Analysis of Physical Flow Characteristics Supportive of Chinook Salmon to Inform Channel Capacity Selection in the Funding Constrained Framework

Technical Memorandum

SAN JOAQUIN RIVER
RESTORATION PROGRAM

March 2018

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation’s natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Abbreviations and Acronyms

CalSim	California Statewide Integrated Model
CCC	Columbia Canal Company
CCID	Central California Irrigation District
cfs	cubic feet per second
CVP	Central Valley Project
Delta	Sacramento–San Joaquin Delta
DMC	Delta–Mendota Canal
DFW	California Department of Fish and Wildlife
DWR	California Department of Water Resources
ESA	Endangered Species Act
FCWD	Firebaugh Canal Water District
FNF	full natural flow
GRF	Gravelly Ford
HSA	Hydraulically Suitable Area
HSI	Habitat Suitability Index
LSJLD	Lower San Joaquin Levee District
NMFS	National Marine Fisheries Service
NRDC	Natural Resources Defense Council
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RWA	SJRRP (see below) Reclaimed Water Account
Secretary	U.S. Secretary of the Interior
Settlement	Stipulation of Settlement in *NRDC, et al. v. Kirk Rodgers, et al.*
SJFMWG	San Joaquin Fish Management Work Group
SJREC	San Joaquin River Exchange Contractors
SJRRP	San Joaquin River Restoration Program
SLCC	San Luis Canal Company
SWP	State Water Project
TAF	thousand acre–feet
USFWS	U.S. Fish and Wildlife Service
WY	water year

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1.0 Statement of Purpose

In the process of revising the 2015 Framework for Implementation to align with the available funding (termed the Funding Constrained Framework), it was apparent that the San Joaquin River Restoration Program (SJRRP) total cost was sensitive to channel capacity constraints. Thus, a phased approach is recommended under the Funding Constrained Framework. In lieu of attaining the 4500 cubic feet per second (cfs) channel capacity throughout the Restoration Area all at once, this analysis explores a lower interim channel capacity that may make meaningful progress toward the Restoration Goal and determines whether the tools are available at a given lower interim channel capacity to achieve success in spring-run and fall-run Chinook salmon survival. A lower interim channel capacity may substantially reduce the cost of major construction projects, levee improvements, and seepage projects (e.g. easements, purchases, slurry walls, interceptor drains) across Stage 1. While the long-term costs of achieving 4500 cfs as written in the Settlement will remain, this timely analysis informs the relative potential progress towards the Restoration Goal linked to an interim channel capacity. The potential monetary savings of an interim channel capacity are beyond the scope of this analysis and are covered in the Funding Constrained Framework.

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2.0 Overview

There are many high-priority Restoration Goal actions, among them providing suitable salmonid rearing and migration habitat. Adequate water temperatures for migrating adult spring-run Chinook salmon and emigrating juvenile spring-run and fall-run Chinook salmon, and adequate rearing habitat for juveniles from both runs, are stressors that are closely linked to channel capacity. Water temperature is influenced by flow: greater flow can suppress water temperature below lethal thresholds, and rearing habitat is strongly influenced by floodplain inundation: flooded acres that are the appropriate depth and velocity provide fish cover and food. Additionally, the potential to minimize the impact of stressors for juveniles via channel capacity are linked in that improved bioenergetic conditions on floodplains can increase the threshold for temperature tolerance in juveniles (Sommer et al. 2001, Poletto et al. 2017). Greater channel capacity also produces collateral benefits such as better flood protection and lower channel maintenance.

To inform the selection of a suitable channel capacity target in the Funding Constrained Framework, an interrelated suite of analyses was synthesized. Five aspects of channel capacity were analyzed and synthesized here: (1) available volume of Restoration Flows dictated by the Restoration Allocation, (2) likelihood of flood flows, which may accomplish restoration objectives without the limitations prescribed by channel capacity constraints and preempt Restoration Flows, (3) temperature–flow relationships, (4) rearing habitat–flow relationships, and (5) riparian vegetation recruitment potential by channel capacity. The analysis presented here examines water temperature at the head of Reach 4A (i.e. Sack Dam) and at the head of Reach 5. It examines the physical characteristics of rearing habitat in Reaches 1B, 2A, 2B and 3. Rearing habitat is also found in Reach 4 and 5, and potentially the Eastside bypass, however those lower sections of the Restoration Area were excluded from this analysis for simplicity. It is assumed that all water is routed through the Eastside Bypass instead of entirely or partially through Reach 4B. A discussion is also presented examining a somewhat higher channel capacity above Sack Dam than below it in lieu of a consistent channel capacity throughout the Restoration Area. The analysis focuses on Normal-Wet and Wet year types (representing a 50% probability across all years) with the understanding that while other year types are biologically important, wetter year types are presumed to have higher flow rates than the drier year types. Capacity constraints are not likely to limit drier year types if they are adequate for the larger Restoration Allocation available during wetter year types.

To synthesize these somewhat disparate data, six discrete flow scenarios were developed with input from fisheries experts among the Settlement Implementing Agencies and Technical Advisory Committee (TAC). The flow scenarios, labeled A through F, articulate Restoration Flow schedules, each of which have their own resultant water temperature and rearing habitat. The flow scenarios were developed with the goal of optimizing adult spring-run migration (upstream movement) and juvenile spring-run and fall-run outmigration (downstream movement or emigration). The migration of fall-run adults expected to occur October through December was not analyzed, as the available flows during that period are not anticipated to be constrained by future channel capacities.

The flow scenarios encompass a range of likely flow strategies, avoid unrealistic or unproductive flow schedules, and are assembled by various flow components (e.g. pulse flow, inundation flow, ramp-down, base flow, etc.). They each represent a strategic release of water to achieve biological and geomorphic objectives. They are not to be taken as encyclopedic and exact; instead, the scenarios capture the range of flow release strategies likely to be used over the next 10+ years. If all scenarios are achievable under a particular channel capacity, then there is reasonable assurance that a wide range of tools are available to the Program unhindered by channel capacity. The application of these flow scenarios across four different hydrologic conditions, spanning from the low end of Normal-Wet upward to Wet conditions, yields a suitable range of channel capacities. Selection of a channel capacity above this range is likely to result in higher costs associated with easements, levee improvements, and structure design, and a diminishing cost–benefit ratio. Selection of a channel capacity below this range is unlikely to provide adequate tools for restoring a successful fishery in Stage 1.

The TAC has previously developed a set of “template hydrographs” that distribute water in a logical manner given the uncertainty in Restoration Allocation, flood flows, and other factors. The length of floodplain inundation in the TAC templates is generally shorter than what is currently being discussed by fisheries experts as an ideal inundation period, and the template hydrographs assumed an unimpeded channel capacity of 4500 cfs. However, they provide a valuable starting point and inspiration for this discussion.

2.1 Relationship to Fisheries Framework

The *Fisheries Framework: Spring-run and Fall-run Chinook Salmon* technical report developed by the Program provides a complete articulation of fisheries objectives, including the definition of success, the identification of stressors, and survival across the entire salmon life cycle (Reclamation 2017). Many factors, such as genetic diversity, spawning gravels, and volitional passage are critically important to success, yet are not directly linked to channel capacity and are thus not analyzed here. It is worth noting that one of the parameters for the Restoration Goal of self-sustaining fish populations in good condition, or the conservation biology concept of Viable Salmonid Population described in the *Fisheries Framework*, is spatial structure with the attribute for resilience to catastrophic events (Reclamation 2017). Channel capacity does influence spatial structure through the establishment of vegetation on the floodplain, which then provides food, cover, and resistance to erosion, among other ecological benefits.

The stressors to spring-run and fall-run Chinook salmon in the Restoration Area have also been identified in the *Fisheries Framework*. Through the period of 2020–2024 and beyond, the most significant stressors are expected to be (1) inadequate flows, (2) high water temperatures, and (3) predation. Inadequate flows are directly linked to channel capacity. High water temperatures are strongly influenced by channel capacity, among other factors. Predation is only indirectly influenced by channel capacity. Thus, the constraints imposed by channel capacity have a fundamental influence on the ability to meet fisheries objectives and operate over the life stages of adult migration and juvenile rearing and outmigration. Other life stages such as spawning, adult holding, egg incubation/emergence, and ocean phase are not directly affected by the range of channel capacities currently being discussed. For example, although water temperature is a factor for adult holding, the existing channel capacity is expected to be adequate to control summer water temperatures throughout the relevant reach. The relationship between channel capacity and the life stages and stressors identified in the *Fisheries Framework* is shown in Table 2-1.

Table 2-1. Relationship of the Channel Capacity Constraint to Life Stages and Stressors.

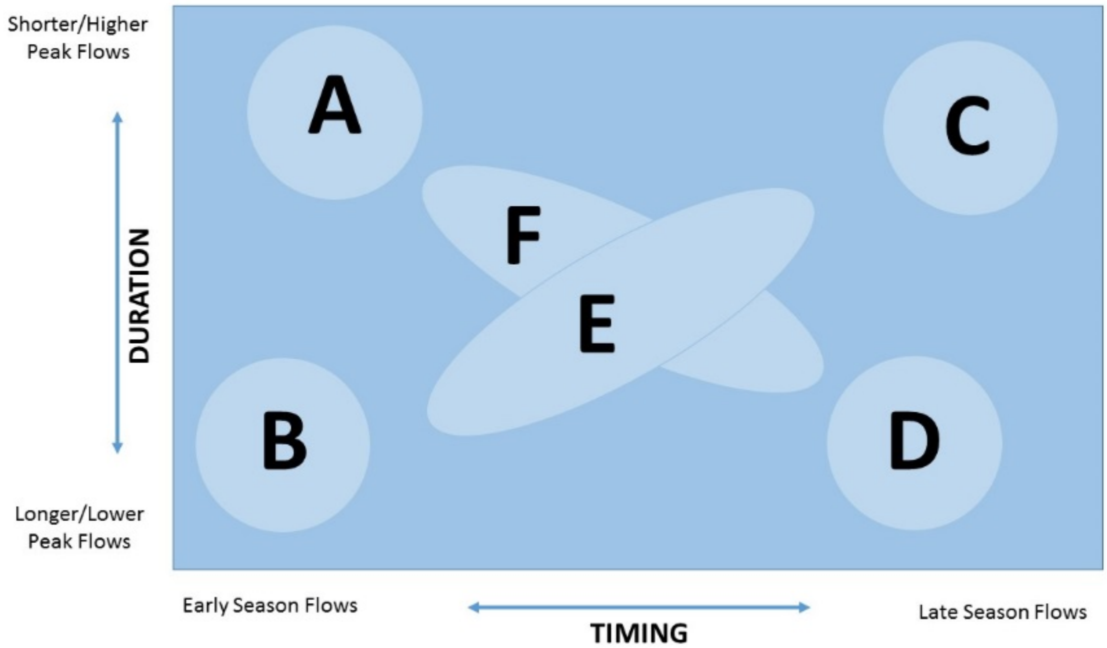
Constraint	Life Stage Affected	Stressor Affected	Operating Factors
Inadequate channel capacity to convey flows through all reaches	Adult migration	High water temperatures	Timing and amount of flows, shade (floodplain vegetation)
	Juvenile rearing and outmigration	High water temperatures	Timing and amount of flows, shade (floodplain vegetation)
		Inadequate food resources	Timing and amount of flows, floodplain vegetation
		Predation	Indirectly – timing and amount of flows, cover (floodplain vegetation)
		Lack of cover	Timing and amount of flows, floodplain vegetation

2.2 Flow Scenario Concept

Six flow scenarios have been developed in conjunction with input from fisheries experts. The flow scenarios are expected to be viable alternatives for the 10 years following Stage 1 completion (2024–2033) and factor in reasonable uncertainties. Uncertainties include seasonal temperature variations, interannual variations in hydrology, outmigration and migration timing of salmonids, changes in scientific knowledge, and plasticity in fish behavior – particularly in response to flow changes and temperature. Given the relatively short time horizon of the Funding Constrained Framework (approximately 10 years), any change in climate is likely to be handled within the range of flow actions encompassed by the scenarios. Each flow scenario has been adjusted to ensure it provides some degree of water temperature control and floodplain inundation, though the relative balancing of these two objectives varies from one flow scenario to another. Each flow scenario fully expends the Restoration Allocation volume available in the various water year types, and expresses the limitations of that volume in terms of duration and magnitude of high flows.

It is important to recognize that channel capacity constraints only pertain to Restoration Flows; flood flows are released regardless of the limitations imposed upon the Program. Flood flows have the potential to meet restoration objectives at flow rates higher than the designed channel capacity. There is the potential for flood flows to be shaped to benefit the Restoration Program, within the constraints of safety of life and property; however, the degree to which flood flows achieve Restoration Goal objectives is beyond the scope of this analysis. The likelihood of flood flows increases with wetter hydrologic conditions. The propensity for flood flows under certain conditions is discussed later in this analysis.

A diagram of the six flow scenarios is conceptually depicted by plotting inundation flow duration with inundation flow timing (Figure 2-1). These flow scenarios represent various degrees of compromise between rearing habitat area, duration of floodplain inundation, water temperature control, and timing of adult migration and juvenile outmigration.



Scenarios A through D establish the corners of the scenario space and are the extreme cases of what is likely to be a future flow schedule. Scenario E is an average of the available possibilities, and represents a quasi-hybrid of Scenario B and C. Scenario F is a quasi-hybrid of Scenario A and D, with some similarities to the "template hydrographs" developed by the TAC.

Figure 2-1. Conceptual Diagram of the Six Flow Scenarios.

3.0 Flow Scenarios

The following flow scenarios, labeled A through F, depict Restoration Flows at Gravelly Ford (GRF), at the end of Reach 1B and the head of Reach 2A. The scenario hydrographs apply three discrete accounts of water from within the Restoration Allocation volume:

1) Base flows that extend from May 1 through February 28. For this analysis, they are unchangeable;
2) Spring flows from March 1 through April 30 that can be applied flexibly between February 1 and May 28; and
3) Riparian Recruitment Flow, which is only available in the upper range of Normal-Wet and Wet year types, and can be applied as a gradual ramp-down after the peak spring flows. All scenario hydrographs fall within permissible flow schedules as described by the Restoration Flow Guidelines. Note that the availability of Riparian Recruitment Flow in the upper range of Normal-Wet is in dispute and that volume of water may be moved to spring flows in a future edition of the Restoration Flow Guidelines.

No additional Restoration Flow volume from Buffer Flows or Unreleased Restoration Flow (URF) exchanges are included in this analysis. Buffer Flows, if included, could potentially add up to 10% more to the daily flow rate (e.g. a 2000 cfs flow would become a 2200 cfs flow with the addition of Buffer Flows). Additionally, a flexible volume of up to 5000 acre-feet could be applied in the spring period on top of the 10% daily increment.

The Restoration Allocation, the volume of water available to the Program, is set and adjusted numerous times between January 20 and July 1, based on the forecasted full natural flow (FNF, also known as the unimpaired inflow or natural river) for Millerton Lake Reservoir behind Friant Dam. In years that are trending toward a Normal-Wet year type (between 1450 thousand acre-feet [TAF] and 2500 TAF FNF), the 75% exceedance forecast is used in February and the 50% exceedance is used in March through June. In years that are trending toward a Wet year type, the 50% exceedance is used throughout. Thus, there is roughly an equal chance that the Restoration Allocation will decrease or increase after March 1. This variability must be managed for in planning Restoration Flow releases. Confidence in the Restoration Allocation improves markedly in late April or early May as the snowfall season ends and the runoff season begins.

The available volume of water within the spring period that was analyzed, exclusive of Buffer Flows, is distributed over several flow components. These scenario hydrographs are both idealized and simplified, yet provide enough information to assess various biological and physical parameters. The flow scenario hydrographs are shown at Gravelly Ford in an idealized manner. In actuality, the distance between Friant Dam and Gravelly Ford will cause the hydrographs to be more smoothed — flows will increase and decrease less rapidly at Gravelly Ford. Further downstream, this attenuation will become more pronounced — sharp pulses and stark changes in flow will be significantly smoothed.

3.1 Flow Scenario Components

- **Pulse Flows –** these are modest pulses of a few hundred cfs and last only a few days, replicating a winter or spring freshet flow. These pulses prompt juvenile fish to mobilize, and can be used to encourage dispersal. They may provide a cue for migrating adults, though they would be nearly completely attenuated by the time the pulse arrived at the confluence with the Merced River. All flow scenarios except B utilize pulse flows. They are depicted as uniform sharp pulses reaching 1000 cfs; in practice they may be higher or lower depending on the timing and relationship to the remaining hydrograph. For the purposes of this analysis, pulse flows are depicted in February; however, they can be employed in other months and atop other flow components. For example, a pulse flow can be added atop a ramp-down.

- **Flow for Temperature Control –** this is the minimum flow during the spring period required to maintain a wetted low water channel, provide sufficient attraction and upstream fish passage for migrating adult spring-run Chinook salmon, and maintain non-lethal water temperatures for adult migrating fish in Reach 5. These bench flows are adjusted to account for the travel time of flows from Gravelly Ford to Reach 5, and they increase on a schedule such that they cover one standard deviation of timing in the water temperature model (see Section 4.8 and Appendix B for further discussion). These bench flows are set at 255 cfs in February and early March, increase gradually until mid-March, then increase sharply after that to compensate for warming air temperatures. This flow component is capped at 1000 cfs; temperature control beyond that point will require an additional flow component, or a flood flow. Temperature control flows are continued at 1000 cfs through April 17 at Gravelly Ford, the date at which the lethal temperature threshold for adult migrants is reached in Reach 5 for the lower standard deviation of temperature and considering flow travel time.

- **Riparian Recruitment Flow –** similar to a ramp-down (see below), these are available in Wet year types and the upper range of Normal-Wet year types to provide conditions for natural riparian vegetation establishment and recruitment on floodplains. These are typically scheduled after May 1 when conditions are optimal for vegetation growth (and typically after the period critical for adult migrating salmon) and recede more gradually than a normal ramp-down. The timing of Riparian Recruitment Flow is approximately shown in the flow scenarios. The actual timing will depend upon anticipated flood flows and the phenology of the species targeted for recruitment. Most recruitment flows would begin between May 15 and June 15, possibly later.

- **Contingency Volume –** a quantity of water that is scheduled near the end of the spring flexible flow period that is sacrificial should the Restoration Allocation diminish due to a changing runoff forecast. If the Restoration Allocation holds steady or increases, this contingency volume can be applied to extend floodplain inundation flows, ramp-downs, or other purposes. Typically, the Restoration Allocation does not change significantly after late April; thus, this contingency volume would be held until at least April 20 before being released or devoted to another purpose. In the following flow scenarios, it is depicted as a block flow (no ramp-down) for simplicity. Scenarios D and F do not have a specific contingency volume; instead, the last several days of the planned inundation flow can be curtailed if the Restoration Allocation shrinks.

- **Floodplain Inundation Flow –** this high flow over an extended period is designed to inundate a floodplain to a particular depth and flow velocity in order to provide juvenile rearing habitat. The degree of inundation (dictated by the flow rate), the period of inundation, and the timing of inundation are the critical factors in the efficacy of these flows. The magnitude of each inundation flow is the maximum possible given the intended duration after other flow components are accounted for. In this analysis, they are shown as stable bench flows of a constant flow rate; in reality these inundation flows would have a slight drawdown followed by a re-inundation to maximize food production for juvenile fish.

- **Ramp-down –** this is a gradual change in flow rate after a high flow or inundation flow that is designed to gradually reduce depth of water over a floodplain so that fish do not become stranded. Ramp-downs are designed to be slower when the floodplain is inundated to minimize stranding (above approximately 1300 cfs), and somewhat faster when the river is within its banks to conserve allocation volume (below approximately 1300 cfs). The ramp-down rates depicted into the six flow scenarios are approximate. It may be prudent to ramp-down flows even more gradually over a wider span of time, in which case the ramp-down component would require more volume, and inundation flows would be correspondingly lower. Flows will be naturally attenuated downstream, such that ramp-down rates will be slower than depicted below Gravelly Ford, to the benefit of fisheries. In addition to a ramp-down, there is a brief ramp-up prior to a high flow to meet certain dam safety requirements incorporated into this flow component. The ramp-downs and ramp-ups are deterministically driven by the floodplain inundation flow component such that higher inundation flows result in longer ramp-downs.

3.2 Flow Scenarios

The six flow scenarios represent the range of strategic approaches that are expected to be taken with spring flows in Wet and Normal-Wet year types (Figure 3-1a–c). The scenarios were developed independent of and unconstrained by any projected channel capacity. The predominant control and what differentiates one scenario from another is the duration of the floodplain inundation flow(s) and the timing of the initiation of the inundation flow(s). Scenarios with shorter and higher inundation pulses (A and C) are intended to maximize success for a portion of the adult and juvenile salmon population, focusing effort (flow) among a smaller fraction of the total population. This is a “leveraged” approach. Scenarios with longer and lower inundation pulses (B and D) are intended to provide modest success for a larger portion of the adult and juvenile salmon population and compensate for uncertain conditions such as adult arrival time, juvenile growth rates, climate, etc. This is then a “hedged” approach. The latter two of the six scenarios (E and F) are “blended” approaches, hybridizing elements of other strategies.

The inundation flow duration in each of these flow scenarios is shown for a longer period than had been assumed under the default hydrograph of Exhibit B in the Settlement (Appendix D). The default hydrograph shows the maximum inundation flow period occurring for 15 days in late April. It is reasonable to assume that the default hydrograph was never intended to be implemented exactly as shown, and the flexible flow provisions in the Settlement provide substantial latitude to shape the volume of water associated with the spring flows. Because of several factors, including (1) the indication in the scientific literature that the optimal floodplain inundation period should be greater than 15 days, (2) the desire to have pulse flows and temperature control flows in addition to the inundation flows, and (3) the need to have gradual ramp-downs, all of the flow scenarios have substantially lower peak flow rates than is indicated in the default hydrograph. This reduces the demand for channel capacity as compared to the default hydrograph for the purposes of this investigation’s objectives.

The characteristics of each flow scenario and their strategic purpose are presented below. The scenarios should not be viewed as flow release alternatives to be selected; rather they are intended to capture the range of reasonable flow release strategies into the future. Throughout the document, these six flow scenarios are compared for the purpose of understanding the relationship between channel capacity and the two critical fisheries objectives of water temperature control and rearing habitat. The reader is discouraged from selecting an "optimal" flow scenario and discounting the others.

3.2.1 Flow Scenario A — Early-season inundation with a 20-day duration inundation flow

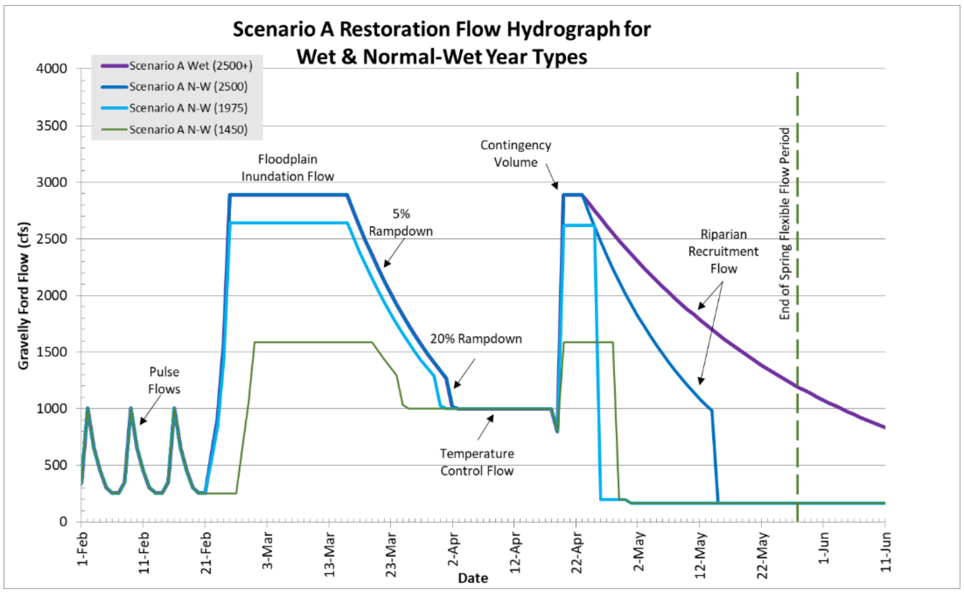


Figure 3-1a. Flow Scenario A.

This strategy is to spend the majority of Restoration Flow volume early with the expectation that flood flows will occur later in spring, to emphasize benefit to the cohort of early emigrating juveniles. The contingency volume and Riparian Recruitment Flow, if available, are released as early as practical.

- Modest pulse flows February 1 through February 20, that could be scheduled at other times of the spring as needed.
- Minimum flow to maintain temperature control, fish passage, and river connectivity.
- 20-day high (inundation) flow beginning February 25 to inundate floodplain for rearing habitat.
- 5% per day ramp-downs above 1300 cfs, 20% ramp-downs below 1300 cfs.
- Lower & mid-range of Normal-Wet years (FNF of 1450 TAF to 1975 TAF, respectively)
  - Retention of 28 TAF for contingency of shrinking Restoration Allocation (equivalent to 200 TAF FNF into Millerton for forecast errors), to be released on April 20 as second floodplain inundation flow, late pulse flow to move juveniles downriver, as a temperature control flow, or "bridging" of any flood flows that

may occur if contingency volume is not needed to cover a Restoration Allocation shortfall.

- Wet years & upper range of Normal-Wet years (FNF of above 1975 TAF)
  - Retention of 14 TAF for contingency of shrinking Restoration Allocation (equivalent to 100 TAF FNF into Millerton for forecast error), to be released on April 20 to produce a second floodplain inundation peak against which to abut Riparian Recruitment Flow or as late pulse flows to move juveniles downriver, as a temperature control flow, or as a bridge between flood flows if contingency volume is not needed to cover a Restoration Allocation shortfall.
  - Utilize Riparian Recruitment Flow as additional contingency if needed for shrinking Restoration Allocation, and/or as Riparian Recruitment Flow that gradually ramps down over a period of 60–90 days in Wet year types, and more abruptly otherwise.

3.2.1 Flow Scenario B — Early-season inundation with a 60-day duration inundation flow

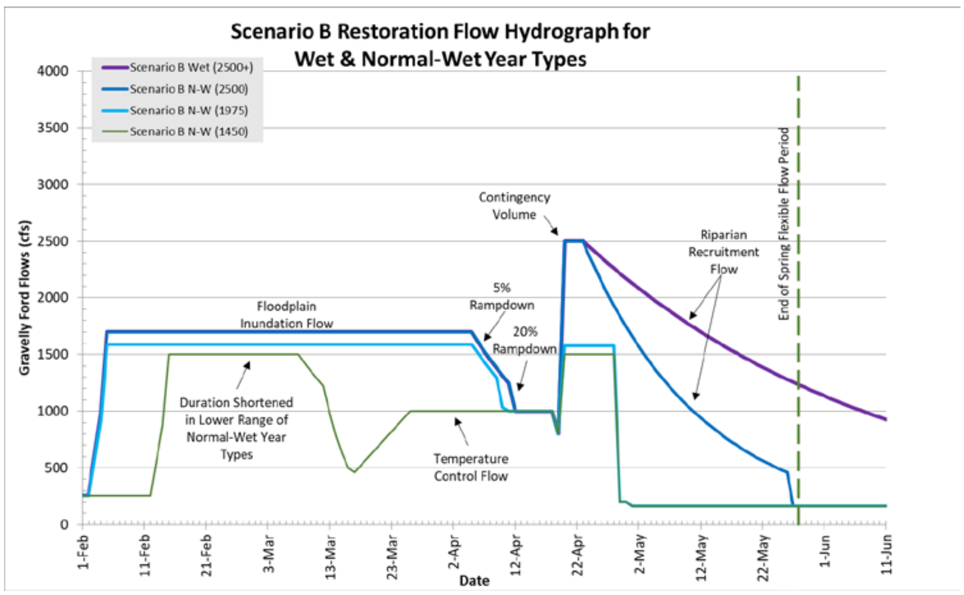


Figure 3-1b. Flow Scenario B.

This strategy is to maximize the period of floodplain inundation, to have a longer period to attract adult migration when arrival is uncertain, and to provide modest habitat for diverse cohorts of emigrating juveniles (i.e. pulse, early, and late juveniles). The contingency volume and Riparian Recruitment Flow, if available, are released as early as practical.

- Minimum flow to maintain temperature control, fish passage, and river connectivity.
- 60-day high (inundation) flow beginning February 5 to inundate floodplain for rearing habitat.
- 5% per day ramp-downs above 1300 cfs, 20% ramp-downs below 1300 cfs.
- Lower & mid-range of Normal-Wet years (FNF of 1450 TAF to 1975 TAF, respectively)

    - Retention of 28 TAF for contingency of shrinking Restoration Allocation (equivalent to 200 TAF FNF into Millerton for forecast errors), to be released on April 20 as second floodplain inundation flow, late pulse flow to move juveniles downriver, as a temperature control flow, or bridging of any flood flows that may occur if contingency volume is not needed to cover a Restoration Allocation shortfall.
    - Shorten inundation flow duration below midpoint of Normal-Wet years to achieve at least 1500 cfs floodplain inundation.
- Wet years & upper range of Normal-Wet years (FNF of above 1975 TAF)
    - Retention of 14 TAF for contingency of shrinking Restoration Allocation (equivalent to 100 TAF FNF into Millerton for forecast error), to be released on April 20 to produce a second floodplain inundation peak against which to abut Riparian Recruitment Flow or as late pulse flows to move juveniles downriver, as a temperature control flow, or as a bridge between flood flows if contingency volume is not needed to cover a Restoration Allocation shortfall.
    - Utilize Riparian Recruitment Flow as additional contingency if needed for shrinking Restoration Allocation, and/or as Riparian Recruitment Flow that gradually ramps down over a period of 60–90 days in Wet year types, and more abruptly otherwise.

3.2.2 Flow Scenario C — Late-season inundation with a 20-day duration inundation flow

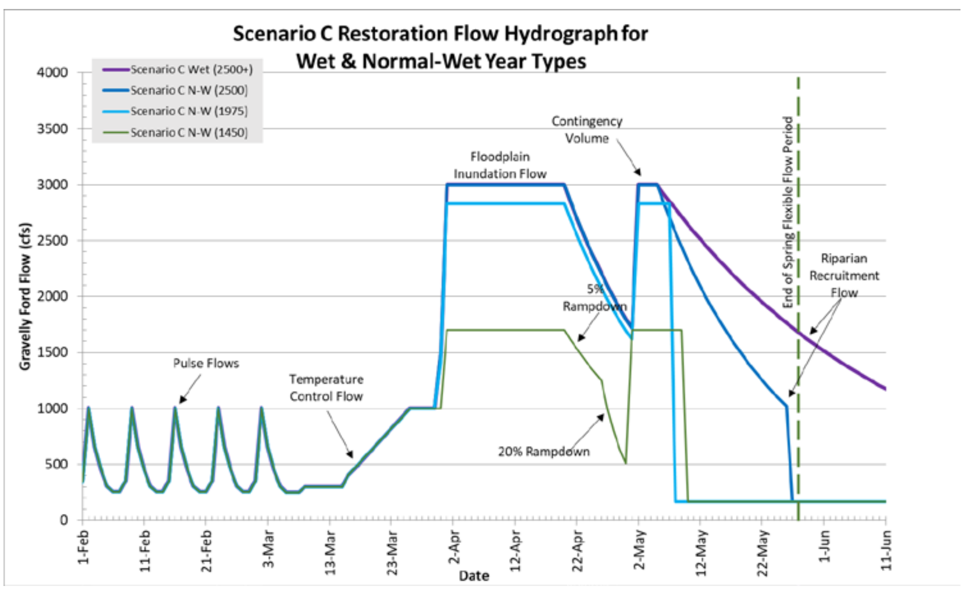


Figure 3-1c. Flow Scenario C.

This strategy is to create a high inundation flow to maximize rearing habitat over a shorter period of time and release the majority of the spring flexible flow volume later in spring in order to have inundation flows simultaneously provide temperature control late into the spring.

- Modest pulse flows February 1 through March 5, that could be scheduled at other times of the spring as needed.
- Minimum flow to maintain temperature control, fish passage, and river connectivity.
- 20-day high (inundation) flow beginning April 1 to inundate floodplain for rearing habitat.
- 5% per day ramp-downs above 1300 cfs, 20% ramp-downs below 1300 cfs.
- Lower & mid-range of Normal-Wet years (FNF of 1450 TAF to 1975 TAF, respectively)
    - Retention of 28 TAF for contingency of shrinking Restoration Allocation (equivalent to 200 TAF FNF into Millerton for forecast errors), to be released after May 1 as second floodplain inundation flow, late pulse flow to move juveniles downriver, or bridging of any flood flows that may occur if contingency is not needed to cover a Restoration Allocation shortfall.
- Wet years & upper range of Normal-Wet years (FNF of above 1975 TAF)
    - Retention of 14 TAF for contingency of shrinking Restoration Allocation (equivalent to 100 TAF FNF into Millerton for forecast error), to be released after May 1 to produce a second floodplain inundation peak against which to abut Riparian Recruitment Flow or as late pulse flows to move juveniles downriver, as a temperature control flow, or as a "bridge" between flood flows if contingency volume is not needed to cover a Restoration Allocation shortfall.
    - Utilize Riparian Recruitment Flow as additional contingency if needed for shrinking Restoration Allocation, and/or as Riparian Recruitment Flow that gradually ramps down over a period of 60–90 days in Wet year types, and more abruptly otherwise.

3.2.3 Flow Scenario D — Late-season inundation with a 60-day duration inundation flow

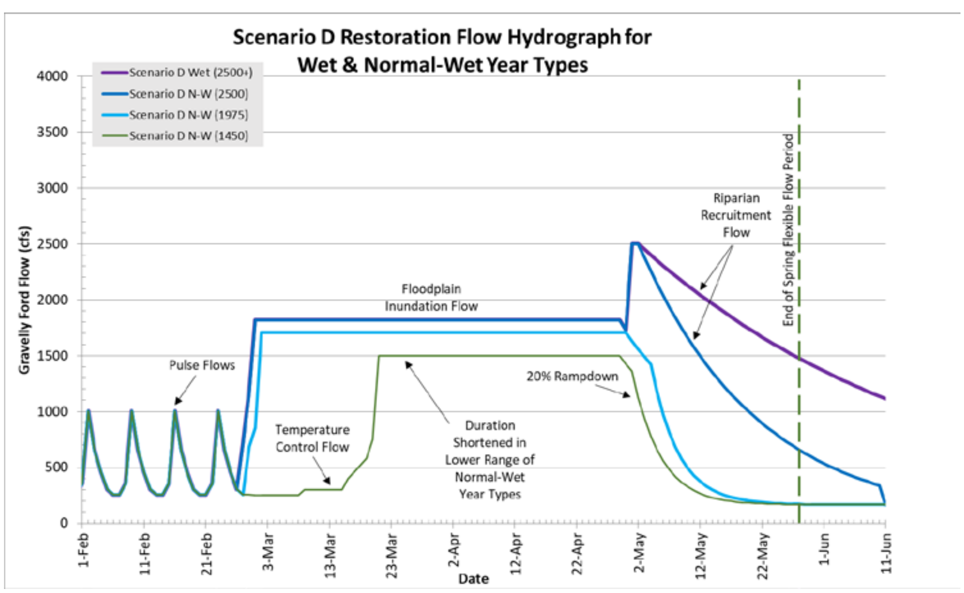


Figure 3-1d. Flow Scenario D.

Scenario D is similar to Scenario B and intended to maximize inundation duration. Unlike Scenario B, however, the initiation of inundation flow has been delayed to extend temperature control later into spring and utilize the latter portion of the inundation flow as a contingency flow in case of a shrinking allocation.

- Modest pulse flows February 1 through February 28, that could be scheduled at other times of the spring as needed.
- Minimum flow to maintain temperature control, fish passage, and river connectivity.
- 60-day high (inundation) flow beginning Mar 1 to inundate floodplain for rearing habitat.
- 5% per day ramp-downs above 1300 cfs, 20% ramp-downs below 1300 cfs.
- Lower & mid-range of Normal-Wet years (FNF of 1450 TAF to 1975 TAF, respectively)
    - No retention of additional Restoration Allocation, use last several days of inundation flow for reduced Restoration Allocation contingencies.
    - Shorten inundation flow duration below midpoint of Normal-Wet years to achieve at least 1500 cfs floodplain inundation.
- Wet years & upper range of Normal-Wet years (FNF of above 1975 TAF)
    - No retention of additional Restoration Allocation, use last several days of inundation flow and/or Riparian Recruitment Flow for reduced Restoration Allocation contingencies.

3.2.4 Flow Scenario E — Mid-season inundation with a 40-day duration inundation flow

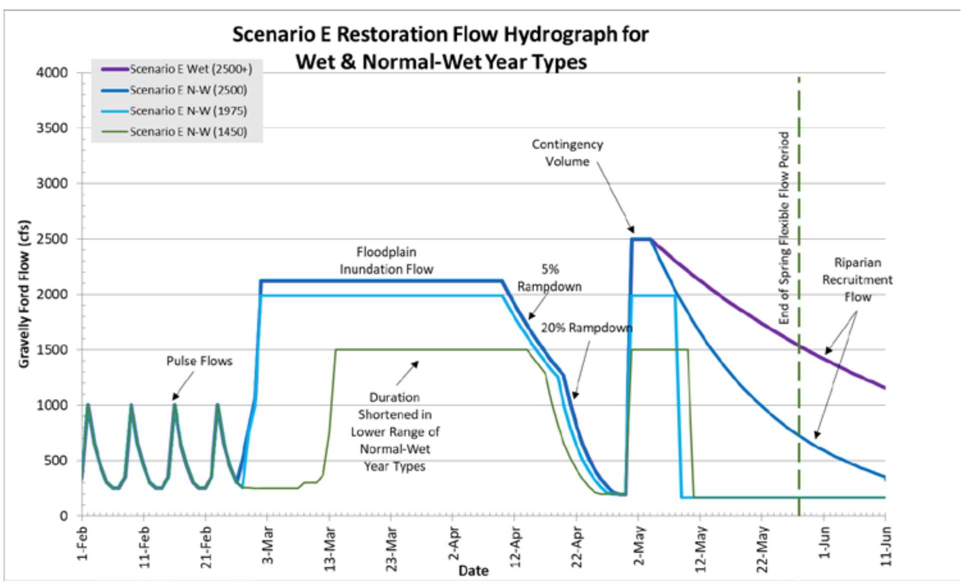


Figure 3-1e. Flow Scenario E.

This strategy is a blend of Scenario B and C, averaging their inundation period and timing. This is the middle-of-the-road strategy that has elements of protecting a diverse cohort of fish while trading some of that broad approach for somewhat higher inundation flows.

- Modest pulse flows February 1 through February 28, that could be scheduled at other times of the spring as needed.
- Minimum flow to maintain temperature control, fish passage, and river connectivity.
- 40-day high (inundation) flow beginning March 1 to inundate floodplain for rearing habitat.
- 5% per day ramp-downs above 1300 cfs, 20% ramp-downs below 1300 cfs.
- Lower & mid-range of Normal-Wet years (FNF of 1450 TAF to 1975 TAF, respectively)
  - Retention of 28 TAF for contingency of shrinking Restoration Allocation (equivalent to 200 TAF FNF into Millerton for forecast errors), to be released after May 1 as second floodplain inundation flow, late pulse flow to move juveniles downriver, as a temperature control flow, or bridging of any flood flows that may occur if contingency is not needed to cover a Restoration Allocation shortfall.
- Wet years & upper range of Normal-Wet years (FNF of above 1975 TAF)
  - Retention of 14 TAF for contingency of shrinking Restoration Allocation (equivalent to 100 TAF FNF into Millerton for forecast errors), to be released after May 1 to produce a second floodplain inundation peak against which to abut Riparian Recruitment Flow or as late pulse flows to move juveniles downriver, as a temperature control flow, or as a bridge between flood flows if contingency is not needed to cover a Restoration Allocation shortfall.
  - Utilize Riparian Recruitment Flow as additional contingency if needed for shrinking Restoration Allocation, and/or as Riparian Recruitment Flow that gradually ramps down over a period of 60–90 days in Wet year types, and more abruptly otherwise.

3.2.5 Flow Scenario F — Early and late-season inundation with two 20-day duration inundation flows

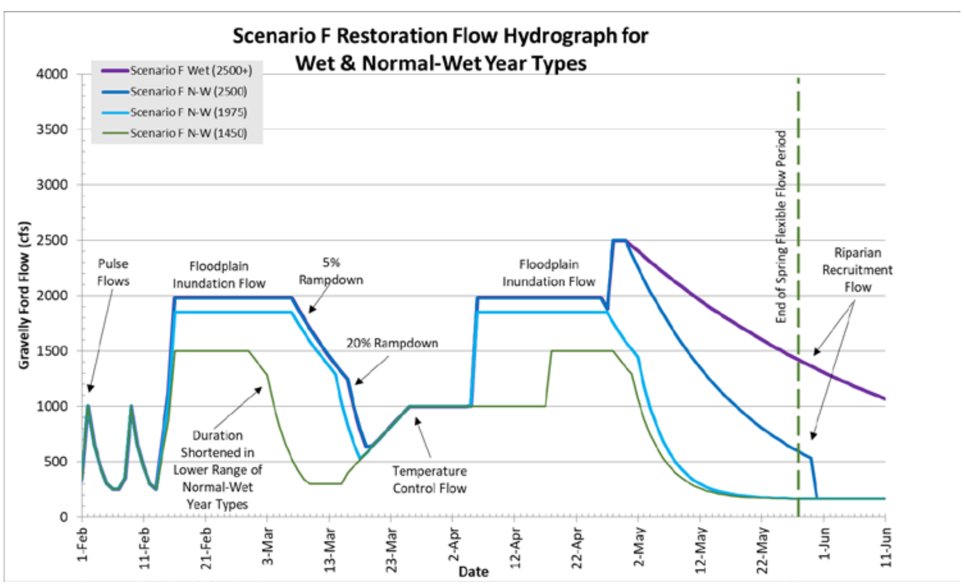


Figure 3-1f. Flow Scenario F.

This strategy is a blend of Scenario A and D, with dual inundation flows with different timing, emphasizing early and late cohorts and using the second inundation flow as temperature control and also as a contingency flow in case of a shrinking allocation. This scenario is closest to the template hydrograph approach developed by the TAC.

- Modest pulse flows February 1 through February 15, that could be scheduled at other times of the spring as needed.
- Minimum flow to maintain temperature control, fish passage, and river connectivity.
- 20-day high (inundation) flow beginning February 15 to inundate floodplain for rearing habitat.
- 5% per day ramp-downs above 1300 cfs, 20% ramp-downs below 1300 cfs.
- Additional 20-day high (inundation) flow beginning April 5 to inundate floodplain and rear juvenile salmon.
- Lower & mid-range of Normal-Wet years (FNF of 1450 TAF to 1975 TAF, respectively)
    - No retention of additional Restoration Allocation, use last several days of second inundation flow for reduced Restoration Allocation contingencies.
    - Shorten inundation flow duration below midpoint of Normal-Wet years to achieve at least 1500 cfs floodplain inundation.
- Wet years & upper range of Normal-Wet years (FNF of above 1975 TAF)
    - No retention of additional Restoration Allocation, use last several days of second inundation flow and/or Riparian Recruitment Flow for reduced Restoration Allocation contingencies.

3.3 Flow Scenario Discussion

SJRRP Implementing Agencies were given the opportunity to evaluate the flow scenarios for both their ability to capture the range of conditions and flow strategies likely to be utilized, and in terms of their utility to meet the current understanding of the fishery. All respondents concluded that the flow scenarios covered the range of potential release strategies, at least in general hydrograph shape and strategy. Flow Scenario A was modified from its original design based on feedback from fisheries agencies; the inundation flow was moved later into the spring by 10 days to make it more pragmatic. Flow Scenario C was optimized for migrating adult water temperature thresholds by moving the inundation earlier by 5 days. And finally, Flow Scenario F was adjusted to move both inundation flows earlier by 5–10 days.

Based on the temperature analysis (Section 4.8 and Appendix B), the temperature control flow component was revised from its original design. The analysis indicated that slightly less flow was needed to maintain non-lethal water temperatures for adult salmon in February and March, with significantly more flow necessary to maintain non-lethal water temperatures for adults in April. This temperature control flow was capped at 1000 cfs for the development of these six flow scenarios; thus, unless there was a high inundation flow, flood flow, or Riparian Recruitment Flow to address impending temperature thresholds, water temperatures would continue to climb in each scenario’s temperature response after certain point during the late spring. If the temperature control flow was left uncapped, it would have consumed the entirety of the available volume of water to the detriment of inundation flows for rearing habitat. An example of a flow scenario solely addressing temperature control is provided in Appendix E for reference. Other small adjustments were made based on expert feedback to ensure that the flow scenarios realistically captured the range of foreseeable flow releases. All of the analyses incorporated these adjustments to the flow scenarios.

The adjustments to the flow scenarios increased confidence that each scenario was a reasonable strategy to release Restoration Flows, and thus an appropriate test for investigating channel capacity selection. The collection of flow scenarios would provide reasonable balances between temperature control and rearing habitat, and would provide adequate flexibility for the Restoration Administrator to respond to changes in the Restoration Allocation.

Throughout this technical memorandum, the performance of the six flow scenarios relative to water temperature influence and rearing habitat is compared. Comparisons are intended to fully describe the flow scenarios and to communicate the relative trade-offs between these somewhat competing objectives. Comparisons are not made to promote the selection of the preferred scenario or best flow strategy. We encourage the reader to consider all of the flow scenarios as plausible strategies given the current state of knowledge of hydrology and biology on the San Joaquin River. To provide additional understanding as to the trade-offs and nuances of the flow strategies, qualitative assessments regarding the flow scenarios provided by fisheries experts are presented in Table 3-1 below.

Table 3-1. Expert Qualitative Assessment of Flow Scenarios.

Flow Scenario	Comments
A	Inundation period may be too short in duration and too early in the season, though this strategy may be employed when flooding later in the spring is certain to maximize the biological utility of flood flows and the Restoration Allocation.
B	Inundation period may be too early in the season based on our current estimate of juvenile outmigration timing; however, if temperatures prove to be higher expected early in spring, this scenario could be ideal.
C	Best flow release for temperature control during adult migration and late spring. Shorter inundation period may restrict juvenile rearing and growth potential. May be more advantageous to fall-run juveniles than spring-run juveniles. Resembles the natural hydrograph in certain circumstances.
D	Given current understanding of biology, thought by some experts to be most advantageous compromise for both rearing habitat and temperature control.
E	An intermediate compromise between optimizing rearing habitat area, rearing habitat duration, and temperature control. Resembles the natural hydrograph in certain circumstances.
F	An intermediate compromise between optimizing rearing habitat area, rearing habitat duration, and temperature control. Resembles the natural hydrograph in certain circumstances.

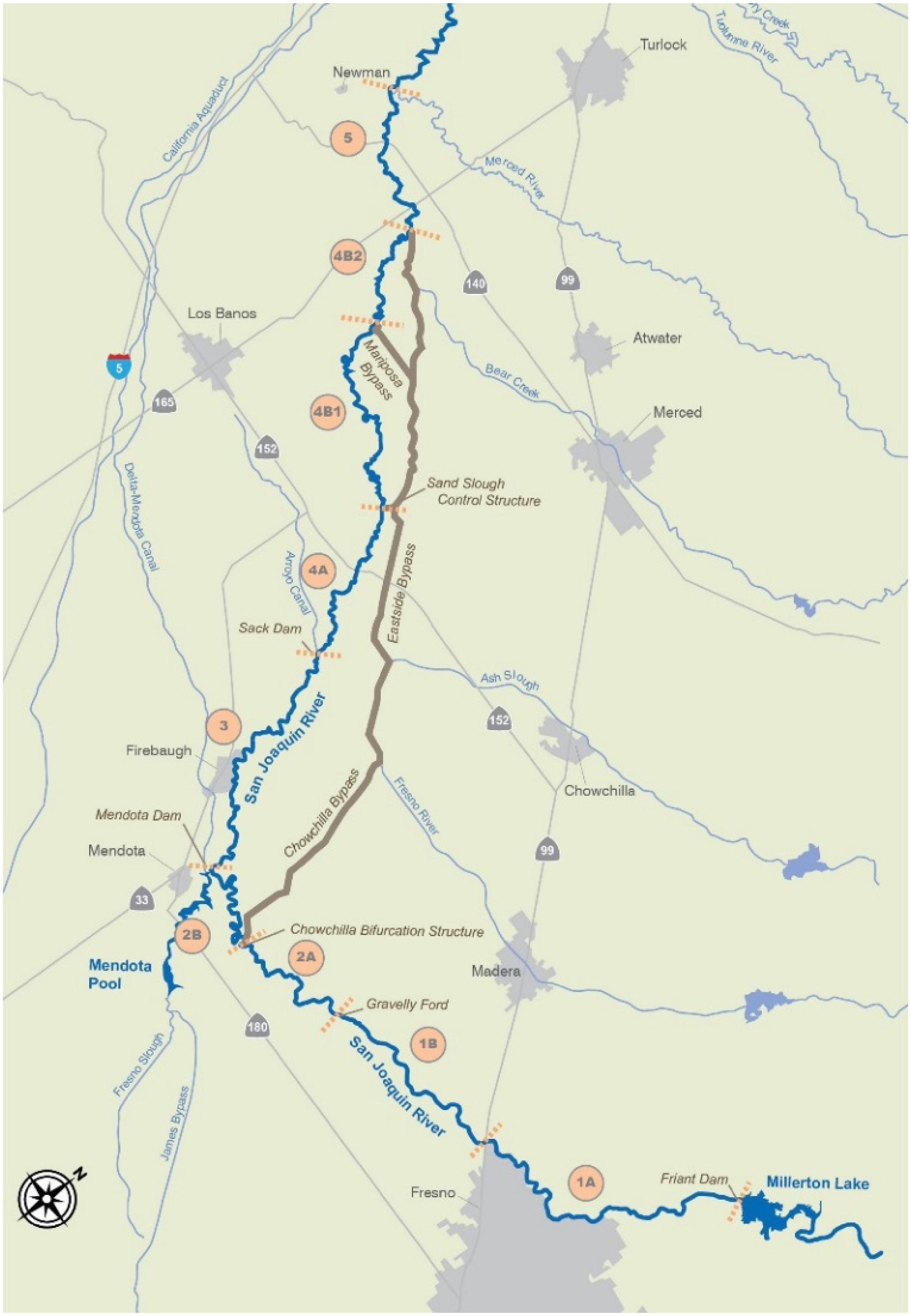
4.0 Technical Information & Methods

4.1 Scope of Analysis

Analysis aspects of the Restoration Allocation and flood frequencies were modeled at Friant Dam, Gravelly Ford, and at points downstream using reasonable assumptions of channel losses, diversion losses, and tributary inputs (See Figure 4-1). The temperature–flow analysis used a step-wise model of water temperature reach by reach, but results are expressed at the head of Reach 4 (i.e. Sack Dam) and at the head of Reach 5 for simplicity. The rearing habitat–flow analysis used a two-dimensional (2-D) hydraulic model separated by reach, with results expressed for Reach 1B, Reach 2A, Reach 2B, and Reach 3. Due to time constraints of preparing this analysis, Reaches 1A, 4A, 5, and the Eastside Bypass were not modeled. Additional information on the rearing habitat available in Reach 4A and 5 is available in the *Minimum Floodplain Habitat Area: for Spring and Fall-Run Chinook Salmon* technical report (Reclamation 2012b). Rearing habitat potential in Reach 4B and the Eastside Bypass is largely unknown. For clarity, relevant Restoration Flow rates and volumes are depicted always at Gravelly Ford, and at other locations when applicable.

This analysis is intended to be relevant across a 10-year time frame. Factors such as future climate change and future subsidence, which have a strong influence over hydrology and land surface elevation over long time spans, were omitted for this relatively short time frame to be congruent with the temporal scope of the interim Funding Constrained Framework.

Because of the pattern of allowable Restoration Flow releases set forth in Exhibit B of the Settlement, channel capacities (in the range of 1000–4500 cfs) are only expected to be limiting during the period of the spring flexible flow period and the early portion of the Riparian Recruitment Flow. Thus, this analysis was limited to the months of February through June.

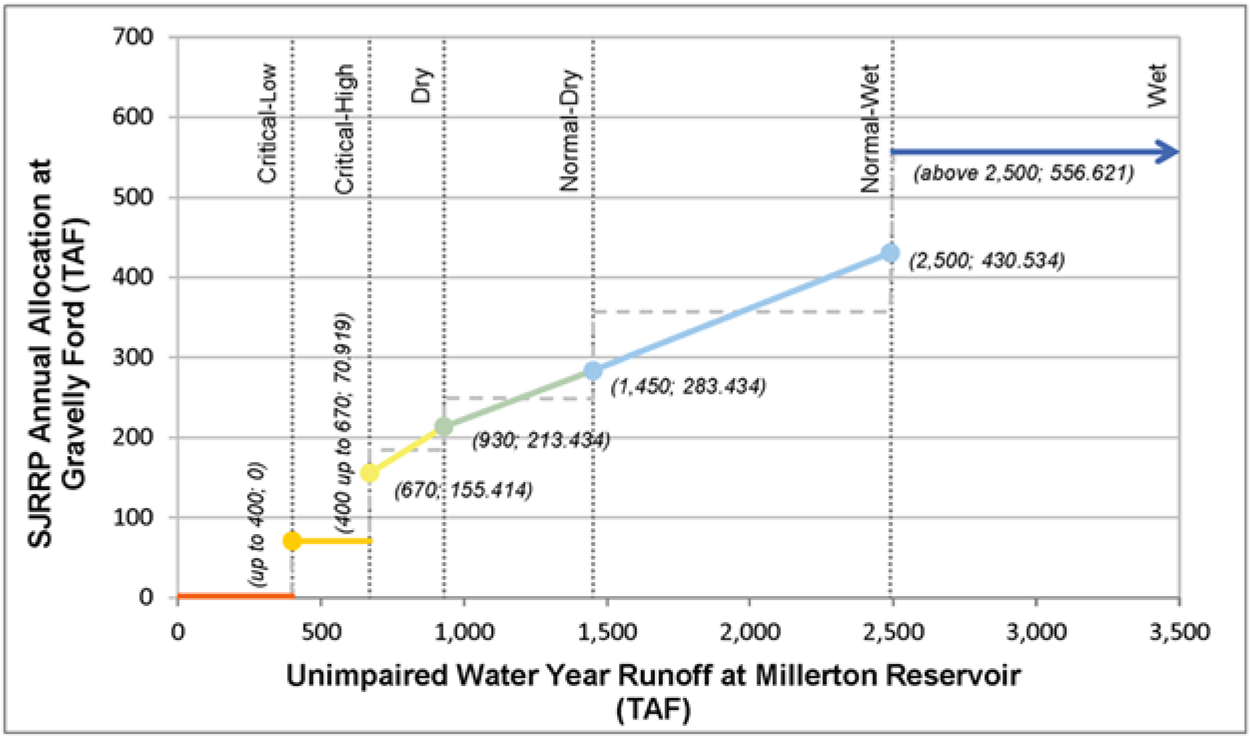


Reaches of the San Joaquin River are shown, stretching from Reach 1 to Reach 5 near the confluence with the Merced River.

Figure 4-1. Map of Restoration Area.

4.2 Restoration Allocation

Restoration Flow releases must result in a cumulative volume within the water budget provided by the Restoration Allocation. Table 4-1 depicts the relationship between runoff and Restoration Allocation. The total amount of the Restoration Allocation increases proportional to the forecasted runoff (Millerton FNF) from the lower range of the Dry year type to the upper range of the Normal-Wet year type. When the runoff is forecasted to be above 2500 TAF, it is a Wet water year type and the Restoration Allocation does not change with the runoff forecast. Instead, it is held static at 673.487 TAF at Friant Dam, or 556.542 TAF at Gravelly Ford (the volume at Gravelly Ford is less because of the flow losses and holding contracts in Reach 1). See Figure 4-2 for the total Restoration Allocation at Gravelly Ford and its relationship to runoff.



This graph indicates the volume of water that is available to the Program at Gravelly Ford as a function of FNF forecast.

Figure 4-2. Restoration Flow Allocation.

The spring flow period is from March 1 to April 30 in the Settlement Exhibit B, and the volume of water allocated during this period can be applied flexibly up to four weeks prior (February 1) and four weeks later (May 28). The volume of water allocated for the spring flow period is shown in Table 4-1, and maxes out at the midpoint of the Normal-Wet year type. Above the midpoint of Normal-Wet year types, Riparian Recruitment Flow is incrementally added proportional to the forecasted inflow until the upper-range of Normal-Wet year type is reached. Above that point, the volume available for Riparian Recruitment Flow jumps considerably, and is held constant at that volume for all Wet year types.

Table 4-1. Relevant Flow Allocations.

Year Type (FNF at Millerton Forecast)	Allocation at Friant Dam (TAF)	Allocation at Gravelly Ford (TAF)	Spring Flow Period at Gravelly Ford (TAF)	Riparian Recruitment Flow at Gravelly Ford (TAF)
Wet (> 2500 TAF)	673.487	556.542	239.552	199.637
Normal-Wet (2500 TAF)	547.400	430.454	239.552	73.549
Normal-Wet (1975 TAF)	473.850	356.904	239.552	0
Normal-Wet (1450 TAF)	400.300	283.354	166.002	0
Normal-Dry, Dry, Critical-High, Critical-Low (<1450 TAF)	<400.300	<283.354	<166.002	0

This table indicates the volume of water that is available to the Restoration Administrator in certain year types and hydrologic conditions. Spring period flows are increased with wetter hydrology until 1975 TAF forecasted FNF is reached. With wetter hydrology, volume is then added to the Riparian Recruitment Flow. Hydrologic conditions drier than 1450 TAF FNF were not considered in this investigation.

The Restoration Flow Guidelines provide for an additional water account of Buffer Flows that can be up to 10% of daily flow rates. For example, Buffer Flows could be applied to a 1000 cfs flow to produce an 1100 cfs flow rate. Additionally, there is a flexible volume associated with summer base flows that can be applied during the spring flow period if scheduled by the Restoration Administrator; this flexible Buffer Flow volume is limited to 5000 acre-feet. For the purposes of this analysis, Buffer Flows were not included in the flow scenarios.

Normal-Dry, Dry, Critical-High, and Critical-Low water year types were not included in this analysis. The volume of spring flows available in those year types is unlikely to allow a flow rate that exceeds the flow rates in the flow scenarios under Wet or Normal-Wet year types. Thus, if a particular flow scenario is viable in a Normal-Wet year for a particular channel capacity, it would be viable for a drier year type as well. For reference, the statistical frequency of year types is shown in Table 4-2.

Table 4-2. Statistical Frequency of Year Types.

<table>
<tr><th>Year Type
(FNF at Millerton Forecast)</th><th colspan="4">Statistical Frequency of Year Types</th></tr>
<tr><td>Wet (> 2500 TAF)</td><td>20%</td><td></td><td></td><td></td></tr>
<tr><td>Normal-Wet (2500 TAF)</td><td></td><td rowspan="2">13%</td><td></td><td></td></tr>
<tr><td>Normal-Wet (1975 TAF)</td><td></td><td rowspan="2">17%</td><td></td></tr>
<tr><td>Normal-Wet (1450 TAF)</td><td></td><td></td><td></td></tr>
<tr><td>Normal-Dry, Dry, Critical-High, Critical-Low (<1450 TAF)</td><td></td><td></td><td></td><td>50%</td></tr>
</table>

50% of year types are likely to be Wet or Normal-Wet. The overall frequency of Normal-Wet year types is 30%. This table breaks out that statistical frequency by the upper range and lower range of Normal-Wet. Because of the uncertainty in runoff forecasting, the final year type may not be known until later in the spring — it will be common for year types to change from January through March, with some occasional changes in April and May.

4.3 Flood Frequency Analysis

An analysis of the frequency of flood releases at Friant Dam and flood flows at James Bypass was conducted to determine the influence of such flood flows upon Restoration Flows. The SJRRP Daily Flow Model, a Riverware™ model combining the CalSim 2 hydrologic record and the expected SJRRP operations, was used to determine the likelihood that flood flows would displace Restoration Flows, and estimated the maximum floodplain inundation flow resulting from flood management actions that could be expected for a given duration. This model was extensively adjusted to incorporate recent understandings of San Joaquin River operations and recent changes to the Restoration Flow Guidelines, in particular the revised forecast exceedance progression adopted in February 2017 that determines the Restoration Allocation. Adjustments to Restoration Flows or flood releases in the model output were not fully mass-balanced; it was assumed that distribution of Unreleased Restoration Flows and/or 16b water (i.e. $10 water) would make up for the mass balance errors. Caution is urged to not overestimate the precision of the model output flood flow rate or flood flow frequency, though there is high confidence in the seasonal pattern and trends by water year.

The SJRRP Daily Flow Model, and the resulting flood frequencies, were driven by the default hydrograph from Exhibit B of the Settlement. The unique flow releases from each flow scenario were not run through the SJRRP Daily Flow Model. If each flow scenario was included, those that release water early (Flow Scenario A, B, and to some extent E and F) would have slightly lower flood frequencies in late February and March as compared to the default hydrograph.

A key consideration in selecting a channel capacity under the Funding Constrained Framework is the likelihood of flood flows occurring in a given month or year-type. Flood flows displace Restoration Flows, since both flood flows and Restoration Flows cannot be simultaneously released from Friant Dam, yet flood flows may serve some or all of the intended purpose of Restoration Flows. While Restoration Flows require adequate channel capacity for them to be released, flood flows are released based on a different, less conservative set of channel capacity assumptions. When such a displacement occurs and flood flows exceed the Restoration Flow schedule, the then-current schedule of Restoration Flows is debited from the Restoration Allocation as if those flows had been released, yet all of the water in the river is considered flood flows and is managed as such. Thus, while a larger allocation of water is available to the Restoration Administrator during Wet year types, there is less opportunity to release that water unfettered by flood management operations, including routing decisions.

The higher channel capacity requirements necessitated by a larger Restoration Allocation in Wet year types and the upper range of Normal-Wet year types is counterbalanced by the overall frequency of those year types (Wet = 20% of year types, upper range of Normal-Wet year types = 13%), and makes it likely that flood flows will accomplish some of the Restoration Flow objectives during the overwhelming majority of Wet year types and the minority of Normal-Wet year types. The SJRRP Daily Flow Model depicts a very high likelihood for flood flows between April 15 and June 25 in Wet year types (Table 4-3). The timing of Wet year and upper range of Normal-Wet year flood flows could substantially decrease late spring water temperatures for downstream emigrating juvenile salmon, and possibly provide additional improvement for juvenile rearing habitat, adult upstream migration, and riparian vegetation recruitment. On the other hand, during extremely wet hydrologic conditions, Millerton Lake is thoroughly flushed by high flows, significantly raising the release temperature from Friant Dam, likely resulting in higher water temperatures in the late spring and summer.

Table 4-3. Flood Flow Frequency.

Water Year Type	**Frequency of at Least a 15-Day Period Within a Month Being Flood Flows**				
	February	March	April	May	June
Wet (> 2500 TAF)	56%	75%	94%	100%	100%
Normal-Wet (1450-2500 TAF)	21%	21%	38%	28%	21%

This table depicts the frequency of years that are expected to have at least 15 days of flood flows for a given water year type–month combination. During Wet water year types, there is a high likelihood that Restoration Flows will be preempted by flood flows, increasing toward late May when there is near-certainty that flood flows will occur. This likelihood is reduced sharply in Normal-Wet year types. Thus, in wetter hydrology conditions, the Restoration Flow allocation is more likely to be utilized to “fill-in” before, between, and after flood flows than to produce an uninterrupted floodplain inundation flow.

Notes:
Based on SJRRP Daily Flow Model using an 82-year record of hydrology (1922-2003) — combined with Restoration Flow Operations and current water use patterns from Millerton Lake Reservoir.

Flood frequency was not broken out by the upper range and lower range of Normal-Wet year types, due to an inadequate number of samples from which to derive a suitably accurate monthly frequency; however, the likelihood of flooding is expected to be much lower in the lower range than the upper range of that year type.

In addition to rearing habitat and temperature control, adequate channel capacity for Restoration Flows is also sought to provide the appropriate suite of geomorphic processes that support a healthy river. High Restoration Flows have additional value, such as: scouring of the channel bed to reduce imbrication (hardening) of coarse sediment, flushing fine sediments from spawning gravels, providing disturbance for recruitment of willows, wetting floodplains for recruitment of cottonwoods, and enriching adjacent floodplains with nutrients. Such benefits may not materialize under certain flood flow characteristics (e.g. timing, ramp-down), and such high flows could be detrimental in some circumstances. To evaluate the potential for high flood flows, the SJRRP Daily Flow Model was used to summarize the frequency of flood flows by season (Table 4-4). Flood flows of 4000 cfs or greater for 15 days (an inundation flow) are expected to occur nearly one out of four years of the Wet and Normal-Wet types (which are half of all year types by statistical probability). Shorter duration 4000 cfs flows that mobilize river-bed sediment occur more frequently, especially in March and April.

Table 4-4. Frequency of Floods of a Given Magnitude Across Wet and Normal-Wet Year Types Combined.

Season	4000 cfs Flood Flow		8000 cfs Flood Flow	
	15-Day Flood Period (Inundating Flood)	3-Day Flood Period (Bed-Mobilizing Flood)	15-Day Flood Period (Inundating Flood)	3-Day Flood Period (Bed-Mobilizing Flood)
Winter (December – February)	2%	14%	2%	2%
Spring (March – April)	22%	64%	2%	4%
Summer (May – August)	14%	18%	6%	10%
In any month of a given year	**24%**	**66%**	**9%**	**13%**

These frequencies of occurrence should not be interpreted as exact, as the SJRRP Daily Flow Model they are based on has known inaccuracies and imprecisions; however, the relative trends and seasonal distributions are sound.

Flood releases from Friant Dam are managed to protect life and property, thus they may be ramped up or ramped down in a manner that is deleterious to fisheries objectives. During very wet hydrologic conditions, flood flows may not decrease water temperatures, and may actually increase water temperatures during much of the year as compared to a high Restoration Flow release. Flood flows may also be released in a manner that reduces the productivity of floodplains, thereby reducing rearing habitat, or in a manner that increases fish being stranded on floodplains. Additionally, flood flows may be routed through bypasses and not the designated restoration area, or they may be diverted for irrigation and other uses that result in lower than expected amounts of water.

There are significant uncertainties in the frequency, timing, characteristics, and resulting benefit that flood flows may provide to the Restoration Program. For approximately 33% of hydrologic conditions (in Wet and the upper range of Normal-Wet), the impact of flood releases upon the restoration activities will have to be closely managed. However, regardless of the resulting benefit or detriment of flood flows to restoration objectives, they do displace Restoration Flows, and thus channel capacity constraints do not influence Restoration Flows during those flood periods.

4.4 Stage Buffers

In the development of the flow scenarios, it became apparent that merely designing and building channel capacity to the upper limit of a flow scenario was inadequate. Reach 1 tributary inflows, such as Little Dry Creek and Cottonwood Creek, frequently add sharp pulses to the San Joaquin River during Restoration Flow operations. Furthermore, it is expected that the optimal flow schedule will include small pulses atop inundation flows in order to change the wetted floodplain area, temporarily dry out floodplain vegetation, and add a natural dynamism to rearing habitat. This will require an additional capacity for a change in river stage. These variable flows will be greatly attenuated downstream, such that a pulse at Friant Dam or from Little Dry Creek would likely be less than half of its amplitude by the time it transitioned to Gravelly Ford, and even less further downstream in Reach 2 through Reach 5.

To facilitate some margin for variability of inundation flows, stage–discharge relationships were developed for Reach 1B, 2A, and 3. These indicate the additional channel capacity that would be required for a 0.25-ft (3-inch) or 0.50-ft (6-inch) buffer. Reach 2B is expected to undergo significant changes in channel and floodplain morphology through the Reach 2B and Mendota Pool Bypass Project, and was not included. Because Reach 2A was the most constraining (i.e. had the greatest change in flow rate for a given increment of river stage), its stage–discharge relationship was used for the overall analysis. A reasonable increment for all reaches is thought to be 0.25-ft; however, a 0.50-ft buffer would provide additional flexibility for managing uncertainty. Using a stage buffer allows the Restoration Administrator to pulse atop inundation flows, vary the inundation flows gradually to maximize flood production for salmon, or to accommodate changes in riverbed elevation due to erosion or deposition, or to accommodate inaccuracies in flow gauges.

Incremental stage–discharge relationships indicated the flow rate in cfs that was required in three relevant reaches of the San Joaquin River to add an increment of depth to the water surface elevation (Tables 4-5a-c). An additional increment of depth is often needed to allow for variation or pulsing of floodplain inundation flows and to provide a buffer for flow imprecision.

Table 4-5a. Stage–Discharge Increments Reach 1B.

Flow Rate	Water Depth (ft)	cfs Range for ± 0.25 ft	cfs Range for ± 0.50 ft
1000 cfs	4.2	−60 / +80	−120 / +160
1500 cfs	5.1	−200 / +200	−400 / +400
2000 cfs	5.7	−200 / +200	−400 / +400
2500 cfs	6.4	−200 / +220	−400 / +450
3000 cfs	6.9	−220 / +240	−450 / +500
3500 cfs	7.4	−250 / +250	−500 / +500

Note: Based on USBR (2012a) Hydraulic Studies for Fish Habitat Analysis.
Note: Modeled water surface elevations tend to underestimate measured water surface elevations for Reach 1B.

Table 4-5b. Stage–Discharge Increments Reach 2A.

Flow Rate	Water Depth (feet)	CFS range for ± 0.25 feet	CFS range for ± 0.50 feet
1000 cfs	11.1	−180 / +220	−340 / +450
1500 cfs	11.6	−230 / +250	−450 / +500
2000 cfs	12.1	−250 / +260	−500 / +550
2500 cfs	12.5	−260 / +250	−550 / +500
3000 cfs	13.0	−250 / +270	−500 / +550
3500 cfs	13.4	−270 / +280	−550 / +600

Note: Based on XS 536528, a representative cross-section in Reach 2A above the influence of the Chowchilla Bifurcation Structure

Table 4-5c. Stage–Discharge Increments Reach 3.

Flow Rate	Water Depth (ft)	cfs Range for ± 0.25 ft	cfs Range for ± 0.50 ft
1000 cfs	7.7	−80 / +100	−160 / +200
1500 cfs	9.0	−90 / +120	−190 / +240
2000 cfs	10.0	−110 / +130	−240 / +260
2500 cfs	10.9	−120 / +140	−260 / +280
3000 cfs	11.8	−130 / +150	−280 / +320
3500 cfs	12.6	−160 / +160	−320 / +320

Note: Based on XS 336642 channel cross-section at the end of the reach.
Note: Modeled water surface elevations tend to underestimate measured water surface elevations for Reach 3.

4.5 Channel Losses and Diversions

Exhibit B of the Settlement provides loss estimates by reach, caused by various combinations of diversions, evaporation, transpiration, and seepage. Actual channel losses typically meet or exceed Exhibit B losses, and vary from reach to reach and month to month. An assumption was also made for Arroyo Canal deliveries, which are added at Mendota Pool and diverted into Arroyo Canal at Sack Dam. The average Arroyo Canal demand for February through April is nearly 200 cfs, and was applied as a flow adjustment. It was also necessary to incorporate travel times of flows through the Restoration Area for the temperature analysis.

Reach 3 is between Mendota Dam and Sack Dam, and there are normally irrigation flows present in this reach during the spring period being analyzed. As with channel losses, these adjustments are applied within the individual analyses; there is no need for the reader to further adjust the presented data for losses and travel time.

For example, using Table 4-6, a flow rate of 700 cfs at Gravelly Ford would result in 700 cfs (no adjustment) in Reach 2A, 600 cfs in Reach 2B (100 cfs loss for flow rates below 1000 cfs), 800 cfs in Reach 3 (200 cfs for Arroyo Canal deliveries), and 500 cfs in Reach 4 and Reach 5 (200 cfs diversion at Arroyo Canal and 100 cfs loss in Reach 4). This approximates the recently observed losses rounded to the nearest 100 cfs.

Table 4-6. Channel Losses and Flow Travel Time by Reach.

<table>
<tr><th>Reach</th><th>Location</th><th>Channel Losses Relative to Gravelly Ford Flows</th><th>Change in Flow from Diversions and Deliveries</th><th>Travel Time Relative to Gravelly Ford</th></tr>
<tr><td>Reach 1B</td><td>Above Gravelly Ford</td><td>No adjustment</td><td>No adjustment</td><td>– 1 Day</td></tr>
<tr><td>Reach 2A</td><td>Below Gravelly Ford/ Above Chowchilla Bypass</td><td>No adjustment</td><td>No adjustment</td><td>+ 1 Day</td></tr>
<tr><td>Reach 2B</td><td>Above Mendota Pool/ Below Chowchilla Bypass</td><td rowspan="2">100 cfs loss when flow rates are less than or equal to 1000 cfs, and 200 cfs loss when flow rates are more than 1000 cfs</td><td>No adjustment</td><td>+ 2 Days</td></tr>
<tr><td>Reach 3</td><td>Below Mendota Pool/ Above Sack Dam</td><td>200 cfs addition for average Feb–Apr delivery to Arroyo Canal</td><td>+ 3 Days</td></tr>
<tr><td>Reach 4A & Eastside Bypass</td><td>Below Sack Dam</td><td rowspan="2">As above, plus an additional 50 cfs loss when flow rates are less than or equal to 200 cfs, and 100 cfs loss when flow rates are more than 200 cfs</td><td>200 cfs diversion for average Feb–Apr delivery to Arroyo Canal</td><td>+ 5 Days</td></tr>
<tr><td>Reach 5</td><td>Above Confluence with Merced River</td><td>No adjustment</td><td>+ 8 Days</td></tr>
</table>

To simplify the presentation of data in this report, the loss assumption from this table were incorporated into all analyses. For simplicity, the conditions at the head of the reach were adopted for the entire reach.

4.6 Flow Routing

Restoration Flows in this analysis are assumed to be routed from Reach 2A into Reach 2B (not the Chowchilla Bypass), from Reach 4A into the Sand Slough Bypass (not Reach 4B), and from the Middle Eastside Bypass into the Lower Eastside Bypass (not the Mariposa Bypass). During flood flows, other routings are likely. When flood flows exceed 4500 cfs, and potentially at lower flow rates depending on the design of the Reach 2B bypass and levees, additional flows may be routed into the Chowchilla Bypass at the San Joaquin River Control Structure. Such a routing would send a large proportion of juveniles through the Chowchilla Bypass, circumventing rearing habitat in Reach 2B, Reach 3, and Reach 4A, and likely reducing the overall opportunities for juvenile growth.

Alternate routings of Restoration Flows were not explored in this analysis. The potential rearing habitat at various flow rates in the Chowchilla Bypass, Eastside Bypasses, and Reach 4B is unknown at this time and beyond the scope of this analysis. For a more thorough discussion of rearing habitat and routing, see the *Minimum Floodplain Habitat Area* technical report (Reclamation 2012b).

4.7 Maximum Channel Capacity Utility

To determine the maximum channel capacity utility (i.e. the greatest channel capacity that each flow scenario requires) of each flow scenario, the available volume of Restoration Flows for a given hydrology (e.g. Wet, Normal-Wet) was parsed out over the flow components (e.g. inundation flow, temperature control flow, ramp-down). Temperature control flows, pulse flows, and contingency volumes were allocated first, then the remaining Restoration Allocation was added to inundation flows and the attending ramp-ups and ramp-downs to maximize the inundation area (i.e. flow rate) for a given duration. This process was fully mass-balanced, so if an inundation flow was scheduled atop a temperature control flow, any available volume was appropriately redistributed. The volume distribution followed the current flexible flow rules under the Restoration Flow Guidelines, and Buffer Flows were not included in the available volume. The required ramp-downs were automatically integrated and the associated volume subtracted from the available volume. Through this process, the inundation flow rate was optimized for the given constraints of a flow scenario. When there was inadequate volume to reach 1500 cfs inundation at a given duration, the duration was shortened to maintain minimal contact with the floodplain. It is generally assumed that a 1000 cfs flow is at the threshold between filling the main channel and spilling out onto the floodplain. In reality, this transition is subtle and highly spatially variable; thus 1500 cfs was chosen as a point that generally provides some floodplain connectivity throughout most of the Restoration Area.

What becomes readily apparent across the six flow scenarios is that there is inadequate volume to reach the inundation levels envisioned in the Settlement if one assumes that a minimum inundation period of 20 days is required to create food sources and provide optimal rearing habitat. This 20-day minimum was suggested by fisheries experts for the circumstances found in the San Joaquin River; there may be other factors to suggest a shorter, or longer, minimum inundation period. Other studies and modeling efforts have suggested shorter durations on the order of 7 to 14 days. Regardless of the minimum inundation period, lower inundation levels support longer inundation durations, albeit across a smaller floodplain area.

The channel capacities associated with each scenario are shown in three tables, one for Wet and high point of Normal-Wet year types (Table 4-7a), one for midpoint of Normal-Wet year types (Table 4-7b), and one for the low point of Normal-Wet year types (which is also the high point of the Normal-Dry year type [Table 4-7c]). Tables 4-7a-c also apply a 0.5-ft buffer to the maximum flow rate for each scenario based on the constraining Reach 2A stage–discharge relationships found in Table 4-5b. To calculate the duration of inundation at a given flow rate, only inundation between February 1 and May 1 was included, excluding Riparian Recruitment Flow and any contingency flows after that period.

Table 4-7a. Maximum Channel Capacity Utility Wet & Upper Range of Normal-Wet Year Types (Forecasted FNF of greater than 1975 TAF).

Scenario	Maximum Flow Rate (cfs)	Duration of Floodplain Inundation (days)[1]			Corresponding Channel Capacity (cfs with +0.25-ft Buffer in Reach 2) [2]	Corresponding Channel Capacity (cfs with +0.50-ft Buffer in Reach 2) [2]
		Above 1500 cfs	Above 2000 cfs	Above 2500 cfs		
A	2890	33	27	22	3100	3300
B	1700	62	0	0	2000	2200
C	3000	30	27	23	3300	3500
D	1820	61	0	0	2100	2300
E	2120	46	41	0	2400	2700
F	1980	50	0	0	2200	2500

Maximum flow rate values are at Gravelly Ford. Corresponding channel capacity is given at Reach 2A, which assumes no losses or difference in flow from Gravelly Ford.

[1] Does not include period of contingency flows or Riparian Recruitment Flow, which may fall outside of optimum floodplain rearing periods.
[2] Corresponding channel capacity to provide a stage buffer above the maximum flow rate to allow variability or pulsing of the floodplain inundation flow. This is rounded to the nearest 100 cfs.

Table 4-7b. Maximum Channel Capacity Utility Midpoint of Normal-Wet Year Type (Forecasted FNF of 1975 TAF).

Scenario	Maximum Flow Rate (cfs)	Duration of Inundation (days)[1]			Corresponding Channel Capacity (cfs with +0.25-ft Buffer in Reach 2) [2]	Corresponding Channel Capacity (cfs with +0.50-ft Buffer in Reach 2) [2]
		Above 1500 cfs	Above 2000 cfs	Above 2500 cfs		
A	2640	31	25	21	2900	3100
B	1590	61	0	0	1900	2100
C	2830	30	26	22	3100	3400
D	1710	60	0	0	2000	2200
E	1990	45	0	0	2200	2500
F	1850	49	0	0	2100	2400

Maximum flow rate values are at Gravelly Ford. Corresponding channel capacity is given at Reach 2A, which assumes no losses or difference in flow from Gravelly Ford.

[1] Does not include period of contingency flows or Riparian Recruitment Flows.
[2] Corresponding channel capacity to provide a stage buffer above the maximum flow rate to allow variability or pulsing of the floodplain inundation flow. This is rounded to the nearest 100 cfs.

Table 4-7c. Maximum Channel Capacity Utility Low Point of Normal-Wet / High Point of Normal-Dry Year Types (Forecasted FNF of 1450 TAF).

Scenario	Maximum Flow Rate (cfs)	Duration of Inundation (days)[1]			Corresponding Channel Capacity (cfs with +0.25-ft Buffer in Reach 2) [2]	Corresponding Channel Capacity (cfs with +0.50-ft Buffer in Reach 2) [2]
		Above 1500 cfs	Above 2000 cfs	Above 2500 cfs		
A	1590	21	0	0	1800	2100
B	1500	22	0	0	1800	2000
C	1700	22	0	0	2000	2200
D	1500	40	0	0	1800	2000
E	1500	32	0	0	1800	2000
F	1500	24	0	0	1800	2000

Maximum flow rate values are at Gravelly Ford. Corresponding channel capacity is given at Reach 2A, which assumes no losses or difference in flow from Gravelly Ford.

[1] Does not include period of contingency flows or Riparian Recruitment Flows.
[2] Corresponding channel capacity to provide a stage buffer above the maximum flow rate to allow variability or pulsing of the floodplain inundation flow. This is rounded to the nearest 100 cfs.

4.8 Temperature Analysis

Temperature results from the Programmatic EIS/R (Reclamation 2012c) SJR 5Q model were analyzed in support of evaluating possible scenarios of Restoration Flows (see Appendix B for more details). The model uses real air temperature data from a 23-year record near Fresno, California, and flow data from the SJRRP Daily Flow Model to determine water temperature. Water temperature data were smoothed into 7-day, daily running averages to align with the temperature tolerances known for salmonids (Appendix C). Then, water temperatures were aggregated into bins of flow rate, and regression equations (i.e. trend lines) were derived. The binned approach allowed for a statistically relevant sample size to provide an estimate of temperature per day of the water year given trends of a selected flow range.

For consideration of temperature within the Restoration Flow scenarios, the regression line equations from the binned model data were evaluated in daily time steps. Analysis of each day provided a relationship between flow and temperature. Flow rates from the flow scenario hydrographs then became the independent variables, providing an estimate of temperatures per scenario.

Additional contingency in the data was provided by the application of plus and minus one standard deviation to the 7-day daily running average to determine a range of dates encompassing 68% of the probability range (i.e. the 16th percentile to the 84th percentile). Thus, rather than solely identifying the average date that the 7-day daily running average met a temperature threshold for salmonids, the standard deviation informed a range of dates encompassing 68% of the probability range.

The daily flow–temperature relationships can further be evaluated at incremental flow rates to determine when a temperature may meet temperature tolerances for varying life stages. This was done at the Sack Dam node (Table 4-8a) and the node at the head of Reach 5 (Table 4-8b) in the model. At each node, upper and lower bounds for dates of exceedance were estimated based on the standard deviations of the regression line data. In this case, the upper bound refers to the most restrictive date, and the lower bound suggests a later date than average. At Sack Dam, the standard deviation was ± 1.79 °F and at Reach 5 the standard deviation was ± 2.32 °F. The estimated dates to reach lethal temperatures at each node, for both adult and juvenile life stages, were summarized (Table 4-8a, Table 4-8b). In both tables, flows were evaluated in 100 cfs increments until exceedance dates extended beyond May 28, the end of the spring flexible flow period (when only summer base flows and Riparian Recruitment Flow are available). Blank cells indicate the estimated date occurs after May 28, and therefore are not deemed constraining for this analysis. The data suggest that at Sack Dam, incremental increases of 100 cfs provide approximately two days extension for suitable temperatures (Table 4-8a). At Reach 5, 100 cfs increases provide approximately one day extension (Table 4-8b). The model results suggest a linear trend between the additional time gained (Dt) per additional flow.

For the adult migration life stage, we compared the temperature threshold established in the Fisheries Framework of 68 °F, which is both the upper limit of the critical range and the lethal limit. For juvenile outmigration, we compared the temperature threshold at the upper limit of the critical range, 70 °F, as well as the lethal limit of 75 °F. The juvenile floodplain rearing temperature threshold was not utilized as it was expected to be less constraining than the outmigration threshold — any juvenile fish that were affected by the floodplain rearing temperature threshold would not have adequate time to escape the Restoration Area and reach the higher flows of the Merced River. The juvenile floodplain rearing critical and lethal temperature thresholds were consistent with the outmigration critical and lethal temperature thresholds; however, the temperature on the floodplain varies from the main channel. Thus, the upper limit of the critical range was utilized to be sure that floodplain rearing temperatures remained in a suitable, non-lethal range and river temperatures were adequate when leaving the floodplains during outmigration. A table of relevant temperature thresholds as well as an analysis of optimum temperature thresholds is found in Appendix C.

There is a fair amount of uncertainty in the temperature model, more so for the Reach 5 node than the Sack Dam node since it is further downstream. Calibration of this model is planned to use flood flow data from 2017, which are not yet available for this analysis. There is some concern that the additional time gained per additional flow trend is not as linear as the model indicates, in which case higher flows would not be as effective at suppressing water temperature as modeled, and also that lower flows may be more effective at reducing temperatures than modeled. Additional uncertainty on water temperature threshold dates is due to variations in weather. For example, higher than average seasonal air temperatures would have a strong influence on water temperatures after a number of days. Therefore, the upper range of threshold dates derived from one standard deviation in the modeled data is important to reference in addition to the average date. Also, the influence of James Bypass flows from the Kings River upon water temperatures in the San Joaquin River was not modeled. The model's temperature boundary conditions from Millerton Lake do account for meteorology, flow rate, and a seasonal temperature distribution (Resource Management Associates and Reclamation 2007). Further discussion on water temperature modeling is discussed in Appendix B.

Table 4-8a. Estimated Dates to Upper Limit Critical and Lethal Temperature Thresholds at the Head of Reach 4 (Immediately Below Sack Dam)

Sack Dam Flow	Adult 68 °F (Upper Limit Critical & Lethal Threshold)			Juvenile 70 °F (Upper Limit Critical Threshold)			Juvenile 75 °F (Lethal Threshold)		
	Upper	Average	Lower	Upper	Average	Lower	Upper	Average	Lower
100	4/9	4/21	5/3	4/22	5/5	5/17	5/27	>5/28	>5/28
200	4/12	4/24	5/6	4/25	5/7	5/19	5/28	“	“
300	4/15	4/26	5/8	4/28	5/9	5/21	>5/28	“	“
400	4/17	4/28	5/10	4/30	5/11	5/22	“	“	“
500	4/20	5/1	5/12	5/2	5/13	5/24	“	“	“
600	4/22	5/3	5/14	5/4	5/15	5/26	“	“	“
700	4/24	5/5	5/16	5/6	5/17	5/28	“	“	“
800	4/26	5/7	5/18	5/8	5/19	>5/28	“	“	“
900	4/28	5/9	5/20	5/10	5/21	“	“	“	“
1000	4/30	5/11	5/22	5/12	5/23	“	“	“	“
1100	5/2	5/13	5/24	5/14	5/25	“	“	“	“
1200	5/4	5/15	5/26	5/16	5/27	“	“	“	“
1300	5/6	5/17	5/28	5/18	>5/28	“	“	“	“
1400	5/8	5/19	>5/28	5/20	“	“	“	“	“
1500	5/10	5/21	“	5/22	“	“	“	“	“
1600	5/12	5/23	“	5/24	“	“	“	“	“
1700	5/14	5/25	“	5/26	“	“	“	“	“
1800	5/16	5/27	“	>5/28	“	“	“	“	“
1900	5/18	>5/28	“	“	“	“	“	“	“
2000	5/20	“	“	“	“	“	“	“	“
2100	5/22	“	“	“	“	“	“	“	“
2200	5/24	“	“	“	“	“	“	“	“
2300	5/26	“	“	“	“	“	“	“	“
2400	5/28	“	“	“	“	“	“	“	“
2500	>5/28	“	“	“	“	“	“	“	“

Upper and lower thresholds are derived from plus and minus one standard deviation of temperature data.

Table 4-8b. Estimated Dates to Critical and Lethal Temperature Thresholds at the Head of Reach 5.

Reach 5 Flow	Adult 68 °F (Upper Limit Critical & Lethal Threshold)			Juvenile 70 °F (Upper Limit Critical Threshold)			Juvenile 75 °F (Lethal Threshold)		
	Upper	Average	Lower	Upper	Average	Lower	Upper	Average	Lower
100	3/18	4/3	4/18	3/31	4/16	5/1	5/3	5/19	>5/28
200	3/21	4/4	4/19	4/2	4/17	5/1	5/4	5/18	“
300	3/23	4/6	4/20	4/4	4/18	5/2	5/4	5/18	“
400	3/25	4/7	4/21	4/5	4/19	5/2	5/4	5/18	“
500	3/27	4/9	4/22	4/7	4/20	5/3	5/5	5/18	“
600	3/28	4/10	4/23	4/8	4/21	5/4	5/6	5/18	“
700	3/30	4/11	4/24	4/9	4/22	5/4	5/6	5/19	“
800	3/31	4/12	4/25	4/11	4/23	5/5	5/7	5/19	“
900	4/2	4/14	4/26	4/12	4/24	5/6	5/8	5/20	“
1000	4/3	4/15	4/27	4/13	4/25	5/7	5/9	5/21	“
1100	4/4	4/16	4/28	4/14	4/26	5/8	5/10	5/21	“
1200	4/5	4/17	4/29	4/15	4/27	5/9	5/11	5/22	“
1300	4/6	4/18	4/30	4/17	4/28	5/10	5/12	5/23	“
1400	4/8	4/19	5/1	4/18	4/29	5/11	5/13	5/25	“
1500	4/9	4/20	5/2	4/19	5/1	5/12	5/14	5/26	“
1600	4/10	4/22	5/3	4/20	5/2	5/13	5/15	5/27	“
1700	4/11	4/23	5/5	4/21	5/3	5/15	5/17	5/28	“
1800	4/12	4/24	5/6	4/22	5/4	5/16	5/18	>5/28	“
1900	4/13	4/25	5/7	4/24	5/6	5/17	5/19	“	“
2000	4/14	4/26	5/9	4/25	5/7	5/19	5/21	“	“
2100	4/16	4/28	5/10	4/26	5/8	5/20	5/22	“	“
2200	4/17	4/29	5/11	4/27	5/10	5/22	5/24	“	“
2300	4/18	4/30	5/13	4/29	5/11	5/24	5/25	“	“
2400	4/19	5/2	5/14	4/30	5/12	5/25	5/27	“	“
2500	4/20	5/3	5/16	5/1	5/14	5/27	>5/28	“	“
2600	4/21	5/4	5/17	5/2	5/15	5/28	“	“	“
2700	4/22	5/6	5/19	5/4	5/17	>5/28	“	“	“
2800	4/23	5/7	5/20	5/5	5/18	“	“	“	“
2900	4/24	5/8	5/22	5/6	5/20	“	“	“	“
3000	4/25	5/9	5/23	5/7	5/21	“	“	“	“
3100	4/26	5/11	5/25	5/9	5/23	“	“	“	“
3200	4/27	5/12	5/26	5/10	5/24	“	“	“	“
3300	4/28	5/13	5/27	5/11	5/25	“	“	“	“
3400	4/29	5/14	5/28	5/12	5/26	“	“	“	“

3500	4/30	5/15	>5/28	5/13	5/27	“	“	“	“
3600	4/30	5/15	“	5/13	5/28	“	“	“	“
3700	5/1	5/16	“	5/14	>5/28	“	“	“	“
3800	5/1	5/16	“	5/14	“	“	“	“	“
3900	5/2	5/17	“	5/15	“	“	“	“	“
4000	5/2	5/17	“	5/15	“	“	“	“	“
4100	5/2	5/17	“	5/15	“	“	“	“	“
4200	5/1	5/16	“	5/14	“	“	“	“	“
4300	5/1	5/16	“	5/14	“	“	“	“	“
4400	4/30	5/15	“	5/13	“	“	“	“	“
4500	4/30	5/14	“	5/12	“	“	“	“	“

Upper and lower thresholds are derived from plus and minus one standard deviation of temperature data.

Tables 4-8a and 4-8b provide a relationship between flow rate and temperature thresholds, which can then be combined with the six flow scenarios to understand the extent to which the scenarios achieve temperature control objectives. This resultant information is presented in Section 5.0 (Summary Results).

4.9 Rearing Habitat and Floodplain Inundation Analysis

Suitable rearing habitat for juvenile salmonids can be predicted using physical parameters, such as water depth and velocity, which can be calculated spatially using 2-D hydraulic modeling. Additional parameters such as cover, primary and secondary production, etc., are also necessary for optimum rearing habitat, but these were not considered in this analysis.

The 2-D hydraulic model SRH-2D (Lai 2008) was used to simulate hydraulic conditions at a series of flow rates for Reaches 1B, 2A, 2B, and 3 of the San Joaquin River. This model uses elevation data applied across a model domain and calibrated hydraulic roughness to simulate depth and velocity across the grid cells (mesh) for different boundary conditions. Due to time constraints of preparing this analysis, Reaches 1A, 4A, 4B, 5, and the Eastside Bypass were not modeled. Reach 1A has an entrenched main channel, and floodplain inundation occurs only at relatively high flows. Reach 4A is substantially influenced by recent ground subsidence, and revised elevation data are not yet available. Reach 5 does have suitable rearing habitat at the flow rates being investigated (Reclamation 2012b). Rearing habitat potential in Reach 4B and the Eastside Bypass is largely unknown.

The same meshes that were previously used for the *Minimum Floodplain Habitat Area* Report (Reclamation 2012b) were used in this analysis. Table 4-9 summarizes the mesh sizes by reach. Elevation data for these meshes are sourced from the 2008 airborne LiDAR collected for the Restoration Area by the California Department of Water Resources, in vertical datum NAVD88. Boat surveys from 2009 to 2011 using SONAR were used for bathymetric data. Hydraulic roughness values, which are calibrated by reach, are also taken from these previously developed meshes. Additional information on the generation of these meshes and model calibration is available in *Hydraulic Studies for Fish Habitat Analysis* (Reclamation 2012a).

Table 4-9. Resolution of Computational Meshes.

SJRRP River Reach	Mesh Size (ft)
1B	31
2A	8
2B	30
3	14.5

These values are derived from the *Minimum Floodplain Habitat Area* Report (Reclamation 2012b).

Boundary conditions, primarily downstream rating curves, for Reaches 1B, 2A, and 2B were taken from *Hydraulic Studies for Fish Habitat Analysis* (Reclamation 2012a). Due to significant subsidence in Reach 3 since the collection of the 2008 LiDAR, the downstream boundary conditions for Reach 3 were updated using a one-dimensional (1-D) HEC-RAS model, sourced with data from 2014.

Models were run in 500 cfs increments from 1000 cfs through 4000 cfs by reach. From each run, water depth and velocity were output at each node. These nodes were rasterized into 5 feet by 5 feet cells, then cells were filtered by suitable habitat criteria for depth and velocity (Table 4-10).

Table 4-10. Suitable Habitat Hydraulic Values.

Suitable Habitat	Depth (ft)	Velocity (ft/s)
Juvenile Rearing	0.5–3.5	0–2

These values are derived from the *Minimum Floodplain Habitat Area* Report (Reclamation 2012b)

The area which met both the depth and velocity criteria from Table 4-10 for each flow rate was recorded as an index of the area of hydraulically suitable rearing habitat. Total inundated area for each flow rate was also calculated, using the spatial area of raster cells with depths greater than 0.01 feet. Intermediate values were interpolated to match the floodplain inundation flow values in the scenarios discussed in Section 3.2. An example of this spatial analysis, showing the increase in hydraulically suitable spawning area with increased flow rate, is shown below for Reach 1B (Figure 4-3). More detailed results of the spatial analysis can be found in Appendix A.

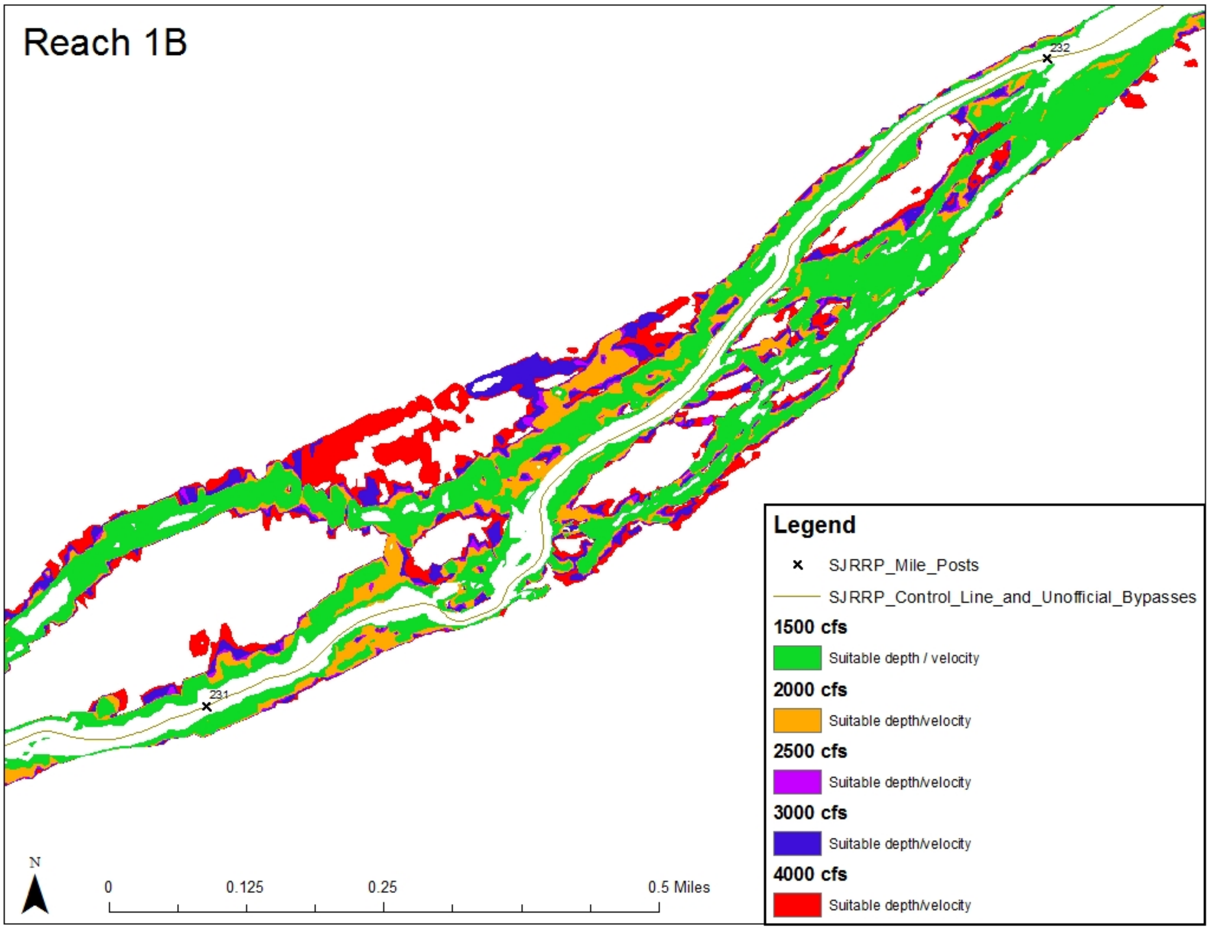


Figure 4-3. Inundated Area at a Series of Flow Rates in a Sample Section of Reach 1B of the San Joaquin River, Near River Mile 231.

During the Funding Constrained Framework process, multiple levee extents and design options for Reach 2B were discussed (Table 4-11). The primary scenarios that have been discussed are described and compared below.

1. **Full Project Buildout –** Full project buildout matches the selected alternative in the Reach 2B and Mendota Pool Bypass Improvements Project EIS/R, with the floodplain grading option presented in the *Conceptual Hydraulic Design of the Mendota Bypass* (Reclamation 2015). Levees would be set back along the entire reach, and floodplain grading would occur throughout the entire reach. The compact bypass channel would be connected to Reach 2B and water surface elevation lowered below that of Mendota Pool, and Mendota Pool would be disconnected. The San Joaquin River would function as a free-flowing river through Reach 2B. This is the same flow condition that would be present in the South Canal option, as this variation to the Reach 2B project retains the full project buildout conditions for the levees, river channel, and floodplain grading.
2. **San Mateo Road –** The San Mateo Road option includes the construction of levee setbacks and floodplain grading only up to where San Mateo Road crosses Reach 2B. It is otherwise similar to the full project buildout; the compact bypass channel would be connected and water surface elevations lowered to below the elevation of Mendota Pool.

3. **Checked Condition –** The final option is a checked condition where Mendota Dam interrupts the flow of water and flattens the gradient of the channel at a higher water surface elevation than anticipated in the full project buildout. In this checked condition, the compact bypass would not be fully connected and water surface elevations in Reach 2B would remain elevated to maintain deliveries to Mendota Pool, creating ponding at the lower end of Reach 2B. Levees would be completed to their full extent within Reach 2B. This option was not fully developed, so the location and extent of any floodplain regrading is undefined; therefore, analysis for this option is based on earlier models of floodplain habitat, included in Appendix C of the *Conceptual Hydraulic Design of the Mendota Bypass* report (Reclamation 2015). This analysis uses the current channel and ground surface elevations, but breaches the existing levees to allow for floodplain inundation. The analysis does not modify the current ground topography with any regrading. Table 4-12 compares the hydraulically suitable area in Reach 2B for these three options.

Table 4-11. Summary of Reach 2B Analysis Assumptions by Option.

Option	Full Buildout	Levees to San Mateo	Checked
Levee Work	Full	To San Mateo	Full
Grading Upstream San Mateo	Yes	No	No[1]
Grading Downstream San Mateo	Yes	Yes	No[1]

[1] *Actual project design would include some floodplain grading.*

Table 4-12. Comparison of Reach 2B Funding Constrained Options to Full Buildout of the Reach 2B Project.

Flow	Total Inundated Area (acres)			Hydraulically Suitable Area (acres)		
	Full Buildout	Levees to San Mateo	Checked	Full Buildout	Levees to San Mateo	Checked
1000	557	380	356	290	244	121
1500	668	448	662	337	252	232
2000	776	491	997	406	249	329
2500	1059	640	1170	381	239	316
3000	1264	707	1242	474	242	335
3500	1422	788	1275	557	280	357
4000	1517	831	1308	656	319	392

At low flows, total inundated area for the checked condition is less than both full buildout and levees to San Mateo Road. From 1000 cfs to 1500 cfs, the wetted area is generally still within the main channel, and is sensitive to the creation of low flow channels introduced by floodplain grading. Although the current analysis for the checked condition does not include floodplain grading, some combination of low flow channels will likely be added to the checked condition if this option is brought forward, which will increase its total inundated area under low flows. As flows increase, the total inundated area in the checked condition roughly matches that of the full buildout, as the levee alignment is the same. The San Mateo Road option has less total inundated area, because the existing levees upstream of San Mateo Road still prevent access to some of the floodplain.

Hydraulically suitable area for rearing habitat at low flows is lower in the checked option than full buildout or the San Mateo Road option. Pooled conditions behind Mendota Dam lead to generally deeper water within the main channel under the checked option, which results in less in-channel suitable habitat. At intermediate flows, water inundates the floodplain and increases the hydraulically suitable acres for both the checked condition and full buildout. The San Mateo Road option remains lower due to the lack of access to floodplain above San Mateo Road. At high flows, water depth again limits the hydraulically suitable area in the checked condition, resulting in lower acreages than full buildout. If carried forward, the hydraulically suitable area for the checked option will likely increase with floodplain grading; estimates presented here are therefore conservative at present.

The full buildout condition was carried through to the summary analysis in this report. Other scenarios can be analyzed and carried forward to represent the hydraulically suitable rearing habitat in Reach 2B as consensus is reached over the Funding Constrained Framework option for the Reach 2B project.

Hydraulic modeling of Reach 1B through Reach 3 allows for the calculation of inundation area (acres of channel and floodplain inundation) and an index of juvenile rearing hydraulically suitable area (HSA). A compilation of inundation area and HSA by flow scenario for full buildout is depicted for Wet and high point of Normal-Wet year types (Table 4-13a), the midpoint of Normal-Wet year type (Table 4-13b), and the low point of Normal-Wet year type (Table 4-13c). Also calculated is the habitat acre-days, an index of area (Tables 4-13a-c) and duration (Tables 4-7a-c). Only inundation between February 1 and May 1 was calculated in the habitat acre-days index, excluding Riparian Recruitment Flow and any contingency flows after that period.

Table 4-13a. Acres Inundated and Hydraulically Suitable Rearing Habitat Wet & Mid to High Point of Normal-Wet Year Types (Forecasted FNF of greater than 1975 TAF).

Scenario	GRF Flow	Inundation Area (ac)				Hydraulically Suitable Area (ac)				Thousand Habitat Acre-Days
		Reach 1B	Reach 2A	Reach 2B[1]	Reach 3	Reach 1B	Reach 2A	Reach 2B[1]	Reach 3	
A	2890	798	752	1137	887	282	304	416	348	43.2
B	1700	645	628	668	590	255	296	337	183	68.0
C	3000	814	762	1182	907	284	304	437	357	41.9
D	1820	664	645	694	625	260	297	354	203	69.6
E	2120	703	681	759	711	270	300	395	252	55.6
F	1980	689	667	728	671	267	299	376	229	60.5

[1] *Reach 2B values assume the levees are constructed to their full extent.*

Table 4-13b. Acres Inundated and Hydraulically Suitable Rearing Habitat Midpoint of Normal-Wet Year Type (Forecasted FNF of 1975 TAF).

Scenario	GRF Flow	Inundation Area (ac)				Hydraulically Suitable Area (ac)				Thousand Habitat Acre-Days
		Reach 1B	Reach 2A	Reach 2B[1]	Reach 3	Reach 1B	Reach 2A	Reach 2B[1]	Reach 3	
A	2640	760	729	1025	841	277	304	384	327	40.2
B	1590	628	613	644	557	250	294	327	164	64.5
C	2830	784	744	1100	870	280	304	400	341	39.6
D	1710	647	629	670	593	255	296	339	184	66.1
E	1990	690	668	731	674	268	299	377	231	54.6
F	1850	668	649	700	633	261	297	358	207	55.9

[1] *Reach 2B values assume the levees are constructed to their full extent.*

Table 4-13c. Acres Inundated and Hydraulically Suitable Rearing Habitat Low Point of Normal-Wet & High Point of Normal-Dry Year Types (Forecasted FNF of 1450 TAF).

Scenario	GRF Flow	Inundation Area (ac)				Hydraulically Suitable Area (ac)				Thousand Habitat Acre-Days
		Reach 1B	Reach 2A	Reach 2B[1]	Reach 3	Reach 1B	Reach 2A	Reach 2B[1]	Reach 3	
A	1590	628	613	644	557	250	294	327	164	22.2
B	1500	614	600	624	531	246	293	318	150	22.6
C	1700	661	642	690	619	259	297	351	199	24.1
D	1500	614	600	624	531	246	293	318	150	42.1
E	1500	614	600	624	531	246	293	318	150	32.8
F	1500	614	600	624	531	246	293	318	150	24.6

[1] *Reach 2B values assume the levees are constructed to their full extent*

Further analysis was conducted to separate the HSA into its two components – HSA found on the floodplain versus HSA found in the main channel. Floodplain rearing habitat is likely to have more ideal characteristics, including vegetative cover and greater opportunities for predator avoidance. HSA on the floodplain was estimated by removing the in-channel HSA area under the assumption that the waterline at 1000 cfs marked the edge of the channel and the start of the floodplain. As with Tables 4-13a-c, Tables 4-14a-c depict three conditions: Wet and high point of Normal-Wet year types (Table 4-14a), the midpoint of Normal-Wet year types (Table 4-14b), and the low point of Normal-Wet year type (Table 4-14c). Thousands of habitat acre-days from Tables 4-13a-c are included for comparison. Note that the difference in HSA when the in-channel HSA area is removed is minimal, with most difference occurring at lower flow rates while the floodplain becomes activated.

Table 4-14a. Floodplain Acres Inundated and Rearing Habitat Wet & Mid to High Point of Normal-Wet Year Types (Forecasted FNF of Greater than 1975 TAF).

Scenario	GRF Flow	Hydraulically Suitable Area on Floodplain (ac)				Thousand Habitat Acre-Days in Floodplain	Thousand Habitat Acre-Days Overall (from Table 4-13a)
		Reach 1B	Reach 2A	Reach 2B[1]	Reach 3		
A	2890	281	297	390	342	42.2	43.2
B	1700	253	275	287	175	65.1	68.0
C	3000	283	298	412	351	41.1	41.9
D	1820	259	280	306	196	67.0	69.6
E	2120	269	288	355	247	54.0	55.6
F	1980	266	285	332	224	58.5	60.5

[1] Reach 2B values assume the levees are constructed to their full extent.

Table 4-14b. Floodplain Acres Inundated and Rearing Habitat Midpoint of Normal-Wet Year Type (Forecasted FNF of 1975 TAF).

Scenario	GRF Flow	Hydraulically Suitable Area on Floodplain (ac)				Thousand Habitat Acre-Days in Floodplain	Thousand Habitat Acre-Days Overall (from Table 4-13b)
		Reach 1B	Reach 2A	Reach 2B[1]	Reach 3		
A	2640	277	296	354	322	39.1	40.2
B	1590	248	271	270	156	61.6	64.5
C	2830	280	297	372	335	38.7	39.6
D	1710	254	276	289	177	63.4	66.1
E	1990	267	286	334	225	52.8	54.6
F	1850	260	281	311	201	53.8	55.9

[1] Reach 2B values assume the levees are constructed to their full extent.

Table 4-14c. Floodplain Acres Inundated and Rearing Habitat Low Point of Normal-Wet & High Point of Normal-Dry Year Types (Forecasted FNF of 1450 TAF).

Scenario	GRF Flow	Hydraulically Suitable Area on Floodplain (ac)				Thousand Habitat Acre-Days in Floodplain	Thousand Habitat Acre-Days Overall (from Table 4-13c)
		Reach 1B	Reach 2A	Reach 2B[1]	Reach 3		
A	1590	248	271	270	156	21.2	22.2
B	1500	244	268	256	140	21.5	22.6
C	1700	258	279	303	192	23.1	24.1
D	1500	244	268	256	140	40.0	42.1
E	1500	244	268	256	140	31.2	32.8
F	1500	244	268	256	140	23.4	24.6

[1] *Reach 2B values assume the levees are constructed to their full extent.*

Analysis for this report only measures suitable habitat area with respect to depth and velocity. The *Fisheries Framework* (Reclamation 2012c) includes a measure of cover in addition to depth and velocity. Therefore, the two measures of suitable habitat cannot be readily compared. See Table 11 from the Fisheries Framework (Reclamation 2017), showing "Required Suitable Habitat to meet Population Target (acres)" values of 109, 183, 144, and 203 for Reach 1B, 2A, 2B and 3, respectively. These are actual suitable habitat, and include a measure of cover (which our HSA does not).

4.10 Riparian Recruitment Flow

In addition to temperature control and rearing habitat, another critical factor for Restoration Goal success is the natural recruitment of riparian vegetation through gradual ramp-downs in early summer. The development of riparian vegetation on the floodplain provides habitat complexity and cover for juvenile fish and also provides shade to keep water temperature low. Riparian Recruitment Flow operates by wetting a floodplain surface prior to or during seed dispersal. Cottonwood trees and willow species reproduce by aerial seed dispersal and seeds floating upon the water surface. Seeds germinate in the moist soil and send down roots to maintain contact with saturated soils. If the rate of root growth, commonly approximated as 1 foot per week in the scientific literature, is as fast or faster than the rate of decline in the subsurface saturation zone, then survival of seedlings is high. High flows can also can also transplant cottonwood and willow vegetation to new locations downstream, where they can take root in a similar process, aided by Riparian Recruitment Flow.

Riparian vegetation recruitment success involves proper timing, a proper receding flow, and suitable surfaces for establishment. If floodplain inundation is restricted by channel capacity, and thus a narrow ribbon of floodplain along the river bank is regularly inundated during seed dispersal, it may result in a narrow linear zone of vegetation. Such an arrangement would encourage scour on poorly vegetated floodplain surfaces, potentially leading to geomorphic instability during higher flood flows. It could also encourage fine sediment deposition within the narrow band of vegetation, leading to bank immobilization and berm formation, which could potentially reduce overall rearing habitat. As a greater fraction of the floodplain is made available for natural recruitment, the ecological benefits are greater as well.

It is important to consider that Riparian Recruitment Flow, a 200 TAF volume designed to be gradually ramped down over May, June and July, is only available in Wet year types, and as a small volume (0–74 TAF) in the upper range of the Normal-Wet year types. The volume of water dedicated to Riparian Recruitment Flow in Normal-Wet years is inadequate to do an effective ramp-down from a high flow rate; thus, this volume of water in Normal-Wet year types either needs to be applied to a lower elevation floodplain surface (in the range of 1500–2000 cfs), or applied in conjunction with flood flows to be effective in that year type.

To produce a quantitative index of riparian vegetation recruitment and compare that to channel capacity, the modeled inundation area from the SRH-2D model runs was examined. Although a map of the edge of the floodplain surface where it meets the channel was not readily available, using the 1000 cfs inundation elevation allowed the extent of the main channel to be estimated and thus the fraction of the floodplain that is inundated for a given flow rate could be determined. Reaches 1B through 3 were examined. Potential riparian recruitment is available downstream of Reach 3, particularly in Reach 4A and the Eastside Bypass, though there are complicating issues of channel capacity maintenance, and those areas were not examined here due to time constraints. To produce an index of riparian recruitment potential, the floodplain inundation area was summed with equal weighting for each modeled reach. The use of relative weighting factors, specifically giving more weight to Reach 2A, which has the highest potential for riparian vegetation improvement, was explored but resulted in minimal influence to the overall index and was not included in the final analysis. The index was then normalized to 1.0 being the full Settlement channel capacity of 4500 cfs (see Table 4-15).

Table 4-15. Modeled Floodplain Inundation Area and Index of Riparian Vegetation Recruitment Potential.

Flow at Gravelly Ford (cfs)	Inundation Area (ac)				Index of Riparian Recruitment Potential
	Reach 1B	Reach 2A	Reach 2B[1]	Reach 3	
1000	0	0	0	0	0.00
1500	89	76	111	85	0.15
2000	166	146	219	231	0.31
2500	213	192	502	369	0.51
3000	289	238	707	460	0.68
3500	338	284	865	516	0.81
4000	388	330	960	571	0.90
4500	437	376	972	698	1.00

[1] Reach 2B assumes inundation at the full buildout.
Note: All reaches are adjusted for channel losses for proper calculation of inundation area.

5.0 Summary Results

Data from the independent analyses presented in Section 4.0 — Restoration Allocation, Flood Frequency Analysis, Stage Buffers, Channel Losses, Maximum Channel Capacity Utility, Temperature, Rearing Habitat and Floodplain Inundation, and Riparian Vegetation Recruitment — were synthesized using the six flow scenarios and are condensed and presented in this summary section. This provides a more holistic way of examining the influence of channel capacity upon the critical biological factors.

5.1 Temperature Results

Water temperature is primarily influenced by ambient air temperature. Changes in flow rates also have an influence upon water temperatures, but only within a range controlled by the ambient air temperature. Other factors such as groundwater seepage into the channel (river gaining flow) and shading from trees and other vegetation play a secondary role. Adjustment of the spring flows is the primary method for controlling water temperatures for migrating spring-run adult salmon — higher flows attract the fish and cool the water. The average date that the adult lethal temperature threshold is reached is shown in Table 5-1a. Beyond approximately mid to late April, the flow rate required to keep water temperatures in all reaches below the 68 °F lethal threshold for adults becomes difficult to attain; even if the channel capacity existed to convey such flows, there would not likely be the volume available to support such flows (and the requisite ramp-down to prevent fish stranding) unless other objectives such as floodplain rearing were sacrificed in favor of temperature control (see Appendix E).

The upper limit of juvenile critical temperature theshold is typically reached in early May, with the lethal temperature threshold reached later in May — near or after the very end of the spring flexible flow period (see Table 5-1b and 5-1c). Maintaining water temperatures below the 75 °F lethal threshold for emigrating juveniles in all reaches can typically be accomplished through the end of the spring flexible flow period with flows at or below the range of channel capacities being considered. However, channel capacity does influence the ability to maintain juvenile critical temperature thresholds in all reaches.

When Riparian Recruitment Flow is available, those flows may substantially extend the period of suitable temperatures. However, it will be an infrequent occurance that that Riparian Recruitment Flow is available in late May and early June without the presence of flood flows, which are typically in the range of 2000 to 4000 cfs at that time. Therefore, flood flows may be able to contribute to an extended period of suitable temperatures; however, high runoff conditions producing flood flows may also contribute to reducing or eliminating the cold-water pool in Millerton Lake. This may negatively impact the potential to suppress lethal threshold temperatures for relevant salmon life-stages within the Restoration Area in wetter year types. Calibration results from the modeled data indicate the inflow temperature algorithm performs well under high runoff conditions, as compared with 2005 Wet water year data (Resource Management Associates and Reclamation 2007). Thus, the model should sufficiently capture temperature trends at higher flows.

The Fisheries Framework (Reclamation 2017) identifies an adult spring-run migration window of March 1 through June 30, and a juvenile migration window of October 1 through June 30 (the months of October through December are for the outmigration of yearlings and are not expected to be temperature constrained). When the values in Table 5-1a are compared to the overall adult migration window, an average of 34% to 51% of the total window period is kept below the lethal temperature threshold depending on the flow scenario and water year type. When the values of Table 5-1b and 5-1c are compared to the overall juvenile outmigration window, an average of 75% to 79% of the total window period is controlled for the upper limit critical temperature threshold, and 84% to 89% for the lethal temperature threshold, again depending on the flow scenario and water year type. The expected migration and outmigration windows for Chinook salmon in the San Joaquin River are somewhat uncertain as they are estimated from other tributaries of the Sierra Nevada and adjusted for geographic position and runoff characteristics.

Table 5-1a. Average Date that 68 °F Lethal Water Temperature Threshold is Reached for Adult migration at the Head of Reach 5.

Water Year Type	Average Date of Temperature Threshold for Each Flow Scenario					
	A	B	C	D	E	F
Wet (> 2500 TAF)	4/11	4/17	5/1	4/21	4/21	4/23
Normal-Wet (2500 TAF)	4/11	4/17	5/1	4/21	4/21	4/23
Normal-Wet (1975 TAF)	4/11	4/16	4/30	4/20	4/21	4/22
Normal-Wet (1450 TAF)	4/11	4/11	4/20	4/17	4/17	4/11

Table 5-1b. Average Date that 70 °F Critical Water Temperature Threshold is Reached for Juvenile Outmigration at the Head of Reach 5.

Water Year Type	Average Date of Temperature Threshold for Each Flow Scenario					
	A	B	C	D	E	F
Wet (> 2500 TAF)	4/22	4/22	5/5	5/1	4/27	5/3
Normal-Wet (2500 TAF)	4/22	4/22	5/5	5/1	4/27	5/3
Normal-Wet (1975 TAF)	4/22	4/22	5/5	4/29	4/26	5/2
Normal-Wet (1450 TAF)	4/22	4/22	4/29	4/28	4/25	4/28

Table 5-1c. Average Date that 75 °F Lethal Water Temperature Threshold is Reached for Juvenile Outmigration at the Head of Reach 5.

Water Year Type	Average Date of Temperature Threshold for Each Flow Scenario					
	A	B	C	D	E	F
Wet (> 2500 TAF)	5/24	5/23	>5/28	5/27	5/27	5/26
Normal-Wet (2500 TAF)	5/20	5/20	5/25	5/22	5/23	5/21
Normal-Wet (1975 TAF)	5/20	5/20	5/20	5/18	5/20	5/18
Normal-Wet (1450 TAF)	5/20	5/20	5/20	5/18	5/19	5/18

The scenario hydrographs were plotted with daily temperatures as determined by SJR 5Q temperature model data (Figures 5-1 to 5-6). This includes the model nodes at Sack Dam at the head of Reach 4A and at the head of Reach 5. Temperature is compared across the hydrographs from February 1 to May 28. These incorporate the channel losses and flow travel times in Table 4-6. The lethal threshold for adult migration of 68 °F is referenced, which is the same temperature as the upper limit of the critical range. For juveniles, both the upper limit of the critical range, 70 °F, and the lethal threshold, 75 °F, is referenced. A more complete description of these biological temperature thresholds is found in Appendix C.

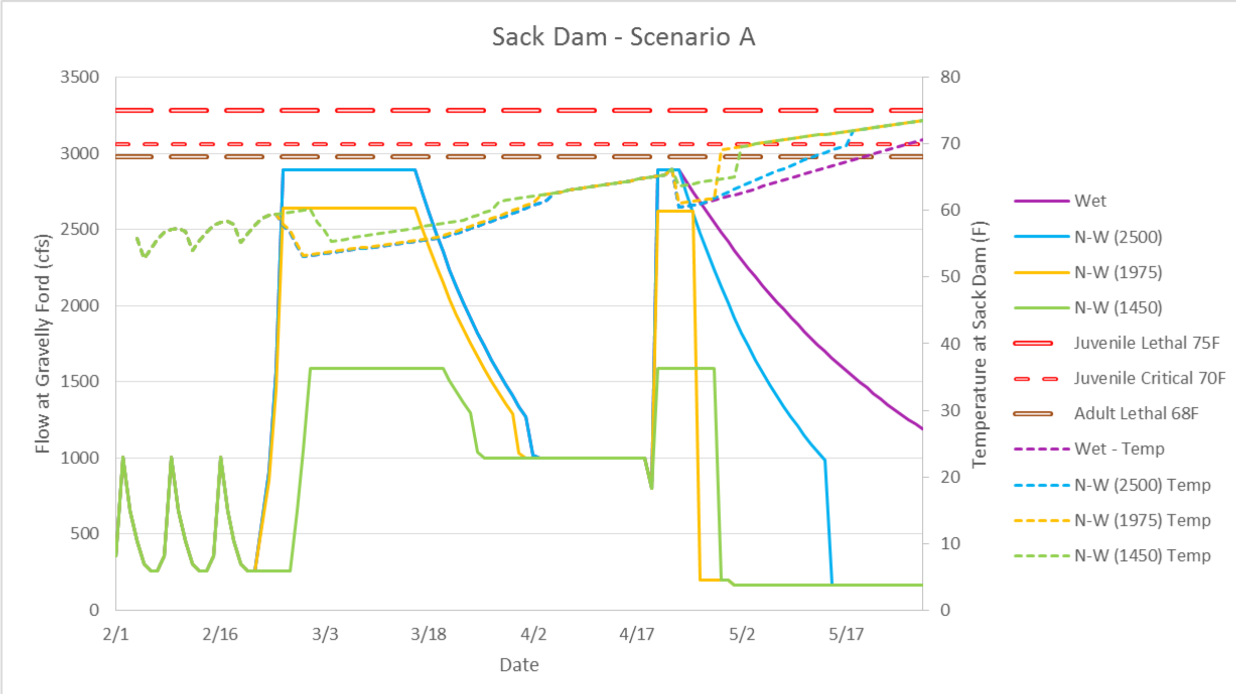


Figure 5-1a. Scenario A Temperature Response at Sack Dam.

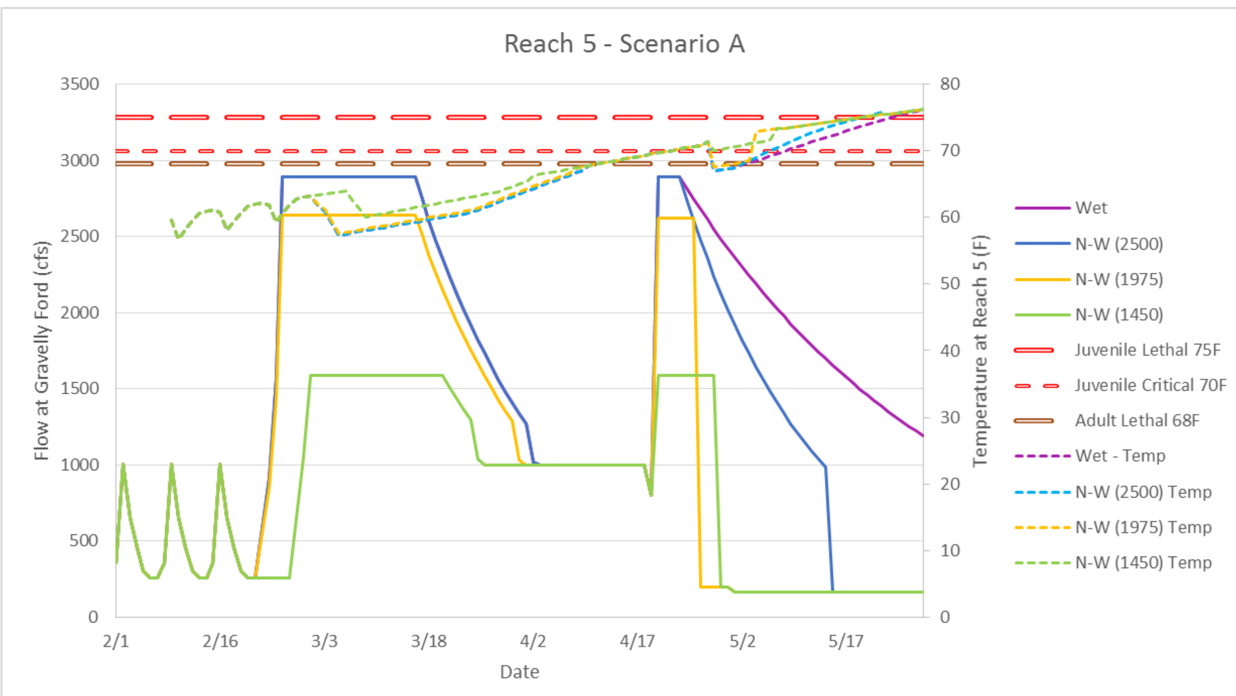


Figure 5-1b. Scenario A Temperature Response at Reach 5.

Figures 5-1a and 5-1b. Flow Scenario A water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and has been adjusted for losses and flow lag times.

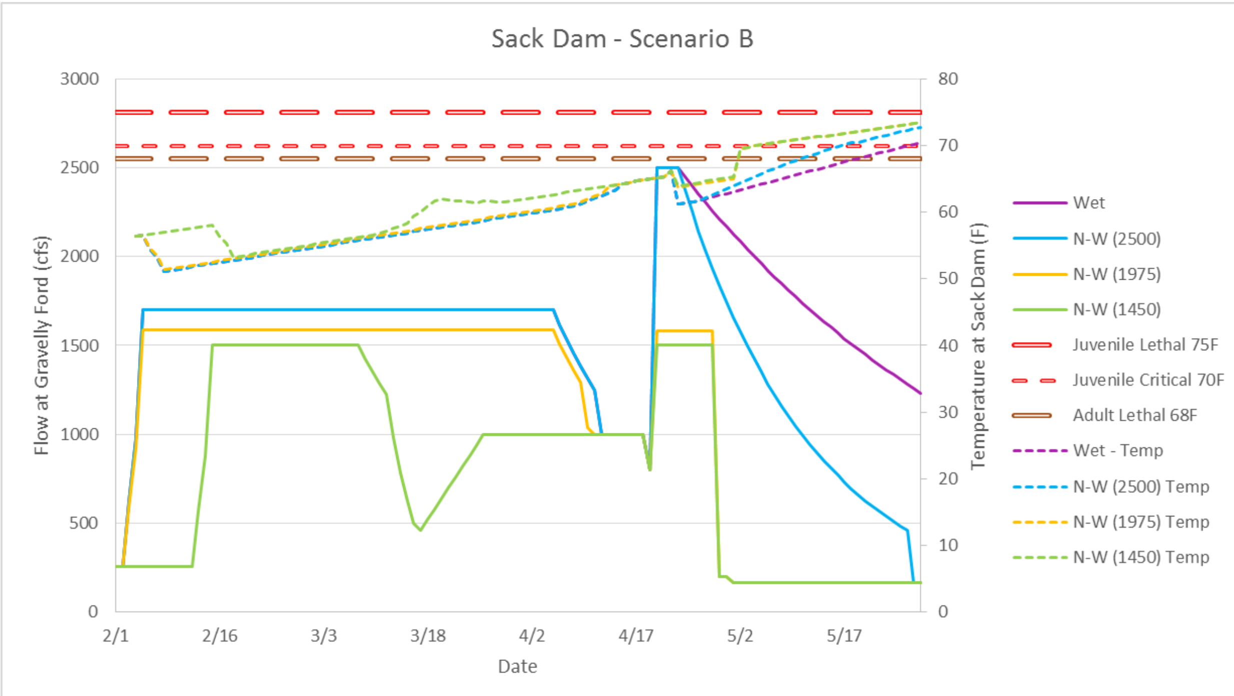


Figure 5-2a. Scenario B Temperature Response at Sack Dam.

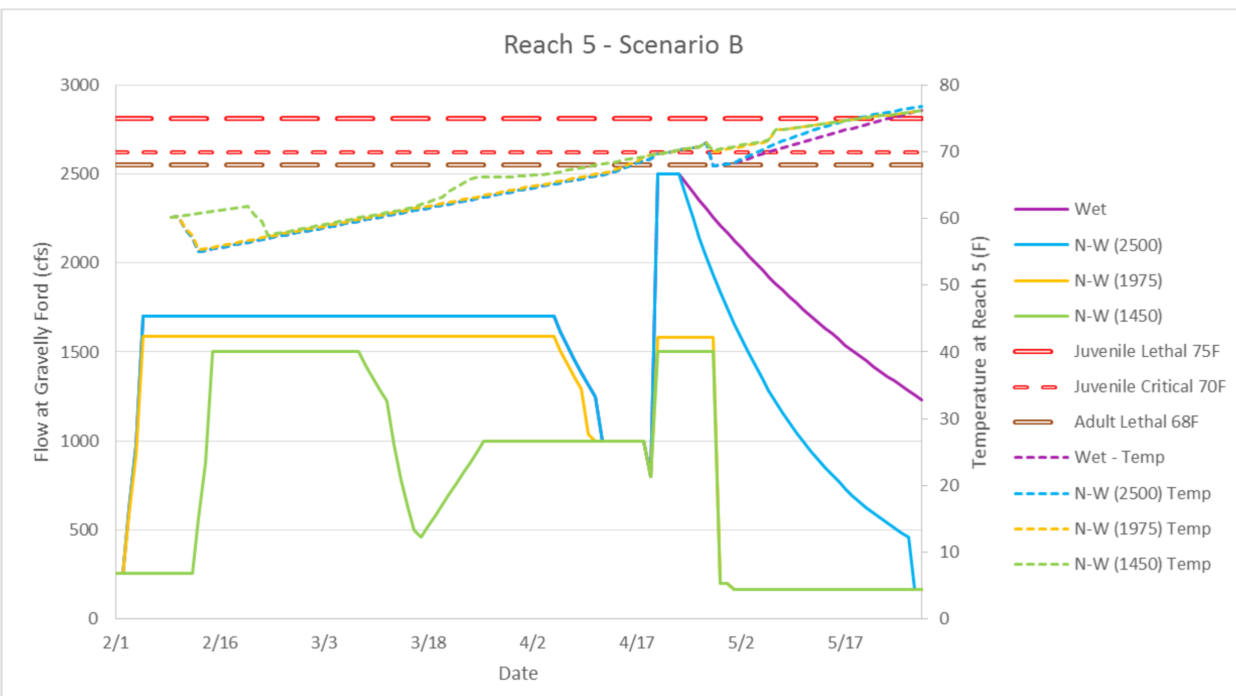


Figure 5-2b. Scenario B Temperature Response at Reach 5.

Figures 5-2a and 5-2b. Flow Scenario B water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and has been adjusted for losses and flow lag times.

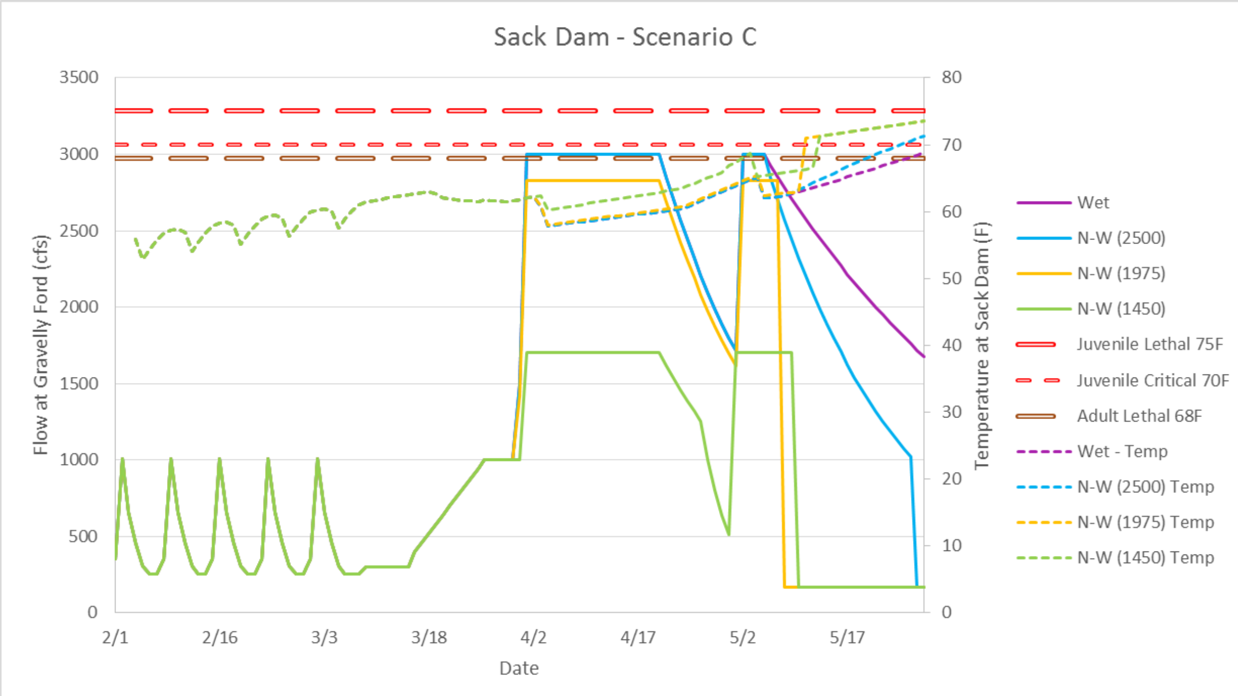


Figure 5-3a. Scenario C Temperature Response at Sack Dam.

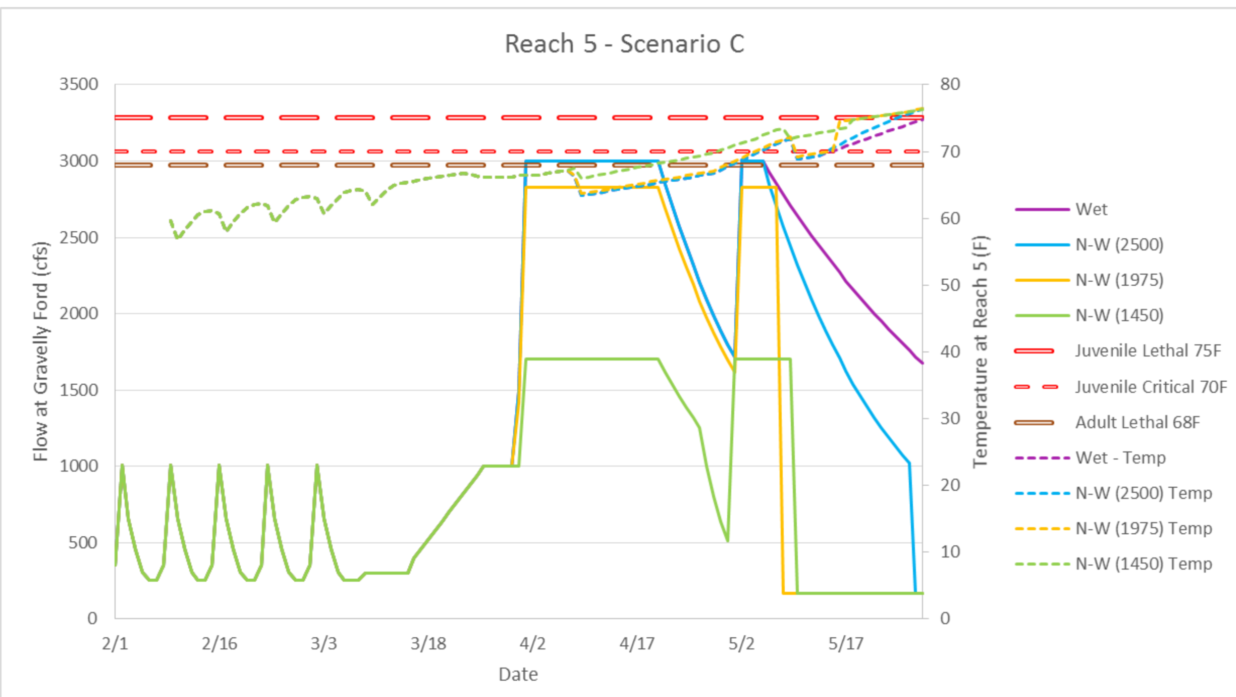


Figure 5-3b. Scenario C Temperature Response at Reach 5.

Figures 5-3a and 5-3b. Flow Scenario C water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and has been adjusted for losses and flow lag times.

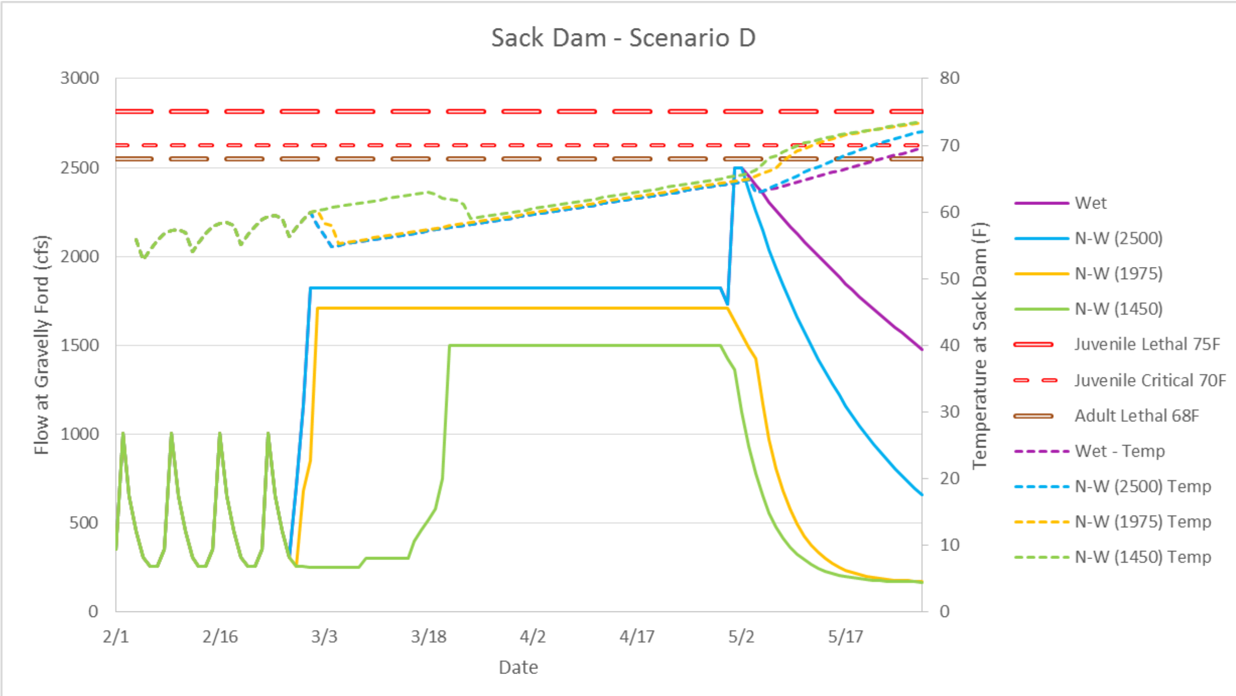


Figure 5-4a. Scenario D Temperature Response at Sack Dam.

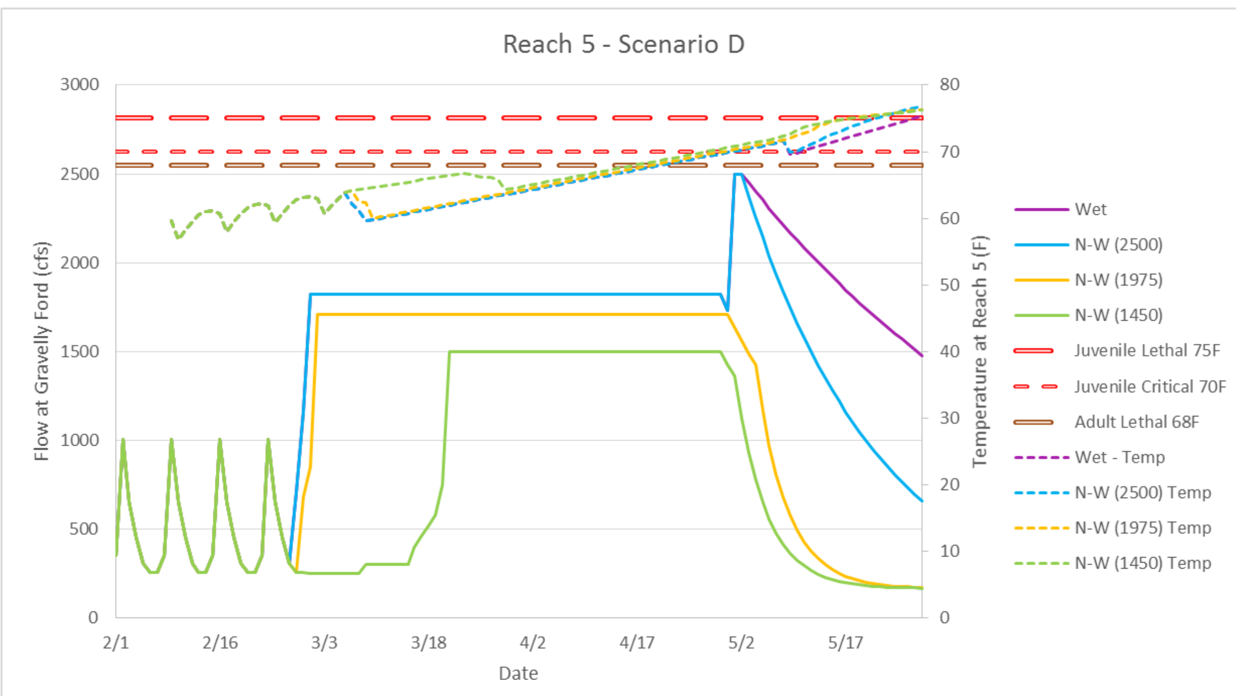


Figure 5-4b. Scenario D Temperature Response at Reach 5.

Figures 5-4a and 5-4b. Flow Scenario D water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and has been adjusted for losses and flow lag times.

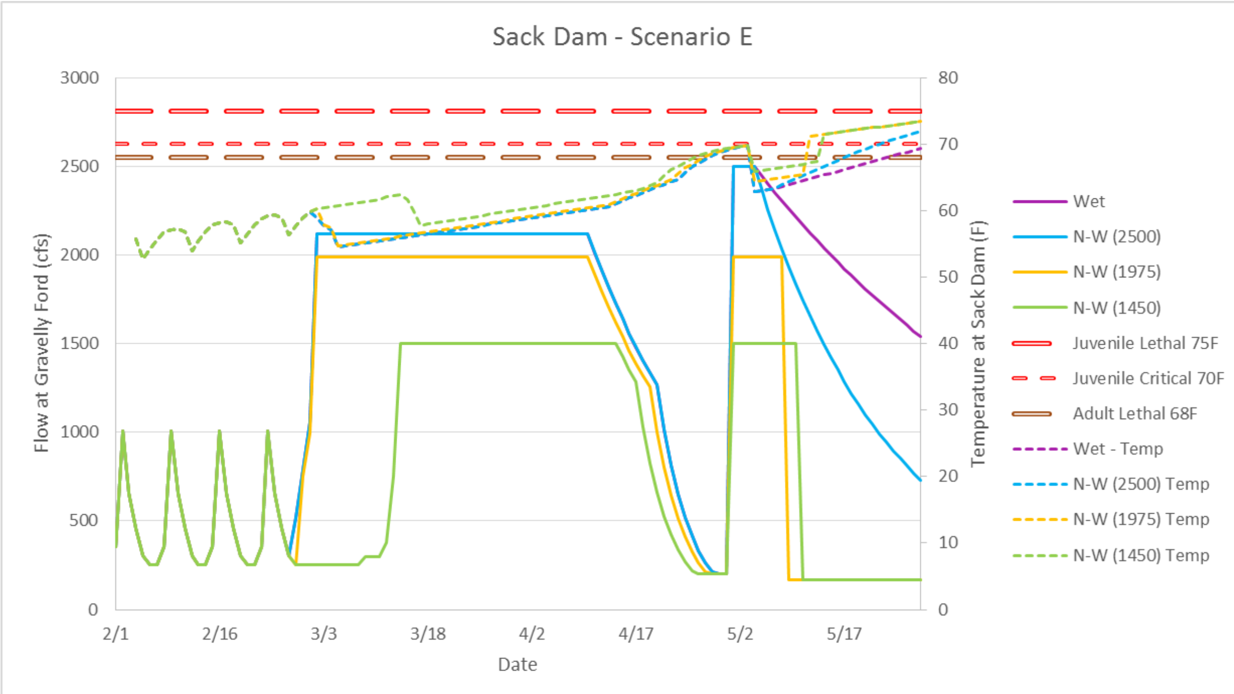


Figure 5-5a. Scenario E Temperature Response at Sack Dam.

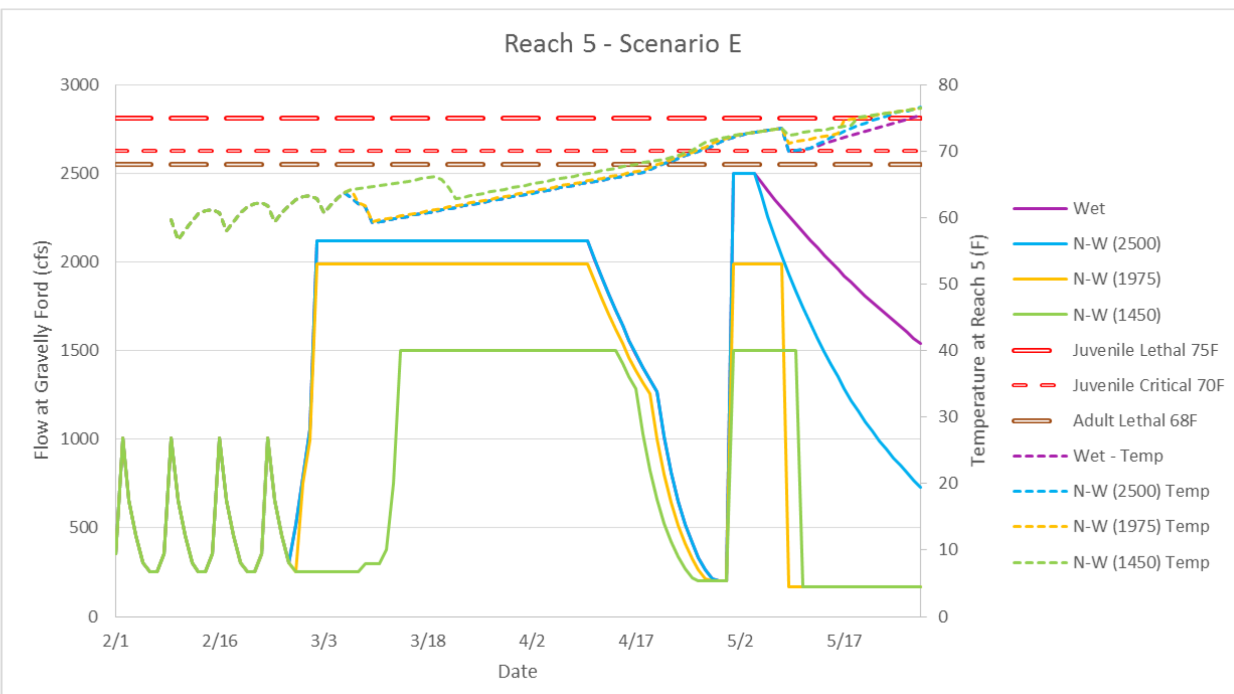


Figure 5-5b. Scenario E Temperature Response at Reach 5.

Figures 5-5a and 5-5b. Flow Scenario E water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and has been adjusted for losses and flow lag times.

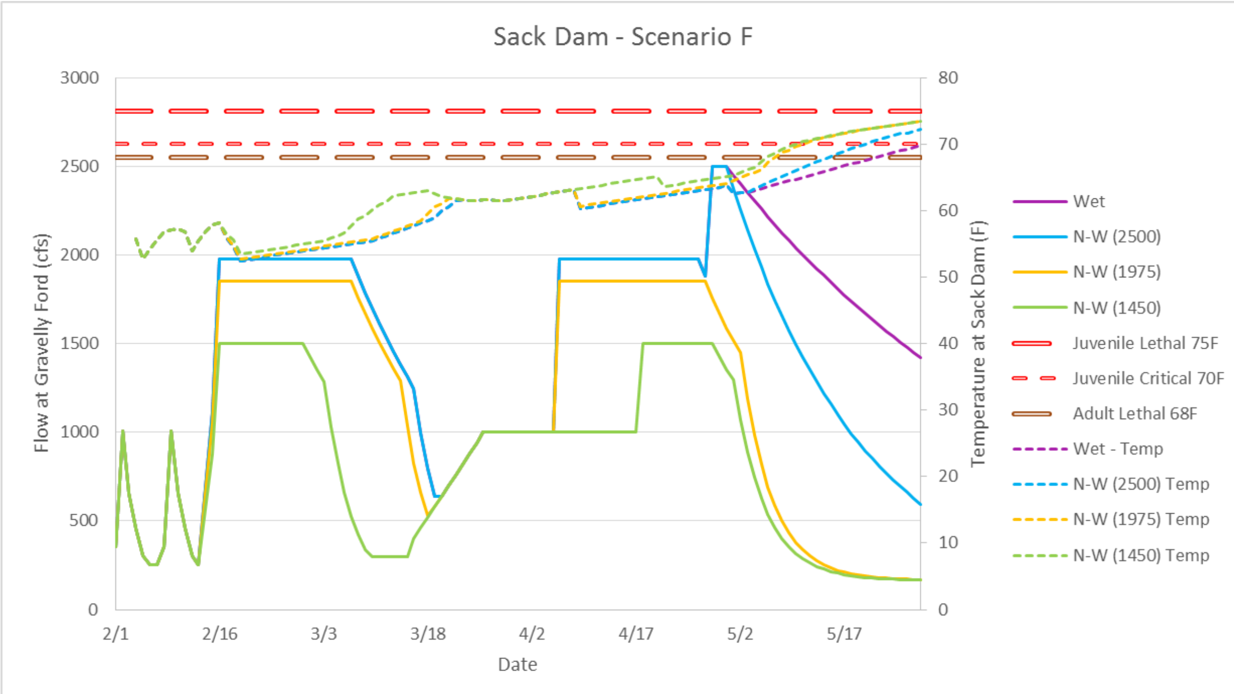


Figure 5-6a. Scenario F Temperature Response at Sack Dam.

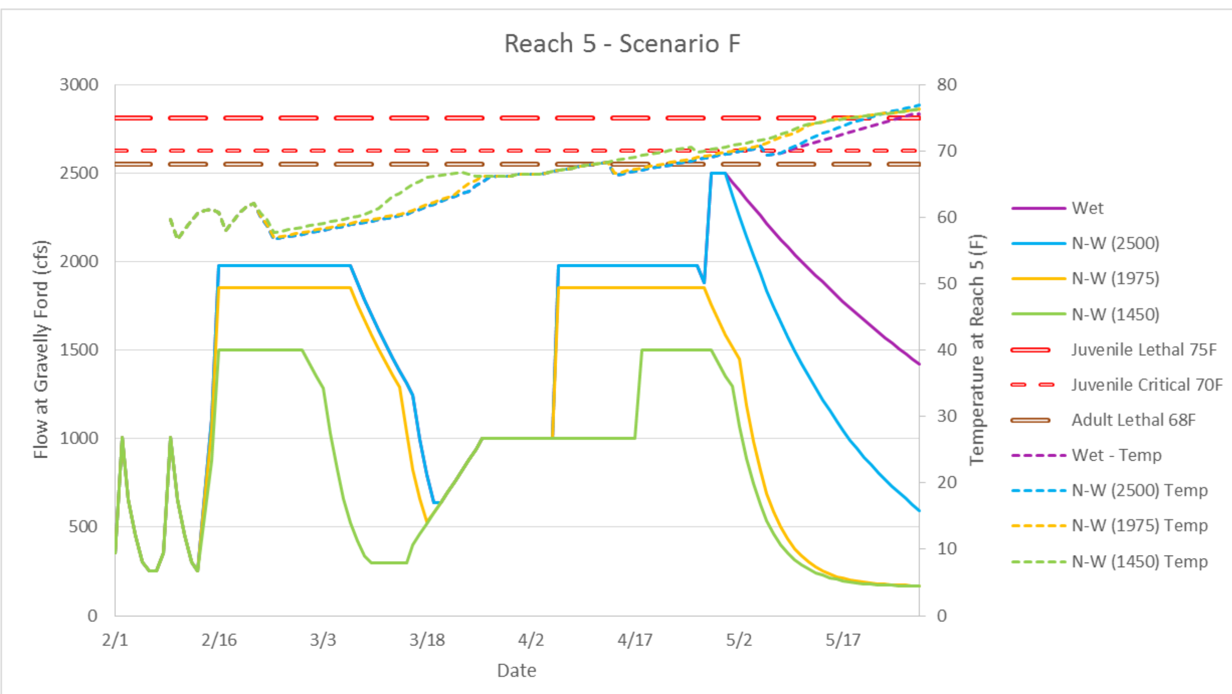


Figure 5-6b. Scenario F Temperature Response at Reach 5.

Figures 5-6a and 5-6b. Flow Scenario F water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and has been adjusted for losses and flow lag times.

5.2 Juvenile Salmonid Rearing Habitat

Hydraulic modeling of Reach 1B through Reach 3 and a simplified HSA calculation allowed the calculation of habitat acre-days, an index of HSA and duration of inundation. Habitat acre-days were also calculated for only the HSA that was estimated to occur on the floodplain thereby omitting in-channel habitat (Table 5-2). The most favorable values are shaded in blue to identify those flow scenarios that perform well by reach.

Table 5-2. Habitat Acre-Days by Reach per Each Water Year Type and Scenario.

Year Type and Scenario		Thousand Habitat Acre-Days					Floodplain Thousand Habitat Acre-Days
		Reach 1B	Reach 2A	Reach 2B	Reach 3	Total	Total
Wet and High Point of Normal-Wet (2500 TAF)	A	9.1	10.0	14.1	10.1	43.2	42.2
	B	15.8	18.3	22.6	11.3	68.0	65.1
	C	8.6	9.4	13.8	10.0	41.9	41.1
	D	15.9	18.1	23.2	12.3	69.6	67.0
	E	12.3	13.8	18.3	11.3	55.6	54.0
	F	13.5	15.2	20.2	11.6	60.5	58.5
Midpoint of Normal-Wet (1975 TAF)	A	8.7	9.7	12.6	9.2	40.2	39.1
	B	15.2	18.0	21.3	10.0	64.5	61.6
	C	8.3	9.1	12.8	9.4	39.6	38.7
	D	15.3	17.7	22.0	11.1	66.1	63.4
	E	12.2	13.7	18.4	10.3	54.6	52.8
	F	12.7	14.5	18.7	9.9	55.9	53.8
Low Point of Normal-Wet (1450 TAF)	A	5.2	6.2	7.3	3.4	22.2	21.2
	B	5.4	6.5	7.4	3.3	22.6	21.5
	C	5.6	6.5	8.0	4.0	24.1	23.1
	D	10.1	12.0	13.8	6.1	42.1	40.0
	E	7.9	9.4	10.8	4.8	32.8	31.2
	F	5.9	7.0	8.1	3.6	24.6	23.4

Blue shaded values are the most favorable

5.3 Graphical Depiction of Channel Capacity

A summary of the flow scenarios supported by a given channel capacity were graphically depicted (Tables 5-3a-c and Figure 5-7). Tables 5-3a-c present scenario viability in 100 cfs increments. By reading horizontally across the table for a selected channel capacity, one can quickly determine which flow scenarios can be supported. In Wet year types (Table 5-3a), all flow scenarios are viable at 3300 cfs channel capacity at Gravelly Ford, assuming a 0.25-ft buffer. Four of the six flow scenarios are viable at 2400 cfs, with none of the six viable at 1900 cfs. The necessary channel capacities at the lower range of Normal-Wet (Table 5-3c) fall sharply as compared to the wet year types due to the overall lower volume of available Restoration Flows, with all six flow scenarios available at 2000 cfs. Figure 5-7 presents the lowest channel capacity at which each scenario is viable by water year type. In general, Scenario C requires the highest channel capacity while Scenario B requires the lowest, regardless of water year type. A curve of channel capacity optimized for water temperature control only is shown for comparison.

Table 5-3a. Suitability of Various Channel Capacity Constraints for a Given Scenario Wet & High Point of Normal-Wet Year Types (Forecasted FNF of 2500 TAF or greater).

Channel Capacity Limitation at Gravelly Ford (cfs)[1]	Channel Capacity Limitation at Reach 2B (cfs)	Flow Scenario						Index of Riparian Vegetation Recruitment
		A	B	C	D	E	F	
3500	3300							**0.8**
3400	3200							
3300	3100							
3200	3000							
3100	2900							**0.7**
3000	2800							
2900	2700							
2800	2600							**0.6**
2700	2500							
2600	2400							
2500	2300							**0.5**
2400	2200							
2300	2100							**0.4**
2200	2000							
2100	1900							
2000	1800							**0.3**
1900	1700							
1800	1600							
1700	1500							**0.2**
1600	1400							
1500	1300							
1400	1200							
1300	1100							**0.1**
1200	1000							

The matrix is color coded to express the suitability from the values in Table 4-7a. Additionally, an index of the likely success of Riparian Vegetation Recruitment in Reach 1B through Reach 3 at various flow rates is presented for these water year types since Riparian Recruitment Flow is available (from Table 4-15). An index of 1.0 is equivalent to a 4500 cfs channel capacity.

[1] Applies to Reach 1B, 2A, and 3.

Key

	Viable, including a 0.50 ft stage buffer
	Viable, including a 0.25 ft stage buffer
	No stage buffer / Marginal at this channel capacity
	Not a viable flow strategy at this channel capacity

Table 5-3b. Suitability of Various Channel Capacity Constraints for a Given Scenario Midpoint of Normal-Wet Year Type (Forecasted FNF of 1975 TAF).

Channel Capacity Limitation at Gravelly Ford (cfs)[1]	Channel Capacity Limitation at Reach 2B (cfs)	Flow Scenario							Riparian Vegetation Recruitment
		A	B	C	D	E	F		
3500	3300								
3400	3200								
3300	3100								
3200	3000								
3100	2900								
3000	2800								
2900	2700								
2800	2600								
2700	2500								
2600	2400								
2500	2300								
2400	2200								Riparian Recruitment Flow Not Available
2300	2100								
2200	2000								
2100	1900								
2000	1800								
1900	1700								
1800	1600								
1700	1500								
1600	1400								
1500	1300								
1400	1200								
1300	1100								
1200	1000								

The matrix is color coded to express the suitability from the values in Table 4-7b. No Riparian Recruitment Flow is available in this water year type.

[1] *Applies to Reach 1B, 2A, and 3.*

Key

	Viable, including a 0.50 ft stage buffer
	Viable, including a 0.25 ft stage buffer
	No stage buffer / Marginal at this channel capacity
	Not a viable flow strategy at this channel capacity

Table 5-3c. Suitability of Various Channel Capacity Constraints for a Given Scenario Low Point of Normal-Wet & High Point of Normal-Dry Year Types (Forecasted FNF of 1450 TAF).

Channel Capacity Limitation at Gravelly Ford (cfs)[1]	Channel Capacity Limitation at Reach 2B (cfs)	Flow Scenario							Riparian Vegetation Recruitment
		A	B	C	D	E	F		
3500	3300								
3400	3200								
3300	3100								
3200	3000								
3100	2900								
3000	2800								
2900	2700								
2800	2600								
2700	2500								
2600	2400								
2500	2300								
2400	2200								Riparian Recruitment Flow Not Available
2300	2100								
2200	2000								
2100	1900								
2000	1800								
1900	1700								
1800	1600								
1700	1500								
1600	1400								
1500	1300								
1400	1200								
1300	1100								
1200	1000								

The matrix is color coded to express the suitability from the values in Table 4-7c. No Riparian Recruitment Flow is available in this water year type.

[1] *Applies to Reach 1B, 2A, and 3.*

Key

	Viable, including a 0.50 ft stage buffer
	Viable, including a 0.25 ft stage buffer
	No stage buffer / Marginal at this channel capacity
	Not a viable flow strategy at this channel capacity

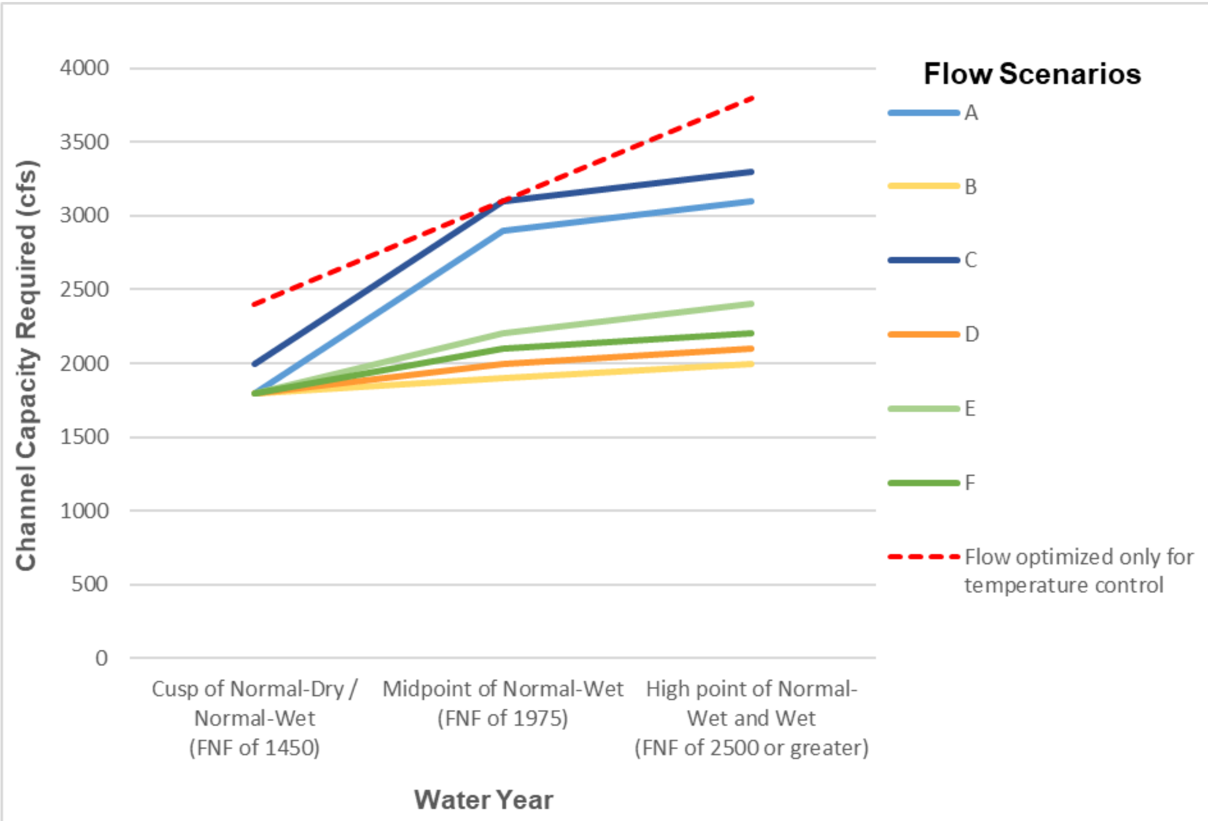


Figure 5-7. Required channel capacity for each flow scenario. A hypothetical flow strategy solely addressing temperature control, foregoing other fisheries objectives, is plotted as a reference (see Appendix E).

6.0 Conclusions

These results and conclusions inform the selection of channel capacities for a future stage of buildout in the Funding Constrained Framework. This analysis provides a range of reasonable flow scenarios that provide the physical characteristics known to be required by spring-run and fall-run Chinook salmon within the constraints of the Settlement and hydrologic conditions on the San Joaquin River. The flow scenarios were designed to serve the Program over the next 10+ years, and are for Wet and Normal-Wet year types, representing a 50% probability across all water years.

While this analysis does not conclude whether or not meaningful progress on fisheries restoration can be made at a given channel capacity, it does determine whether the tools (e.g. flow volume, flow timing, temperature control, inundation opportunities) are available at a given channel capacity to facilitate a fisheries restoration effort for the interim of funding constraints (Table 6-1a-c). It also examines the potential for recruitment of riparian vegetation, another ecological factor that is related to channel capacity.

6.1 Realistic Flow Scenarios

The six flow scenarios developed for this analysis differ substantially from the default hydrograph found in Exhibit B of the Settlement (see Appendix D). The biological need for both temperature control and rearing habitat of adequate duration, combined with other realities in flow scheduling such as reserving a portion of the Restoration Allocation for contingencies and pulse flows to encourage salmon movement, result in a set of realistic flow scenarios that all have lower channel capacity requirements than the 4000 cfs or greater channel capacity implied by the default hydrograph. There may be other reasons to maintain higher channel capacities in order to release higher flows, but those circumstances appear to be less frequent. This conclusion may substantially affect the assumptions of a variety of Program activities and facilities, and provides an opportunity for a phased approach to be planned around an intermediate channel capacity that enables a wide range of flow release options and strategies.

6.2 Temperature and Rearing Habitat

Adequate springtime water temperatures are constrained most in Reach 5, the lowermost section of the Restoration Area. The lethal threshold for adult Chinook salmon of 68 °F during their migration upstream is expected to be more of a constraint than the lethal threshold for juvenile Chinook salmon of 75 °F during the emigration downstream. There is a fair amount of uncertainty in the accuracy of the temperature model; however, the model is still valuable for comparing different flow scenarios and understanding the relationship between flow and water temperature. The six flow scenarios vary by 20 days in reaching the adult threshold, and 3 days in reaching the juvenile threshold in Wet years, and 19 days and 2 days respectively at the midpoint of Normal-Wet years.

Rearing habitat, calculated using a simplified Habitat Suitability Index (HSI), is present in all the reaches analyzed at flows as low as 1000 cfs. However, at such low flow rates, rearing habitat is limited to channel margins; floodplains and side channels are assumed not to be inundated until flows exceed 1000 cfs. The relationship between flow and suitable habitat is not linear, and varies by reach due to the diversity of floodplain configurations found along the San Joaquin River. Additionally, as flow rate increases, the stage of the river rises and inundates more floodplain, and the in-channel habitat becomes unsuitable due to increasing water depth and velocity. Thus, there is not a demarcation in the flow-inundated area data where suitable habitat increases sharply with increasing flow, and there is a variety of rearing habitat available at flow rates far lower than the maximum 4000 cfs inundation flows envisioned in the Settlement.

6.3 Riparian Vegetation Recruitment

Natural riparian vegetation recruitment through the use of gradual flow ramp-downs is more likely to be effective with higher channel capacities. At 1800 cfs channel capacity, one-quarter (index of 0.25) of the potential riparian vegetation recruitment is available with Restoration Flows compared to full 4500 cfs channel capacity. At 2500 cfs, over half (index of 0.51) of the potential is available, and at 3300 cfs, three-quarters (index of 0.75) of the potential is available. Riparian vegetation recruitment is also possible with flood flows, which are forecast to exceed 4000 cfs an estimated 7% of all years during the suitable time for riparian vegetation recruitment.

6.4 Suitable Channel Capacities

The six flow scenarios presented in this report all require less channel capacity than the 4500 cfs channel capacity set forth in the Settlement or the 4000 cfs maximum flow depicted in Exhibit B of the Settlement (Table 6-1a through c). Depending on the scenario and water year type, they require between 1800 cfs to 3300 cfs, assuming a 0.25-ft stage buffer. This substantial difference in flow rate as compared to the Settlement mandate is due to current fisheries experts' knowledge on rearing habitat and optimization of fisheries needs, in particular the need to inundate floodplains for longer periods of time during the early winter and spring fry and juvenile salmon rearing period. This longer duration redistributes the Restoration Allocation, lowering the necessary channel capacity for Stage 1 activities; however, greater capacity may be necessary in the future to provide further flexibility in flow allocations. Selection of an interim channel capacity in the Funding Constrained Framework should fall between 1500 cfs and 3300 cfs at Gravelly Ford. Channel capacities below 1800 cfs do not provide the necessary flexibility to address rearing habitat and water temperature. Channel capacities above 3300 cfs are more likely to provide diminishing cost-benefit for fisheries; flood flows are likely to replicate physical benefits to the river channel, reducing the need to accomplish such benefits with Restoration Flows above 3300 cfs. The appropriate Stage 1 channel capacity should be chosen using a cost-benefit analysis combined with the factors summarized in Figure 6-1.

Table 6-1a. Summary Information for Wet Water Year Types (Forecasted FNF above 2500 TAF).

Channel Capacity at Gravelly Ford (cfs)	Number of Viable Flow Scenarios	Viable Flow Scenarios[1]	Best Performing Scenario			Chance of Flood Flows Preempting Restoration Flows[4]	
			Latest Date of Adult Lethal Temperature Threshold[2]	Latest Date of Juvenile Critical Temperature Threshold[2]	Highest Floodplain Habitat–Acre Days[3]	For 15 or more days	For 30 or more days
3500	6 of 6	ABCDEF	May 1	May 5	67.0	94%	75%
3000	4 of 6	B DEF	April 23	May 3	67.0		
2500	4 of 6	B DEF	April 23	May 3	67.0		
2000	1 of 6	B	April 17	April 22	65.1		
1500	0 of 6	—	—	—	—		
Wet year types occur with 20% frequency across all years and range above 2500 TAF FNF. Table assumes a 0.25 ft stage buffer.							

[1] See the discussion of the flow scenarios in Section 3.2.
[2] For all reaches of the Restoration Area.
[3] In thousands. Suitable habitat acres in Reaches 1B through 3, multiplied by number of days that suitable habitat is available. These numbers represent the maximum inundation period of Flow Scenario D.
[4] For the period February 1 through May 1.

Table 6-1b. Summary Information for Midpoint of Normal-Wet Water Year Types (Forecasted FNF of 1975 TAF).

Channel Capacity at Gravelly Ford (cfs)	Number of Viable Flow Scenarios	Viable Flow Scenarios[1]	Best Performing Scenario			Chance of Flood Flows Preempting Restoration Flows[4]	
			Latest Date of Adult Lethal Temperature Threshold[2]	Latest Date of Juvenile Critical Temperature Threshold[2]	Highest Floodplain Habitat–Acre Days[3]	For 15 or more days	For 30 or more days
3500	6 of 6	ABCDEF	April 30	May 5	63.4	38%	25%
3000	5 of 6	AB DEF	April 21	May 2	63.4		
2500	4 of 6	B DEF	April 21	May 2	63.4		
2000	2 of 6	B D	April 17	April 29	63.4		
1500	0 of 6	—	—	—	—		
Normal-Wet year types occur with 30% frequency across all years and range from 1450 to 2500 TAF FNF. Table assumes a 0.25 ft stage buffer.							

[1] See the discussion of the flow scenarios in Section 3.2.
[2] For all reaches of the Restoration Area.
[3] In thousands. Suitable habitat acres in Reaches 1B through 3, multiplied by number of days that suitable habitat is available. These numbers represent the maximum inundation period of Flow Scenario D.
[4] For the period February 1 through May 1.

Table 6-1c. Summary Information for Low Point of Normal-Wet Water Year Types (Forecasted FNF of 1450 TAF).

Channel Capacity at Gravelly Ford (cfs)	Number of Viable Flow Scenarios	Viable Flow Scenarios[1]	Best Performing Scenario			Chance of Flood Flows Preempting Restoration Flows[4]	
			Latest Date of Adult Lethal Temperature Threshold[2]	Latest Date of Juvenile Critical Temperature Threshold[2]	Highest Floodplain Habitat–Acre Days[3]	For 15 or more days	For 30 or more days
2000	6 of 6	ABCDEF	April 20	April 29	40.0	23%	10%
1500	0 of 6	—	—	—	—		
Normal-Wet year types occur with 30% frequency across all years and range from 1450 to 2500 TAF FNF. Table assumes a 0.25 ft stage buffer.							

[1] See the discussion of the flow scenarios in Section 3.2.
[2] For all reaches of the Restoration Area.
[3] In thousands. Suitable habitat acres in Reaches 1B through 3, multiplied by number of days that suitable habitat is available. These numbers represent the maximum inundation period of Flow Scenario D.
[4] For the period February 1 through May 1.

<table>
<tr><th></th><th>1400</th><th>1600</th><th>1800</th><th>2000</th><th>2200</th><th>2400</th><th>2600</th><th>2800</th><th>3000</th><th>3200</th><th>3400</th></tr>
<tr><td>Water Temperature</td><td></td><td colspan="2">Limited temperature control in normal (median) and drier hydrologic conditions</td><td colspan="2">Limited temperature control in wetter hydrologic conditions; moderate temperature control in normal and drier conditions</td><td colspan="4">Moderate temperature control in wetter conditions; maximum temperature control in normal and drier conditions</td><td colspan="2">Maximum temperature control in all conditions</td></tr>
<tr><td>Rearing Habitat</td><td>Inadequate flexibility in normal (median) and drier conditions</td><td>Marginal flexibility in normal (median) and drier conditions</td><td colspan="2">Adequate flexibility in normal (median) and drier year types; inadequate flexibility in wetter conditions</td><td>Marginal flexibility in wetter conditions</td><td colspan="4">Excellent flexibility in normal (median) and drier year types; adequate flexibility in wetter conditions</td><td colspan="2">Excellent flexibility in all conditions</td></tr>
<tr><td>Vegetation Recruitment Potential</td><td>10%</td><td colspan="2">20%</td><td>30%</td><td>40%</td><td colspan="2">50%</td><td>60%</td><td colspan="2">70%</td><td>80%</td></tr>
</table>

Figure 6-1. Summary Infographic for Informing the Selection of Suitable Channel Capacities at Gravelly Ford for Stage 1.

6.5 Channel Capacity by Reach

Because of the expected losses in Reach 2, it is permissible to design the channel capacity for Reach 2B 200 cfs lower than the channel capacity at Reach 1B or Reach 2A and maintain continuity of Restoration Flows. Below Sack Dam, there is also the potential to step down in channel capacity by intentionally recapturing a portion of Restoration Flows at Arroyo Canal. The average Arroyo Canal demand for the months of February through April is 200 cfs. This would result in negatively affecting temperatures in Reach 4 and Reach 5, but would only be necessary at the peak flow rates. Once an inundation flow or Riparian Recruitment Flow dropped 200 cfs below the channel capacity limitation, it would no longer be necessary to intentionally recapture water at Exchange Contractor facilities. Therefore, it is reasonable to select different channel capacities by reach, with Reach 2B being 200 cfs less than upstream reaches, and Reach 4 and Reach 5 being 200 cfs less than Reach 2B in Stage 1 of the Funding Constrained Framework.

6.6 Beyond Stage 1 Channel Capacity

Five aspects of channel capacity were analyzed and synthesized to guide the selection of an interim channel capacity. Additional information will undoubtedly be gleaned in the coming years, which will sharpen the analyses provided here. These recommendations outline how the Program can attain full channel capacity as described in the Settlement. Recommendations are intended to maximize cost-benefit over the initial Stage 1 while avoiding regrettable limitations based on the primary concerns that we currently identified. Results of this analysis should not be extrapolated beyond Stage 1 without further and more detailed investigations.

7.0 Citations

Lai, Y (2008). *SRH-2D version 2: Theory and User's Manual, Sedimentation and River Hydraulics – Two-dimensional River Flow Modeling*, US Bureau of Reclamation, Technical Service Center, Denver, CO.

Poletto J.B., D.E. Cocherell, S.E. Baird, T.X. Nguyen, V. Cabrera-Stagno, A.P. Farrell, and N.A. Fangue (2017). *Unusual aerobic performance at high temperatures in juvenile Chinook salmon, Oncorhynchus tshawytscha*. Conservation Physiology 5(1):1-13.

Reclamation (2012a). *Hydraulic Studies for Fish Habitat Analysis*, Technical Report No. SRH-2012-15. Prepared for San Joaquin River Restoration Project, Mid-Pacific Region, US Bureau of Reclamation, Technical Service Center, Denver, CO.

Reclamation (2012b). *Minimum Floodplain Habitat Area: for Spring and Fall-Run Chinook Salmon*, Technical Report. San Joaquin River Restoration Program, Mid-Pacific Region, US Bureau of Reclamation, Sacramento, CA.

Reclamation (2012c). *San Joaquin River Restoration Program Programmatic EIS/EIR*, US Bureau of Reclamation

Reclamation (2015). *Conceptual Hydraulic Design of the Mendota Bypass*, Technical Report No. SRH-2015-26. Prepared for San Joaquin River Restoration Program, Mid-Pacific Region, US Bureau of Reclamation, Technical Service Center, Denver, CO.

Reclamation (2017). *Fisheries Framework: Spring-run and Fall-run Chinook Salmon*, Technical Report. San Joaquin River Restoration Program, Mid-Pacific Region, US Bureau of Reclamation, Sacramento, CA.

Resource Management Associates, Inc., and Reclamation (2007). *San-Joaquin Basin Water Temperature Modeling and Analysis*, US Bureau of Reclamation, Sacramento, CA.

Sommer, T.R., M.L. Nobriga, W.C. Harrell, W. Batham, and W.J. Kimmerer (2001). *Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival*. Canadian Journal of Fisheries and Aquatic Sciences 58(2): 325-333.

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APPENDIX A

Inundation Scenario Mapping

This appendix includes inundation maps for the post-processing analysis of various model runs evaluating suitable floodplain habitat. The flows evaluated vary by reach, but generally include 1500–4000 cfs flow.

Reach 1B

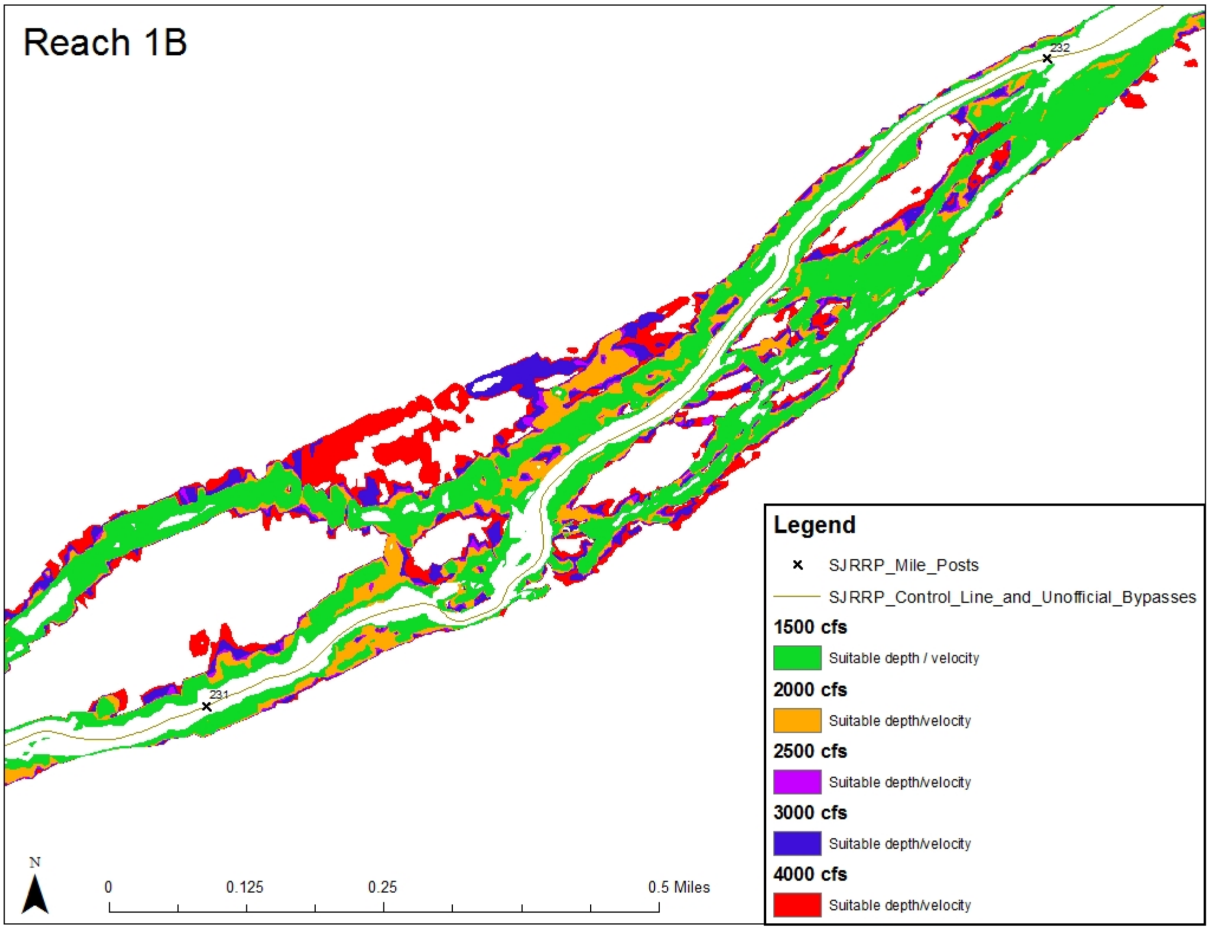


Figure A-1. Reach 1B at River Mile 231.

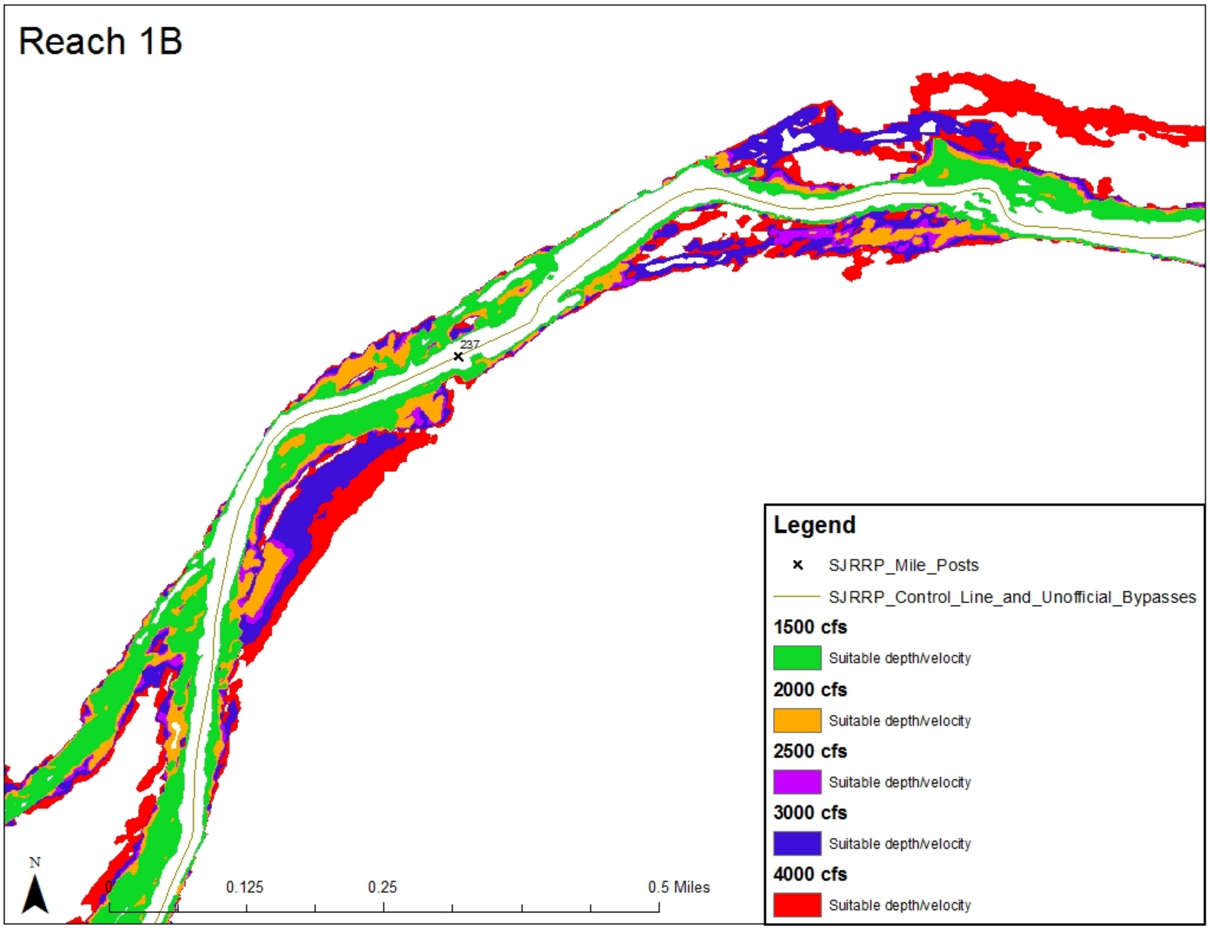
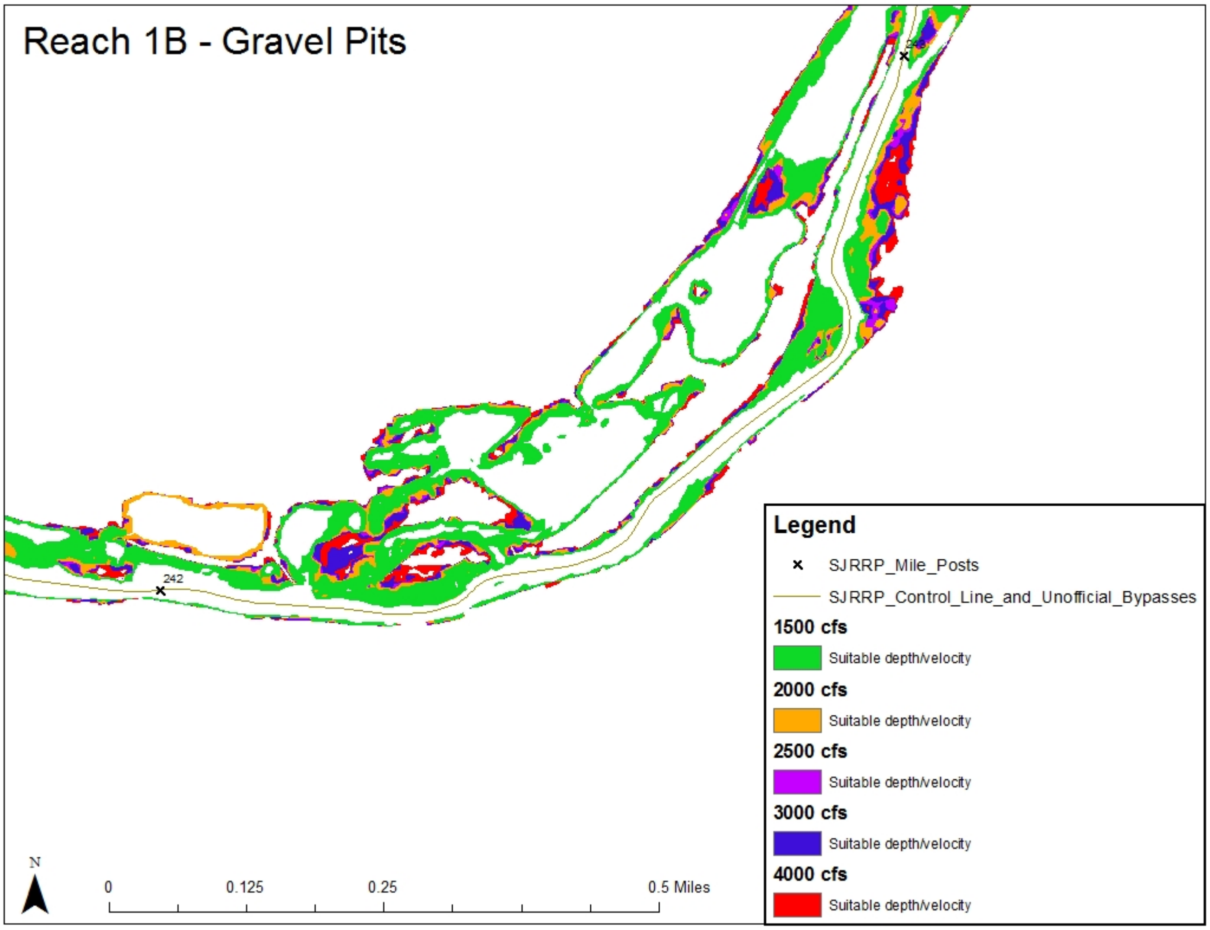


Figure A-2. Reach 1B at River Mile 237.



There is minimal hydraulically suitable floodplain habitat near gravel pits.

Figure A-3. Reach 1B at River Mile 242.

Reach 2A

Inundation maps for Reach 2A depict that floodplain activity varies through the reach. In multiple locations at low flows, the hydraulics of depth and velocity are suitable. As flows increase, more complex habitat is activated.

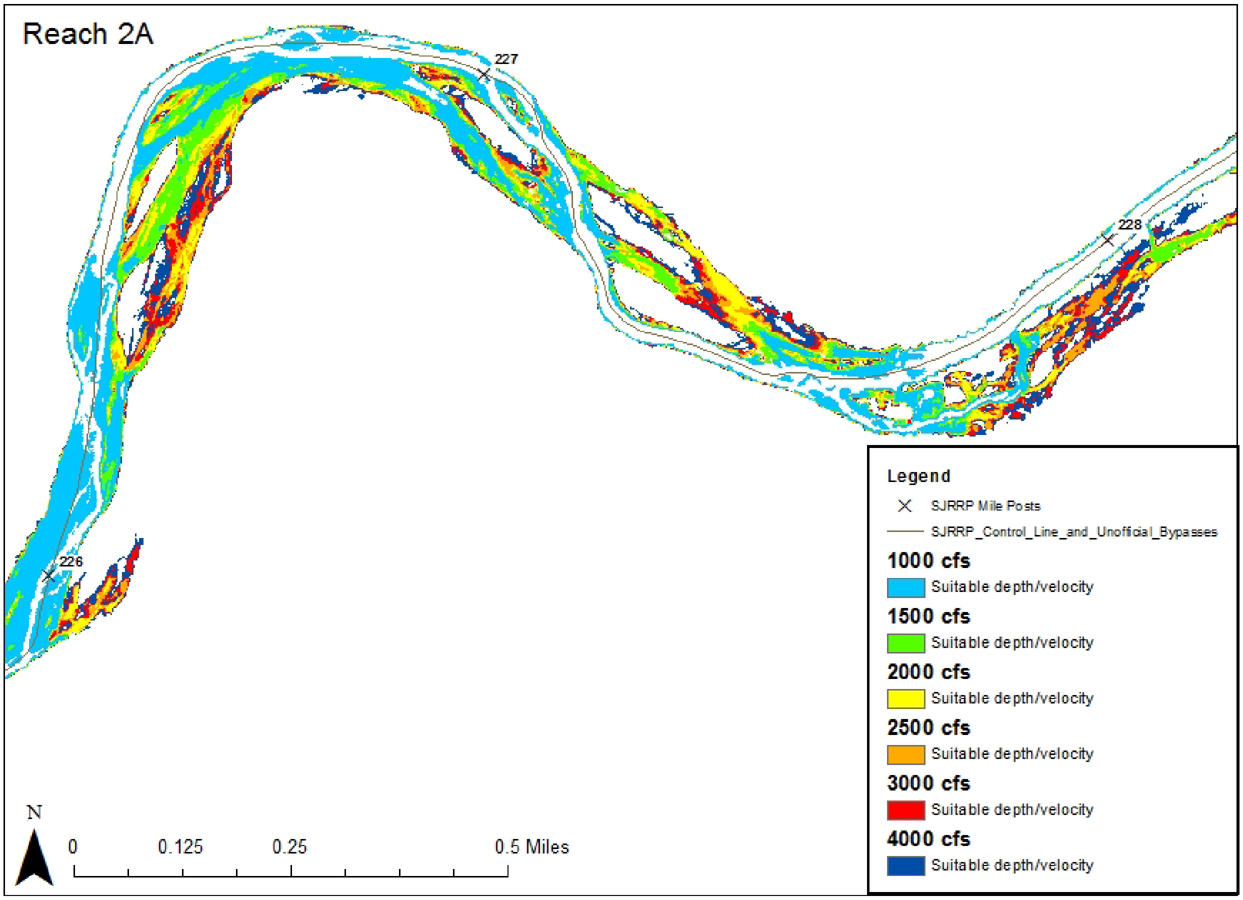


Figure A-4. Reach 2A at River Mile 227.

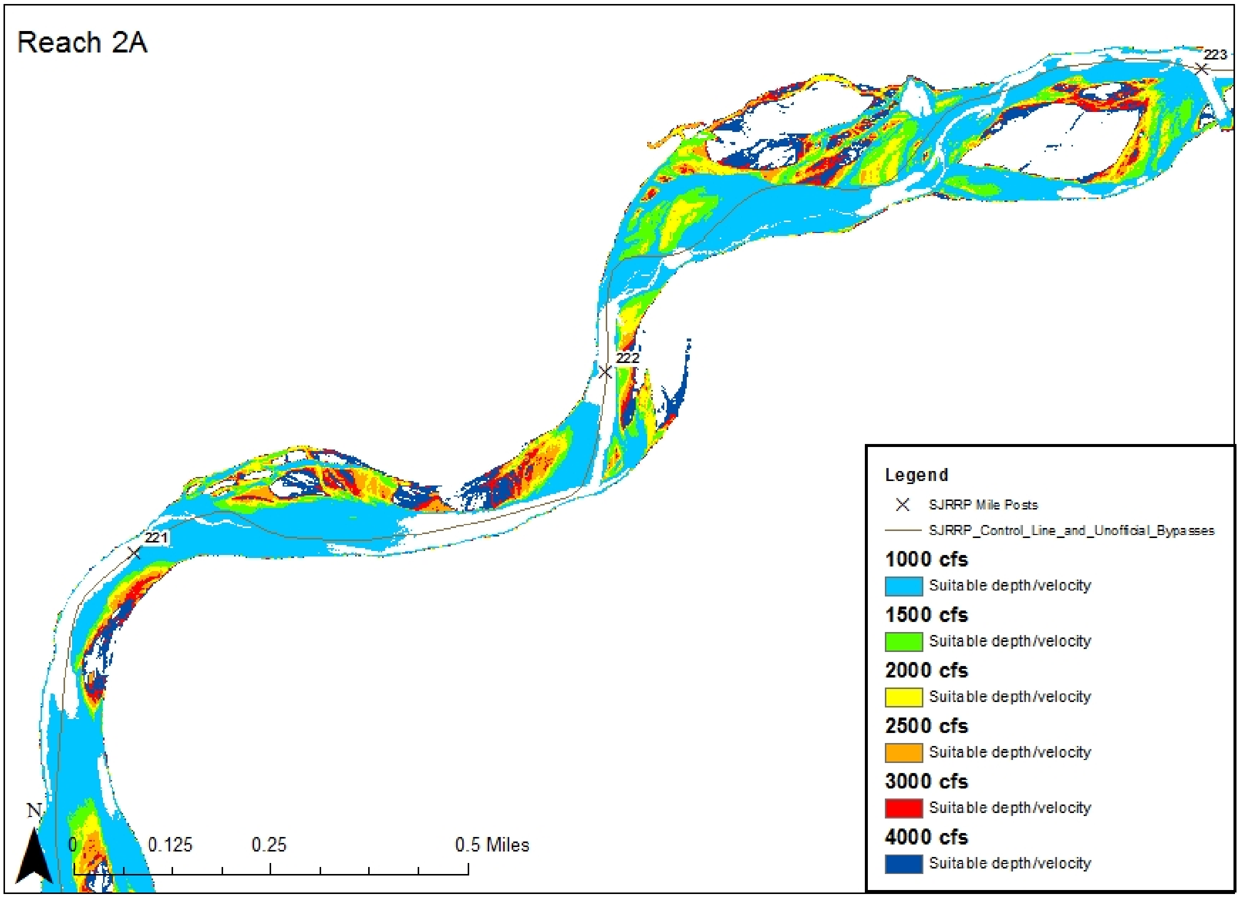


Figure A-5. Reach 2A at River Mile 222.

Reach 2B

Full buildout of Reach 2B, with the current plan of floodplain grading, results in side channels that meet the depth and velocity criteria of this analysis at flows below 1000 cfs. The center of many of these channels no longer meets criteria at 2500 cfs, resulting in a slight decrease of suitable rearing habitat acres at 2500 cfs. At 3000 cfs and above, flows begin to move out of the channel into the floodplain, and suitable rearing habitat area again increases.

The area of hydraulically suitable rearing habitat is nearly even when comparing the available habitat upstream of San Mateo Road with the available habitat downstream of San Mateo Road until flows of 4000 cfs and above.

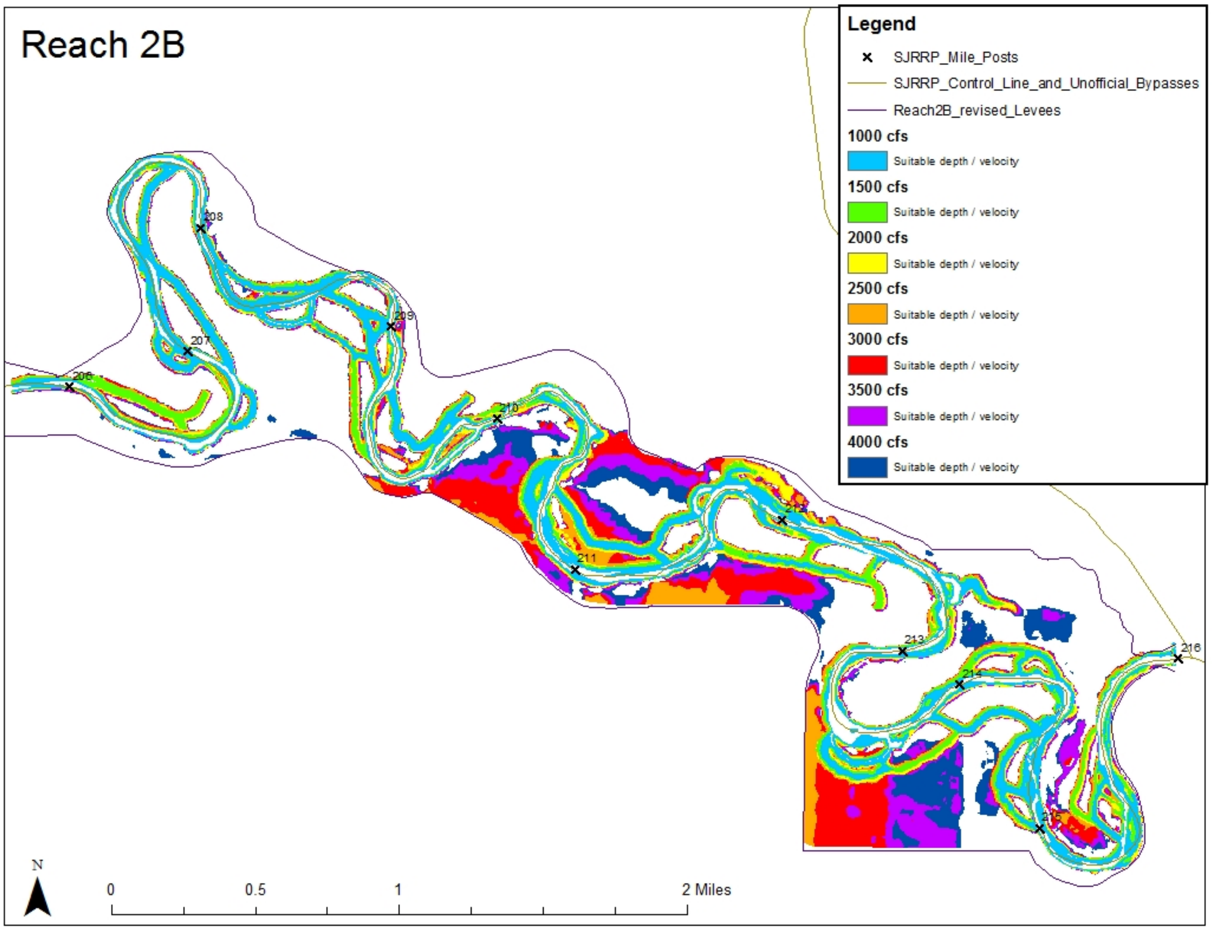


Figure A-6. Reach 2B Overview.

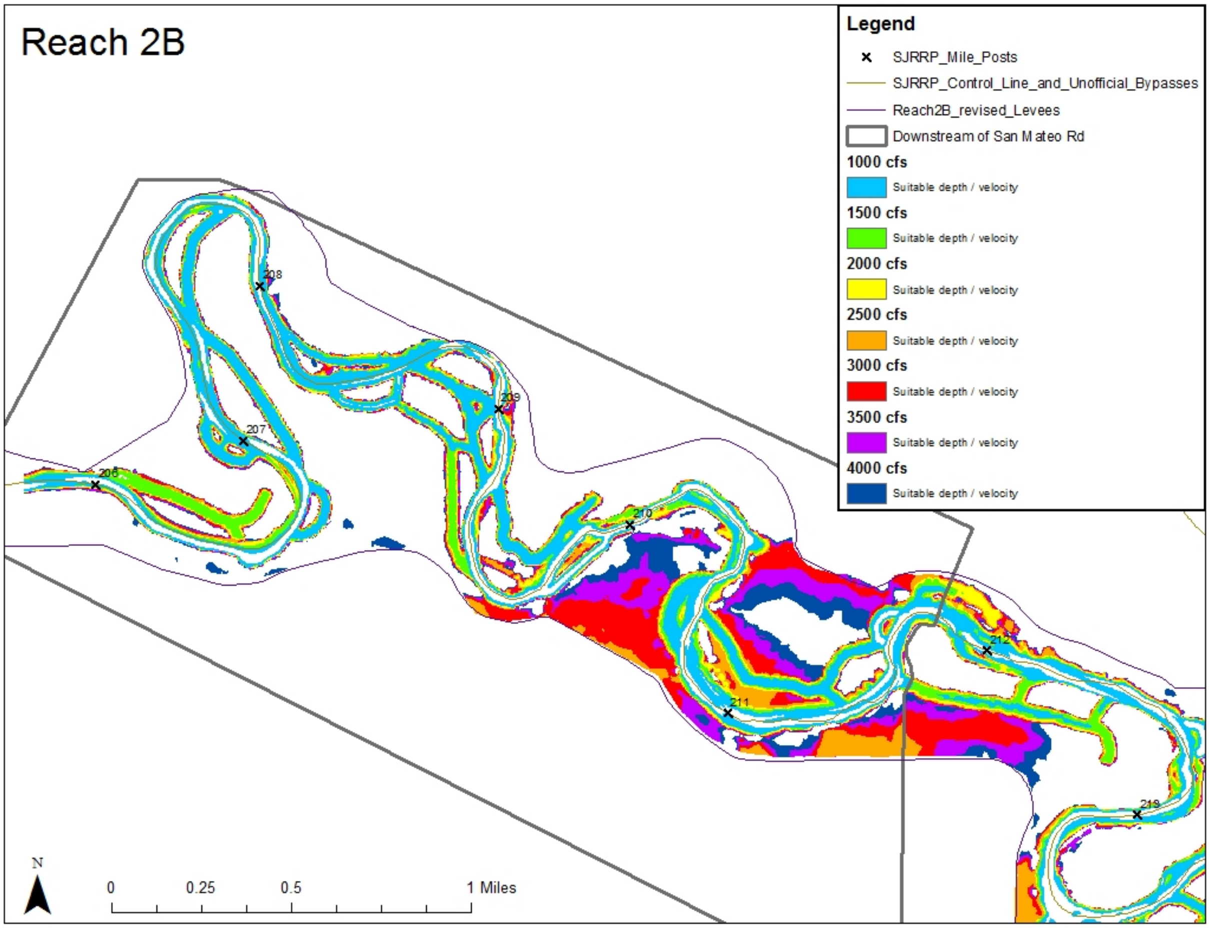


Figure A-7. Reach 2B Downstream of San Mateo Road.

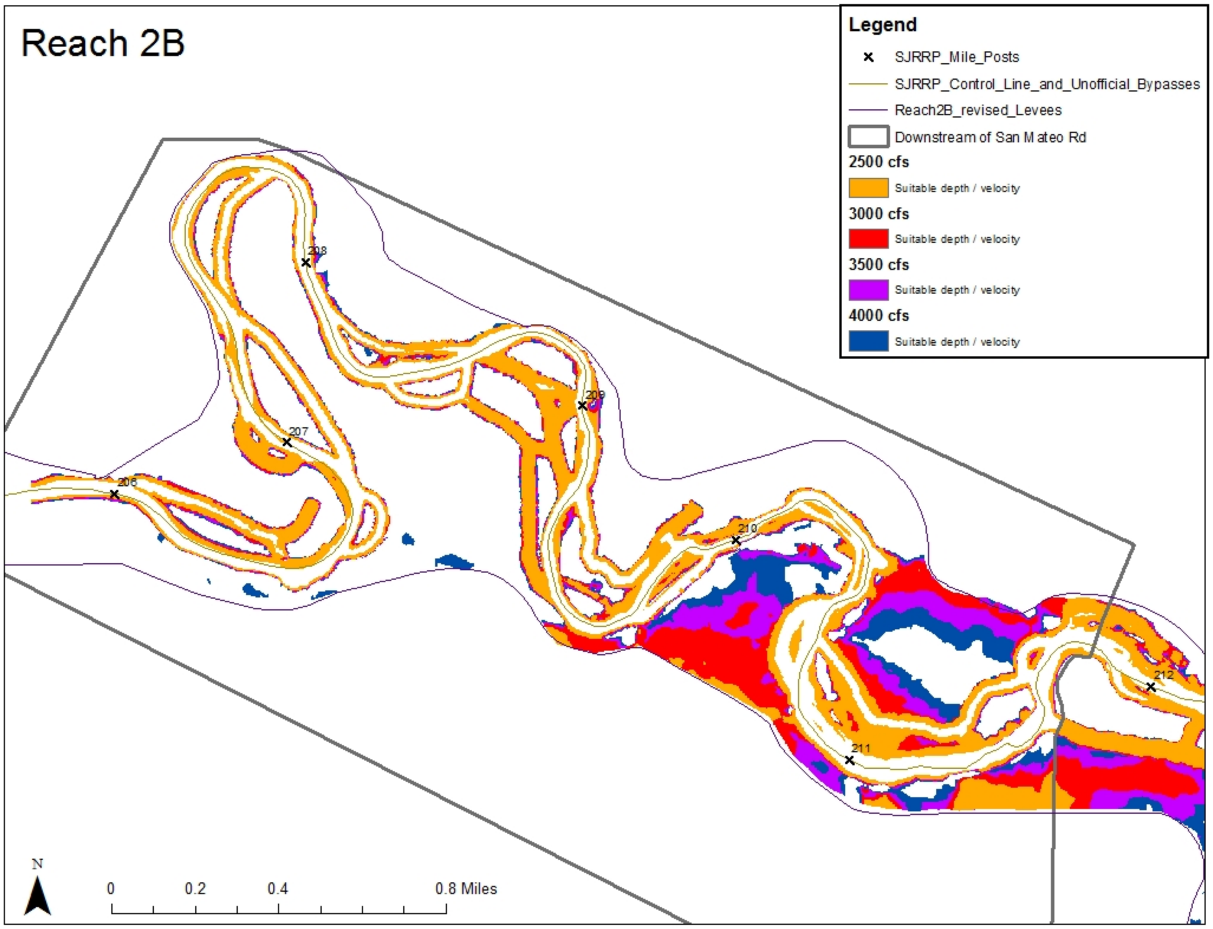


Figure A-8. Reach 2B Downstream of San Mateo Road at High Flows (2500 cfs and above).

At flows of 2500 cfs and above, there is loss of hydraulically suitable rearing habitat within the main and side channels, and an increase of hydraulically suitable rearing habitat in the off-channel floodplain.

The Funding Constrained Framework proposes several cost saving options for the Reach 2B project, one of which is the construction of levees and floodplain habitat to San Mateo Road, while leaving the channel upstream of San Mateo Road in its present condition. This scenario was evaluated for the Reach 2B project, as shown in Figure A-8.

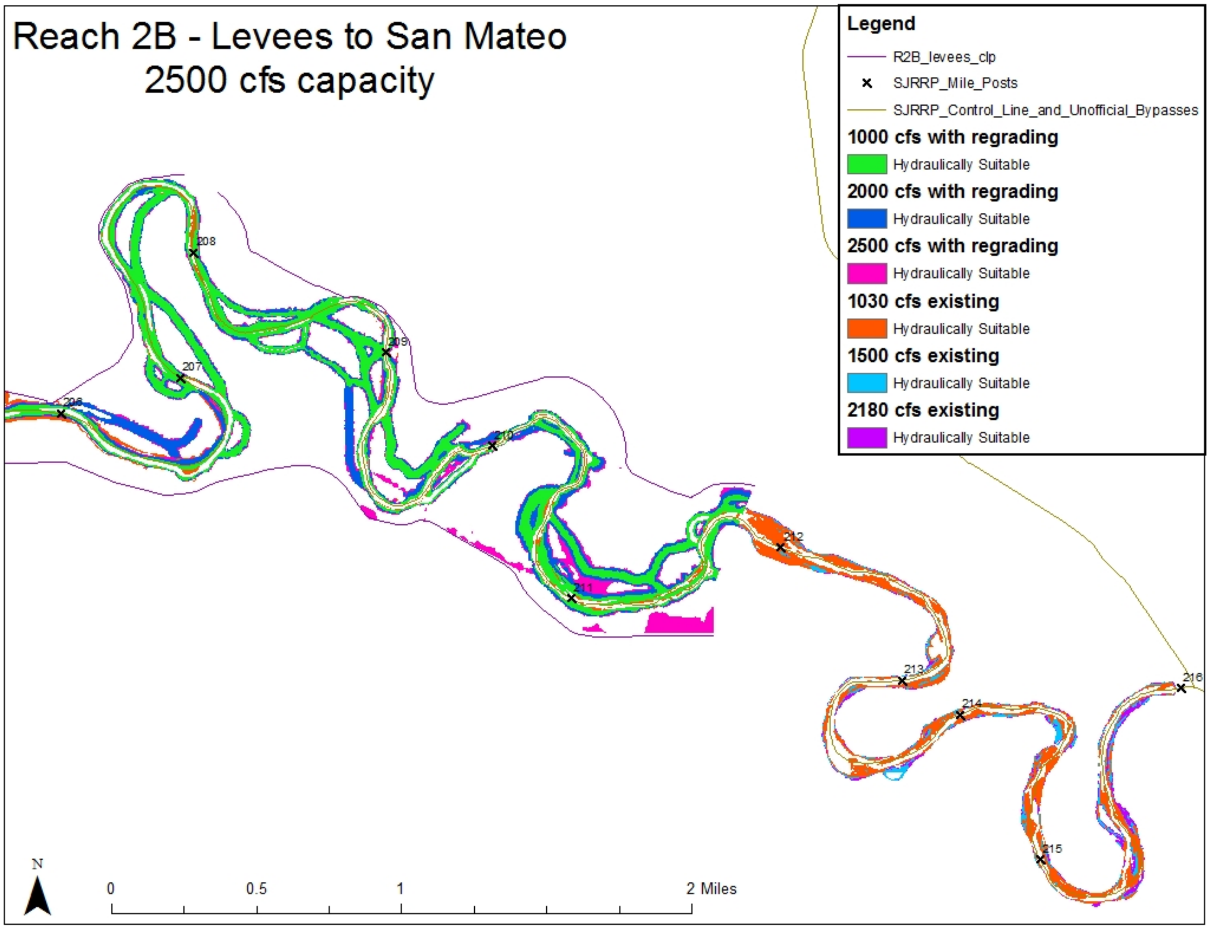


Figure A-9. Reach 2B with Levee Buildout to San Mateo Road and 2500 cfs Capacity Throughout Reach.

Table A-1. Breakdown of Hydraulically Suitable Rearing Habitat-acres by Section of Reach 2B.

	Flow (cfs)	Total Inundated Acres	Total Hydraulically Suitable Acres	Hydraulically Suitable in Compact Bypass	Hydraulically Suitable downstream San Mateo	Hydraulically Suitable upstream San Mateo
Reach 2B	1000	557	290	12	166	112
	1500	668	337	21	179	138
	2000	776	406	25	186	195
	2500	1059	381	20	187	174
	3000	1264	474	25	223	226
	3500	1422	557	31	257	270
	4000	1517	656	40	289	327
Total Hydraulically Suitable Acres sums the three blue columns representing segments of Reach 2B.						

Reach 3

Figure A-10 depicts an example of floodplain habitat in Reach 3 that is activated at higher flows. In contrast, Figure A-11 illustrates floodplain habitat activated at lower flows.

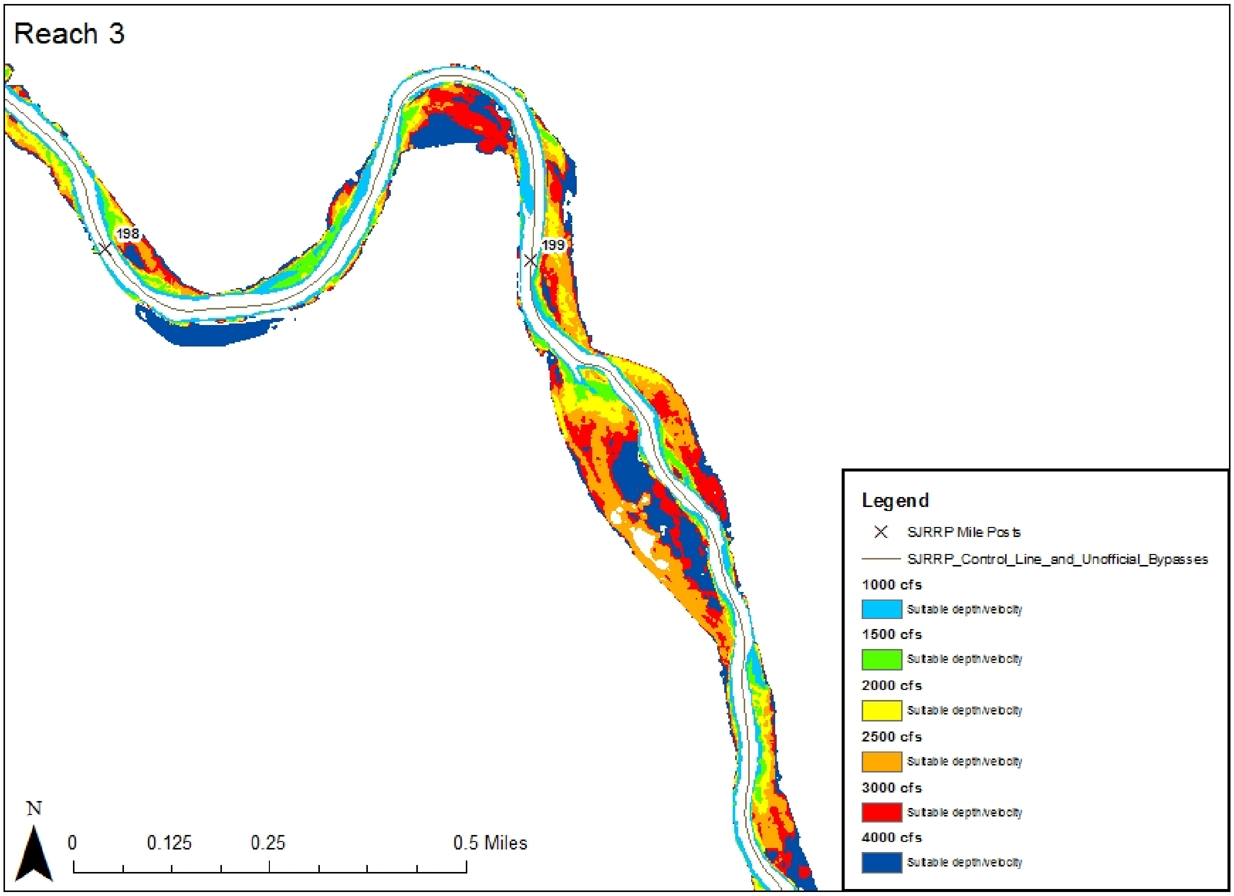


Figure A-11. Reach 3 at River Mile 199.

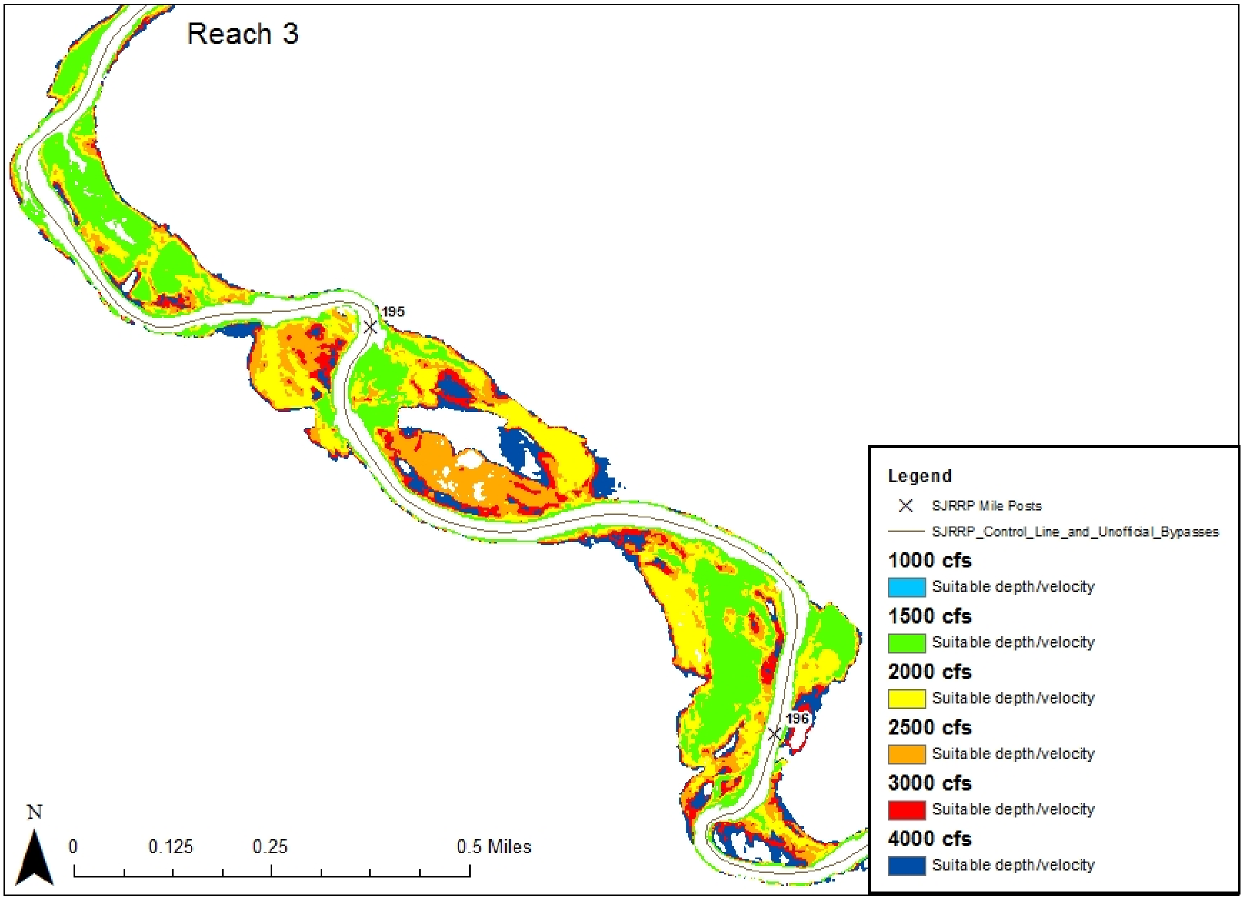
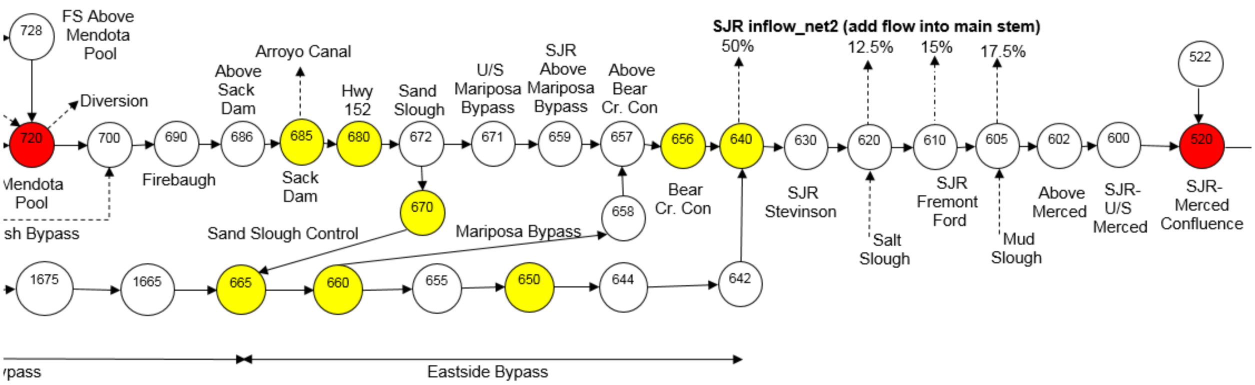


Figure A-12. Reach 3 at River Mile 195.

APPENDIX B

B.1 Temperature Analysis

Temperature results from the Programmatic EIS/R (Reclamation 2012c) SJR 5Q model were analyzed in support of Reclamation's effort to assess possible scenarios of Restoration Flows. The yellow-highlighted SJR 5Q model nodes in Figure B-1 were selected to compare temperature data. The nodes extend from Sack Dam to Reach 5, and represent sites in the system where temperature is most critical, see Table B-1. That is, this analysis focuses downstream of Sack Dam because it is expected that fish are most likely to encounter lethal temperatures at critical times in these reaches, with Reach 5 expected to be most constraining as the reach furthest downstream. The purpose of the Programmatic EIS/R SJR 5Q model was to inform in-channel temperature trends. No consideration was made of temperature patterns on inundated floodplains. In reality, shallow inundation depths and hydraulics such as reduced velocities are expected to create increased temperature conditions in relation to the main channel depending on vegetation. Appendix C assesses temperature thresholds at various life stage temperature objectives to account for this floodplain and main channel discrepancy.



It was assumed that all flows would be routed through the Eastside Bypass in lieu of Reach 4B.

Figure B-1. SJR 5Q Schematic of Model Nodes.

Table B-1. SJR 5Q Model Nodes Indicated by Name and Reach.

Node	Name	Reach
685	Sack Dam	4A
680	Highway 152	4A
670	Sand Slough Bypass	4A/Middle ESB Connector
665	Eastside Bypass D/S Sand Slough	Middle ESB
660	Eastside Bypass D/S Mariposa	Lower ESB
656	San Joaquin River D/S Mariposa	4B2
650	Eastside Bypass at Bear Creek	Lower ESB
640	San Joaquin River D/S ESB	5

The model extends from January 1980 to September 2003, and determines temperature and flow data per node based on the Riverware™ model, which superimposes Restoration Flows over history.

Comparing the temperature data across the bins in Table B-2 informs regression lines (i.e. trend lines) per flow range. The binned approach allows for a statistically relevant sample size to provide an estimate of temperature per day of the water year given trends of a known flow range. The resulting trend lines for the Sack Dam node are plotted in Figure B-2 as an example, with related results also plotted in Figures B-3 and B-4. In Figure B-2, note that at higher flow bins, there is less influence on temperature; as evidenced by decreased slope and less spread/spacing between the regression lines. Also note that where there is noise in the model results, there is crossover in the trend lines; for example, this is reflected in Figures B-3 and B-4 with the skew in Bin 8 results. There is also a visible jump between Bin 2 and 3, but this is due to the selected breaks for flow bin values. Ultimately, Figure B-4 demonstrates a tapering increase in temperature with increased flow bin.

The coefficients of determination (R^2), a statistical measure of how close the data are fitted to a regression line, indicate there is variability within the model and the relationship of flow, time of year, air temperature, and water temperature. For this analysis, the fit of the regression lines is deemed reasonable.

Table B-2. Bins for Analysis by Flow Rate.

Flow Bins (cfs)	
0	<350
1	350-500
2	500-700
3	700-1500
4	1500-2000
5	2000-2250
6	2250-2500
7	2500-3000
8	3000-3500
9	3500-4000
10	4000-4500

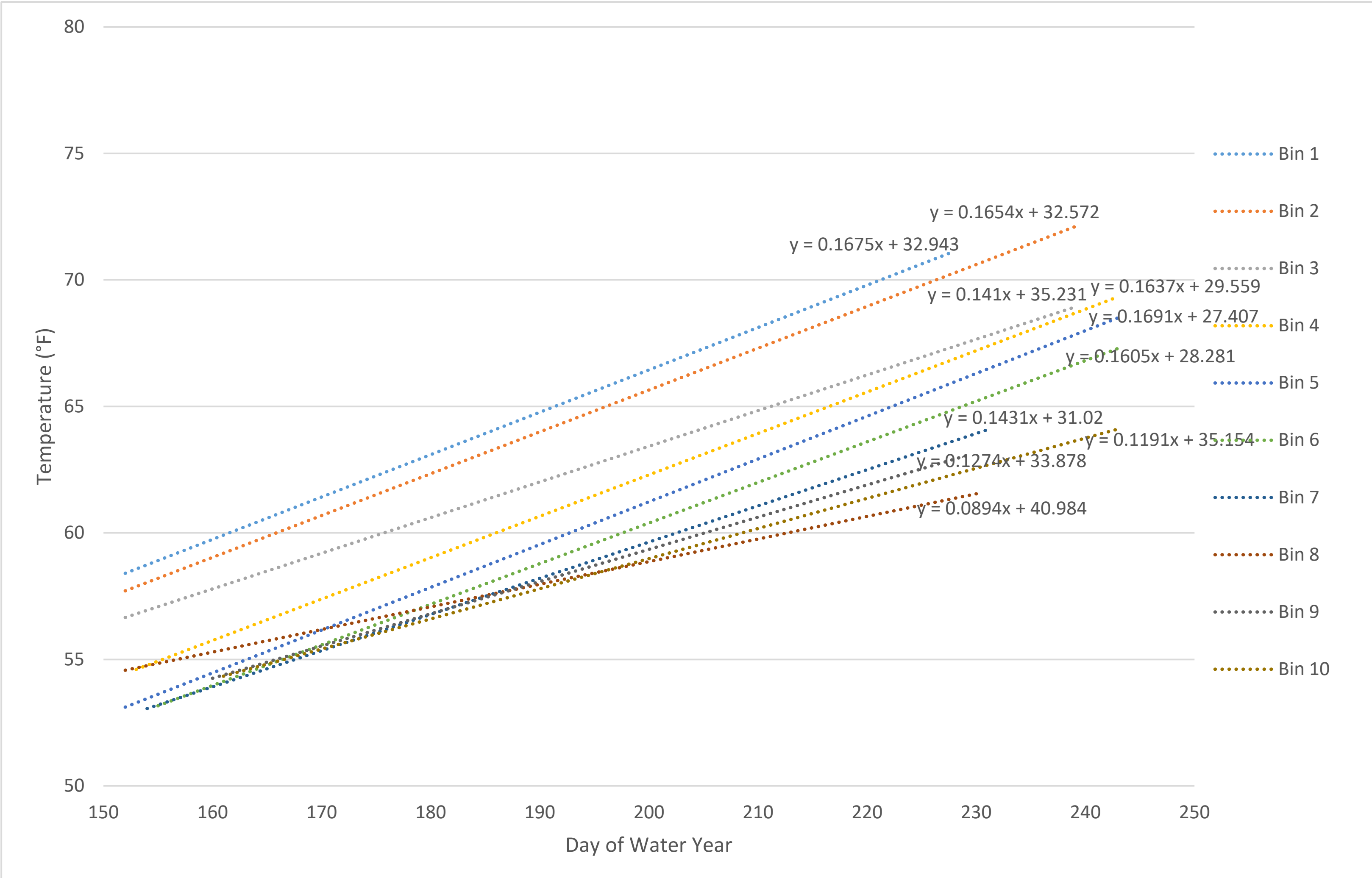


Figure B-2. Regression Lines per Bin for the Node at Sack Dam.

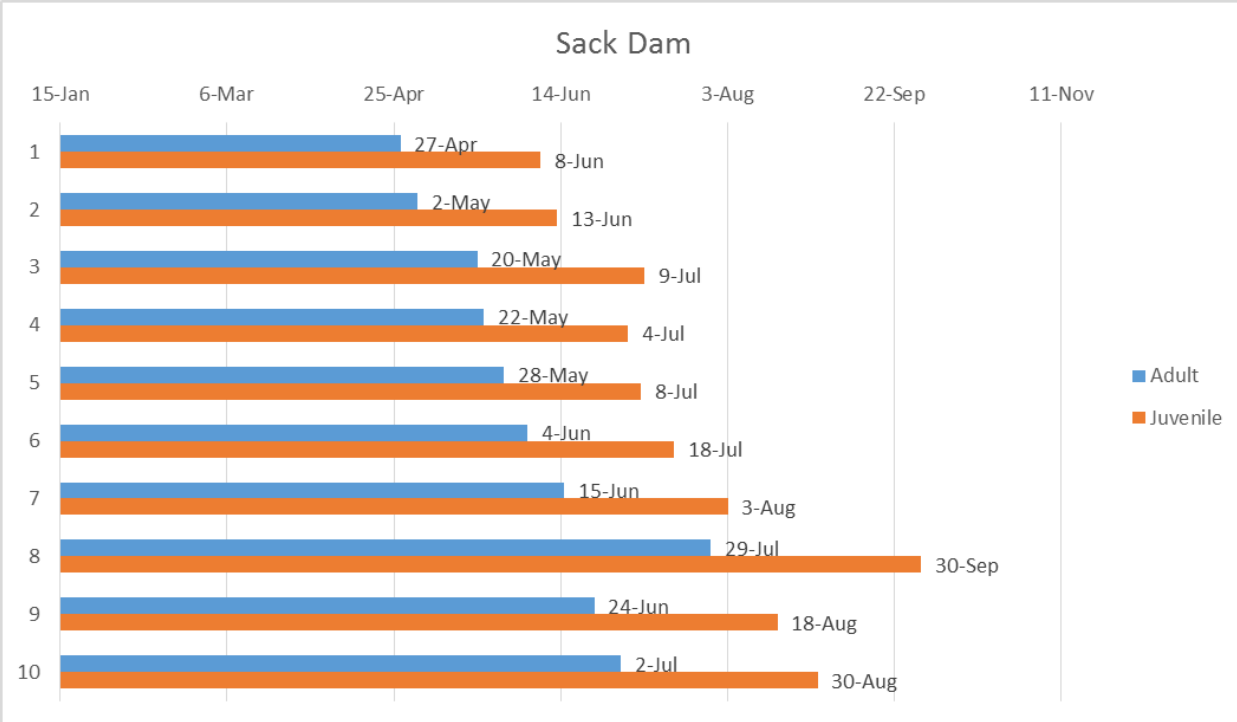


Figure B-3. Estimated Dates of Exceedance at Sack Dam per Salmon Life Stages.

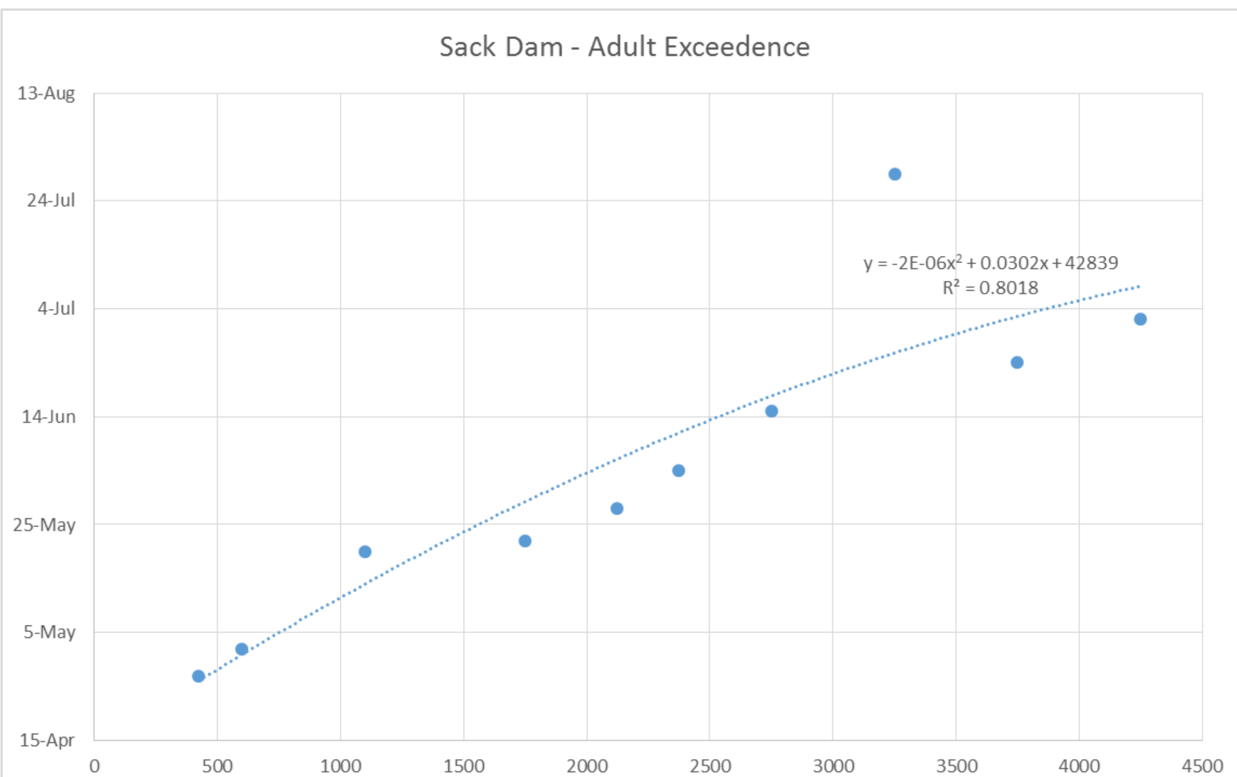


Figure B-4. Trend Line of Adult Exceedance Dates per Flow Bin at Sack Dam.

For consideration of temperature within Restoration Flow scenarios, the regression line equations from Figure B-2 were evaluated in daily time steps. Analysis of each day provides a relationship between flow and temperature as seen in Figure B-5 for Sack Dam on April 1. Flows from the scenario hydrographs become the independent variables, providing an estimate of temperatures per the scenario.

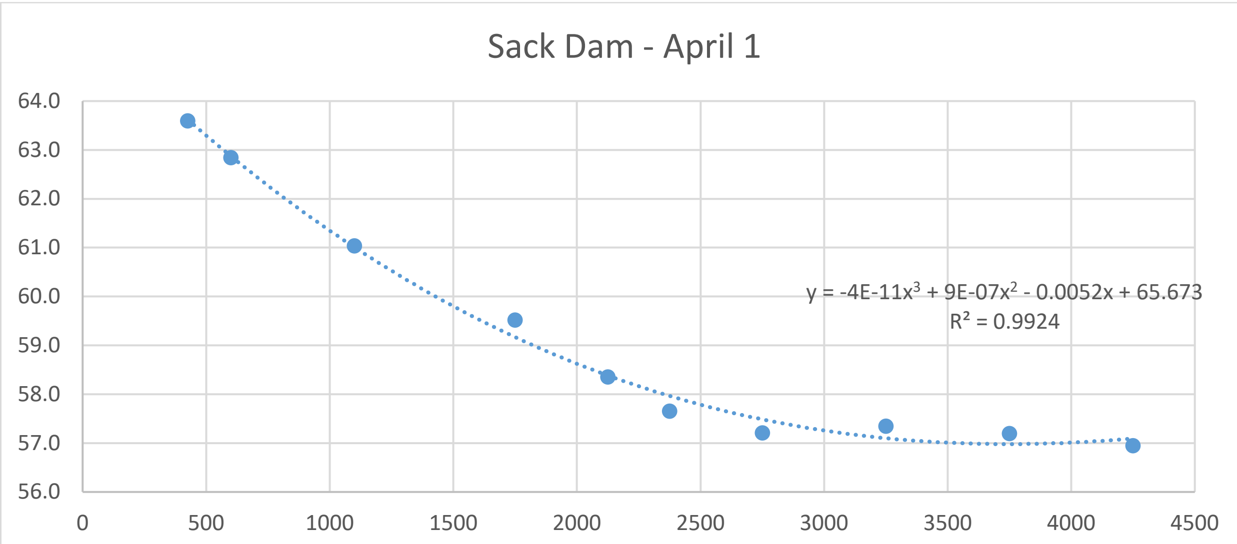


Figure B-5. Flow and Temperature Relationship for Sack Dam on April 1.

As seen in Figure B-5, a third order polynomial was used to fit the regression line each day from February 1 to May 28. Flows were evaluated as determined at Gravelly Ford with Exhibit B loss assumptions applied to Sack Dam and the head of Reach 5. Temperatures can then be estimated daily per the scenario at the model nodes, see Figure B-6.

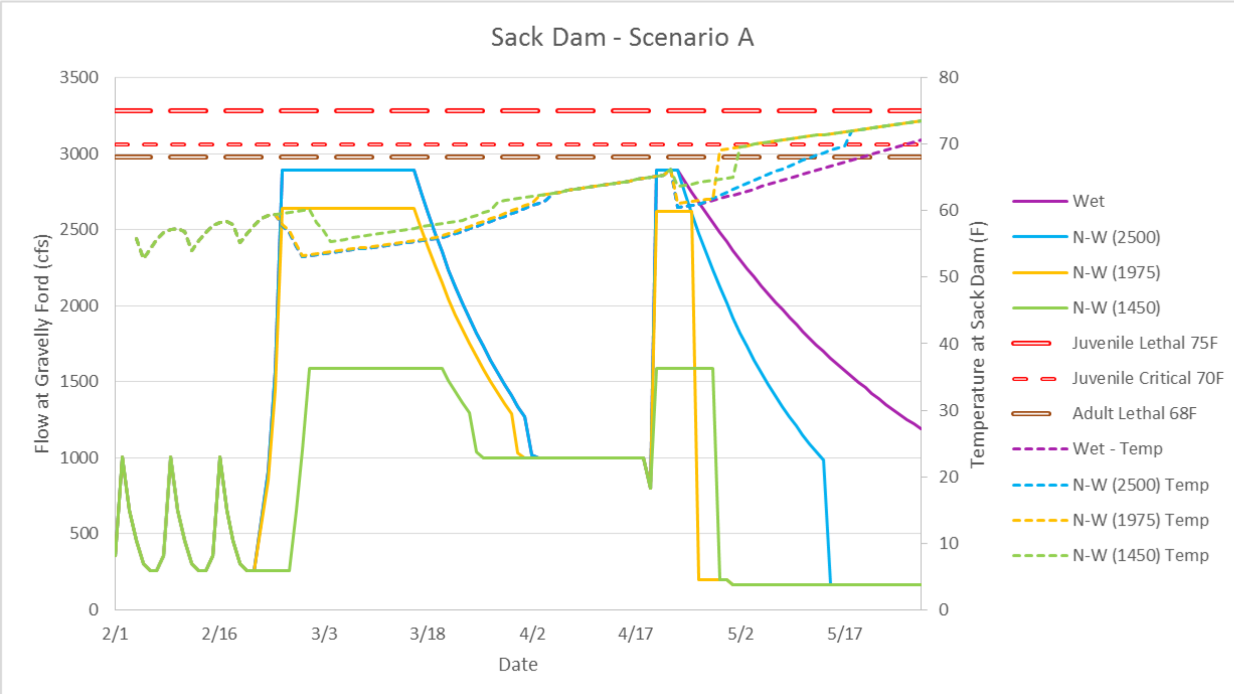
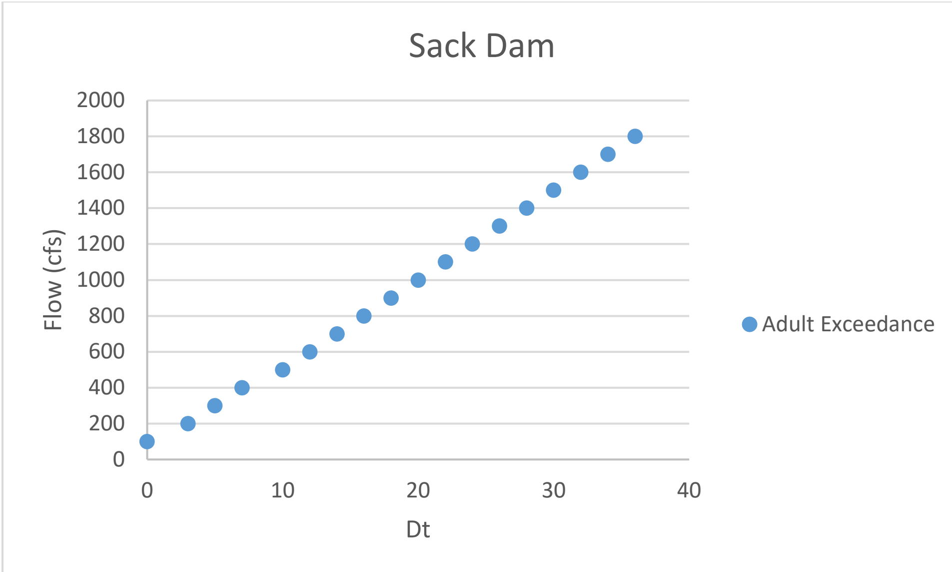


Figure B-6. Hydrograph Scenario A for Sack Dam Relating Temperature and Flow.

The third order polynomials, evaluated in daily time steps, provide a relationship between flow and temperature. Evaluating this relationship in 100 cfs intervals at the date that lethal temperatures are reached informs the amount of time gained (Dt) for temperature control by increasing flow. The model suggests a linear relationship between Dt and increasing flow (Figure B-7). There is some concern that the additional time gained per additional flow trend is not as linear as the model indicates. It is reasonable to suggest that in reality, as flows increase, the amount of additional time gained decreases, indicating that at some flow rate, flows are no longer the driving factor in temperature control. In this case, the linear model trend results would be less conservative at higher flow rates (i.e. indicate more time until exceeding lethal limits). Therefore, the upper range of threshold dates derived from one standard deviation in the modeled data is important to reference in addition to the average date.



Time gained for temperature control by increasing flow in 100 cfs increments. The model indicates a linear trend. There are uncertainties within the model, however the trend is informative for analyzing flow scenarios.

Figure B-7. Linear Trend in Temperature Control

APPENDIX C

Temperature Analysis Results for Optimal Thresholds

The methodology for temperature analysis presented in Appendix B was repeated using optimal life stage thresholds (critical and lethal thresholds are presented in the main body of this Technical Memorandum).

Table C-1. Chinook Salmon Temperature Objectives Shown for the Entire Year.

Water Temperature Objectives for the Restoration of Central Valley Chinook Salmon Spring-Run and Fall-Run Chinook Salmon												
Life Stage	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Adult Migration			Optimal: < 59 °F (15 °C) Critical: 62.6–68 °F (17–20 °C) Lethal: >68 °F (20 °C)									
Adult Holding (Spring-Run Only)			Optimal: <55 °F (13 °C) Critical: 62.6–68 °F (17–20 °C) Lethal: >68 °F (20 °C)									
Spawning								Optimal: < 57 °F (13.9 °C) Critical: 60–62.6 °F (15.5–17 °C) Lethal: 62.6 °F or greater (17 °C)				
Incubation and Emergence	Optimal: <55 °F (13 °C) Critical: 58–60 °F (14.4–15.6 °C) Lethal: >60 °F (15.6 °C)											
In-River Fry/Juvenile	Optimal: <60 °F (15.6 °C), young of year rearing; <62.6 °F (18 °C), late season rearing (yearling; primarily spring-run) Critical: 64.4–70 °F (18–21.1 °C) Lethal: >75 °F (23.9 °C), prolonged exposure											
Floodplain Rearing	Optimal: 55–68 °F (13–20 °C), unlimited food supply											
Outmigration	Optimal: <60 °F (15.6 °C) Critical: 64.4–70 °F (18–21.1 °C) Lethal: >75 °F (23.9 °C), prolonged exposure											

Thresholds for the period March through June, and the life stages~~phases~~ of adult migration, Floodplain Rearing, and Outmigration are most relevant to the discussion on channel capacity. Relevant months are shown in blue shading.

Source: Modified from SJRRP 2010a; EPA 2003, Rich 2007, Pagliughi 2008, Gordus 2009.

Table C-2. Estimated Dates to Optimal Temperature
Table C-2. Threshold at the Head of Reach 4A (immediately below Sack Dam).

Reach 4A Flow	Adult – 59 °F (Optimal Threshold)			Juvenile – 60 °F (Optimal Threshold)		
	Upper	Average	Lower	Upper	Average	Lower
100	2/6	2/18	3/2	2/13	2/25	3/9
200	2/11	2/23	3/7	2/18	3/1	3/13
300	2/15	2/27	3/10	2/22	3/5	3/17
400	2/19	3/3	3/14	2/26	3/9	3/20
500	2/23	3/6	3/17	3/1	3/12	3/23
600	2/26	3/9	3/20	3/4	3/15	3/26
700	3/1	3/12	3/22	3/7	3/18	3/28
800	3/3	3/14	3/25	3/9	3/20	3/31
900	3/6	3/16	3/27	3/12	3/22	4/2
1000	3/8	3/19	3/29	3/14	3/24	4/4
1100	3/10	3/21	3/31	3/16	3/27	4/6
1200	3/12	3/22	4/2	3/18	3/28	4/8
1300	3/14	3/24	4/4	3/20	3/30	4/10
1400	3/15	3/26	4/6	3/21	4/1	4/12
1500	3/17	3/28	4/7	3/23	4/3	4/13
1600	3/18	3/29	4/9	3/24	4/4	4/15
1700	3/20	3/31	4/11	3/26	4/6	4/17
1800	3/21	4/1	4/12	3/27	4/7	4/19
1900	3/22	4/3	4/14	3/29	4/9	4/20
2000	3/23	4/4	4/15	3/30	4/10	4/22
2100	3/25	4/5	4/17	3/31	4/12	4/23
2200	3/26	4/6	4/18	4/1	4/13	4/25
2300	3/27	4/8	4/20	4/2	4/14	4/26
2400	3/28	4/9	4/21	4/3	4/16	4/28
2500	3/29	4/10	4/22	4/4	4/17	4/29
2600	3/29	4/11	4/24	4/5	4/18	5/1
2700	3/30	4/12	4/25	4/6	4/19	5/2
2800	3/31	4/13	4/26	4/7	4/20	5/4
2900	4/1	4/14	4/27	4/8	4/22	5/5
3000	4/1	4/15	4/29	4/9	4/23	5/6
3100	4/2	4/16	4/30	4/10	4/24	5/8
3200	4/2	4/16	5/1	4/10	4/24	5/9
3300	4/3	4/17	5/2	4/11	4/25	5/10
3400	4/3	4/18	5/2	4/11	4/26	5/11

3500	4/3	4/18	5/3	4/12	4/26	5/11
3600	4/3	4/18	5/4	4/12	4/27	5/12
3700	4/3	4/19	5/4	4/12	4/27	5/13
3800	4/3	4/19	5/4	4/12	4/27	5/13
3900	4/3	4/19	5/4	4/12	4/27	5/13
4000	4/3	4/19	5/4	4/12	4/27	5/13
4100	4/3	4/18	5/4	4/12	4/27	5/13
4200	4/3	4/18	5/3	4/11	4/27	5/12
4300	4/2	4/18	5/3	4/11	4/26	5/11
4400	4/2	4/17	5/2	4/10	4/25	5/10
4500	4/1	4/16	5/1	4/10	4/24	5/9

Table C-3. Estimated Dates to Optimal Temperature Threshold at the Head of Reach 5.

Reach 5 Flow	Adult – 59 °F (Optimal Threshold)			Juvenile – 60 °F (Optimal Threshold)		
	Upper	Average	Lower	Upper	Average	Lower
100	< 2/1	2/2	2/18	< 2/1	2/9	2/24
200	< 2/1	2/7	2/21	< 2/1	2/13	2/28
300	< 2/1	2/11	2/25	2/3	2/17	3/3
400	< 2/1	2/14	2/28	2/7	2/20	3/5
500	2/4	2/17	3/2	2/10	2/23	3/8
600	2/7	2/20	3/4	2/13	2/25	3/10
700	2/10	2/22	3/6	2/15	2/27	3/12
800	2/12	2/24	3/8	2/17	3/1	3/14
900	2/14	2/26	3/10	2/19	3/3	3/15
1000	2/16	2/28	3/12	2/21	3/5	3/17
1100	2/17	3/1	3/13	2/22	3/6	3/18
1200	2/19	3/3	3/14	2/24	3/8	3/19
1300	2/20	3/4	3/16	2/25	3/9	3/21
1400	2/21	3/5	3/17	2/26	3/10	3/22
1500	2/22	3/6	3/18	2/28	3/11	3/23
1600	2/23	3/7	3/19	3/1	3/12	3/24
1700	2/24	3/8	3/20	3/1	3/13	3/25
1800	2/25	3/9	3/21	3/2	3/14	3/26
1900	2/26	3/10	3/22	3/3	3/15	3/27
2000	2/27	3/11	3/23	3/4	3/16	3/28
2100	2/27	3/11	3/24	3/5	3/17	3/29
2200	2/28	3/12	3/25	3/5	3/17	3/30

2300	2/28	3/13	3/25	3/6	3/18	3/31
2400	3/1	3/13	3/26	3/6	3/19	4/1
2500	3/1	3/14	3/27	3/7	3/20	4/1
2600	3/2	3/15	3/28	3/7	3/20	4/2
2700	3/2	3/15	3/28	3/8	3/21	4/3
2800	3/2	3/16	3/29	3/8	3/21	4/4
2900	3/3	3/16	3/30	3/8	3/22	4/5
3000	3/3	3/17	3/30	3/9	3/23	4/5
3100	3/3	3/17	3/31	3/9	3/23	4/6
3200	3/3	3/17	4/1	3/9	3/24	4/7
3300	3/3	3/18	4/1	3/10	3/24	4/7
3400	3/3	3/18	4/2	3/10	3/24	4/8
3500	3/4	3/18	4/2	3/10	3/25	4/8
3600	3/4	3/19	4/2	3/10	3/25	4/9
3700	3/4	3/19	4/3	3/10	3/25	4/9
3800	3/4	3/19	4/3	3/10	3/25	4/10
3900	3/4	3/19	4/3	3/11	3/26	4/10
4000	3/4	3/19	4/3	3/11	3/26	4/10
4100	3/4	3/19	4/3	3/11	3/26	4/10
4200	3/4	3/19	4/3	3/11	3/26	4/10
4300	3/4	3/19	4/3	3/11	3/26	4/9
4400	3/5	3/19	4/3	3/11	3/26	4/9
4500	3/5	3/19	4/3	3/11	3/25	4/9

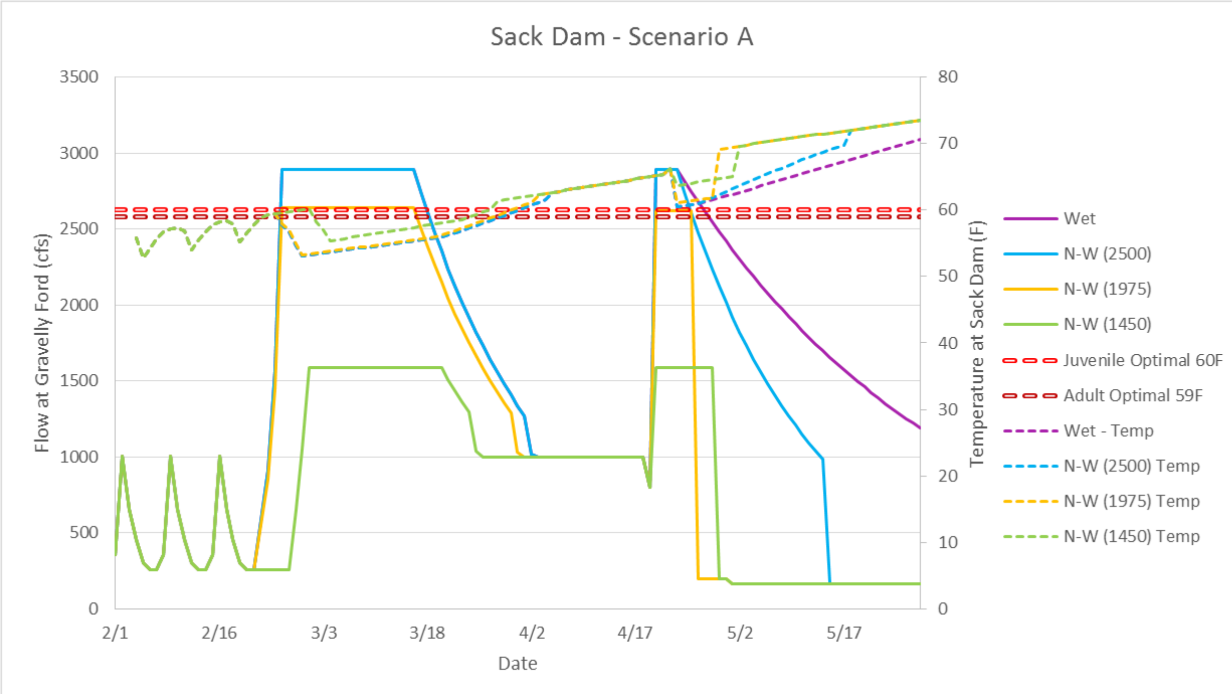


Figure C-1a. Scenario A Temperature Response at Sack Dam

Figure C-1b. Scenario A Temperature Response at Reach 5

Figure C-1a and C-1b. Flow Scenario A water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and adjusted for losses and flow lag times prior to presenting the temperature plots. Optimal thresholds are shown as horizontal dashed lines.

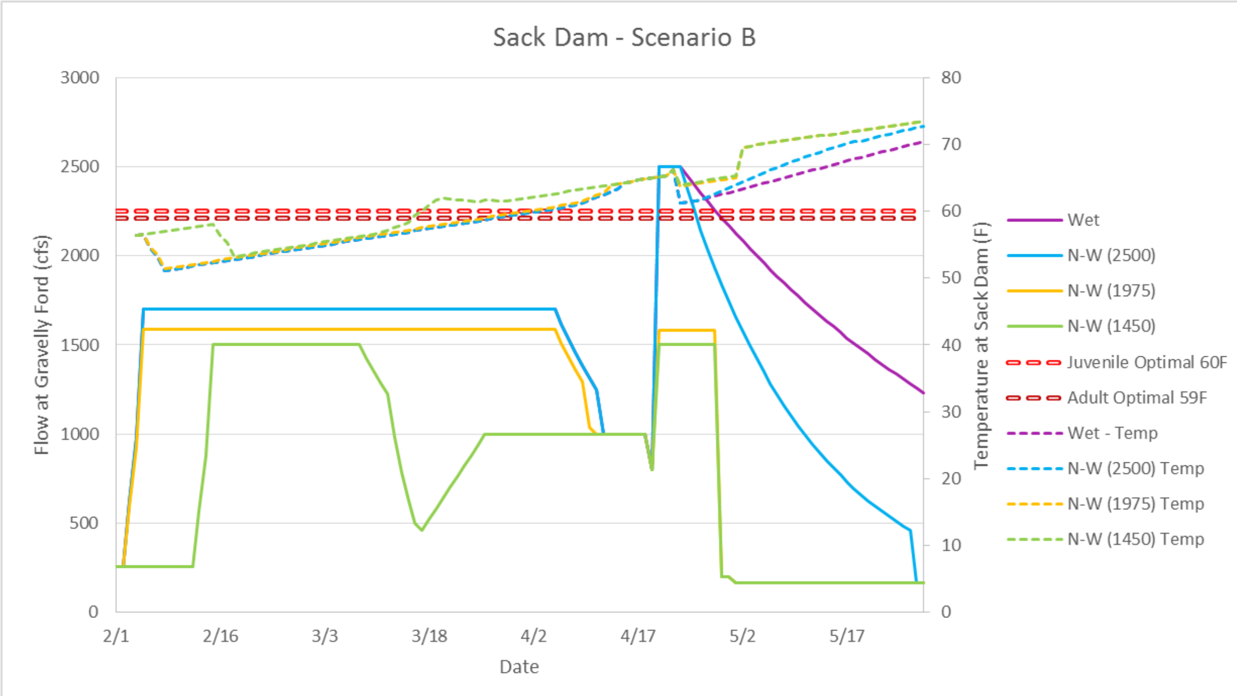


Figure C-2a. Scenario B Temperature Response at Sack Dam

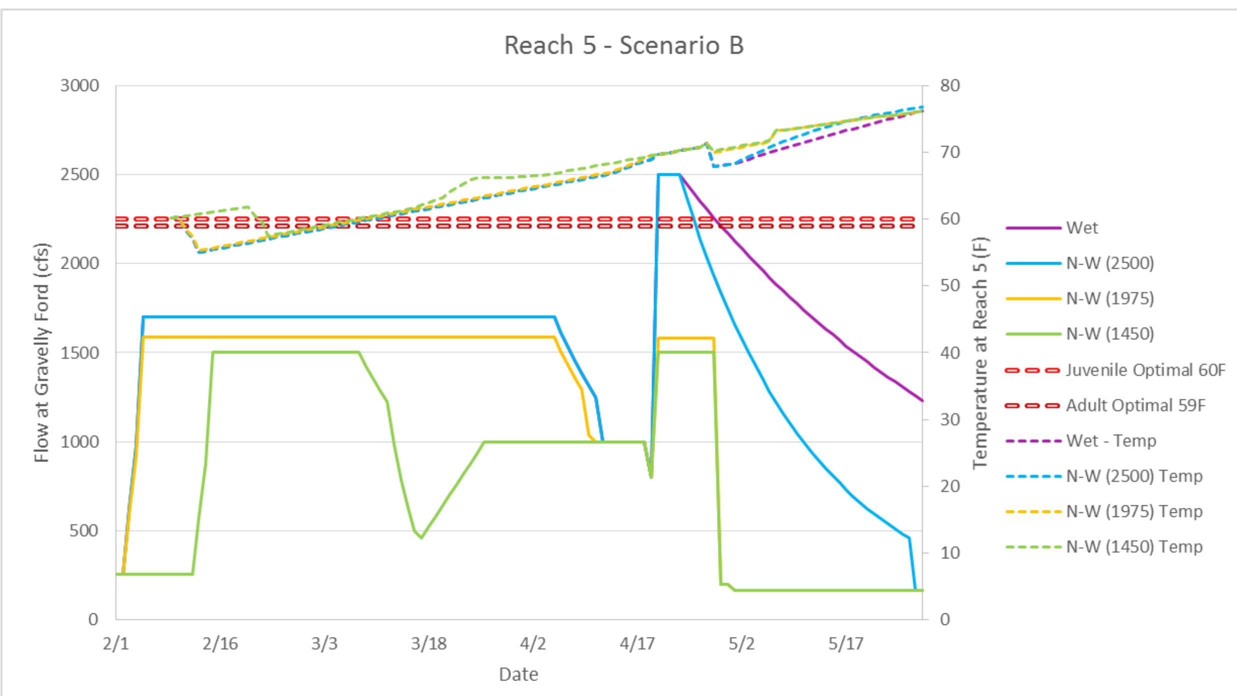


Figure C-2b. Scenario B Temperature Response at Reach 5

Figure C-2a and C-2b. Flow Scenario B water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and adjusted for losses and flow lag times prior to presenting the temperature plots. Optimal thresholds are shown as horizontal dashed lines.

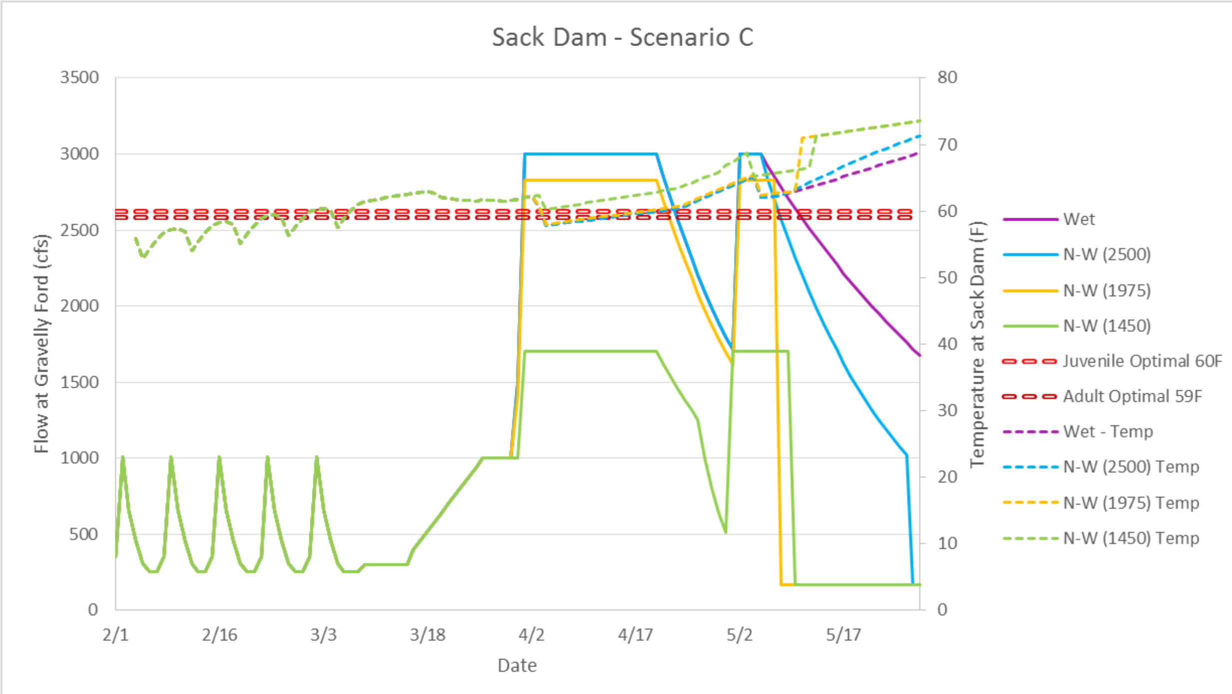


Figure C-3a. Scenario C Temperature Response at Sack Dam

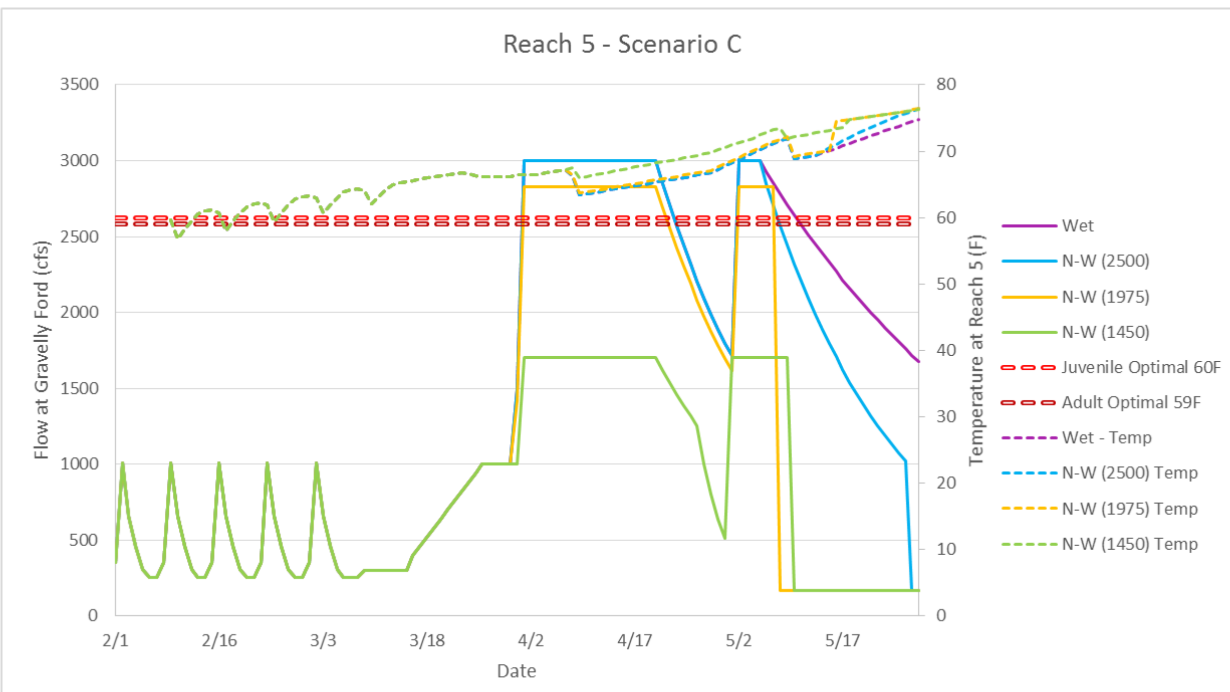


Figure C-3b. Scenario C Temperature Response at Reach 5

Figure C-3a and C-3b. Flow Scenario C water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and adjusted for losses and flow lag times prior to presenting the temperature plots. Optimal thresholds are shown as horizontal dashed lines.

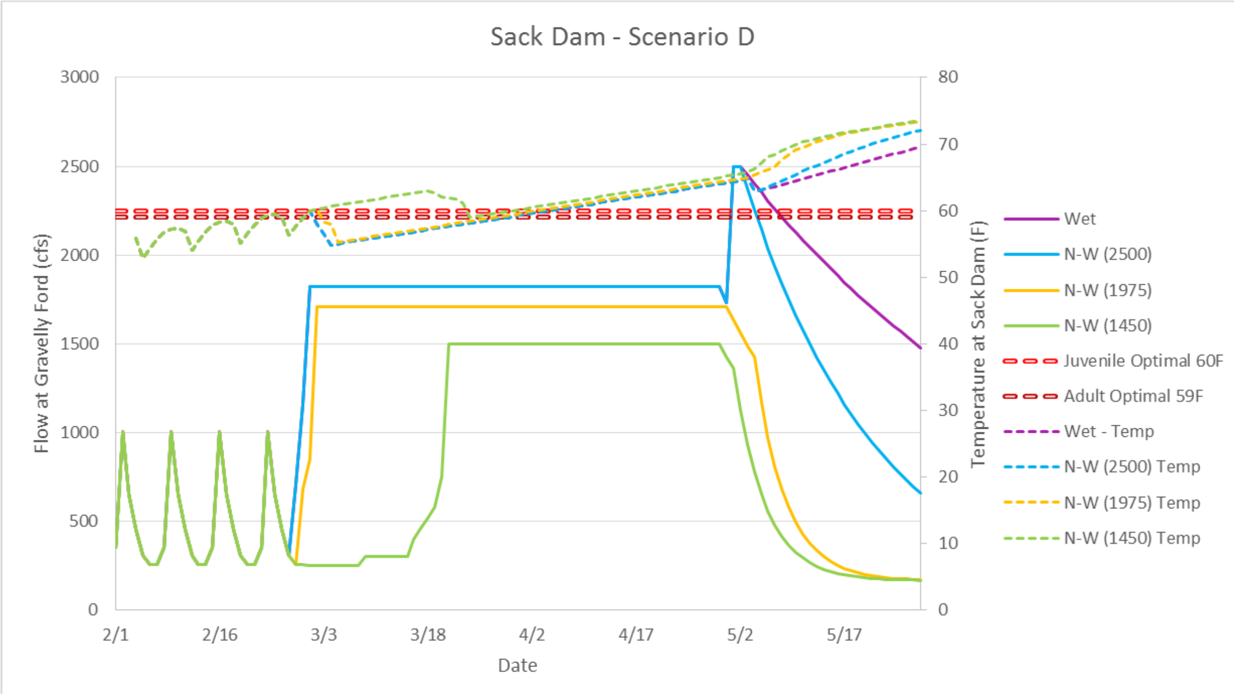


Figure C-4a. Scenario D Temperature Response at Sack Dam

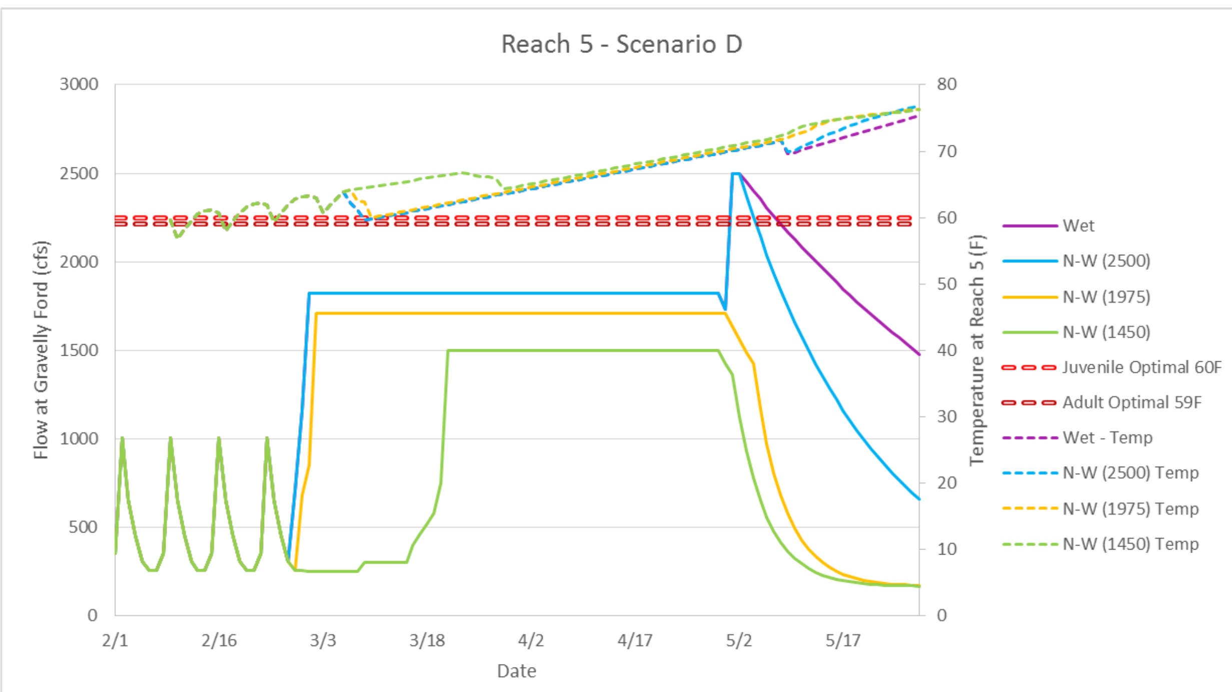


Figure C-4b. Scenario D Temperature Response at Reach 5

Figure C-4a and C-4b. Flow Scenario D water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and adjusted for losses and flow lag times prior to presenting the temperature plots. Optimal thresholds are shown as horizontal dashed lines.

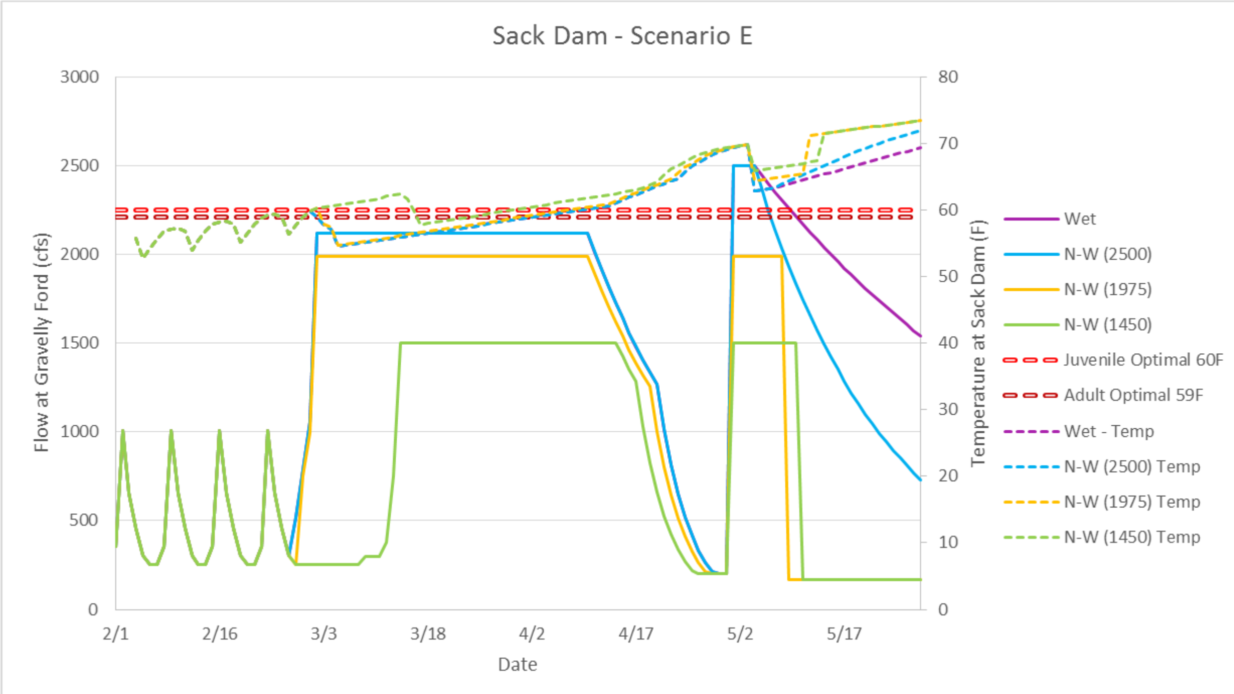


Figure C-5a. Scenario E Temperature Response at Sack Dam

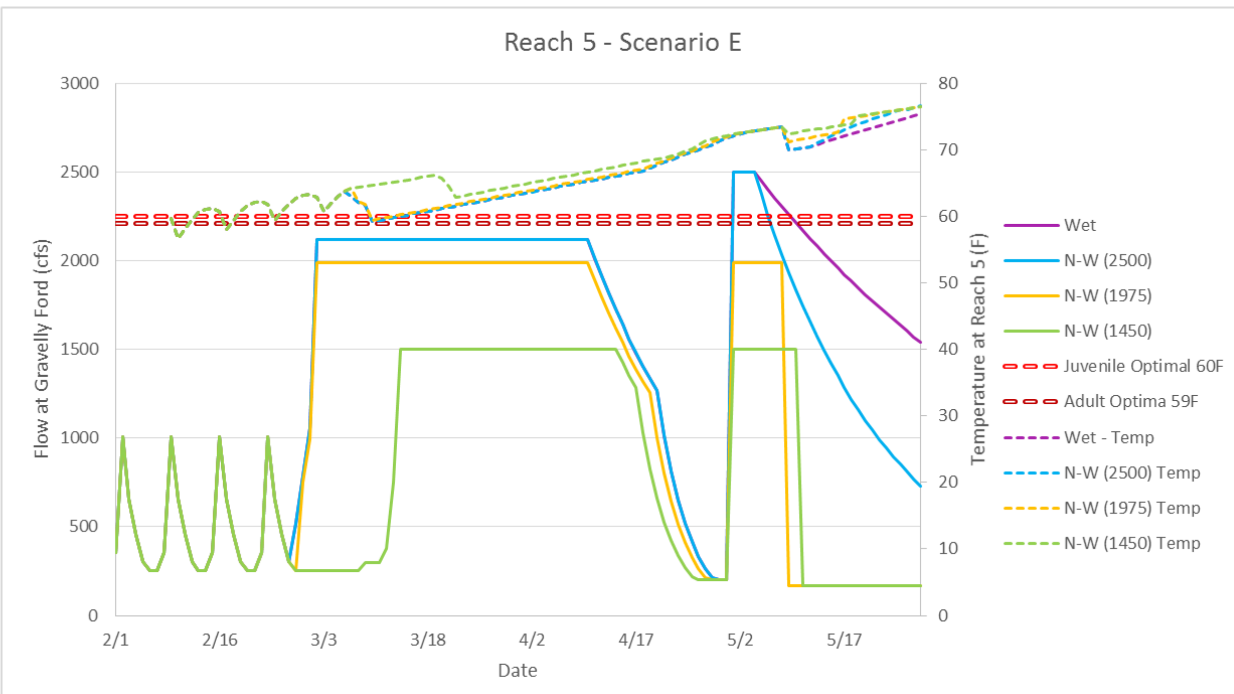


Figure C-5b. Scenario E Temperature Response at Reach 5

Figure C-5a and C-5b. Flow Scenario E water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and adjusted for losses and flow lag times prior to presenting the temperature plots. Optimal thresholds are shown as horizontal dashed lines.

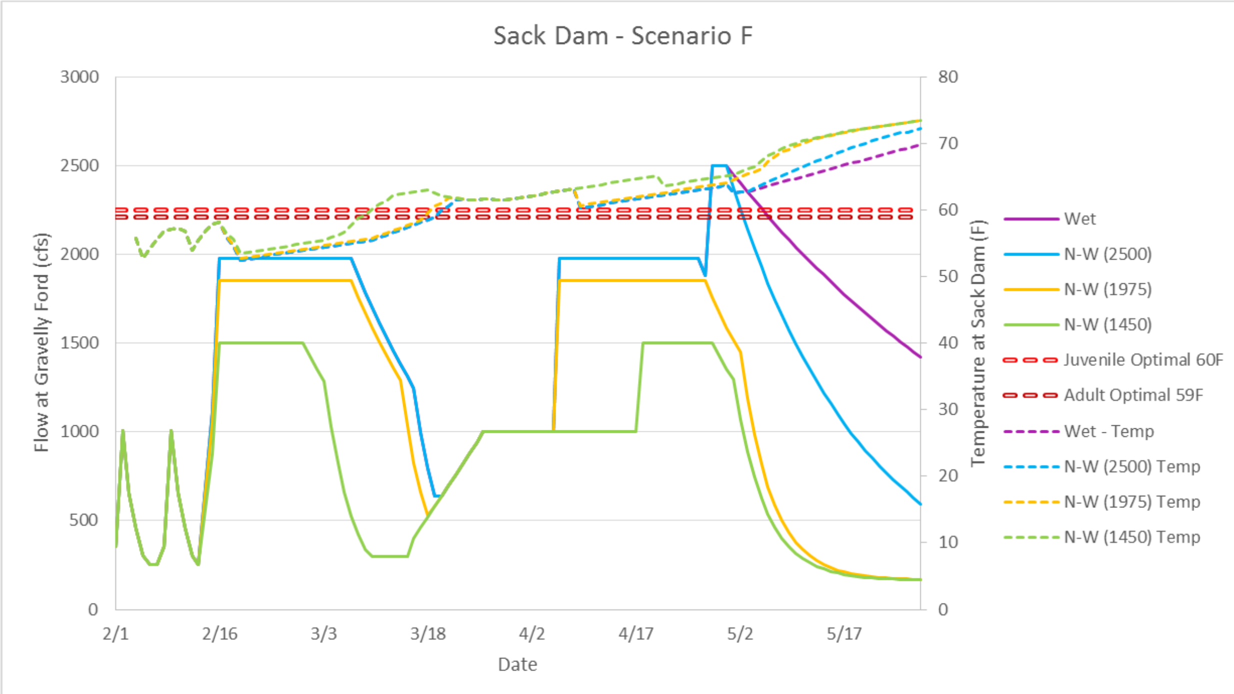


Figure C-6a. Scenario F Temperature Response at Sack Dam

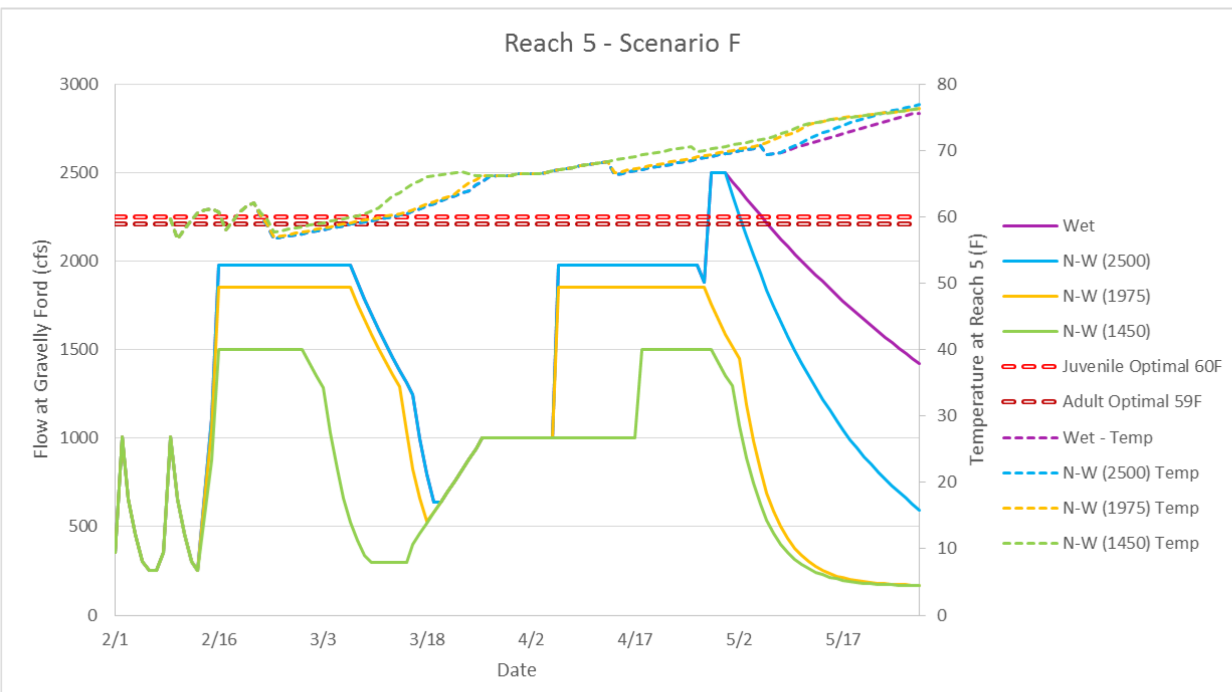


Figure C-6b. Scenario F Temperature Response at Reach 5

Figure C-6a and C-6b. Flow Scenario F water temperatures superimposed on the hydrograph for Sack Dam (at the head of Reach 4) and Reach 5. Flow rate is shown for Gravelly Ford, and adjusted for losses and flow lag times prior to presenting the temperature plots. Optimal thresholds are shown as horizontal dashed lines.

APPENDIX D

Default Hydrograph from Exhibit B of the Settlement

For comparison, the Exhibit B flow schedule, also known as the default hydrograph, is shown below in Figure D-1 for Gravelly Ford with the same formatting as the six flow scenarios. The default hydrograph only has two flow components – a floodplain inundation flow and a Riparian Recruitment Flow (in the relevant year types).

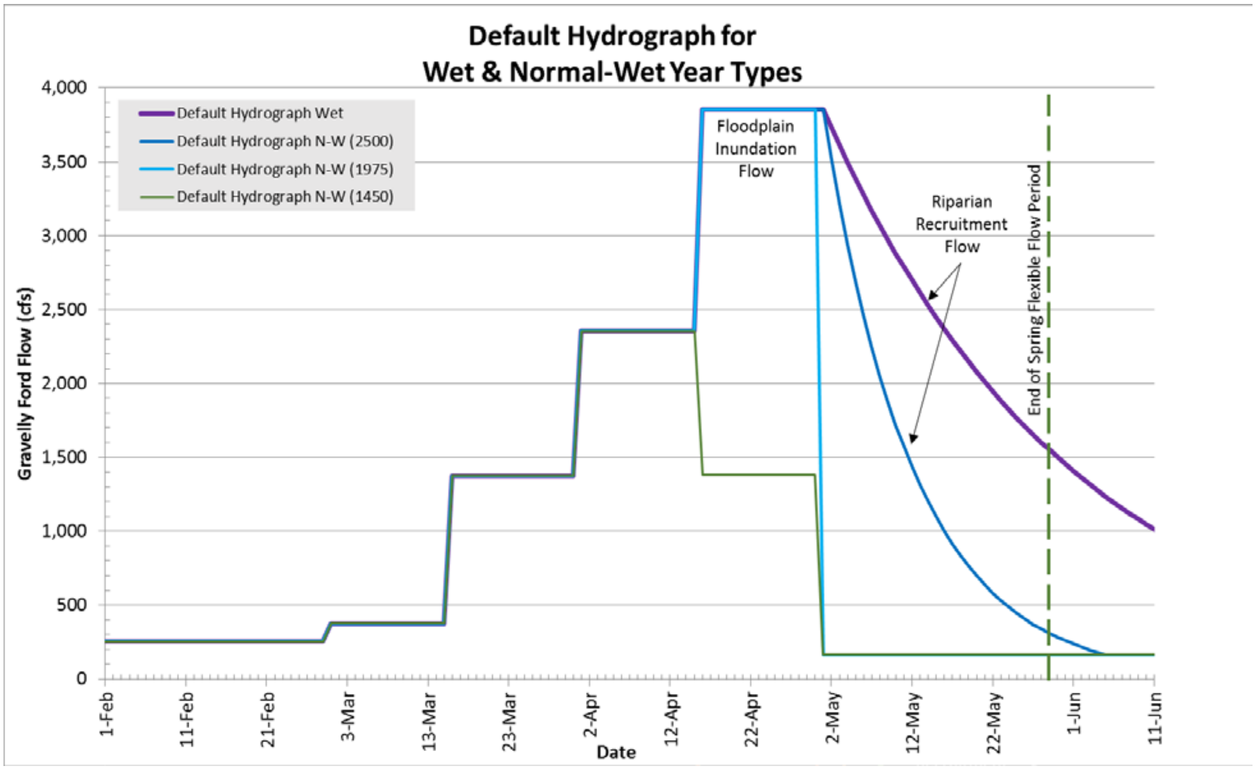


Figure D-1. Default Hydrograph for Wet & Normal-Wet Year Types Shown for Gravelly Ford

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APPENDIX E

Temperature Control Flow Optimization

To compare the flow scenarios against a focused strategy on maintaining water temperatures at the cost of other considerations, a set of hydrographs were developed to optimize staying within the adult lethal temperature threshold at Reach 5. Figure E-1 depicts hydrographs for the range of water year types. The temperature control flow is advanced by seven days as compared to the six flow scenarios to tolerate daily variations in air temperature without exceeding thresholds. Thus, one standard deviation of warmer air temperatures (approximately 70% of daily temperature excursions about the mean) would be compensated for by this shift of flows earlier in the spring. Appropriate ramp-downs are incorporated into the hydrographs of Figure E-1 to prevent fish stranding on the floodplain and to encourage migration and outmigration of fish. For the upper range of Normal-Wet and all Wet year types, Riparian Recruitment Flow is available and can also serve as a suitable ramp-down for fishery purposes.

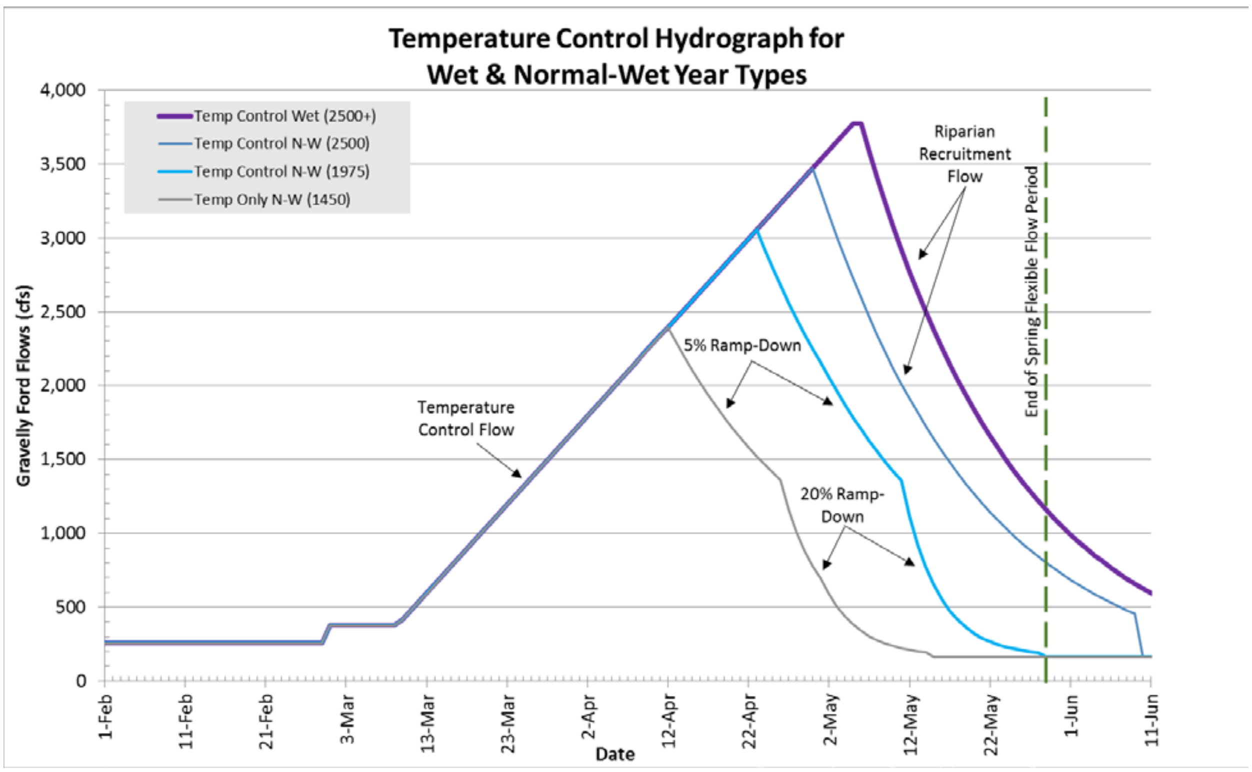

Figure E-1. Temperature-Control Hydrograph for Wet & Normal-Wet Year Types shown for Gravelly Ford

The temperature-control hydrographs above result in channel capacities of 3775 cfs, 3475 cfs, 3055 cfs, and 2395 cfs for their respective water year types. Assuming a stage–discharge buffer of 0.25 feet, this results in required channel capacities of 4100 cfs, 3800 cfs, 3300 cfs, and 2600 cfs (rounded to the nearest 100 cfs).

The temperature-control hydrograph results in water temperatures remaining below the lethal threshold for adult migration for a longer period of time due to the optimization of flows solely for that purpose. The temperature response at Reach 5 is shown in Figure E-2. The corresponding dates for the temperature-control hydrograph are compared to those of the six flow scenarios (from Tables 5.1) for the relevant thresholds in Table E-1. A hydrograph optimized only for temperature control can extend the period of non-lethal adult migration in Reach 5 3 to 14 days over the best temperature performing flow scenario, depending on the water year type. For the period of critical juvenile outmigration, an advantage of 0 to 14 days over the best temperature performing flow scenario is realized. There is no advantage of the temperature-control hydrograph for maintaining below the juvenile lethal threshold as compared to the best performing flow scenario; this is primarily due to the flexibility limitations of when spring flows can be applied.

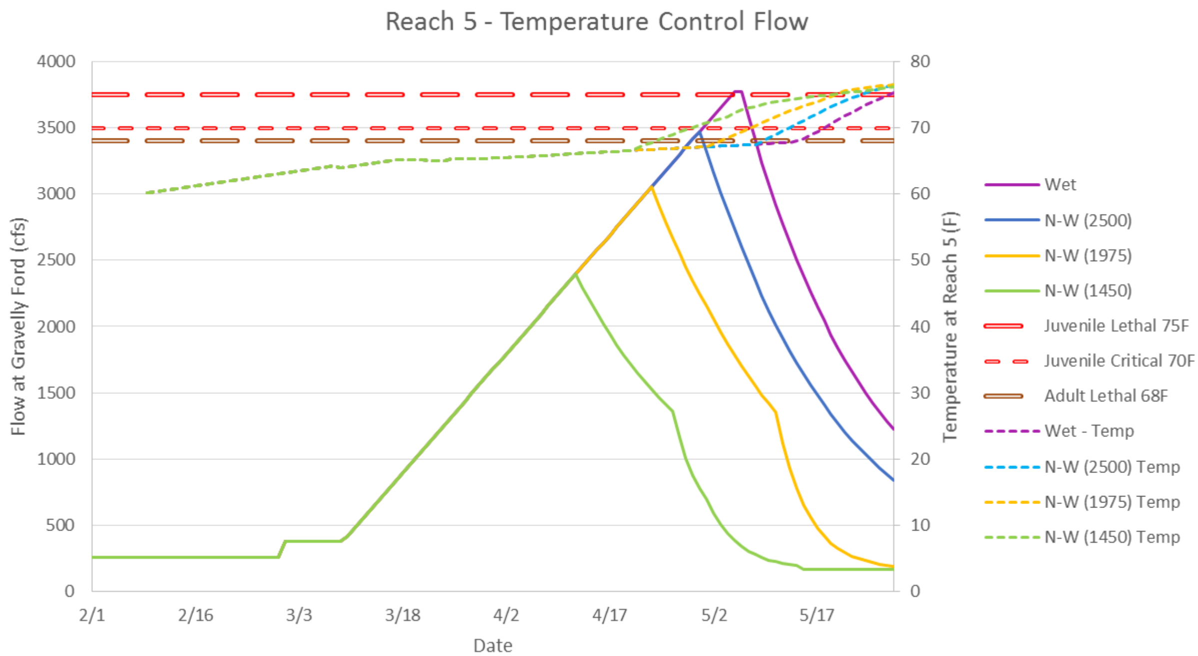

Figure E-2. Temperature-Control Hydrograph Temperature Response at Reach 5.

Table E-1a. Average Date that 68 °F Lethal Water Temperature Threshold is Reached for Adult Migration at the Head of Reach 5.

Water Year Type	Average Date of Temperature Thresholds for each Flow Scenario						
	A	B	C	D	E	F	Temp-Control
Wet (> 2500 TAF)	4/11	4/17	5/1	4/21	4/21	4/23	5/15
Normal-Wet (2500 TAF)	4/11	4/17	5/1	4/21	4/21	4/23	5/10
Normal-Wet (1975 TAF)	4/11	4/16	4/30	4/20	4/21	4/22	5/3
Normal-Wet (1450 TAF)	4/11	4/11	4/20	4/17	4/17	4/11	4/24
Data shaded in blue from Table 5-1a.							

Table E-1b. Average Date that 70 °F Critical Water Temperature Threshold is Reached for Juvenile Outmigration at the Head of Reach 5.

Water Year Type	Average Date of Temperature Thresholds for each Flow Scenario						
	A	B	C	D	E	F	Temp-Control
Wet (> 2500 TAF)	4/22	4/22	5/5	5/1	4/27	5/3	5/19
Normal-Wet (2500 TAF)	4/22	4/22	5/5	5/1	4/27	5/3	5/14
Normal-Wet (1975 TAF)	4/22	4/22	5/5	4/29	4/26	5/2	5/8
Normal-Wet (1450 TAF)	4/22	4/22	4/29	4/28	4/25	4/28	4/29
Data shaded in blue from Table 5-1b.							

Table E-1c. Average Date that 75 °F Lethal Water Temperature Threshold is Reached for Juvenile Outmigration at the Head of Reach 5.

Water Year Type	Average Date of Temperature Thresholds for each Flow Scenario						
	A	B	C	D	E	F	Temp-Control
Wet (> 2500 TAF)	5/24	5/23	>5/28	5/27	5/27	5/26	5/28
Normal-Wet (2500 TAF)	5/20	5/20	5/25	5/22	5/23	5/21	5/25
Normal-Wet (1975 TAF)	5/20	5/20	5/20	5/18	5/20	5/18	5/20
Normal-Wet (1450 TAF)	5/20	5/20	5/20	5/18	5/19	5/18	5/20
Data shaded in blue from Table 5-1c.							