) are expected to develop more slowly than spring chinook, since the water temperatures will be cooler in November when fall chinook spawn, than in September. If flows are dropped after spring chinook spawning, or after fall chinook spawning, redd desiccation could result. Redd stranding should be evaluated as part of the adaptive management strategy.

Model parameterization

The survival-to-emergence parameter in the population model is based on existing information on gravel permeability from the San Joaquin River above Lane's Bridge. Permeability was measured before and after disturbance that was applied to mimic the movement of gravels that occurs when chinook dig redds. The permeability rate was then used to estimate survival to emergence based on McCuddin (1977). Permeability was highest in disturbed riffles at RM 267 (just below Friant Dam) and dropped immediately downstream. Survival to emergence was estimate at 40% for the gravels with highest permeability, and 20% for spawning gravels in lower Reach 1.

3.2.4.5 Freshwater rearing

The target size for rearing chinook is 3.2 in (80mm), which is the average size of Tuolumne River smolts (Hume et al. 2001). Opportunities to provide rearing habitat for juvenile chinook salmon depend on providing suitable habitat conditions to promote growth and survival. Reach 1 provides the best habitat conditions for rearing in the San Joaquin River; however, juveniles may disperse downstream into less suitable reaches and as they outmigrate, they will need to move through the lower reaches. Below Reach 1, channel conditions, temperatures, and food production may be less suitable for rearing. Screening diversions and creating or rebuilding new channels will also likely be required. If new channels are created, they can be designed to provide surfaces targeted specifically for floodplain rearing habitat.

Predators (large mouth bass in particular) have been found as far upstream as Reach 1A in temperatures as low as 60ºF (16°C), at which temperatures become conducive for feeding and growth (Mohler 1966, as cited in Stuber et al. 1982; Hathaway 1927, as cited by Heidinger 1976). The restoration strategy will avoid creating conditions favorable for large mouth bass predation on rearing fry by maintaining temperatures below 60ºF (16°C) and providing floodplain habitat with shallow inundation depths, particularly in Reach 1.

The ability of juvenile chinook to grow during the rearing period will be crucial to ensure that smolts outmigrate at a size that will increase their chances of surviving in the delta and ocean. Juvenile chinook salmon often seek refuge in low-velocity habitats where they can rest and drifting invertebrates will tend to be deposited. Because of the energetic demands of both retaining position within the water column and obtaining prey items, as well as the metabolic demands on ectotherms as water temperatures increase, fish feeding and growth in lotic system depend on a number of factors working in concert. Energy required to maintain position within the water column is generally a function of body size (Chapman and Bjornn 1969, Everest and Chapman 1972). For example, small fish and newly emerged fry typically inhabit slower-water habitats, often found at the margins of mainstem channels, backwaters, or side channels. Larger fish typically move into more faster-flowing habitats, where larger prey are usually available (Lister and Genoe 1970). This shift is also energetically more economical, since larger fish would require more prey items, and capturing one prey item is energetically more efficient than capturing many.

Food availability and water temperature directly influence fish growth. On maximum daily rations, growth rate increases as temperature increases up to a certain optimal temperature and then declines with further increases in temperature. Rations reduced from maximum levels reduce growth rates, and so declines in juvenile salmonid growth are a function of both temperature and food availability. Brett et al. (1982) found the highest growth rates under maximum daily ration to occur at 64.4–71.8°F (18.0–22.0°C), with declines in growth rates at higher temperatures and much reduced growth at 75.6°F (24.8°C). Rich (1987) showed only slightly reduced growth rates at 66 and 70°F (19 and 21°C) for American River juvenile chinook salmon under constant exposure for 45 days, with the highest growth rates occurring at 56–60°F (13–15°C).

Estimated growth rates of juvenile chinook were modeled to assess flow strategies for the San Joaquin River for various water year types by determining if fish could attain a minimum size for outmigration before lower Reach temperatures warmed to stressful or lethal levels. Based on growth rates calibrated using Tuolumne River Chinook, ration was estimated at 70%. Ration is likely similar or higher in the gravel-bedded Reach 1 of the San Joaquin River based on a comparison of macroinvertebrates with the Tuolumne River, although there is greater uncertainty about ration levels in the sand-bedded reaches and the floodplains of the San Joaquin River.

Because of the many factors associated with fish growth, it is difficult to predict the time required for juvenile fish in the San Joaquin River to grow to an adequate size before outmigrating. Since success of juvenile salmonids outmigrating through the Delta and to the ocean likely depends on fish size, and since the water cost of maintaining suitable temperatures in downstream reaches into late spring months is high, our governing assumption for juvenile rearing is to provide conditions that encourage growth and potentially shift peak outmigration to earlier in the season. Invertebrate production is typically higher in gravel-bedded reaches than in sand-bedded reaches, so as juveniles move downstream, food availability will likely decrease and temperatures will increase. Rearing habitat for both spring and fall chinook will be provided primarily in Reach 1, and on seasonally inundated flood plains. Inundated floodplain habitat is expected to provide an abundance of low-velocity habitat, increased food availability, and slightly higher water temperatures, all which are expected to increase growth rates.

The river temperatures that were modeled to determine an appropriate flow strategy to maximize growth have inherent uncertainties that affect growth rate predictions. For example, the model estimates thalweg temperatures, whereas chinook are expected to rear on channel margins (Everest and Chapman 1972), or on inundated floodplains (Sommer et al. 2001). River temperatures vary across the width across the channel (Bartholow 1989), due to varying water velocities and water depths. Actual temperatures encountered by rearing chinook are likely to be higher than those modeled for the thalweg of the main channel. Swales et al. (1986, 1988) found that water temperatures in British Columbia rivers are often 1.8 to 4.5°F (1.0 to 2.5ºC) higher in side-channel or off-channel habitat than in main channel habitat. Sommer et al. (2001) found that water temperatures were up to 41°F (5ºC) higher in the flooded Yolo bypass than in the main channel of the Sacramento River. Remote thermal imagery has shown that during the summer, water temperatures vary with microhabitats, and that fish respond to these variations, apparently to maximize habitat suitability. Actual growth rates that will be achieved by rearing chinook remain a critical uncertainty, and should be addressed as a component of the Adaptive Management Strategy.

Spring-run chinook salmon

Butte Creek spring-run chinook salmon are a prime candidate for parent stock for restoring spring-run chinook salmon to the San Joaquin River. In Butte Creek, the majority of the spring chinook migrate as subyearlings during high flows in November, but some fish rear during the winter and outmigrate during the spring, and another group rears for up to a year and outmigrates the following October (Hill and Webber 1999). Nicholas and Hankin (1989a) suggested that the duration of freshwater rearing in the Pacific Northwest is tied to water temperatures, with juveniles remaining longer in rivers with cool temperatures.

In other Sacramento tributaries, the yearling life history strategy is more common. In both Deer and Mill creeks, spring-run chinook tend to migrate as yearlings in the fall and winter (State Water Resources Control Board 1998). There is uncertainty about which life history strategy will be exhibited by spring-run in the San Joaquin River, but this uncertainty should be addressed through monitoring and adaptive management.

Rearing habitat for fry and older stages of spring-run chinook should be available in Reach 1, where habitat includes gravel-bedded pools that provide suitable velocities, temperatures, and food production (Appendix B, Figure B-7). However, only seasonal rearing habitat will be available downstream of Reach 1 due to increases in air and water temperatures in late spring and summer. Reach 1 contains gravel-bedded pool habitats that are likely to be ideal for rearing juveniles and that provide ample invertebrate production. The strategy for determining appropriate temperatures incorporates the interaction between temperature and ration on juvenile growth and the effects of temperature at release from Friant Dam as it warms downstream. The main constraint for juvenile rearing is to attain a size (3.2 in [80 mm] fork length) at which juveniles can outmigrate through the lower reaches prior to temperatures reaching levels that are stressful or lethal (the chronic upper lethal limit for juvenile Central Valley chinook salmon has been estimated at approximately 77°F [25°C][Myrick and Cech 2001]).

Release temperatures from Friant Dam currently range from 48 to 52ºF (9 to 11°C), and temperatures increase with distance downstream. Based on existing release temperatures, if spring-run spawn by October 1, juveniles can attain 3.2 in (80 mm) on 60% ration before the end of April just below Friant Dam (Figure 3.2-4). Juveniles that rear 5 mi (8 km) downstream reach 3.2 in (80 mm) even earlier, due to the warming that accelerates growth. Flows will be provided to inundate floodplain habitats. Temperatures in off-channel and flood plain habitats are likely to be a few degrees higher than in the main channel. Increased temperature and increased food availability on floodplains (Sommer et al. 2001) are expected to provide conditions that allow most juvenile spring chinook to reach 3.2 in (80 mm) prior to outmigrating. Spring-run chinook salmon that move downstream in late fall or winter as fry are not likely to encounter temperatures exceeding 68°F (20°C) through Reach 5 until early to mid-April.

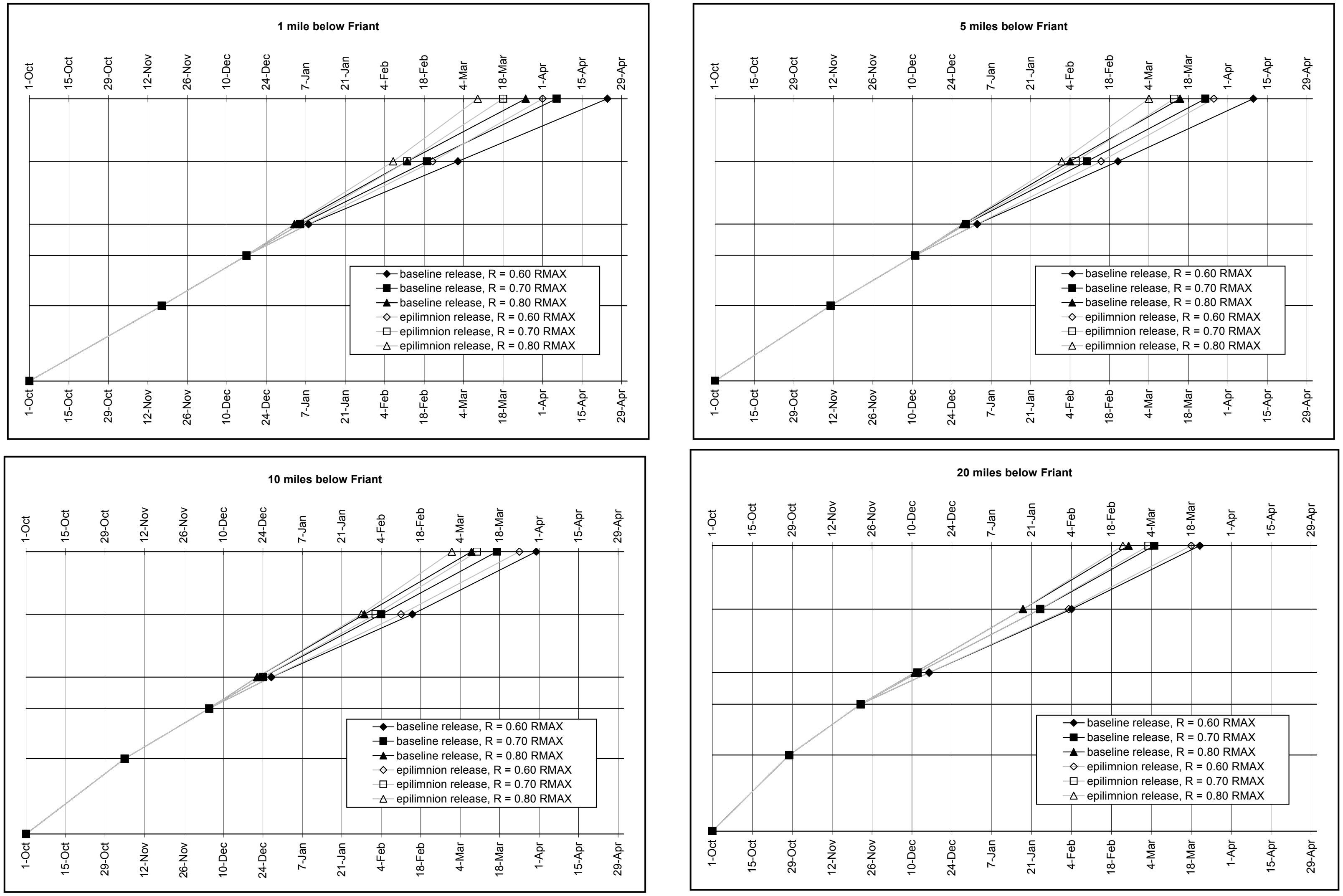

Figure 3.2-4. Emigration calendars for spring-run chinook salmon. Fry growth is dependent upon a function of water temperature and food availability. Based on degree-day modeling, we expect that epilimnetic releases would result in faster growth since the water would be warmer than baseline releases. As a result of faster fry growth, the salmon would exit the system by up to one month earlier, with important implications for managed flow release schedules. This enhanced growth effect can be expected to gradually diminish downstream from Friant Dam, as the epilimnetic release would thermally diffuse into the cooler water. The benefits of an epilimnetic release would thus be more concentrated in the upstream area close to Friant Dam. Spring-run chinook have a natural competitive advantage over fall-run chinook because they exit the system earlier in the season. These calendars assume a 60% maximum food availability ration, which best estimates optimal food availability conditions in a stream. A 100% maximum ration is only found in controlled laboratory conditions, and is therefore not appropriate for use in this model.

Fall-run chinook salmon

Fall-run chinook salmon do not have a life history with extended rearing—they tend to rear only for a few months before emigrating. The restoration vision for fall-run chinook is to provide flows to inundate floodplains for 45 to 60 days. Floodplain inundation has been demonstrated to provide particularly high survival and growth opportunities for juvenile fall chinook (Sommer et al. 2001). Based on the population model and existing release temperatures, if fall chinook spawn by November and juveniles experience 70% ration, they would attain emigration size (3.2 in [80 mm]) by mid-May. Juvenile fall-run chinook, more so than spring-run chinook, risk exposure to stressful or lethal temperatures in downstream reaches as they emigrate, in part due to their later time of spawning, and typically smaller outmigrant size.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Spring chinook and fall chinook require very similar rearing conditions. However, a least a proportion of spring chinook will likely rear for a few months longer than fall chinook due to their earlier emergence timing, and will thus outmigrate at a larger size than fall chinook. Another group of spring chinook are expected to rear for up to a year before outmigrating, and thus would require suitable habitat conditions during the summer, in addition to winter and spring.

Model parameterization

Juvenile rearing is a complex life stage to model. The population model addresses movement among reaches and accounts for the different conditions for growth in different segments of the river. For example, growth conditions are modeled differently for fry rearing in the gravel-bedded reaches near the spawning areas, and for those dispersing downstream into the sand-bedded reaches of the lower river. Currently the model simply assigns fixed fractions of the fry to various reaches of the river; a model of fry development (Stauffer 1973) is used to determine growth rates (using temperature output from the temperature model and reach-specific feeding rations); and survival is a reach-specific constant.

To address daily growth as a function of temperature and ration, the model assesses the distribution of fish relative to temperatures at different river miles under different flow scenarios. The river was divided into 8 areas for rearing: Reaches 1, 2A, 2B, 3A, 4A, 4b, and 5. Temperatures were estimated using the temperature model at the middle of each reach. The model assumes that 10% of the emergent fry migrate to the Delta immediately after emergence, and die. Of the remaining 90% of the emergent fry, 80% would remain in the gravel-bedded Reach 1, and 20% would be distributed in equal densities in the sand-bedded Reaches 2 to 5.

Ration was calibrated using data from the San Joaquin and Tuolumne rivers. The model was calibrated for growth rate and estimated ration based on Tuolumne River data (Vick et al. 2000). The estimated ration in the Tuolumne River to achieve the observed growth rates was 70%; temperatures in the Tuolumne and upper San Joaquin are similar. Macroinvertebrate production in the upper San Joaquin River in Reach 1 is higher than production in the Tuolumne, providing increased confidence in using a ration of 70%. Macroinvertebrate production in the sand-bedded reaches is unknown but was set at 20% of maximum rations.

3.2.4.6 Smoltification and outmigration

The onset of smoltification and outmigration depends on several factors, such as the attainment of appropriate minimum size (Bradford et al. 2001, Folmar and Dickhoff 1980). Larger juvenile chinook also have a greater tendency to move downstream earlier in the season than smaller juveniles (Nicholas and Hankin 1989). The minimum size must be reached before temperatures in downstream reaches warm to stressful or lethal levels. For smoltification and outmigration, juveniles need to encounter appropriate conditions that allow them to prepare physiologically, morphologically, and behaviorally to emigrate from freshwater habitats to the estuary and eventually to the ocean. The restoration goal for smoltification and outmigration is to provide suitable average daily temperatures in the lower reaches (<68ºF [20ºC]) with increased spring flows, which will also provide a stimulus for outmigration. In addition to providing adequate water depth, increased flows are required to ensure suitable water quality for outmigration. Providing sufficient flows to allow adequate passage past barriers is not expected to be a constraint, but providing sufficient flows to lower water temperatures in the lower river will be a challenge. Although the expected strategy for providing suitable water temperatures is to increase flows, initial analysis suggests that it is not certain that increased flows from Friant Dam will lower water temperatures in the lower reaches of the San Joaquin River, as discussed in section 2.5.x.

Spring-run chinook salmon

In Butte Creek, spring chinook outmigrate as subyearlings during high flows in November, during spring flows in March and April, and as yearlings in the following October (Hill and Webber 1999). The majority of fish outmigrate as subyearlings in the fall at sizes typically less than 1.6 in (40 mm). Subyearlings outmigrating in the spring reaches sizes of 3.2 in (80 mm) or more, and yearlings that remain in Butte Creek over the summer outmigrate at sizes up 5.9 in (150 mm), and emigrate in the fall after rains have fallen and flows increase (Hill and Webber 1999). It is anticipated that if spring-run chinook spawn in upper Reach 1 in September, juveniles will attain the target minimum size (3.2 in [80 mm]) for outmigration by at least the end of April (Figure 3.2-3). It is not known whether yearlings contribute more to escapement than young-of-the-year, though outmigration and marine survival tends to increase with smolt size. Appropriate temperatures (<68ºF [20°C]) will be ensured though summer spring flows for outmigration in February through April, and May in wet years. Suitable outmigration temperatures will be provide in the fall as well, in part to ensure successful fall chinook upstream migration. The pulse of outmigration of subyearlings in the fall may have decreased survival due to their relatively small size (<1.6 in [<40 mm]). An adaptive management strategy will need to address the timing and size of outmigrants in the San Joaquin River, and their relative survival to the Delta.

Fall-run chinook salmon

Juvenile fall-run chinook salmon will not likely attain the minimum target size (3.2 in [80mm]) for outmigration until later than juvenile spring-run without some manipulation of temperatures to accelerate growth during rearing. Based on the population models, juvenile chinook can optimistically (at 60% ration) attain 3.2 in [80 mm] by the end of May. This assumes that growth conditions in the San Joaquin River will be similar to those in the Tuolumne, which is a critical uncertainty.

Along the migration route within the planning area, temperatures at RM 150 begin to exceed 68ºF (20°C) in mid-May at 4,500 cfs and at the end of April at 2,500 cfs. A driving factor for restoring fall-run chinook salmon will be providing conditions to rear juveniles as fast as possible to attain the minimum migration size before flow releases from Friant Dam are unable to maintain downstream temperatures below stressful or lethal levels. The strategy will depend on appropriate selection of early spawning fall-run chinook stocks, and increasing water temperatures by floodplain inundation to accelerate growth during rearing.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Spring pulse flow will provide suitable water temperatures and outmigration stimulus for both spring and fall chinook. It is anticipated that spring chinook will outmigrate earlier than fall chinook, since they spawn and emerge earlier. Suitable flows will be available from February through April, and thus more than one peak in outmigration will be supported in most years.

Model parameterization

Water temperatures in the lower San Joaquin River reach stressful and even lethal levels during the spring. Fall chinook salmon in particular face the risk of exposure to excessive water temperatures during outmigration. The model assumes 100% mortality of juveniles that do not reach smolt size (3.2 in [80 mm]) by August 1; there is no mechanism in the model for starvation, so if they don't grow, they die. The model assumes 17% survival (83% mortality) of outmigrating smolts, based on Tuolumne River coded wire tag studies (Hume et al. 2001).

3.2.5 Population dynamics

One of the main objectives in restoring chinook populations to the San Joaquin River is the establishment of viable populations. A viable salmon population is an independent population with a negligible risk of extinction due to threats from demographic variation, local environmental variation, and changes in genetic diversity over a 100-year time frame (McElhany et al. 2000). To achieve viable populations, population dynamic parameters need to be considered, including:

- salmon abundance,
- population growth rate, and
- genetic diversity.

Chinook salmon abundance (or the total number of individuals at any life stage) is important because small populations typically face a greater risk of extinction than larger ones. Population-level effects operate differently in small populations than in large ones, primarily because density-dependent effects, environmental variation, genetic processes, ecological feedback, and catastrophes all have impacts that are progressively greater as the number of individuals in a population declines (McElhany et al. 2000). San Joaquin River chinook populations will need to be large enough to withstand stochastic events such as floods and droughts, as well as varying estuarine and ocean conditions. A restoration strategy and adaptive management plan that identify factors limiting production and enhance or augment limiting habitats, will likely succeed in restoring a viable salmon population, in the San Joaquin River. For example, if spawning habitat is limiting production, increasing spawning gravel quality and area for fall and spring chinook with flow and gravel augmentations will allow a larger number of fish to reproduce successfully.

Fall and spring chinook have different life history strategies that can affect the potential to restore viable populations. For example, some proportion of spring chinook will outmigrate as yearlings, which are larger than subyearlings and therefore more likely to survive subsequent life-stages than subyearling outmigrants. The overall viability of spring chinook populations may depend more on the number of yearling outmigrants, and less on the number of spawners, whereas because fall chinook outmigrate solely as subyearlings, their population viability relies on the number of spawners.

Population growth, or the productivity of chinook over their entire life cycle, is a measure of their performance. The goal for the San Joaquin River is to establish a viable population that is capable of replacing itself, and adapting to unstable environmental conditions. In any given cohort, life-stage-specific survival rates vary, and survival through any one life stage may or may not have a population-level effect. For example, survival to emergence, growth rates, and size at outmigration each can potentially affect population viability by altering population abundance and the ability to survive the subsequent life stage. Chinook salmon population growth will be achieved in the San Joaquin River in part by increasing life-stage-specific survival or productivity.

Genetic diversity has important effects on population viability (McElhany et al. 2000). Diversity allows a species to use a wide variety of environments, and protects it against short- and long-term environmental change. Human-caused selection (e.g., hatchery influence) typically reduces the characteristics of a stock that it has adapted to allow it to survive in its environment. As described in below, selection of a parent stock for the San Joaquin River focused on a stock from an environment with similar conditions as San Joaquin River, and on reducing the influence of human-caused selection through hatchery influence.