PROTECTING RIVERS AND SALMON · WATER ISSUE OVERVIEW

Protecting rivers and salmon

Can California's rivers support healthy ecosystems and salmon populations, while also providing water for people and farms?

INTRO

Rivers are essential sources of water, but they are more than channels that move water from mountains to farms and cities. They are also living systems that support a great diversity of species. Salmon depend on river flows, cold water, and connected habitat for spawning, rearing, and migration to and from the ocean. Wetlands, birds, other fish, and other wildlife depend on healthy rivers too.

California's rivers are defined by strong seasonal and annual variation in flows. In the winter and spring, rivers swell with rain and snowmelt, sometimes spilling onto floodplains and moving sediment, nutrients, plants, and animals across the landscape. In summer, flows recede and waters warm. California's native freshwater species evolved with these changing conditions. Salmon, in particular, depend on different river conditions at different stages of their life cycle.

Winter-run Chinook salmon life cycle

Sacramento River winter-run Chinook have a unique life history. Spawning adults (age 2, 3, or 4 years old) enter the Sacramento River as early as November, and most migrate far up the Sacramento River, where they hold in the upper river for several months before spawning. After spawning, the eggs incubate in the gravel for approximately 3 months before emerging as fry.

Fry can rear in the freshwater environment for 5-10 months before transitioning to the smolt outmigration lifestage. From January through April, smolts migrate downstream and enter the Gulf of the Farallones. Once in the Pacific Ocean, they mature for 1-3 years before re-entering the Sacramento River to spawn again to start the next generation.

WHY THIS MATTERS

California's rivers begin in the mountains and flow through valleys to the Delta and ocean. Along the way, they sustain ecosystems and provide water for farms and communities. Rivers are deeply interconnected with California's water management system. Dams, reservoir operations, and water diversions have altered the timing and amount of river flows on which native species depend. Decisions about how much water to store, release, and deliver for different purposes therefore create trade-offs that can ripple across the system.

Salmon are among California's most iconic species. Different salmon runs migrate between rivers and the ocean at different times of the year, supporting Tribal cultural practices, recreational and commercial fisheries, local economies, and ecosystem health. Because salmon depend on river conditions throughout multiple life stages, they are often used as indicators of the overall health of river ecosystems and the effectiveness of environmental flow management.

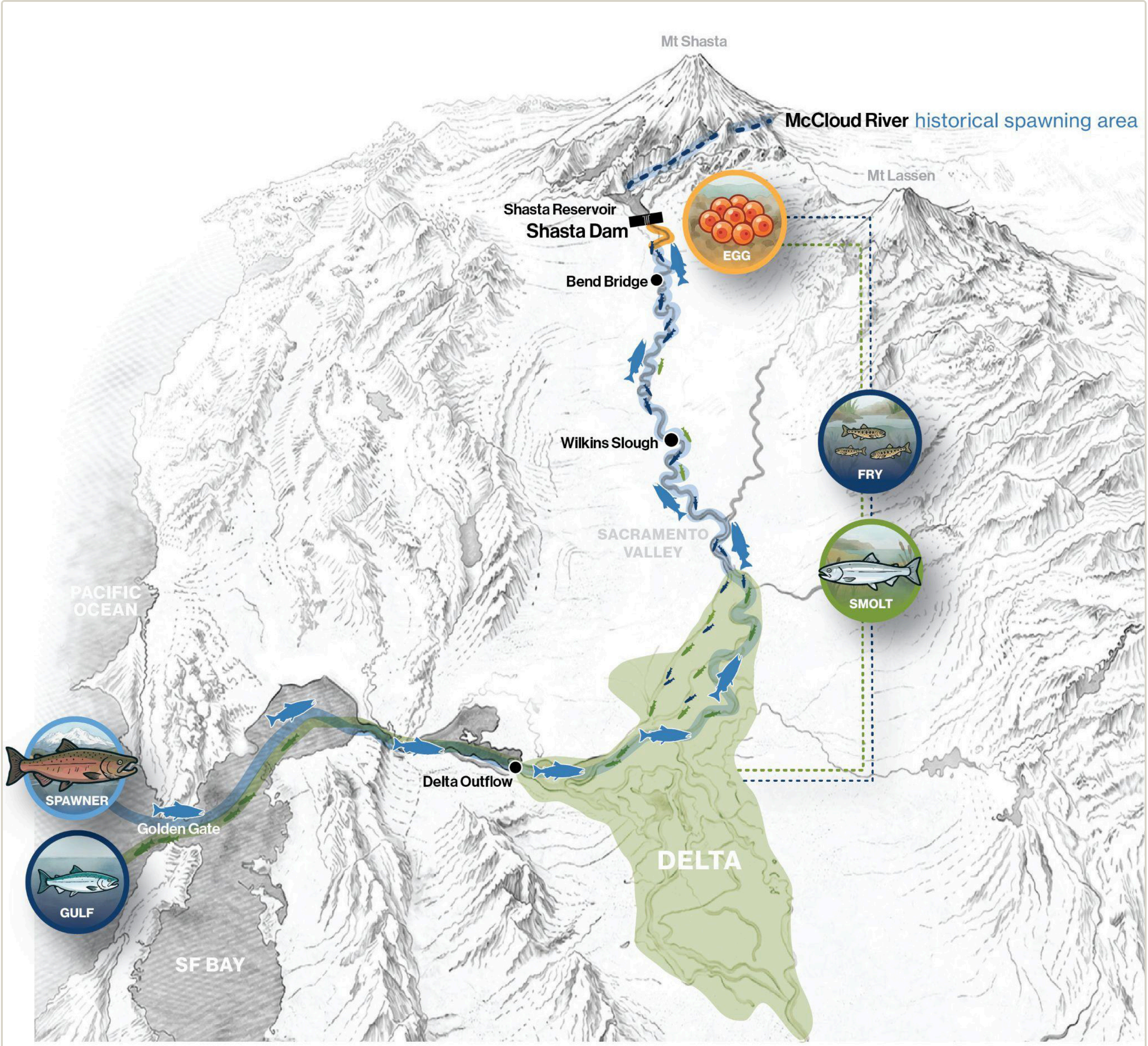
The tension between water operations and salmon conservation is particularly acute in the Sacramento River, where winter-run Chinook salmon are endangered and remain at high risk of extinction. Winter-run salmon historically spawned in cold, spring-fed headwaters and tributaries of the Sacramento River. Today, Shasta Dam blocks access to most of those habitats, and winter-run primarily spawn downstream of Shasta Dam during the warmest part of the year. Their egg survival now depends heavily on cold water stored in Shasta Reservoir and released downstream during summer.

Reintroducing winter-run to cold-water habitat above Shasta Dam offers another potential pathway for recovery by giving fish access to habitat that is less dependent on reservoir releases. COEQWAL explores how this could change salmon outcomes alongside alternative flow-management strategies.

Restoring important elements of natural flow patterns can benefit salmon and other freshwater species, but integrating environmental flows into a highly managed water system creates difficult choices. Climate change makes those choices harder. Shrinking snowpack, earlier snowmelt, intensifying drought, and higher temperatures affect both the amount and timing of river flows and the cold water available for salmon.

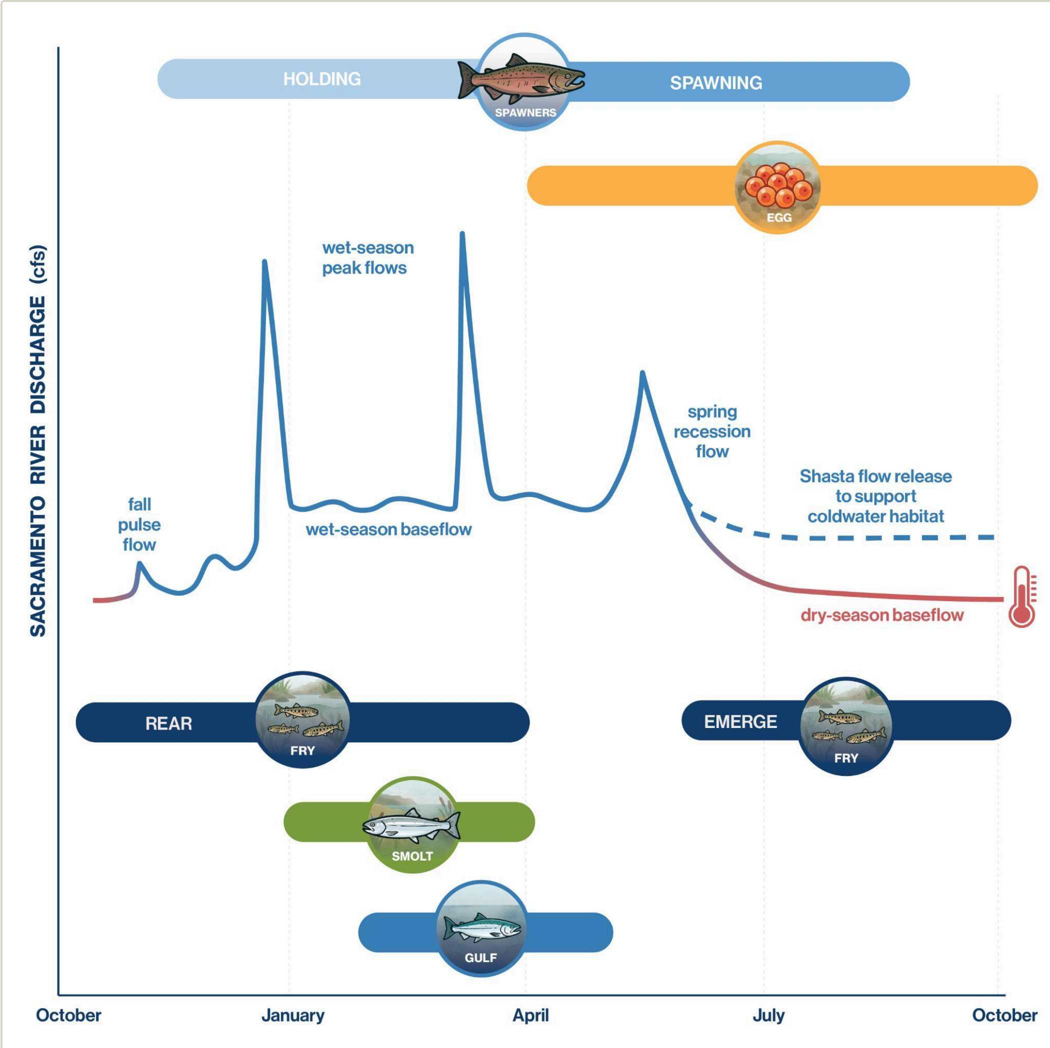
Winter-run Chinook salmon depend on connected habitats throughout their life cycle

Historically, most winter-run Chinook salmon spawned in cold headwater streams upstream of what is now Shasta Dam. Today, most spawn below the dam. Young salmon then move through the Sacramento River, floodplains, Delta, and Bay before reaching the ocean, while returning adults make the journey back upstream. Their survival depends on suitable flows, temperatures, and habitat at each stage of this life cycle.



Winter-run Chinook salmon need different river conditions throughout the year

Winter-run chinook salmon depend on seasonal flows for migration and rearing and on cold summer water for successful spawning and egg survival. Because Shasta Dam blocks access to historical cold-water habitat, reservoir operations now play a critical role in maintaining suitable downstream temperatures.



WHAT THIS WATER ISSUE FOCUSES ON

Seasonal flow and year-to-year variability

California's rivers exhibit distinct seasonal patterns. Winter and spring rains and snowmelt increase flows, sometimes spreading onto floodplains and creating habitat for fish and other species. In summer and fall, flows naturally decline and water temperatures rise. Native species have evolved with these seasonal changes.

California rivers vary considerably from year to year. Wet years, dry years, floods, and droughts are part of this natural variability, while modern water management often reduces or shifts these fluctuations to improve water-supply reliability and meet other objectives. Water allocated to rivers for ecosystem benefits are known as environmental flows. Environmental flows generally protect a minimum amount of water in rivers throughout the year. Functional environmental flows are designed to preserve key elements of these natural seasonal and year-to-year patterns.

Cold-water needs of Winter-run Chinook salmon

Winter-run Chinook salmon differ from most other California salmon runs. They spawn during summer, when river temperatures are naturally warm, and historically relied on cold spring-fed habitats at higher elevations to survive. Today, Shasta Dam blocks access to much of this habitat, making winter-run salmon highly dependent on cold-water releases from Shasta Reservoir.

As a result, managing reservoir storage is not only a water supply issue, it is also a fish survival issue. If Shasta's cold-water pool becomes depleted during summer, egg mortality can increase even when river-flow targets are met. For winter-run salmon, the temperature and timing of water releases can therefore be as important as the amount of water released.

Reintroduction above Shasta Dam could reduce this dependence by restoring access to cold, spring-fed habitat. COEQWAL examines how reintroduction could affect winter-run outcomes under different management and climate conditions.

System connections and trade-offs

Rivers are deeply interconnected with California's water supply system. Water released from reservoirs for environmental flows can affect the amount and timing of water remaining in storage or available for other uses. For winter-run salmon, there can also be trade-offs within environmental management itself: releasing more water to restore natural flow patterns may reduce the cold-water storage needed to protect eggs during summer. These connections mean that a strategy that benefits one ecological process or life stage may create different effects elsewhere in the system.

WHAT TO KEEP IN MIND

- Rivers ecosystems are shaped not only by how much water flows, but when it flows and its temperature.
- Reservoirs provide important water storage benefits for people and farms, but they also alter natural flow patterns, temperatures, and habitat conditions.
- Minimum environmental-flow requirements generally maintain a baseline amount of water in rivers but may not preserve the seasonal and year-to-year variability important to ecosystem processes. Functional environmental flows are designed to restore key elements of that variability.
- Salmon depend on different conditions at different life stages. Winter-run Chinook salmon are especially dependent on cold-water releases from Shasta Reservoir.
- Improving environmental flows does not necessarily improve winter-run salmon outcomes. For winter-run, releasing more water at one time of year can reduce the cold-water storage needed at another.
- Flow management alone cannot fully restore river ecosystems. Habitat conditions, water temperature, landscape changes, invasive species, and access to historical habitat also influence ecological outcomes.

WHAT MANAGEMENT STRATEGIES ARE EXPLORED

This water issue explores strategies designed to improve river ecosystem conditions and winter-run Chinook salmon populations. Some scenarios establish functional environmental flows that preserve key elements of natural seasonal and year-to-year flow variability. Other strategies adjust reservoir operations to protect cold-water storage and flows that provide refuge for multiple life stages of winter-run salmon. Many of these scenarios are also evaluated with groundwater pumping limits and/or reintroduction of winter-run above Shasta Dam.

This water issue focuses on the following scenarios:

- Functional environmental flows
- Functional environmental flows with reduced crop acreage
- Winter-run refuge flows
- Winter-run refuge flows with reduced crop acreage
- No flow requirements

Scenarios with reintroduction of salmon above Shasta Reservoir include:

- Current operations with reintroduction
- Functional environmental flows with reintroduction
- Functional environmental flows with reduced crop acreage and reintroduction
- Winter-run refuge flows with reintroduction
- Winter-run refuge flows with reduced crop acreage and reintroduction

For more information about those scenarios, and additional scenarios modeled with reintroduction alternatives, visit **Data and Documentation** (https://coeqwal.org/data).

Together, these scenarios examine how environmental flows, reservoir operations, groundwater management, and access to historical habitat influence river and salmon outcomes and create trade-offs elsewhere in the water system.

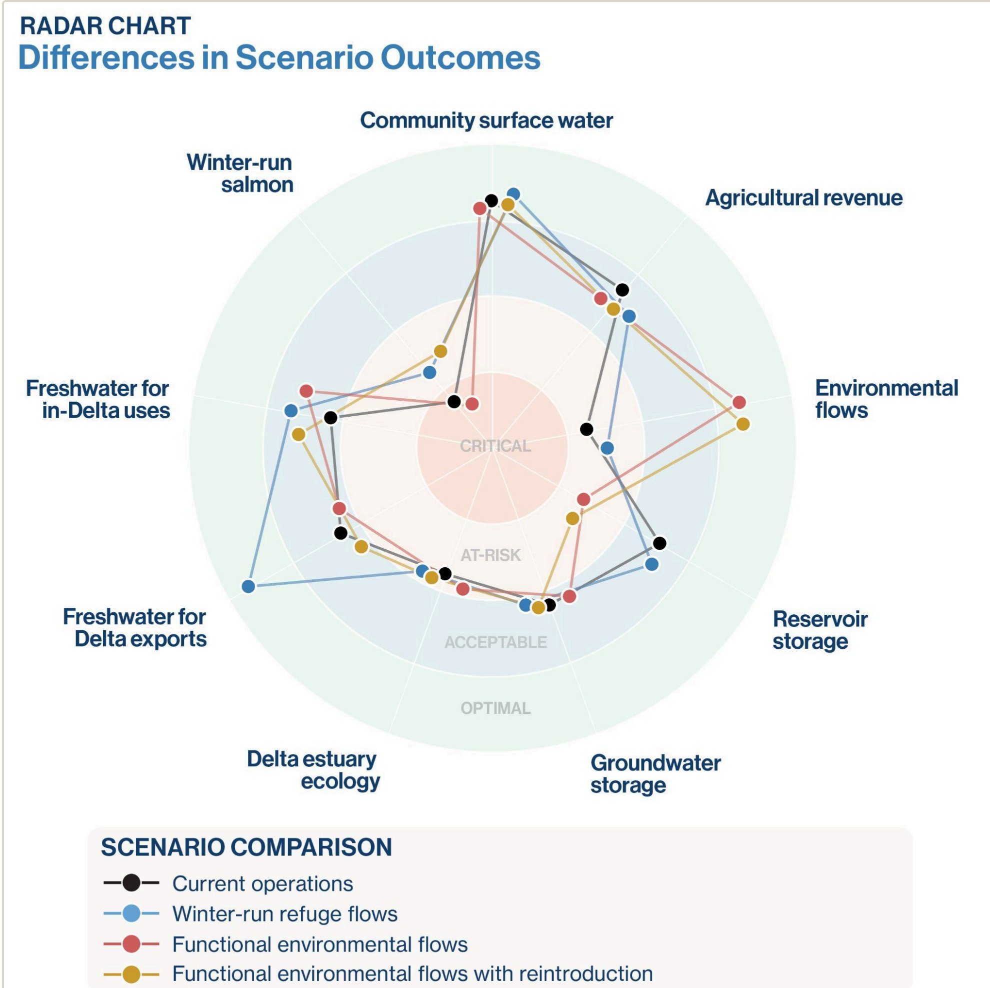
WHAT THE MODELS SHOW

The **Explore Tool** (https://coeqwal.org/explore) allows you to explore how scenario outcomes compare under alternative management strategies and climate conditions. There are complementary ways to visualize tradeoffs, equity, and resilience of water management strategies. The examples below illustrate results from select scenarios for this water issue.

Trade-offs

How do different management strategies affect overall system performance across multiple outcomes?

The radar chart in the **Explore Tool** (https://coeqwal.org/explore) summarizes performance across nine key outcomes, revealing broad system-level trade-offs within and between scenarios. This example compares **Current operations** with two approaches to protecting rivers and salmon: **Functional environmental flows**, which seek to restore key elements of natural flow patterns, and **Winter-run refuge flows**, which prioritize cold-water releases from Shasta along with functional flows shaped to benefit winter-run Chinook salmon. The **Functional environmental flows with reintroduction** strategy is also included to show how reintroduction of winter-run Chinook salmon above Shasta Dam changes outcomes. The chart specifically compares **Current operations** (black), **Functional environmental flows** (red), **Functional environmental flows with reintroduction** (yellow), and **Winter-run refuge flows** (blue) under the historical hydroclimate. The points show the average conditions of all locations of interest for each outcome and are classified into four outcome levels: optimal, acceptable, at-risk, and critical. See **Data and Documentation** (https://coeqwal.org/data) for more information on how these categories are defined.



The results show that **Functional environmental flows** substantially improve the environmental flow outcome, shifting average conditions from "At-Risk" under current operations to "Optimal". This improvement is accompanied by lower reservoir storage and poorer conditions for winter-run salmon, unless functional environmental flows are paired with the reintroduction of winter-run Chinook salmon above Shasta. The result reflects an important challenge for winter-run: releasing water to restore more natural flow patterns can reduce the cold-water reserves in Shasta Reservoir needed to protect eggs during summer. However, if winter-run can spawn above Shasta where cool spring-fed tributaries support egg survival, then these actions are complementary with functional flows that can support instream rearing and outmigration habitat. As a result, all winter-run lifestages are supported with the **Functional environmental flows with reintroduction** scenario, and move winter-run from a “Critical” to “At-Risk” population.

The **Winter-run refuge flows** scenario also moves the winter-run population from “Critical” to “At-Risk”, but does so by managing reservoir operations to protect Shasta’s cold-water pool. It then allocates the remaining water to functional flows, adding pulse flows to support rearing habitat and salmon outmigration survival. While this scenario provides flows for later in-river lifestages in the mainstem Sacramento River, it has flow requirements at fewer locations than the **Functional environmental flows** scenario. As a result, the **Winter-run refuge flows** scenario improves reservoir storage and winter-run salmon outcomes relative to **Functional environmental flows**, but performs less well against the broader environmental-flow objective.

The scenarios also affect water availability elsewhere in the system. All scenarios increase freshwater available for in-Delta uses, relative to **Current operations**, while the **Winter-run refuge flows** produce a particularly large improvement in freshwater available for Delta exports. Agricultural revenue and community surface water deliveries change relatively little at the system-wide scale, as do groundwater storage and Delta estuary ecology.

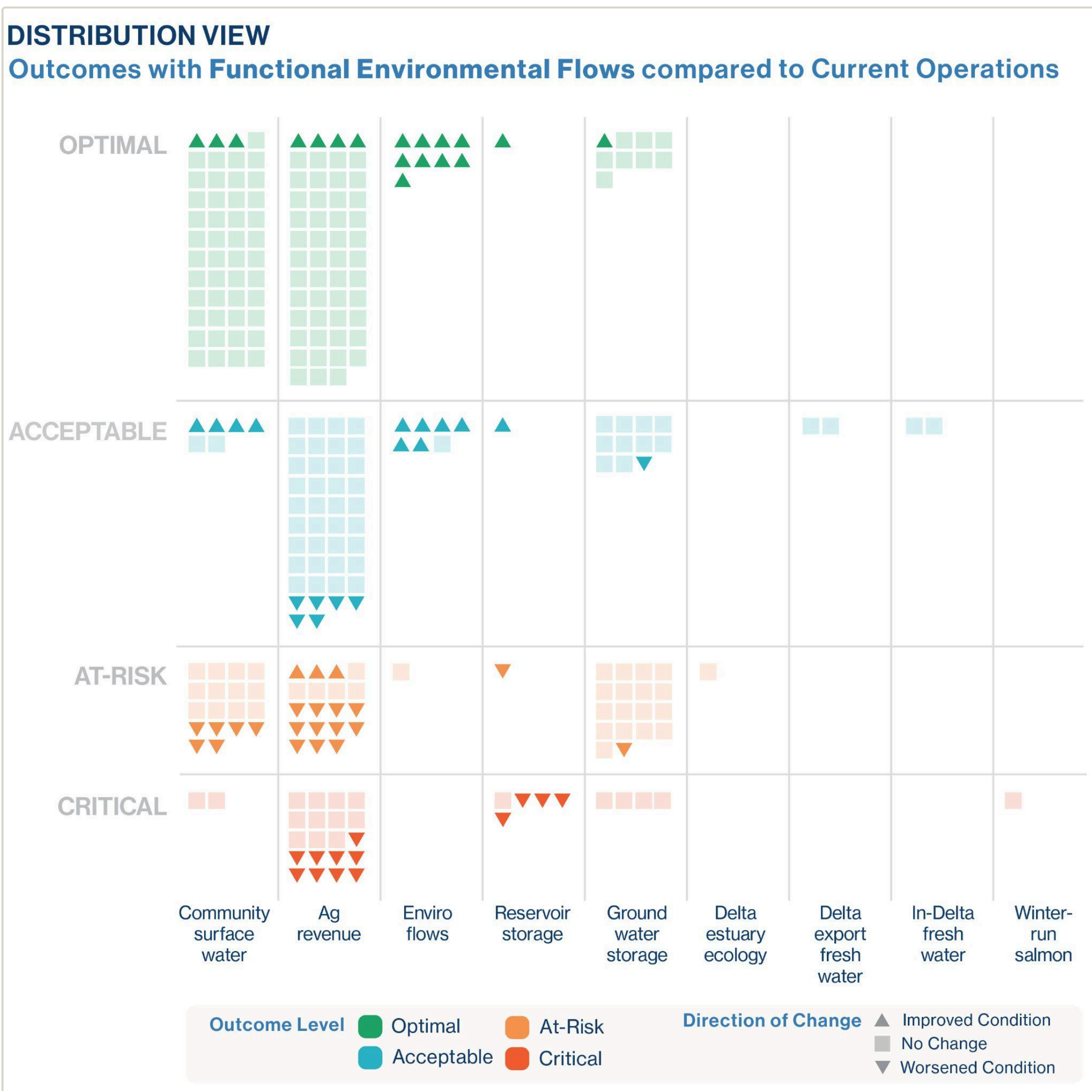
Overall, these results show that strategies intended to protect rivers and winter-run salmon can produce different trade-offs depending on how water is managed. A strategy that improves broader river-flow conditions may not necessarily improve survival of winter-run salmon if it does not preserve cold-water storage needed for their early life stage. Reintroduction changes this relationship by reducing winter-run dependence on downstream cold-water releases from Shasta Reservoir.

Equity

Where do benefits and impacts occur, and who is most affected?

System-wide averages can hide important differences in scenario impacts. River conditions, water availability, ecosystem needs, and competing demands vary considerably across the Central Valley, meaning that the same river management strategy can create different benefits and burdens in different places.

The Distribution view in the **Explore Tool** (https://coeqwal.org/explore) shows results for individual locations of interest. The figure summarizes how outcomes shift at all locations under the **Functional environmental flows** scenario relative to **current operations**. Arrows indicate direction of change relative to current operations and color represents optimal (green), acceptable (blue), at-risk (orange), or critical (red) outcomes for the scenario. Boxes represent locations for which the outcome results remain the same.



Compared with **Current operations**, **Functional environmental flows** have mixed effects on community surface water deliveries and agricultural revenues. Conditions improve at some locations, decline at others, and remain the same at most locations. Environmental flow outcomes substantially improve, while groundwater storage, freshwater for in-Delta uses, Delta estuary ecology, and winter-run salmon generally remain at the same outcome level. Reservoir storage experiences mixed effects. In the Sacramento Valley, more water is released for functional flows and other uses and results in lower storage; the San Joaquin Valley sees some increases in reservoir storage and some declines.

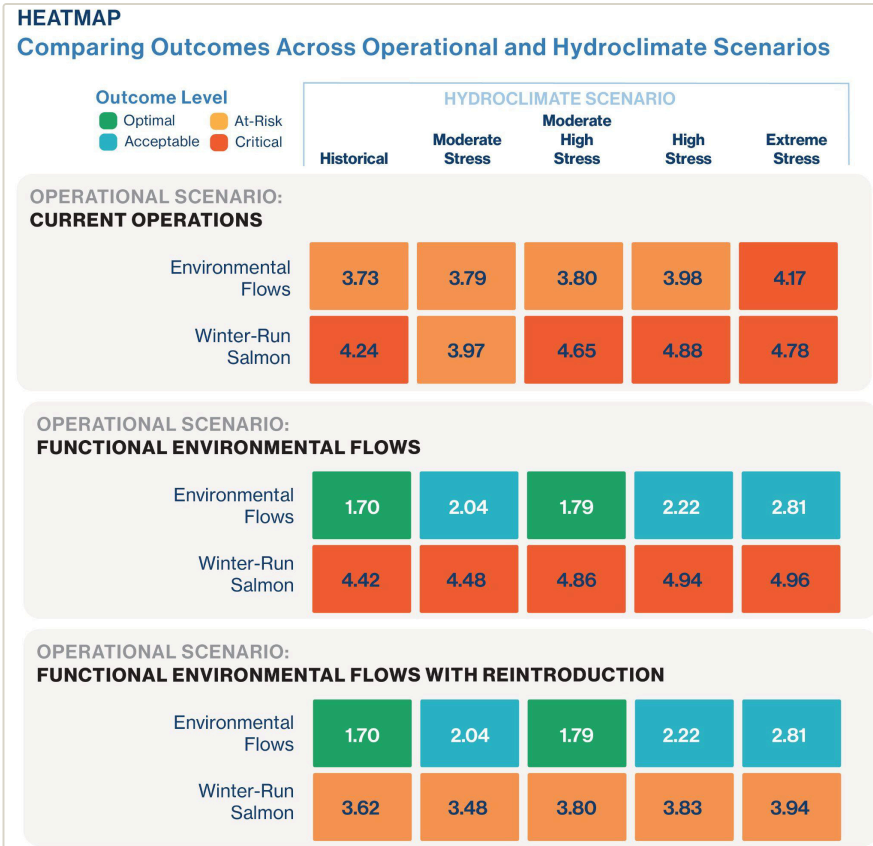
Overall, the Distribution view reveals spatial patterns hidden by system-wide averages and helps identify where a management strategy creates benefits, where it creates burdens, and how evenly those effects are distributed.

Resilience

How consistently do management strategies perform under different climate futures?

Climate change is expected to place increasing stress on California's water system. A management strategy that performs well today may respond differently as droughts become more frequent, temperatures rise, and water availability changes. The Resilience heatmap in the **Explore Tool** (https://coeqwal.org/explore) examines how management strategies perform across a range of plausible hydroclimate futures, representing increasing levels of stress to the water system. See **Data and Documentation** (https://coeqwal.org/data) for more information about hydroclimate futures.

The Resilience heatmap summarizes environmental flow and winter-run salmon outcomes for the **Current operations, Functional environmental flows**, and **Functional environmental flows with reintroduction** scenarios, under the historical hydroclimate and under future hydroclimates representing Moderate, Moderate-High, High and Extreme levels of stress. Outcomes are categorized as optimal (green, 1.00 - 1.99), acceptable (blue, 2.00 - 2.99), at-risk (orange, 3.00 - 3.99), or critical (red, 4.00 - 4.99), with higher numerical values indicating worse performance.



Under **Current operations**, environmental flows are “at risk” under historical climate and future climates representing Moderate, Moderate-high, and High stress to the water system. On average, environmental flows fall to critical levels under Extreme climate stress. Implementing functional environmental flows in Central Valley rivers substantially improves environmental flow outcomes across all climate futures. For the **Functional environmental flows** and **Functional environmental flows with reintroduction** scenarios, environmental flow outcomes remain "Acceptable”, even under Extreme climate stress.

Under **Current operations**, winter-run salmon remain at critical levels across the majority of hydroclimates. This is also true for the **Functional environmental flows** scenario, where winter-run remains at critical levels across hydroclimate futures because functional flows deplete Shasta cold-water reserves and provide less protection for the egg lifestage. However, if functional flows are paired with reintroduction of winter-run above Shasta, access to cold-water habitat supports the egg lifestage and functional flows support rearing and migration lifestages in the Sacramento River. As a result, the winter-run population responds positively and moves out of "Critical" levels and into “At-Risk” levels for all hydroclimate futures. The results suggest that the combination of functional environmental flows and reintroduction can improve conditions for both environmental flow metrics and winter-run salmon under historical and future climates. This also underscores the potential importance of complementary approaches, such as reintroduction, for mitigating climate impacts to winter-run salmon.

Overall, the heatmap shows how the effectiveness of management strategies can change under different climate futures and helps identify where benefits remain robust and where they begin to break down as California’s climate changes.

HOW TO EXPLORE FURTHER

Together, these data visualizations make trade-offs, equity, and resilience visible, providing a common foundation for comparison, discussion, and learning. Visit the **Explore Tool** (https://coeqwal.org/explore) to learn more about how different groundwater management strategies affect environmental flows, winter-run salmon, and other outcomes across regions and climate conditions.

If this is the first time using the **Explore Tool** (https://coeqwal.org/explore), we recommend visiting the **Get Started** (https://coeqwal.org/learn) section of the site before you begin your exploration.

CONTACT US

Do you have questions or feedback about this water issue and the COEQWAL project? Please email coeqwal@berkeley.edu (mailto:coeqwal@berkeley.edu)