# 4.0 CONCEPTUAL MODELS OF LOWER AMERICAN RIVER ECOSYSTEM STRUCTURES, FUNCTIONS, AND PROCESSES

The conceptual models and hypotheses presented in this chapter are based on the status of aquatic species and habitat within the lower American River ecosystem, as summarized in Chapter 3. Background information on the aquatic species of priority management concern, their use and need of habitat types, physical processes, and ecosystem functions provided the foundation for identifying the stressors affecting these fish species. In this chapter, conceptual models are presented that incorporate our knowledge of the stressors to fall-run chinook salmon, steelhead, and splittail, by lifestage, as well as the corresponding hypotheses. As discussed in Chapter 2, although species of priority management concern also include other native fish and the non-native American shad and striped bass, federal ESA and CESA species listings (and candidate listings) direct a management focus upon fall-run chinook salmon, steelhead, and splittail in the lower American River. In addition, although the focus of this report is on these three species, restoration priorities will be based on ecosystem-based management. Ecosystem-based management achieves species management objectives by sustaining and enhancing the fundamental ecological structures and processes that contribute to the well-being of the species. Improving conditions for these three species, therefore, also will generally provide suitable conditions for other native fish species, and for American shad and striped bass.

## 4.1. IDENTIFICATION OF STRESSORS AND INTERCONNECTIONS WITHIN THE LOWER AMERICAN RIVER ECOSYSTEM

Conceptual models were developed that depict the lifestage cycle of fall-run chinook salmon, steelhead, and splittail, their use of lower American River reaches by lifestage, and the temporal and geographic distribution corresponding to each stressor. Key stressors that were identified in the draft *Baseline Report* are presented here with an attempt to define the linkages/relationships between the stressors and species responses (e.g., high water temperatures delay the onset of fall-run chinook salmon spawning).

The conceptual models describe the causal interconnections among key ecosystem components, demonstrating how physical and biotic system components respond to stressors. Using the information gained in the *Baseline Report,* the conceptual models consider the environmental (e.g., water temperature), ecological (e.g., food availability, predation by non-native species), physical (e.g., barriers), hydrologic (e.g., flow) and geomorphic (e.g., channel structure) factors that affect the various lifestages of fish species of priority management concern in the lower American River. Expected seasonal variations are included in the above factors as a component in the models.

The temporal and geographic distribution of lifestage activities and stressors presented are a general characterization based on information presented in the lower American River *Baseline Report*. Specific distributions for any particular year depend on many factors that vary each year. The ranges shown encompass what was found to be typical, or normal ranges for each activity based on available knowledge.

### 4.1.1. FALL-RUN CHINOOK SALMON

**Figure 4-1** is a conceptual model of the lifecycle of lower American River fall-run chinook salmon. The model displays the temporal distribution of each lifestage activity, and provides a brief description of the activities that characterize each lifestage. This model was informed by the lower American River *Baseline Report* and represents the best available knowledge of the lifestage periodicity of lower American River fall-run chinook salmon.

Conceptual models are subsequently presented which identify the stressors associated with each lifestage activity, with respect to river conditions. In these models, the temporal and geographic distribution of each individual stressor is identified. Figure 4-1 includes the adult bay entry and estuarine migration, juvenile estuarine residence and maturation, and smolt ocean entry and maturation lifestages. However, conceptual models of stressors which do not take place in the lower American River are not presented.

Fall-run chinook salmon reside in the Pacific Ocean from one to four years, but most often from two to three years, prior to returning as adults to spawn in the lower American River. Many natural ocean processes (e.g., El Niño/La Niña, distribution fronts and gyres, global warming) may affect the success of maturing fish to feed and grow, compete with other species or escape predation, resulting in periodic changes in natural mortality during the 1 to 4 years of ocean life. High oceanic natural mortality, particularly when combined with high harvest rates, affects the number of adults returning to spawn in the lower American River annually. Because the Pacific Ocean and Bay-Delta are outside of the scope of the FISH Plan for the lower American River, no conceptual model is presented for out-of-basin stressors.

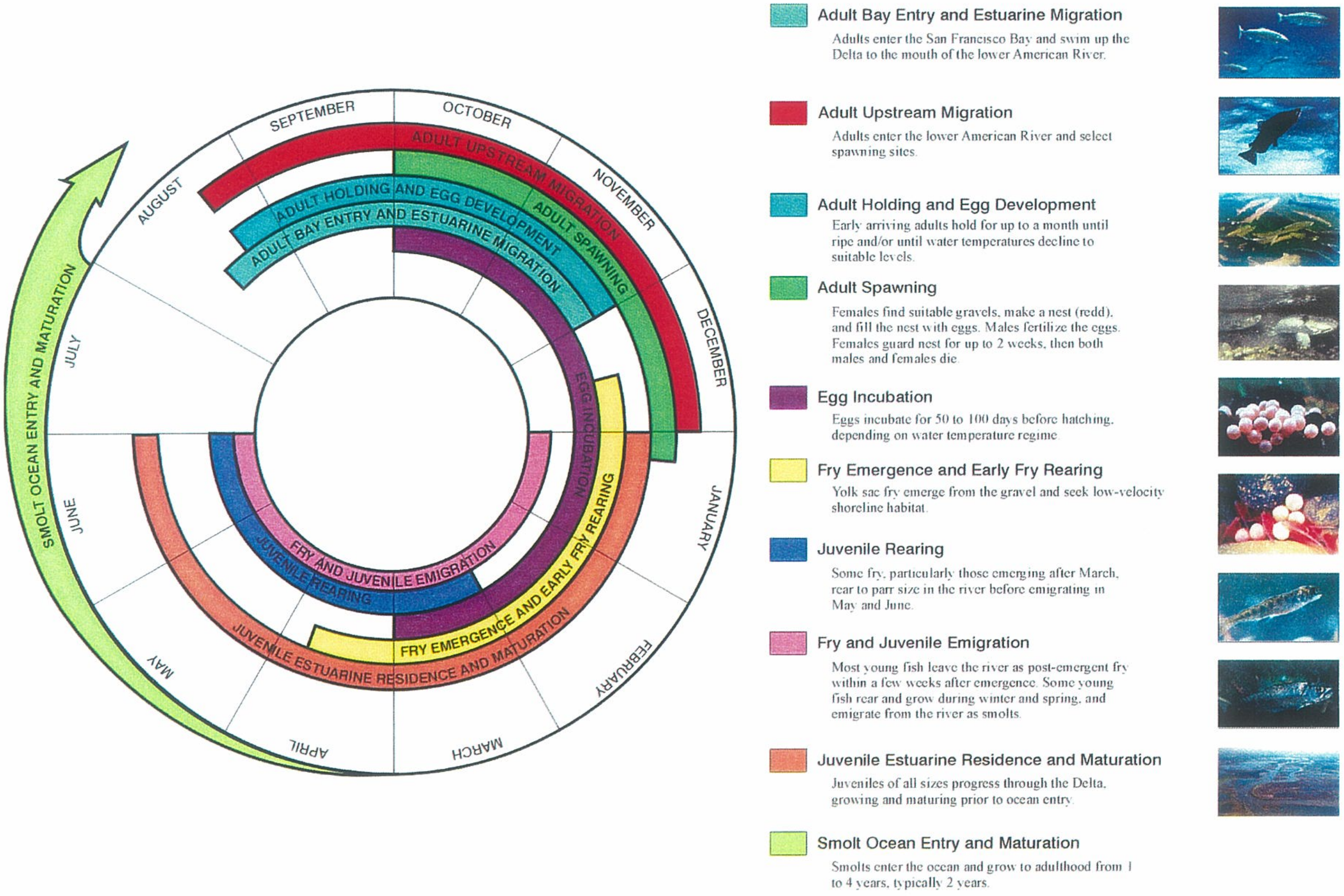
#### ADULT UPSTREAM MIGRATION

In the lower American River, the only stressor identified for adult fall-run chinook salmon upstream migration is high water temperature (**Figure 4-2**).

#### High Water Temperature

Adult fall-run chinook salmon generally migrate through the lower American River from late August through December. Water temperatures during late summer and fall are largely controlled by the operations of Folsom and Nimbus dams. Although migrating adults have been observed to tolerate short-term exposure to water temperatures from 77°F to 80°F, water temperatures over 65°F in the lower reaches of the Sacramento River and along the migration corridor of the lower American River (RM 0 to 5) may deter or delay upstream migration, resulting in late and less successful spawning, incubation and emergence (e.g., decreased fertilization, increased egg retention, reduced embryo viability, presence of abnormalities in the emergent fry).

**Figure 4-1. American River fall-run chinook salmon life cycle.**



🟦 **Adult Bay Entry and Estuarine Migration**

Adults enter the San Francisco Bay and swim up the Delta to the mouth of the lower American River.

🟥 **Adult Upstream Migration**

Adults enter the lower American River and select spawning sites.

🟦 **Adult Holding and Egg Development**

Early arriving adults hold for up to a month until ripe and/or until water temperatures decline to suitable levels.

🟩 **Adult Spawning**

Females find suitable gravels, make a nest (redd), and fill the nest with eggs. Males fertilize the eggs. Females guard nest for up to 2 weeks, then both males and females die.

🟪 **Egg Incubation**

Eggs incubate for 50 to 100 days before hatching, depending on water temperature regime.

🟨 **Fry Emergence and Early Fry Rearing**

Yolk sac fry emerge from the gravel and seek low-velocity shoreline habitat.

🟦 **Juvenile Rearing**

Some fry, particularly those emerging after March, rear to parr size in the river before emigrating in May and June.

🟪 **Fry and Juvenile Emigration**

Most young fish leave the river as post-emergent fry within a few weeks after emergence. Some young fish rear and grow during winter and spring, and emigrate from the river as smolts.

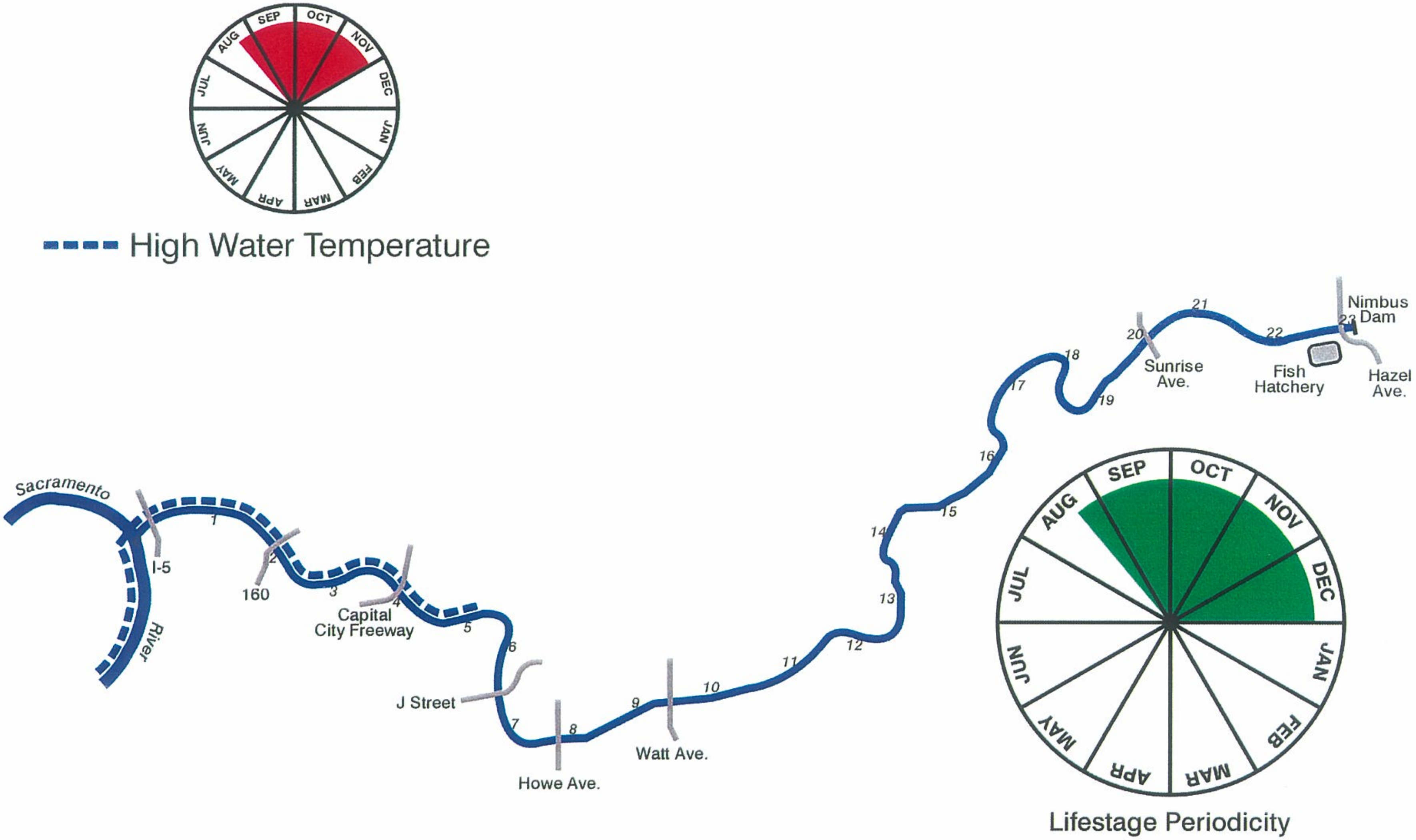
🟧 **Juvenile Estuarine Residence and Maturation**

Juveniles of all sizes progress through the Delta, growing and maturing prior to ocean entry.

🟩 **Smolt Ocean Entry and Maturation**

Smolts enter the ocean and grow to adulthood from 1 to 4 years, typically 2 years.

Figure 4-2. Adult fall-run chinook salmon upstream migration, and temporal and geographic distribution of potential stressors.



## ADULT HOLDING AND EGG DEVELOPMENT

In the lower American River, the egg stressor identified to adult holding and egg development is high water temperature (**Figure 4-3**). The geographic distribution presented corresponds to the entire reach of the river encompassing spawning locations.

### High Water Temperature

Although pre-spawning adults have been observed to tolerate short-term exposures to temperatures from 77°F to 80°F during migration, extended exposures to high water temperatures can cause decreased egg fertilization, increased egg retention, reduced embryo viability, and presence of abnormalities in the emergent fry.

## ADULT SPAWNING

Identified below and in **Figure 4-4** are the stressors associated with fall-run chinook salmon adult spawning. The geographic distribution of the stressors to the spawning lifestage corresponds to spawning site locations. Note that low gravel permeability may be a stressor throughout the primary spawning grounds.

### High Water Temperature

Fall-run chinook salmon do not initiate spawning until water temperatures in the primary spawning grounds (RM 9.3 to RM 22.9) decrease to about 60°F (*Baseline Report*, Figure 2-19). Moreover, it is known that exposure to elevated water temperatures upon entering the river prior to spawning may result in fatty acids being sequestered from the ova, resulting in an improper embryo development under the declining fall water temperatures (*Baseline Report*, p. 2-41).

### Low Substrate Permeability

As result of a 1994 CDFG quantitative evaluation of spawning habitat, intra-gravel permeability was identified as the main physical attribute that differentiates habitat currently used for spawning from apparently suitable habitat that remains unused (*Baseline Report*, p. 2-57). Gravel size alone does not appear to explain the fall-run chinook salmon female's choice of a particular site to build its nest (redd). High gravel permeability would allow intra-gravel flows, permitting sufficient cleansing and dissolved oxygen for successful egg incubation.

### Low Flow Rate

Although substrate composition is an important factor in spawning site selection, flow rate directly influences physical spawning habitat availability. Low flows and, therefore, low physical spawning habitat availability may limit the number of adults which can spawn, and may result in increased egg retention. Moreover, flow rate influences the potential for redd superimposition, with greater imposition occurring at lower flows.

### Figure 4-3. Adult fall-run chinook salmon holding and egg development, and temporal and geographic distribution of potential stressors.

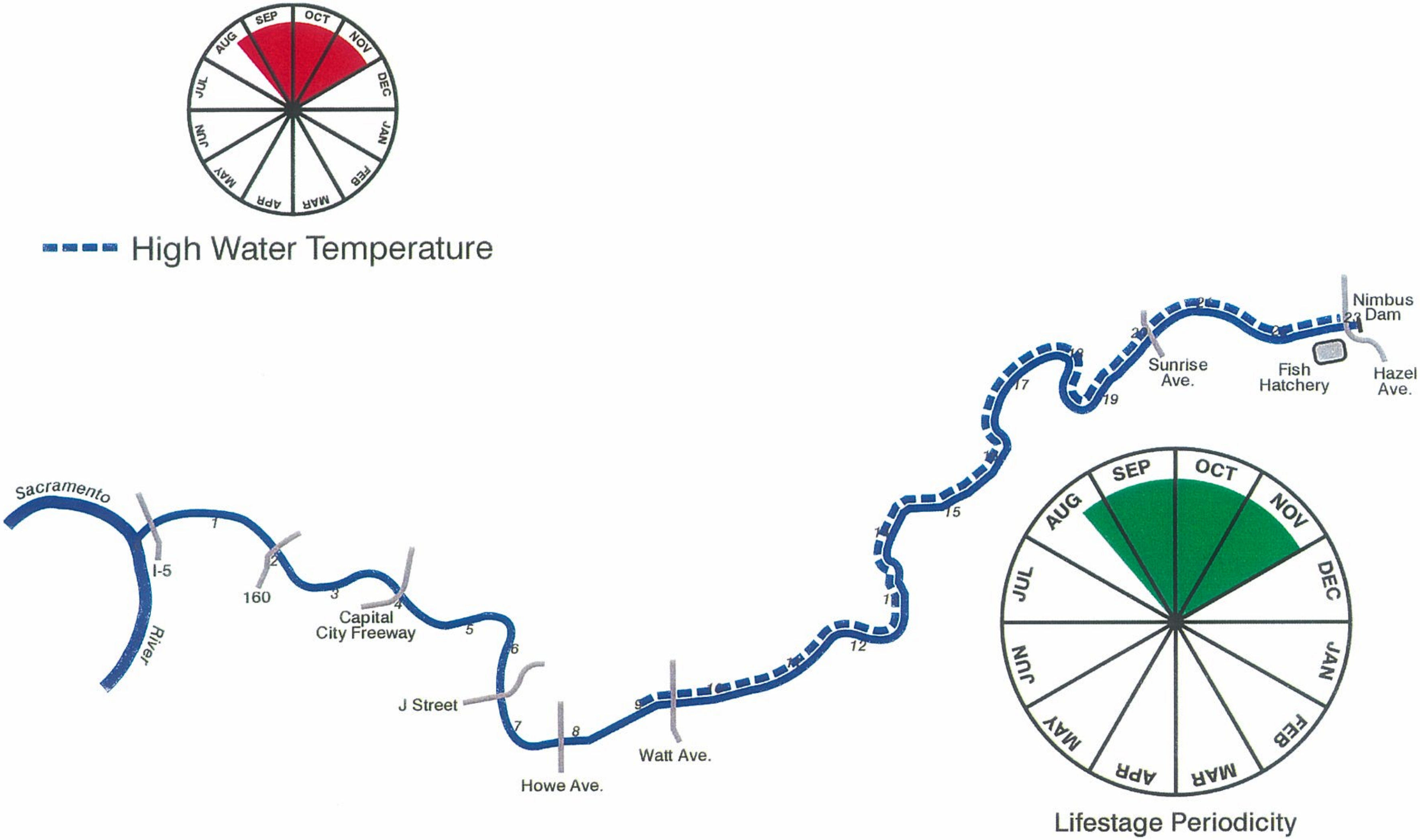
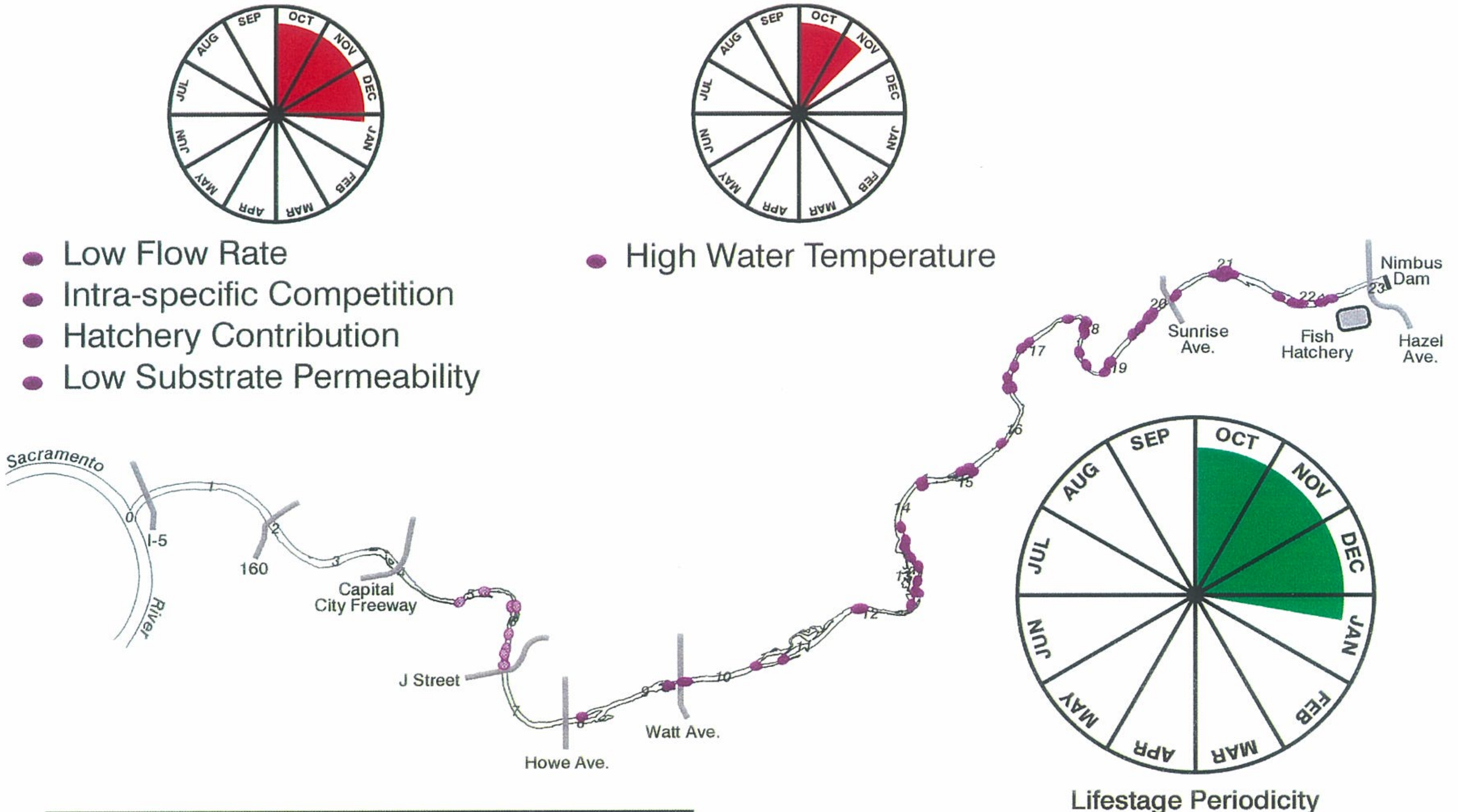


**Figure 4-4. Adult fall-run chinook salmon spawning, and temporal and geographic distribution of potential stressors.**



*Note: The geographic distribution of the stressors to the spawning lifestage corresponds to spawning site locations. Note that low substrate permeability may be a stressor throughout the primary spawning grounds. At the locations marked by hatching ▨, spawning activity has been observed only in low water years.*

### Intra-Specific Competition

When physical spawning habitat availability is limited, the incidence of redd superimposition increases. Spawning habitat availability is associated with flow rate.

### Hatchery Contribution

It presently is unknown what proportion of the annual number of adults spawning in the river is composed of hatchery-origin fish. It has been suggested, however, that the majority of in-river fall-run chinook salmon spawners are of hatchery origin. Currently, it is uncertain to what extent hatchery-origin fish compete with naturally spawned fish for available habitat. A second concern is that hatchery practices have decreased the genetic diversity of the population of fall-run chinook salmon spawning in the lower American River.

## EGG INCUBATION

Identified below and in **Figure 4-5** are the stressors associated with fall-run chinook salmon egg incubation. The geographic distribution of the stressors to the egg incubation lifestage corresponds to spawning site locations.

### High Water Temperature

Laboratory studies performed on incubating chinook salmon eggs from Sacramento and American River stocks, often under constant water temperatures, have indicated that high water temperatures during egg incubation increases egg mortality (see *Baseline Report*, Appendix B). For example, constant incubation temperatures over 62°F and below 38°F reportedly may result in 100 percent egg mortality (Hinze 1959). Moreover, high water temperatures appear to increase the incidence of abnormal embryo development and the rate of embryo development. An increase in the rate of embryo development shortens the incubation period, leading to an altered schedule of subsequent life stages.

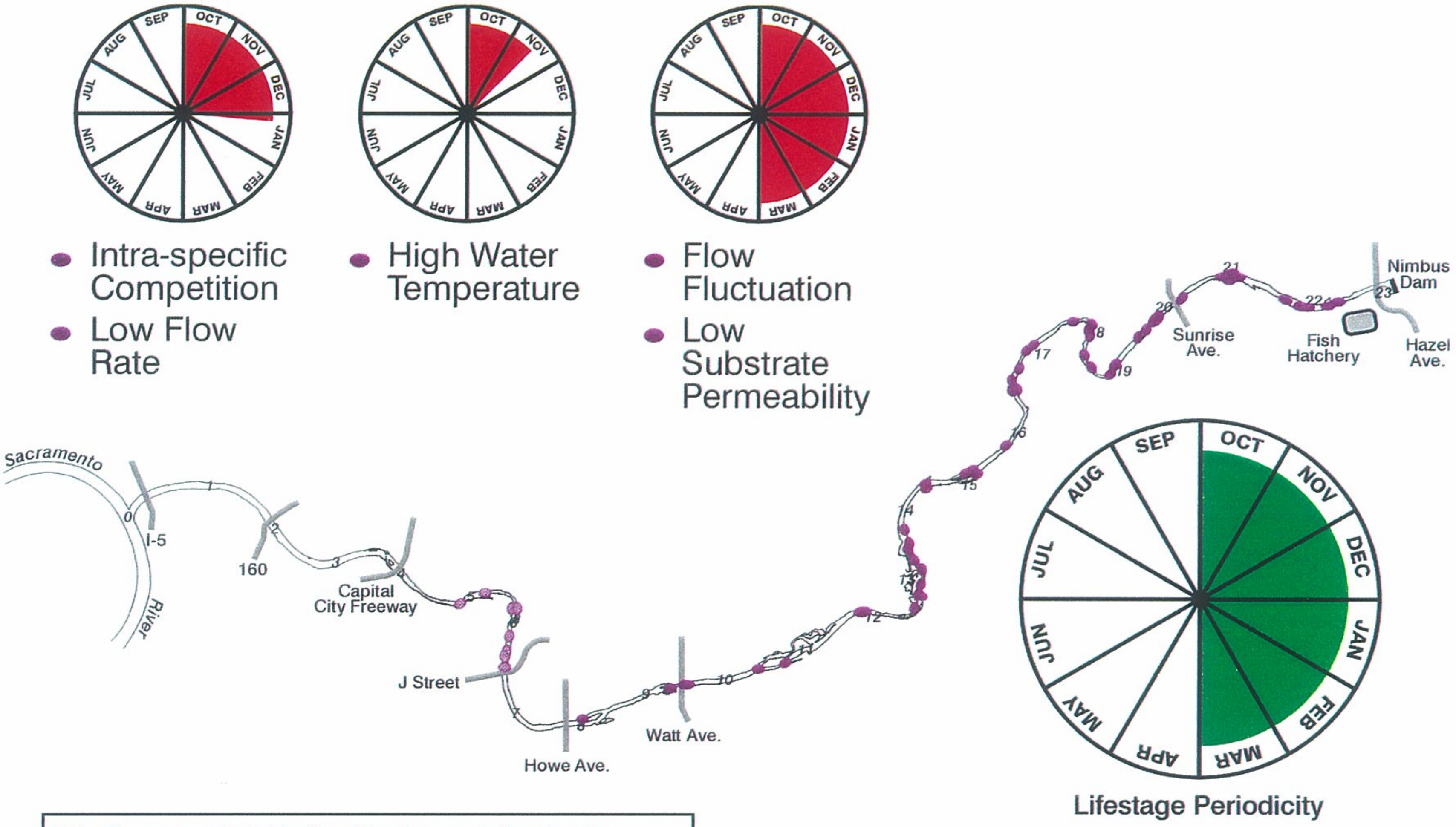
### Low Substrate Permeability

For a successful incubation, gravel must be sufficiently free of fine sediment to allow water to flow through it and bring dissolved oxygen to the eggs and carry off metabolic wastes (*Baseline Report*, p. 2-66). Consequently, intra-gravel permeability must be high to allow a successful incubation. When suitable spawning gravel is limited, redds may be built on gravel with less than suitable intra-gravel permeability, reducing the egg survivability.

### Flow Fluctuations

Flow reductions can expose redds to the atmosphere, causing desiccation (i.e., redd dewatering) and egg mortality (*Baseline Report*, p. 2-58 to 2-60).

**Figure 4-5. Fall-run chinook salmon egg incubation, and temporal and geographic distribution of potential stressors.**



*Note: The geographic distribution of the stressors to the spawning lifestage corresponds to spawning site locations. Note that low substrate permeability may be a stressor throughout the primary spawning grounds. At the locations marked by hatching ●, spawning activity has been observed only in low water years.*

#### Intra-Specific Competition

As mentioned earlier, one indication of limited habitat for spawning salmon is the degree of redd superimposition. When superimposition occurs, a newly arrived spawning female builds a new redd on top of an existing one, by digging up the existing redd (*Baseline Report,* p. 2-57). This digging process reduces egg survival.

### FRY EMERGENCE AND EARLY FRY REARING

Identified below and in **Figure 4-6** are the stressors associated with fall-run chinook salmon fry emergence and early fry rearing, and the lower American River reach to which each stressor corresponds.

#### Reduced Habitat Complexity and Diversity

After emergence, fry seek low velocity areas near shore (Briggs 1954; Brown et al., 1991; *Baseline Report*, p. 2-77 to 2-78). The preponderance of rip-rap downstream of Howe Avenue has resulted in a decrease in habitat complexity and diversity.

#### Low Flow Rate

Flow rate directly affects rearing physical habitat availability in the river channel. Low flow rates also may reduce accessibility of nearshore habitat characterized by habitat complexity and diversity in the form of large woody debris and SRA cover. Also, during spring, flow rate is related to water temperature and low flow rates are often associated with warmer water temperatures.

#### Flow Fluctuations

Large fluctuations in flow risk stranding fry near the river edges and in shallow pools which, in turn, may affect the size of the emigrating population (*Baseline Report*, p. 2-78).

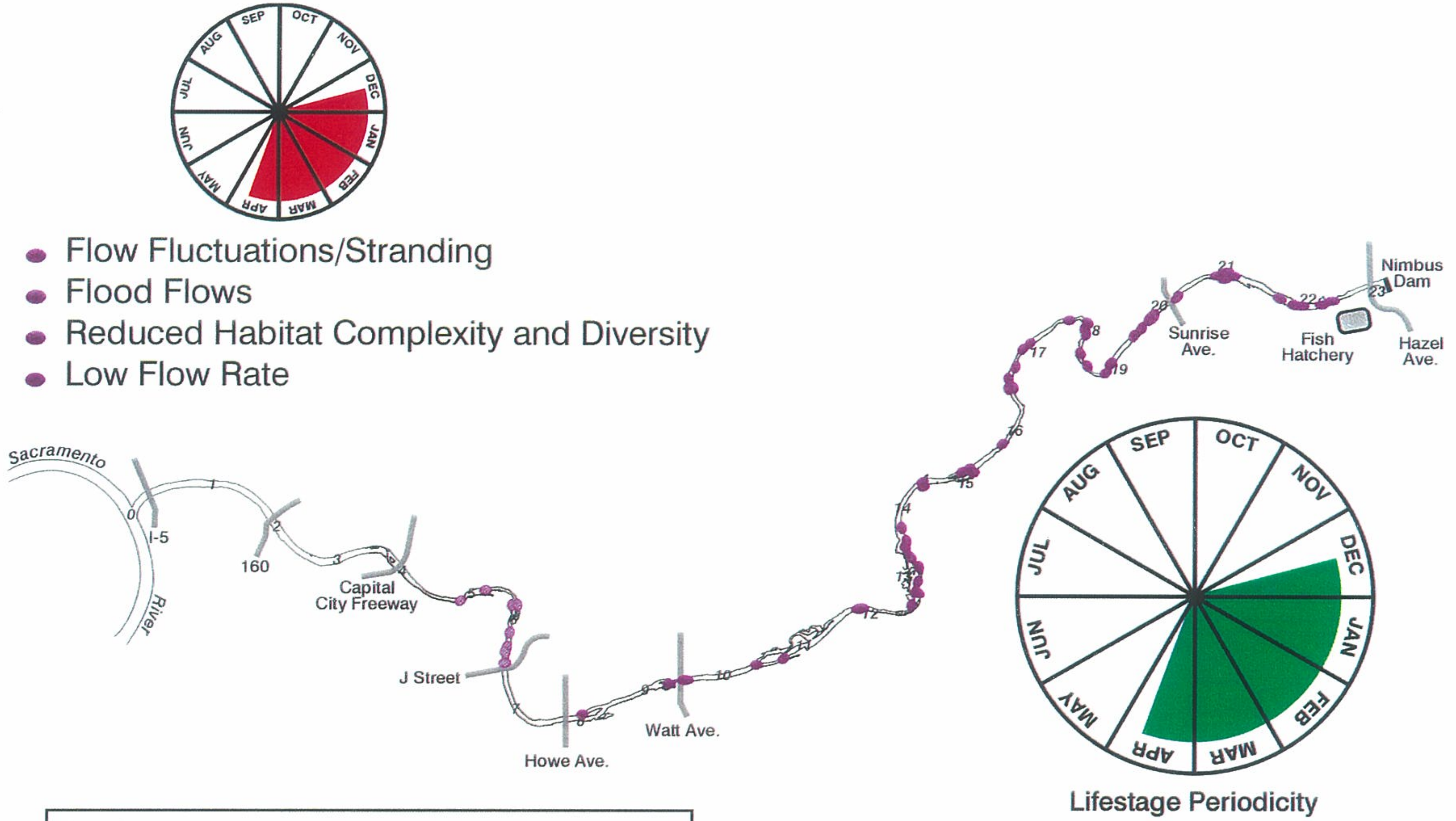
#### Flood Flows

Flood flows can be deleterious to recently emerged young fry; mortality may result from physical injury, stranding, or displacement and subsequent predation.

### FRY AND JUVENILE EMIGRATION

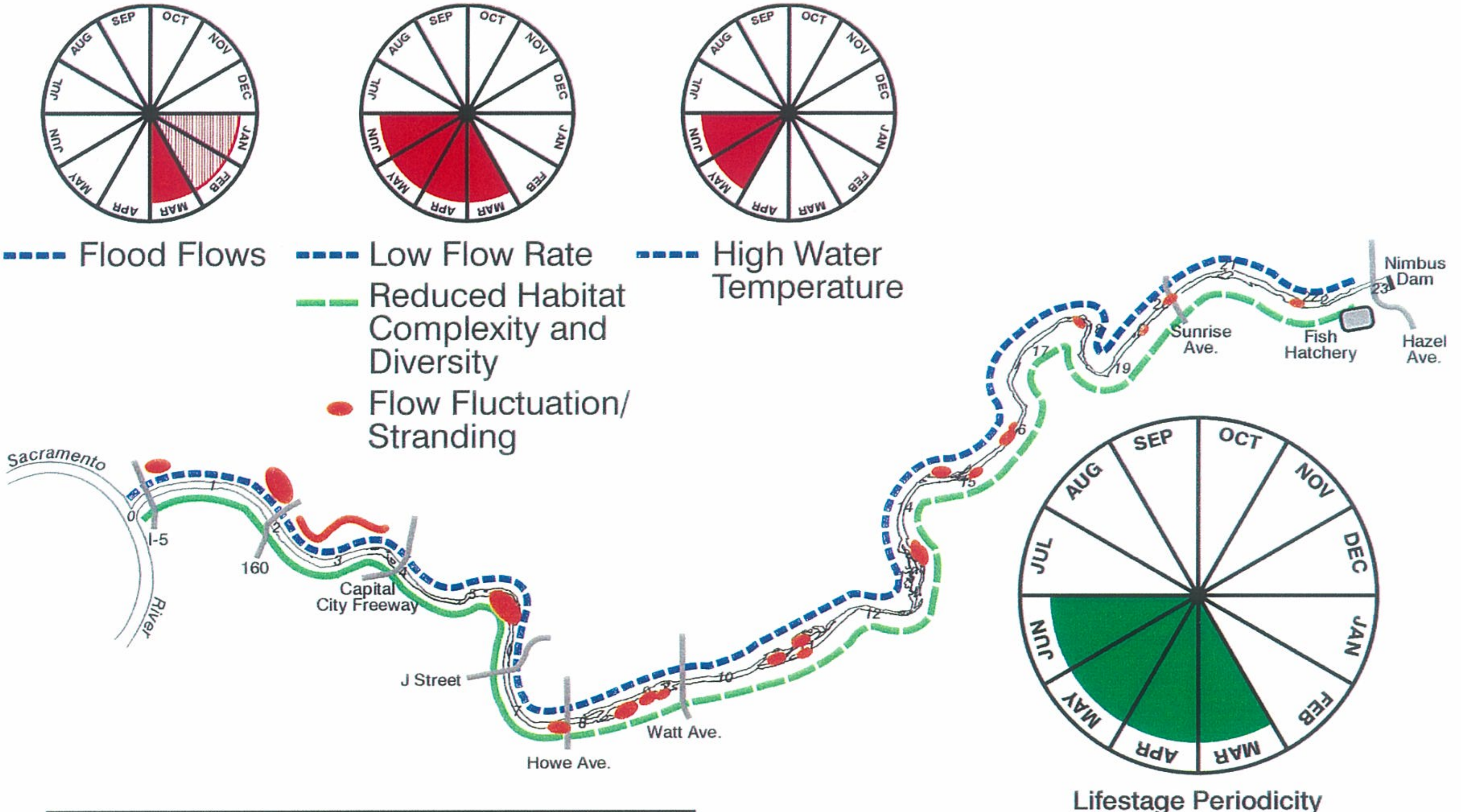
Identified below and in **Figure 4-7** are the stressors associated with fall-run chinook salmon fry and juvenile emigration, and the lower American River reach to which each stressor corresponds. Juveniles emigrating from the lower American River when Delta conditions are least favorable for juvenile chinook salmon can severely reduce the survival rate for those fish. Changing diversion practices, temperature conditions, and flow conditions in the Delta can affect survival of emigrating juvenile chinook salmon.

Figure 4-6. Fall-run chinook salmon fry emergence and early fry rearing, and temporal and geographic distribution of potential stressors.



*Note: Reduced habitat complexity and diversity primarily applies to areas downstream of Howe Avenue that are bordered by levees. However, reduced habitat complexity and diversity also applies, to a lesser extent, to upstream areas. At the locations marked by hatching ▨, spawning activity has been observed only in low water years.*

**Figure 4-7. Fall-run chinook salmon juvenile rearing, and temporal and geographic distribution of potential stressors.**



*Note: Reduced habitat complexity and diversity primarily applies to areas downstream of Howe Avenue that are bordered by levees. However, reduced habitat complexity and diversity also applies, to a lesser extent, to upstream areas.*

### High Water Temperature (RM 9.5 to 23)

Elevated spring water temperature is one factor suspected of influencing downstream migration of juvenile fall-run chinook salmon. Water temperatures that are too high, too early in the spring may prematurely evacuate salmon from the river. Water temperature during the spawning and incubation stages also affects the emigration timing of fry and juveniles. High temperatures accelerate spawning and incubation periods, contributing to early emigration and a reduction in emigration survival (*Baseline Report*, p. 2-89).

### Flow Fluctuations

Large fluctuations in flow risk stranding emigrating fry and juveniles near the river edges and in shallow pools (*Baseline Report*, p. 2-78), which, in turn, may affect the size of the emigrating population.

### Reduced Habitat Complexity and Diversity

After emergence, fry seek low velocity areas near shore. As they grow, juvenile fall-run chinook salmon seek faster moving water and harbor around channel obstructions (*Baseline Report*, p. 2-77 to 2-78). The stream channel has simplified due to channel constriction, levee construction, rip-rapping of the shoreline, removal of woody debris, and has resulted in reduced fry and juvenile habitat quality.

SRA cover consists of instream object cover and overhanging cover. Instream object cover provides structure which promotes hydraulic diversity and microhabitats for juvenile salmonids, as well as escape cover from predators. Overhanging cover provides localized shading and potential reduction in surface water temperatures, and also may serve as a food source of terrestrial insects.

## JUVENILE REARING

Identified below and in **Figure 4-8** are the stressors associated with fall-run chinook salmon juvenile river rearing, and the lower American River reach to which each stressor corresponds.

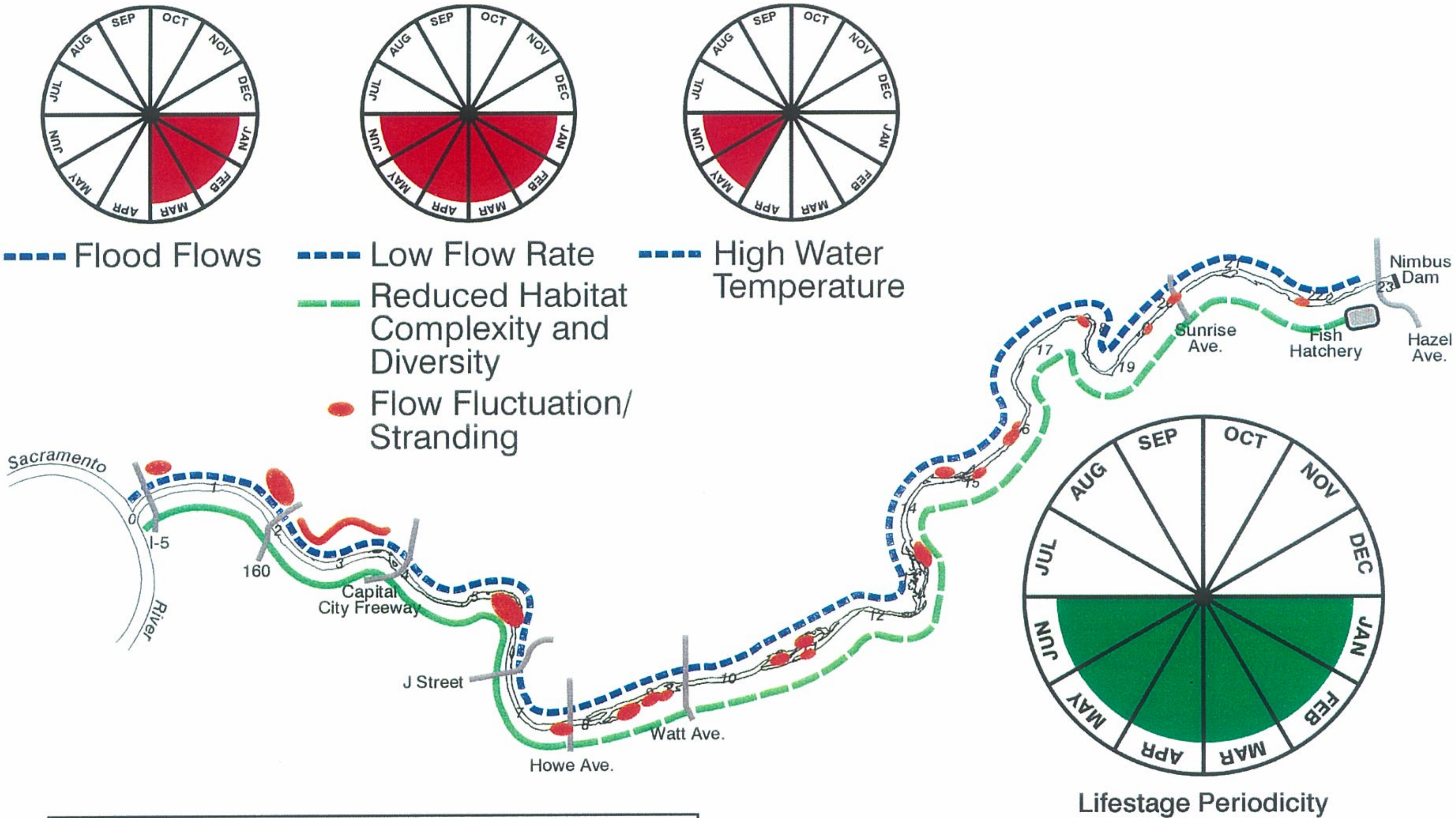
### High Water Temperature

High water temperatures negatively impact the health, behavior and survival of rearing juvenile chinook salmon (*Baseline Report*, p. 2-83). With high water temperatures, the level of predation and the risk of disease affecting rearing juvenile chinook salmon are increased. Direct effects to the fish physiologic function also can lead to increases in mortality (see explanation for Post Emergent Fry and Juvenile River Emigration).

### Low Flow Rate

See explanation for Fry Emergence and Early Fry Rearing and Fry and Juvenile Emigration.

Figure 4-8. Fall-run chinook salmon fry and juvenile emigration, and temporal and geographic distribution of potential stressors.



*Note: Reduced habitat complexity and diversity primarily applies to areas downstream of Howe Avenue that are bordered by levees. However, reduced habitat complexity and diversity also applies, to a lesser extent, to upstream areas.*

### Flow Fluctuation

Large fluctuations in flow risk stranding emigrating fry and juveniles near the river edges and in shallow pools (*Baseline Report*, p. 2-78), which, in turn, may affect the size of the emigrating population.

### Reduced Habitat Complexity and Diversity

See explanation for Fry Emergence and Early Fry Rearing and Fry and Juvenile Emigration.

## 4.1.2. STEELHEAD

**Figure 4-9** is a conceptual model of the lifecycle of lower American River steelhead. The model displays the temporal distribution of each lifestage activity, and gives a brief description of the activities that characterize each lifestage. This model was informed by the lower American River *Baseline Report* and represents the best available knowledge of the lifestage periodicity of lower American River steelhead.

Conceptual models are subsequently presented which identify the stressors associated with each lifestage activity, with respect to river conditions. In these models, the temporal and geographic distribution of each individual stressor is identified. Conceptual models of stressors which do not take place in the lower American River are not presented.

### ADULT SPAWNING AND EGG INCUBATION

Identified below and in **Figure 4-10** are the stressors associated with steelhead adult spawning and egg incubation. The geographic distribution of the stressors to the spawning and egg incubation lifestages corresponds to spawning site locations. Note that substrate composition and permeability may be a stressor throughout the primary spawning grounds.

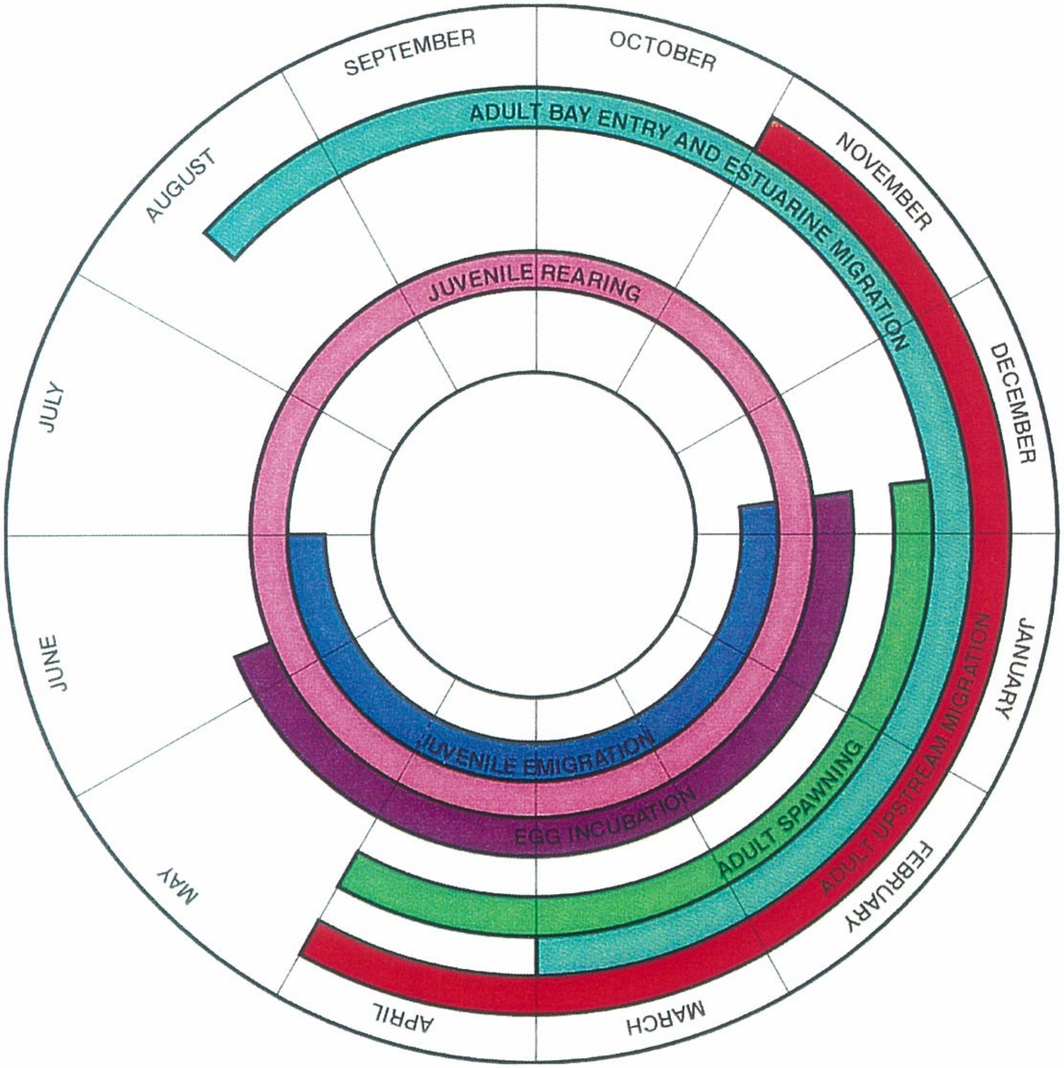
### High Water Temperature

Water temperatures exceeding those reported for successful spawning and egg incubation can occur as early as mid-April in the lower American River.

### Substrate Composition and Permeability

Substrate size, particularly in the upper reaches of the lower American River, may exceed that which is commonly reported for steelhead spawning. Also, as result of a 1994 CDFG quantitative evaluation of fall-run chinook salmon spawning habitat, intra-gravel permeability was identified as the main physical attribute that differentiates habitat currently used for spawning from apparently suitable habitat that remains unused (*Baseline Report*, p. 2-57).

Figure 4-9. American River steelhead life cycle.



**Adult Bay Entry and Estuarine Migration**

Adults enter San Francisco Bay and swim up the Delta to the mouth of the lower American River.

🟥 **Adult Upstream Migration**

Adults enter the lower American River and select spawning sites.

🟩 **Adult Spawning**

Females find suitable gravels, make a nest (redd), and fill the nest with eggs. Males fertilize the eggs. Females guard nest for up to 2 weeks.

🟪 **Egg Incubation**

Eggs incubate for 50 to 100 days before hatching, depending on prevailing water temperature.

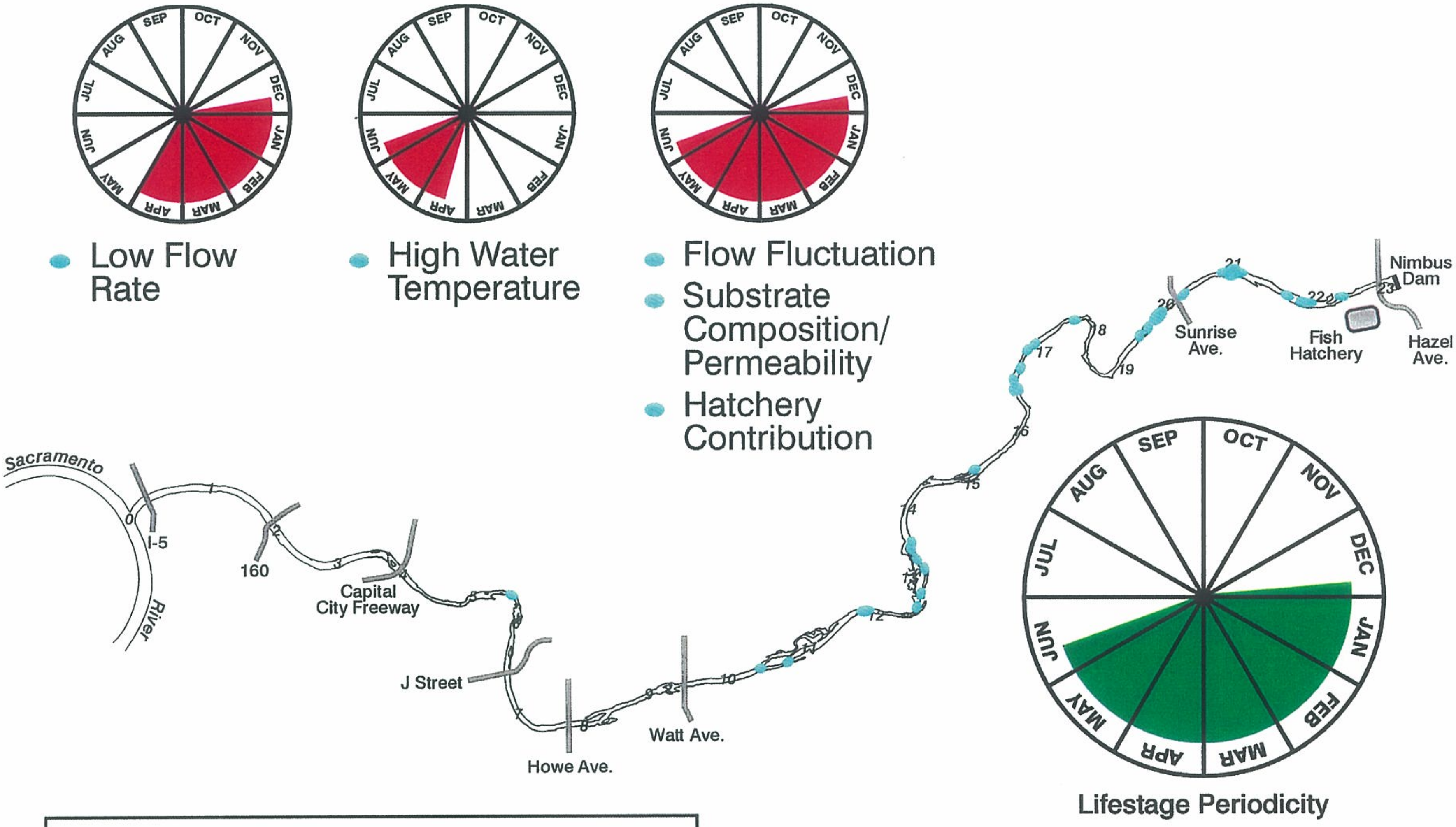
**Juvenile Rearing**

Rearing takes place year-round; from 1-4 years.

🟦 **Juvenile Emigration**

Emigration takes place from late December through June.

**Figure 4-10. Steelhead spawning and egg incubation, and temporal and geographic distribution of potential stressors.**



*Note: The geographic distribution of the stressors to the egg incubation lifestage corresponds to spawning site locations. Note that low substrate permeability may be a stressor throughout the primary spawning grounds.*

Substrate permeability considerations also may pertain to steelhead. High gravel permeability would allow intra-gravel flows, providing sufficient cleansing and dissolved oxygen for successful egg incubation.

### Low Flow Rate

Although substrate composition is an important factor in spawning site selection, flow rate directly influences physical spawning habitat availability. Low flows and, therefore, low physical spawning habitat availability may limit the number of adults which can spawn, and may result in increased egg retention.

### Hatchery Contribution

It presently is unknown what proportion of the annual number of adults spawning in the river is composed of hatchery-origin fish. It has been suggested, however, that the majority of in-river steelhead spawners are of hatchery origin. Currently, there is no way to verify the concern that hatchery origin fish compete with naturally spawned fish for available habitat. A second concern is that hatchery practices have decreased the genetic diversity of the population of steelhead spawning in the lower American River.

### Flow Fluctuation

Flow reductions can expose redds to the atmosphere, causing desiccation (i.e., redd dewatering) and egg mortality.

## JUVENILE REARING

Identified below and in **Figure 4-11** are the stressors associated with juvenile steelhead rearing, and the geographic and temporal distribution to which each stressor corresponds.

### High Water Temperature

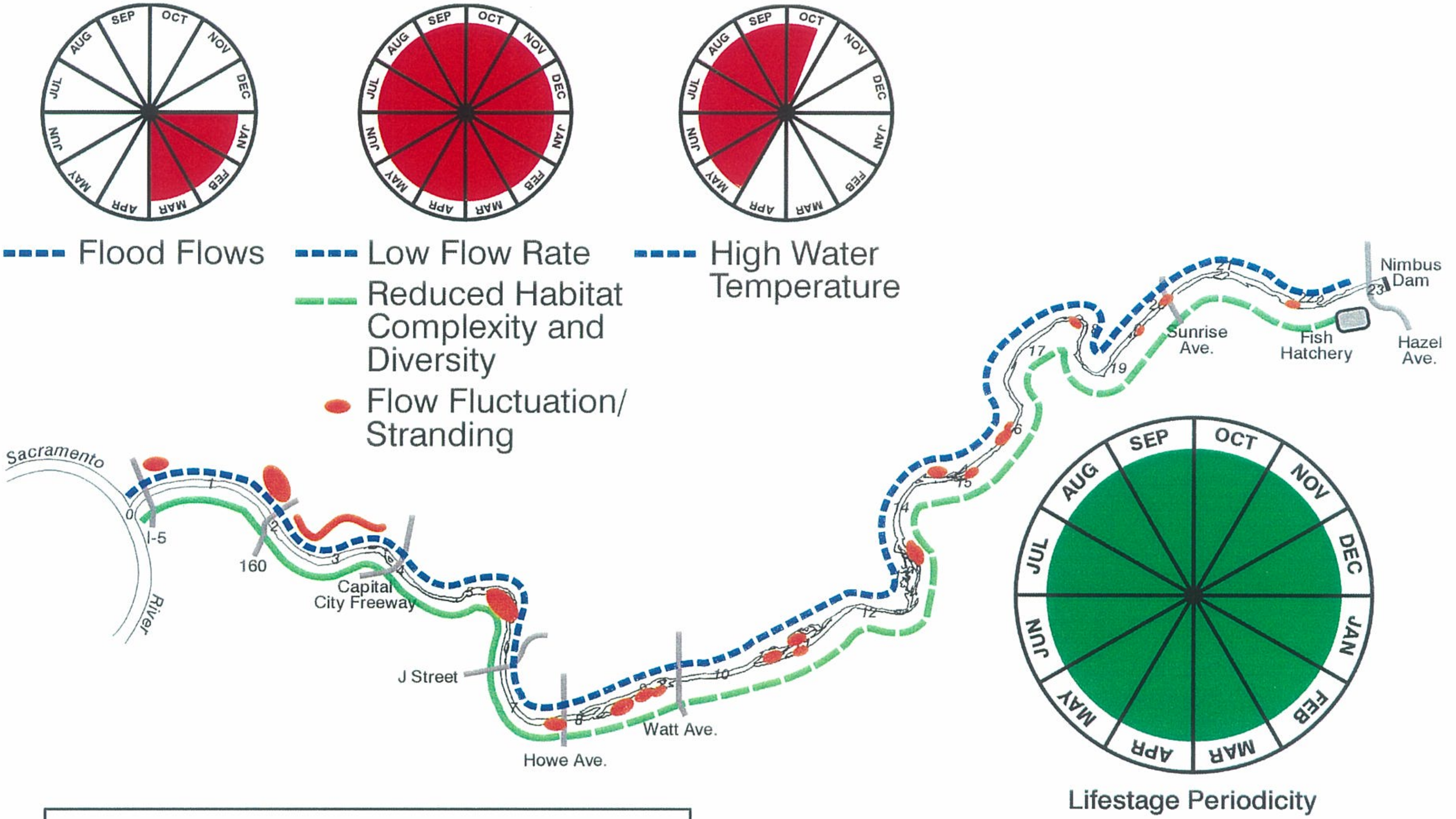
The environmental factor probably most limiting to natural production of steelhead in the lower American River is high water temperatures during summer and fall (Snider and Gerstung 1986; *Baseline Report*, p. 2-119). Water temperatures in the lower American River normally exceed 60°F from July to September, and often exceed 70°F. With these high water temperatures, the health, behavior and survival of rearing juvenile steelhead can be negatively affected.

For example, high summer and fall water temperatures may increase predation and the risk of disease, effectively leading to increased mortality among the rearing juvenile steelhead. Direct effects on fish physiology/bioenergetics can also lead to increases in mortality.

### Low Flow Rate

Flow rate directly affects rearing physical habitat availability in the river channel. Low flow rates also may reduce accessibility of nearshore habitat characterized by habitat complexity and diversity in the form of large woody debris and SRA cover. Also, during spring, flow rate is related to water temperature and low flow rates are often associated with warmer water temperatures.

**Figure 4-11. Steelhead juvenile rearing, and temporal and geographic distribution of potential stressors.**



*Note: Reduced habitat complexity and diversity primarily applies to areas downstream of Howe Avenue that are bordered by levees. However, reduced habitat complexity and diversity also applies, to a lesser extent, to upstream areas.*

#### Flow Fluctuations

Large fluctuations in flow risk stranding fry near the river edges and in shallow pools which, in turn, may affect the size of the emigrating population (*Baseline Report*, p. 2-78).

#### Flood Flows

Flood flows are deleterious to recently emerged young fry; mortality may result from physical injury, stranding, or displacement and subsequent predation.

#### Reduced Habitat Complexity and Diversity

After emergence, fry seek shallow, low velocity areas near shore. As they grow, juvenile steelhead seek faster moving water and harbor around channel obstructions (*Baseline Report*, p. 2-77 to 2-78). The stream channel has simplified due to channel constriction, levee construction, rip-rapping of the shoreline, removal of woody debris, and has resulted in reduced fry and juvenile habitat quality.

SRA cover consists of instream object cover and overhanging cover. Instream object cover provides structure which promotes hydraulic diversity and microhabitats for juvenile steelhead, as well as escape cover from predators. Overhanging cover provides localized shading and reduction in surface water temperatures, and also may serve as a food source of terrestrial insects.

## 4.1.3. SPLITTAIL

Adult splittail inhabit the Delta and Sacramento and San Joaquin rivers for most of their lifestages; they also inhabit the lower reaches of tributary rivers, particularly in high flow years. Splittail primarily spawn in the lower American River for short periods of time between February and May. Hatching to swim-up to the Sacramento River takes two to three weeks. Therefore, conceptual models for other lifestages of splittail are not presented, and the discussion of stressors affecting splittail focuses exclusively on the spawning lifestage.

### SPAWNING

Identified below and in **Figure 4-12** is the stressor associated with splittail spawning, and the geographic and temporal distribution to which each stressor corresponds.

#### Reduced Shallow Inundated Habitat

The lower American River has limited shallow areas with frequent, periodic flooding. This type of habitat is used by splittail for spawning and early rearing. Flow levels contribute to the flooding of these floodplains increasing survival of rearing splittail juveniles. For example, in 1998, high flows and consistent floodplain inundation resulted in record Age-0 abundance for abundance indices to date (*Baseline Report*, p. 2-126). Potential splittail spawning habitat may exist in the lower American River, particularly from the river mouth to Gristmill, near RM 12.

Figure 4-12. Splittail spawning and early rearing, and temporal and geographic distribution of potential stressors.