

Operationalizing Functional Flows to Inform and Evaluate Flood-Managed Aquifer Recharge (Flood-MAR) Diversion Approaches



SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

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EXECUTIVE SUMMARY

Advancement of Flood Managed Aquifer Recharge (Flood-MAR) has received considerable interest in California amongst State, Federal, Tribal, and local entities as a water management strategy that can provide broad benefits for Californians and ecosystems, including water supply reliability, flood risk reduction, drought preparedness, aquifer replenishment, ecosystem enhancement, subsidence mitigation, water quality improvement, working landscape preservation and stewardship, and climate change adaptation. Flood-MAR entails diversion of flood waters and wet-season flows from surface waters for strategic groundwater recharge. Floods and wet-season flows are not just surplus water; they provide functional ecological processes and diversions can put additional pressure on surface water systems and aquatic ecosystems that depend on natural flow patterns, and which may already be stressed. Further, despite considerable attention and investment, including feasibility studies, legislation, and pilot projects, Flood-MAR implementation at scale remains somewhat unrealized in California, due to a range of cooperation, governance, legal, and technical barriers (DWR, 2018).

Ongoing efforts to continue advancing Flood-MAR must consider all beneficial uses and users, including those associated with environmental benefits, and there is a growing need to better understand and evaluate the ecological functions supported by winter flows, and a corresponding opportunity to proactively integrate ecosystem considerations into Flood-MAR implementation from the outset, rather than addressing them after the fact. The California Environmental Flows Framework (CEFF) provides a science-based approach for defining the streamflow conditions needed to support ecological functions in rivers and streams and provides a unique opportunity to both develop alternative diversion approaches for defining water available for recharge and conditions under which diversion can occur. CEFF also provides a practical framework for informing and evaluating diversion approaches through the lens of functional flows. To that end, this case study had three objectives:

1. Develop a CEFF or functional flow-informed workflow for defining wet-season diversion criteria
2. Explore approaches for assessing streamflow alteration resulting from alternative diversion scenarios
3. Evaluate the tradeoffs between streamflow alteration and water available for recharge under different diversion scenarios.

To illustrate and compare alternative diversion approaches, three watersheds spanning Northern California were selected as case study locations: Scott River, Stony Creek, and Elder Creek. At each site, multiple diversion approaches were simulated, including functional flow-

informed scenarios based on wet-season flow metrics from CEFF, a cumulative wet season approach (e.g., 80/50), and the State Water Board's streamlined permitting approach for Flood-MAR (the "90/20" rule). Additional ecohydraulic-based scenario was simulated at Scott River, where the necessary hydraulic data was available.

For each scenario, daily diverted flow and remaining instream flow were calculated, then used to measure two things: water availability for recharge (magnitude, frequency, and duration of diversion opportunities), and streamflow alteration (how much each approach changed flow conditions compared to current and natural conditions). Together, these two sets of measures provide a basis for evaluating tradeoffs between water supply reliability and ecological flow support across the different approaches.

Regarding water availability, across all three case study sites, there were consistent gradients between scenarios in terms of how each performed according to the magnitude, frequency, and duration recharge metrics. This shows that despite the varying hydrologic conditions at these sites, each scenario yielded reliable tradeoffs in terms of water availability. The general trends for each approach are summarized as follows:

- 90/20: Provides short duration diversion opportunities with intermediate frequency that yield relatively low magnitudes of water available for recharge.
- Functional Flow-Informed:
 - Wet-season median thresholds (FF-50 and FF-75): Provides long duration diversion opportunities with high frequency that yield relatively high magnitudes of water available for recharge.
 - 2-Year Peak: Provides short duration diversion opportunities with low frequency that yield relatively low magnitudes of water available for recharge.
- Ecohydraulic: Provides long duration diversion opportunities with high frequency that yield high magnitudes of water available for recharge.
- 80/50: Provides long duration diversion opportunities with relatively low frequency that yield intermediate magnitudes of water available for recharge.

A standard method for detecting whether a site's flow conditions have shifted away from natural flow patterns did not distinguish between any of the diversion scenarios tested, at any of the sites. This means that this single test alone was not sensitive enough to tell the approaches apart, and not that no differences exist between them; other measures below do show differences. Results point to the following key findings:

- At Elder Creek and Scott River, every flow metric evaluated stayed close to natural conditions under every scenario tested. This reflects each metric’s typical value falling within the expected natural range; it does not mean every aspect of the flow pattern was unaffected, see bullet 3 below.
- At Stony Creek, one flow metric (wet-season baseflow magnitude) was already rated as lower than natural conditions before any new diversion was applied, most likely due to an existing dam upstream, not the diversion scenarios themselves.
- 90/20 (percentile-based) and cumulative wet-season approaches narrowed the range of flood duration (how long) and frequency (how many flood events) at all three sites, while functional flow-based scenarios resulted in flood flow patterns closer to current conditions.
- Which scenario came out “best” changed depending on how water availability was measured. No single scenario ranked best across every way of measuring recharge opportunity.
- Two scenarios illustrate this well: a functional flow-based scenario protects flood events directly but otherwise operates similarly to the cumulative wet-season scenario; the cumulative wet-season scenario doesn’t explicitly protect flood events but offers steadier, more predictable operations. Which is preferable depends on local priorities.

This analysis compared streamflow measures across diversion scenarios and did not evaluate real-world ecological outcomes directly (e.g., fish survival or population health). Testing that connection directly is a priority for future work.

Ultimately, findings from the case study demonstrate that different diversion approaches result in varying magnitude, frequency, timing, and duration of water available for recharge and different degrees and types of flow alteration, supporting a toolbox approach rather than a single-best recommended approach. It is important for practitioners implementing recharge projects to select diversion approaches and criteria based on their project objectives, specific site conditions (e.g., infrastructure), capacity for project tracking and operations, environmental needs, and protection of existing water rights holders. There is no single diversion approach that is “one-size-fits-all.” The step-by-step evaluation framework developed here: screening functional flow metrics against recharge opportunity and evaluating alteration under each candidate criterion; provides a way to make site-specific selections systematic, transparent and data-driven rather than defaulting to a single statewide rule. This will provide a defensible approach for selecting a preferred diversion strategy.

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INTRODUCTION

Many California rivers face significant demands on their water resources. As a consequence, aquatic ecosystems that depend on natural flow patterns can be increasingly stressed by increased diversions (Poff & Zimmerman, 2010). These pressures are intensifying with climate change, which is shifting the timing and magnitude of streamflow and adding urgency to water management decisions throughout the state.

A river's natural flow pattern is defined by not only how much water moves through it, but by the timing, magnitude, frequency, duration, and rate of change of flow across the year (Poff et al., 1997). Distinct seasonal aspects of the natural flow regime, such as the fall pulse, wet-season baseflow, peak flows, spring recession, and dry-season baseflow, are referred to as functional flows (Figure 1)(Yarnell et al., 2015). Each of these components support different ecological and geomorphic processes, described below, that native species are adapted to.

Peak flows and wet-season baseflow, in particular, are not just surplus water; they provide functional ecological processes (Postel & Richter, 2003; Yarnell et al., 2010). Peak flows redistribute sediment, reset geomorphic and ecological processes, limit encroachment by vegetation and species not adapted to periodic flooding, and, where floodplain space is available, connect rivers to their floodplains. Wet-season baseflows sustain stream network connectivity and prolonged aquatic habitat availability, support fish passage, and maintain flow levels higher than during the dry-season, a seasonal pattern that many native species, including anadromous salmonids, depend on for lifecycle timing. A key concept underlying a functional flows approach is that all components of the hydrograph work together to support ecosystem function, not any single component in isolation (Yarnell et al., 2015; Yarnell et al., 2020). Many existing alterations, including dams and diversions, reduce this natural variability and make flows more uniform throughout the year, even where total annual volume is unchanged, which can degrade the ecological processes that depend on natural flow variation (Figure 2).

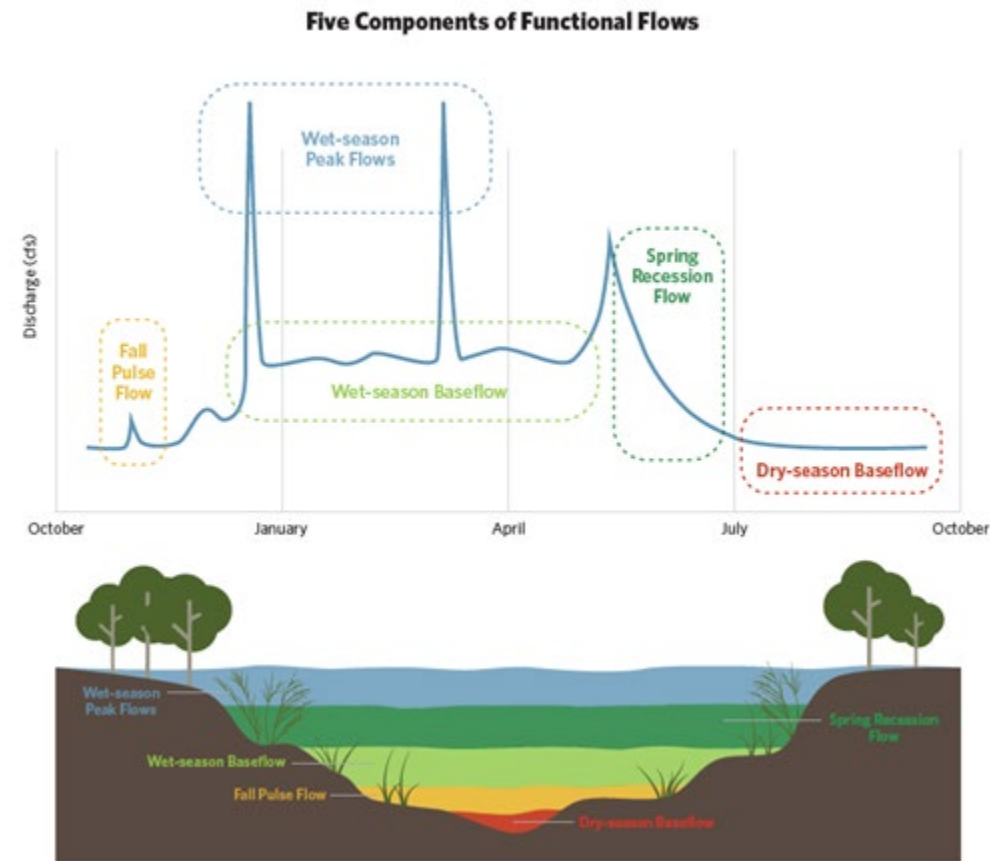


Figure 1. Functional flow components of a natural hydrograph, including the fall pulse, wet-season baseflow, wet-season peak flows, spring recession flow, and dry-season baseflow. Each component supports distinct ecological and geomorphic functions across the water year. Source: California Environmental Flows Working Group (CEFWG), 2024.

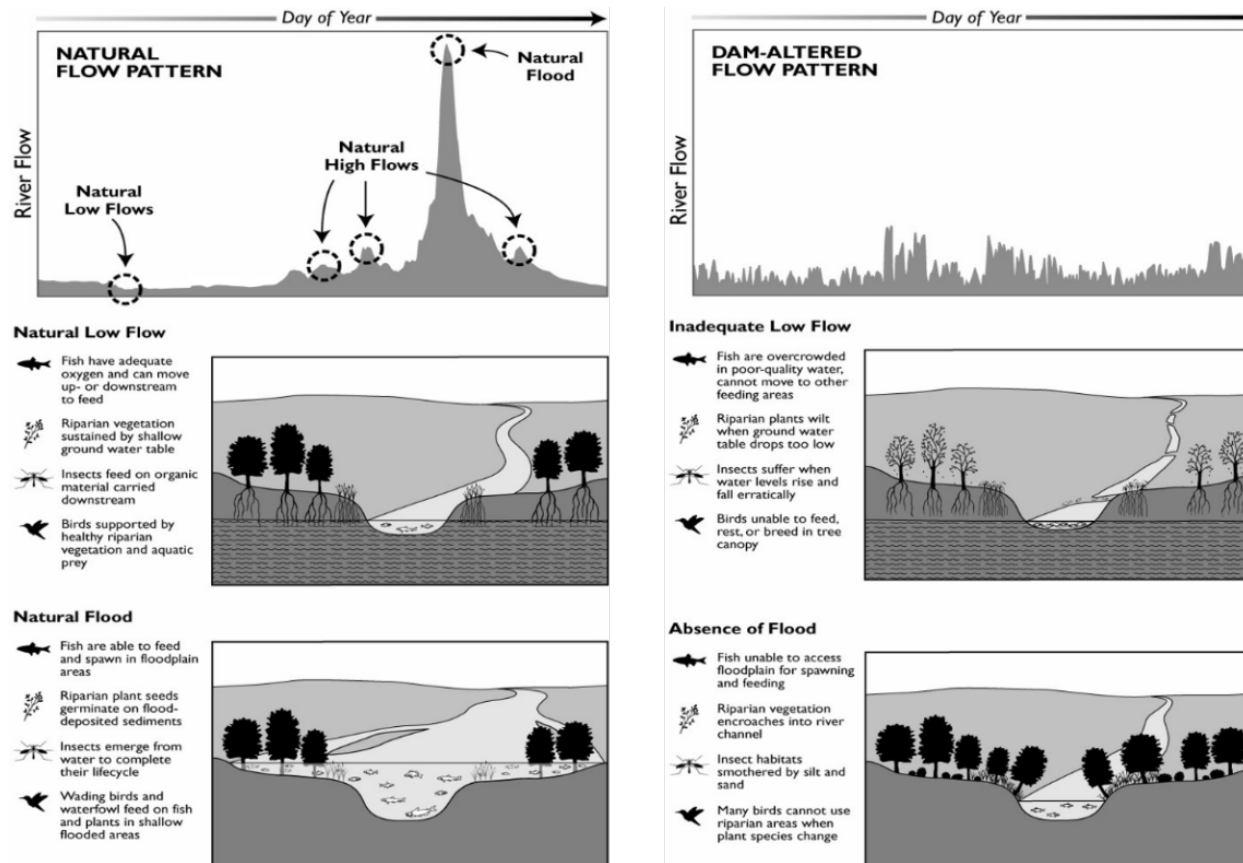


Figure 2. Comparison of a natural and dam-altered flow pattern representing the same total annual flow volume. Natural low flows, high flows, and floods each support distinct ecological functions. A dam-altered pattern with reduced variability, despite equivalent total volume, provides inadequate low flow conditions and eliminates the ecological benefits of natural flooding. Source: Postel & Richter, 2003.

The California Environmental Flows Framework (CEFF) provides a science-based approach for defining the streamflow conditions needed to support these functional flows in rivers and streams (Stein et al., 2021; CEFWG, 2021a). Rather than relying on static minimum flow thresholds or focusing on a single season of interest, this approach emphasizes maintaining the timing, magnitude, duration, and variability of flows across the entire hydrograph needed to sustain ecosystem health.

California's Sustainable Groundwater Management Act (SGMA) has created an urgent and ongoing need to improve conjunctive management, the coordinated and planned use of groundwater and surface water in time and space, which can increase available water for beneficial uses and improve drought resiliency (DWR, 2023). Flood-Managed Aquifer Recharge (Flood-MAR) is one strategy for advancing this integration, using flood water resulting from, or in anticipation of, rainfall or snowmelt to recharge groundwater on agricultural lands and working landscapes, including refuges, floodplains, and flood bypasses (DWR, 2018). Despite considerable attention and investment, including feasibility studies, legislation, and pilot projects, Flood-MAR implementation at scale remains largely unrealized in California (DWR, 2018; DWR 2026), due to a range of cooperation and governance, policy, legal, and technical implementation barriers. These include fragmented water and flood management authority across many federal, tribal, State, and local agencies; water rights and permitting processes that can be slow for landowners to navigate; policy gaps, such as aquifer replenishment not currently being considered an eligible use for State grant funding; and technical uncertainties around conveyance capacity, water quality, and the ecological effects of diversion during high-flow events (DWR, 2018). Advancing Flood-MAR must also consider all beneficial uses and users, including those associated with environmental benefits, and realizing these potential ecosystem benefits requires more than simply identifying "excess" water available for diversion. As Flood-MAR and other wet-season diversion efforts expand across the state, there is a growing need to better understand and evaluate the ecological functions supported by winter flows, and a corresponding opportunity to proactively integrate ecosystem considerations into Flood-MAR implementation from the outset, rather than address them after the fact.

Existing diversion approaches used to define water available for recharge and conditions under which diversion can occur, and which are typically included as conditions of new water rights or temporary permits for diversion, vary in how directly they incorporate these functional flow concepts (see Diversion Scenarios, below, for a description of each approach evaluated in this study). The State Water Board's streamlined "90th percentile/20 percent" (90/20) method, inspired by Richter et al. (2011), provides a simplified, conservative framework intended for broad, streamlined permitting application (SWB, 2019), but it does not explicitly account for the full range of ecologically relevant flow components. Other approaches, such as a cumulative

wet-season approach intended to extend the duration of diversion events and reduce daily operator burden, or site-specific ecohydraulic thresholds tailored to sensitive species and geomorphic conditions, reflect different tradeoffs between operational simplicity, recharge opportunity, and ecological specificity. Functional flow-informed diversion criteria on the other hand can be intended to preserve the wet-season river functions described above. This range of diversion approaches, and the lack of a consistent framework for comparing them, highlights the need to link diversion criteria to environmental flow needs.

This project addresses that gap with three objectives to:

1. Develop a CEFF or functional flow-informed workflow for defining wet-season diversion criteria
2. Explore approaches for assessing streamflow alteration resulting from alternative diversion scenarios
3. Evaluate the tradeoffs between streamflow alteration and water available for recharge under different diversion scenarios.

For this case study historical streamflow data are used to simulate and compare a range of diversion approaches, including the Board's streamlined 90/20 method, a cumulative wet season approach, existing instream flow-based criteria (ecohydraulic), and functional flow-informed alternatives, across three case study sites. This work provides a practical framework for informing and evaluating diversion approaches and better understanding tradeoffs between water capture and supporting ecological benefits. The framework will hopefully result in more multi-benefit recharge projects as Flood-MAR implementation expands.

APPROACH

This study evaluates functional flow-informed diversion approaches alongside other diversion approaches (e.g., 90/20, cumulative wet season, and minimum instream flow requirements) to assess tradeoffs between water availability and ecological flow protection. Historical daily streamflow observations are used to simulate and compare diversion scenarios reflective of each approach under consistent hydrologic conditions. The overall study approach is summarized in Figure 3 and is described in more detail in subsequent sections.

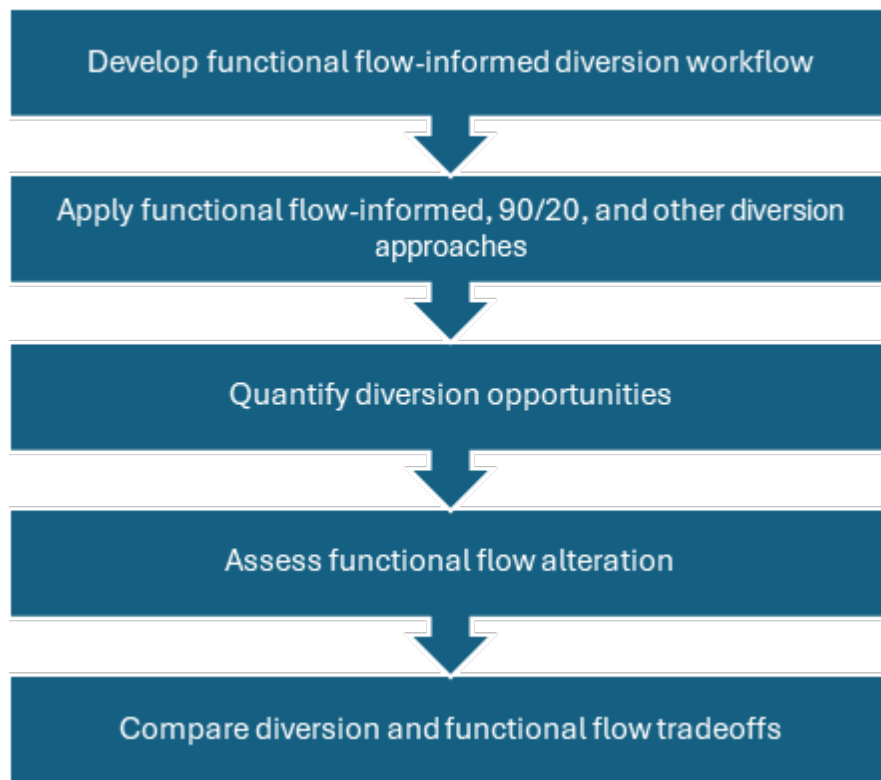


Figure 3. General approach for developing and evaluating diversion scenarios using historical streamflow data.

Case Study Locations

To illustrate and compare alternative diversion scenarios, three watersheds and associated stream gages were selected as case study locations (Figure 4): Scott River (USGS gage ID 11519500), Stony Creek (CDEC gage ID BLB), and Elder Creek (USGS gage ID 11379500). Case study sites were selected based on the availability of long-term streamflow records, representation of diverse hydrologic stream classes, and a range of flow alteration levels, from less impaired to regulated systems. Additional considerations included the existence of existing temporary permits for groundwater recharge and relatively straightforward water rights contexts.



Figure 4. Case study watersheds: Scott River and Stony and Elder Creeks in the Sacramento Valley.

Where possible, the period of record used for Baseline (observed gaged data) and scenario simulations at each site should be matched to the period of record of the natural flow reference used for alteration comparisons. In this study, the Natural Flows Database (CEFWG, 2021b) provided predicted natural flow percentiles for the 1950-2014 water year period, and Baseline and scenario time series at each site were constrained to this period for consistency in alteration comparisons. Where a site's available streamflow record does not fully overlap with this period, the full available period of record was used instead. At Stony Creek, where the streamflow record begins in approximately 1990, the natural flow reference period could not be fully matched. Where a daily unimpaired flow model or a long-term unimpaired reference gage is available for a site, matching Baseline and scenario period of record to that dataset's period of record is preferable to using the Natural Flows Database's default predicted period, as this provides a more direct, site-specific basis for alteration comparison.

Scott River

The Scott River watershed encompasses about 812 square miles from the confluence with the Klamath River, and about 650 square miles upstream of the USGS Fort Jones gage (USGS gage ID 11519500; COMID¹: 3798909). There are no large impoundments in the Scott River watershed and flows in the Scott River and its tributaries vary widely within any given year, but they generally exhibit a low-volume snowmelt and rain hydrologic classification that is characterized by a bi-model snow-rain hydrograph driven by a spring snowmelt pulse and winter rains (Lane et al. 2018). During spring and summer, flows in the Scott River are substantially diverted primarily for agricultural purposes. From a surface water supply perspective, all surface water rights in the Scott River watershed above the USGS Fort Jones gage are adjudicated. Based on best available information, the only legally defined instream flow requirements in the valley are those allocated to the U.S. Forest Service (USFS) pursuant to the 1980 Scott River Adjudication, which include a set of minimum instream flows as measured at the Fort Jones gage. Additional instream flow recommendations, measured at the Fort Jones gage, were developed by CDFW (2017b) using three statistical and empirical flow standard setting techniques. The State Water Board has also issued minimum instream flow recommendations to protect coho and Chinook salmon in the Scott River as part of emergency drought regulations issued in 2021 and 2022.

For this project, historical daily streamflow observations for Scott River are those observed at the USGS Fort Jones gage. The period of record available for this gage was October 1, 1941

¹ COMID is the Common Identifier in the National Hydrography Dataset (NHD) used to identify each specific surface water feature, such as a stream segment or flowline. COMID's were used to link to the Natural Flows Database, which provides modeled natural streamflow data and functional flow metrics for stream segments by COMID (see *Diversion Scenarios* section for more details).

through September 30, 2024. Since 2016, Scott Valley Irrigation District has intermittently diverted water from the Scott River to groundwater recharge (underground storage) at times of flood/higher discharge during the non-irrigation season (e.g., January 1–March 31). These diversions have been authorized by the State Water Board through issuance of a series of Temporary Permits. The previously issued permits included two parameters for determining whether and when water could be diverted and the flow rate of water able to be diverted. The first parameter relates to the observed flow at the USGS Fort Jones gage that must be met for diversions to occur. The values specified in the previously authorized Temporary Permits is as follows:

No water shall be diverted under this temporary permit unless the daily mean flow or the calculated average flow during the preceding 10 days is above 440 cubic feet per second, as measured at USGS Fort Jones Gage. If the daily mean flow or the calculated average flow during the preceding 10 days is above 440 cubic feet per second but below 470 cubic feet per second, the Permittee shall limit its diversion rate such that it does not cause the stream flow to fall below 440 cubic feet per second.

The value of 440 cubic feet per second (cfs) is intended to be protective of the existing downstream USFS water right, which amounts to 426 cfs at USGS gage #11519500 during the authorized periods of diversion. Each previously authorized Temporary Permit included the additional term that the diversion threshold value could be reduced from 440 cfs to 362 cfs upon written confirmation by USFS.

Stony Creek

The Stony Creek Watershed is a 777-square-mile drainage basin spanning Glenn, Colusa, Tehama, and Lake Counties in Northern California. Unimpaired streamflows in Stony Creek generally exhibit a flashy, ephemeral rain hydrologic classification that is characterized by sporadic, intense rainfall events with high flow variability, extended extreme low flows and large floods, and low average daily flow (Lane et al. 2018). Contemporary streamflows in Upper Stony Creek are regulated by East Park and Stony Gorge Reservoirs. Lower Stony Creek flows are controlled by releases from Black Butte Dam. Black Butte Dam was completed by the United States Army Core of Engineers (USACE) in 1963 with a design capacity of 160,000 acre-feet. Reservoir sedimentation has reduced the capacity to around 130,000 acre-feet. The USACE operates the reservoir from October 15 to March 15 for flood control and the United States Bureau of Reclamation operates it from March 15 to October 15 for irrigation supply. Current reservoir operations limit peak dam outflows to 15,000 cfs. Prior to Black Butte Dam, the 50-year flood was 80,000 cfs.

Compared to pre-dam flows, post-dam flows in lower Stony Creek are characterized by significantly decreased peak flows, longer duration “bankfull” flows, higher and more variable

summer and early fall flows, and more variable, and more frequently near-zero, late fall and early winter flows. Black Butte Dam blocks any upstream anadromous fish migration. The United States Fish and Wildlife Service Anadromous Fish Restoration Program lists Stony Creek as high priority for increasing migratory salmonid populations that are currently adversely affected by temperature, hydrology, and channel habitat conditions (Sacramento River Watershed Program, 2026a).

For this project, historical daily streamflow observations for Stony Creek are the calculated difference between flows observed at the Black Butte Dam & Lake (BLB) and South Diversion Canal gages maintained by USACE (COMID: 12074576). This calculation is consistent with flows used in temporary permit 21479 (5-year permit) issued by the State Water Board on December 8, 2025 to the Corning Subbasin Groundwater Sustainability Agency authorizing diversions to underground storage from Stony Creek during periods of high flow. The period of record that flow data was available for Stony Creek is January 1, 1990, through March 31, 2025.

The temporary permit for Stony Creek applies the State Water Board's 90/20 criteria. The permit also specifies that diversion may only occur if when the mean daily flow rate for the previous 24-hour period, measured at the Hamilton City (gage HMC) operated by DWR is at or above 8,629 cfs, 9,439 cfs, 10,072 cfs, and 11,435 cfs during the months of December, January, February, and March, respectively. The permit also includes standard conditions for the Sacramento-San Joaquin Delta (Delta), such that the Delta must be in "excess" for any diversion to occur (e.g., Term Code: 0000091 and Term Code: 0450300).

Elder Creek

The Elder Creek Watershed is a 150-square-mile drainage basin located within the broader Tehama West Watershed in Tehama County in Northern California. There are no large impoundments in the Elder Creek watershed and flows in the valley portion (i.e. downstream) of Elder Creek generally exhibit a perennial groundwater and rain hydrologic classification that is characterized by stable, groundwater driven baseflows during summer and high magnitude, rain driven, winter peak flows with low annual streamflow (Lane et al. 2018). Elder Creek typically goes dry or near dry by July in the lower reaches, and significant surface flows do not return until late fall. Early stages of anadromous species such as Chinook salmon and steelhead are believed to occupy habitat provided near the confluence of Sacramento River and Elder Creek (Sacramento River Watershed Program, 2026b).

For this project, historical daily streamflow observations for Elder Creek are those observed at the USGS Elder Creek near Paskenta gage (USGS gage ID 11379500; COMID: 12068798). This is consistent with flows used in temporary permit 21485 (5-year permit) issued by the State Water Board on February 11, 2026 to the Tehama County Flood Control and Water

Conservation District authorizing diversions to underground storage from Elder Creek during periods of high flow. The period of record that flow data was available for Elder Creek is October 1, 1948, through March 31, 2025. The temporary permit for Elder Creek applies the State Water Board's 90/20 criteria. The permit also specifies that diversion may only occur when the mean daily flow rate for the previous 24-hour period, measured at the at Vina (gage VIN) operated by DWR is at or above 10,500 cfs, 11,309 cfs, 11,943 cfs, and 13,462 cfs during the months of December, January, February, and March, respectively. The permit also includes standard conditions for the Sacramento-San Joaquin Delta (Delta), such that the Delta must be in "excess" for any diversion to occur (e.g., Term Code: 0000091 and Term Code: 0450300).

Diversion Scenarios

Multiple diversion scenarios were simulated for each study site, including functional flow-informed approaches based on wet-season flow metrics from CEFF, a cumulative wet season approach, and the State Water Board's streamlined permitting approach for Flood-MAR (the "90/20" rule) (Table 1). Additional ecohydraulic based scenarios were simulated where data was available (i.e., Scott River). The following criteria or considerations were applied for all scenarios at all sites:

- Diversions were only allowed during the wet-season, December 1st through March 31st.
- Daily diversions were limited to no more than 20 percent of the daily observed flow. This is consistent with the State Water Boards 90/20 approach.
- Beyond 20 percent, no additional capacity or volumetric limit was assumed. This reflects a watershed-based, cumulative approach that assumes all available water is diverted regardless of the capacity of existing diversions.
- All diversion scenario simulations included the criteria that diverted flows do not reduce the daily flow below any diversion thresholds (i.e., bypass flow criteria above which diversion may occur).
- To the extent practicable, diversion scenario simulations accounted for water rights of existing legal users of water or other factors that may limit water availability (e.g. Delta conditions), as noted in the case study locations section above

For case study locations in the Sacramento River basin (Stony and Elder Creeks), all diversion scenarios were further conditioned based on requirements associated with temporary permits issued by the State Water Board (temporary permit 21479 and 21485, respectively). Specifically, diversions were only allowed when the Sacramento–San Joaquin Delta was in excess water conditions to protect downstream Delta water supply operations and when other

downstream requirements were met (see Case Study Locations section for description of temporary permits and downstream requirements).

Outputs from each simulation were timeseries of daily diversions and post-diversion instream flow for each diversion scenario.

Table 1. Diversion scenarios evaluated in this study.

Scenario	Start Diversions	Diversion Constraints
90/20	Flow exceeds daily 90th percentile	20% daily diversion cap
FF-WS50	Flow exceeds wet-season median flow (50 th percentile)	Preserve key flood events (2-year, 5-year, 10-year events); 20% daily diversion cap
FF-WS75	Flow exceeds wet-season median flow (75 th percentile – higher, more protective)	Preserve key flood events (2-year, 5-year, 10-year events); 20% daily diversion cap
FF-Pk2	Flow exceeds 2-year peak threshold	Preserve key flood events (2-year, 5-year, 10-year events); 20% daily diversion cap
Ecohydraulic	Flow exceeds site-specific ecohydraulic-defined flow threshold	20% daily diversion cap
80/50¹	Cumulative flow exceeds 80th percentile cumulative flow	Cumulative flow < cumulative 50 th percentile; wet-season median bypass flow; 20% daily diversion cap

¹ The term 80/50 is used as shorthand in tables and graphics throughout this document for the cumulative wet season scenario.

Functional Flow-Informed Diversion Scenarios

Functional flow-based diversion scenarios were developed building on previous work (Stanford et al., 2024). This approach utilizes a functional flows approach from the CEFF (Stein et al., 2021) and seeks to preserve key wet-season functional flow metrics including the wet-season

baseflow (10th and 50th percentile of wet-season flows) and peak flow magnitudes (2-year, 5-year, and 10-year events).

Diversion scenarios were developed using observed daily streamflow timeseries from USGS or CDEC gages. Lower limit flow thresholds for diversion were defined using either the wet-season median flow or the 2-year peak flow magnitude. Upper limits were established to preserve key peak flow events (2-year, 5-year, and 10-year flood) when they occur. Because flow variability is a critical component of the flow regime that supports biophysical processes (Biggs et al., 2005; Naiman et al., 2008) and to remain consistent with other diversion approaches being evaluated, all functional-flow based scenarios included a maximum diversion cap of 20 percent of instantaneous daily flow.

The proposed workflow for developing functional flow-informed diversion scenarios is presented below. This workflow is intended as a starting framework to guide scenario development and is not meant to be prescriptive; specific approaches and thresholds should be adapted based on local hydrologic conditions, management objectives, and site-specific constraints.

Workflow:

1) Define natural range of functional flow metrics

- a) Obtain the natural range of wet-season functional flow metrics from:
 - i) the Natural Flows Database (CEFWG, 2021b),
 - ii) a watershed model of unimpaired daily flow (if available), or
 - iii) a relatively unimpaired reference gage (if available).
- b) If continuous daily timeseries of unimpaired flow is available for at least a 15-year period of record (options 1b or 1c), calculate functional flow metrics using the Functional Flows Calculator (CEFF Technical Team et al., 2025).
- c) If using the Natural Flows Database, use the natural ranges of functional flow metrics.

2) Adjust wet-season metrics for local constraints, if necessary²

- a) Evaluate whether wet-season functional flow metrics need to be adjusted based on local constraints (see CEFF Section B). For example, where a site-specific study for a target species (e.g., salmonids) are available, wet-season baseflow values can be refined

² For this study, wet-season metrics are not adjusted based on local constraints due to time and data limitations.

to ensure that unimpaired flow values from the Natural Flows Database will support ecological functions for that species. For systems with flood control constraints:

- b) Identify the maximum allowable flow based on channel capacity to prevent infrastructure impacts. When flows exceed or approach this threshold, diversions may be allowed to reduce flood risk and additional caps on diversion rates (e.g., percentage-based limits) should not be applied (Figure 5).

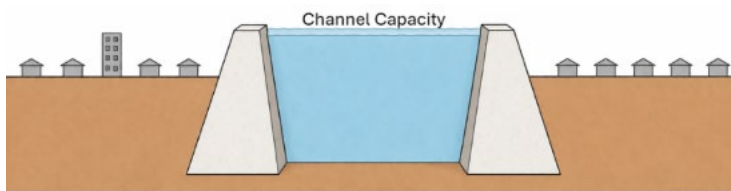


Figure 5. Example system with flood control constraints. The maximum allowable flow should not exceed the channel capacity to prevent flood impacts.

- c) For systems where floodplain connectivity is important:
 - i) Evaluate whether unimpaired peak flow magnitudes (e.g., 2-year flood) are sufficient to access the floodplain under current channel conditions.
 - ii) In incised or enlarged channels, flows higher than unimpaired may be required to achieve inundation (Figure 6).

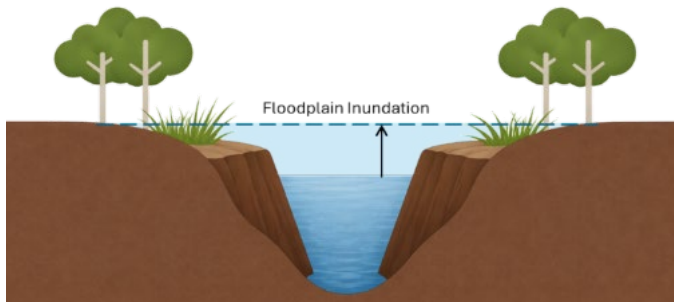


Figure 6. Example incised channel where floodplain inundation is a priority. In this example, the unimpaired peak flow magnitude should be higher to ensure floodplain connectivity.

3) Simulate diversion scenarios by water year

a) For each water year during the December 1st to March 31st timeframe, diversion rules were applied as follows:

i) **Minimum flow threshold for diversion:** diversions are only allowed when streamflow exceeds a defined minimum threshold. Two threshold approaches were evaluated:

(1) **Wet-season median flow threshold:** thresholds were defined using percentile values³ of the wet-season median flow metric:

(a) 50th percentile

(b) 75th percentile

(2) **2-year peak flow threshold:** a single, fixed threshold based on the 2-year flow magnitude was applied across all years.

(3) **Note on existing water rights:** if existing water rights or permits exist at study location, the minimum threshold should add in the water right flow with the functional flow threshold (i.e., existing water right of 2 cfs + wet-season median flow threshold)

ii) **Preserve peak flow events:**

(1) Key peak flow events (**2-year, 5-year, and 10-year flood magnitudes**) are preserved the first time they occur in a water year⁴. Diversion rules are applied hierarchically to ensure these events are maintained:

(a) The first time flows reach the 2-year flood magnitude in a water year, flows up to the 2-year threshold are preserved, and diversion is only allowed on flows exceeding this magnitude, up to the 5-year flood magnitude.

³ The 50th and 75th percentiles were simulated for this study to compare with the higher 2-year peak flow threshold. A 90th percentile of wet-season median flow could be used; a substantially lower percentile (e.g., 25th) is not recommended, as it would set the minimum diversion threshold too low to meaningfully protect wet-season flow function. Alternatively, a water-year percentile-matched approach could be taken, if annual unimpaired flow metric data is available (Yarnell et al., 2024).

⁴ Once a given flood magnitude tier has been preserved once in a water year, subsequent events reaching that same tier are treated as available for diversion (up to the standard 20 percent cap) rather than preserved again. For example, if a 2-year event occurs twice in one water year, only the first is preserved; the second is available for diversion up to the 20 percent cap. Similarly, in a year with a 2-year event followed by a 5-year event followed by another 2-year event, the first 2-year event and the 5-year event are both preserved (as distinct, higher tiers), while the second 2-year event is available for diversion up to the 20 percent cap.

- (b) The first time flows reach the 5-year flood magnitude in a water year, flows up to the 5-year threshold are preserved, and diversion is allowed on flows between the 5-year and 10-year magnitudes.
- (c) The first time flows exceed the 10-year flood magnitude, all flows above the 10-year threshold are available for diversion.
- (2) If flood control constraints exist, peak flows are capped at the identified channel capacity to prevent potential flood damage in step 2.

iii) Maximum diversion rate (variability constraint):

- (1) To preserve wet-season variability, scenarios include limits on daily diversion rates.
- (2) One maximum diversion threshold was evaluated:
 - (a) 20 percent of daily flow
- (3) Diversions are limited to a percentage of instantaneous flow on any given day.

90/20 Scenario

The 90th Percentile/20 Percent (90/20) Method is described in detail in the “Water Availability Analysis for Streamlined Recharge Permitting” documentation from the State Water Board (SWB 2019). The 90/20 approach limits water available to divert to only those flows that are above the daily 90th percentile flow value, and the volume diverted is capped at 20 percent of the daily flow. The approach is based on the broad assumption that flows above the 90th percentile daily flow, between December 1st and March 31st, are protective of aquatic ecosystem functionality if diverted water is limited to a maximum of 20 percent of the daily flow, and so long as diverted flows do not reduce the daily flow to below the 90th percentile daily flow (Richter et al. 2011). Note that Richter et al.’s (2011) method was developed and validated using unimpaired flow conditions, while the Board’s 90/20 approach as implemented here is applied to historical observed flow, which may already reflect some degree of flow alteration. As a result, the 90th percentile threshold calculated from observed flow does not necessarily represent the same level of ecological protection as the same percentile calculated from unimpaired flow, particularly at sites where observed flow is substantially altered from natural conditions.

For the 90/20 approach, the simulation model steps through the input hydrology and for each day checks if the daily discharge exceeds the 90th percentile value for that day and is within the wet-season. If the day is within the wet-season and flow exceeds the 90th percentile value for

that day, diversion is made as the lesser of the two following quantities: 20 percent of the flow, or the daily discharge minus the 90th percentile value. Where applicable, other criteria discussed at the beginning of this section (i.e., existing water rights, etc.) are applied to constrain diversions.

Cumulative Wet-Season Scenario

For the cumulative wet season approach, water is available for diversion when the following conditions are met:

- 1) During the period of December 1 to March 31
- 2) Beginning on the date that cumulative water year runoff exceeds the 80th percentile of historical cumulative runoff for that same calendar date
- 3) Flow is greater than the 50th percentile median wet-season baseflow from the Natural Flows Database plus the full face of existing water rights
- 4) Delta is in an excess condition, if diversions are within the Delta watershed.

Diversions must cease if the cumulative water year runoff falls below the 50th percentile of historical cumulative runoff for that same calendar date or if the bypass flow or Delta conditions are no longer met.

The total amount of daily water diverted is also limited to no greater than 20 percent of the daily flow after bypass of the 50th percentile wet-season median flow from the Natural Flows Database and after downstream senior diverter demand is satisfied. The simulation model for the cumulative wet season approach was effectively the same as the 90/20 approach but implemented with the above criteria.

For simplicity in reporting results, this approach is called the “80/50 Approach” hereafter.

Ecohydraulic Scenario

Broadly, ecohydraulic scenarios are those based on detailed site-specific analysis of river flows necessary to support ecological and geomorphic functions (e.g., instream flow studies). This project leveraged a Fish Ecohydrology Assessment completed by ESA (2024) for the Scott River to develop an ecohydraulic scenario for that case study location. No instream flow studies or other detailed ecohydraulic assessments were available for Stony Creek and Elder Creek, and thus ecohydraulic scenarios were not developed for those case study locations.

As discussed in the Case Study Locations section above, previously authorized temporary permits for the Scott River have included an additional term that the diversion threshold value

at the Fort Jones gage could be reduced from 440 cfs to 362 cfs upon written confirmation by USFS. Findings from ESA (2024) concluded that a flow of 362 cfs at the USGS Fort Jones gage provides nearly unimpeded passage for adult and juvenile anadromous salmonids along the Scott River, would not result in disconnection of relevant tributaries, and that reduction of the diversion threshold from 440 cfs to 362 cfs would be unlikely to have any substantive negative effect on anadromous salmonids in the study reach during a potential diversion period of December 1–March 31. Based on these findings, a diversion threshold of 362 cfs was used to develop an ecohydraulic scenario for the Scott River. The simulation model for the Scott River ecohydraulic scenario was effectively the same as those above but implemented with this criterion.

Notably, the Fish Ecohydrology Assessment by ESA (2024) and associated findings were based on a maximum diversion capacity of 30 cfs, which limited potential impacts to high flows and declines in water levels. The Scott River ecohydraulic scenario for this project, like other scenarios, does not limit daily diversion beyond imposing that daily diversions are limited to no more than 20 percent of the daily observed flow.

Water Availability

Water available for recharge (water availability) under each diversion scenario was evaluated by calculating a series of recharge metrics focused on the magnitude, frequency, and duration of water availability (Table 2). Most metrics summarize water availability over the complete period of analysis, thus additional metrics including “diversion volume”, “average number of diversion days”, and “average duration of diversion events” were also calculated for each water year. Diversion volumes represent the total potential water available for diversion under each scenario and do not account for operational and infrastructure constraints (e.g., pump capacity, diversion infrastructure, land requirements, infiltration capacity, etc.). These metrics were used to compare diversion scenarios in terms of both total water available for recharge and the likelihood of diversion opportunities occurring within and across years. Together, these metrics provide a quantitative basis for evaluating tradeoffs between water supply reliability and ecological flow protection across alternative diversion approaches. For magnitude metrics it is relevant to again note that beyond the 20 percent cap, no other limits were placed on daily diversions, and thus magnitudes are the theoretical total water available under each approach. Current constraints with existing, physical diversion capacities in the case study locations would reduce the magnitude of water available under each scenario.

Table 2. Recharge metrics calculated for each scenario and watershed.

Characteristic	Recharge Metric (unit)	Description
Magnitude	Average Annual Diversion (TAF)	Expected annual water available for recharge based on average of annual series of diversion volumes.
	Median Annual Diversion (TAF)	Expected annual water available for recharge based on median of annual series of diversion volumes.
	Max one year volume (TAF)	Maximum water available in a single water year based on annual series of diversion volumes.
	Average Annual Diversion — For WY with Diversion (TAF)	Expected annual water available for recharge based on average of annual series of diversion volumes subset to only those years when diversions occur.
Frequency	Number of Years with no Diversion	Number of years with no water available for diversion.
	AEP Zero Diversion (Poisson Distribution)	Annual exceedance probability of no water being available for diversion assuming data follow a Poisson distribution
	Return Probability of Zero Diversion	Expected yearly return frequencies of no water being available for diversion assuming data follow a Poisson distribution.
Duration	Avg Annual No. of Diversion Days - For WY with Diversion (Days)	Expected number of days per water year that diversions would occur based on average of annual series of number of diversion days per water year subset to only those years when diversions occur.
	Avg Annual No. of Diversion Events - For WY with Diversion (n)	Expected number of discrete diversion events per water year based on average of annual series of number of diversion days per water year subset to only those years when diversions occur.
	Avg Duration of Diversion Events - For WY with Diversion (days)	Expected duration of discrete diversion events per water year based on average of annual series of average diversion durations per water year subset to only those years when diversions occur.

Notes: TAF = Thousand acre-feet

Functional Flows Alteration Assessment

Functional Flow Metric Calculation

Functional flow metrics were calculated for Baseline, or observed flow from the gage, and each diversion scenario at all three case study sites using the Functional Flows Calculator (California Environmental Flows Framework Technical Team et al., 2025), based on the daily streamflow time series generated for each scenario. This produced annual functional flow metric values across the historical period of record for every scenario-site combination, allowing metric distributions to be compared directly against Baseline and against the natural range of variability. Metric distributions across scenarios were visualized using boxplots showing the median and interquartile range (25th to 75th percentile) for each scenario relative to Baseline and the natural flow reference range from the Natural Flows Database for each site (Figure 7).

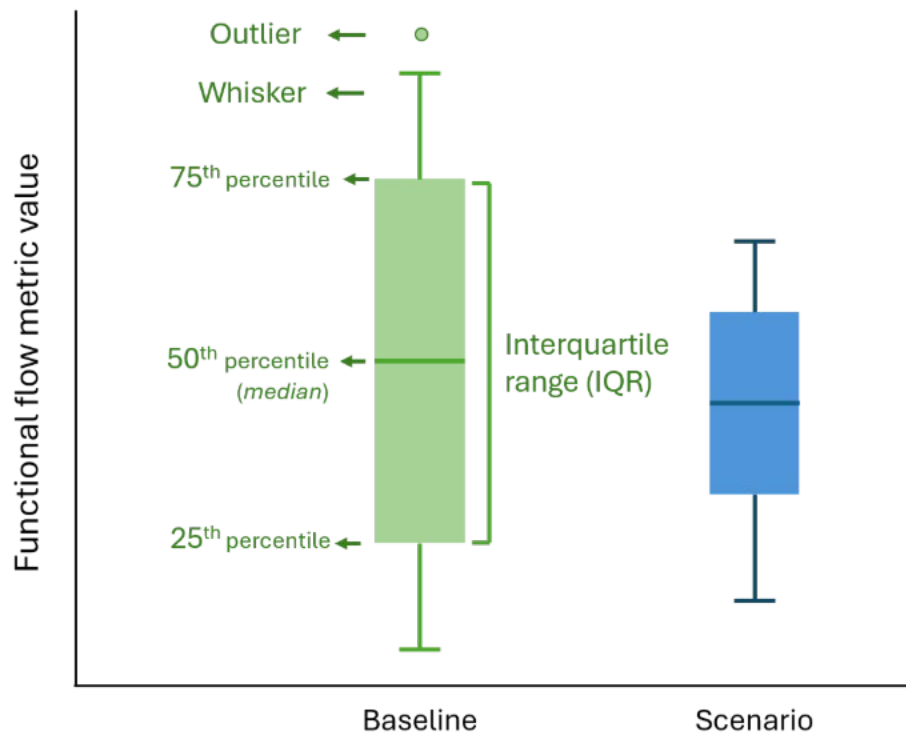


Figure 7. Illustrative example boxplots spanning the interquartile range (IQR, middle 50% of values from 25th to 75th percentile). Line inside box is the median, whiskers extend to the 10th and 90th percentiles, and points beyond the whiskers are outliers.

Flow Metric Issues and Corrections

Two artifacts in the standard functional flow metric calculation were identified during this analysis and corrected before use. Table 3 summarizes both and corrections are described in more detail below.

Table 3. Flow metric calculation artifacts and corrections applied.

Metric Affected	Standard Calculation Method	Artifact	Correction Applied	Sites Affected
Peak 2-year, 5-year, and 10-year duration and frequency	Duration is the cumulative number of days meeting or exceeding each flood flow threshold in a water year; frequency is the number of distinct events meeting or exceeding that threshold. Both are calculated relative to the 2-year, 5-year, and 10-year peak magnitude thresholds.	The peak magnitude threshold is recalculated separately for each scenario's own flow record; scenarios with lower peak magnitudes (due to diversions) appear to have higher duration/frequency simply because a lower threshold is exceeded more often and longer, not because peaks are better preserved	Recalculated using a single, fixed peak magnitude threshold from the Natural Flows Database, applied identically to Baseline and all scenarios	All three sites
Wet-season baseflow magnitude	Magnitude is the 10th and 50th percentile of daily flows within the wet-season window, which is bounded by detected spring recession timing.	Because the wet-season window is bounded by detected spring recession timing, a scenario-driven shift in that timing changes which days are included in the magnitude calculation, altering apparent magnitude even with no true change in baseflow	Recalculated using Baseline's wet-season window (matched year by year) rather than each scenario's own detected window	Scott River only (Elder Creek and Stony Creek showed consistent timing across scenarios; no adjustment needed)

Peak flow duration and frequency metrics (e.g., peak 2-year, 5-year, and 10-year duration and frequency) are calculated relative to a peak magnitude threshold. If this threshold is derived from each scenario's own time series rather than a consistent reference, scenarios with lower peak magnitudes (due to diversions) will appear to have higher peak duration and frequency simply because a lower threshold is exceeded more often and for longer, not because the scenario preserves peak events more effectively (Figure 8). To avoid this artifact, peak duration and frequency metrics should be recalculated for all scenarios, including Baseline, using the

peak magnitude thresholds from the Natural Flows Database rather than each scenario's own detected peak magnitude. This ensures duration and frequency are compared against a single, consistent peak threshold across all scenarios, isolating true differences in how long and how often flows exceed a fixed reference magnitude. Peak magnitude itself should not be recalculated in this way, as the objective of the magnitude comparison is to determine whether diversion scenarios reduce peak flow magnitude relative to Baseline and the natural range. Substituting a fixed reference threshold for peak magnitude would obscure that comparison. This recalculation is recommended for all scenarios regardless of whether a discrepancy is apparent, since a scenario's own peak magnitude threshold is not, by itself, a reliable basis for comparing duration or frequency across scenarios.

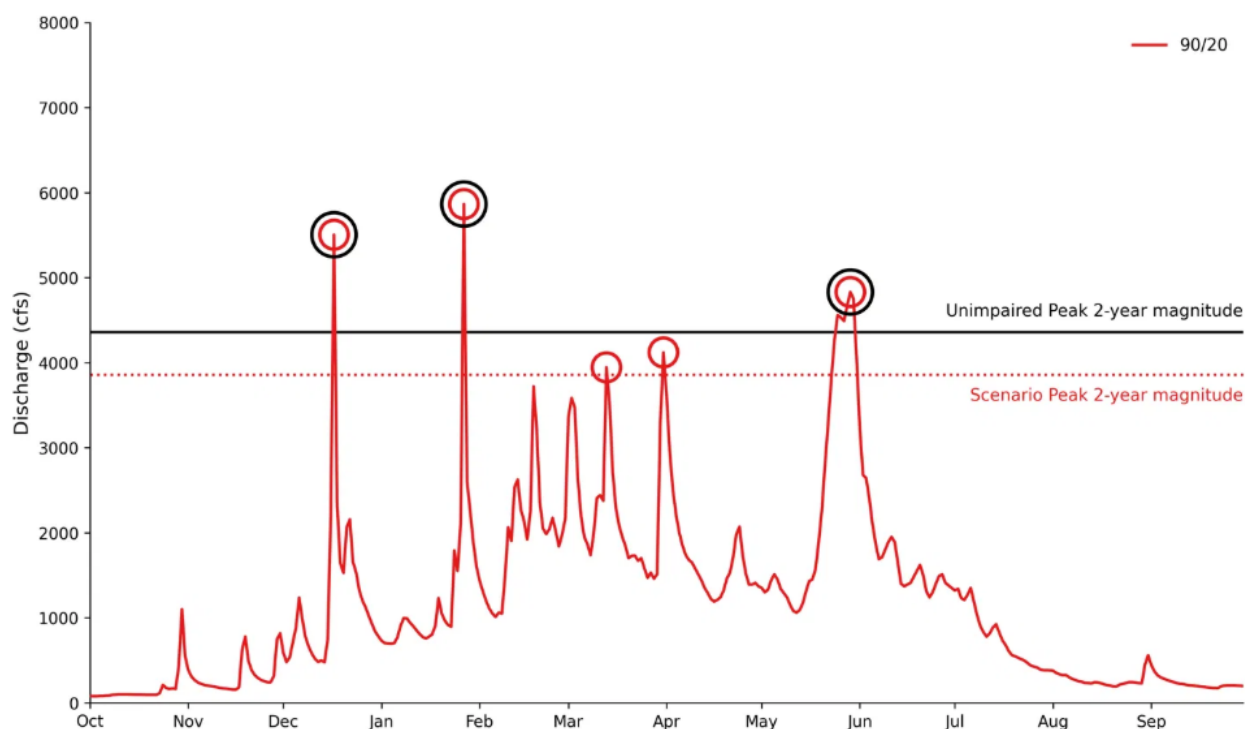


Figure 8. Scott River WY1983, showing how peak duration and frequency depend on which threshold is used. Solid horizontal line: unimpaired Peak 2-year magnitude (4,360 cfs). Dotted horizontal line: 90/20's own, lower, peak threshold (3,860 cfs). Black circles mark the 3 events that cross the unimpaired threshold; red circles mark the 5 events that cross 90/20's own threshold, including two smaller events (mid-to-late March) that register only against the lower self-detected threshold.

CEFF's wet-season duration metric is derived from wet-season start timing and spring recession timing. A scenario-driven shift in spring recession timing therefore changes the apparent wet-season duration, even when there is no underlying change in baseflow. Because wet-season baseflow magnitude is calculated over this same wet-season window, a shift in duration also changes the calculated magnitude, independent of any actual change in baseflow. Before

interpreting wet-season baseflow magnitude comparisons across scenarios, practitioners should first compare spring recession timing boxplots across scenarios relative to Baseline. If timing is consistent across scenarios, as was the case at Elder Creek and Stony Creek, no further adjustment is needed. If timing diverges, as at Scott River, where all diversion scenarios delayed detected spring recession timing relative to Baseline, wet-season baseflow magnitude should be recalculated for each scenario using Baseline's wet-season duration for the corresponding water year (matched year by year) to isolate the actual magnitude effect from this timing artifact.

At Scott River, this divergence traced back to a small number of wet years with a single very large peak event, where even a proportional reduction consistent with the standard diversion cap was enough to shift the Functional Flows Calculator's detected spring recession date by several months (Figure 9); years without a comparably extreme peak were unaffected regardless of scenario. Practitioners encountering a similar divergence should not assume it reflects an actual change in baseflow magnitude caused by the diversion scenario before checking whether it is concentrated in this type of year.

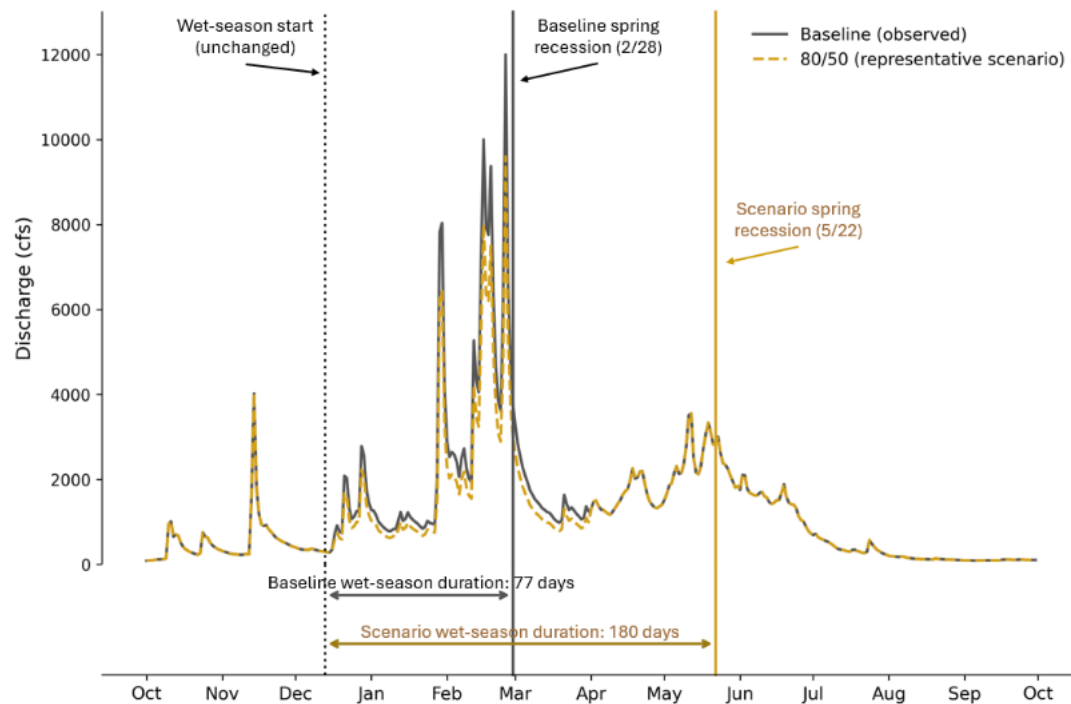


Figure 9. Scott River WY1958, illustrating how a proportional reduction in a single large peak event shifts detected spring recession timing and wet-season duration. Wet-season start timing (dotted line) is unchanged between Baseline and Scenario. Under Baseline, spring recession is detected on 2/28 compared to 5/22 for Scenario. Wet-season duration is more than doubled as a result of a later spring timing. Wet-season baseflow magnitude, as a result, will change simply due to a change in wet-season duration.

Streamflow Alteration Assessment

The streamflow alteration assessment used revised functional flow metrics described above. Alteration of wet-season functional flow metrics was evaluated by comparing metric values under each scenario, including Baseline, to the natural range of variability from the Natural Flows Database. For each case study location and scenario, annual values of key wet-season functional flow metrics, including wet-season baseflow (10th and 50th percentile flows) and peak flow (2-year, 5-year, and 10-year events) metrics, were computed and summarized across the period of record. Changes in these metrics were evaluated relative to the natural range of variability from the Natural Flows Database, applied consistently across Baseline and all diversion scenarios.

Alteration was assessed following guidance in CEFF Appendix J (California Environmental Flows Working Group, 2021), which evaluates both the magnitude and frequency of deviation from expected natural conditions (Figure 10). Metrics were compared to determine whether diversion scenarios resulted in measurable shifts in wet-season flow characteristics, including reductions in peak flow magnitude, changes in baseflow conditions, and dampening of flow variability. The resultant end-member classifications from this analysis are likely unaltered (the scenario's values fall within the natural range of variability), likely altered (the scenario's values fall outside of the natural range, in either the high or low direction), or indeterminate (the available data does not support a confident classification either way).

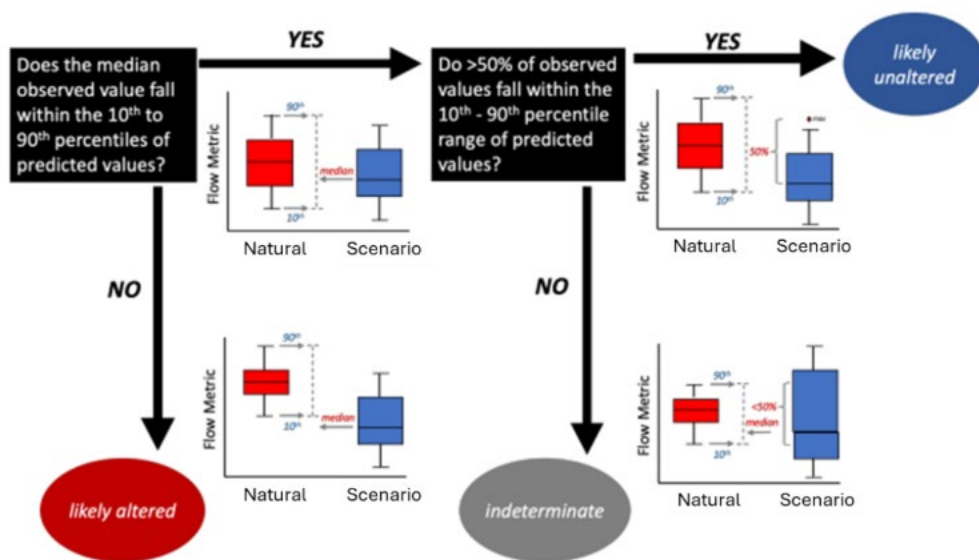


Figure 10. Criteria for assigning functional flow alteration status from CEFF Appendix J (figure adapted from California Environmental Flows Working Group, 2021). Natural represents the natural ranges of functional flow metrics and Scenario is the range from the diversion scenarios. Questions in the black boxes refer to the diversion scenarios.

Flow Metric Range Compression Screening

The streamflow alteration classification and deviation from baseline, described above, can both miss a specific kind of change: a diversion scenario can produce a median flow value similar to natural conditions, and show only a small deviation from baseline, while still narrowing the natural spread of variability around that median (Figure 11). This narrowing, referred to here as range compression, indicates that natural flow variability, the year-to-year difference between wetter and drier conditions, is being reduced.

This variability is ecologically important because native species have evolved life histories adapted to the natural pattern of flow variation, including both wetter and drier conditions, and maintaining that variability supports the diversity, resilience, and long-term productivity of river ecosystems (Naiman et al., 2008). Compressing that variability toward a narrower, more uniform range, effectively flattening the natural contrast between wet and dry conditions, can work against this, even in years where the median or typical flow value looks unchanged.

Range compression was calculated as each scenario's interquartile range (IQR, the range between 25th and 75th percentile of a flow metric's values) expressed as a percentage of the predicted natural flow IQR for that same metric. A value below 100 percent indicates the scenario narrows natural variability relative to unimpaired conditions; a value at or above 100 percent indicates variability comparable to, or greater than, natural conditions. This provides a screening diagnostic for whether a functional flow metrics variability from a diversion scenario is narrowed relative to natural conditions, even in cases where the median remains within the natural range and would not otherwise be flagged by the streamflow classification alone. This screening was applied across all wet-season and peak metrics as an initial step to identify which metrics warranted detailed presentation in the results.

Metrics were excluded from detailed presentation in the main results where they did not support a meaningful comparison. Peak magnitude metrics (2-year, 5-year, and 10-year) are calculated as a single value per scenario rather than a distribution of values across years, so there is no year-to-year range to compare. Peak 5-year and 10-year duration and frequency were also excluded: these events are large enough that they occur in very few years within the period of record, meaning most years show no qualifying event at all, which makes a percentile-based range comparison unreliable for these metrics. Spring recession timing was excluded for a different reason: as described earlier in this memo (see Flow Metric Issues and Corrections), a modest change in peak flow magnitude can shift when the tool detects the start of spring recession by months, even without any change in recession timing, which would distort a range compression comparison for this metric specifically. The complete set of range compression results across all screened metrics, including those excluded from detailed presentation, is provided in the appendix.

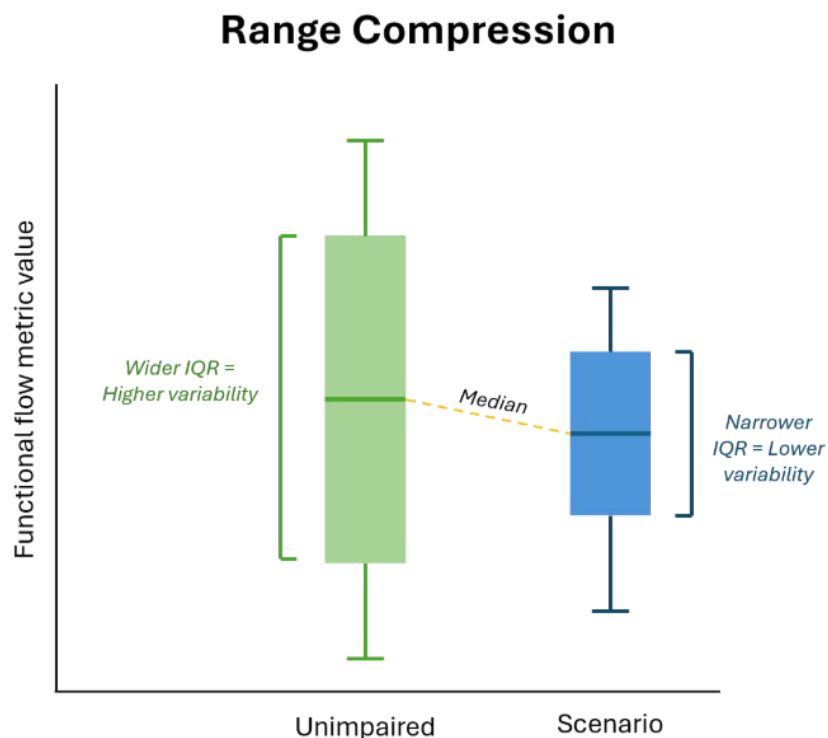


Figure 11. Illustration of range compression. A diversion scenario can produce a similar median flow value to unimpaired conditions while still narrowing the natural spread of variability around it (compression). A wider interquartile range (IQR) indicates higher natural variability; a narrower IQR indicates lower variability, even when the median is comparable. This example is illustrative only and does not represent data from any case study site.

Deviation from Unimpaired and Baseline

The streamflow alteration assessment provides a discrete alteration category for each metric and scenario (likely altered, likely unaltered, or indeterminate), but this classification may not discriminate among scenarios that all fall within the same category. In addition to this classification, two complementary approaches were explored to provide a more continuous measure of change in functional flow metrics: deviation from unimpaired conditions and deviation from Baseline conditions. Deviation means the difference between a scenario's value for a given metric and a reference value for that same metric, expressed either as a raw number or as a percentage of the reference value. A larger deviation means the scenario differs more from that reference condition; a smaller deviation means it is closer to it.

Ideally, deviation from unimpaired would be calculated on a year-to-year basis, comparing each scenario's functional flow metric value for a given water year directly to that same water year's unimpaired value. However, the Natural Flows Database provides unimpaired flow percentiles

by water year type (wet, moderate, dry) rather than an annual unimpaired time series, so a true year-matched comparison to unimpaired conditions is not possible. As an approximation, annual functional flow metric values were instead compared to the water-year-type-matched unimpaired median. For example, a scenario's value in a wet year is compared to the median unimpaired value across all wet years on record, rather than to an unimpaired estimate specific to that wet year, since no such year-specific unimpaired estimate exists. This approach is less robust and harder to interpret than a true annual comparison would be, since a given year is being compared to a general wet, moderate, or dry year rather than to its own specific unimpaired counterpart.

Because Baseline (observed) functional flow metric values are available on an annual basis, deviation from Baseline was also calculated as a second, complementary approach. This allows a direct year-to-year comparison of each scenario to Baseline for that same water year, without the water-year-type approximation required for the unimpaired comparison. Both raw deviation and percent deviation were calculated for each metric, scenario, and year, using both the water-year-type-matched unimpaired median and Baseline as reference points.

Response Curves

Response curves show the relationship between a recharge opportunity metric (e.g., annual diversion volume) and a functional flow metric's deviation from Baseline, for a given scenario. They provide a way to see, visually, whether more recharge opportunity is associated with more deviation from Baseline, less deviation, or no clear relationship at all. Given the number of functional flow metrics and recharge opportunity metrics involved, a response curve could in principle be built for any pairing of the two, referred to here as a combination (for example, wet-season baseflow magnitude paired with annual diversion volume is one combination; the same flow metric paired with total diversion days is a different combination). Not every combination shows a meaningful relationship, so two screening steps were used to identify which combinations to feature as response curves.

The first was a correlation screen. Correlation measures whether two variables tend to trend together, in this case, whether a metric's deviation from Baseline tends to increase or decrease consistently as recharge opportunity increases. A strong, consistent correlation means the relationship is dependable across the scenarios evaluated, worth featuring as a response curve; a weak or inconsistent correlation means there is no clear, reliable relationship for that combination, and it was not carried forward. For each combination of functional flow metric and recharge opportunity metric, Spearman correlation⁵ was calculated between the recharge

⁵ Spearman correlation (or Spearman's rank correlation) measures how consistently two variables increase or decrease together, based on their relative rank rather than their exact values, with a value ranging from -1 (perfectly consistent decrease) to 1 (perfectly consistent increase).

metric and percent deviation from Baseline, separately for each scenario, and combinations were carried forward if the correlation was reasonably strong and consistent in direction and magnitude across scenarios, rather than driven by one or two scenarios alone.

The second was a screen for interpretability and management relevance. A statistically strong correlation does not guarantee a usable result, thus the underlying response curves for the combinations that passed the correlation screen were inspected visually and evaluated for whether they represented a relationship meaningful to diversion-scenario decision-making, since a numeric correlation can be driven by non-monotonic fluctuation that doesn't hold up as an interpretable curve. For example, a relationship that increases, then decreases, then increases again, would not support a clear decision-making conclusion even if the correlation statistic looks strong. Together, these two steps were used to prioritize which response curves were examined in detail, rather than treating every metric and recharge opportunity combination as equally informative.

Screening was based on deviation from Baseline rather than deviation from unimpaired, for two reasons. First, deviation from Baseline is a true year-to-year comparison, while deviation from unimpaired relies on the water-year-type-matched median rather than a year-specific reference, introducing additional approximation error into the measure being correlated. Second, deviation from unimpaired conflates each scenario's own effect with any pre-existing deviation of Baseline from unimpaired conditions, which could produce a misleadingly strong or weak correlation unrelated to the recharge metric itself. Deviation from Baseline isolates each scenario's effect directly, independent of Baseline's own offset from natural conditions.

Tradeoffs

Response curves relating deviation to recharge opportunity were explored using both reference points described above: deviation from the water-year-type-matched unimpaired median, and deviation from Baseline. Deviation from Baseline was ultimately used to characterize tradeoffs between water supply and instream flow effects, for the same reasons described above: it is a true annual comparison rather than an approximation based on water year type, and it isolates each scenario's own effect independent of Baseline's offset from unimpaired conditions.

Multiple annual recharge opportunity metrics were explored as candidate x-axis variables for these response curves: annual diversion volume (TAF), number of diversion events, total diversion days, and average diversion event length (Table 2). Using the correlation screening process described above, the functional flow metric and recharge opportunity metric combinations showing the strongest and most consistent relationships across scenarios were identified for detailed presentation. Deviation from Baseline was evaluated as a function of the corresponding recharge opportunity metric for each scenario, using a LOESS-smoothed

response curve⁶. LOESS fits a smooth trend line to the data without assuming a specific shape in advance, which sometimes produces a curve that dips, rises, and dips again in a way the underlying data doesn't clearly support, an artifact of the smoothing method rather than a real pattern. Where this happened, an alternative fitting method that enforces a consistently increasing or decreasing trend was used instead, since a scenario's deviation from Baseline decreasing as diversion volume increases has no clear mechanism to explain it. This alternative was not used, however, where a curve's irregular shape reflects an actual, identifiable event rather than a smoothing artifact: for example, at Stony Creek, one scenario's response curve shows an apparent reversal driven entirely by a single unusually wet year (WY1995), a real feature of that specific year rather than noise from the smoothing method, so the original LOESS curve was retained there to avoid smoothing over a real result.

This approach characterizes the relationship between water available for recharge and the degree of change from Baseline conditions, providing a basis for evaluating tradeoffs between water supply benefit and instream flow cost across scenarios. By comparing the position and shape of each scenario's response curve, scenarios can be evaluated for how much deviation to instream flow is associated with a given level of water supply benefit, allowing direct comparison of the water supply benefit and instream flow cost associated with each diversion approach across the range of recharge opportunities represented in the historical period of record.

RESULTS

Water Availability

The complete suite of recharge metrics from Table 2 for the three case study locations are presented in Table 4. Annual (i.e., water year) diversion volumes, the average number of diversion days per water year, and the average duration of discrete diversion events per water year are presented as boxplots in Figure 12. The following subsections summarize results according to recharge metric type.

⁶ LOESS (locally estimated scatterplot smoothing) is a statistical method for drawing a smooth trend line through scattered data points, used here to show the general pattern of how deviation from Baseline changes as recharge opportunity increases, without assuming the relationship follows a specific mathematical shape in advance

Table 4. Recharge metrics for each scenario and study location. Highlighted blue metrics are associated with magnitude, pink with frequency, and green with duration.

Scott River						
Recharge Metric	90/20	80/50	FF-WS50	FF-WS75	FF-Pk2	Ecohydraulic
Average Annual Diversion (TAF)	17	22	37	32	7	42
Median Annual Diversion (TAF)	6	0	29	22	0	33
Max one year volume (TAF)	76	121	118	117	50	121
Average Annual Diversion - For WY with Diversion (TAF)	21	62	38	34	13	42
Number of Years with no Diversion	17	53	3	6	41	1
AEP Zero Diversion (Poisson Distribution)	0.2	0.5	0.0	0.1	0.4	0.0
Return Probability of Zero Diversion	5	2	28	14	3	84
Avg Annual No. of Diversion Days - For WY with Diversion (Days)	16	88	65	50	5	81
Avg Annual No. of Diversion Events - For WY with Diversion (n)	3	2	3	3	2	3
Avg Duration of Diversion Events - For WY with Diversion (days)	5	67	33	20	2	48

Stony Creek

Recharge Metric	90/20	80/50	FF-WS50	FF-WS75	FF-Pk2
Average Annual Diversion (TAF)	26	31	44	41	11
Median Annual Diversion (TAF)	11	2	33	30	0
Max one year volume (TAF)	152	140	169	166	114
Average Annual Diversion - For WY with Diversion (TAF)	39	63	55	60	28
Number of Years with no Diversion	12	18	7	11	22
AEP Zero Diversion (Poisson Distribution)	0.3	0.4	0.2	0.3	0.5
Return Probability of Zero Diversion	4	3	6	4	2
Avg Annual No. of Diversion Days - For WY with Diversion (Days)	19	44	41	36	7
Avg Annual No. of Diversion Events - For WY with Diversion (n)	3	3	3	3	2
Avg Duration of Diversion Events - For WY with Diversion (days)	6	19	16	12	4

Elder Creek					
Recharge Metric	90/20	80/50	FF-WS50	FF-WS75	FF-Pk2
Average Annual Diversion (TAF)	4	5	7	6	2
Median Annual Diversion (TAF)	3	0	5	4	1
Max one year volume (TAF)	23	28	27	26	12
Average Annual Diversion - For WY with Diversion (TAF)	5	10	8	7	3
Number of Years with no Diversion	13	43	6	7	21
AEP Zero Diversion (Poisson Distribution)	0.2	0.4	0.1	0.1	0.2
Return Probability of Zero Diversion	6	2	13	12	4
Avg Annual No. of Diversion Days - For WY with Diversion (Days)	13	52	41	30	5
Avg Annual No. of Diversion Events - For WY with Diversion (n)	5	4	4	5	3
Avg Duration of Diversion Events - For WY with Diversion (days)	2	16	10	6	2
% Change in Average Diversion from 90/20 (%)	-	7%	68%	48%	-46%
Average Diversion Rate - During Diversions (cfs)	197	100	94	116	343

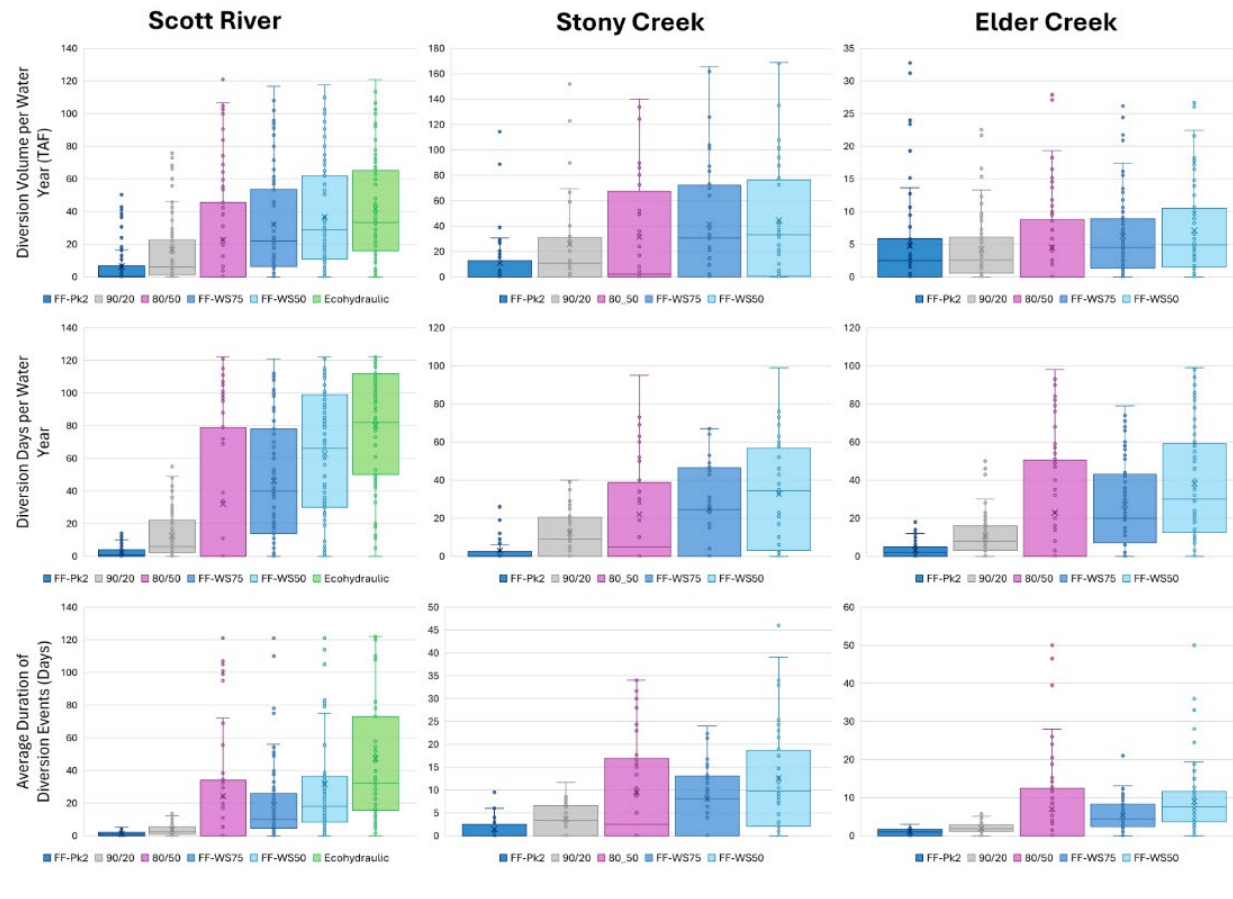


Figure 12. Boxplots of simulated volumes of water available for diversion per water year (top row), number of diversion days per water year (middle row), and the average duration of discrete diversion events per water year (bottom row) for each diversion scenario for the Scott River, Stony Creek, and Elder Creek case study locations. Note variable y-axes.

Magnitude

Magnitude metrics focused on the volumes of water available for recharge. A summary of results of the magnitude metrics both between approaches at the same case study location and across case study locations is as follows:

- Across metrics and case study location there was a relatively consistent gradient across approaches in terms of the volume of water available for recharge. The FF-Pk2 approach yielded the least water available for recharge across various metrics followed by 90/20, then 80/50, then FF-WS75, and lastly by FF-WS50, which tended to yield the most water available for recharge across various metrics. For the Scott River study location, the ecohydraulic scenario yields the most water available for recharge across various metrics (Table 4).
- A relevant caveat to the broad interpretation above is that when looking at both the “max one year volume” metric and the “average annual diversion for water years with diversion” metric the 80/50 values are either the largest or amongst the largest (Table 4). This is interpreted to mean that in years when diversions under the 80/50 approach occur, the approach tends to facilitate relatively large volumes of water to be available for recharge.
- Across case study locations there was a consistent gradient across approaches in terms of the distributions of volume of water available for recharge by water year that was consistent with other recharge metrics (Figure 12). However, for the Elder Creek location there was much greater overlap of these distributions across approaches than at other study locations. Elder Creek watershed hydrology differs from the other study locations and is characterized by flashy, rain driven high flow events, which may help explain this difference, but this inference requires further evaluation.
- The 80/50, FF-WS75, and FF-WS50 approaches had wider ranges of annual water available compared to FF-Pk2 and 90/20.
- Lastly, the 80/50 distributions of annual volume of water available for recharge tended to be highly positively (right)⁷ skewed because there are many years with no or low volumes of water available, but when diversions occur the approach tends to facilitate relatively large volumes of water to be available for recharge.

⁷ A positively skewed distribution is a data set where most values cluster on the left side (lower values), and a long tail extends toward the right side (higher values).

Frequency

Frequency metrics focused on how often water was available for recharge at both annual and daily time scales. A summary of results of the frequency metrics both between approaches at the same case study location and across case study locations is as follows:

- Across metrics and case study location there was a relatively consistent gradient across approaches in terms of the annual frequency of when water was available for recharge. The 80/50 approach yielded the lowest frequency of water available for recharge across various metrics followed by FF-Pk2, then 90/20, then FF-WS75, and lastly by FF-WS50. For the Scott River study location, the ecohydraulic scenario yields the highest frequency of water available for recharge across various metrics (Table 4).
- Study locations varied substantially in terms of the annual frequency of when water was available for recharge. For instance, return probabilities of zero diversion (i.e., no water available for recharge) were much greater at the Scott River location than Stony and Elder Creeks, meaning years with diversions occurred more frequently at the Scott River location. The difference in annual frequency of when water was available for recharge between approaches was also much smaller at Stony and Elder Creeks (Table 4). Stony Creek has the greatest instances of zero diversions across all approaches. Stony Creek is the only study locations with a large flow regulation feature (i.e., Black Butte Dam) and water control operations likely influence the availability of water for recharge, which requires further evaluation.
- Across case study locations there was a consistent gradient across approaches in terms of the distributions of days per water year water was available for recharge that was consistent with other recharge metrics (Figure 12).
- The 80/50, FF-WS75, and FF-WS50 approaches had wider ranges of days per water year water was available for recharge compared to FF-Pk2 and 90/20.
- Lastly, the 80/50 distributions of days per water year water was available for recharge tended to be highly positively (right) skewed, indicating that while there may be many years with no or low volumes of water available, when diversions occur the approach tends to facilitate high frequency of daily water availability.

Duration

Duration metrics focused on the length of time water was available for recharge. A summary of results of the duration metrics both between approaches at the same case study location and across case study locations is as follows:

- Across metrics and case study locations there was a relatively consistent gradient across approaches in terms of the average number of days per water year water was available for recharge, the average number of discrete diversion events per year water, and the average duration of discrete diversion events. The FF-Pk2 approach yielded the shortest durations of water available for recharge across various metrics followed by 90/20, then FF-WS75, then FF-WS50, and lastly by 80/50 (Table 4).
- Study locations varied in terms of the duration of when water was available for recharge. For instance, all duration metrics were greater at the Scott River location than Stony and Elder Creeks. The Scott River is relatively unregulated and late season snowmelt may enable longer period of water availability relative to the more rain-driven hydrology of Stony and Elder Creeks.
- Across case study locations there was a consistent gradient across approaches in terms of the distributions of average annual durations of discrete diversion events that was consistent with other recharge metrics (Figure 12).
- The 80/50, FF-WS75, and FF-WS50 approaches had wider ranges of average annual durations of discrete diversion events compared to FF-Pk2 and 90/20.
- Lastly, the 80/50 distributions of average annual durations of discrete diversion events tended to be highly positively (right) skewed, indicating that while there may be many years with no or low volumes of water available, when diversions occur the approach tends to facilitate long periods of daily water availability.

Hydrograph Comparisons

The preceding results characterize how much water each scenario makes available and how often, but not when diversion occurs relative to the shape of the hydrograph itself. Whether a scenario diverts during a peak event or only in the periods between peaks has direct implications for which functional flow components it influences and is examined here using representative wet and dry year hydrographs at each site.

Typical Wet and Dry Years

Hydrographs for a representative wet year and dry year at each site are provided in the Appendix (Figure A 1-Figure A 5). Scott River's wet-year example (WY1983) is shown here (Figure 13) as representative of the patterns observed across sites.

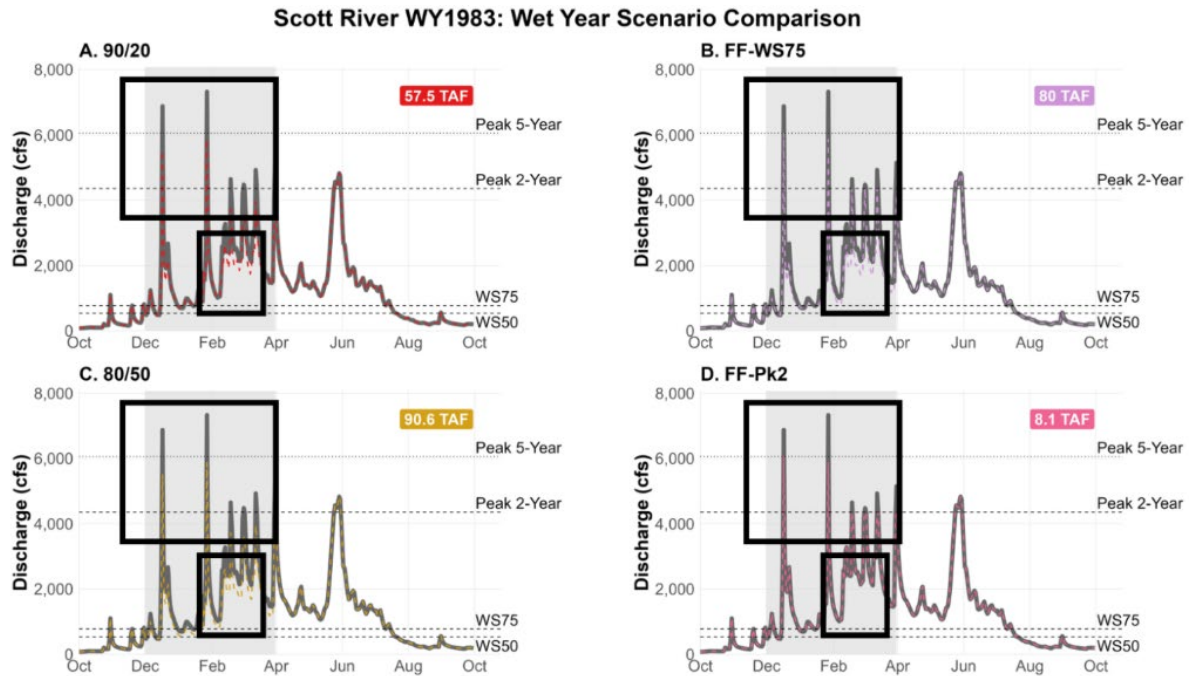


Figure 13. Scott River hydrograph comparison by diversion scenario for a representative wet year (WY 1984). Grey line is observed flow with no diversion; colored dashed lines show remaining flow under each scenario. The larger black box highlights the water year's larger peak events, where FF-WS75 and FF-Pk2 do not affect these events, holding flow at or above the peak threshold, while 90/20 and 80/50 divert flow below threshold during the same events. The smaller black box highlights the inter-storm period, where only FF-Pk2 remains conservative; FF-WS75 diverts at volumes comparable to 80/50 in this window.

Beyond total annual diversion volume, whether and when a scenario influences flow above key peak thresholds differs by scenario. The larger black box in Figure 13 highlights the peaks of the two largest events along with several subsequent peaks. FF-WS75 and FF-Pk2 explicitly do not affect the first 2-year and 5-year flood events when they occur, holding flow at or above the peak threshold rather than diverting below it. 90/20 and 80/50, by contrast, divert flow down below these same peak thresholds during these events, as neither are designed to preserve a flood event. The smaller black box highlights the inter-storm period that follows. Here, only FF-Pk2 remains conservative, tracking closely with observed flow throughout. FF-WS75 does not: it diverts on nearly every day in this window, at volumes comparable to 80/50. Thus, FF-Pk2 is the only scenario evaluated that does not affect both the peak events and the periods between them; FF-WS75 does not affect the peak events specifically but behaves like 80/50 otherwise.

Across all three sites, FF-WS50 and FF-WS75 divert substantial volumes in wet years, while FF-Pk2 consistently diverts the least, by design. 80/50 also diverts substantially in wet years at Scott and Elder, where it is the largest or among the largest volumes diverted; at Stony Creek,

however, 80/50's wet-year diversion volume is comparable to 90/20 and substantially smaller than either FF-threshold scenario.

In dry years, 80/50's diversion volume drops sharply, to zero at Scott and Elder's respective dry-year examples, while the FF-threshold scenarios continue diverting modest volumes even under dry conditions. This suggests 80/50's diversion is more sensitive to water year type than the FF scenarios, which remain active, at reduced volumes, across a wider range of hydrologic conditions. Stony Creek is again an exception: 80/50 diverts 36.2 TAF in its driest comparison year a more prominent share of diversion relative to the other scenarios than in its own wet-year example, where 80/50 ranked near the bottom of the five scenarios evaluated.

Functional Flows Alteration Assessment

Streamflow Alteration Assessment

Across Elder Creek and Scott River, all wet-season and peak flow metrics evaluated were classified as likely unaltered under every scenario, including 90/20, 80/50, and all FF scenarios, meaning that the majority of flow metric values fell within the natural range. Peak flow duration and frequency (2-year, 5-year, and 10-year) were classified as likely unaltered under all scenarios at all three sites. Peak flow magnitude was not evaluated in this comparison, as it is calculated as a single value across the period of record rather than an annual distribution. At Elder Creek, wet-season timing was classified as indeterminate (i.e., the available data did not support a confident classification as either altered or unaltered) under 80/50, FF-BF50, and FF-BF75, though the median remained within the natural range in all cases.

At Stony Creek, wet-season baseflow magnitude (10th percentile) was classified as likely altered in the low direction (i.e., below the natural range of variability, rather than above it) under all scenarios, including Baseline (i.e., pre-diversion, observed conditions), and the wet-season median flow was classified as indeterminate. Stony Creek is a regulated system downstream of a dam, and its observed flow record likely reflects existing flow modification compared to unimpaired conditions; the alteration (flow depletion) is consistent with dam operations attenuating wet-season flows relative to the expected unimpaired flows. Because the CEFF classification compares all scenarios against the unimpaired flow metric range, this result likely reflects pre-existing alteration from dam operations rather than an effect of the alternative diversion criteria evaluated here. A more relevant question at this site may be whether the diversion scenarios cause additional alteration beyond what already exists under current conditions (Baseline scenario). This is explored further in the sections below.

Peak 2-Year Duration and Frequency Across Case Study Sites

Across the three case study sites, 90/20 and 80/50 consistently compressed peak 2-year duration and/or frequency relative to Baseline and the natural range of variability, though the specific pattern of compression differed by site and scenario (Figure 14). The complete set of range compression results across all screened wet-season and peak flow metrics, including those not discussed in detail here, is provided in the Appendix (Figure A 6 - Figure A 8).

At Scott River, 90/20, 80/50, and Ecohydraulic scenarios compressed peak 2-year duration to 44-47% of the natural interquartile range (IQR), while Baseline and all FF scenarios (FF-WS50, FF-WS75, FF-Pk2) remained at 58% of natural IQR.

At Elder Creek, 90/20 and 80/50 showed zero-inflation and shorter durations for peak 2-year duration, with peak 2-year frequency similarly depressed under both scenarios relative to Baseline (Figure 14). FF scenarios tracked Baseline more closely across both metrics. Note that this pattern is evident in the shape of the annual value distributions (boxplots) rather than in interquartile range alone; measures of range compression based on IQR width do not necessarily capture a shift in values toward zero.

At Stony Creek, 90/20 and 80/50 compressed peak 2-year duration to 17% of natural IQR, while Baseline and all FF scenarios (FF-BF50, FF-BF75, FF-Pk2) remained at 50% of natural IQR. Peak 2-year frequency, however, appeared unchanged under any scenario, including 90/20 and 80/50. This distinguishes Stony Creek from Elder Creek, where frequency was depressed under the same two scenarios, and suggests that at Stony Creek, the lower-threshold scenarios shorten individual peak events without reducing how often peak events occur.

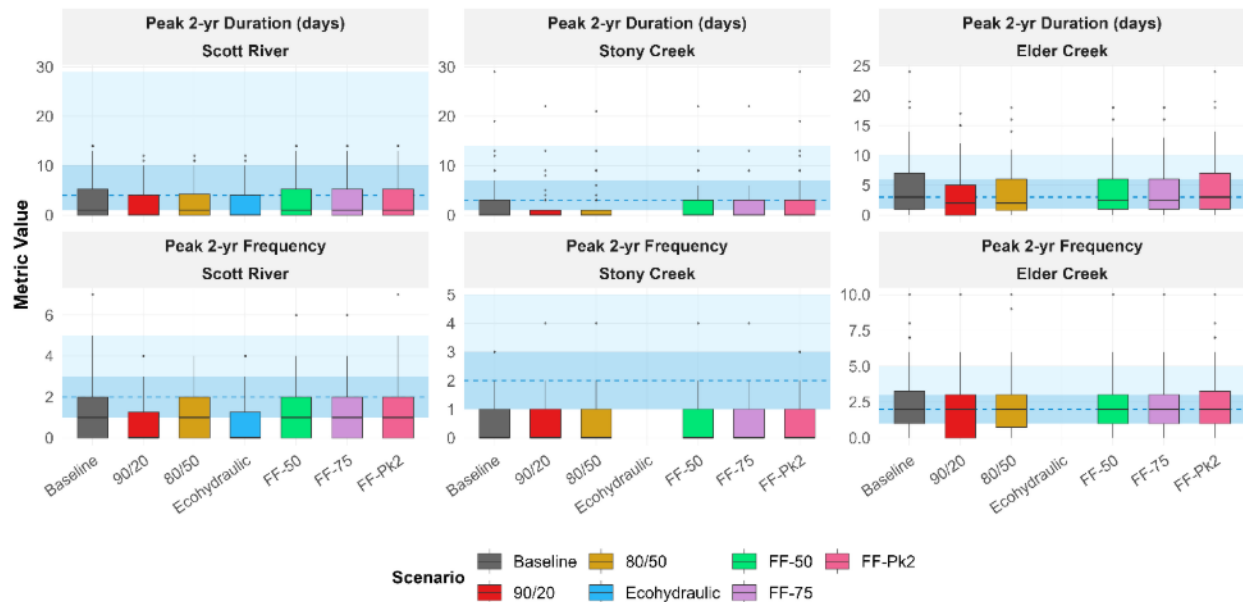


Figure 14. Boxplots of annual peak 2-year flood duration (number of days 2-year magnitude is met) and frequency (number of 2-year events) across the three sites. Blue bands show the predicted natural p10-p90 (light) and p25-p76 (dark) for each metric and site. Blue dashed line is the natural p50 for each metric and site.

Wet-Season Baseflow Across Case Study Sites

Wet-season baseflow metrics, magnitude (10th and 50th percentile), duration, and timing, were compared across scenarios at all three sites. Wet-season baseflow median (Wet_BFL_Mag_50) showed the clearest scenario-driven effects at Elder Creek and Scott River and is presented as the key metric in the boxplot panels for these two sites (Figure 15; Figure 16); the other wet-season baseflow metrics are discussed in text below.

At Elder Creek, FF-BF50 compressed wet-season median flow to 84% of natural IQR, which was visibly narrower than every other scenario, including Baseline (108%), 90/20 (106%), 80/50 (94%), FF-BF75 (107%), and FF-Pk2 (107%) (see Figure 15). Because FF-BF50's diversion threshold is defined at the wet-season baseflow median itself, this compression is consistent with the scenario's own rule to actively manage flow toward that value. Wet-season baseflow duration and the 10th percentile magnitude showed no comparable scenario-specific effect at Elder Creek; duration was nearly identical across all scenarios, and while the 10th percentile magnitude varied somewhat across scenarios, Baseline itself was elevated relative to the natural reference, consistent with a reference-curve mismatch at this metric rather than a diversion effect.

At Scott River, two distinct effects were observed for wet-season median flow (Figure 16). FF-WS50 and FF-WS75 compressed variability the most of any scenario (128% of natural IQR), and were narrower than Baseline, 90/20, and FF-Pk2 (all 169%), 80/50 (142%), and Ecohydraulic (148%). Separately, the Ecohydraulic scenario shifted the median of wet-season baseflow downward relative to Baseline without showing the same degree of variability compression as FF-WS50/75, consistent with the scenario's fixed 362 cfs threshold pulling the typical value down when flow falls below that threshold, rather than narrowing the spread of outcomes the way a percentile-based rule does. Ecohydraulic also showed the most compression of any scenario for the 10th percentile magnitude (140% of natural IQR, compared to 185-205% for all other scenarios), a second indication that it behaves differently from the percentile-based rules, particularly at the low end of the wet-season flow distribution. Wet-season baseflow duration compressed uniformly across all diversion scenarios at Scott River (79-82% of natural IQR, versus 108% at Baseline); this compression is attributable to the spring recession timing detection artifact described previously (see Flow Metric Calculation Artifacts and Corrections) rather than an independent effect of any specific scenario.

At Stony Creek, wet-season baseflow median, 10th percentile magnitude, duration, and timing were essentially indistinguishable across all six scenarios, with no scenario showing meaningful compression relative to Baseline or natural variability.

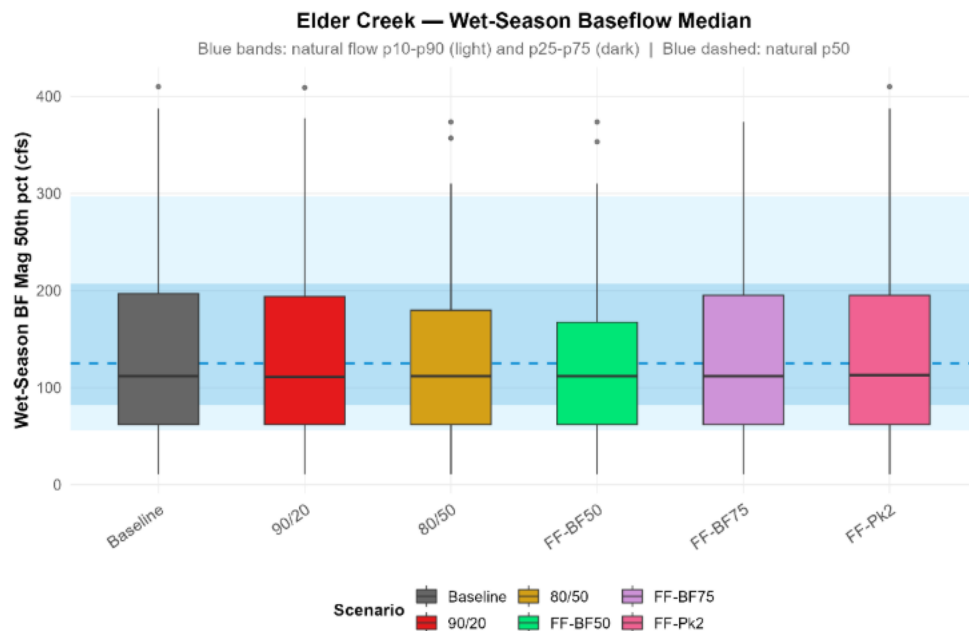


Figure 15. Boxplots of annual wet-season median flow for each scenario at Elder Creek. Blue bands show the predicted natural p10-p90 (light) and p25-p76 (dark). Blue dashed line is the natural p50 for this metric.

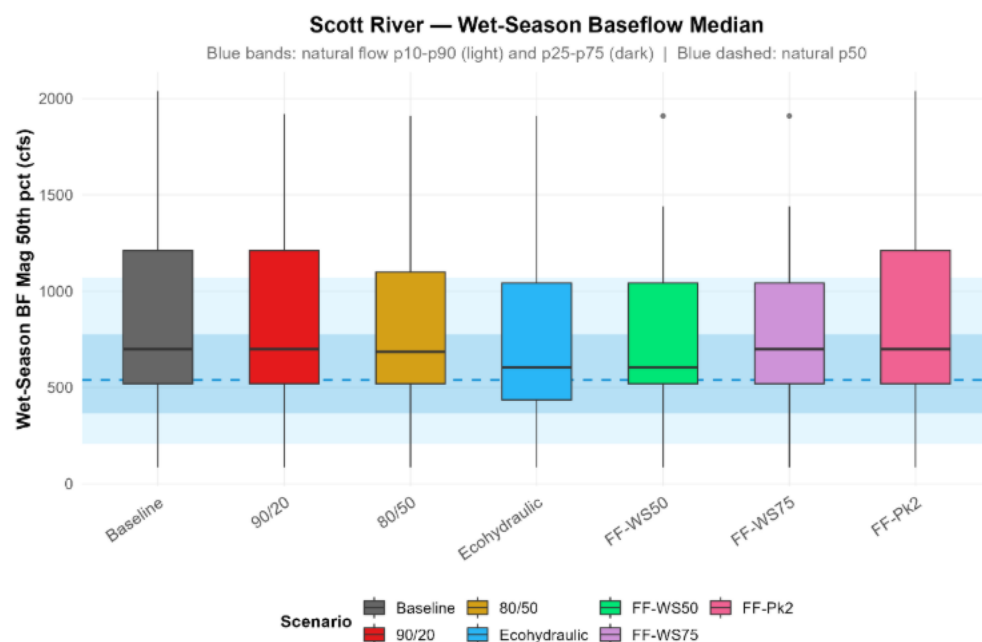


Figure 16. Boxplots of annual wet-season median flow for each scenario at Scott River. Blue bands show the predicted natural p10-p90 (light) and p25-p76 (dark). Blue dashed line is the natural p50 for this metric.

Deviation from Unimpaired and Baseline

As described in the Approach section, each pairing of a functional flow metric and a recharge opportunity metric (referred to here as a combination) was screened for a strong, consistent correlation, a relationship where the flow metric's deviation from Baseline reliably increases or decreases as the recharge metric increases, before being considered for a response curve. Deviation from Baseline was used for the correlation screen rather than deviation from unimpaired, for the reasons described above (a true year-to-year comparison, isolating each scenario's own effect from Baseline's pre-existing offset from unimpaired conditions).

Across the 28 functional flow metric and recharge opportunity metric combinations screened at Scott River, 6 passed the correlation screen (Figure 17), meaning the large majority of possible metric pairings did not show a reliable, consistent relationship and were not considered further. This low pass rate is itself informative as it indicates that most functional flow metrics are not meaningfully related to recharge opportunity in a way that would support a general tradeoff conclusion, and that the specific choice of which metric pairing to examine matters and a conclusion drawn from one combination does not necessarily extend to others. The screen for interpretability and management relevance was then applied to these 6: Wet-Season Baseflow Magnitude (10th and 50th percentile) paired with Annual Diversion Volume and Total Diversion Days were carried forward, while the remaining combinations showed non-monotonic

fluctuation on inspection of the underlying curve and are not featured. Wet-Season Baseflow Magnitude (10th percentile) paired with Annual Diversion Volume, and Wet-Season Baseflow Magnitude (50th percentile) paired with Total Diversion Days, are the two combinations carried into the selected response curves below.

The same two-step screening was applied at Elder Creek and Stony Creek, provided in the Appendix (Figure A 9, Figure A 10). At Elder Creek, 4 of 28 combinations passed the correlation screen: Wet-Season Baseflow Magnitude (50th percentile) paired with Annual Diversion Volume and Total Diversion Days, and Peak 2-Year Duration paired with Annual Diversion Volume and Total Diversion Days. Wet-Season Baseflow Magnitude (50th percentile) and Peak 2-Year Duration, both paired with Annual Diversion Volume, held up on visual inspection; the corresponding Total Diversion Days pairings did not. Wet-Season Baseflow Magnitude (50th percentile) is featured in the main Tradeoffs curves above; Peak 2-Year Duration is provided in the Appendix.

At Stony Creek, 3 of 20 combinations passed the correlation screen; only Wet-Season Baseflow Magnitude (50th percentile) paired with Annual Diversion Volume was carried forward, as the remaining two combinations did not hold up on visual inspection.

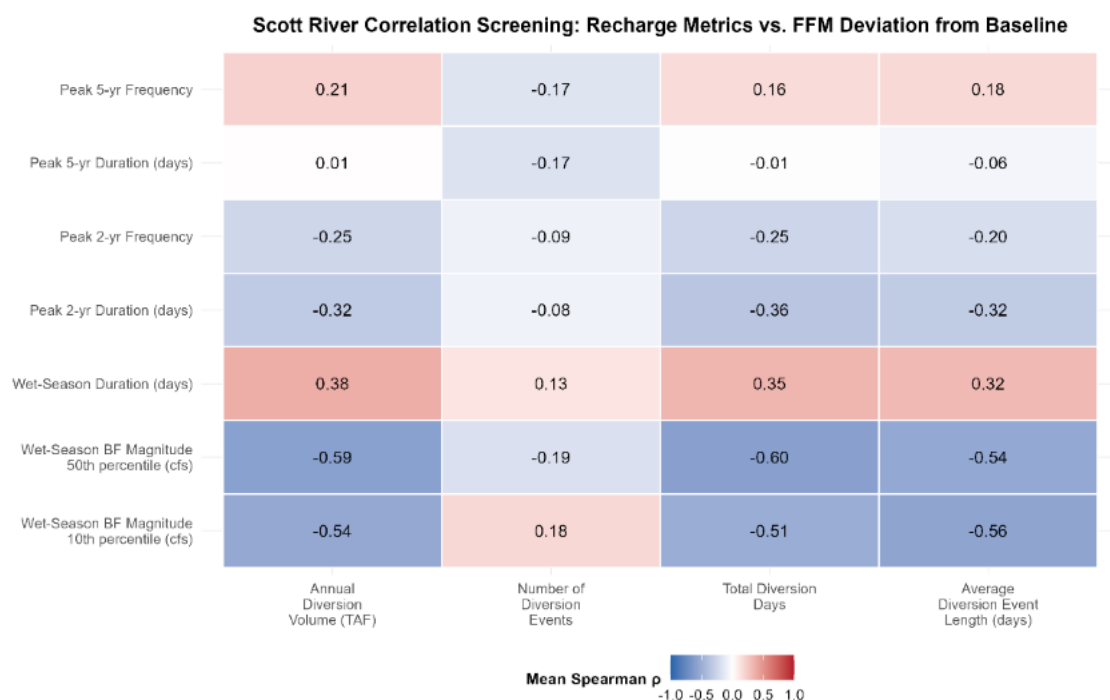


Figure 17. Scott River correlation screening results. Each cell shows the mean Spearman ρ (a measure of how consistently two variables move together, ranging from -1 to 1) between a recharge opportunity metric (columns) and percent deviation from Baseline in a functional flow metric (rows), averaged across the five diversion scenarios (90/20, 80/50, FF-BF50, FF-BF75, FF-Pk2).

Tradeoffs

Response curves compare how much each scenario deviates from Baseline relative to other scenarios, not whether a given amount of deviation is ecologically significant on its own. A scenario showing smaller deviation than another is not necessarily “safe,” and a scenario showing larger deviation is not necessarily harmful; deviation is a relative measure of how much a scenario shifts a flow metric, not a direct measure of ecological consequence (see Study Limitations). This is in part because Baseline itself may already be altered from unimpaired conditions, as is the case at Stony Creek (see Streamflow Alteration Assessment, above); a scenario showing little deviation from an already-altered Baseline says less about ecological protectiveness than deviation from unimpaired conditions would, were daily unimpaired flow data available to support that comparison directly. Whether a scenario’s functional flow metrics fall within the natural range of variability at all is addressed separately by the streamflow alteration classification (see Streamflow Alteration Assessment, above). The response curves in this section are intended to compare scenarios against one another for a given site and metric, not to independently establish that any given approach is protective.

Response curves relating functional flow metric deviation from Baseline to recharge opportunity were developed for all three case study sites, following the screening process described above. Scott River is presented here as the representative example, as its wider range of diversion volumes shows the clearest separation between scenarios.

Two curves are shown for Scott River: wet-season baseflow magnitude (10th percentile) versus Annual Diversion Volume (TAF; Figure 18), and wet-season baseflow magnitude (50th percentile) versus Total Diversion Days (Figure 19).

Across both curves, FF-Pk2 and the 90/20 scenario show the smallest deviation from Baseline in wet-season baseflow magnitude, but this comes at the cost of capturing the least recharge opportunity: their response curves do not extend past roughly the lower end of the diversion-volume and diversion-day ranges shown, meaning the smallest deviation is achieved only where diversion volume and diversion days are also smallest. This is a tradeoff rather than a demonstrated advantage: neither scenario is shown to hold its position at higher levels of recharge opportunity, since neither reaches that range in the historical record.

Beyond the relative ranking among scenarios, the shape of each response curve carries its own management-relevant information. Some curves show a relatively gradual, continuous increase in deviation as diversion volume increases, while others show a sharp inflection point, a diversion volume beyond which deviation increases substantially. In Figure 18, 80/50’s deviation from Baseline remains near zero until diversion volume exceeds approximately 50 TAF, after which it drops sharply. Ecohydraulic shows a comparable but earlier inflection, with

deviation increasing steadily from a much lower diversion volume, well before 25 TAF. Where a scenario's response curve shows this kind of inflection, it identifies a diversion volume threshold below which alteration remains limited. This has a direct practical application: a project with a known maximum diversion capacity, whether due to pump capacity, permit terms, or other infrastructure constraints, can use this information to determine whether its expected diversion volume falls below or above a given scenario's inflection point, informing both scenario selection and permit term negotiation.

Among the scenarios that span the full range of recharge opportunity, which scenario shows the smallest deviation from Baseline in wet-season baseflow depends on which recharge metric is used. Measured against Total Diversion Days, 80/50 shows the smallest deviation from Baseline; FF-WS75 shows the greatest deviation of the four scenarios, with Ecohydraulic and FF-WS50 falling in between. This is a reversal from the ranking measured against Annual Diversion Volume, where FF-WS75 showed the smallest deviation and Ecohydraulic and FF-WS50 showed the greatest. This indicates that the relative standing of these scenarios in terms of change in wet-season baseflow is sensitive to which measure of recharge opportunity is used to evaluate them, rather than fixed across metrics; not only does the best-performing scenario change between the two metrics, so does the worst-performing one.

Elder Creek and Stony Creek response curves in Appendix (Figure A 11-Figure A 13) show a broadly similar pattern to Scott River, with smaller overall deviation from Baseline at both sites: FF-Pk2 and 90/20 show the smallest deviation from Baseline within their available diversion range, and 80/50 and the FF-BF50/FF-BF75 scenarios span a wider range of deviation as diversion volume increases, with FF-BF75 consistently showing smaller deviation than FF-BF50. At Stony Creek, an apparent reversal in which 90/20 shows greater deviation from Baseline than 80/50 at the highest diversion volumes is driven by a single water year (WY1995) and is not supported by a sufficient sample of years to be interpreted as a general pattern.

Peak 2-year duration at Elder Creek showed a similar relationship to Annual Diversion Volume, passing both the correlation screen and visual inspection (Appendix, Figure A 14). In the highest-diversion-volume year in the record (WY1958, Baseline duration 24 days), 90/20 and 80/50 reduced peak 2-year duration by 9 and 10 days respectively, while FF-BF50 and FF-BF75 reduced it by 6 days each, producing identical outcomes for this metric in every year evaluated despite differing in overall annual diversion volume. FF-Pk2 showed no reduction in peak 2-year duration in any year. This is consistent with the pattern already noted for peak 2-year duration and frequency (Figure 14): the FF scenarios track Baseline more closely than either 90/20 or 80/50, here shown to hold not just as a fixed-year comparison but across the full range of diversion volumes evaluated.

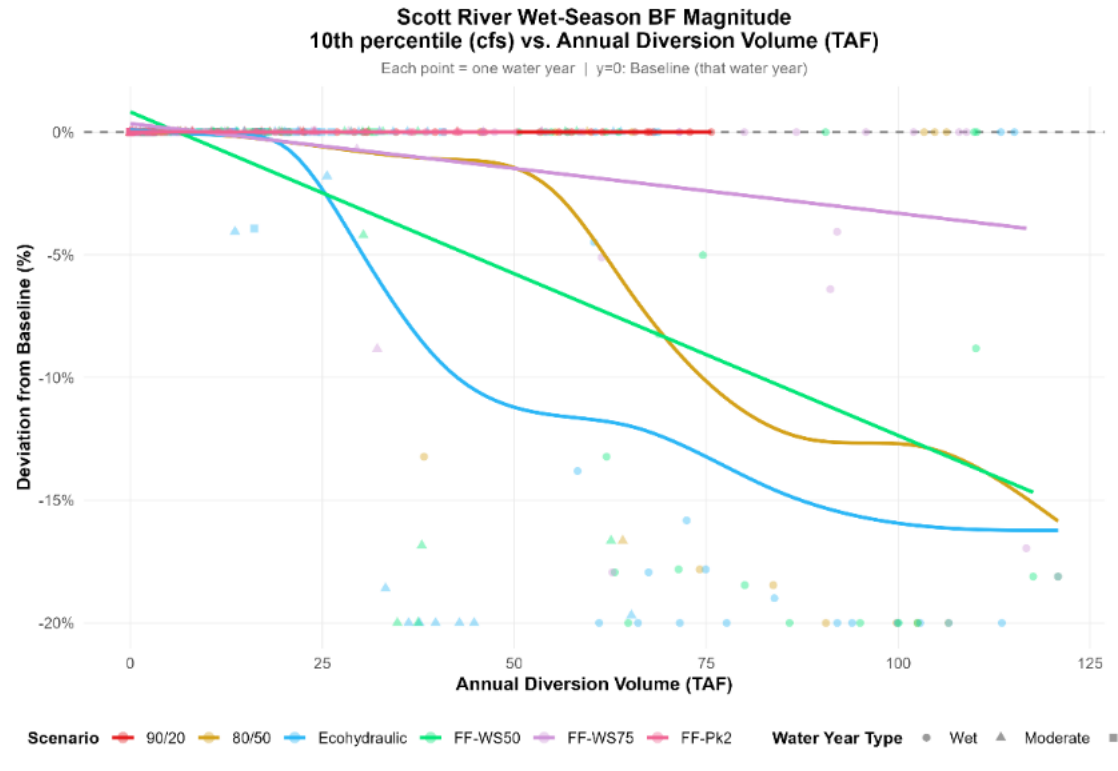


Figure 18. Scott River wet-season baseflow magnitude (10th percentile), percent deviation from Baseline, as a function of Annual Diversion Volume (TAF) for each scenario. Each point is one water year; lines show a smoothed, consistently decreasing trend by scenario.

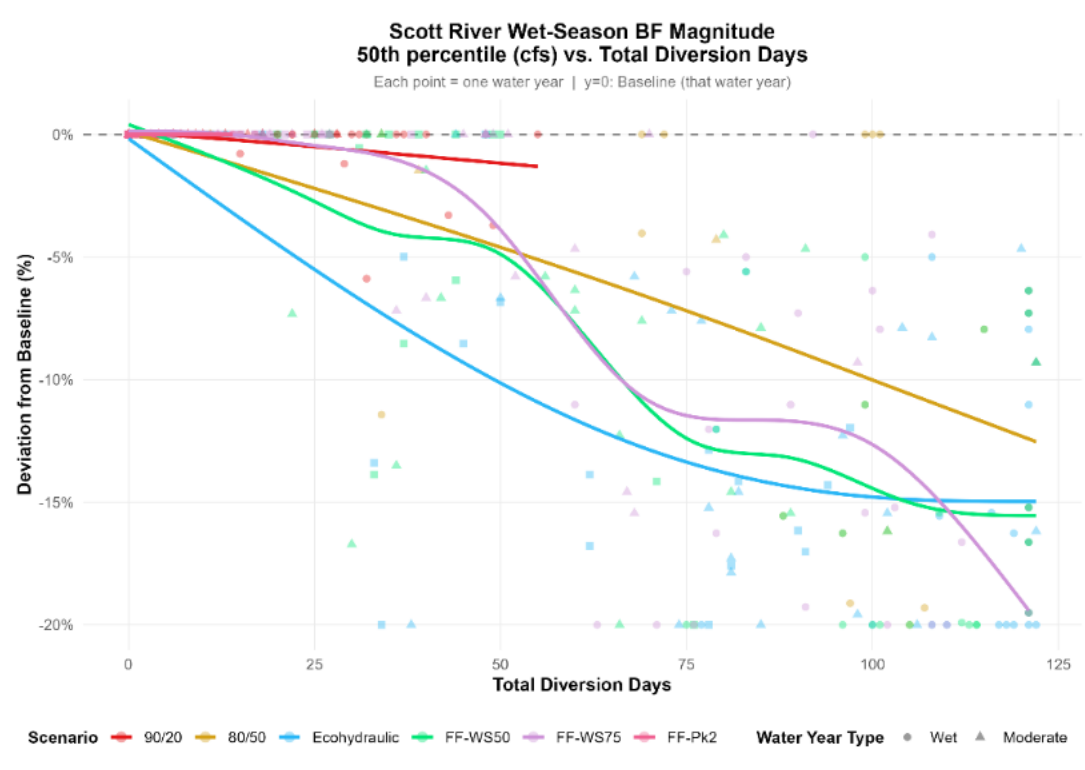


Figure 19. Scott River wet-season baseflow magnitude (50th percentile), percent deviation from Baseline, as a function of Total Diversion Days for each scenario. Each point is one water year; lines show a smoothed, consistently decreasing trend by scenario.

DISCUSSION

Water Availability

Across all three case study sites, there were consistent gradients between approaches in terms of magnitude, frequency, and duration recharge metrics. This finding supports that despite the varying hydrologic conditions at these sites each approach yields reliable tradeoffs in terms of water availability. The general trends for each approach are summarized as follows:

- **90/20:** Provides short duration diversion opportunities with intermediate frequency that yield relatively low magnitudes of water available for recharge. Daily varying diversion thresholds (e.g., 90th percentiles) introduce operational complexity and uncertainty.
- **Functional Flow-Informed:**
 - **Wet-season median thresholds:** Provides long duration diversion opportunities with high frequency that yield relatively high magnitudes of water available for

recharge. Constant diversion thresholds reduce operational complexity and uncertainty, while prescriptions to bypass high flow events (e.g., first 2-yr, 5-yr, and 10-yr flood each water year) introduce some operational complexity.

- **2-Year Peak:** Provides short duration diversion opportunities with low frequency that yield relatively low magnitudes of water available for recharge.
- **Ecohydraulic:** Provides long duration diversion opportunities with high frequency that yield high magnitudes of water available for recharge. Constant diversion thresholds reduce operational complexity and uncertainty. Findings limited to application at only one case study location.
- **80/50:** Provides long duration diversion opportunities with relatively low frequency that yield intermediate magnitudes of water available for recharge. During wet years, magnitudes of water available for recharge can be amongst the highest. The ability to divert varies daily, based on cumulative flow conditions, which introduce some operational complexity and uncertainty but less than the 90/20 approach given the cumulative nature of the requirements (e.g., while the cumulative flow varies daily, once cumulative flows are above the 80th percentile threshold there is more certainty regarding ongoing water availability).

Several site-specific properties emerged with regard to water availability. Both the number of days when water was available for recharge and the duration of discrete recharge opportunities were higher at Scott River relative to Stony and Elder Creek, which were relatively similar to each other. Scott River wet-season hydrology is characterized by low-volume snowmelt and rain, and the study location is substantially further north of Stony and Elder Creek. Snowmelt and seasonably differing precipitation patterns likely play a role in observed differences in recharge metrics. Stony Creek exhibited the highest percentage of total annual flow being available for recharge and had the highest percentage of years with no water availability across all scenarios except 80/50. Stony Creek was also the only study location with significant flow regulation infrastructure. As noted in the Water Availability results section, at Elder Creek there was much greater overlap in the distributions of annual volumes of water available for recharge (Figure 12) across approaches than at other study location. Elder Creek watershed hydrology differs from the other study locations and is characterized by flashy, rain driven high flow events, which may help explain this difference. Ultimately, each study locations' somewhat unique hydrologic setting appears to translate into site specific differences in different aspects of water availability. Further evaluation could help elucidate these interactions and similar analysis at additional study locations with similar hydrologic regimes could help to confirm if these are generalized or unique trends.

Functional Flows Alteration Assessment and Tradeoffs

Across all three case study sites, no diversion scenario evaluated shifted a functional flow metric into a different streamflow alteration category (likely altered, likely unaltered, or indeterminate) than Baseline already occupied for that metric. At Elder Creek and Scott River, this meant that all wet-season and peak flow metrics remained classified as likely unaltered under every scenario. At Stony Creek, wet-season baseflow magnitude (10th percentile) was classified as likely altered under Baseline itself, consistent with pre-existing flow modification from upstream dam operations rather than an effect of any diversion scenario evaluated here; every alternative scenario retained that same likely-altered classification, neither improving nor worsening it relative to Baseline. This is the central finding of this analysis: across all three sites and all metrics evaluated, the streamflow alteration classification did not discriminate among diversion scenarios, every scenario at a given site fell into the same classification, whether that initial baseline classification was likely unaltered (Elder Creek, Scott River) or likely altered due to a pre-existing condition (Stony Creek, wet-season baseflow magnitude).

This result should be read as a boundary condition, not as evidence that every scenario tested is ecologically protective. A “likely unaltered” classification means a metric’s typical value fell within the expected natural range, not that the scenario has been demonstrated to be ecologically protective; the streamflow alteration classification does not evaluate biological or geomorphic outcomes directly. At Stony Creek in particular, this boundary condition reflects a pre-existing condition that the diversion scenarios neither caused nor resolved, not evidence that any approach is protective under all conditions.

This finding is also relevant to the ecological functions described in the Introduction and Background: at Elder Creek and Scott River, the wet-season and peak-flow metrics and associated functions they are intended to represent, including seasonally elevated baseflows compared to the dry-season, habitat connectivity, and peak-driven geomorphic and disturbance processes, are not indicated as altered under any diversion scenario evaluated, at least in terms of falling within the natural range of variability. At Stony Creek, the likely-altered classification for wet-season baseflow magnitude suggests these functions may already be constrained under Baseline conditions, independent of the diversion scenarios tested. Range compression screening found the peak 2-year duration and frequency were consistently compressed under 90/20 and 80/50 relative to Baseline and the natural range of variability at all three sites, while the FF scenarios tracked Baseline more closely on both metrics; at Elder Creek, this is corroborated by the response curve for peak 2-year duration, which shows FF-WS50 and FF-WS75 producing smaller, and identical, deviations from Baseline relative to 90/20 and 80/50 across the full range of diversion volumes evaluated. Wet-season baseflow showed a related

but more mechanistically varied pattern. At Elder Creek, FF-WS50 compressed the interquartile range of wet-season median flow to 84 percent of the natural range, narrower than every other scenario including Baseline, consistent with the scenario's own threshold being defined at that median value. At Scott River, FF-WS50 and FF-WS75 compressed variability the most of any scenario, while the Ecohydraulic scenario instead shifted the median downward without a comparable reduction in variability, a difference attributable to this scenario's fixed-threshold design rather than a percentile-based rule. As discussed above, reduced variability of this kind is a potential ecological concern independent of whether the median value itself shifts, though this analysis did not evaluate the ecological significance of the specific compression observed here. At Stony Creek, wet-season baseflow metrics were indistinguishable across scenarios, consistent with the site's flashier hydrology limiting how much any scenario can divert before self-limiting, independent of scenario design.

Taken together, these results support a toolbox approach rather than a single-recommendation approach to scenario selection: FF-WS75 and 80/50, for example, each represent different tradeoffs, and which is better suited to a given site depends on management priorities and site conditions rather than one being universally preferable. FF-WS75 explicitly does not affect the 2-year and 5-year flood events, holding flow at or above the peak threshold rather than diverting below it, a design feature 80/50 lacks (see Hydrograph Comparisons, above); this is corroborated by the range compression results, where FF-WS75 tracked Baseline more closely than 80/50 on peak 2-year duration and frequency across the full period of record at all three sites. Which scenario shows smaller deviation from Baseline in wet-season baseflow, however, depends on which recharge metric is used to evaluate it: FF-WS75 showed the smallest deviation when measured against Annual Diversion Volume, but the greatest deviation of the four scenarios when measured against Total Diversion Days, while 80/50 showed the reverse pattern (see Tradeoffs, above). 80/50, in turn, sustains diversion more continuously across a wider range of conditions, which may better suit contexts prioritizing consistent, predictable diversion operations over explicit peak-event protection. Beyond this comparison, the practical tradeoff between any two scenarios depends on which functional flow metric and which recharge opportunity metric are being weighed against each other, and no single metric combination is likely to represent the tradeoff space at every site.

Wet-season baseflow magnitude, the metric featured in this memo's response curves, was the metric most consistently associated with recharge opportunity across all three sites, but other metrics, such as peak 2-year duration at Elder Creek, showed comparable or clearer relationships and may be more decision-relevant depending on the ecological or management question being asked. Similarly, whether Annual Diversion Volume or Total Diversion Days is the more informative recharge metric was itself shown to depend on the site and scenario in question (e.g., the FF-WS75/80-50 ranking reversal between these two metrics at Scott River).

Selecting a single metric combination to represent scenario performance is therefore a simplification, and the choice of which combination to prioritize should be revisited for each new site or application rather than assumed to transfer from the three sites evaluated here.

This also points to a broader limitation of the current analysis: three case study sites, while sufficient to demonstrate that scenario performance is site-dependent, are not sufficient to generalize which site characteristics predict that dependence. Additional sites spanning a wider range of hydrologic flashiness, Baseline alteration, and diversion infrastructure would help clarify which of the patterns identified here (e.g., Stony Creek’s self-limiting behavior under flashy hydrology) are broadly predictable from watershed characteristics versus specific to the sites evaluated. This is discussed further in Future Work.

Practical Applications for Alternative Diversion Criteria

The findings of this case study demonstrate that different diversion approaches result in varying magnitude, frequency, timing, and duration of water available for recharge. It is important for practitioners implementing recharge projects to select diversion approaches and criteria based on their project objectives, specific site conditions (e.g., infrastructure), capacity for project tracking and operations, environmental needs, and protection of existing water rights holders. There is no single diversion approach that is “one-size-fits-all.”

For example, meeting project objectives may require different strategies for desired water availability in magnitude, frequency, timing, and duration. Projects with an objective to have winter recharge contribute to in-channel summer and late fall baseflows may prioritize diversion approaches and criteria that allow diversions in every or most years. Whereas a project that is focused on the recovery of a significantly overdrafted basin may prefer diversion approaches and criteria that maximize magnitude and duration of diversions.

Additionally, practitioners may have limitations related to diversion infrastructure. Many projects rely on renting temporary pumps to divert water for recharge. Renting pumps for the entire winter diversion season (e.g., December through March) may be cost prohibitive for landowners. For projects using rented temporary pumps, it may be preferred to have more consecutive days of diversion in a shorter window. Alternatively, projects with permanent infrastructure, especially with remote operation, would not have issues operating the projects for short windows at a time (e.g., a half day) and non-consecutive days.

The following are practical considerations for recharge project practitioners considering the diversion approaches evaluated in this case study, summarized in Table 5 and described in more detail below.

Table 5. Practical considerations for diversion approach selection.

Approach	Best Suited When	Key Limitation
90/20	Fast permitting; flexible, automated infrastructure	Frequent, short, scattered diversion windows; daily flow monitoring
80/50	Minimizing rented-pump time; basin recovery volumes	High chance of no diversion in dry years; tracking daily cumulative flow
FF-WS50/WS75	Balancing recharge with flow protection; simple thresholds	Tracking flow day-to-day to protect peak events
FF-Pk2	Active floodplain inundation management	Lower volume/frequency; tracking flow day-to-day to protect peak events
Ecohydraulic ¹	Protecting specific species' life history needs	Requires a dedicated site- and species-specific study to establish the threshold, a higher upfront cost and longer timeline than hydrology-based approaches; may focus on preserving one aspect (e.g., baseflow) rather than the full suite of flow components

¹Evaluated at Scott River only

- 90/20: Conservative, simple approach that can be used broadly by local agencies across the state.
 - Conditions when 90/20 diversion criteria may be preferred:
 - Diverter wants to use the expedited and cheaper streamlined permitting process for water rights. For example, diverter would like to implement a fast-tracked pilot recharge project for the upcoming winter and would need a permit within 6 months.

- Diverter has permanent infrastructure that can be operated quickly and flexibly to changing daily conditions (e.g., diversion infrastructure that can be turned on and off remotely).
 - Practical limitations of 90/20 diversion criteria:
 - Diversions may be short-duration (less than half a day) and non-consecutive days, requiring more activation and deactivation of diversion infrastructure, which may be difficult for diverters to respond to.
- 80/50: Site-specific approach that focuses diversions to wet periods and can extend the duration of diversion events.
 - Conditions when 80/50 diversion criteria may be preferred:
 - Diverter must rent temporary pumps and wants to reduce the timeframe that the pumps are needed, while increasing the reliable duration of use of rental equipment.
 - Diverter has limited resources or ability to quickly respond to rapidly changing daily conditions.
 - Diverter wants to focus on periods with greater volumes of water available for recharge to support basin recovery.
 - Diverter wants to avoid diversions in dry or critical years to protect flows for other purposes.
 - Diverter wants repeat or longer applications during a water year to support soil flushing and/or limit impacts to aquifer water quality.
- Practical limitations of 80/50 diversion criteria:
 - Approach has moderate operational complexity because diverters must calculate and monitor daily cumulative and bypass flows.
 - Relatively high annual probability of no water available for recharge, thus requiring divertors to potentially wait for suitable wet year conditions to begin diversions.
- Functional Flows-Wet Season 50th and 75th percentile: Site-specific approach that preserves wet-season river functions.
 - Conditions when WS-50 or WS-75 diversion criteria may be preferred

- Diverter is focused on protecting functional flows.
 - Diverter wants to balance maximizing recharge opportunities during most years with preserving functional flows.
 - Diverter wants simple, constant diversion thresholds across the diversion season to reduce operational complexity and uncertainty.
 - Diverter wants to avoid the first high flow events in a water year that tend to have high sediment loads, since these explicitly preserve the first qualifying peak event when it occurs each water year.
- Practical limitations of WS-50 or WS-75 diversion criteria
 - Diverter needs to closely track daily flow to protect 2-year, 5-year, and 10-year peak flow events; this does not necessarily require a predictive forecast, a simple day-to-day comparison (e.g., did flow already cross a given threshold yesterday, and is it higher today) can provide sufficient signal to divert cautiously and protect the event in progress.
- Functional Flows-Peak 2-year: Site-specific approach that limits diversions to flows above a 2-year peak flood event.
 - Conditions when FF-Pk2 diversion criteria may be preferred
 - Diversions will occur in reach with priority floodplain habitat where 2-year inundation is being actively managed and protected.
 - Diverter wants a simple, constant diversion threshold across the diversion season to reduce operational complexity and uncertainty.
 - Diverter wants to avoid the first high flow events in a water year that tend to have high sediment loads, since these explicitly preserve the first qualifying peak event when it occurs each water year.
 - Practical limitations of FF-Pk2 diversion criteria
 - Because this approach diverts relatively infrequently and in smaller volumes than other approaches, it may not be well suited to projects that depend on recharging most years to reliably support dry-season baseflow, or to projects aiming for rapid, high-volume basin recovery.

- Diverter needs to closely track daily flow to protect 2-year, 5-year, and 10-year peak flow events; this does not necessarily require a predictive forecast, a simple day-to-day comparison (e.g., did flow already cross a given threshold yesterday, and is it higher today) can provide sufficient signal to divert cautiously and protect the event in progress.
- Ecohydraulic: Site- and species-specific approach that preserves biological and geomorphic thresholds for sensitive species.
 - Conditions when ecohydraulic diversion criteria may be preferred
 - Diverter wants to apply recharge water in every, or most, years.
 - Diverter is focused on protecting site-specific ecological functions of target species (e.g., salmonids).
 - Diverter wants simple, constant diversion thresholds across the diversion season to reduce operational complexity and uncertainty.
 - Practical limitations of ecohydraulic diversion criteria
 - Likely best suited for projects that recharge water to increase annual summer/fall baseflow for sensitive aquatic species. Approach may not be appropriate for maximizing recharge for most consumptive use (e.g., irrigation).
 - Requires a dedicated site- and species-specific ecological or hydraulic study to establish the diversion threshold, a higher upfront cost and longer development timeline than approaches based on general percentile statistics from hydrology.
 - Because the threshold reflects one species' specific requirements, it may not represent the fuller suite of functional flow components that functional flow-informed approaches are designed to preserve.

STUDY LIMITATIONS

The alternative diversion scenarios explored in this study are intended as a starting point and should be adapted based on local hydrologic conditions, infrastructure constraints, and management objectives. Site-specific factors such as channel capacity, flood risk, water rights,

and geomorphic conditions may influence the applicability and performance of different diversion approaches.

This analysis also evaluates diversion scenarios from a cumulative impact perspective rather than as a project-specific permitting analysis. It asks what streamflow at a given gage would look like if a specified volume or rate of diversion occurred under each rule, not what an individual proposed diversion's actual permit conditions would produce. Maximum diversion or pump capacity caps that would apply to an individual project are not incorporated; an individual diverter's actual infrastructure may limit diversion below what a given rule would otherwise allow, but this analysis is agnostic to any single project's physical capacity. Similarly, the duration limits associated with temporary permits (180 days and 5-years) are not incorporated; diversion potential is evaluated across the full Flood-MAR diversion period (December to March) under each rule's own criteria rather than truncated to a permit-specific window. Both simplifications are appropriate to the cumulative question this analysis is designed to answer, but the results should not be read as a prediction of what any single permitted diversion would produce.

In this analysis, peak flow preservation was evaluated primarily based on flow magnitude (e.g., 2-year, 5-year, and 10-year events). The frequency and duration of peak flow events, which are also important components of the flow regime, were not explicitly incorporated into the diversion rules. However, protecting peak flow magnitude of the first peak flow event each water year appears to have incidentally protected its duration and frequency as well, based on the streamflow alteration and range compression assessments at all three sites. Additional work is needed to evaluate how peak duration and frequency can be more directly integrated into functional flow-informed diversion scenarios.

This analysis also applies diversion thresholds uniformly across years and does not explicitly account for water year type. If information on water year classification or seasonal forecasting is available, applying water year type-specific flow thresholds may improve alignment with hydrologic conditions and ecological needs. Approaches such as those used in the Collaboratory for Equity in Water Allocation (COEWAL; <https://coeqwal.berkeley.edu/>) or the Functional Flows Adaptive Implementation Model (FFAIM, Yarnell et al., 2024), which adjust thresholds based on water year percentiles, could be incorporated to refine diversion criteria that are more specific to yearly climatic conditions.

The magnitude of deviation from Baseline is not necessarily proportional to ecological significance. A given percent deviation represents a larger absolute change in flow during wet years, when Baseline flows are highest, than the same percent deviation represents in a dry year, when flows may already be low. This means a small percent deviation in a dry year could actually matter more ecologically than a larger percent deviation in a wet year, if dry-year flows

are already close to a level some species or process depends on. Because of this, the response curves in this memo show relative (percent) deviation and should not be treated as a direct stand-in for ecological risk without also considering the actual flow level in the water year where a given deviation occurs.

Response curves in this memo characterize deviation from Baseline rather than deviation from unimpaired conditions, for the reasons described in the Approach section (a true year-to-year comparison, avoiding conflation of a scenario's own effect with Baseline's pre-existing offset from unimpaired conditions). This choice supports a cleaner relative comparison among diversion scenarios but means the response curves do not directly indicate how close any scenario is to unimpaired conditions. At Elder Creek and Scott River, Baseline was found to be likely unaltered under the streamflow alteration assessment, which limits the practical consequence of this distinction at those two sites; at Stony Creek, where Baseline itself is classified as likely altered for wet-season baseflow magnitude, the distinction is more consequential, since a scenario's deviation from Baseline there does not indicate whether that scenario moves flow toward or away from unimpaired conditions.

This analysis approximates each scenario's flow record by subtracting the diverted volume from the observed Baseline record. This approach is reasonably direct for peak flow and wet-season baseflow metrics, which respond fairly directly to volumetric subtraction, but it does not capture how a diversion scenario might alter spring recession timing or rate, or dry-season baseflow, since these components can involve watershed processes, such as groundwater-surface water interaction and recession dynamics, that a simple subtraction from the historical record cannot represent. A watershed-scale hydrologic model would be needed to characterize potential changes, or benefits, to these components under the scenarios evaluated here. Future work would ideally extend both the CEFF alteration assessment and the response-curve analysis to the full suite of functional flow components across all relevant seasons, rather than focusing primarily on peak flows and wet-season baseflow as done in this analysis.

Finally, this analysis relies on historical streamflow observations to simulate diversion scenarios, which may not fully capture future hydrologic variability associated with climate change or shifts in land use and water management. The historical period of record also limited the range of diversion volumes realized under some scenarios, particularly 90/20 and FF-Pk2 at the sites where response curves were developed. Future studies could incorporate modeled flow scenarios, or a longer historical or climate-projected record spanning a wider range of water year types, both to evaluate the robustness of diversion approaches under changing conditions and to characterize response curves more completely at diversion volumes beyond those simulated using the historical period of record.

FUTURE WORK

Additional case studies are needed to further test and refine guidance for alternative diversion scenarios across a broader range of hydrologic and management contexts. The step-by-step functional flow-informed approach developed and applied here provides a starting roadmap for this kind of evaluation; expanding it to systems throughout California that represent diverse stream classes, levels of flow alteration and regulation, and Flood-MAR opportunities would help build toward statewide guidance on functional flow alteration assessment for wet-season diversions, while also testing the transferability and robustness of the approach itself. Site selection for this expansion should proceed cautiously: statewide unimpaired flow models used to characterize unimpaired conditions (via the Natural Flows Database) perform better in some regions than others (Grantham et al., 2022), and a detailed watershed model of current and unimpaired flows would be the ideal basis for piloting this assessment at any new site. Practically, this suggests prioritizing sites with existing watershed models, spanning a range of alteration levels, and with varying availability of daily unimpaired and/or future-projected flow data, over a purely geographic or opportunistic expansion.

Where daily unimpaired flow estimates are available, a priority for future work is reworking the tradeoff curves developed here to measure deviation from unimpaired conditions directly, rather than the deviation from Baseline used in this analysis (see Study Limitations). This would allow identification of key inflection points along each curve, the points at which additional recharge opportunity is associated with a meaningfully larger departure from unimpaired conditions, and support a more direct characterization of the ecological risk or impact associated with each inflection point, rather than the relative, scenario-to-scenario comparison of deviation from Baseline presented here.

This expansion also creates an opportunity to incorporate forecasting into the diversion criteria themselves, for example by applying water year percentile forecasts to adjust thresholds within a season rather than relying on a single fixed rule applied uniformly regardless of how a water year is developing. A related but distinct need is incorporating projected future climate conditions into the underlying natural flow reference itself, since the historical period used to define thresholds in this analysis may not fully represent the flow conditions diversion criteria will need to account for as climate change continues to shift streamflow patterns.

Future work should also consider whether additional metrics for assessing hydrologic alteration would better capture intra-seasonal variability, flow timing, and event dynamics. The 20 percent cap applied to diversion under each scenario in this analysis already helps preserve the natural shape of the hydrograph, since diversion is limited to a percentage of that day's flow rather than a fixed volume, constraining how much any scenario can flatten day-to-day

variability. Even so, a more direct evaluation of variability-sensitive metrics, rather than relying on the streamflow alteration classification and deviation-from-Baseline approach used here, may still help distinguish more precisely between diversion approaches that preserve hydrograph shape incidentally, as a byproduct of the rate cap, versus those that do so as a more explicit design objective.

A preliminary look at one wet-to-dry transition year at each site found that some scenarios held instream flow at a fixed threshold for several consecutive days during spring recession. This differed from how those same scenarios typically behaved across the broader set of water years evaluated. This was examined too narrowly, in a single stress event per site, to characterize how common this behavior is, how it varies with site hydrology, or whether it carries ecological significance. Future work should evaluate this kind of stress-event behavior systematically, across multiple wet-to-dry transition years and sites, and, where possible, in connection with the flow-ecology relationships described below, before treating it as a basis for distinguishing between diversion approaches.

Finally, this analysis assessed diversion scenarios against flow metric alteration, not against ecological outcomes directly. Where site-specific ecological models or established flow-ecology relationships exist, for example, relationships between baseflow magnitude and salmonid rearing habitat, or between peak flow characteristics and riparian recruitment, these could be used to test the ecological protectiveness of diversion scenarios more directly than flow metric deviation alone allows. Pairing the approach developed here with such models at a subset of case study sites would help close the gap between hydrologic alteration and demonstrated ecological risk (Lane et al., In Review).

CONCLUSION

Results across case study locations indicate that diversion approaches differ meaningfully in how they balance water available for recharge against deviation from Baseline in ecologically important flow components, and that these differences play out differently depending on site conditions. Rather than pointing to a single best approach, these results support the premise that a suite of diversion approaches, applied selectively based on site hydrology, management goals, and ecosystem context, is more useful than any single approach applied uniformly.

The State Water Board's 90/20 rule showed the smallest deviation from Baseline of the scenarios evaluated but also yielded amongst the smallest volumes of water available for recharge and the narrowest range of diversion volumes in the historical record, making it best suited to contexts where a simple, conservative, broadly applicable rule is the management priority and lower recharge volumes are an acceptable tradeoff. This reflects 90/20's basis in

ambient flow conditions (the 90th percentile of observed daily flow) combined with a 20 percent diversion cap, rather than the unimpaired flow conditions the original framework it draws from (Richter et al., 2011) was developed against. As anticipated, this distinction proved more consequential at some sites than others: at Stony Creek, where Baseline itself is classified as likely altered for wet-season baseflow magnitude, no scenario, including 90/20, was distinguished from that pre-existing condition, since all scenarios are compared against the same already-altered ambient Baseline rather than an unimpaired reference. This is a context where a criterion tied more directly to unimpaired conditions, rather than ambient flow, may be a more suitable tool.

Functional flow-informed diversion scenarios showed a different response, better suited to contexts where extending recharge opportunity is a higher priority alongside preserving wet-season flow function: FF-WS75 yielded water availabilities comparable to or approaching 80/50, while explicitly protecting 2-year, 5-year, and 10-year flood events rather than diverting below them, a design feature 80/50 lacks. This is corroborated by the range compression results, where FF-WS75 tracked Baseline more closely than 80/50 on peak 2-year duration and frequency across the full period of record at all three sites. 80/50, in turn, sustained diversion opportunities more continuously across a wider range of conditions, which may suit contexts prioritizing consistent, predictable diversion operations over explicit peak-event protection.

Overall, these results support a toolbox rather than a single-recommendation approach: each diversion approach evaluated here represents a different, legitimate tradeoff among water availability, operational simplicity, and preservation of flow function, and which tool is best suited to a given site depends on that site's hydrology, existing alteration, and management priorities. The step-by-step approach developed here, screening functional flow metrics against recharge opportunity and evaluating alteration status under each candidate criterion, provides a way to make that site-specific selection systematically rather than defaulting to a single statewide rule.

DATA AVAILABILITY

The analysis code supporting this report is available at <https://github.com/kristaniguchi/floodmar-ceff-diversion-criteria.git>. The repository contains R scripts organized by workflow stage, with README files describing each stage and its contributors. Input data and full simulation outputs are not included in the repository because of file size and are available upon request from the corresponding author (kristinetq@sccwrp.org).

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SUPPLEMENTAL FIGURES

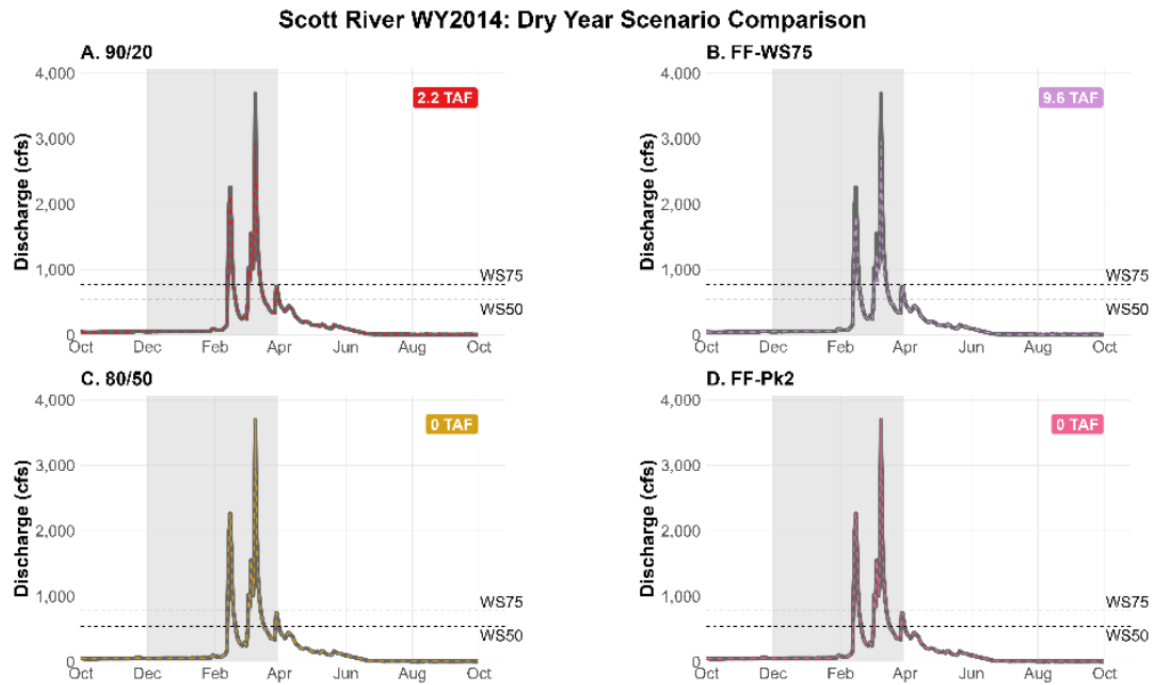


Figure A1. Scott River hydrograph comparison by diversion scenario for a dry water year (WY 2014). Grey shading is the Flood-MAR diversion period (December to March). Dashed horizontal lines are the unimpaired wet-season median flow thresholds (75th and 50th percentiles). Colored box is the total annual diversion volume (TAF).

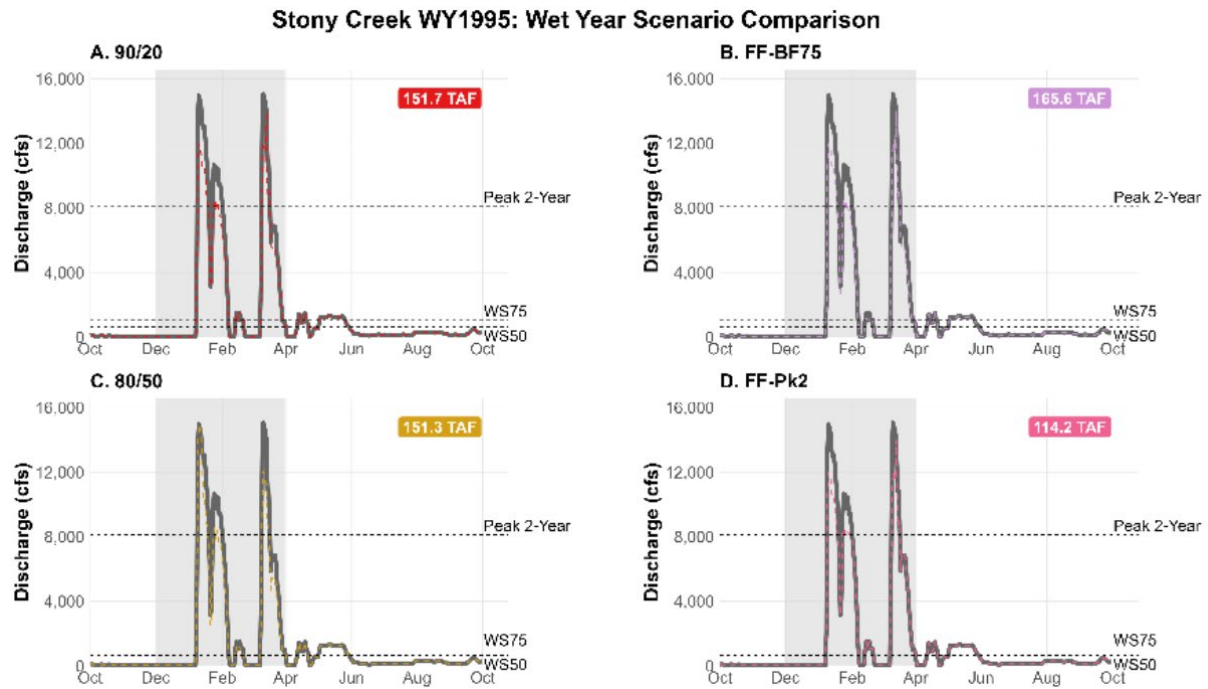


Figure A2. Stony Creek hydrograph comparison by diversion scenario for a wet water year (WY 1995). Grey shading is the Flood-MAR diversion period (December to March). Dashed horizontal lines are the unimpaired 2-year peak flow magnitude and the wet-season median flow thresholds (75th and 50th percentiles). Colored box is the total annual diversion volume (TAF).

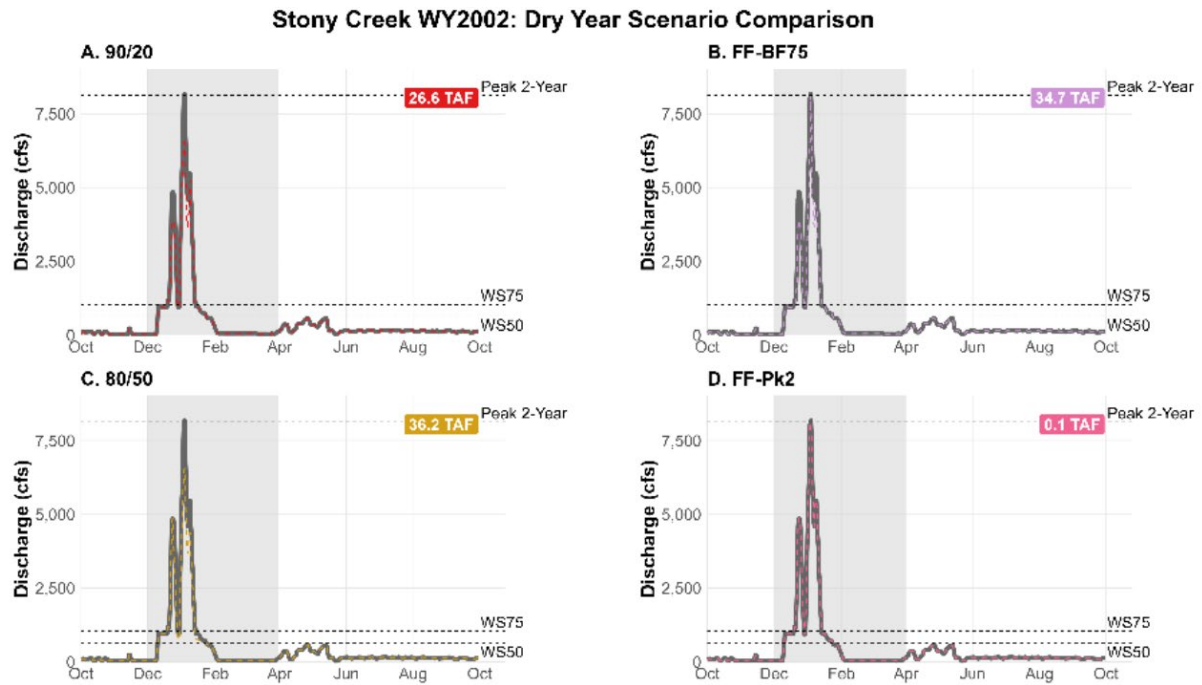


Figure A3. Stony Creek hydrograph comparison by diversion scenario for a dry water year (WY 2002). Grey shading is the Flood-MAR diversion period (December to March). Dashed horizontal lines are the unimpaired 2-year peak flow magnitude and the wet-season median flow thresholds (75th and 50th percentiles). Colored box is the total annual diversion volume (TAF).

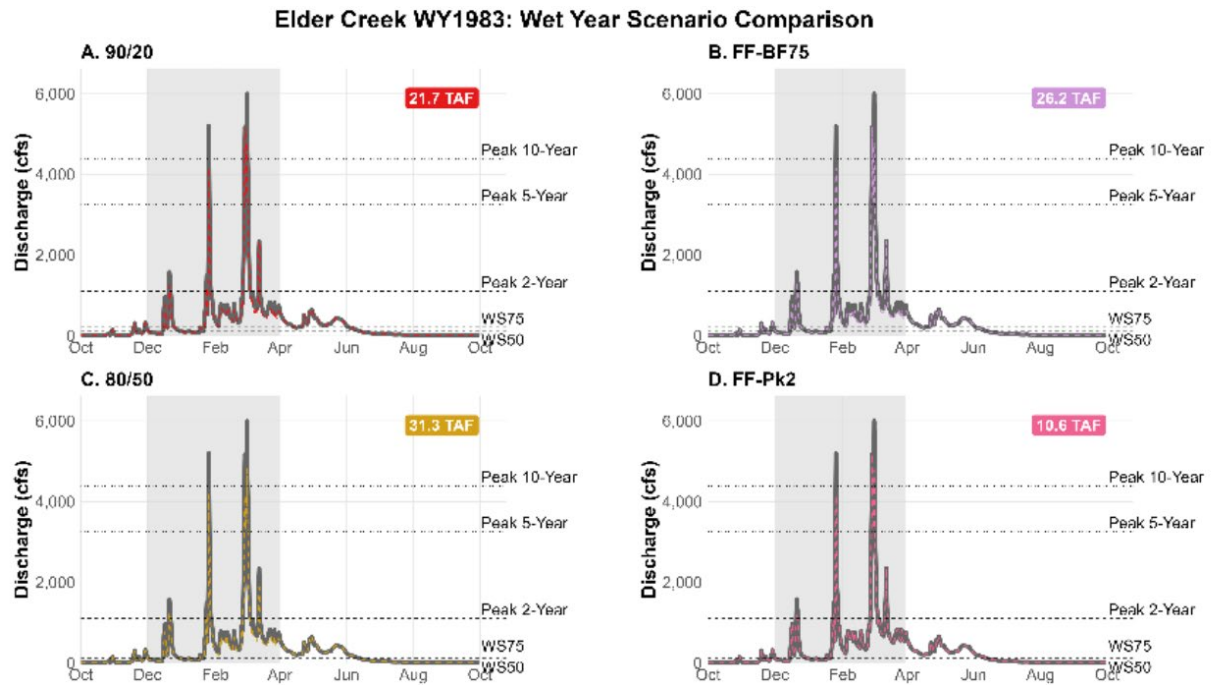


Figure A4. Elder Creek hydrograph comparison by diversion scenario for a wet water year (WY 1983). Grey shading is the Flood-MAR diversion period (December to March). Dotted horizontal lines are the unimpaired 10-year and 5-year peak flow magnitudes; dashed horizontal lines are the unimpaired 2-year peak flow magnitude and the wet-season median flow thresholds (75th and 50th percentiles). Colored box is the total annual diversion volume (TAF).

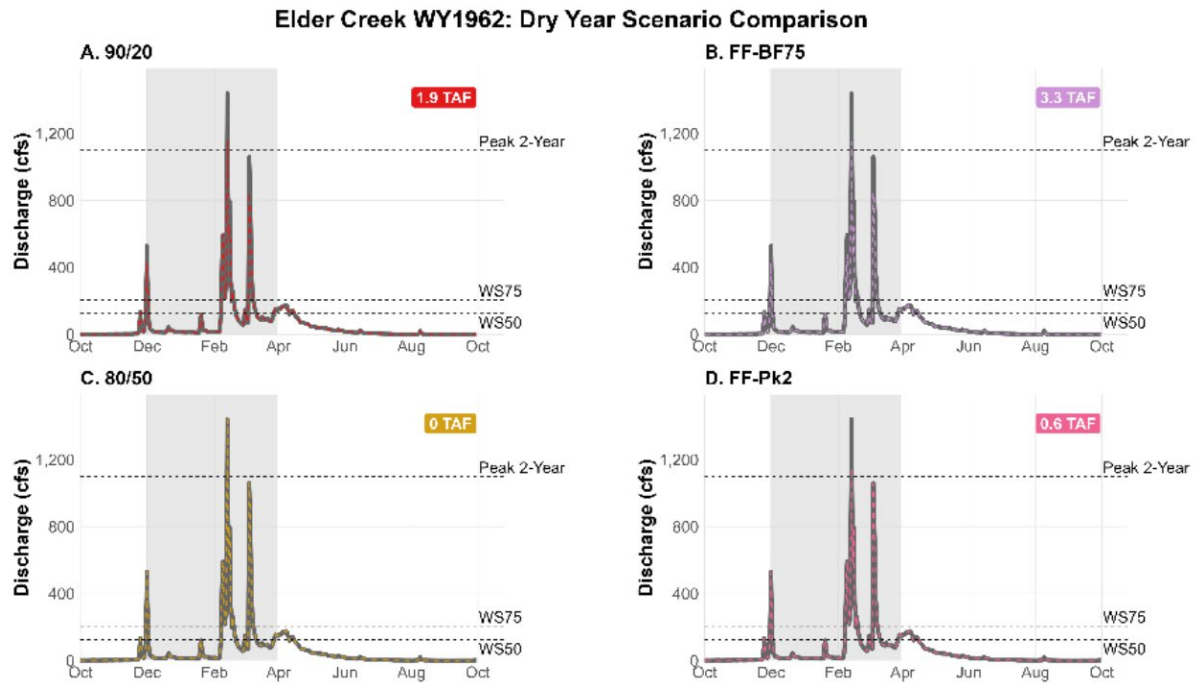


Figure A5. Elder Creek hydrograph comparison by diversion scenario for a dry water year (WY 1962). Grey shading is the Flood-MAR diversion period (December to March). Dashed horizontal lines are the unimpaired 2-year peak flow magnitude and the wet-season median flow thresholds (75th and 50th percentiles). Colored box is the total annual diversion volume (TAF).

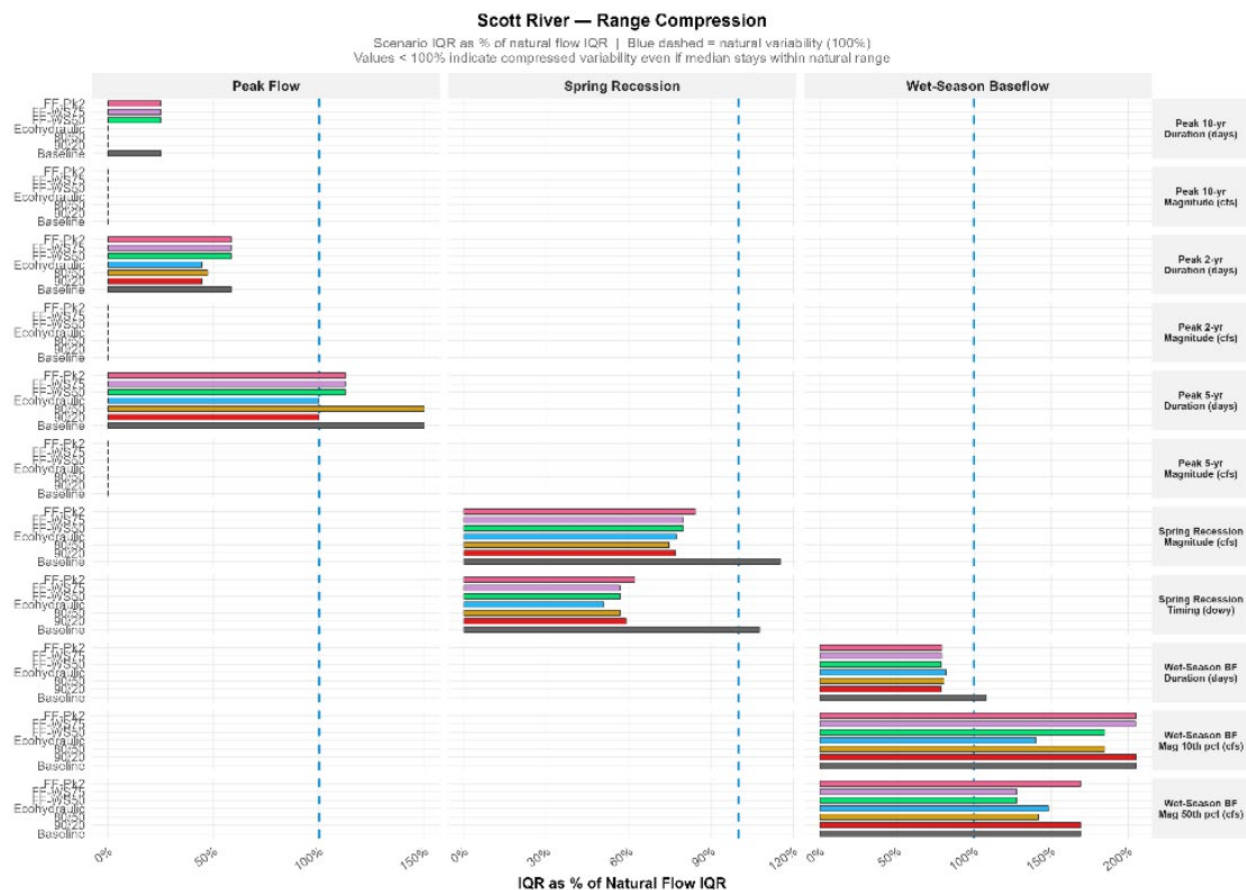


Figure A6. Scott River range compression across all screened functional flow metrics. Bars show each scenario’s interquartile range (IQR) as a percentage of natural flow IQR; values below 100% (blue dashed line) indicate compressed variability relative to natural conditions, even where the median remains within the natural range.

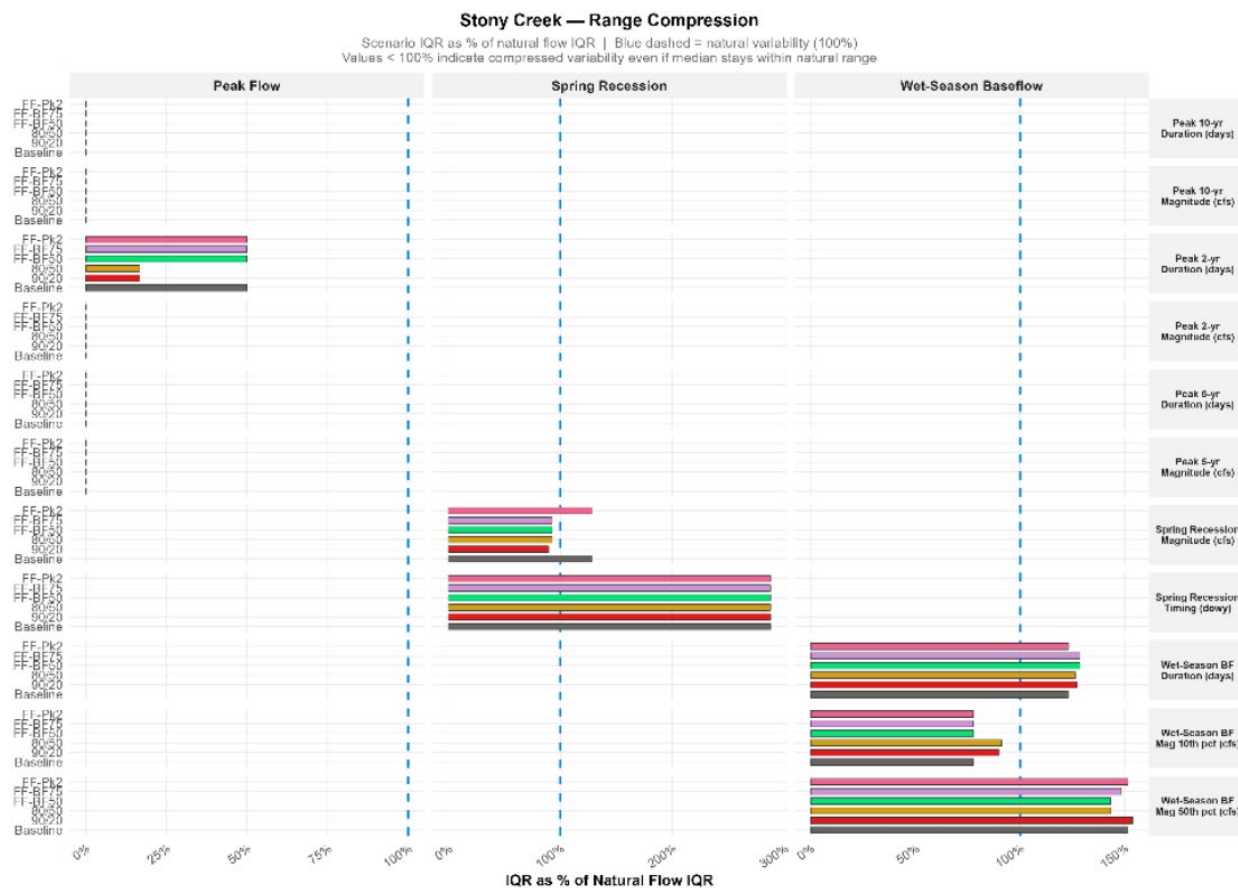


Figure A7. Stony Creek range compression across all screened functional flow metrics. Bars show each scenario's interquartile range (IQR) as a percentage of natural flow IQR; values below 100% (blue dashed line) indicate compressed variability relative to natural conditions, even where the median remains within the natural range.

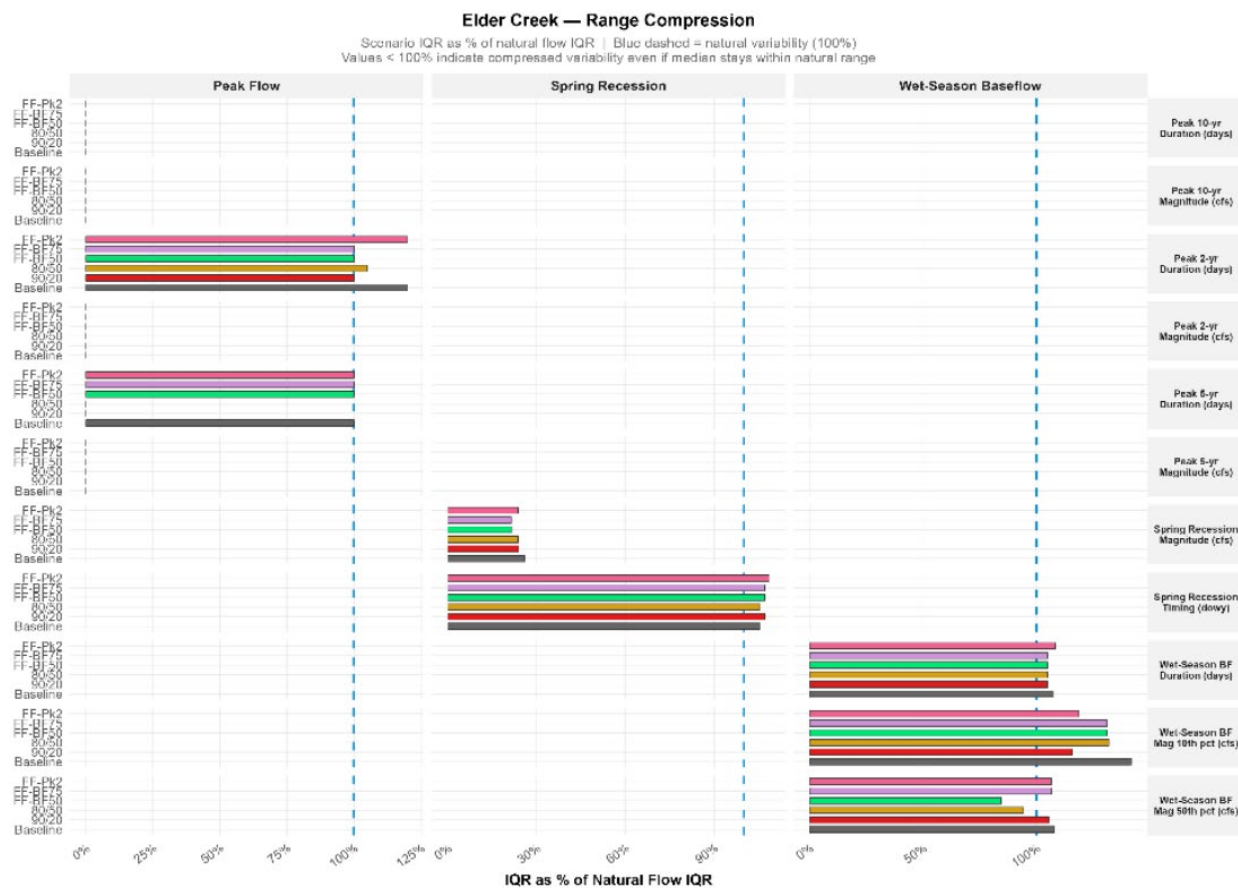


Figure A8. Elder Creek range compression across all screened functional flow metrics. Bars show each scenario's interquartile range (IQR) as a percentage of natural flow IQR; values below 100% (blue dashed line) indicate compressed variability relative to natural conditions, even where the median remains within the natural range.

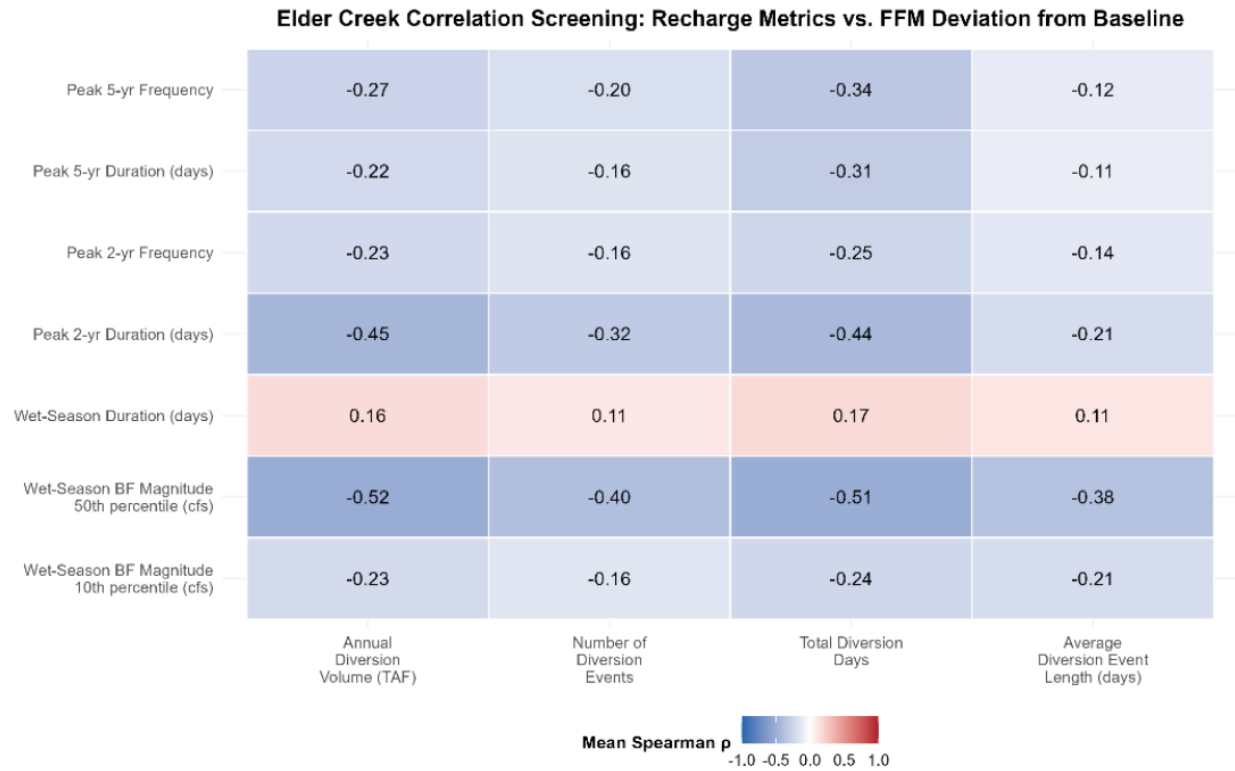


Figure A9. Elder Creek correlation screening results. Each cell shows the mean Spearman ρ between a recharge opportunity metric (columns) and percent deviation from Baseline in a functional flow metric (rows), averaged across the five diversion scenarios (90/20, 80/50, FF-BF50, FF-BF75, FF-Pk2).

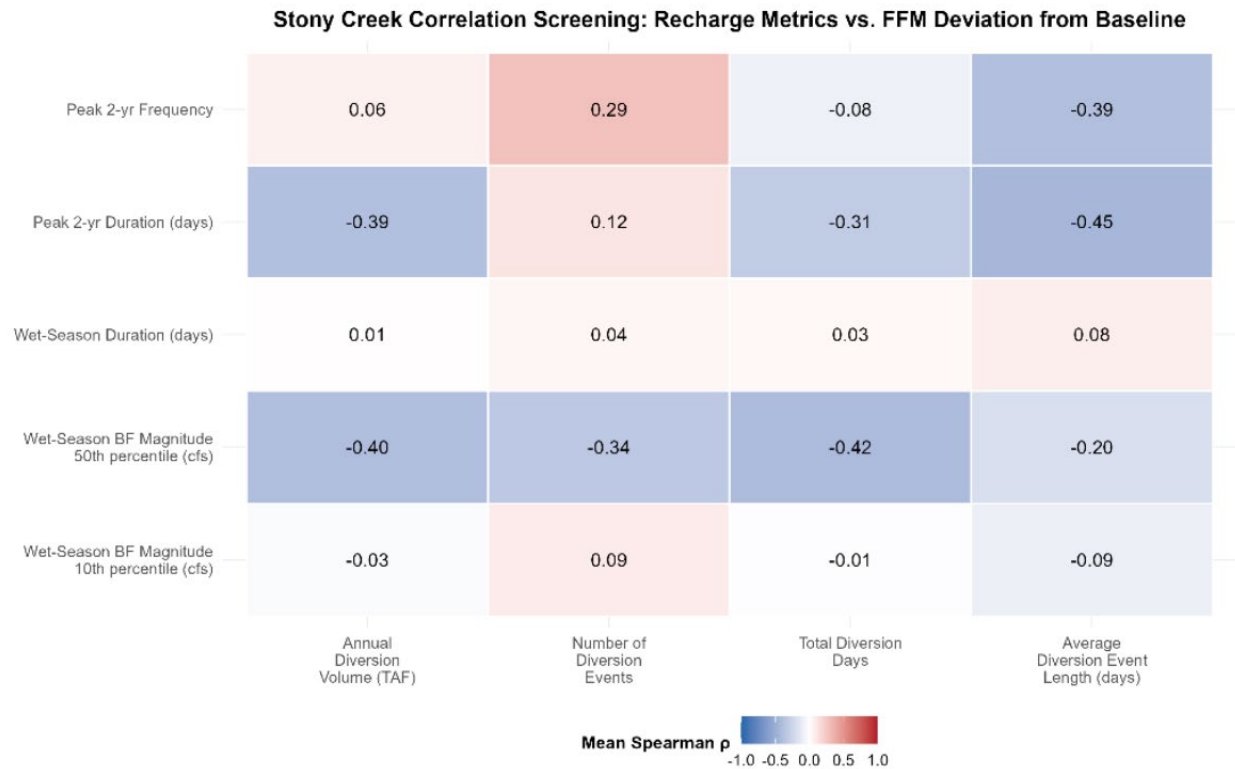


Figure A10. Stony Creek correlation screening results. Each cell shows the mean Spearman ρ between a recharge opportunity metric (columns) and percent deviation from Baseline in a functional flow metric (rows), averaged across the five diversion scenarios (90/20, 80/50, FF-BF50, FF-BF75, FF-Pk2).

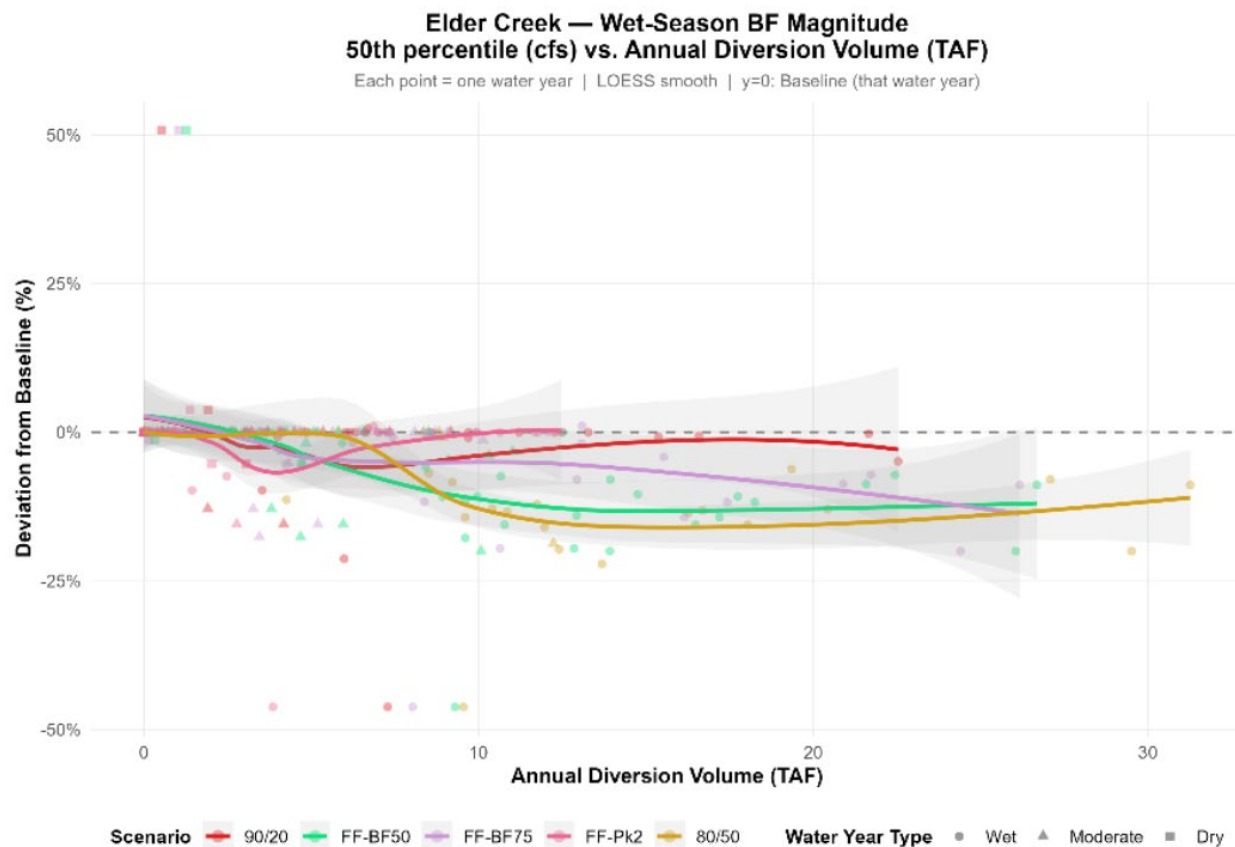


Figure A11. Elder Creek wet-season baseflow magnitude (50th percentile) percent deviation from Baseline, as a function of Annual Diversion Volume (TAF) for each scenario. Each point is one water year; lines are LOESS-smoothed trends by scenario.

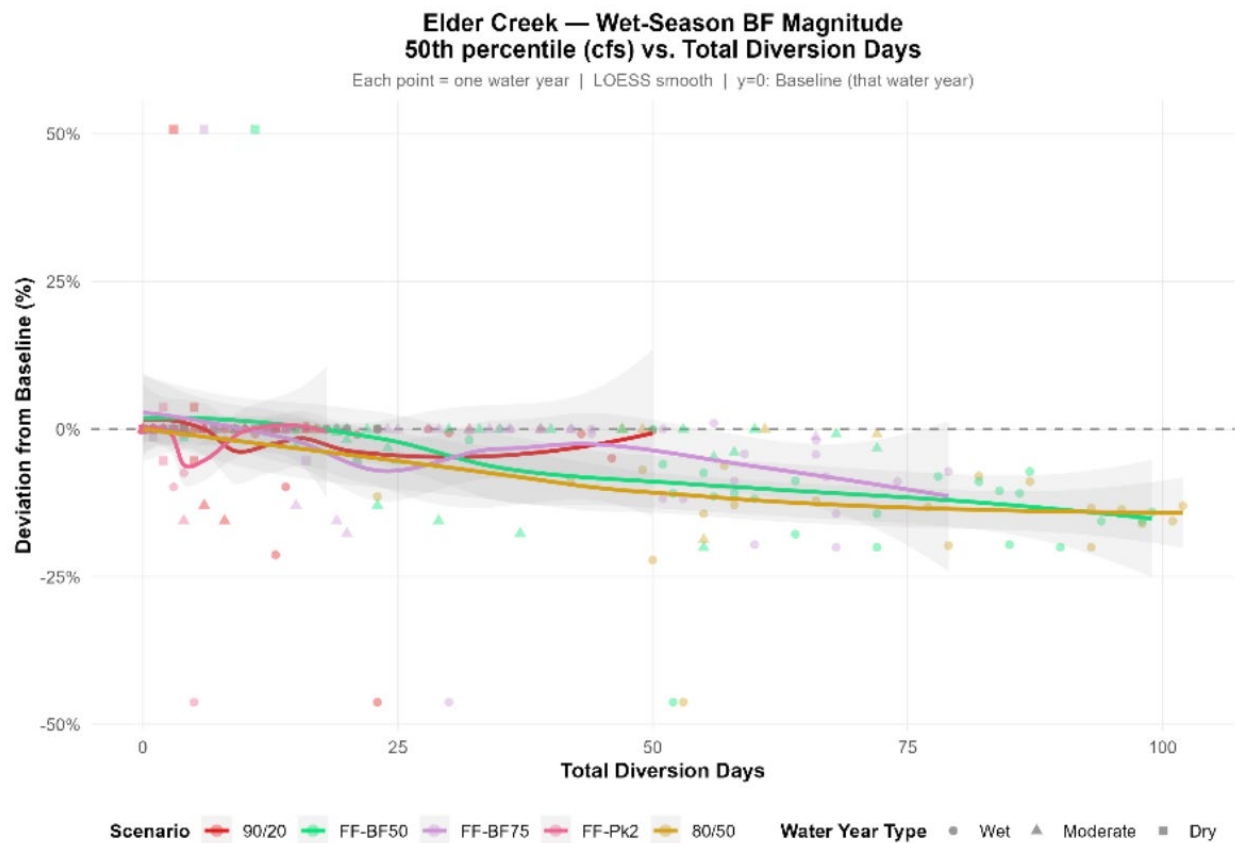


Figure A12. Elder Creek wet-season baseflow magnitude (50th percentile) percent deviation from Baseline, as a function of Total Diversion Days for each scenario. Each point is one water year; lines are LOESS-smoothed trends by scenario.

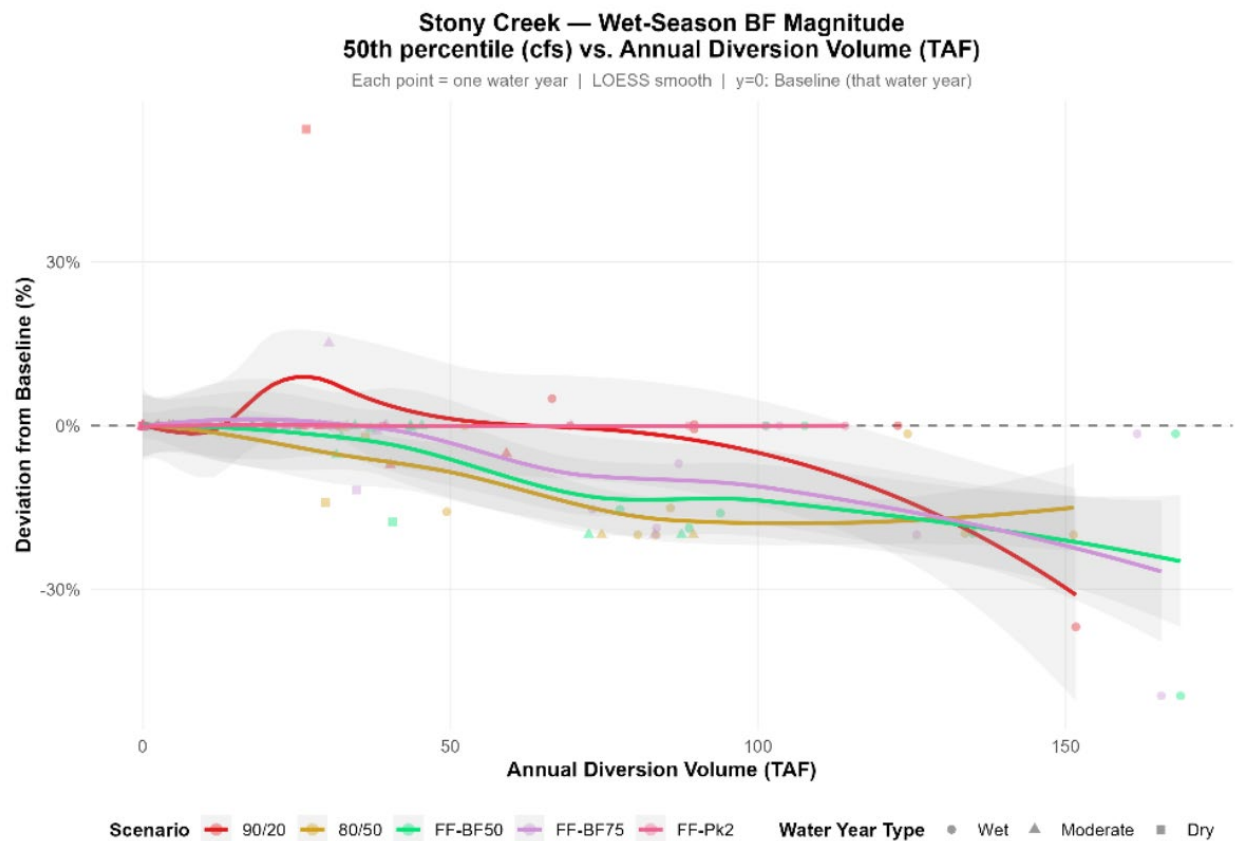


Figure A13. Stony Creek wet-season baseflow magnitude (50th percentile) percent deviation from Baseline, as a function of Annual Diversion Volume (TAF) for each scenario. Each point is one water year; lines are LOESS-smoothed trends by scenario.

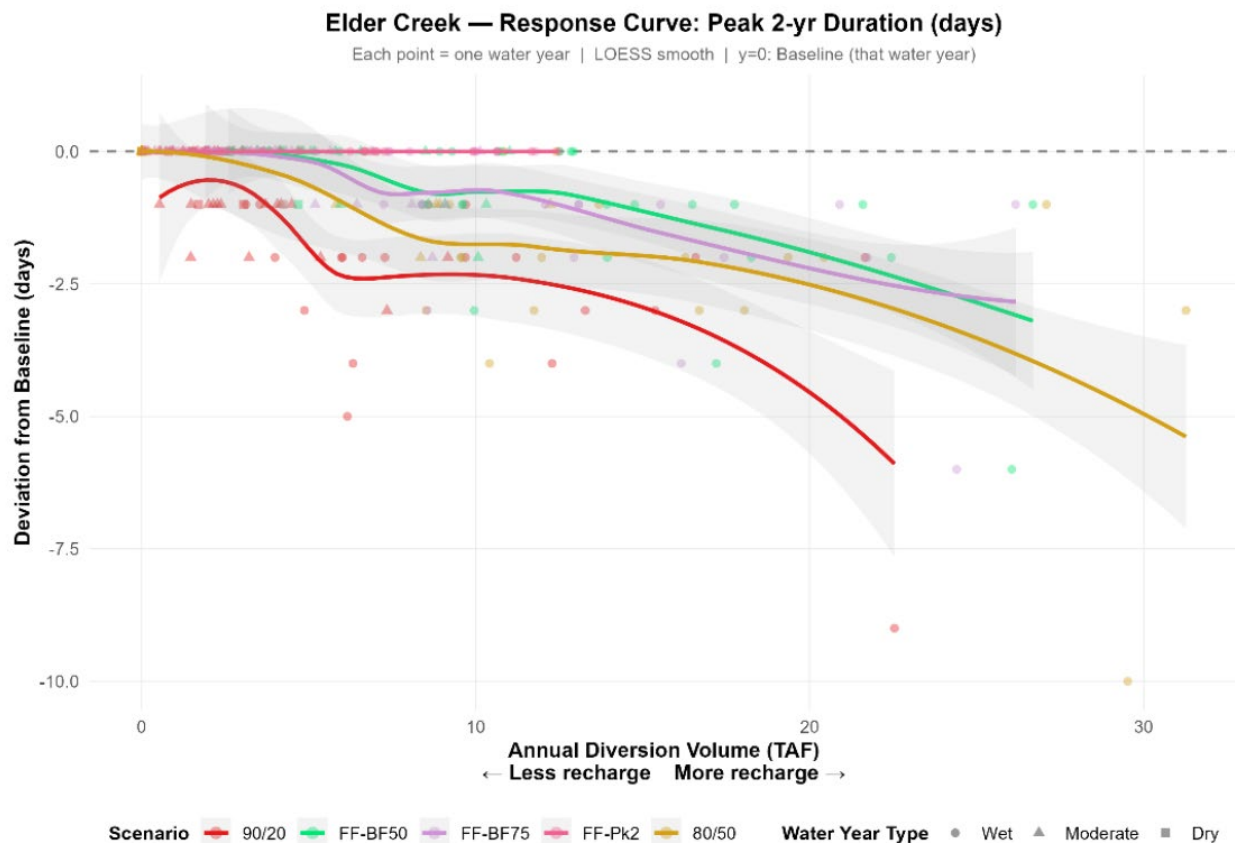


Figure A14. Elder Creek peak 2-year duration (days) deviation from Baseline, as a function of Annual Diversion Volume (TAF) for each scenario. Each point is one water year; lines are LOESS-smoothed trends by scenario.