APPENDIX I: MONITORING, RESEARCH, AND ADAPTIVE MANAGEMENT STRATEGIES TO ADDRESS KEY UNCERTAINTIES

1 PURPOSE

The purpose of this appendix is to distill some of the *key uncertainties and information gaps that underlie the three restoration strategies*. There are two major categories of uncertainties that should be addressed in an adaptive management program for the San Joaquin River: (1) uncertainties related to the primary models used in developing the draft restoration strategies (salmon population model, temperature model, hydraulic model, riparian recruitment model), and (2) uncertainties about the restoration strategies themselves and particular restoration actions. The appendix discusses both types of uncertainty by general resource category (salmonids, native resident fish, vegetation and wildlife, and geomorphology). Because this appendix focuses primarily upon uncertainties related to the three restoration strategies, it does not represent an exhaustive, comprehensive inventory of uncertainties and data gaps for the San Joaquin River. This appendix also suggests, where possible, potential monitoring, research, and adaptive management approaches to address some of these key uncertainties. Numerous monitoring activities that are mentioned in the Restoration Strategies Report but do not seek to resolve key uncertainties are not included in this appendix, but should be included in a monitoring plan that is developed to complement the restoration plan.

2 SALMON

The design of the three restoration strategies has been influenced significantly by the objective of restoring populations of fall-run and spring-run salmon to the San Joaquin River. This section describes some of the uncertainties and assumptions about salmon populations that influenced the development of the three restoration strategies. This section also describes potential monitoring, research, and adaptive management activities to address the identified uncertainties and test the identified assumptions.

2.1 Establishing a Population

There are several methods available to re-establish salmon populations on the San Joaquin River, each with advantages and disadvantages. Potential methods include:

- allowing strays to colonize the newly restored river;
- trapping adult parent stock from their natal streams and transporting them to the San Joaquin River to spawn naturally;
- stripping and fertilizing eggs from parent stock, and planting the eggs in San Joaquin River spawning areas using deep matrix planting or Whitlock-Vibert boxes; and,
- introducing hatchery-raised fry or smolts to the river.

Restoring populations of chinook salmon to the San Joaquin River would likely use a combination of these methods, each of which lends itself to different types of experiments. Some of these methods would be used to initially establish a population, some as interim measures while other restoration efforts are being implemented, and some as measures to supplement the population in the final phases of restoration. This section briefly describes these phases of establishing the population, and the uncertainties associated with each.

2.1.1 Initial establishment of population

Restoring salmon populations in the San Joaquin River would require initial efforts to establish a population where none currently exists. These efforts would likely employ a combination of techniques to introduce the selected stocks into the San Joaquin River. Some of the methods likely to be used are described below.

2.1.1.1 Egg seeding

One method for initially seeding salmon populations would involve stripping and fertilizing eggs from adult salmon collected from parent stock and planting those eggs in spawning riffles in Reach 1 of the San Joaquin River. The advantages of such egg seeding activities in early stages of population reintroduction include greater egg survival and the ability to conduct concurrent adaptive management experiments.

One method of egg seeding is deep matrix planting, which involves placing eggs in a vertical chamber interspersed with clean gravel and burying the chamber in a riffle. A 1 m x 9 m (3 ft x 30 ft) chamber can contain approximately 40,000 eggs, and Bams (1985) found that eggs in the deep matrix units had survival rates averaging 60%, so deep matrix planting is well suited for mass production. Deep matrix planting can be used in experiments that test the effect of gravel quality on survival-to-emergence. For example, different mixtures of gravel, representing different levels of gravel quality, can be placed in a series of deep matrix chambers with a known number of eggs in each chamber. Subsequent emergence trapping can compare the number of fry that successfully emerge from each chamber representing different levels of gravel quality.

Egg seeding can also be accomplished with Whitlock-Vibert boxes, which are small plastic boxes that can be buried in riffles (Whitlock 1995). Whitlock-Vibert boxes typically have greater egg survival (>90%) than deep matrix chambers, although the boxes have a significantly smaller capacity than deep matrix chambers—approximately 200–300 eggs per box. However, the boxes are more available commercially, so they require less effort than the deep matrix chambers (which have to be constructed). Whitlock-Vibert boxes can also be used in adaptive management experiments for the egg and emergent fry life history stages. For example, known numbers of eggs can be placed in the boxes and buried in the channel substrate in different sections of Reach 1 to reflect different water temperature conditions. Subsequent emergence trapping will indicate the number of fry that successfully emerge from the boxes, thereby supporting an evaluation of the temperature tolerances for incubating eggs, as described below in Section 3.2.1 of this appendix.

2.1.1.2 Hatchery production of juveniles

A widespread method used to establish and supplement salmon populations is the hatchery production of fry and smolts, which can be introduced to the river in large numbers. Eggs can be stripped and fertilized from females collected in their natal stream (e.g., Butte Creek and the Tuolumne River). The fry can then be raised in rearing ponds in hatchery facilities for release directly into the San Joaquin River. Survival rates of eggs to juveniles are typically much higher at hatcheries than in natural conditions, and because fish can be introduced to the river at a relatively large size, survival to subsequent life stages can be higher. However, the use of hatchery facilities generally contradicts the mutual goals statement, which emphasizes the restoration of *self-sustaining* populations of salmonids. In addition, hatchery-produced smolts may not be fully imprinted on the upper San Joaquin River. The use of hatchery facilities may also reduce the population's ability to form an adaptive fit to their environment by reducing natural selective forces inherent to the San Joaquin River environment.

Nevertheless, it may be necessary to use hatchery facilities to help establish an initial population of salmon. If hatchery facilities are used to restore salmon populations to the San Joaquin River, then it will be advantageous to use the CDFG hatchery operated at Lost Lake Park, rather than the larger hatchery facility on the Merced River. The trout hatchery at Lost Lake Park uses water from the San Joaquin River, which will likely help salmon imprinting. Use of the Lost Lake Park facility will also reduce transport distances from the hatchery to introduction locations within the planning area, minimizing loss and risk of mortality of juveniles. Use of the Lost Lake Park hatchery may require upgrading, and possibly expanding, facilities.

If hatchery-produced smolts are used to establish salmon populations in the San Joaquin River, it will facilitate the use of coded-wire and passive integrated transponder tag studies to monitor the movement, growth, and survival of smolts. These studies examine how smolts use existing and restored aquatic and floodplain habitats, the growth response in different habitats, and the survival to adulthood.

2.1.2 Interim measures

Establishing self-sustaining populations of chinook salmon to the San Joaquin River will require eliminating several barriers to upstream and downstream migration, and restoring portions of the river channel. Providing continuous fish passage will likely involve retro-fitting water supply infrastructure with fish passage facilities, or replacing some structures with alternative designs that facilitate fish passage. Modifying infrastructure to provide fish passage and restoring channels will likely require years to implement. In the interim, steps can be taken to bypass passage barriers and begin to establish a self-sustaining populations of chinook salmon, as described below.

2.1.2.1 Trap and transport adult salmon past passage barriers

One interim measure to establish self-sustaining chinook populations prior to providing continuous fish passage is developing adult trapping facilities in Reach 5, and transporting fish past barriers to spawning areas in Reach 1. Trapping and transporting adult salmon provides an opportunity for salmon to become established prior to complete restoration of the river, and for conducting early research in Reach 1 to assess how restored populations of salmon will use existing and restored habitats, which will support the evaluation of assumptions about fish behavior that underlie the three restoration strategies. For example, transporting adult spring-run and fall-run salmon to Reach 1 and allowing them to spawn naturally will support early experiments regarding the lateral segregation of spawning through the control of flow releases (described below in Section 2.5 of this appendix). Such experiments can lead to refinements in the hydrograph components of the restoration plan tailored to support spring-run and fall-run spawning. Similarly, transporting adult spring-run to Reach 1 will allow assessments of the quality of holding habitat, and will support early experimentation with fall freshets as potential spawning cues (as described below in Section 2.4 of this appendix). Natural spawning in Reach 1 will also permit early studies to evaluate the effects of water temperature and gravel permeability on egg survival (described below in Section 3.2.1 of this appendix)

There are several types of structures designed to trap upstream-migrating adult salmon. On the Columbia River, adult salmon are commonly trapped to transport fish around extensive barriers. Trapping facilities often consist of a permanent velocity barrier, a fish ladder, and a trap. Adult salmon are transferred from the trap by means of an Alaska Steep Pass Ladder to a large (e.g., 500-gallon) bucket that is lifted by an overhead hoist to a truck equipped with a tank for transport upstream. Facilities can be designed to allow unimpeded movement of resident fish around the velocity barrier when trapping operations are not in progress. A fish-counting fence provides another approach to trapping adult salmon in large, low-velocity water, and can also double as a counting facility for outmigrating salmon smolts. The basic fish-counting fence is an adjustable aluminum "rake-like" weir that reaches the bottom and spans the width of the river. When used to capture returning adult salmon, the rake fingers are half immersed and they direct fish through a "funnel" and into a box trap. (For capture of downstream-migrating juveniles in spring, the weir is fully immersed and covered with plastic mesh, which keeps the small fish from passing between the fingers of the weir and helps direct them into a box trap, where they can be counted and measured before being released downstream.) Adults collected in the upstream migrant trap will be used to collect eggs for hatchery rearing, or direct egg seeding methods (as described above).

Although adult trapping and introduction methods have been successful in other basins, there are uncertainties associated with trapping adults in Reach 5 and transporting them to Reach 1. For example, it is not clear if salmon that are trapped in Reach 5 and transported to Reaches 1 or 2 will migrate upstream to spawn, because they could become disoriented by potentially radical changes in flow conditions and water quality parameters. The abrupt change in water quality (including differences in flow, water temperature, and chemical constituents) between Reach 5 and Reach 1 will present very different cues to adults that may interfere with natural spawning instincts. If significant numbers of adult salmon migrate downstream when transported and released in Reach 1, then it may be necessary to install a barrier downstream of the release point to prevent downstream migration. Such a barrier can be similar to the one operated by CDFG on the San Joaquin River at the confluence with the Merced River, to prevent Merced river fall-run salmon from migrating upstream in the mainstem San Joaquin River.

It is also uncertain how handling of adult salmon will affect their survival and spawning success. Spring chinook in particular are very sensitive to handling during upstream migration, and may require antibiotics to prevent an increased incidence of disease resulting from handling.

2.1.2.2 Trap and transport salmon smolts

Efforts to begin establishing salmon populations by trapping and transporting adults past barriers must be complemented by efforts to collect and transport juvenile outmigrants past those same barriers. In this manner, it may be possible to jump-start populations of naturally reproducing chinook salmon during the time required to equip water supply infrastructure with passage facilities and to restore channel and flow conditions that support passage in Reaches 2 through 4.

Constructing and operating a facility to capture juvenile salmon in Reach 1 for transport to Reach 5 provides the opportunity for monitoring the abundance, size, and timing of outmigrants. Monitoring abundance will allow assessment of the success of early implementation methods, and measuring the outmigrants will support an evaluation of rearing and growth potential in Reach 1. One of the key uncertainties for restored salmon populations in the San Joaquin River is the time required for young salmon to smolt and emigrate from the planning area. Each of the restoration strategies assumes that young salmon are ready to smolt when they reach 80 mm (3.2 in) in length (based upon rotary screw trap data from the lower Tuolumne River). However, it is difficult to estimate growth rates to determine when juvenile salmonids will achieve 80 mm (3.2 in) in the San Joaquin River. The time required to achieve smolt size has significant implications for all three restoration strategies, including the feasibility of restoring a self-sustaining population of fall-run chinook salmon, and the timing, duration, and magnitude of several hydrograph components. The trapping facility will also support monitoring of outmigration timing, and assessment of the influence of flow magnitude in stimulating outmigration—assessments that will direct the timing, duration, and magnitude of spring pulse flow releases.

It will be important to construct a permanent and highly efficient smolt trapping facility in Reach 1, such as a concrete weir spanning the width of the channel. Whereas equipment such as rotary screw traps is designed to capture a sub-sample of outmigrants, the proposed facility will be designed to capture all outmigrants for transport downstream past barriers. When downstream passage is assured, the facility will act as a permanent and effective monitoring station. The location of a smolt trapping facility in Reach 1 should balance the objectives of maximizing potential rearing habitat upstream of the facility with minimizing the risk of mortality associated with water temperature and predation, which increases with distance from Friant Dam. All smolts collected at the outmigrant trap in Reach 1 will be transported downstream and released in Reach 5. Although the initial purpose of the trapping facility will be to capture outmigrating smolts, it can also be designed so that in the future, when adult salmon are able to migrate upstream on their own, it can serve as a counting facility for adult salmon returning to Reach 1.

There are uncertainties associated with trapping and transporting salmon smolts. For example, it is not clear if smolts will imprint on Reach 1 or Reach 5 and how this may affect the migration behavior of returning adults. Incomplete imprinting could increase straying rates of returning adults. Because fall chinook outmigrate at a younger age, imprinting is expected to be more of an issue for them than for spring chinook. Smolt mortality rates associated with trapping, transport, and re-introduction to the channel are also unclear, though presumably far lower than if smolts attempted to outmigrate through Reaches 2–5 in the early stages of river restoration. Mortality can be caused by handling, as well as by the potential congregation of predators at locations where smolts are returned to the channel in Reach 5.

2.1.3 Supplementing the population

It is likely that restoration actions will be required to supplement introduced salmon populations until they become established and self-sustaining. These efforts may still be required even after continuous fish passage is provided in the San Joaquin River so that adult upstream migrants and juvenile outmigrants can successfully navigate the river without human intervention. Although the intention will be to decrease direct management of the population over time, supplementing the population will involve a combination of traditional population enhancement approaches, including trapping adults and collecting eggs for hatchery rearing and direct seeding with Whitlock-Vibert boxes into spawning habitat, as described above.

2.2 Life History Timing

Salmon often have many different populations with different run timing that are usually delineated by their natal streams or basins (e.g., Tuolumne River fall-run chinook salmon). Chinook salmon runs are defined, in part, by their life history strategy and timing, such that individual populations of a given type exhibit broadly similar life history timing (e.g., populations of fall-run chinook salmon can be expected to spawn between October and December). However, there can be slight differences in life history timing between different populations of a species, which are either the genetic adaptation to the unique characteristics of a population's natal stream, or the response to environmental stimuli in that stream.

The search for a potential parent stock for establishing salmon populations in the San Joaquin River focused on Central Valley rivers because of their proximity to the San Joaquin River. The specific life history timing exhibited by salmon populations from Central Valley rivers was a key criterion in selecting a parent stock. For example, one of the key reasons that the Butte Creek population of spring-run salmon was selected as potential parent stock was that adult salmon from that population appear to have the earliest upstream migration of all populations of spring-run salmon in the Sacramento River basin. Similarly, Butte Creek stock has been selected for establishing a spring-run chinook salmon population in the San Joaquin River in large part because it appears that Butte Creek chinook spawn earlier than other spring-run chinook in the Central Valley. The selection of a spring-run parent stock that spawns relatively early is intended to reduce the threat of hybridization between spring-run and fall-run salmon. The assumed life history timing has a significant bearing on how the three restoration strategies were developed, in particular the hydrographs that are part of each restoration strategy. The restoration strategy hydrographs were developed, in large measure, to satisfy the presumed life history timing of restored salmon populations assuming that this timing will not change in response to different environmental conditions.

This life history-based approach to hydrograph development produces hydrograph components that do not necessarily resemble historical flow patterns on the San Joaquin River. For example, historical populations of spring-run salmon likely migrated upstream during the large snowmelt peak flows that occurred in late spring and early summer. Hallock and Van Woert (1959) said that the historical population of spring-run salmon migrated up the San Joaquin River in late spring, passing the Merced River between mid-April and mid-June, peaking in early May. Historical California Fish and Game Commission reports (1921) indicate that adult spring chinook salmon ascended the San Joaquin River between May and early July. Hatton and Clark (1942) suggest that the historical population of spring-run salmon migrated up the San Joaquin River earlier, passing the Mendota Weir between March and May. These different reports of the historical timing of spring-run upstream migration do not necessarily conflict with one another, because there can be inter-annual variation in the timing of a life history stage in response to environmental conditions.

In contrast to the upstream migration timing of the historical population of spring-run salmon on the San Joaquin River, the selected parent stock of spring-run salmon (Butte Creek) are believed to migrate upstream earlier, between February and April (Yoshiyama et al. 1996). This may raise the question of why a parent stock was selected that exhibits life history timing different from the historical population of spring-run salmon on the San Joaquin River. The difference can be attributed to the altered state of the San Joaquin River and the continued management and use of San Joaquin River water supplies for beneficial uses. Selecting a parent stock that migrates upstream earlier in the spring may reduce the magnitude of flows that are required for maintaining suitable temperature conditions, thereby reducing potential conflicts with water supply operations.

It would be possible to develop restoration hydrographs that mimic historical patterns of late-spring/early-summer snowmelt floods—reduced in magnitude in order to limit disruptions to water supply operations and downstream flooding—and thereby select a parent stock that more closely resembles the upstream migration timing of the historical San Joaquin River population of spring-run salmon. However, such an approach would be unlikely to produce a self-sustaining population of spring-run salmon, because of the changes imposed by Friant Dam and Millerton Reservoir. The water temperatures of Friant Dam releases are generally constant between 48^{o}F (9^{o}C) and 52^{o}F (11^{o}C), which are likely warmer than the water temperatures associated with the historical snowmelt floods. Mimicking the historical snowmelt hydrograph by releasing flows from Friant Dam between mid-April and mid- to late June would likely produce water temperature conditions that are not suitable for adult spring-run salmon migrating upstream during that time frame. For example, water temperature modeling suggests that, assuming average meteorological conditions, flows of 7,000 cfs (a pre-dam, 1.5-year flood) cannot maintain the temperature target for adult salmon migrating upstream (65^{o}F [18^{o}C]) past late April at RM 150.

The three restoration strategies assume that restored populations of fall-run and spring-run salmon will exhibit the life history timing of their parent stock. However, it is not known if the observed life history timing of the Tuolumne and Butte stocks is genetically determined, or if it controlled by flow patterns, temperature regimes, or other environmental cues. Therefore, it is unclear if restored salmon populations will have the same life history timing as the parent populations, especially when introduced to the unique environmental conditions of the San Joaquin River. If restored populations of fall-run or spring-run chinook salmon exhibit life history timing that differs substantially from their parent stock, then significant components of the restoration strategies would need to be re-evaluated. For example, if spring-run salmon spawn later than expected (September), this would necessitate shifting the timing of the hydrograph component designed to support spring-run spawning. Similarly, if a restored population of fall-run chinook salmon begins its upstream migration run later than expected (October), this would precipitate revisions to the timing and magnitude of flows that have been defined to support upstream migration of fall-run adults.

Significant differences in life history timing could bring into question the feasibility of restoring self-sustaining populations of fall-run chinook salmon given the constraints imposed by the altered conditions of the river. If fall-run adults migrate upstream later than expected, their progeny many not be ready to smolt before spring water temperatures become lethal or stressful. They could leave the system as fry before water temperatures get too warm, but then likely would experience greater mortality in the Delta as fry. There is also uncertainty about juvenile fall-run chinook and whether they will rear in Reach 1 or will move downstream to rear. Two of the strategies assume rearing occurs in Reach 1 only, while the Salmon-oriented Strategy assumes rearing can occur throughout the San Joaquin River. Several of the monitoring, research, and adaptive management activities described below can be designed to track the life history timing exhibited by restored populations of chinook salmon in the San Joaquin River, and are necessary to fully evaluate the likelihood of the restoration strategies succeeding.

Uncertainties about the life history strategies of spring-run salmon also influence the likelihood of success of restoring their population. Typically, a portion of a spring-run cohort will outmigrate as subyearlings, with the remaining fraction rearing in the river for a year before migrating as yearlings. Differences in the proportion of spring-run smolts that outmigrate as subyearlings or yearlings can have a significant impact upon the population dynamics of a restored population. Yearlings typically have higher survival rates, because their larger size at the time of outmigration helps them avoid some sources of mortality, such as predation. Salmon population modeling indicates that the fraction of spring-run smolts that outmigrate as yearlings may have a significant effect on escapement rates. For example, the model predicts that if 90 percent of spring-run juveniles outmigrate as subyearlings, then adult escapement rates would be approximately 700 adults. In contrast, if 90 percent of spring-run juveniles outmigrate as yearlings, then adult escapement rates are predicted to be approximately 3,400 adults. The fraction of Butte Creek spring-run salmon that exhibit the yearling and subyearling life history strategy is unknown; therefore, it is difficult to predict what fraction of a restored population of spring-run chinook would exhibit the yearling or subyearling life history strategy. Life history strategies would be monitored at outmigrant traps, as described below.

A key uncertainty regarding life history timing of salmon in a restored San Joaquin River is the timing and rate of upstream migration of adults. The magnitude of flow releases needed to support the upstream migration of adult chinook salmon are influenced greatly by the timing of those releases. For example, the magnitude of flows released to support the upstream migration of fall-run adults will need to be higher in early and mid-October than would be required later in the fall in order to achieve the target temperature of 65°F (18°C). Water temperature modeling suggests that flows up to 7,000 cfs can achieve the temperature target of 65°F (18°C) at RM 150 in early to mid-October under average meteorological conditions. In contrast, the magnitude of upstream passage flows released in late October and early November can be significantly lower, because declining mean air temperatures make it easier to achieve water temperature targets. For example, water temperature modeling suggests that flows of 1,500 cfs are able to achieve a water temperature of 65°F (18°C) at RM 150 by the third week of October, assuming average meteorological conditions. (It should be noted, however, that if upstream passage conditions are not provided for adult fall-run until late October and early November, then the risk of their progeny being subjected to thermal stress in late spring increases.) There is a significant uncertainty underlying the timing and pattern of adult upstream migration for restored salmon populations on the San Joaquin River, which in turn complicates the process of defining the hydrograph components related to upstream passage flows.

The window provided to support the upstream migration of adult fall-run salmon is determined in part by the rate at which adult salmon migrate upstream. The longer the time required to migrate to spawning habitat in Reach 1, the earlier passage flows will need to be released to maintain suitable water temperatures. A review of the scientific literature indicates that upstream migration rates vary from 5 to 16 miles/day (8–26 km/day) (Bernatchez and Dodson 1987). For the development of the restoration strategies, we assumed an adult upstream migration rate of 10 miles/day, reasoning that the difficulty in satisfying the target temperature of 65°F (18 °C) in the San Joaquin River means that upstream migration conditions will likely be less than ideal. The distance from the confluence with the Merced River (RM 118) to suitable spawning habitat in Reach 1A (~RM 243 to RM 267) is approximately 150 miles (240 km); therefore, an assumed migration rate of 10 miles/day means an adult salmon will require 15 days to reach spawning habitat in Reach 1A. In contrast, an assumed migration rate of 15 miles/day (24 km/day) means adult salmon would require only 10 days of transit to reach spawning habitats. Different assumptions about migration rates affect the timing and duration of flow releases to support upstream migration, which in turn influence the magnitude of flow releases required to achieve the temperature target of 65°F (18 °C) for adult migrants. For example, if adult fall-run salmon are able to migrate upstream more quickly than the assumed 10 miles/day, the duration of flow releases to support upstream migration can be compressed and staged later than the release date incorporated into the restoration hydrographs (October 5th), such that lower-magnitude flows will be able to achieve the temperature target. In this manner, adults would be able to migrate upstream later, yet still build redds and spawn before the end of November, which is the target cut-off for spawning so that fry can emerge and achieve smolt size before water temperature conditions become lethal in the spring. A variety of methods that will be used to assess chinook salmon migration rates are described below.

2.2.1 Monitor adult fall-run salmon upstream migration timing at the CDFG barrier

CDFG currently operates a barrier in the mainstem San Joaquin River upstream of the confluence with the Merced River. The purpose of the barrier is to prevent fall-run salmon that are native to other San Joaquin basin tributaries from straying up the San Joaquin River, where they would be unable to reach spawning areas and spawn successfully. Before channel and flow conditions are restored in the San Joaquin River to permit the restoration of salmon populations, it is possible to monitor the timing of arrival of adult fall-run salmon at the CDFG barrier to refine our understanding of when adult fall-run may begin their upstream migration. Such monitoring will likely capture adult salmon native to the Merced River, rather than the Tuolumne River fall-run population recommended as parent stock. Nevertheless, such monitoring will likely improve our understanding of when a restored population of fall-run salmon can be expected to begin their upstream migration, and thus refine management of migration flow releases.

Such monitoring will likely require capturing and tagging adult fish that appear at the barrier, to prevent double-counting of recalcitrant strays. Monitoring the number of fish appearing at the barrier may also enhance our understanding of the pattern of adult upstream migration, including the period when a majority of adults begin their upstream migration. Monitoring of adult salmon can be complemented by monitoring of local water temperatures, to evaluate hypotheses about water temperature as a potential trigger for adult upstream migration.

Tagging adult fish at the barrier can also support an experiment designed to improve our understanding of the migration rate of adult fall-run salmon, as described below.

2.2.2 Assess migration rate of adult fall-run chinook salmon

Research experiments that consist of tagging and tracking adult salmon can improve our understanding of their migration rates. These experiments can be conducted in a number of ways. For example, prior to the restoration of salmon populations on the San Joaquin River, tagging and tracking experiments could be conducted on salmon populations in the Tuolumne River and/or the Merced River. Adult salmon can be captured and marked at each river's confluence with the mainstem San Joaquin River, and then the spawning habitat in each river can be monitored to indicate when the marked fish appear in spawning areas. Similarly, radio-tagging adult salmon can support tracking the movements of marked adults more specifically to determine the effect of water quality (e.g., temperature and dissolved oxygen) on migration rate and timing, as well as other potential physical and biological passage barriers. Tracking the upstream migration of adult salmon on the Merced River can be coordinated with the capture and marking of fish at the CDFG barrier, as described above.

Though tagging and tracking of adult fall-run salmon on the Tuolumne River and/or the Merced River can improve our general understanding of upstream migration rates, they will not reflect conditions in the mainstem San Joaquin River. Differences in passage conditions, water temperatures, and potential migration cues (e.g., the infusion of Delta water via the Delta-Mendota Canal) may result in different upstream migration rates for adult salmon in the San Joaquin River than occurs in the Tuolumne River and Merced River. Restoration of channel and flow conditions in the San Joaquin River, coupled with improvements in physical passage of key infrastructures that can allow unimpeded upstream migration of adult salmon, will need to be complemented by tagging and tracking studies to develop an understanding of upstream migration rates and behavior in the San Joaquin River.

2.2.3 Retrofit key infrastructure with fish-counting facilities

Restoring self-sustaining salmon populations to the San Joaquin River will require improving passage conditions at several key pieces of infrastructure throughout the planning area, including: the Sand Slough Control Structure (~RM 168), Sack Dam (~RM 182), Mendota Dam (~RM 205), and the Chowchilla Bifurcation Structure (~RM 216). The required retrofitting or replacing of these structures with fish passage facilities provides a valuable opportunity to add monitoring systems that will facilitate tracking the upstream migration of adult salmon. Tracking the arrival and number of adult salmon at each waypoint will contribute to a broader understanding of the pattern of upstream migration, which will support adaptive management of flow releases to support salmon populations while maximizing the efficient use of limited water resources.

Retrofitting or replacing the infrastructure listed above to facilitate fish passage and counting will span approximately 48 river miles, or less than 33% of the planning area. Consequently, establishing fish-counting facilities in other upstream and downstream reaches will provide better coverage of the planning area. The proposed adult trapping facility (~RM 119) and the smolt collection facility described in Section 2.1.2 of this appendix (~RM 255) can also serve as fish-counting facilities to contribute to tracking the upstream migration of adult salmon.

2.3 Spring-run adult holding densities and distribution

There are number of pools in Reach 1 that potentially could provide suitable holding conditions for adult spring-run salmon (e.g., water depths greater than 8 feet [2.4 m] at summer baseflows and water temperatures below 70^{o}F [21 ^{o}C] through the holding period). However, it is unclear how adult spring-run salmon will distribute throughout the pools in Reach 1. Development of the restoration strategies assumed that all adult spring-run salmon would hold in the largest of these pools, located at RM 267.1. This assumption is based on historical observations of a large number of salmon holding in this pool following the construction of Friant Dam (Clark 1942). The salmon population model that was created to support the development of the restoration strategies assumes that all adult spring-run salmon will hold in this one pool. If, however, spring-run holding is distributed more widely, then potential production of spring chinook from the San Joaquin River could be much higher.

The salmon population model that was created to support the development of restoration strategies also includes assumptions about the density of adults in holding pools. Different assumptions about the number of adults than can safely hold in the large pool at RM 267.1 affect predictions about population dynamics of a restored spring-run salmon population. In addition, high densities of fish can cause stress and potentially increase susceptibility to disease and pre-spawn mortality.

Direct observation and snorkel surveys can be used to monitor the distribution and density of spring-run salmon holding in Reach 1 pools. All potential holding pools in Reach 1 would likely need to be surveyed to estimate the number of chinook holding in each. All pools would be mapped to determine the volume of the holding space, and the density of chinook would be estimated. During the direct observation surveys, any signs of stress related to holding densities, such as labored breathing and fungus, would be monitored. The sub-sample of spring chinook that would be radio-tagged as part of other recommended experiments (see Section 2.5.3 of this appendix) would also support an evaluation of holding pool selection and distribution.

Because of widespread recreational and subsistence fishing in Reach 1 and Millerton Reservoir, it may be necessary to implement measures to prevent poaching of spring-run adults holding in pools. If spring-run salmon are found to be distributed widely throughout Reach 1, then poaching prevention could become more complicated and expensive than if spring-run holding is concentrated in the large pool at RM 267.1.

2.4 Spring-run spawning cue

The proposed hydrographs for the three restoration strategies include a three-day fall freshet flow of 1,000 cfs as part of a broader adaptive management experiment to evaluate potential spawning cues for spring-run salmon. To prevent hybridization with fall-run chinook salmon, spring-run salmon will need to disperse from holding areas and spawn in early September, before the arrival of fall chinook beginning in late October. In order to stimulate spring-run spawning in September, it may be necessary to provide some form of cue. Potential spawning cues include photoperiod, water temperature, and flow. A multi-year adaptive management experiment can be implemented to test the relative importance of these potential spawning cues for a restored population of spring-run salmon. The results of the experiment can then feed back into changes in the hydrograph components designed to support spring-run spawning.

The adaptive management experiment could begin by testing if natural changes in photoperiod alone are sufficient to stimulate a restored population of spring-run salmon to begin spawning. This experimental component would involve simply releasing the targeted spawning flow, without any fall freshet preceding the spawning flow.

If photoperiod alone is insufficient to stimulate spawning, then the experiment could test the potential of changes in flow as a spawning cue. This phase of the experiment would involve releasing short-duration flows with a magnitude higher than summer baseflows. The magnitude and duration of spawning cue flows could be manipulated as controlled experiments conducted over a series of years, supplemented by monitoring of adult spring-run spawning behavior. The results of the experiment could indicate not only the effectiveness of changes in flow as a spawning cue, but also the duration and magnitude of a flow release that stimulates spawning.

If the combination of photoperiod and changes in flow are insufficient to stimulate spawning in September, then a re-evaluation of the restoration strategies will be required, because it will be difficult to test the effects of water temperature as a potential spawning cue. Friant Dam releases have generally constant water temperatures between 48^{o}F (9 ^{o}C) and 52^{o}F (11 ^{o}C), because Millerton Reservoir dampens the effects of air temperatures on water temperatures in Reach 1. If photoperiod and flow changes do not effectively stimulate spring-run spawning in September, then infrastructural changes to deliver colder water to Reach 1 may need to be explored, or other ways for reducing the risk of hybridization with fall-run salmon may need to be explored.

2.5 Spawning distribution and timing

Planning for spring- and fall-run chinook salmon spawning must consider 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). Section 2.5.1 describes an approach that uses the control of flow releases to help segregate spring-run and fall-run spawning both laterally and longitudinally, thereby helping to prevent redd superimposition. This approach involves releasing flows to support spring-run spawning that concentrate preferred microhabitat conditions in the center of the channel (water depths and velocities) and closer to Friant Dam (water temperatures). Flows to support fall-run spawning would be higher magnitude flows designed to shift preferred water depths and velocities more toward the channel margins, thereby providing lateral segregation with spring chinook spawning. Higher magnitude flows in November would also extend suitable water temperatures farther downstream so that fall-run salmon can be distributed more widely, potentially reducing fall-run spawning use of upstream riffles where spring-run redds will likely be concentrated.

The spawning behavior of fall-run and spring-run salmon will need to be monitored to evaluate the effectiveness of this approach in preventing redd superimposition. A multi-year adaptive management experiment that involves a series of different flow magnitudes for fall-run and spring-run spawning could be implemented to evaluate not only the effectiveness of this approach in segregating spawning, but also the combination of flows that most supports spawning segregation. If the management of flow releases to segregate spring-run and fall-run spawning are ineffective, then spring-run salmon populations could be endangered, because redd superimposition is a greater risk for spring-run salmon because they spawn prior to fall-run salmon. Other measures for separating fall-run and spring-run spawning, such as physical barriers, might need to be explored. Elements of a monitoring program to evaluate the effectiveness of spawning segregation are described below.

2.5.1 Segregation of fall-run and spring-run chinook spawning

The U.S. Fish and Wildlife Service conducted an IFIM study of the San Joaquin River in 1993 to assess the potential for restoring chinook salmon (USFWS 1994). This study included PHABSIM modeling of a few spawning riffles in Reach 1 to assess the potential amount of existing spawning habitat in the river. Using the data from this study, we conducted a follow-up PHABSIM analysis to examine the concept of laterally segregating fall-run and spring-run salmon spawning through the control of flow releases at two spawning reaches. Figure I-1 and I-2 illustrate that it may be possible to achieve lateral and longitudinal segregation of spawning through the control of flow magnitudes. These figures also show that at lower flows, preferred microhabitat conditions (water depth and velocity) are concentrated in the center of the channel, and higher flows shift preferred water depths and velocities toward the channel margin. However, the data used for this follow-up PHABSIM modeling was collected by the USFWS in 1993, before the large flood of 1997, which may have altered the spawning riffles that were sampled by the USFWS. As a result, the current condition of spawning riffles may be different than what was modeled.

To further test the concept of lateral segregation of fall-run and spring-run spawning, additional PHABSIM modeling would require the acquisition of data that reflects the current condition of potential spawning riffles in Reach 1. This data would need to be collected in conjunction with the release of a series of steady-state flows that represent the potential spawning flows for restored populations of fall-run and spring-run salmon. For each steady-state flow, the following habitat characteristics would be measured: water surface elevation, water depth, depth-integrated water velocities, and bed texture. These measurements would be made at a number of different potential spawning riffles that are thought to be representative of spawning habitat quality and hydraulic conditions of the spawning habitat in Reach 1 in terms.

2.5.2 Redd surveys

Once fall-run and spring-run salmon are restored to the San Joaquin River, annual monitoring of the location of redds would further test the concept of lateral and longitudinal segregation of spring-run and fall-run spawning through the control of flows. Daily surveys of redds during the spawning season could involve recording the location and timing of each new redd. These redd surveys can include marking each redd with a unique tag, locating each redd with a GPS unit, mapping redd locations on an up-to-date aerial photograph.

Mapping the location of redds can provide direct evidence of redd superimposition. Monitoring redd locations over a period of years, during which different spawning flows are released as part of the adaptive management experiment described in briefly Section 2.5 of this appendix, will also help test how different flows affect the location of redds because of shifts in water depths and velocities.

2.5.3 Spawning behavior

Spawning by spring-run and fall-run salmon is expected to be concentrated in Reach 1A; however, it is not known which riffles will be selected for spawning, and what the influence of flow releases will be on spawning behavior. Spring-run salmon could be fitted with radio tags to determine what distances they move from holding pools to spawn, and which riffles they prefer for spawning. Fall-run salmon could also be fitted with radio tags to determine which riffles they select for spawning and how far downstream they will spawn.

Also, monitoring the spawning behavior of spring-run and fall-run adults can help inform a strategy of where to focus gravel supplementation efforts. Because there is no current population of salmon on the San Joaquin River, we can only make assumptions about where they are likely to spawn based upon the spawning habitat preferences and behavior of salmon on other similar streams. Radio-tagging adult salmon will allow us to monitor where individuals construct test redds, but do not spawn because gravel lenses may not be sufficiently deep. By conducting research on riffle selection prior to augmentation, gravel supplementation efforts can be placed more strategically to enhance the potential for success.

2.6 Spawning riffle creation

Section 4.3.1 of the main report explores the possibility of expanding spawning habitat in Reach 1 by transforming locations with high gradients. Much of Reach 1A is composed of long reaches with low channel slopes, punctuated by discrete slope breaks that create depth and velocity conditions unsuitable for spawning by chinook salmon. The steep drops at the slope breaks provide an opportunity to create chinook spawning habitat by adding gravel in a way that reduces the local slope to a range that can support salmon spawning. An analysis of available topographic data derived from a digital terrain model (DTM) identified 18 candidate sites where the addition of spawning gravel to a locally steep slope may produce a lower gradient suitable for salmon spawning. The information from the DTM, however, is too coarse to confirm the suitability of these candidate sites. Focused ground surveys will be required to further assess this concept and the candidate sites. Another key uncertainty associated with this action is whether the treatment sites will remain in place after high flow events. The most suitable locations for augmentation occur where a natural grade-control structure (such as a bedrock outcrop or other topographic high point on the bed) can help stabilize the constructed riffle at both the upstream and the downstream end of the treatment site, to help prevent the material from simply sliding downstream.

Salmon population dynamics modeling provides context for the importance of increasing spawning habitat within the San Joaquin River. Modeling indicates that increased spawning habitat will result in increased population-level benefits. For example, the salmon population model predicts that a doubling of spawning habitat could result in a doubling of the adult escapement rate. Thus, actions that would significantly increase the available spawning habitat could potentially cause an increase in the population size, helping to achieve a self-sustaining viable salmon population. Additional studies required to successfully implement this action and potentially increase salmon spawning habitat are described below.

2.6.1 Ground surveyed topographical data

Determining the precise location and feasibility of these additional spawning habitats will require additional analyses centered on data collected from detailed ground surveys. Ground surveys would include surveying the longitudinal profile of Reach 1A, and surveying cross-sections at potential treatment sites. The ground surveys can help determine: (a) the amount of gravel required to create appropriate slopes, (b) the presence of potential upstream and downstream gradient controls, and (c) the hydraulic design required to create suitable spawning conditions. The 18 identified sites likely represent the maximum number of areas where a gravel augmentation project is feasible, and it is likely that fewer sites would be chosen when higher-resolution topographic information and additional factors are considered.

2.6.2 Engineering feasibility studies

Some feasibility studies will be required to determine whether a gradient of 0.0010–0.0015 and channel widths between 75–100 ft (23–30 m) can provide suitable hydraulic conditions for salmonid spawning, and to what extent this habitat can be maintained. Observations of heavily used spawning riffles on the Tuolumne River show that these estimates of slope and channel width provide preferred conditions of velocity and depth at spawning flows ranging from 100 to 500 cfs (McBain and Trush 1998). Grade control features provided by bedrock outcrops may be the most suitable control features to maintain the habitat, but geomorphic controls provided by riffle crests could also be used. Artificial drops provided by cobble weirs may also be used, although they would not be as stable as bedrock control features. Downstream channel constrictions such as bridges may also provide suitable controls.

2.6.3 Pilot study

A pilot study would likely be conducted at a selected site once candidate sites have been evaluated using the information gathered in the studies outlined above (Sections 2.6.1 and 2.6.2). Once the treatment has been applied at the pilot site, the site would be surveyed with a total station survey. Subsequent releases of high flows would provide a test of how the treatment site responds. Following each high flow event, the site would be surveyed with a total station to document any changes. After a series of high flows, it would be possible to determine if constructed sites designed to locally alter channel gradient can be stable; that is, it will be possible to see if the sites simply blow out or slide and if the channel returns to the original channel gradient. This pilot study would support an assessment of the feasibility and duration of habitat benefits associated with this approach for increasing spawning habitat.

2.7 Time to emergence

Incubation temperatures influence the rate of embryo development, with warmer temperatures decreasing time to emergence. The timing of salmon emergence is a critical variable, particularly for fall chinook, as described in Section 3.2 of the main report. Spring-run salmon eggs will likely develop faster and emerge earlier than fall-run salmon on the San Joaquin River, not only because spring-run spawn earlier, but also because spring-run spawning occurs earlier in the season when the water is warmer. Fall chinook emergence and rate of development may be an important factor in determining if juveniles outmigrate too late in the spring when higher water 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. Modeling to estimate emergence timing is typically based on degree-day relationships developed with hatchery data. However, in a natural environment actual emergence times can differ substantially. Monitoring of chinook salmon emergence timing will be conducted to study the effect of temperature on embryo development, and determine if particular river reaches (and thus temperature regimes) will be prone to late emergence and subsequent exposure to high spring temperatures.

As described in Section 3.2.1 of this appendix, adaptive management experiments can be conducted on temperatures tolerances of incubating eggs. These experiments will focus on assessing the influence of the longitudinal temperature gradient that exists downstream of Friant Dam. Monitoring of emergence timing would be conducted in conjunction with these studies by monitoring the emergence of eggs from Whitlock-Vibert boxes in artificial redds. In addition, emergence traps would also be placed on natural redds. In these monitoring efforts only emergence timing and fry size information would be collected, and thus the exact number of eggs naturally spawned by females would not be required information, as it is for the survival studies described in Section 3.2.1 of this appendix. However, the natural redds selected for monitoring would be selected from spawning riffles representing the longitudinal temperature gradient in Reach 1, similar to the experimental design described in Section 3.2.1 of this appendix. Continuously recording thermographs would be placed at each monitored redd, so that degree-day analysis can be conducted. When degree-day models are better calibrated for conditions in the San Joaquin River, predicting the emergence timing of redds from different riffles could be achieved by simply monitoring temperature profiles.

2.8 Growth rates

One of the key uncertainties in restoring salmon populations in the San Joaquin River is the time required for rearing salmon to smolt and outmigrate from the planning area. Each of the restoration strategies assumes that young salmon are ready to smolt when they reach 80 mm in length (based upon rotary screw trap data from the lower Tuolumne River). However, it is difficult to estimate when juvenile salmonids will achieve this size threshold in the San Joaquin River. The time required to achieve smolt size has significant implications for all three restoration strategies, including the feasibility of restoring a self-sustaining population of fall-run chinook salmon, and the timing, duration, and magnitude of several hydrograph components. Rearing habitat conditions and juvenile growth rates that are achieved in the restored San Joaquin River will be determined by monitoring the physical and biological parameters that influence growth, and by measuring and comparing growth rates in distinct habitat types.

Depending on the restoration strategy that is selected, the physical parameters that influence growth rates would be monitored in selected reaches within the planning area. The depth, velocity, and water temperature of rearing habitat throughout the river would be measured, along with detailed measurements of food availability. Food availability can be used to estimate ration size, and would be monitored by measuring invertebrate production. Monitoring the density and composition of invertebrate production in different habitats would expand current information on the relationship between habitat characteristics and food availability. For example, it is likely that invertebrate production, and thus ration size, is less in sand-bedded reaches. With detailed information on invertebrate production in various habitat types, a model could be used to predict ration size could be predicted based on habitat parameters throughout the river, possibly in a GIS-based approach. By combining temperature data with food availability parameters, growth models can better predict the rearing time required for juveniles to reach threshold size under various management scenarios.

In addition to collecting information to better parameterize growth models, actual growth rates achieved by juvenile rearing in the San Joaquin River could be monitored in distinct habitats. Research to examine growth rates may consist of “cage” experiments, wherein fish are contained to specific habitats and their growth is monitored, or more traditional mark-and-recapture experiments may be used. By comparing growth rates in floodplains and main channel habitat, for example, the influence of habitat restoration on growth rates can be better interpreted. Specific parameters and observed growth rates will be used to refine the growth model, and thus the ability to predict the effect of management on the timing of outmigration, and the size of smolts.

3 WATER TEMPERATURE UNCERTAINTIES

Water temperature regimes under the proposed restoration strategies constitute one of the most significant uncertainties underlying the restoration strategies. Concerns about the effects of elevated water temperatures on different life history stages of native fish have influenced the restoration strategies in several ways, including:

- The selection of a parent stock for both fall-run and spring-run chinook salmon and the targeted timing of life history stages;
- The timing, magnitude, and duration of several hydrograph components; and,
- The amount of suitable habitat available for different life history stages of native fish.

Despite the importance of water temperature as a key variable influencing the restoration strategies, there is very little water temperature data, both historical and current, available for the planning area. The USGS Fremont Ford gauge (no. 11261500) and the DWR CDEC gauge near Stevinson (SJS) have collected water temperature data in Reach 5 of the planning area; however, the period of record for each gauge is very short.

Because of the paucity of water temperature data available, the development of the restoration strategies was supported by a water temperature model developed by Jones and Stokes Associates (JSA). The model tracks water temperatures from Friant Dam, accounting for the effects of such variables as water depth, ambient air temperatures, humidity, and solar radiation. The reliability of the water temperature model is greatest in reaches close to Friant Dam, because water temperatures of Friant Dam releases are relatively constant (between 48°F and 52°F [9°C and 11°C]) and because of the availability of flow and water temperature data to calibrate the model. Confidence in the accuracy of the model's water temperature predictions decreases with distance from Friant Dam, because of the growing complexity of factors that can affect water temperatures (e.g., flow splits, the cumulative uncertainty underlying model assumptions) and because of the lack of flow and water temperature data in lower reaches to calibrate the model.

Despite the growing uncertainty underlying the water temperature model with distance from Friant Dam, it still provided the best available tool for exploring the relationship between discharge and water temperatures as part of the strategy development process. However, as additional discharge and water temperature data is collected when flows are returned to all reaches of the San Joaquin River, there will be a better opportunity to examine relationships between discharge and water temperature. Different flow-water temperature relationships would likely result in adjustments to the hydrograph components discussed in Chapters 5 through 7 in the main body of this report.

As the southernmost population of chinook salmon, the historical fall-run and spring-run stocks on the San Joaquin River likely experienced water temperature conditions that were among the warmest experienced by chinook salmon populations. This raises questions about whether the temperature targets for different life history stages of salmon, which are based primarily on values found in the scientific literature, are applicable to restored populations of salmon on the San Joaquin River. The following sections discuss an adaptive management approach for addressing the uncertain effects of temperature on re-established chinook salmon populations under the proposed restoration strategies. Temperature issues pertaining to native resident fish are covered in Section 4.

3.1 Expanded water temperature monitoring in all reaches

Although water temperature concerns are a key driver influencing the restoration strategies, there is very little continuously collected water temperature data available for the planning area. This has occurred in part because of the lack of continuous flow in the planning area. The USGS Fremont Ford gauge (no. 11261500) and the DWR CDEC gauge near Stevinson (SJS) have collected water temperature data in Reach 5 of the planning area; however, the period of record for each gauge is very short. With the reestablishment of flow in the San Joaquin River, there is a strong need to develop a water temperature database, which will feed into the pool of regional water temperature monitoring data. Some sites that are appropriate for expanded continuous water temperature monitoring are USGS and CDWR sites that currently record other variables (e.g., flow). These established data collecting sites, both within and downstream of the planning area include:

- San Joaquin River Below Friant (SJF)
- Chowchilla Bypass (CBP)
- San Joaquin River at Gravelly Ford (GRF)
- Madera (MDR)
- San Joaquin River Below Bifurcation (SJB)
- San Joaquin River Near Mendota (MEN)
- San Joaquin River Near Vernalis (VNS)

In addition to adding continuously-recording temperature loggers to these sites, other monitoring sites may also be warranted to achieve an appropriate distribution of site locations throughout the river corridor. All sites could be linked to current regional data servers, and available to the public.

Expanding the collection of water temperature data would serve several uses. The distribution of water temperature collection sites throughout the planning area could support an analysis of how temperature may affect the upstream and downstream migration of salmon, as well as other fish species, as described in Section 3.2 of this appendix. The water temperature data could also be used to help calibrate water temperature models by providing better information about the relationship between discharge and water temperature.

3.2 Water temperature tolerances of salmon

3.2.1 Assess water temperature tolerance of incubating eggs

The temperature target for the egg incubation and emergent fry life history stages of salmon is 58^{o}F (14°C). Water temperature modeling suggests that, assuming average meteorological conditions, only the first 7 miles (11 km) of spawning habitat downstream of Friant Dam will achieve the temperature target during the month of September when spring-run salmon are expected to spawn. Different assumptions about what constitutes an appropriate temperature target for incubating eggs produces different estimates of the amount of spawning habitat that will have suitable habitat conditions during spring-run spawning. Developing a better understanding of the thermal tolerance of incubating eggs will support better estimates of how much spawning habitat will have suitable conditions during spring-run spawning, which will in turn support an assessment of any need to increase spawning habitat for spring-run salmon.

During the effort to jump-start salmon populations, it is expected that eggs will be put into Whitlock-Vibert boxes (W-V boxes) and placed in the substrate. The W-V box is a salmon egg stocking device that has an egg incubator compartment, and a nursery compartment that protects developing egg and fry from predators or entrapment. They have been shown to promote high survival from egg to emergence, and produce larger fry than natural conditions. During this initial effort to seed the population, a proportion of the planted eggs could be used in an adaptive management experiment to evaluate the effects of water temperatures in Reach 1 on survival-to-emergence. This experiment would involve placing a known number of chinook eggs in W-V boxes, which would be planted in Reach 1 along a longitudinal axis that represents the temperature gradient. Some of the W-V boxes would be planted in riffles that are predicted to have water temperatures that are below the 58°F (14°C) temperature target, and other W-V boxes would be planted in riffles expected to have water temperatures in excess of 58°F (14°C). To help control for other variables, all W-V boxes would be planted in areas that have similar gravel quality and permeability. This may require importing clean spawning-sized gravels to the locations where the W-V boxes would be planted. In addition, locations with similar depths and velocities will be selected to further ensure that the primary treatment difference between sites is water temperature.

Redd traps would be placed over each buried W-V box to trap emergent fry and thus measure survival-to-emergence. In addition to measuring survival to emergence, a proportion of W-V boxes could be retrieved at various stages of development to measure survival to distinct life-stages. A thermograph would be placed at each location to measure the temperature regime at each location.

A simultaneous laboratory experiment could be conducted in a hatchery as a control to assess the potential mortality associated with the handling of eggs. When eggs are initially deployed for the field experiment, a sub-sample would be transferred to the field and handled like the other eggs, and then transferred back to the hatchery where they would be monitored during incubation to assess the effects of handling. Although it will be challenging to match natural stream temperature regimes in the hatchery, technology is available to computer-control laboratory water temperatures to emulate conditions observed in the San Joaquin River.

3.2.2 Research and monitor the affect of temperature on growth and survival of juvenile salmon

The goal of the juvenile rearing strategy is to provide temperatures warm enough to promote faster growth of juvenile salmonids to enhance their downstream survival, but cool enough to avoid the deleterious effects of temperatures that are too warm. It has long been recognized that growth rates of fish are based on the relationship between available ration and temperature regime (Brett et al. 1969). Growth can occur only when energy consumed exceeds basic metabolic and behavioral needs (McCullough 1999, Sullivan et al. 2000). However, Sullivan et al. (2000) noted that food supply has more influence on population productivity than temperature. On maximum daily rations, growth rates increase with temperature up to a species-specific temperature threshold, at which point growth rates decline with further increases in temperature. Research and monitoring of the interaction between temperature and ration and the resulting influence on juvenile salmon growth in the San Joaquin River is required to determine appropriate rearing temperatures for restoration.

Research on salmon growth rates would be similar to, and likely will be conducted concurrently with, components of growth research described in Section 2.9 of this appendix. The objective of this research is to examine the effects of water temperature both at release from Friant Dam and with warming downstream. As temperatures increase downstream from Friant Dam, growth rates are likely to increase, until the point that stress from high temperature is of a greater metabolic demand than the available food supplies. The key to adaptive management monitoring is to determine where this point of diminishing returns is along the river, and the way in which flow releases from Friant Dam adjusts the longitudinal position of that point. Experimental approaches could include field experiments on the abundance and distribution of juveniles, observed growth rates, and food availability along the longitudinal temperature gradient downstream of Friant Dam. Small radio tags and other individual marks may be used to track individual juveniles and their growth rates as temperatures increase during the spring and into the summer, and also as temperatures increase downstream of Friant Dam.

A more thorough understanding of the bioenergetic ecology of rearing chinook salmon would allow meaningful flow targets to be selected that would optimize the interaction among temperature, ration size, and growth.

3.2.3 Monitor water temperature tolerance for outmigrating salmon

During 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 temperature target to support smoltification and outmigration is to provide average daily water temperatures less than 68ºF (20ºC). However, this temperature target will be extremely challenging to achieve in the San Joaquin River. Also, the 68ºF (20ºC) temperature target for salmon smolts is based primarily on values established in the scientific literature, much of which is based upon research conducted on rivers in California, the Pacific Northwest, and Alaska that experience very different meteorological conditions than the San Joaquin River. As is shown in Table 2-1 in the main report, the 68ºF (20ºC) target is often exceeded in the lower reaches of the Tuolumne River for numerous days during April and May when chinook salmon smolts outmigrate, yet the population persists. It is not known, however, if fish are successfully outmigrating during the days when 68ºF (20ºC) is exceeded on the Tuolumne River, or what potential sublethal effects could be. For example, Clarke et al. (1981) demonstrated that survival during the ocean stage may be lower for fish outmigrating in high temperatures.

Hydrograph components designed to support the outmigration of salmon smolts are defined, in large measure, by the need to maintain water temperatures below 68ºF (20ºC). A different temperature standard would likely have significant effects upon the timing, magnitude, and duration of hydrograph components to support salmon smolts. Research and monitoring can be conducted to assess the water temperature tolerance for outmigrating chinook smolts in the lower San Joaquin River.

To help assess thermal tolerances for smolts, a sample of smolts can be fitted with radio tags to monitor their behavior as they migrate downstream in the San Joaquin River, where they will likely experience increasingly warmer water temperatures as they move downstream. Unsuitably warm temperatures may impede or block their downstream migration, which could indicate temperature as a barrier to passage. A separate sample of smolts could be fitted with thermodata tags, which continuously record the water temperature that fish encounter. When fish are recaptured at lower traps, the data is downloaded and the actual temperature regime encountered by that fish can be analyzed. Fish can also be captured in a series of outmigrant traps placed at strategic intervals in the Lower San Joaquin River to monitor survival though the lower river, though this method will make it difficult to separate temperature as a source of mortality from other sources. The condition (e.g., condition factor and stress hormone production) of smolts can also be assessed at traps to assess if sub-lethal temperatures could reduce survivorship during migration to the delta.

Prior to the restoration of salmon populations on the San Joaquin River, these same research projects could be conducted on the Tuolumne River. Determining temperatures tolerances of chinook in the Tuolumne would aid the management of that river, and it would be applicable to the San Joaquin River, because the genetics between the populations would be similar, as would environmental conditions.

3.2.4 Monitor water temperature tolerance for summer rearing by yearlings

Fall chinook typically outmigrate in the spring as subyearlings. However, spring chinook may rear in their natal streams for up to a year and outmigrate as yearlings. Juveniles rearing for the summer in the upper San Joaquin could potentially be exposed to lethal water temperatures. The temperature tolerance of rearing chinook in natural summer conditions is complicated by other environmental factors, such as food availability, and is not well understood. Monitoring could be conducted to assess the temperature tolerances for chinook that rear over summer.

The objective of the research would be to determine an appropriate threshold to protect juvenile chinook salmon from acute effects of exposure to summer water temperatures. In early June, before temperatures have increased, specific habitat units would be sampled for juvenile chinook abundance. As water temperatures increase during summer, sampling would be repeated to assess changes in abundance. As temperature thresholds are approached, which is likely in habitat units located in lower Reach 1, abundance would likely decline, and eventually fish would be extirpated from units exceeding thresholds. During initial sampling, individuals could be marked, so that it could be determined if temperatures cause fish to move to other habitat units, or if they perish. A logistic regression analysis can be used to associate probabilities of fish presence with different temperature regimes.

4 NATIVE RESIDENT FISH UNCERTAINTIES

Little information is available regarding the historical abundance and distribution of native fish species or the current abundance and distribution of native and non-native fish species in the San Joaquin River. Evaluating responses to restoration measures may require collecting some baseline information on abundance and distribution in the affected reaches. In addition, little is known regarding the life histories and habitat requirements of many of the Central Valley's native resident fish species or lampreys. Factors that potentially limit populations in the San Joaquin River remain largely unknown for both native and non-native species. Monitoring efforts may help to illuminate the habitat relationships of some species and increase the potential for management measures to enhance native fish populations and reduce populations of non-native species.

There are two primary restoration goals for resident fish populations. One is to reduce predation by non-native fish on juvenile salmon, and the other is to enhance populations of native fish species. The goals for monitoring and adaptive management efforts for native resident fish therefore include (1) identifying habitat types or habitat characteristics that tend to support species that are known to be important predators of juvenile salmon, but that provide little habitat for native species, and (2) identifying habitat types or habitat characteristics that promote native resident fish populations over non-native fish. Predation studies on the Tuolumne River indicated that black bass (*Micropterus* spp.; e.g., largemouth bass, smallmouth bass) are likely to be the most important non-native fish predators on juvenile salmon in the planning area. Striped bass are also likely to be important predators on juvenile chinook salmon, but are less likely to be found in substantial numbers in the planning area.

Coordination of fish monitoring efforts with water quality sampling in the San Joaquin River will be important for identifying potential factors limiting native and non-native fish distribution that are unrelated to habitat and temperature conditions. Non-native fish species are often more tolerant of poor water quality than native species. Water quality parameters found to be important in accounting for fish distributions in the Willamette River basin included minimum daily dissolved oxygen concentrations, pesticide concentrations, and total phosphorus (Waite and Carpenter 2000).

4.1 Pre-implementation Monitoring

4.1.1 Resident fish and lamprey abundance and distribution

Baseline information on the current abundance and distribution of resident fish and lamprey species would be useful for monitoring the effects of restoration measures and guiding management efforts. Such surveys may identify important spawning and rearing areas for native resident fish and lampreys, as well as "hot spots" of native resident fish diversity or abundance. Incidental observations of external abnormalities (e.g., lesions, external parasites) could be collected during any surveys that involve collecting fish. Percent external abnormalities was associated with high abundance of introduced species in the Willamette River basin (Waite and Carpenter 2000) and may offer clues regarding factors limiting native fish distribution. Many non-native fish species appear to be more tolerant of poor water quality conditions than native fish species; a higher incidence of lesions and parasites may indicate that water quality is reducing fish health and survival. Snorkel surveys (where water quality permits), electrofishing, beach seining, and minnow traps can all be used to sample fish. Gill nets could also be used to sample fish, but would likely result in higher mortality rates than other methods. Sampling during the summer low-flow season may be best for determining the maximum distribution of non-native fishes in a certain year, while sampling during spring may provide information on spawning distribution and success. Some specific uncertainties regarding fish abundance and distribution, which could guide the development of a monitoring plan, include: (1) the abundance and distribution of potential predators on juvenile salmon, and (2) the abundance and distribution of species believed to be declining in the San Joaquin basin.

4.1.2 Resident fish and lamprey habitat conditions and habitat relationships

Baseline habitat conditions for native and non-native resident fish species in the planning area have not been evaluated. Very little research has been conducted on the habitat relationships of native Central Valley non-salmonid fishes. In addition, little is known regarding habitat preferences of non-native fishes in the San Joaquin basin and what factors limit their abundance and distribution. Specific questions that warrant investigation include:

- What types of habitats support the greatest densities of adult black bass?
- What temperatures are black bass associated with? Do black bass move downstream in response to temperature reductions?
- Where distributions of native and non-native species overlap, what types of habitats are preferred by both native and non-native fish species?
- Do habitat preferences shown by native fish species appear to differ based on the presence of non-native species?
- What habitats known to be used by native fish species appear to be limited?

Habitat conditions for resident fishes and lampreys will change with restoration efforts that affect instream flows, temperatures, channel and floodplain morphology, habitat connectivity, and riparian habitats. Information on baseline habitat conditions and habitat responses to various management measures will be valuable for refining restoration measures aimed at benefiting resident fish. Specific habitat types and habitat requirements of selected native and non-native fish outlined in Section 4 of the Restoration Objectives report will be used to guide habitat characterization and monitoring. Habitat characteristics that may be important to measure include:

- macrohabitat type (e.g., pool, run, riffle),
- key habitat type (e.g., deep/slow, shallow/vegetated),
- habitat area,
- habitat persistence and hydrological connectivity (i.e., is it available all year or is it only seasonally available?) (see Freeman et al. 2001, Scheerer 2002),
- depth,
- velocities,
- temperature,
- turbidity,
- substrate,
- aquatic and emergent vegetation cover, and
- associated riparian habitat.

Information from monitoring habitat would be used in association with information on population abundance and distribution (described above) to refine the understanding of the habitat relationships of native and non-native resident fishes and lampreys in the San Joaquin River and to evaluate the benefits and costs of adjusting flow schedules to better meet the needs of these species.

4.1.3 Habitat connectivity for resident fish and lampreys

Surveys should be conducted to identify current barriers or obstacles to the movements and migrations of resident native fish and the potential for modifying these barriers to improve resident fish passage. Under current conditions, barriers may be preventing upstream or downstream movements to important spawning or rearing habitats, or preventing recolonization of reaches from which some species may have been extirpated. Fish passage facilities designed for juvenile salmon may not be adequate for providing passage to anadromous lampreys.

4.2 Post-implementation Monitoring

4.2.1 Floodplain inundation and Sacramento splittail

Inundation of floodplains and enhancement of floodplain habitats within the planning area are being proposed as measures to increase native resident fish spawning and rearing habitat, particularly for Sacramento splittail. There is little doubt that Sacramento splittail will be able to locate suitable flooded habitat if it is provided in the planning area. Sacramento splittail used to be distributed as far upstream as Friant Dam. In recent years, Baxter (1999a, 2000) documented Sacramento splittail in the San Joaquin River basin as far upstream as 10 km up Salt Slough during high outflow years. His observations on splittail distribution in high flow years indicate that splittail are able to "locate flooded habitat well upstream in the San Joaquin River and spawn when conditions were suitable" (Baxter 1999). Although some information is available on the factors producing strong splittail year-classes in the Yolo Bypass on the Sacramento River, many uncertainties remain about the potential effects of floodplain enhancement measures, including:

- What floodplain inundation depths, velocities, and other habitat characteristics will promote successful reproduction by Sacramento splittail?
- What temperatures are suitable for Sacramento splittail?
- How long do floodplains need to remain inundated to produce strong year-classes of Sacramento splittail?
- At what temperatures do centrarchids (non-native black bass and sunfish species) move onto floodplains to spawn?
- What floodplain inundation depths inhibit black bass and centrarchid movement onto floodplains?

Sampling in floodplain habitats and in main channels following dewatering of floodplains can likely help to answer many of these questions. Techniques may include beach seining, ichthyoplankton sampling, minnow traps, and invertebrate drift nets for evaluating food availability. Habitat characteristics to measure may include:

- inundation depth,
- inundation duration,
- inundation timing,
- water velocities on floodplain surface,
- temperature,
- substrate and vegetative cover,
- food availability,
- selenium and pesticide concentrations, and
- dissolved oxygen concentrations.

Stranding surveys should be conducted on floodplain surfaces after downramping events to determine the types of factors that may increase stranding of Sacramento splittail and other native fishes. This information could be helpful for restoring floodplain habitats or enhancing already available habitats to reduce stranding potential.

4.2.2 Perennial wetlands and Sacramento perch

Creation and enhancement of perennial wetlands on floodplains may increase native fish habitat and create opportunities for reintroducing Sacramento perch to the San Joaquin basin. It is uncertain what types of wetland habitats would best support native fish such as Sacramento perch, hitch, and Sacramento blackfish. The degree to which these habitats would be colonized and used by non-native species is also unknown. Fish sampling and habitat characterization should be used as part of an adaptive management approach to determining the types of wetlands best suited as native fish habitat. Fish sampling methods could include electrofishing and minnow traps. Habitat characteristics that could be measured include:

- wetland size,
- area occupied by open water,
- depth,
- temperatures,
- aquatic and emergent vegetation characteristics,
- turbidity,
- food availability, and
- colonization by non-native fish species.

Experiments could be conducted involving the seeding of native fish into perennial wetlands or experimental ponds with different characteristics to see which are most likely to benefit native species and which may be least likely to be colonized by non-native species.

4.2.3 Flow management and resident fish populations

Managing instream flows may be useful for reducing the abundance and distribution of black bass and other non-native fish species. High flows may reduce habitat quantity and quality for many non-native fish species by increasing velocities and reducing temperatures, but may also affect habitat and spawning success of native species. Flow fluctuations during the spring and summer may disrupt spawning of black bass or reduce survival of eggs and larvae. Downramping events may dewater spawning habitats or nests, or result in stranding of larval and juvenile fish. High flows may displace larval or juvenile fish to habitats that are not suitable for rearing. It is not known how native and non-native fish populations will respond to the proposed hydrographs for the various water years. This information will be necessary as part of an adaptive management approach for refining instream flow measures that benefit native fish populations over non-native fish populations. Monitoring and research efforts may be needed to resolve the following questions:

- How do high flows affect the distribution of adult resident fish?
- How do flows in wet water years affect spawning distribution and success?
- If high flows are associated with reduced numbers of non-native fishes in specific reaches and habitats, how quickly will different species recolonize these habitats?
- How much stranding occurs when floodplains are dewatered?
- What species and life stages may be affected by downramping events in the various reaches?

Snorkel surveys and electrofishing conducted during summer low flows could be used to monitor the distribution and relative abundance of adult fish of native and non-native species. Larval sampling, beach seining, and electrofishing would be used to monitor the distribution and relative abundance of young-of-the-year fish. The results will be compared with the current and previous year's hydrograph and temperature data to evaluate whether changes in distribution of adult or young-of-the-year fish are associated with changes in flows and temperatures. Stranding surveys can be conducted in floodplain habitats and other areas to determine the species, life stages, and habitats that may be most affected by downramping of flows.

4.2.4 Mendota Pool

Mendota Pool is proposed as a potential area for establishing a native resident fish community. In order to develop strategies for enhancing native fish habitat in Mendota Pool, it will be useful to gather information on baseline conditions, including habitat characteristics, species composition, and relative abundance of the various native and non-native species present. Such information would be used to determine Mendota Pool's potential as habitat for native fish and what measures may be most effective at reducing numbers of non-native fish and establishing a community composed primarily of native fish. If a native resident fish community can be established in Mendota Pool, monitoring of the abundance and distribution of native and non-native species in relation to temperature and habitat conditions in the reservoir can be used to evaluate the relative success of various measures designed to improve native fish habitat and for identifying non-native species that are most successful at colonizing the habitat. Sources of inflow into Mendota Pool could be periodically sampled to evaluate the recruitment of non-native fish larvae into the reservoir. Depending on water quality and habitats to be sampled, snorkel surveys, electrofishing, beach seining, minnow traps, and ichthyoplankton sampling could be used to characterize fish communities in Mendota Pool.

5 RIPARIAN AND WETLAND VEGETATION AND WILDLIFE HABITAT UNCERTAINTIES

The draft restoration strategies include a number of actions directed towards restoration of riparian and wetland habitats and the associated ecosystem functions they can provide. These actions involve (1) flow management to promote natural riparian vegetation establishment and maintenance, (2) floodplain reconstruction and levee setbacks to restore the physical template upon which riparian vegetation can establish, and (3) active planting of desired wetland and riparian vegetation using horticultural techniques to enhance vegetation diversity and provide initial seed/propagule sources where existing vegetation is limited. A number of uncertainties underlie assumptions made in developing the strategies and evaluating the potential benefits (and costs) of selected actions.

Review of revegetation literature, conversations with colleagues and review of findings presented at the recent CALFED Science Conference (January 2003), combined with observations made regarding restoration implementation on other rivers indicate that currently there is no standard method of implementing active (horticultural) riparian revegetation projects, and that using flow management and topographic modification of floodplain surfaces for passive (natural) revegetation is an emerging, but not fully tested, approach to riparian and floodplain wetland restoration in the Central Valley (AMFSTP 2001 and 2002, CALFED 2003). As aptly stated by the CALFED Adaptive Management Forum (AMFSTP 2001), the over-arching question that needs to be answered to improve the success of riparian restoration projects is “Can regulated rivers be managed to allow for natural regeneration of plant species, or is continual intervention in the form of active planting or seeding necessary?” Although much can be learned by reviewing restoration projects and experiments conducted in a wide range of river systems, the degree to which natural regeneration can be relied on in the San Joaquin River restoration project likely depends on a variety of river-, reach-, and site-specific conditions. Therefore, a multi-pronged adaptive management approach is more likely to yield rapid results necessary to reduce uncertainties and increase success of restoration efforts than a single-focus approach.

Some of the uncertainties most directly linked to development of a detailed restoration plan can be reduced by conducting monitoring and focused research during the next few years, prior to full-scale implementation of the final restoration plan. Such efforts should build on the 1999 San Joaquin River riparian flow release pilot project and subsequent monitoring results (DeFlitch and Cain 2002). In addition, the fastest and most efficient (in terms of cost and level of effort) way to reduce some of the key uncertainties may be to coordinate with participants in other riparian and floodplain wetland restoration efforts in the Central Valley. This would promote information exchange and allow review of lessons learned from projects such as the ongoing restoration efforts on the Tuolumne and Merced rivers (McBain & Trush 2000, AMFSTP 2001 and 2002, Stillwater Sciences 2002, Stella et al. 2003 and *in press*), the lower San Joaquin River (Griggs and Sperber 2003), Clear Creek (McBain & Trush et al. 2000), and the Sacramento River (Golet et al. *in press*, Griggs and Golet 2002), and older revegetation efforts reported in various conference proceedings (e.g., Sands 1977, Abell 1989, Warner and Hendrix 1984). In addition, the potential for valuable information from restoration projects in areas outside of California should not be ignored, particularly those in semi-arid or arid environments of the Southwest, such as flow management and floodplain regrading to promote cottonwood establishment along the Truckee River in Nevada (S. Rood, pers. comm. 2002), the role of hydrology and topographic complexity in promoting native riparian vegetation diversity in Colorado and Montana (Scott et al. 1997, 1996; Auble et al. 1997).

In particular, pilot studies designed to test key assumptions and improve our ability to optimize the ecological benefits through managed flow releases are cost-effective, provide valuable data and "lessons learned" to improve larger-scale restoration efforts planned for the future, and are suitable for implementation beginning almost immediately as part of the planned high flow experimental releases. Additional basic monitoring studies and experimental treatments incorporated into any pilot restoration projects planned for the first phase of restoration implementation would also be very valuable. Such pilot studies could help reduce critical uncertainties related to our assumptions about:

- stage-discharge and discharge-inundation area relationships throughout the river corridor,
- surface water and shallow alluvial groundwater dynamics,
- rates of root growth and tolerable rates of water table decline,
- appropriate timing of recruitment flows relative to seed dispersal periods for desired plant species,
- effectiveness of encroachment prevention flows,
- effectiveness of seedbed preparation flows, and
- the interaction of flow management and floodplain reconstruction on restoration success using natural and horticultural revegetation techniques.

Further discussion of these uncertainties and brief descriptions of the types of studies that might be appropriate are presented below. There are other uncertainties that will need to be resolved during more detailed restoration and implementation plan development (e.g., selection of focal species for implementation monitoring, impacts of restoration on non-native invasive species [see Section 3.5 of this Draft Restoration Strategies Report for more specific discussion]).

5.1 Stage-Discharge and Discharge-Inundation Area Relationships

Estimates of natural riparian recruitment expected under the various strategies depend on stage-discharge and discharge-inundation area relationships derived from hydraulic modeling. The hydraulic modeling used in developing the restoration strategies relies on topographic information derived from merging elevation data generated from aerial photogrametry and bathymetry. The spot elevation data from these two sources were then used to create a digital terrain model (DTM) of the 150-mile river corridor. The individual cross sections used in the hydraulic (HEC-2) modeling were generated using the DTM rather than conducting more labor-intensive ground surveys. The accuracy of the DTM-derived cross sections has been assumed adequate for the preliminary, strategic-level planning needed for restoration strategy development. However, we have no precise quantitative estimate of their accuracy relative to traditional, ground-surveyed cross sections, nor do we have estimates of how any errors in cross section data might affect HEC-2 model outputs. Another potential uncertainty relates to the various flow splits among low or high water channels found in some reaches that are not likely to be fully captured by the HEC-2 model. This can affect our predictions of location and area of inundation under various flow scenarios, which in turn affects predictions of fish floodplain rearing habitat or maximum potential riparian seedling recruitment area.

Another critical uncertainty affecting fish habitat and riparian recruitment modeling predictions is the assumption of static channel geometry and stage-discharge relationships for each cross section. We know that channel geometry can change over time, particularly in the sand-bedded reaches under the higher flows anticipated if flood conveyance capacity is increased. Changes in channel geometry, particularly channel incision, could substantially alter stage-discharge relationships and introduce an unknown amount of error into predictions of inundated habitat or recruitable area under various flow scenarios.

As the 1999 riparian flow pilot study (DeFlitch and Cain 2002) and subsequent monitoring have indicated, some of these assumptions will likely need to be corrected as new information is developed, particularly in reaches that have a highly mobile sand bed and/or losing reaches in areas with a depleted groundwater table. The following types of studies are likely to generate useful new information:

- A focused study that could help assess the accuracy of the DTM-based cross sections used in the HEC-2 model, and could be conducted almost immediately to provide data that could help direct the development of the detailed restoration plan. Such a study would involve conducting a ground survey in a short section of Reach 2. The ground survey results would be used to construct accurate topography, which would then be used to rerun the HEC-2 model. In addition, field data on discharge and water surface elevation at the study reach could be collected and used to calibrate the HEC-2 model by adjusting certain parameters (e.g., Manning's n). The accurate topography and calibrated HEC-2 model results would then be used to rerun the San Joaquin River Riparian Recruitment Model. The comparison of the refined riparian recruitment model results and the original model results would provide a valuable accuracy assessment of the original riparian model, and help determine whether the original model results are adequate for restoration plan development or if a revised model incorporating more accurate topographic information, at least at some sites, might be required to improve the detailed restoration plan.
- The above data could also be used to refine the GIS-based analysis of relative elevation zones and predicted areas of inundation under various flows.
- Repeated monitoring of ground-surveyed cross sections before and after experimental high flow releases to detect potential changes in channel geometry under some of the higher flows proposed in the draft restoration strategies hydrographs. The results of the 1999 pilot study indicate a particular need for this type of monitoring in sand-bedded Reaches currently lacking well-developed riparian vegetation because of flow diversions, such as Reach 2. Improving our ability to predict stage changes and area of inundation associated with specific targeted flows in these reaches will help ensure that managed recruitment flows achieve their desired ecological objectives and would allow more accurate estimates of environmental water costs for such actions.
- Conducting more detailed ground surveys in areas subject to flow splits (e.g., high flow channels, back channels, and swales) to assess whether the hydraulic modeling captures the essential patterns of flow and inundation, which in turn determines the potential fisheries habitat and riparian vegetation potential at these sites under different potential flow regimes.
- Conducting additional ground surveys in Reaches under consideration for potential levee setbacks to improve our ability to predict flood control and ecological benefits associated with alternative setback configurations, and compare those benefits with the estimated costs of each alternative.

5.2 Surface water-groundwater dynamics

Although successful germination of native riparian seedlings depends on a variety of hydrologic and geomorphic variables, seedling survival following germination appears to be contingent on constant contact with the water table and/or its capillary fringe throughout the growing season (Mc Bride and Strahan 1984, Stromberg et al. 1991). Research indicates that when the water table decline is more rapid than the rate of root growth, cottonwood seedlings become isolated from their water source, resulting in increased mortality (McBride et al. 1989, Stromberg 1996). In the Central Valley, where instream flows on the mainstem Sacramento and San Joaquin rivers and their tributaries have been highly regulated, the receding limb of spring floods is often abrupt, precluding successful establishment of native riparian seedlings.

Standard approaches for designing environmental flow releases for habitat restoration assume that groundwater levels fall at the same rate as surface water stage, and use river stage patterns to assess groundwater availability for seedlings (see Section 3.5 of this Draft Restoration Strategies Report, Chapter 8 of McBain and Trush 2002, and Stillwater Sciences 2003). Although this assumption may be valid in certain circumstances, it is not likely to be the case along all Reaches of the San Joaquin River where heterogeneous alluvial stratification, complex channel-floodplain geometry, groundwater pumping, and cumulative groundwater depletion in certain areas makes the relationship far more complex. Preliminary data from the San Joaquin River 1999 riparian flow pilot study monitoring conducted in Reach 2 illustrate the complexity of this relationship and clarify the need for further research (NHI 2001, DeFlitch and Cain 2002). In order to design environmental flow releases that optimize both water use and the establishment and maintenance of native riparian species, a better understanding of groundwater dynamics across a variety of different river flow conditions, substrates, and floodplain configurations is necessary.

Across native riparian taxa, seedlings are significantly more susceptible to mortality induced by water stress than mature trees, especially during the first few growing seasons (Smith et al. 1991, Sacchi and Price 1992, Stromberg 1996). Plants whose evaporative water demands are met during the first three growing seasons are more likely to join the population of reproductively mature plants. Furthermore, comparative studies indicate that some non-native invasive plant species tend to be more vigorous and drought-tolerant than natives, and thus better able to compete along reaches with extreme inter- and intra-annual water table fluctuations (Smith et al. 1991, Freidman et al. 1995, Shafroth et al. 1998 and 2000). Thus, in order to restore self-sustaining hardwood riparian forest, we need to better understand the role of groundwater in species survivorship across time and across species.

In addition to the importance of groundwater levels for seedling survival, groundwater levels may play an integral role in determining post-seedling survivorship and riparian community composition (Smith et al. 1991). The role of dry-season groundwater in plant demography is of particular interest along the highly modified rivers of the Central Valley, such as the San Joaquin River above the Merced confluence, where in-stream flow alterations have reduced overbank flows and the resulting floodplain recharge, and modified growing season base flows that often support local groundwater.

Groundwater dynamics have been highly altered by historical and current land and water uses in the San Joaquin River project area. Some reaches that were historically “gaining” reaches are now “losing” reaches. Resumption of perennial baseflows throughout the river corridor, coupled with higher-magnitude flows prescribed for various ecological restoration objectives, will provide additional groundwater recharge compared with current conditions. The ultimate effects of these changes in flow management regime on local and regional groundwater dynamics are unknown, primarily because interactions between surface water and groundwater in the project area are poorly understood (at least at the finer scale that would affect site-specific restoration efforts). For example, in the San Joaquin River Riparian Recruitment Model, a 1:1 relationship is assumed between surface water elevation and the elevation of the shallow groundwater table critical to riparian plants. Deviations from this assumed relationship could cause substantial over- or underestimation of the potential area available for natural recruitment of riparian vegetation. In addition, various desired wetland habitat types require shallow groundwater levels that provide a sufficient duration of surface inundation or soil saturation to establish and maintain desired wetland plants, support aquatic invertebrate production, and support habitat conditions for targeted wildlife species. Additional site-specific information on spatial and temporal variability in surface water and groundwater interactions would be very valuable in moving from conceptual restoration strategies to the development and implementation of a detailed restoration plan.

In addition to having insufficient information on surface-groundwater dynamics to fully assess the feasibility of many of the acreage targets for vegetation habitat types, groundwater conditions will likely change as a result of the restoration of flows in the mainstem San Joaquin River. We expect that groundwater elevations in the immediate vicinity of the mainstem channel will rise with restored, perennial flows in the river. It is currently unknown, however, how far from the river channel groundwater conditions can be expected to rise, and there will likely be considerable local variation. This is confounded in part by the uncertain level of groundwater extraction that currently occurs within the planning area. Significant levels of pumping could create a cone of groundwater depression that will affect the vegetation types that can be established, and therefore estimates of potential vegetation that can be restored.

It will be important to monitor groundwater conditions along the length of the main channel as flow is restored. Initiating a program of synoptic measurements of river stage, groundwater table elevation, and capillary fringe development along both longitudinal (upstream-downstream) and horizontal (channel-floodplain-upland) gradients would be very valuable. Extending the surface water and groundwater monitoring efforts developed for Reach 2 in the 1999 riparian flow pilot study (NHI 2001) to other Reaches as part of this synoptic study would be a logical first step. This would collect more baseline data and provide the foundation for detecting changes in shallow alluvial groundwater dynamics in response to alterations in flow management under the restoration plan. A valuable experiment that could be tied to planned experimental flow releases in the near future would involve releasing a long duration, steady-state base flow into currently dry portions of the channel, while tracking groundwater levels at various distances from the channel, using stage recorders in the channel, groundwater monitoring wells or piezometers on the floodplains, and soil moisture probes to track changes in the capillary fringe zone.

5.3 Seedling root growth rates and mortality rates

In running the SJR Riparian Recruitment Model, we have used maximum growth rate of 0.1 ft/day (or 1.2 in/day) based on values commonly reported in the literature. Numerous studies have reported adequate seedling survival at water table decline rates of 1 to 1.5 in/day (McBride et al. 1989, Segelquist et al. 1991, Mahoney and Rood 1998, Amlin and Rood 2002). In contrast, experiments conducted on newly-germinated cottonwood (*Populus fremontii*) and willow (*Salix gooddingii* and *S. exigua*) by Stillwater Sciences in summer 2002 indicate that actual average root growth rates can be substantially less (0.01–0.02 in/day). In addition, the seed germination studies conducted as part of the 1999 riparian flow pilot study (Wolfe & Assoc. 2000, DeFlitch and Cain 2002) also suggest that root growth rates of young seedlings may be much less than 0.1 ft/day (the 10-day old seedlings that were excavated had roots that were only 0.5 inches long).

The hypothetical wet year recruitment flow hydrographs presented for each of the draft restoration strategies incorporate a period of about a week during which flow would be maintained at a relatively constant or very gradually decreasing level, to allow for seeds on target recruitment surfaces to become saturated, germinate (typically within 24–48 hours) and initiate root growth. The potential for physiological stress and mortality of seedlings following this period depends on a variety of factors, including: age- or size-dependent seedling root growth rates, the rate of river stage decline as flows decrease, the interaction between river stage and shallow alluvial groundwater level with distance from the channel, and soil texture and the depth of the capillary fringe zone. The effects of rapidly declining river stage may be buffered in gaining reaches where other sources of groundwater can help maintain soil moisture available to growing seedlings. A well-developed capillary fringe zone can also serve to buffer adverse effects of rapid stage declines, at least in the short term, by maintaining available soil moisture within the seedling root zone even when groundwater levels may be dropping below the root zone.

Additional studies to help resolve uncertainties about root growth rates and the capillary fringe zone might include:

- Additional experimental laboratory or greenhouse studies to test seedling root growth rates, physiological stress, and mortality under various rates of declining water table and soil texture conditions more closely matching conditions in the targeted Reaches of the San Joaquin River, using a factorial design experiment and methods similar to McBride and Strahan (1984), Amlin and Rood (2002), and Stillwater Sciences (2003).
- In situ (field-based) monitoring of seedling density, growth rates, and survival following experimental recruitment flows (similar to the 1999 riparian flow pilot study in Reach 2 [DeFlitch and Cain 2002], but expanded to include other Reaches as well). In particular, monitoring of seedlings of known age and periodic sacrificial sampling (by careful excavation) at 1–2 week intervals throughout the first (and possibly the second) growing season to measure root growth would provide valuable, site-specific data that could be used to adjust the rate of acceptable stage decline during the recession limb of recruitment flow hydrographs.
- Monitoring of the capillary fringe zone in response to varying water table levels and soil texture could be combined with either of the two studies described above to better understand how seedlings at sites with more developed capillary fringe zones might be able to withstand more rapid rates of stage decline.

The results of such studies should be useful in developing reach- and site-specific restoration actions using both passive and active revegetation approaches.

5.4 Timing of riparian recruitment flows and seed availability

Restoration of self-sustaining riparian forests along the San Joaquin River will require designing stream hydrographs with appropriate timing, magnitude, and duration to ensure that flows facilitate recruitment of riparian vegetation, foster seedling survival, maintain a diverse and complex species composition and stand structure, and support natural succession of native woody riparian species. The competing demands for and high cost of water in the planning area necessitate that biological responses to environmental conditions be understood adequately to ensure the most efficient allocation and timing of flows. In other words, flow releases need to be timed to coincide with the appropriate life-history stages of riparian plant species (i.e., when the maximum amount of viable seed of the desired target species is available) to obtain maximal benefits of increased water releases.

Seed release timing (a function of fruit maturation and capsule dehiscence) in conjunction with flow patterns largely determine natural recruitment success and survival for riparian plant species, and thus affect the composition and condition of riparian forests. For willows and cottonwoods, whose seeds are viable only for several weeks, seed release must coincide with wet conditions and seedbed availability to produce a successful cohort. Appropriate flow timing is therefore the first condition necessary for a successful recruitment flow, and constraining flood timing will conceivably benefit some species over others.

Climatic and other physical factors affect the timing of seed release for pioneer riparian species such as cottonwoods and willows. For cottonwoods and willows, spatial/temporal variability in peak seed dispersal is potentially affected by photoperiod, temperature, relative humidity, and/or genetics. Photoperiod and temperature change with latitude and elevation, and presumably affect the maturation of cottonwood fruit. Less clear are the influences that relative humidity exerts on fruit maturation and capsule dehiscence, or that genetics exerts on seed dispersal timing.

Photoperiod, latitude/elevation, and relative humidity are all linked to temperature, which controls the development of many organisms. Plants and some animals require a certain cumulative quantity of heat to develop from one life stage to another (e.g., the amount of heat required to flower, develop, and disperse seeds). The measure of accumulated heat is known as "physiological time" and is a common developmental reference for plants because the amount of heat required to reach the next life stage does not vary (Wilson and Barnett 1983, Zalom et al 1983). Physiological time is often quantified using the degree-day, which is a measure of the departure of the mean daily temperature from a lower and sometimes upper developmental threshold. Each species has its own specific requirement for the number of degree-days needed to reach another developmental stage (e.g., fish emergence, insect pest emergence, or seed dispersal [Wilson and Barnett 1983, Zalom et al. 1983]).

Generalized seed dispersal periods are graphed in Figures 8-36 through 8-39 of the Background Report (McBain and Trush 2002) and proposed recruitment flow timing is discussed in Section 3.5.3.4 of this Draft Restoration Strategies Report, but these assumptions are based on spatially and temporally limited field data, and several key uncertainties remain. Additional data are necessary to more completely define the average peak seed release and viability periods for key pioneer species (cottonwood, black willow, narrow leaf willow, and arroyo willow) and the between-year variability in these periods of seed availability, and to determine whether seed availability is a limiting factor in certain reaches. In addition, the 2002 seed release phenology studies (Stillwater Sciences 2003, and summarized in Chapter 8 of McBain and Trush 2002) indicate that cottonwood trees at some sites (e.g., the Firebaugh study site in Reach 3) exhibit a wider range of seed release patterns. This variation among reaches may have important implications for the timing of recruitment flows targeted at specific reaches. Although willow and other native plant species are important for diversity and complexity, we propose that the adaptive management approach be focused initially on addressing data gaps for cottonwood, with more limited data gathering on willow species. Among willow species, the most attention should be given to arroyo willow, which has the most limited dataset specific to the San Joaquin River.

The key uncertainties to address are:

- the year-to-year variability in peak seed release timing,
- variation in seed release timing among reaches,
- whether this variability can be predicted using more widely available data on physical variables such as local weather conditions (e.g., degree-day modeling), and
- whether seed itself is limiting in certain reaches.

An additional year of phenological study, following the approach described in the Background Report (McBain and Trush 2002, Figures 8-36 through 8-39), would be a reasonable minimum effort to address uncertainties of year-to-year and reach-by-reach variation in seed release timing (and to collect local temperature data). If seed release is shown to be highly variable, the ability to correlate it with more easily measurable and available weather data would allow increased predictability and, therefore, fine tuning of timing of flow releases to promote natural recruitment. If there appears to be a large amount of annual variability in seed release timing, several more years of focused data collection might be warranted to provide the data needed to develop accurate predictive models.

The ability to correlate seed dispersal timing with variables (e.g., temperature and relative humidity) that are widely monitored, are established as mechanisms for biological development, and can be measured and evaluated remotely (by following weather station data), should result in an accurate predictive seed dispersal model that can be readily applied to flow management. As a result, managed recruitment flows would be released with the highest certainty that regeneration and subsequent recruitment would occur on suitable floodplain surfaces, ensuring the most efficient allocation and timing of flows.

In addition to more accurately defining the window within which flow releases are most likely to achieve the highest recruitment benefit, additional field studies are needed to identify any areas within the planning area where existing seed availability is limited. Although the DWR mapping (CDWR 2001) provides a general overview of the distribution of vegetation types along the river corridor, strategic field surveys would help identify areas that would benefit from active (horticultural) restoration to provide an initial seed/propagule source to speed up the restoration process (i.e., a “jump start” to facilitate a more rapid natural revegetation approach). Pilot-scale experiments could be performed in areas where mature trees are not available to test whether cuttings of mature branches would establish quickly enough to provide an initial seed source, or whether more intensive restoration efforts would be necessary (e.g., planting from seed or container stock). The density and spacing of “source” trees may also be important and could be evaluated as part of a pilot study.

Although cottonwood is proposed as the primary target species for the initial restoration effort, a major objective is to increase the diversity of native riparian species and vegetation types. Pilot experiments should also include testing the effectiveness of planting more diverse patches of riparian trees and understory species as a means of more rapidly achieving the desired restoration condition.

5.5 Managing flows for seedbed preparation, encroachment prevention, and long-term disturbance regime

High flows can be used to promote natural disturbance processes that initiate riparian revegetation, reduce the risk of riparian encroachment into the active channel, and help maintain a diverse assemblage of riparian vegetation patches with different ages, structure, and floristic composition.

Scour of vegetation and deposition of sediment on floodplains provides substrate patches needed for riparian colonization, which can facilitate development of structural and age diversity in the riparian community. For example, the availability of saturated, bare mineral substrates at the right times is critical for the establishment of willow and cottonwood seedlings. Floodplain scour and sediment deposition are both affected significantly by local hydraulic conditions, making it difficult to predict the quantity and distribution of surfaces that will be created to support vegetation colonization.

Floodplain sediment deposition is a function of sediment supply, grain size distribution, and local shear stress, which is both spatially and temporally variable. Preliminary geomorphic sediment transport analysis of the San Joaquin River suggests that sand and fine sediment will mobilize at modest flows (approximately 500 – 1,000 cfs), even in pools in Reach 1 where shear stresses are lower than in riffles. While we can expect that fine sediment will be mobilized from upstream sources, thereby making it available for deposition on the floodplain, the rate of such deposition is expected to be low because most of the fine sediment will be moving as bedload rather than as suspended load. Further study and field monitoring is needed to better quantify the floodplain deposition rate and the effect of deposition on vegetation colonization.

If flow management and sediment transport are insufficient to create the desired quantity and spatial-temporal distribution of seedbeds for cottonwoods and willows, it may be necessary to use mechanized disturbance of target areas to remove existing weedy vegetation and expose appropriate bare substrates prior to a targeted riparian establishment flow. Improving the understanding of sediment dynamics would allow a better estimation of the costs and relative merits of natural versus active disturbance approaches.

Encroachment prevention flows may achieve their purpose by causing mortality of seedlings on lower surfaces (e.g., channel bars) due to scour, inundation or sediment deposition. Constraints of managed flow releases at Friant Dam would likely limit the effectiveness of encroachment flows in the gravel substrates of Reach 1. In the sand-bedded reaches (Reaches 2 – 5), we assume that encroachment prevention flows of 5,000 cfs are likely to achieve the desired objectives. Observations made of the effects of winter 2000 flows (which peaked at 2,100 cfs at the Gravelly Ford gauge) on seedlings established during the 1999 riparian flow pilot study indicated that limited scour, channel movement, and sand deposition did occur in association with these flows, causing some mortality of the 1-year-old seedling cohort (JSA 2000, Appendix J in DeFlitch and Cain 2002). These same flows, however, had little effect on older cohorts (2-years or older) of seedlings, suggesting that substantially higher flows are likely needed to achieve the desired level of control over woody plants encroaching onto active channel surfaces. We currently have no other river-specific data on seedling mortality related to high flows.
However, observations made along the sand-bedded reach of the lower Tuolumne River in 2002 suggest that 3,500 cfs peak flows were sufficient to kill seedlings within 2 ft vertical elevation of summer baseflow water surface through scour, sediment deposition (up to 0.5 ft of sand deposited in some sites), or prolonged inundation (Stillwater Sciences, unpublished data). This zone of seedling mortality roughly corresponds to the zone in which we hope to prevent or minimize encroachment.

Based on the Tuolumne River observations, and an added "margin of safety," we have assumed that 5,000 cfs flows should be capable of preventing or greatly reducing encroachment by woody vegetation. This assumption needs to be confirmed through monitoring and adaptive management. One approach would be to plant cottonwood and willow seedlings (and possibly other species that might encroach on the channel, such as alder in Reach 1) of different ages (from a few months to 2 or 3 years old) along an elevation transect perpendicular to the main river channel in a few key sites (either in each Reach, or in Reaches of particular interest such as Reaches 1 and 2). Seedling density, height, and general health should then be monitored before and after planned flows that exceed 2,000 cfs to document effects of flows of various magnitudes on seedling health and survival. It would be best to conduct such monitoring of seedlings in conjunction with monitoring of physical factors, to document the magnitude and location of any channel migration, scour, and sand deposition associated with the high flows. This would provide a better linkage of flow with physical factors that would be the proximate causes of mortality or other adverse impacts on seedlings (and of positive effects on riparian recruitment related to creation of new seedbed surfaces) (see Section 6 for more on the physical factor monitoring component).

5.6 Effectiveness of passive (natural) versus active (horticultural) revegetation approaches

The magnitude of the San Joaquin River Restoration project and the likely cost of such an effort warrant the development of a series of pilot projects to assess the most promising and efficient means of vegetation restoration within each Reach of the San Joaquin River. Such a study might consist of multiple factorial experiments that test the effects of site design factors and planting treatments on the survival and growth of native riparian tree seedlings at a representative site (or sites) in each reach. Ideally, the experiments should compare the relative costs and benefits of various methods, such as:

- flow management to promote natural revegetation processes;
- floodplain regrading to promote natural revegetation processes and to create topographic complexity that favors a more diverse mixture of vegetation types (this could include creating back channels and swales of various depths for recruitment of cottonwoods or wetland species, and creating areas of higher-elevation soils in some sites to promote successful establishment of species such as valley oak);
- floodplain regrading to facilitate successful planting of desired species and to reduce irrigation needs during the establishment period by reducing depth to groundwater;
- various means of regeneration via seed (e.g., natural seed recruitment versus active seeding with and without fertilizers or other soil amendments);
- planting seedlings propagated from local sources;
- planting cuttings;
- various weed control methods (e.g., mechanical control, mulching, herbicides, seeding with native species); and
- planting or seeding native understory species.

To date, research on propagation and survival of native Central Valley species has focused on Fremont cottonwood, various willows (McBride and Strahan 1984; McBride et al. 1989; Stromberg 1997, 1998), and valley oaks (CNPS 1989, as cited in CALPIF 2002; Griggs and Golet 2002; McCreary 1990). Using this research as a starting point, we propose a study that would evaluate establishment success on targeted surfaces (e.g., regraded floodplain surfaces, former agricultural fields included in levee setback areas, dredge materials from channel reconstruction, surfaces currently dominated by non-native herbaceous grasses and forbs, sites in which non-native invasive species such as giant reed or scarlet wisteria have been removed by mechanical or chemical treatment), overwinter survival, and ecophysiological requirements of several native tree species that are key components of Central Valley mixed riparian forests and that have demonstrated different life history traits and a range of geomorphic establishment positions on river banks and floodplains (see Section 3.5 of this Draft Restoration Strategies Report and Stillwater Sciences 2003). A suitable preliminary design might include planting seeds and seedlings of four species: Fremont cottonwood, Oregon ash, box elder, and valley oak (although the species mix might vary by site or reach based on restoration objectives). Establishment success could be evaluated using several criteria, potentially including seedling survival and growth after one year (and longer, although the number of year of monitoring would be governed, at least in part, by the schedule for making decisions on larger-scale restoration plants), xylem water potential or other ecophysiological measures, and cover of native versus non-native vegetation. It would also be valuable to include treatments with and without native understory species to determine if restoration of more diverse and complex habitats can be achieved more quickly than if initial restoration efforts focus only on overstory species.

Prior to and during the proposed experiment, several physical site factors would be measured, such as soil texture (by sieving bulk samples at several locations), soil chemistry (particularly soil salinity), groundwater depth (using piezometers), and river stage (using a pressure transducer and staff gauge). Experimental blocks could be established on cleared floodplain areas that have been graded to two different elevations that represent two water table depths. Some plots at both elevations would be left fallow and would not be irrigated to test the relative effects of recruitment by natural seed dispersal versus direct plantings (seeds and seedlings) on vegetation cover and composition after one year (or several years). Results of this comparison would provide a basis for evaluating passive restoration strategies and the cost, scope, and feasibility of large revegetation projects throughout the river corridor. Within the seeded and seedling-planted blocks, irrigation (using a drip hose or similar system) and mulch treatments would be conducted and results on plant growth and survival assessed. For cottonwood (and willows if they are included in the experimental mix), live cuttings should be substituted for seedlings because of difficulties collecting and germinating seeds during the short-lived seed release and viability window.

5.7 Elevational Patterns of Plant Species Distributions

In many riparian and wetland ecosystems, vegetation along river banks demonstrates non-random patterns of species distributions, which are the result of complex interactions between physical disturbance regimes and species' individual tolerances (e.g. to flooding and scour), life history characteristics (e.g. willows and cottonwoods are phreatophytic, meaning their roots must maintain contact with a perennial water source), and competitive interactions (McBain and Trush 2002). Many studies have documented associations between riparian vegetation assemblages and fluvial landforms in an attempt to provide templates for gradient analysis or restoration (Harris 1987, Hupp and Osterkamp 1985, Osterkamp and Hupp 1984). However, classifying plant habitats by geomorphic surface can be somewhat arbitrary and observer-dependent, and in heavily modified rivers such as the San Joaquin, fluvial landforms may be relicts of past hydrogeomorphic regimes. In such cases a readily measurable and relevant factor to study is the elevation at which native riparian and wetland plants have become successfully established (under the contemporary flow regime) relative to the elevation of the river's water surface during base flow conditions at the end of the summer growing season.

Previous work on the Merced River documented elevational zonation of riparian plant species, and pilot analyses indicated that these differences can be quantified in terms of hydrologic variables that apply across sites and potentially across rivers (Stillwater Sciences 2001a, 2001b, 2003). These variables can be powerful general predictors of long-term vegetation response to flow conditions and can be useful guides for prescribing flow regimes and designing floodplain restoration projects. Inundation duration, a physical variable that can be calculated for individual tree locations from site hydraulic modeling and historical hydrologic data, is a particularly promising and robust measure to quantify species' occurrences within riparian zones (Auble et al. 1994). However, elevation above summer baseflow is a more readily measured variable that can be used as a surrogate for hydroperiod variables such as inundation duration (Mahoney and Rood 1998, Stillwater Sciences 2003). Sampling vegetation and elevation transects at representative sites in each Reach would help validate the GIS-based analysis of restoration potential (especially for wetlands in Reach 2) and the results of the SJR Riparian Recruitment Model, and confirm the applicability of the Merced River data to San Joaquin River restoration planning (or provide San Joaquin River specific data if the Merced River data do not appear to be applicable).

One of the necessary subtasks of this approach would be to determine the age of the riparian vegetation studied to ensure that it established under the current flow regime. An initial, coarse-level assessment of elevational patterns of riparian plant species on the San Joaquin would be conducted using the GIS to assign relative elevations to each CDWR (2001) vegetation plot, and then analyzing the distribution of both individual plant species and vegetation types along an elevational gradient (elevation relative to baseflow or presumed groundwater level). The results of such an analysis could be used to help focus the field surveys proposed above.

5.8 Riparian and Wetland Restoration Targets in Reaches 4 and 5

Developing appropriate restoration targets and actions for riparian and wetland vegetation and wildlife habitat in Reaches 4 and 5 is constrained by a number of uncertainties underlying the results of the hydraulic modeling, riparian recruitment modeling, and GIS-based restoration potential modeling that were an integral part of the draft restoration strategies development. In addition, uncertainties over the likely effects of proposed restoration hydrographs on water quality in these reaches further confounds our ability to predict the likely restoration potential for various plants and animals, particularly those most affected by salinity, selenium, boron, and anthropogenic nutrients.

The limitations of the HEC-2 modeling in the downstream portion of Reach 4B2 and Reach 5 create uncertainties regarding the actual range of hydroperiod conditions that would be created under the restoration plan. Because cross sections end at arbitrary points along the left bank floodplain due to the limited extent of the DTM data rather than at a specific physical barrier to flow (such as a levee, berm, or natural transition to upland), and the presence of several natural sloughs and agricultural return flow inputs in this region, the currently predicted stage-discharge and discharge-inundation area relationships for release flows from Friant Dam are undoubtedly inaccurate, but to an unknown degree. Uncertainty in the HEC-2 output (and in surface water – groundwater relationships) also directly increases the uncertainty in the San Joaquin River Riparian Recruitment Model and GIS model outputs of inundation and elevation relative to a particular base flow water surface. It is possible that prolonged inundation of many floodplain surfaces could limit the potential to recruit native woody riparian vegetation in these areas.

The lower reaches of the project area are currently considered to be impaired with regard to various water quality constituents, such as salinity, selenium, boron, and nutrients (see Chapter 6 of McBain & Trush 2002). Desired species of native woody riparian trees and shrubs, such as cottonwood and black willow, are known to be fairly intolerant of salinity, selenium, and boron. Elevated levels of nutrients are known to increase the risk of invasion by some undesirable, non-native plant species under certain conditions (Cox 1999). It is expected that re-establishment of perennial base flow, combined with more frequent peak flows to meet fisheries and riparian objectives, would also provide some level of water quality improvement in Reach 4 and 5, although the level of likely improvement is currently unknown. Therefore, it is currently unknown to what extent salinity, selenium, boron, or competition from non-native plants adapted to high nutrient levels might limit the potential for establishment of native woody riparian vegetation in these reaches.

Thus, while increased base flows and peak flows similar to those proposed in the draft restoration strategies would undoubtedly provide many benefits to natural aquatic, wetland, and riparian communities, the currently available tools do not allow us to state with confidence what the appropriate restoration targets should be or to predict how the make-up of vegetation types and wildlife habitats might differ under various restoration scenarios. Standard baseline and trend monitoring of water quality, surface water elevation, and groundwater level will help reduce some of these uncertainties but it might require many years of monitoring after the restoration plan flow management regime is implemented to generate sufficient data to resolve key uncertainties. Implementing such a monitoring program soon might allow proposed experimental high flow releases to be used to generate valuable data much faster.

In addition, a controlled experiment using planted seedlings and saplings (propagated from local stock to preserve genetic traits of local populations) of a variety of potential target riparian and wetland plant species could be used to generate project-specific data on plant tolerances to different environmental factors (e.g., salinity, boron, duration of inundation). One potential design involves the use of horticultural restoration techniques to establish seedlings, cuttings, or saplings of various species along a topographic (elevational) gradient at various locations on the main channel and on sloughs, oxbows, and assorted floodplain surfaces. The growth, survival, and indicators of general health of these seedlings would then be periodically monitored, along with selected environmental parameters (soil texture, moisture, pH, and salinity; water chemistry; river stage and groundwater elevation) to see which plants seem best adapted for certain sets of environmental conditions. Monitoring before and after initial high flow experimental releases should provide valuable data for refining restoration targets and actions in these reaches.

6 FLUVIAL GEOMORPHIC UNCERTAINTIES

6.1 Monitor bed mobility in Reach 1

Chapter 3.1 of the main report describes how much of the channel bed in Reach 1 is unlikely to be mobilized by flow releases from Friant Dam, principally because of the low channel gradient in Reach 1. Gravel that is scoured from sections with locally high gradients will likely deposit in pools, where it will be trapped and unavailable to replenish downstream riffles, except at extremely high and rare flow events. This conceptual model of sediment transport dynamics in Reach 1 is based primarily on sediment transport analysis and modeling that used a series of assumptions and the limited data that is currently available. To help test these assumptions, it will be important to monitor potential bed mobility for a variety of geomorphic surfaces within Reach 1, including riffles, point bars, pools, and pool tails. It will also be important to conduct this monitoring in sub-reaches that have different valley slopes. With the collection of additional data, more sediment transport modeling can be conducted to refine our current understanding of the potential for bed mobilization and scour in Reach 1. If bed mobility and scour thresholds are lower than currently predicted, than this could necessitate re-evaluation of the three restoration strategies.

There are a number of methods that can be employed to monitor bed mobility. Ground-surveyed cross sections can help track changes in bedform associated with bed mobilization and scour. The deployment of tracers, in conjunction with different levels of flow releases, can also help identify bed mobility thresholds. Radio-tagging and tracking of rocks can also be used to determine bed mobility thresholds. The placement of scour cores and scour chains can help indicate what flows are required to induce bed scour. Much of the data collected through this field monitoring can be used as input for additional sediment transport modeling, and it can also be used to calibrate sediment transport models.

Another useful complement to the field investigations described above is bulk sampling of the channel bed in different parts of Reach 1, which would support a better understanding of the character of the gravel supply stored in Reach 1.

6.2 Monitor bed mobility at potential spawning sites

Chapter 3.1 of the main report also describes how the channel bed will likely be mobilized at some locally high-gradient sections of Reach 1. Many of these locations may provide suitable spawning habitat for restored populations of salmon. If the release of higher flows scours gravel from these riffles, and if these riffles are not replenished with gravel from upstream reaches because sediment is trapped in pools in Reach 1, then gravel supplementation would be necessary to preserve or enhance the spawning habitat quality. However, gravel that is placed on riffles may also be mobilized by subsequent high flow releases, resulting in the need for periodic recharging of riffles with gravel. Developing a better understanding of local bed mobilization and scour at potential spawning riffles will help support the development of a long-term gravel management plan for Reach 1, so that the volume and periodicity of gravel supplementation efforts can be clear. The methods used to monitor bed mobility and scour at potential spawning sites are the same as those described above in Section 6.1 of this appendix.

6.3 Monitor delivery of fine sediment to Reach 1

Reconnaissance-level field investigations suggest that there is a significant volume of sand stored in the channel in Reach 1, primarily in pools. The source of this fine sediment is unclear. As the only significant tributaries in Reach 1, Cottonwood and Little Dry creeks are potential sources. Both of these tributaries could be monitored to estimate their importance as a source of fine sediment to the mainstem channel. If Cottonwood and Little Dry creeks are significant sources of fine sediment, then monitoring could also help determine if the delivery of sediment to the mainstem channel is continual or episodic.

As a preliminary analysis, it may be possible to conduct an analysis of aerial photographs to identify potential sediment sources in Reach 1. This analysis would involve finding and comparing two sets of aerial photos. One photo set would be following a period of high flow releases from Friant Dam. The other photo set would be selected following a water year in which there was significant precipitation in the basin below Friant Dam, but little flow release from Friant Dam. The goal of this analysis would be to see whether sand deltas are formed at tributary confluences during years when flow was high in the tributaries, but flow releases from Friant Dam were low.

Another potential monitoring method would involve digging sediment traps at the confluence of each tributary, and monitoring how quickly each pit fills, and correlating the pit filling rate with discharge data.

6.4 Monitor fine sediment mobility in Reach 1

Chapter 3.1 of the main report describes how the release of higher flows will likely mobilize and scour sand in Reach 1, even from pools. With the increased flow after restoration, the fine sediment storage in Reach 1 should gradually decrease in time, and reach a new equilibrium. The reduced fine sediment storage in Reach 1 would likely help reducing fine sediment infiltration in riffles during higher flow events. Continuously monitoring fine sediment storage in Reach 1 would help us define whether the new equilibrium state is achieved. In addition, identifying what flow is required to mobilize fine sediment from pools would help to refine hydrograph components to improve their fluvial geomorphic benefits.

6.5 Monitor fine sediment infiltration of framework spawning gravels

Much of the sand that is mobilized and transported in Reach 1 will likely move as bedload; consequently, it is possible that some of this sand will infiltrate framework spawning gravels on riffles, thereby reducing permeability and spawning habitat quality. To help assess the potential for sand to infiltrate spawning gravels, an experiment can be conducted using infiltration bags. Infiltration bags are collapsible bags that are buried in spawning gravels that have been cleaned of sediment that is less than 2 mm in diameter. Following high flow events, the bags can be retrieved and the sediment contained with them can be sorted to isolate the fraction of sediment less than 2 mm in diameter that has been introduced to the substrate from flow events. Determining the rate at which sand infiltrates framework spawning gravels can support an assessment of the duration of habitat benefits that can result from efforts to improve spawning gravel quality, such as the introduction of clean spawning-sized gravels and various methods of mechanical riffle-cleaning.

6.6 Monitor channel migration rates in Reaches 2 through 5

The sand-bedded reaches of the San Joaquin River may experience channel migration as high flows are released, as sediment supply is restored, and as a floodway is dedicated to provide space for the restoration of fluvial geomorphic processes. Reach 2, in particular, likely has the best potential for restoring channel migration. However, it is not clear what flows will be capable of initiating channel migration. As high flows are released to achieve other restoration objectives (e.g., riparian recruitment flows), channel migration should be monitored to understand the relationship between migration rates and discharge. Developing a better understanding of the relationship between discharge and channel migration rates could support the refinement of hydrograph components to improve their fluvial geomorphic benefits. Channel migration rates can be monitored using a time series of aerial photographs, as well as bank erosion monitoring sites.

6.7 Monitor suspended sediment concentrations

The channel will likely be re-connected to a portion of its former floodplain in many of the reaches, and with the release of overbank flows, it may be possible to stimulate floodplain building if there is a sufficient supply of suspended sediment. To develop a better understanding of the potential for restoring floodplain-building processes, especially in the sand-bedded reaches, suspended sediment concentrations could be monitored. Such monitoring could involve deploying suspended sediment instrumentation from bridges throughout the planning area during high flow events.

6.8 Sediment continuity and channel adjustment

Several bifurcation structures and dams may disrupt sediment continuity in the sand-bedded reaches (i.e., Reaches 2 through 5). Dams trap sediment in the pools and, in some cases, periodically release the trapped sediment as a pulse. Bifurcation structures split water and sediment into two or more channels. Because of the non-linear relation between sediment transport and discharge, the combined sediment transport capacity downstream of the bifurcation structure does not necessarily equal that upstream, resulting in channel adjustment. It is expected that the channel will be able to adjust itself to accommodate the structures and dams in time. These issues are discussed in more detail in Sections 3.1.2 and 3.1.3 of this Draft Restoration Strategies Report.

Because of the uncertainties over the effectiveness of restoration plan implementation in restoring sediment continuity and promoting channel adjustment to achieve a new quasi-equilibrium state, it is necessary to establish a monitoring program to characterize baseline conditions and document changes in channel morphology near dams and structures after implementation of the restoration plan. Such a monitoring program could be used to gauge the degree and rate of channel adjustment and to indicate whether human intervention (such as dredging) is needed. Because different reaches usually have different hydrologic conditions and/or channel morphologies even without structures, representative stations should be established in each of the sand-bedded reaches, including monitoring stations at junctions of adjacent reaches even if there are no associated structures. The proposed newly constructed channels (e.g., Reach 4B1) present other places where active channel adjustment should occur, and thus, they too should receive focused monitoring and assessment after the implementation of the restoration plan.

In addition to field-based monitoring associated specifically with structures or junctions, aerial photographs should be taken periodically (e.g., every other year and after larger controlled or uncontrolled releases in wet years) for the entire length of the sand-bedded reaches and cross section surveys should be done at regular intervals (e.g., every 1 to 2 miles) at permanently monumented stations along the river every few years. The aerial photograph analysis, cross-section surveys, and reconnaissance-level assessments of channel conditions in the vicinity of the cross-section stations, along with the focused monitoring near instream structures and junctions, should provide information on how the river responds over time to the restoration actions (i.e., channel migration and other planform changes such as channel widening or narrowing, changes in width:depth ratio and habitat complexity, changes in in-channel storage elements, incision or aggradation) and help the management team to decide whether any intervention should be taken if any potential problem surfaces.

Monitoring cross sections established for sediment continuity and monitoring channel adjustments could also be extended across the floodplain and used as part of a program to assess scour and deposition on floodplain surfaces. Deposition on these surfaces is important for establishing new seedbed areas and generating localized disturbances that can restore a more dynamic, self-sustaining riparian ecosystem supporting a mosaic of different vegetation types, including patches of various ages, structural complexity, and floristic composition (see Appendix I, Section 5 for discussion of uncertainties and monitoring focused on riparian and wetland vegetation and wildlife habitat).

7 REFERENCES

Abell, D. L., Ed. (1989). Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990s. General Technical Report PSW-110, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

AMFSTP (Adaptive Management Forum Scientific and Technical Panel). 2001. Lower Tuolumne River Adaptive Management Forum Report. USFWS Anadromous Fish Restoration Program and CALFED Bay-Delta Program

AMFSTP (Adaptive Management Forum Scientific and Technical Panel). 2002. Merced River Adaptive Management Forum Report. USFWS Anadromous Fish Restoration Program and CALFED Bay-Delta Program

Amlin, N.M. and S.B. Rood. 2002. Comparative tolerances of riparian willows and cottonwoods to water-table decline. Wetlands 22(2).

Auble, G. T., M. L. Scott, J. M. Friedman, J. Back, and V. J. Lee. 1997. Constraints on establishment of plains cottonwood in an urban riparian preserve. Wetlands 17: 138-148.

Auble, G.T., J.M. Friedman, and M.L. Scott. 1994. Relating riparian vegetation to present and future streamflows. Ecological Applications. 4(3): 544-554.

Bams, R. A. 1985. Comparison of three instream incubation techniques for coho salmon. North American Journal of Fisheries Management 5: 159-172.

Baxter, R. 2000. Splittail and longfin smelt. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 13: 19-21.

Baxter, R. D. 1999. Splittail abundance and distribution update. Accessed on February 27, 2003 at http://www.delta.dfg.ca.gov/reports/splittail/.

Bernatchez, L., and J. J. Dodson. 1987. Relationship between bioenergetics and behavior in anadromous fish migrations. Canadian Journal of Fisheries and Aquatic Sciences 44: 339-407.

Brett, J. R., J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. Journal of the Fisheries Research Board of Canada 26: 2363-2394.

CALFED. 2003. Abstracts from the CALFED Science Conference: Advances in science and restoration in the bay, delta, and watershed. Second Biennial CALFED Science Conference. January 14-16, 2003. Sacramento, CA.

CalPIF (California Partners in Flight). 2002. The oak woodland bird conservation plan: A strategy for protecting and managing oak woodland habitats and associated birds in California. Version 2.0. S. Zack, lead author. Point Reyes Bird Observatory, Stinson Beach, CA. http://www.prbo.org/calpif/plans.html.

CDWR (California Department of Water Resources). 2001. RE: Transmittal of Indicators of Hydrologic Alteration data files on CD-ROM, Memorandum to Glenn Pearson from Stacy Cepello and Shawn Pike, CDWR, Sacramento, California. 23 February.

CFGC (California Fish and Game Commission). 1921. Twenty-sixth biennial report for the years 1918-1920. CFGC, Sacramento.

Clark, G. H. 1942. Salmon at Friant Dam-1942. California Fish and Game 29: 89-91.

Clarke, W. C., J. E. Shelbourn, and J. R. Brett. 1981. Effect of artificial photoperiod cycles, temperature, and salinity on growth and smolting in underyearling coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*), and sockeye (*O. nerka*) salmon. Aquaculture 22: 105-116.

Cox, G. 1999. Alien species in North America and Hawaii: impacts on natural ecosystems. Island Press, Washington D.C.

DeFlitch, D. and J. Cain. 2002. 1999 San Joaquin River riparian flow release pilot project. Prepared by Friant Water Users Authority and Natural Heritage Institute for Friant Water Users Authority, Lindsay, CA, and Natural Resources Defense Council, San Francisco, CA.

Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11: 179-190.

Freidman J. M., M. L. Scott, W. M. Lewis, Jr. 1995. Restoration of riparian forest using irrigation, artificial disturbance and natural seed fall. Environmental Management 19 (4): 457-557.

Golet G.H., M.D. Roberts, D.R. Peterson, D.E. Jukkola, E.E. Crone, G.R. Geupel, S.L. Small, S.E. Greco, K.D. Holl, E.W. Larsen, F.K. Ligon, B.K. Orr, J.C. Vick, M.E. Power, W.E. Rainey, J.G. Silveira, D.S. Wilson. [In press]. Using science to evaluate restoration efforts and ecosystem health on the Sacramento River Project, California. In: Faber, P.M., editor. Proceedings of the Riparian Habitat and Floodplains Conference. The Western Section of the Wildlife Society and the Riparian Habitat Joint Venture, March 12-15, 2001, Sacramento, CA.

Griggs, F. T. and G. H. Golet. 2002. Riparian valley oak (Quercus lobata) forest restoration on the Middle Sacramento River, California, USDA Forest Service: 8.

Griggs, F.T. and T. Sperber. 2003. The interaction of biological and physical processes and the long-term survival of riparian forests at the San Joaquin River National Wildlife Refuge. Second Biennial CALFED Science Conference. January 14-16, 2003. Sacramento, CA.

Hallock, R. J., and W. F. Van Woert. 1959. A survey of anadromous fish losses in irrigation diversions from the Sacramento and San Joaquin Rivers. California Fish and Game 45: 227-296.

Harris, R. R. 1987. Occurrence of vegetation on geomorphic surfaces in the active floodplain of a California alluvial stream. The American Midland Naturalist 118(2): 393-405.

Hatton, S. R., and G. H. Clark. 1942. A second progress report on the Central Valley fisheries investigations. California Fish and Game 28: 116-123.

Hayes, J. W. 1987. Competition for spawning space between brown (Salmo trutta) and rainbow trout (S. gairdneri) in a lake inlet tributary, New Zealand. Canadian Journal of Fisheries and Aquatic Sciences 44: 40-47.

Hupp, C. R. and W. R. Osterkamp. 1985. Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. Ecology 66(3): 670-681.

Jones & Stokes Associates, Inc (JSA). 2000. Results of riparian tree seedling monitoring on Reach 2 of the San Joaquin River, Gravelly Ford to Mendota Pool. May 2000. Sacramento, CA. Prepared for Friant Water Users Authority, Lindsay, CA, and Natural Resources Defense Council, San Francisco, CA.

Mahoney, J. M. and S. B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment--an integrative model. Wetlands 18: 634-645.

McBain & Trush, Inc. (eds.). 2002. San Joaquin River Restoration Study Background Report. Prepared for Friant Water Users Authority, Lindsay, CA, and Natural Resources Defense Council, San Francisco, CA.

McBain and Trush. 2000. Habitat restoration plan for the lower Tuolumne River corridor. Prepared for Tuolumne River Technical Advisory Committee (TRTAC) by McBain and Trush, Arcata, with assistance from U. S. Fish and Wildlife Service Anadromous Fish Restoration Program (AFRP).

McBain and Trush. 1998. Tuolumne River corridor restoration plan, Stanislaus County, CA. Prepared for Tuolumne River Technical Advisory Committee (Don Pedro Project, FERC License No. 2299). Prepared by McBain and Trush, Arcata, California.

McBride, J. R., and J. Strahan. 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. The American Midland Naturalist 112: 235-245.

McBride, J. R., N. Sugihara and E. Norberg. 1989. Growth and survival of three riparian woodland species in relation to simulated water table dynamics. Prepared for Pacific Gas and Electric Company, Department of Research and Development, San Ramon, CA.

McCreary, D.D. 1990. Native oaks: the next generation. Fremontia 18(3):44-47.

McCullough, D. A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to chinook salmon. Columbia River Inter-Tribal Fish Commission, Portland, Oregon.

McNeil, W. J. 1964. Redd superimposition and egg capacity of pink salmon spawning beds. 21: 1385-1396.

NHI (Natural Heritage Institute). 2001. Results of 1999 monitoring of shallow alluvial groundwater in Reach 2 of the San Joaquin River, Gravelly Ford to the East Side Bypass. Appendix F in Friant Water Users Authority and NRDC. 1999. 1999 San Joaquin River riparian flow release pilot project, NHI, Berkeley, California.

Osterkamp, W. R. and C. R. Hupp. 1984. Geomorphic and vegetative characteristics along three northern Virginia streams. Geological Society of America Bulletin 95: 1093-1101.

Sacchi, C.F. and P.W. Price. 1992. The relative roles of abiotic and biotic factors in seedling demography of arroyo willow (Salix lasiolepis: Salicaceae). American Journal of Botany 79(4): 395-405.

Sands, A., Ed. 1980. Riparian forests in California: their ecology and conservation. A symposium sponsored by Institute of Ecology, University of California, Davis and Davis Audubon Society, Agricultural Sciences Publications, University of California, Berkeley.

Scheerer, P. D. 2002. Implications of floodplain isolation and connectivity on the conservation of an endangered minnow, Oregon chub, in the Willamette River, Oregon. Transactions of the American Fisheries Society 131: 1070-1080.

Scott, M. L., G. T. Auble, J. M. Friedman l. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications **7**(2): 677-690.

Scott, M. L., J. M. Friedman, G. T. Auble. 1996. Fluvial processes and the establishment of bottomland trees. Geomorphology 14: 327-339.

Segelquist, C. A., M. L. Scott, and G. T. Auble. 1993. Establishment of *Populus deltoides* under simulated alluvial groundwater decline. The American Midland Naturalist 130: 274-285.

Shafroth, P. B., G. T. Auble, et al. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18(4): 577-590.

Shafroth, P. B., J. C. Stromberg, et al. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North America Naturalist 60: 66-76.

Smith, S. D., A. B. Wellington, et al. 1991. Functional responses of riparian vegetation to streamflow diversion in the eastern Sierra Nevada. Ecological Applications 1(1): 89-97.

Stella, J. C., B. K. Orr, J. J. Battles, J. R. McBride. 2003. Reproductive phenology and groundwater requirements for seedlings of three pioneer riparian species on teh lower Tuolumne River, CA. Second Biennial CALFED Science Conference. January 14-16, 2003. Sacramento, CA.

Stella, J., Vick, J., and B.K. Orr. In press. Riparian vegetation dynamics on the Merced River. Riparian Habitat and Floodplains Conference. March 12-14, 2001. Sacramento, California.

Stillwater Sciences. 2001a. Merced River Restoration Plan Phase II. Volume II: Baseline evaluations; geomorphic and riparian vegetation investigations. Prepared by Stillwater Sciences, Berkeley, California for CALFED, Sacramento, California.

Stillwater Sciences. 2001b. Merced River Restoration Plan Phase III. Task 2 Technical Memorandum: Channel and floodplain design guidelines for Technical Advisory Committee Review. Prepared by Stillwater Sciences, Berkeley, California for CALFED, Sacramento, CA.

Stillwater Sciences. 2003. Restoration Objectives for the San Joaquin River. Prepared for Natural Resources Defense Council, San Francisco, California and Friant Water Users Authority, Lindsay, California. Prepared by Stillwater Sciences, Berkeley, CA.

Stillwater Sciences. 2002. Merced River Corridor Restoration Plan. Stillwater Sciences, Berkeley, California. 245 pages.

Stromberg, J. C. 1997. Growth and survivorship of Fremont cottonwood, Goodding willow, and salt cedar seedlings after large floods in central Arizona. Great Basin Naturalist 57(3): 198-208.

Stromberg, J. C. 1998. Functional equivalency of saltcedar (Tamarix chinensis) and Fremont cottonwood (Populus fremontii) along a free-flowing river. Wetlands 18(4): 675-686.

Stromberg, J. C., R. Tiller, B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. Ecological Applications 6(1): 113-131.

Stromberg, J.C., Patten, D.T. and Richter, B.D., 1991. Flood flows and dynamics of Sonoran riparian forests. Rivers, 2(3): 221-235.

Sullivan, K., D. J. Martin, R. D. Cardwell, J. E. Toll, and S. Duke. 2000. An analysis of the effects of temperature on salmonids of the Pacific Northwest with implications for selecting temperature criteria. Draft report. Sustainable Ecosystems Institute, Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 1994. The relationship between instream flow, adult imigration, and spawninghabitat availability for fall-run chinook salmon in the upper San Joaquin River. USFWS, Sacramento, California.

Waite, I. R., and K. D. Carpenter. 2000. Associations among fish assemblage structure and environmental variables in Willamette Basin streams, Oregon. Transactions of the American Fisheries Society 129: 754-770.

Warner, R. E. and K. M. Hendrix, Eds. 1984. California riparian systems: ecology, conservation, and productive management, University of California Press, Berkeley.

Whitlock, D. 1995. The Whitlock Vibert Box handbook. Third revised edition. Federation of Fly Fisherman, El Segundo, California.

Wilson L.T. and W.W Barnett. 1983. Degree days: an aid in crop and pest management. California Agriculture 37:4-7.

Wolfe & Assoc. 2000. Summary of seed germination timing for the 1999 Pilot Project on the San Joaquin River. Report prepared for the Friant Water Users Authority by M.H. Wolfe and Associates Environmental Consulting. 8pp.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 1996. Historical and present distribution of chinook salmon in the Central Valley drainage of California. Sierra Nevada Ecosystem Project: final report to congress. Volume III: Assessments, commissioned reports, and background information, University of California, Center for Water and Wildland Resources, Davis: 309-362.

Zalom F.G., P.B.Goodell, L.T.Wilson, W.W.Barnett, and W.J. Bently. 1983. Degree days: the calculation and use of heat units in pest management. University of California, Division of Agriculture and Natural Resources, Leaflet 2137.

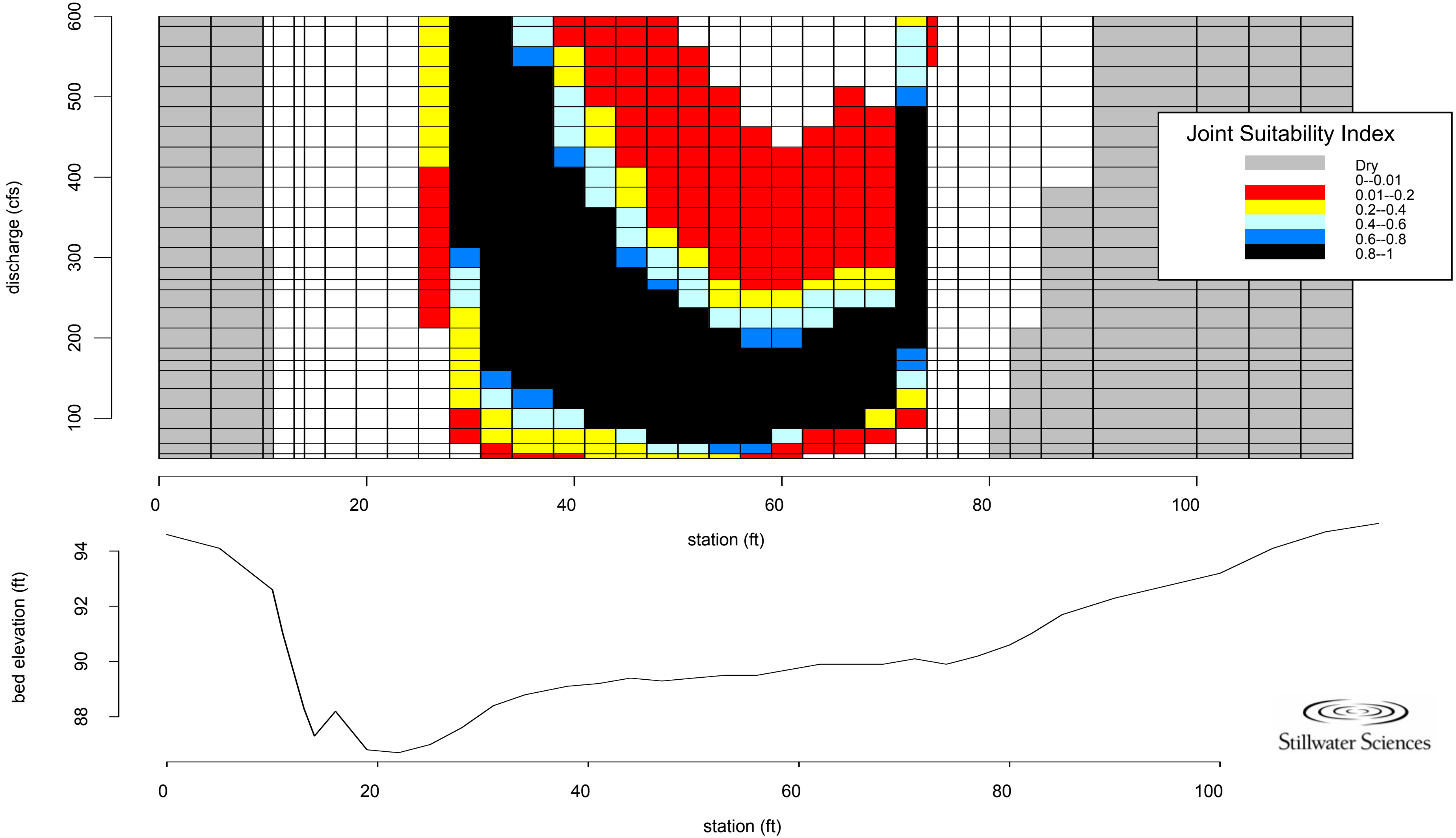

Figure I-1. San Joaquin River IFIM for Lanes Bridge. Transect 1, 1981 Tuolumne River suitability curves. The curves are modified for larger substrate sizes, increased depths to 4 feet, and reduced embeddedness to 0–25%. This diagram illustrates the strategy for lateral segregation of suitable spring- and fall-run chinook salmon spawning habitat that should result in reduced redd superimposition. A discharge of 250 cfs in September would create suitable spawning habitat for spring-run chinook in the center of the channel, and at the same cross-section a discharge of 450 cfs in November would provide suitable fall-run chinook spawning habitat along the channel margins.

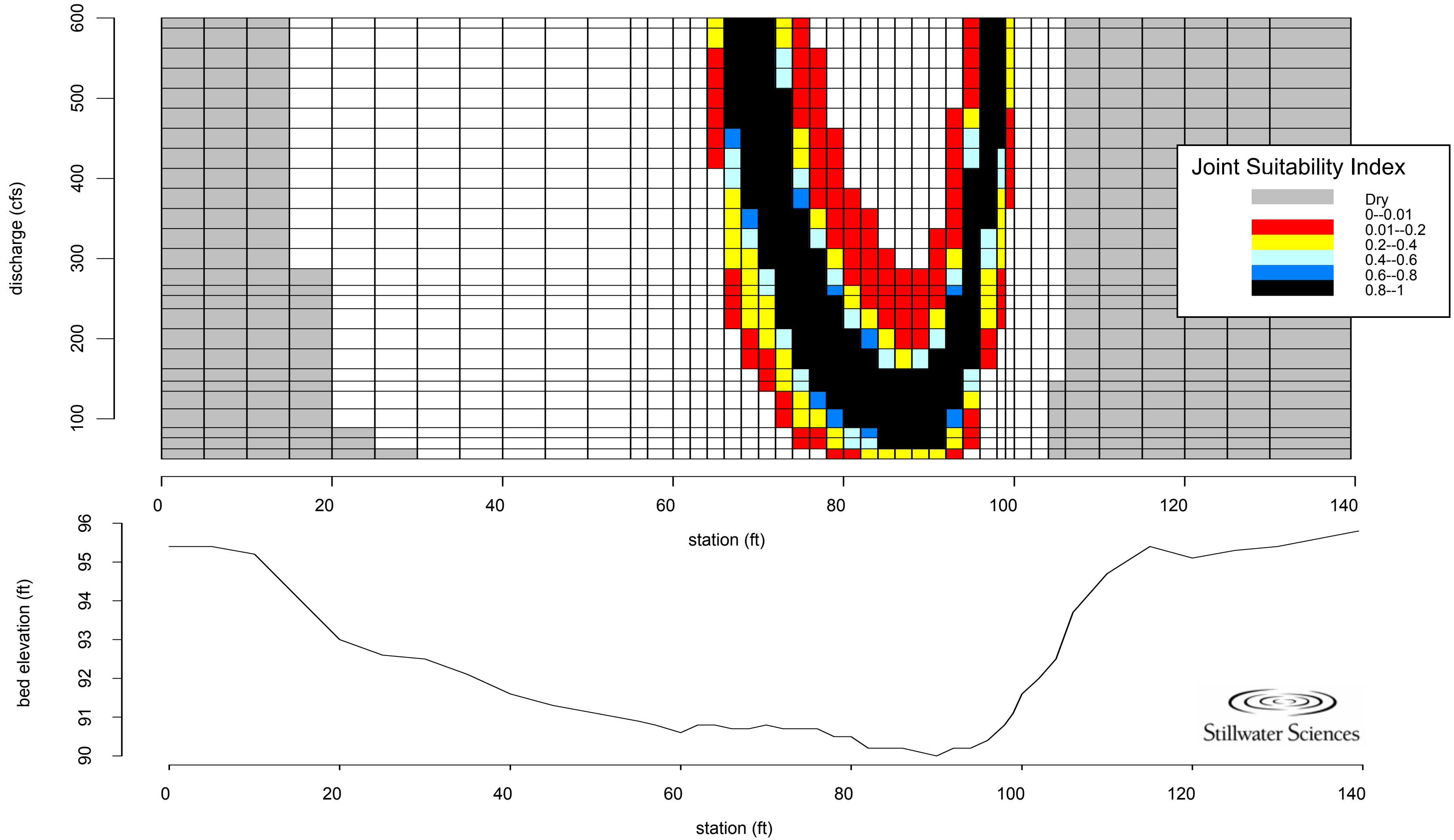

Figure I-2. San Joaquin River IFIM for Ball Ranch. Transect 1, 1981 Tuolumne River suitability curves. The curves are modified for larger substrate sizes, increased depths to 4 feet, and reduced embeddedness to 0–25%. This diagram illustrates the strategy for lateral segregation of suitable spring- and fall-run chinook salmon spawning habitat that should result in reduced redd superimposition. A discharge of 250 cfs in September would create suitable spawning habitat for spring-run chinook in the center of the channel, and at the same cross-section a discharge of 450 cfs in November would provide suitable fall-run chinook spawning habitat along the channel margins.