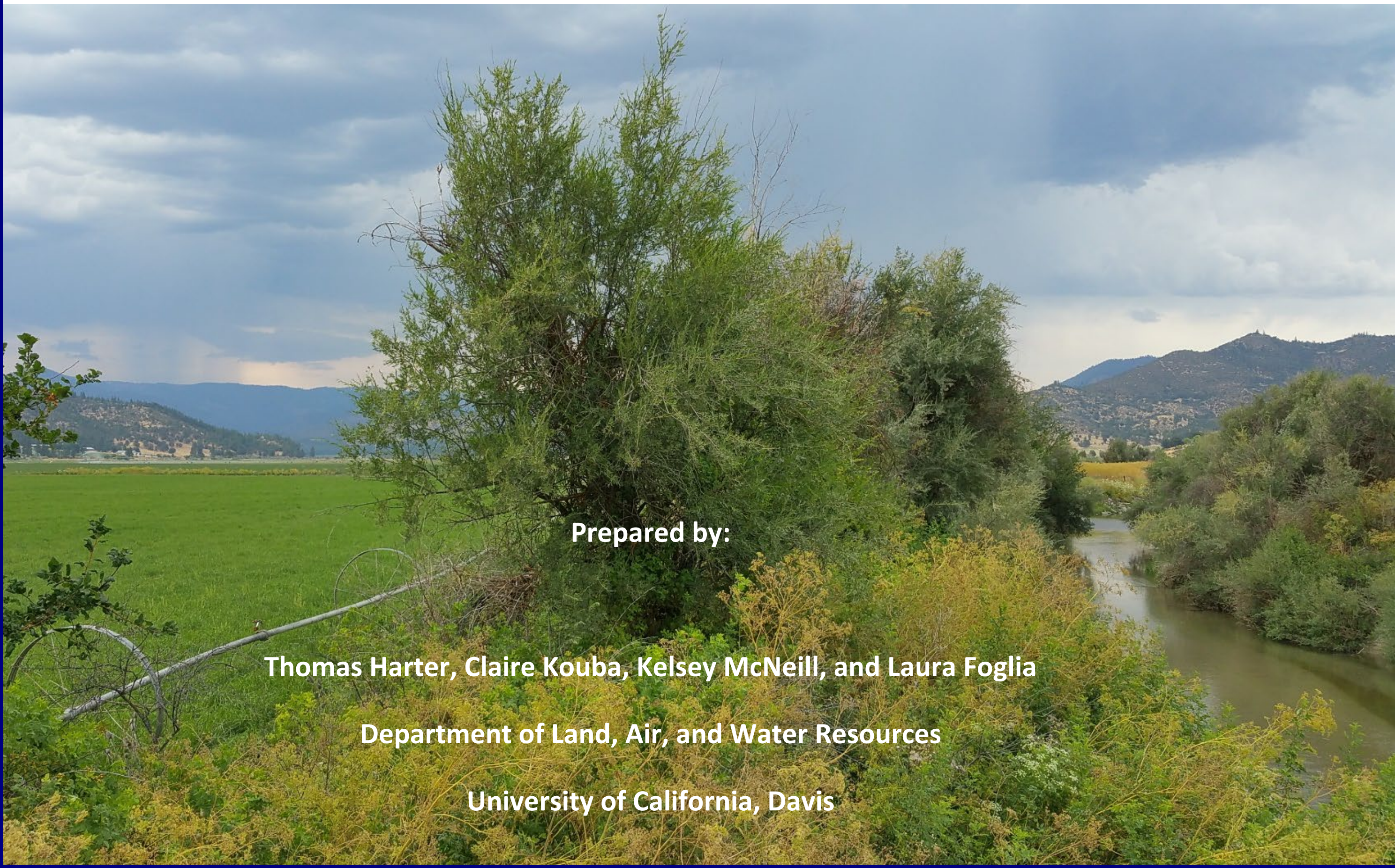
December 2023

North Coast Regional Water Board, SWRCB Contract 19-012-110.

Scott Valley Integrated Hydrologic Model: SVIHM-2018 and Scenario Development

Final Report



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Prepared for:

North Coast Regional Water Board

With funding by:

State Water Resources Control Board, Contract #19-012-110

FINAL REPORT

Version

December 28, 2023

Suggested Citation:

Harter, T., C. Kouba, K. McNeill, and L. Foglia, 2023. Scott Valley Integrated Hydrologic Model: SVIHM-2018 and Scenario Development, Final Report. University of California, Davis, https://groundwater.ucdavis.edu, December 2023. 331 p.

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1 Acknowledgments

Many people have supported our efforts of collecting, analyzing, and interpreting data. We acknowledge the feedback, support, and reviews that we have received from the Scott Valley Groundwater Sustainability Agency Advisory Committee members and the many members of the public that participated in the development of the Scott Valley Groundwater Sustainability Plan. We appreciate the close collaboration with Bryan McFadin and Elias Scott at the North Coast Regional Water Board, with Giuliano Carneiro Galdi at the Siskiyou County Cooperative Extension Office, with Sari Sommarstrom at Sommarstrom & Associates, and with Matt Parker and Elizabeth Nielsen at the Scott Valley Groundwater Sustainability Agency/Siskiyou County. These collaborations were critical for developing both, stream depletion attribution scenarios and future project and management action scenarios. Review comments were helpful in clarifying this report.

Funding has been provided by the North Coast Regional Water Board and the State Water Resources Control Board, through Contract #19-012-110. The opinions and conclusions in this report are those of the authors and are not necessarily shared by the funding agency or any of the project partners, cooperators, or reviewers.

2 Introduction

Scott Valley is an agricultural groundwater basin in Northern California, within the Scott River watershed, part of the Lower Klamath Basin watershed straddling the California-Oregon border. The Scott River provides important habitat for salmonid fish, including spawning and rearing habitat for coho (*Onchorhynchus kisutch*) and fall-run Chinook salmon (*Onchorhynchus tschawytscha*) and steelhead trout (*Onchorhynchus mykiss*). Sufficient flows at adequately low temperatures during summer, for rearing, and fall, for spawning, are critical for healthy fish habitat in the mainstem and tributaries.

During the dry summer, streamflow in the Scott River system is low and relies almost entirely on groundwater return flow (baseflow) from the alluvial aquifer system underlying Scott Valley. Summer streamflow in dry years have been markedly lower since the late 1970s, when compared to the 1940s to 1960s. This change is concurrent with large scale adoption of efficient wheel-line irrigation (and later: center pivot irrigation) using groundwater instead of surface water, which also allowed for extending the alfalfa irrigation season, consistently yielding an additional third cutting. Van Kirk and Naman (2008), using statistical analysis, asserted that groundwater pumping for irrigation and the accompanying increased consumptive water use was a significant cause of the decline in July and August streamflow. The changes have been exacerbated by climate change. Van Kirk and Naman (2008) and Drake et al. (2000) concluded that lower streamflow in the fall is due to climate effects represented by reduced snowpack at lower elevations.

As a result of low streamflow, but also due to the lack of widespread riparian vegetation, temperatures in the Scott River may exceed critically high temperatures during the summer months (North Coast Regional Water Board, Staff Report for the Action Plan for the Scott River Watershed Sediments and Temperature TMDLs, 2005). A groundwater (GW) study plan (Harter and Hines, 2008) was adopted by Siskiyou County to meet the Action Plan for the Scott River Watershed Sediment and Temperature Total Maximum Daily Load (TMDL, adopted Dec. 2005 by the North Coast Regional Water Board [NCRWB]). The Scott Valley Integrated Hydrologic Model (SVIHM) was developed (Foglia et al., 2013a, b, 2018) and calibrated (Tolley et al., 2019) to support the Scott Valley Groundwater Advisory Committee (GWAC) and the implementation of a Groundwater Management Plan (GMP) adopted by Siskiyou County during the 2010s and the development of the Scott Valley Groundwater Sustainability Plan in 2017 - 2021. A key role of SVIHM has been to

1. understand how past and current pumping affects groundwater flows to the Scott River and how alternative future water management activities affect groundwater flow, surface water flows, and water quality.
2. help mediation of conflicts between:
    a. Landowners in Scott Valley, mostly farmers depending on agricultural pumping for crop production,
    b. Indian tribes downstream and commercial fisheries off-coast that depend on healthy fish populations,

c. California Department of Fish and Wildlife, the U.S. Fish and Wildlife Service and the U.S. National Marine Fisheries Service responsible for the implementation of the state and federal Endangered Species Act (ESA; 16 U.S.C. 1531 et seq.)
d. North Coast Regional Water Board, State Water Resources Control Board, and U.S. Environmental Protection Agency responsible for the implementation of California's Porter-Cologne Water Quality Control Act and the Federal Clean Water Act.

The two most promising strategies developed with the support of SVIHM are managed aquifer recharge (MAR) and in-lieu recharge (ILR). In 2015, UC Davis, the GWAC, and the Scott Valley Irrigation District implemented an innovative pilot project to test the feasibility of managed aquifer recharge approaches. The Scott Valley Groundwater Study project, led by UC Davis and funded by the Waterboards, has pioneered approaches for increasing instream flows through conjunctive use of groundwater and surface waters. The project has resulted in a first-of-its-kind water rights project in which surface waters are temporarily stored in the Scott Valley aquifer solely for the benefit of instream flows. This unique approach differs from previous groundwater banking projects in the U.S. that are typically designed to bank water for later retrieval via groundwater pumping. The 2015 pilot project has led to the Water Board's Division of Water Rights considering the permitting of this type of project for the first time. It resulted in development of a water rights permit for groundwater recharge to augment stream flows. (Dahlke et al., 2015 http://www.caes.ucdavis.edu/news/articles/2015/09/farmland-may-provide-key-to-replenishing-groundwater.)

The pilot project was a success, though at a small scale. SVIHM simulation were used to assess the implementation of MAR and ILRP strategies at a larger scale. SVIHM simulation results indicated that MAR and ILR have potential to substantially increase late summer stream flows, as much as 3x-4x of current low flows as estimated by the SVIHM (see UC Davis presentation to NCRWB for more details:
https://www.waterboards.ca.gov/northcoast/board_info/board_meetings/06_2017/3/Item_3_Dr_Harter_Tolly_Presentation.pptx, Tolley et al., 2019). The initial SVIHM scenario results were promising but were conceptually limited. For example, the scenario design did not reflect real-world constraints on diversion amounts, such as bypass flows to protect salmonids.

Since the development and implementation of the original implementation scenarios, other entities have stepped forward with additional modeling ideas. The National Marine Fisheries Service (NMFS) developed a list of scenarios to better define the impacts of groundwater use on stream flows. The outcome of those scenario estimates would be incorporated into NMFS discussions related to their safe harbor process, as well as the SGMA process and related activities.

The SRWC has been implementing an innovative approach to restoring stream habitats using beaver dam analogues (BDA), which mimic the function of beaver dams. Many of the BDAs have been occupied and maintained by beavers since construction. The BDAs provide habitat improvements, and raise the local water table. The increase in water table elevation leads to more groundwater storage, better riparian vegetation conditions, and heat exchange with the aquifer, which will benefit water temperatures. The level of benefits that can be expected from larger scale implementation of the BDA approach is another potential scenario to be evaluated with SVIHM.

Following the adoption of the Sustainable Groundwater Management Act (SGMA) by the State of California in 2014, the Siskiyou County Flood Control and Water Conservation District became the Groundwater Sustainability Agency for the Scott Valley groundwater basin. An advisory committee (AC) was established in 2017 to develop a Groundwater Sustainability Plan (GSP). The GSP was adopted by the GSA Board in December 2021. The GSA Advisory Committee, during development of the Groundwater Sustainability Plan, developed additional projects and management actions related to groundwater management that may potentially benefit streamflow in the Scott River system. These included improvements in irrigation efficiency, reduction in crop consumptive use, and building off-stream surface storage. SVIHM was employed to quantify their potential benefits.

The goals of the work presented in this report included the following:

- Develop and present SVIHM simulation scenarios to further define the impacts of groundwater pumping on instream flows in collaboration with the North Coast Regional Water Board and the Scott Valley Groundwater Sustainability Planning efforts.

- Develop and present scenarios to quantify instream flow benefits from beaver dam analogue structures.

- Refine management actions and anticipated results from aquifer recharge and other stakeholder-identified projects.

- Communicate simulation outcomes to stakeholders to support the development of sustainable management criteria in the Scott Valley Groundwater Sustainability Plan.

Earlier versions of SVIHM simulated water years 1991-2011 and are documented in the report by Foglia et al. (2013a) and the study by Tolley et al (2019). Applications of the model are published in Foglia et al. (2013b) and Foglia et al. (2018). A final calibrated version of the 1991-2011 SVIHM version is currently available as a GitHub repository at https://github.com/UCDavisHydro/SVIHM.

This report summarizes the Water Board-funded efforts performed by UC Davis from 2019-2022. This includes an update of SVIHM to expand the modeling period to 2018 (simulation period from water year 1991 to water year 2018) and documentation of the SVIHM scenario development efforts, and their use in the development of the Scott Valley GSP. These efforts provided the technical underpinnings for the SGMA process in Scott Valley. The 1991-2018 SVIHM model and the many scenarios developed in this project have been designed to constructively inform the development of sustainability criteria and of projects and management actions in the Scott Valley GSP. The GSP for Scott Valley is poised to have statewide ramifications for how these issues are handled in other California groundwater basins.

3 Study Area

3.1 Physical Setting

Scott Valley is located in the Klamath Mountains of Northern California, approximately 30 miles south of the Oregon border in Siskiyou County. Scott Valley is approximately 25 miles long and 10 miles wide at the largest point, although much of Scott Valley is less than 3 miles wide. The Scott River flows through the eastern and northern part of the valley, from south to north and across its northern flank to exit the valley at its northwest corner toward the Klamath River. Approximately 8,000 people live in Scott Valley and its two towns of Fort Jones and Etna. Land use and the local economy are dominated by agriculture, primarily beef cattle-raising and forage production (alfalfa and grain hay and pasture).

The Scott River watershed (8-digit Hydrologic Unit Code 18010208) encompasses 714 sq mi (1,849 sq km) of mountainous terrain centered on 100 sq mi (259 sq km) of valley floor (Figure 1). Along the course of the mainstem of the Scott River, the valley floor slopes from 2900 ft (884 m) amsl near the confluence with Sugar Creek to 2620 ft (799 m) amsl at the north end of the Valley (Figure 1). The area that overlies the aquifer (the Scott River Valley Groundwater Basin, hereafter the Basin) includes the broad central area between the cities of Fort Jones and Etna and the mouths of multiple canyons which convey tributaries on the western side of the Basin and are typically dry gulches on the eastern side.

The valley floor transitions sharply to the mountains bordering the Valley, all of which are subranges of the Klamath Mountain Range. The Scott Bar, Marble, Salmon, and Scott Mountains bound the Watershed to the north, west, southwest, and south, respectively. The mountains on the west side of Scott Valley are steeper and reach higher elevations (8,000 to 8,350 ft amsl; 2438 to 2545 m amsl) than the hills that border the east side of Scott Valley, known as the Mineral Range (6,000 to 7,000 ft amsl; 2,438 to 2,545 m amsl). Elevations in the watershed range from 8,350 ft (2,545 m) amsl on Boulder Peak, part of the Marble Mountains, to 1,535 ft (458 m) amsl where the Scott River joins the Klamath at River Mile 143. Tributaries to the Scott River from the western mountains have deposited steep alluvial fans on the valley floor (Mack 1958).

Vegetation on the mountains to the north, south, and west of Scott Valley mainly consists of mixed conifer and hardwood tree species (ESA 2009). The mountains on the eastern side of the watershed host annual and perennial grasses and shrubs, in addition to conifer stands with ponderosa pine and juniper (ESA 2009; Mack 1958). Scott Valley and headwater tributaries of the surrounding mountains provide key spawning and rearing habitat for native anadromous fish species, including *Oncorhynchus tschawytscha* (Chinook salmon), *Oncorhynchus kisutch* (coho salmon) and *Oncorhynchus mykiss* (steelhead trout). Coho salmon in the Southern Oregon Northern California Coast Evolutionary Significant Unit (SONCC ESU) are listed as threatened at both the federal and state levels (NCRWQCB 2005).

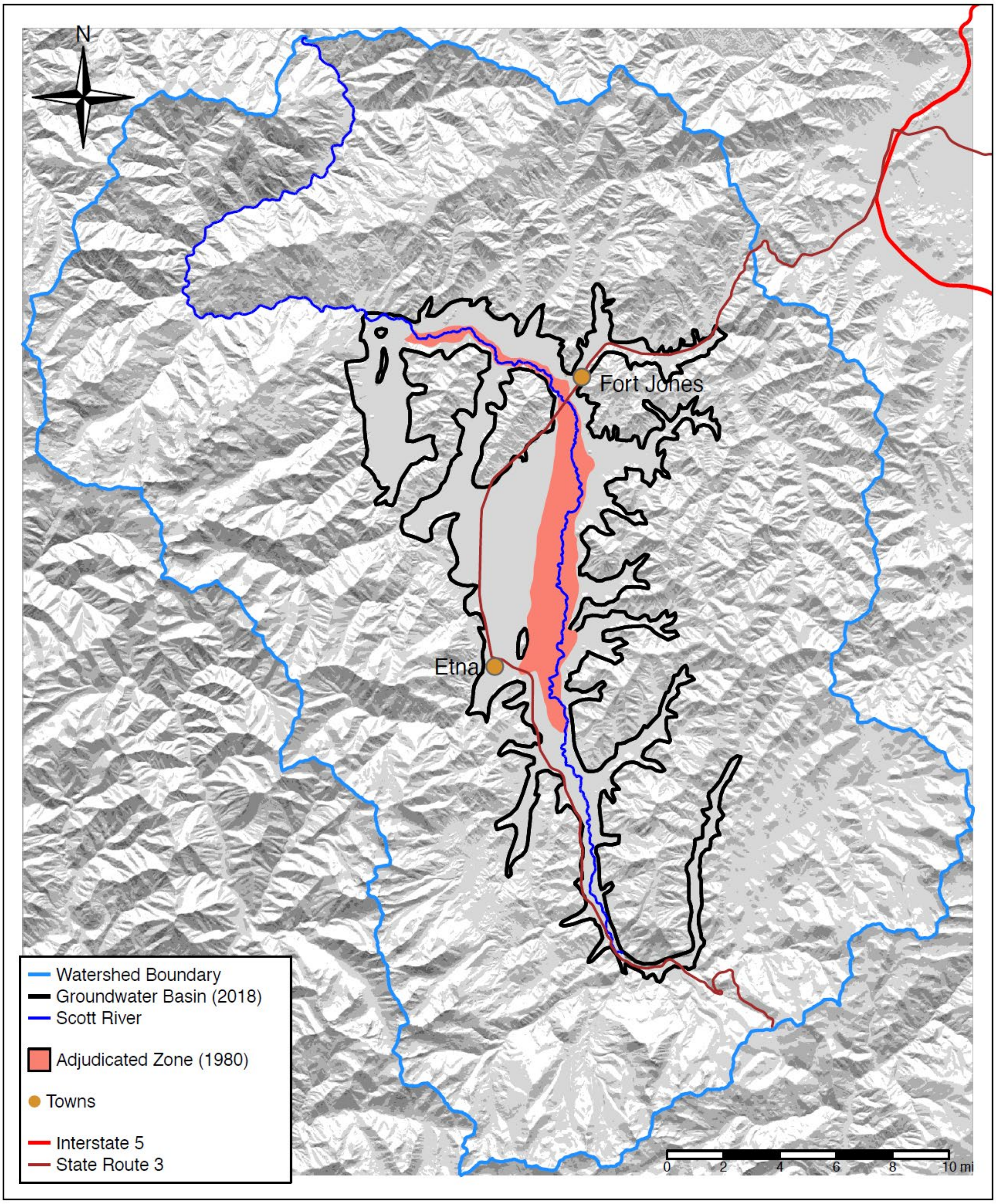


Figure 1: Topography of the Scott River Valley Groundwater Basin and surrounding watershed, Scott River main-stem, and location of the adjudicated zone within the Basin.

3.2 Climate

Scott Valley has a Mediterranean climate with distinctive seasons of cool, wet winters and warm, dry summers. The orographic effect of the mountains to the west and south of the Valley creates a rain-shadow in eastern areas of the Valley. Long-term records are available from National Oceanic and Atmospheric Administration (NOAA) weather stations in and around Scott Valley; relevant stations are listed in Table 1. The higher elevation areas to the west and south of the Valley historically receive greater annual precipitation (60–80 inches (in); 152–203 centimeters (cm)) in comparison to annual precipitation on the east side of the Valley (12–15 ins; 30–38 cm) (Scott River Watershed Council (SRWC) 2005). At elevations below 4,000 ft (1219 m), precipitation mostly occurs as rainfall, as is the case on the valley floor. Precipitation accumulates as snow in the surrounding mountains, with a rain-snow transition zone between 4,000 and 5,000 ft (1219 and 1524 m) (McInnis and Williams 2012). Accumulation of snowfall in the surrounding mountains results in runoff during spring melting (Deas and Tanaka 2006). Long-term mean annual precipitation on the valley floor is 18 in (46 cm) with most accumulation occurring during the winter and early spring months (October–May), with peak precipitation in December and January (Figure 2). Mean daily low and high temperatures for January and July are -5 to 7°Celsius (C) (23–-45°Farenheit (F)) and 9 to 33°C (48–92°F), respectively (Figure 3). Reference evapotranspiration (ET) ranges from 0.01 to 0.31 in/day (0.03-0.79 cm/day) (Figure 3).

The long-term historical precipitation record indicates that recent average precipitation and snowfall are lower than levels recorded in the middle of the 20th century. Between 1945 and 1979, the 10-year trailing rolling average precipitation ranged from 19.1 to 23.5 in (48.5–59.7 cm; water years 1950 and 1959, respectively); since 1980, it has ranged between 11.5 and 18.7 in (48.5-59.7 cm; water years 1989 and 1980, respectively; Figure 2). Additionally, average snow depth at snow measurement stations near the western boundary of the watershed has gradually decreased over time. Although, at three stations near the southern boundary of the watershed the snow depths have remained relatively stable. Regression lines fit through the record of each station suggest that the average snow depths in the five western stations have declined by 0.5 to 1.11 in (1.3 to 2.8 cm) per year. In the southern part of the watershed, long-term average snow depths at three stations have remained stable, increasing at a rate between 0.01 and 0.06 in (0.03 to 0.2 cm) per year (Figure 4).

Table 1: Station details and record length for NOAA weather stations in and near Scott Valley.

Station ID	Station Name	Elevation (ft amsl)	Record Start Date	Record End Date	Record Length (years)	No. Missing Days
USC00041316	CALLAHAN, CA US	3085	1943-10-01	2018-11-30	75.2	62
USC00042899	ETNA, CA US	2960	1930-01-29	1951-09-30	21.7	10
USC00043182	FORT JONES RANGER STATION, CA US	2729	1936-01-09	2020-04-17	84.3	2030
USC00043614	GREENVIEW, CA US	2820	1941-08-01	2008-05-31	66.8	738
USC00049866	YREKA, CA US	2709	1893-02-01	2020-04-18	127.2	1690

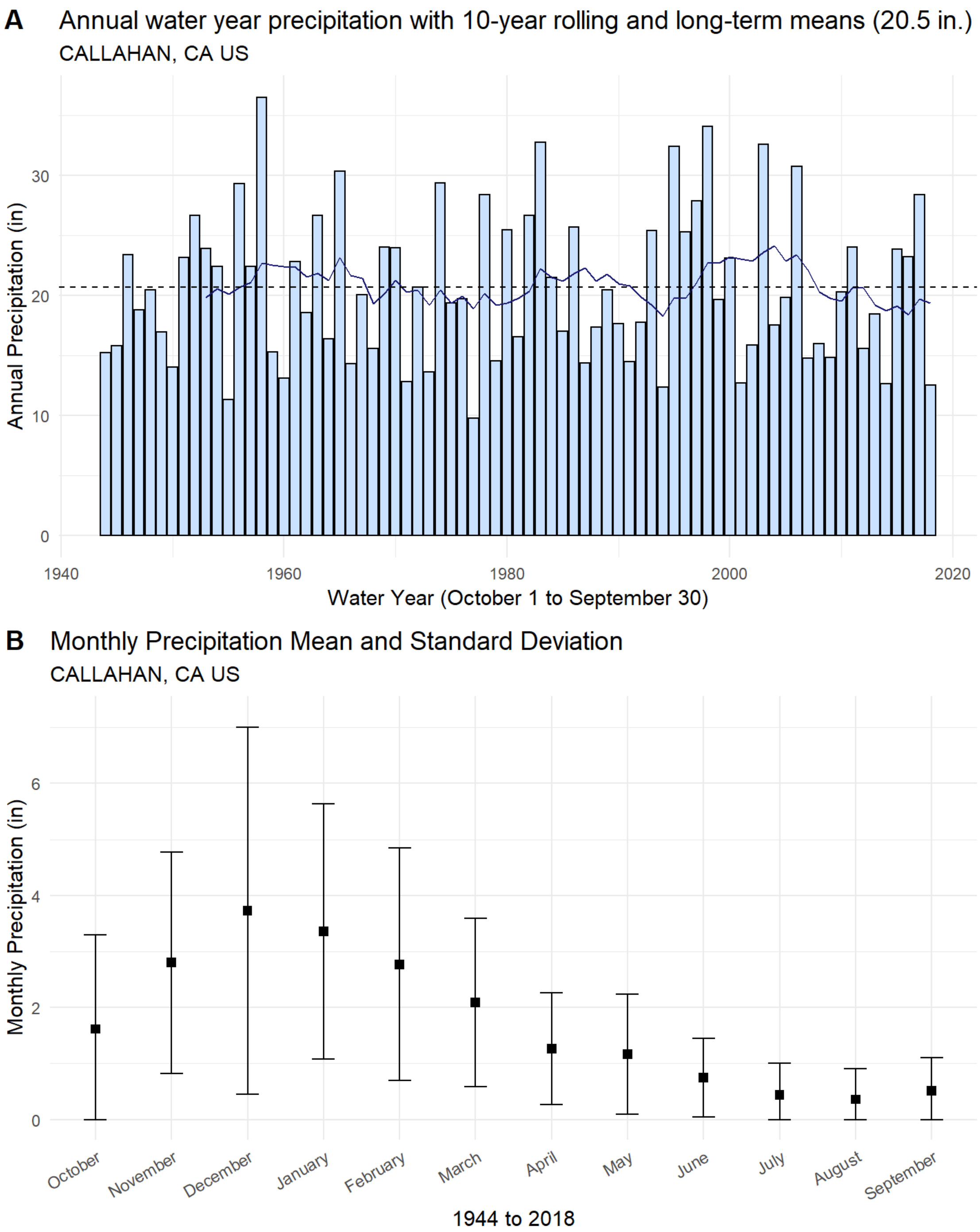


Figure 2: Annual (Panel A) and monthly precipitation (Panel B) over the period 1944-2018 as measured at the Callahan weather station (USC00041316). The Callahan data is shown because this weather station has the most reliable precipitation data (i.e., fewest missing values) over the longest period in Scott Valley.

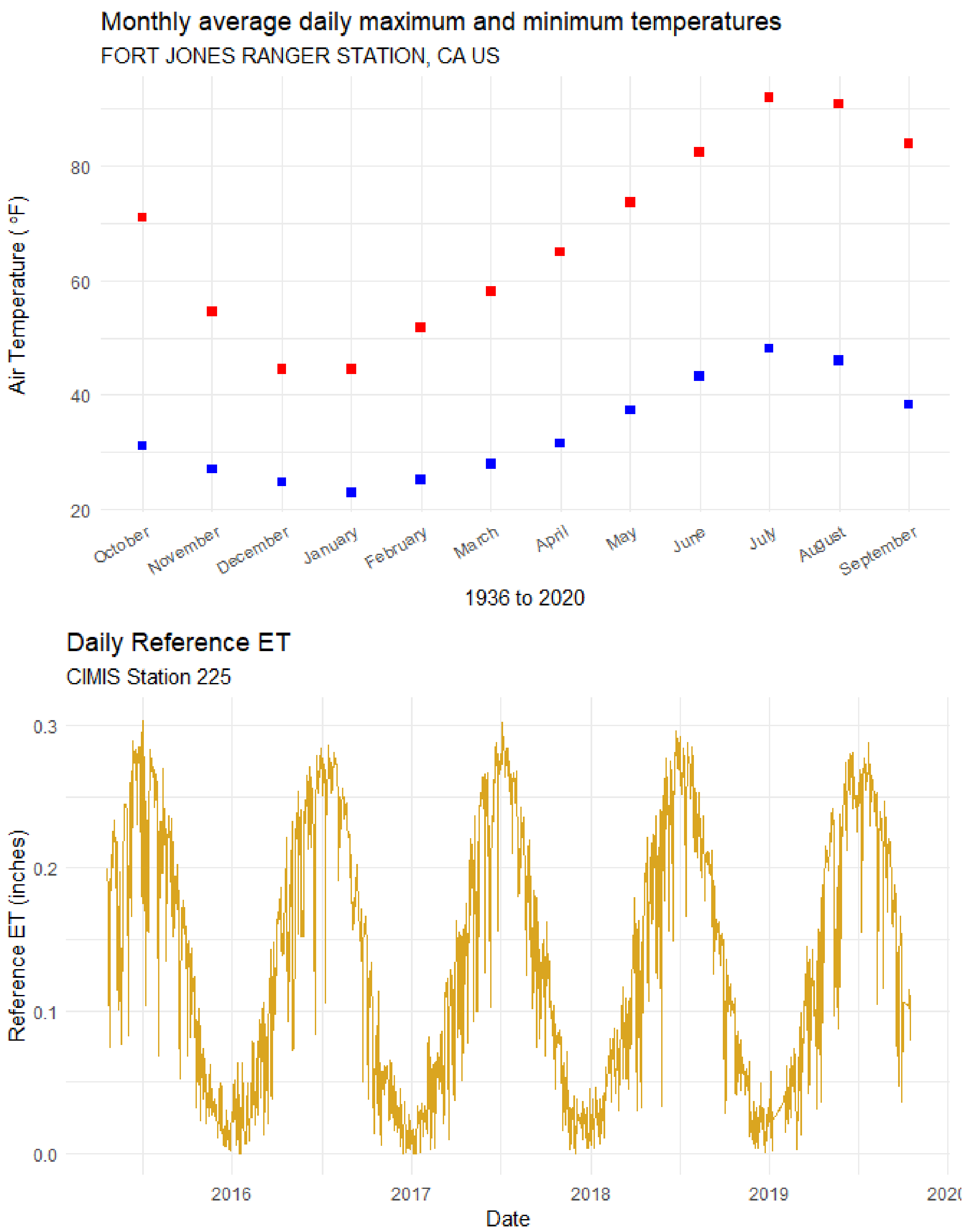
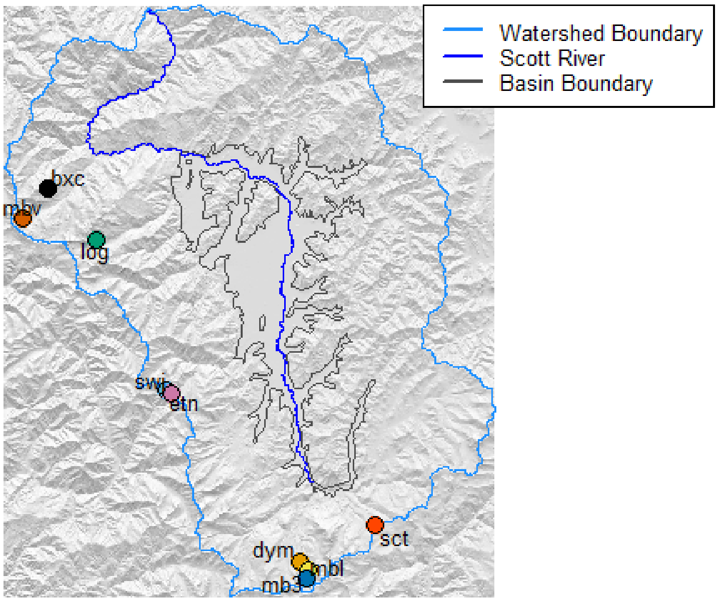


Figure 3: Monthly averages of daily maximum and minimum air temperature (top panel) over the 1936-2019 record at the Fort Jones Ranger Station (USC00043182), and reference evapotranspiration (ET) from 2015-2019 calculated at CIMIS Station 225 near Fort Jones.

Scott CDEC Snow Stations



Maximum Annual Snow Depth

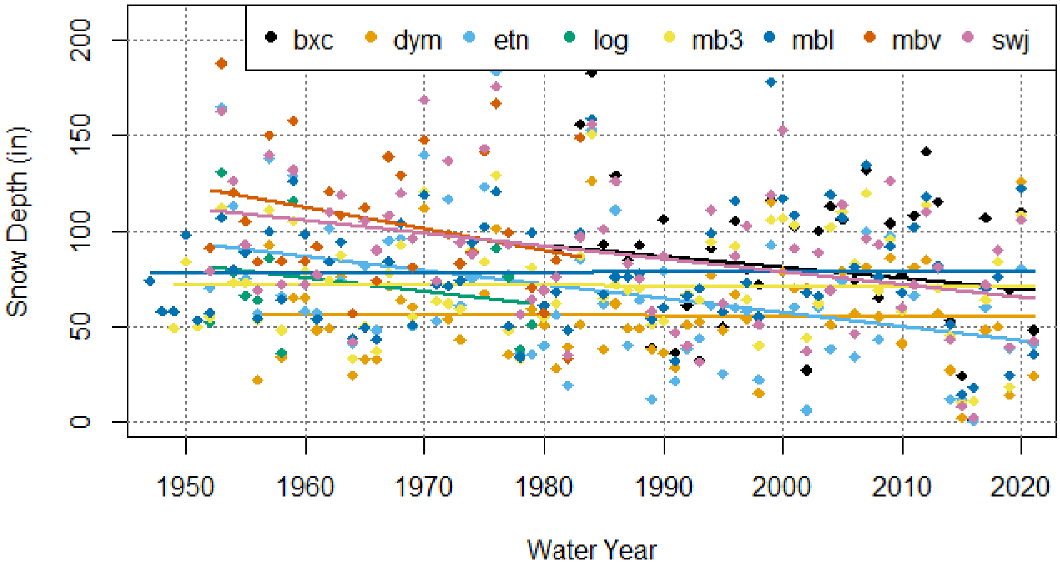


Figure 4: Annual maximum snow depth measured at eight California Data Exchange Center (CDEC) snow stations in the Scott Valley watershed. For more information see table below.

Table 2: Station details CDEC snow measurement stations in the Scott River watershed.

Station ID	Station Name	Elevation (ft amsl)	Operator
mbl	Middle Boulder 1	6,600	Salmon/ Scott River Ranger District
bxc	Box Camp	6,450	Salmon/ Scott River Ranger District
mbv	Marble Valley	5,900	None Specified
mb3	Middle Boulder 3	6,200	US Bureau of Reclamation
log	Log Lake	5,300	None Specified
sct	Scott Mountain	5,900	US Bureau of reclamation
dym	Dynamite Meadow	5,700	Salmon/ Scott River Ranger District
etn	Etna Mountain	5,900	Salmon/ Scott River Ranger District
swj	Swampy John	5,500	Salmon/ Scott River Ranger District

3.3 Geologic Setting

The geologic formations in Scott Valley can be divided into two units, the surficial alluvial deposits, and the underlying bedrock that also comprises the upland areas surrounding the Valley (Figures 5-7). The consolidated bedrock history of the Scott Valley area consists of a complex process and accretion and metamorphosis of several Klamath terranes. The Scott Valley is a tectonic Quaternary basin situated within the Paleozoic/Mesozoic Klamath Mountains Province. The terranes identified in the Scott Valley area contain similar rock type and all are of marine origin, except for plutons and intrusions. The formation of the modern alluvial Scott Valley occurred in recent geologic time, approximately 2 million years ago (MYA), by Basin and Range extensional tectonics.

Consolidated bedrock terranes in the Scott Valley area are, from east to west, progressively younger, with older terranes situated structurally beneath younger deposits. The Trinity and Rail Creek terrane plagiogranites, located in the southeastern uplands of the Scott Valley area and forming a portion of the uplands drained by the East Fork of the Scott River, are the oldest tectonic rocks identified in North America and mark the oldest convergent (non-cratonic) margin identified in North America (Elder, personal communication, 2009). A succession of terranes were accreted or deposited on the area between 450 and 130 MYA and are, in succession: Yreka terrane, Central Metamorphic belt, Stuart Fork terrane, and Western Paleozoic and Triassic belt (Sawyers Bar, Western Hayfork, Rattlesnake terranes). Several intrusive events occurred over this time period as well, creating the mafic intrusive complex (MIC) rocks that intruded into the Trinity terrane and consist of pyroxenite and gabbro, and the intrusion of major Klamath plutons (Russian Peak) consisting of diorite to granodiorite in the period between 174 to 138 MYA (Elder, personal communication, 2009).

Structurally, the Scott Valley consolidated bedrock deposits range from pre-Silurian to Jurassic and possibly Early Cretaceous age and consist of the following strata in order of upward succession: Abrams and Salmon schists, the Chanchelulla formation of Hinds, greenstones which correlate to either the Copley greenstone or the Applegate group, and ultrabasic and granitic intrusive rocks (Mack, 1958; State of California, State Water Resources Control Board, 1975).

Over time, the current Klamath Mountains underwent an uplifting sequence with the last major episode occurring 4 MYA, which accompanied a tilting of the Western Cascade ranges. Faulting and subsequent uplift of the Klamath Mountains caused the formation of a tectonic graben, of which Scott Valley is the western-most portion (Elder, personal communication, 2009). The current hydrographic position of the Scott Valley is controlled by activity that occurred along two of the principal faults forming the tectonic graben, the northern Greenhorn fault and the western Scott Valley fault. Indications are that the early course of the Scott River ran south-north and intersected the Klamath River at a point further to the east than currently, with the area comprising the current lower Scott River canyon belonging to a separate watershed. The activity along the Greenhorn and Scott Valley faults, however, caused a dip in the alluvial Scott Valley during the Quaternary period which resulted in the Scott River altering its course in the northern section of the alluvial valley and turning almost due west, capturing several tributaries as well. The activity along the Scott Valley fault also contributed to this stream capturing, and resulted in the realignment of several existing tributaries, which has left remnant alluvial fans which are now stranded (referred to as Pleistocene alluvium in Mack, 1958). The dip associated with activity along the Scott Valley fault has also resulted in a tilting of the bedrock across the valley floor from east to west, with a dip also in the northerly direction associated with the Greenhorn fault (Elder, personal communication, 2009).

The maximum exposed thickness of these remnant alluvial fan deposits is projected to be less than 50 feet. The deposits are poorly sorted and consist of sand and silty clay with well-rounded granodiorite, serpentine, chert, and quartzite boulders that average one foot in diameter. In the northern portion of the Scott Valley, the remnant alluvial fan deposits are found in isolated patches along the edges of the Oro Fino Creek Valley and Quartz Valley, and possibly near Etna Creek near the town of Etna. Those deposits along Quartz Valley and Etna Creek represent old alluvial fans formed by Shackleford and Etna Creeks. The alluvial fans consist of poorly sorted boulders of western-mountain origin set in a matrix of brown sandy clay to a depth of approximately 100 feet (Mack, 1958).

The remainder of the alluvium located in the Scott Valley is from a more recent time. It is composed of alluvial fan deposits, and stream-channel and floodplain deposits related to the present course of the Scott River and its tributaries. The recent alluvium ranges in thickness from 0 feet to possibly greater than 400 feet in the western portion of the Scott Valley, at its widest point. However, there is no evidence of alluvial material sufficiently coarse to support groundwater pumping below depths of 250 feet. The thickness of the alluvium decreases to both the north and the south. The alluvial deposits vary greatly in composition based on spatial distribution. Along the west side of the valley, from Etna northward to Quartz Valley, the principal streams have built large bouldery and cobbly alluvial fans which are generally most permeable in their mountainward reaches (fan apex). The channel deposits of these streams differ in the percentage of granitic bouldery material which they contain, ranging from mainly finer clay and sand to larger gravel and granitic boulder debris. The composition of the alluvium deposited by the tributary streams to the Scott River differs widely. While most of the tributaries run dry during the early part of the summer, due to irrigation diversions and infiltration of streamflow into the coarse gravel of the fanhead areas, other tributaries such as Crystal Creek maintain flow throughout the year owing to the relatively impervious nature of the underlying granitic rocks which prevent infiltration of streamflow to the groundwater aquifer (Mack, 1958).

At the downstream edge of the alluvial fans, the alluvium becomes progressively less coarse ranging to fine sand, silt, and clay. Groundwater well logs from these areas have shown that alluvium consists of lenses of water-bearing gravel confined between relatively impermeable beds of clay. The alluvium in this zone is much less permeable than the floodplain and stream channel deposits of the Scott River (Mack, 1958).

3.4 Aquifers

The Basin underlying the alluvial floodplain is the primary groundwater feature in the area. Valley alluvium is mostly Recent in age with a few isolated Pleistocene sections along the edges of the Valley as defined by CDWR (2004). The Basin is 28 mi (45km) in length, 0.5 to 4 mi (0.8 to 6 km) in width and covers a surface area of 100 sq mi (259 sq km). The predominant water-bearing units in Scott Valley are Quaternary stream channel, floodplain, and alluvial fan deposits (CDWR 2004). The Basin is recharged by infiltration from Scott River and its tributaries, snowmelt, precipitation, winter flooding of the floodplain, and water used for irrigation (Mack 1958). Recharge affects the groundwater levels, locally determining if sections of the Scott River are gaining or losing streams. In dry years, sections of the Scott River have become dewatered and channels have run dry as the water table dropped to a level beneath the bottom of the river channel (NCRWB 2005).

The Holocene stream channel deposits, comprised of unconsolidated sands, gravels, and clays that were deposited by the Scott River, are up to 260 ft (79 m) in thickness (SWRCB 1975). Permeability varies throughout these deposits with the highest permeability noted in the alluvium in the eastern portion of Scott Valley, a 1.5 mi (2.4 km) wide region between Etna and Fort Jones. This area is noted to have specific capacities of 67 to 100 gallons per minute (gpm) per foot of drawdown (Mack 1958). Wells in this region are mostly used for irrigation. Lower permeability areas located on the floodplain have been found to contain poorly sorted gravel and clay, potentially representative of alluvial deposits form intermittent streams from Hamlin Gulch (Mack 1958). Regions to the west of Fort Jones and to the south of Etna contain mostly shallow, domestic wells.

To the west of the Scott River floodplain are the lower permeability alluvial fans, deposited by streams that discharge from mountains west of the valley (Mack 1958). Gravelly deposits in stream channels and fans from West Patterson, Kidder, Etna, and Shackleford Creeks are the most permeable of these deposits (Mack 1958). Discharge from the base of the alluvial fan deposits in the western portion of Scott Valley, east of Hwy. 3 between Etna and Greenview, has resulted in a series of wet areas (“Discharge Zone”), with the water table close to or at land surface. The most notable of these areas is due to discharge of water from the West Patterson and Kidder Creek alluvial fans. Wells in the alluvial fan deposits generally tap permeable sand and gravel deposits, confined by impermeable clay layers above and below. On the western side of the valley, a perched water table of approximately 100 acres (0.4 sq km) is comprised of permeable alluvial fan material deposited by Kidder and West Patterson Creeks and is located above silty clay deposits. Sources of water inputs include precipitation and seepage from the springs in the surrounding bedrock. The older alluvium is not a significant aquifer as it is generally situated in localized areas above the water table and is limited in extent (Mack 1958).

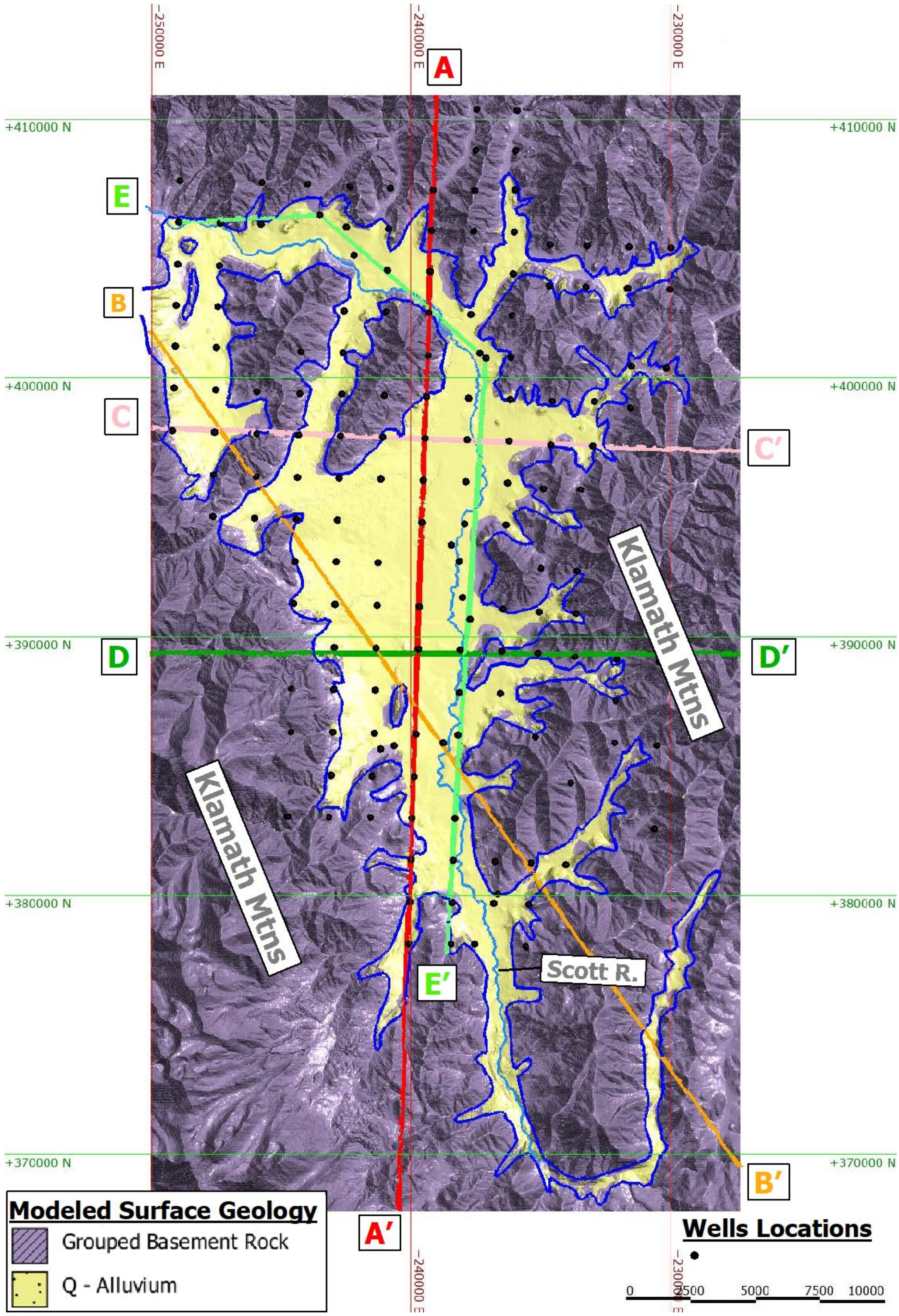


Figure 5: Scott River Valley Groundwater Basin map of cross-section locations.

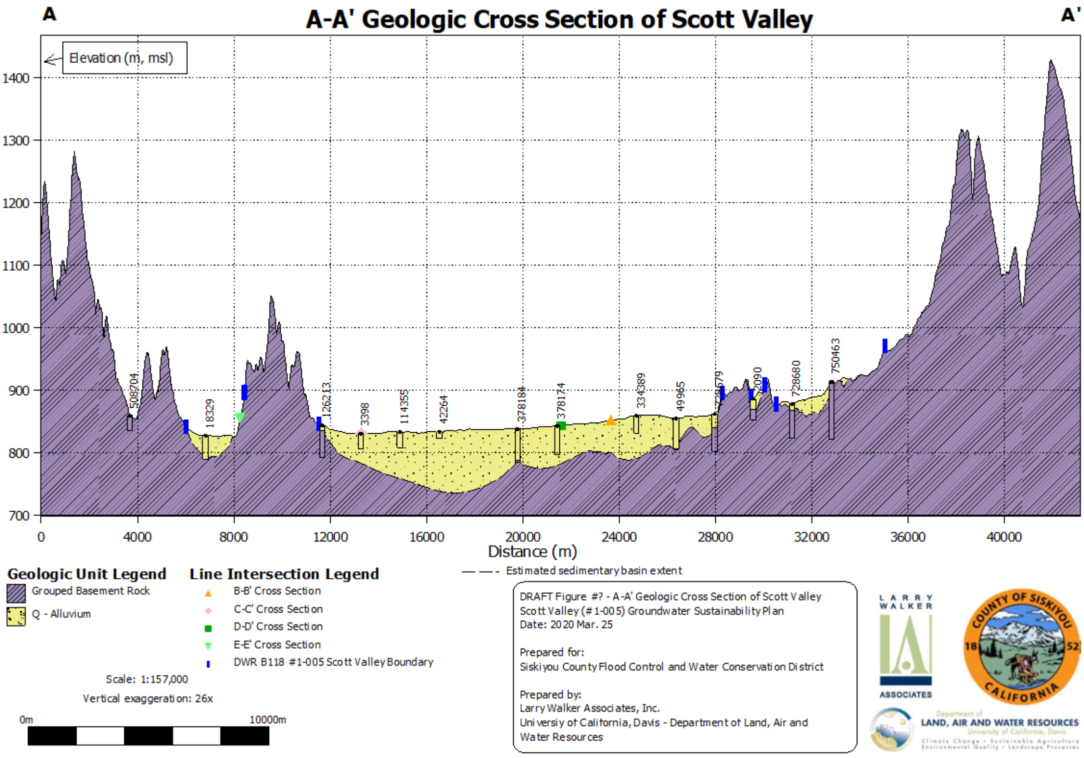


Figure 6: Scott River Valley Groundwater Basin Cross Section A-A'.

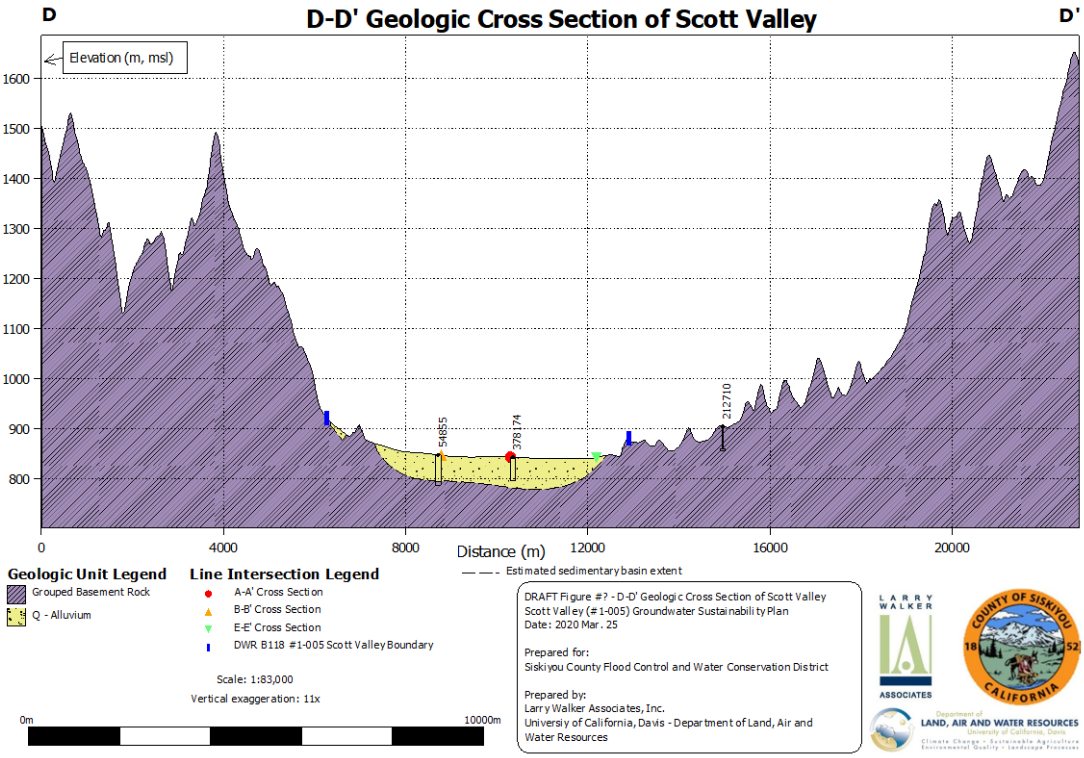


Figure 7: Scott River Valley Groundwater Basin Cross Section D-D'.

3.5 Soils

Soils in Scott Valley have developed on the floodplains, alluvial fans, and mountain slopes, with distinct characteristics in each location. The following discussion references map units, named for major soil components, in the 1983 soil survey of central Siskiyou County (USDA 1983). A map of soil orders in the Watershed is shown in Figure 8. The soil series discussed below are members of the soil orders shown on this map. The Settlemeyer, Diyou, Stoner, Duzel, Copsey, Bonnet, and Esro soils are Mollisols; the Stoner and Odas soils are Inceptisols; the Pit soils are Vertisols and the Deetz soils are Entisols (USDA 2019).

3.5.1 Floodplain Soils

The floodplain soils are deep and level to gently sloping. These soils consist of poorly to somewhat poorly-drained loams derived from medium to moderately fine-textured alluvium derived from various source rock. These soils tend to have a high water table and are prone to flooding in the winter and spring when contributions from rainfall and snowmelt are high. Present on the floodplains to the south of Fort Jones, Settlemeyer and Diyou soils have low slopes of 0 to 5% and 0 to 2% respectively and drainage is generally poor (USDA 1983). Both the Settlemeyer and Diyou soils have a stratified loam profile with fine sandy loam, silt loam, and sandy clay loam (USDA 1983). The floodplain soils also include minor amounts of poorly drained soils including Copsey, Odas, Pit, and Settlemeyer Variant soils, concentrated near streams and in higher areas in the floodplain in addition to Bonnet and Deetz soils. The very poorly-drained Esro soils, Xerofluvents, and Riverwash are present in the lower areas of the floodplain (USDA 1983). The Settlemeyer-Diyou map unit was identified as providing excellent habitat for birds and mammals (USDA 1983).

3.5.2 Alluvial Fan Soils

Alluvial fans form from steep tributary streams that flow onto alluvial deposits of the mainstem and tributaries. The predominant tributaries form expansive alluvial fans, which spread into the valley (ESA 2009). Soils that are formed on alluvial fans are nearly level to strongly sloped gravelly sandy loams that are very deep and well drained. The alluvium from which these soils formed is moderately coarse to medium textured and is derived from a variety of rock sources from tributary source areas. Stoner Soils are primarily located on alluvial fans in Scott Valley and have slopes ranging from 0 to 15%. These soils usually have a profile with a gravelly sandy loam and a very gravelly loam subsoil (USDA 1983). This unit also includes minor amounts of the Atter soil, which is somewhat excessively drained and contains rock fragments, and the well drained Duzel, Kinkel, and Kindeg soils that are located on the upper slopes of the alluvial fans. In the upper Moffett Creek area, Bonnet soil can also be present. It is a gravelly loam and a gravelly loam subsoil with accumulation of lime (USDA 1983).

3.5.3 Klamath Mountain Soils

Soils that develop on the slopes of the Klamath Mountain Range vary in character from shallow to very deep, well drained to excessively drained and medium to moderately coarse textured (USDA 1983).

3.5.4 Soil Agricultural Banking Index (SAGBI)

The Soil Agricultural Banking Index (SAGBI) identifies the potential for groundwater recharge on areas of land based on five factors: deep percolation, root zone residence time, topography, chemical limitations, and the condition of soil surfaces (O'Geen et al. 2015). SAGBI ratings for the soil series in the Scott Valley area can be viewed on a web application (app), developed by the California Soil Resource Lab at the University of California at Davis and University of California Agriculture and Natural Resources (UC Davis Soil Resource Lab and University of California Agriculture and Natural Resources 2019). The soils on the valley floor, predominantly of the Settlemeyer and Diyou type, have SAGBI ratings of "poor". In contrast, areas that are primarily composed of Stoner soils, located on the alluvial fans at the edges of the valley floor, have a SAGBI Rating of "good", and the isolated patches of soils of the Atter series have SAGBI ratings of "excellent".

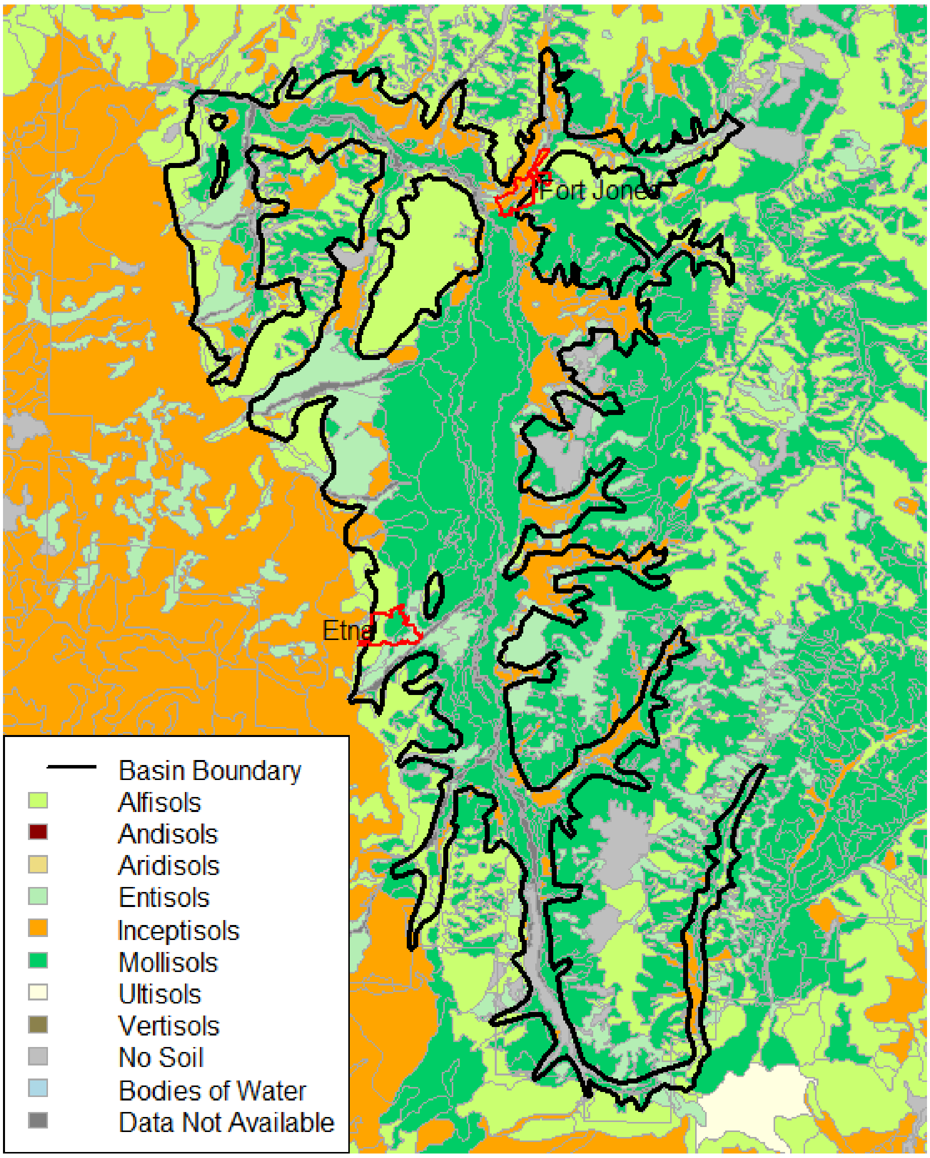


Figure 8: Soil classifications in Scott Valley.

3.6 Development of Land and Water Use

3.6.1 Historic Development of Land Use

Land management practices in the Scott Valley and the surrounding upland areas (Watershed) have had significant impacts on the hydrology and geomorphology of Scott Valley (ESA 2009). Practices such as beaver removal, mining, timber, flood control, population growth, and agriculture methods have altered the natural landscape and influenced current conditions in the Watershed (ESA 2009).

Historically inhabited by the Shasta Tribe, abundant natural resources drew additional people to the Scott Valley area. Hudson's Bay Company trappers arrived in Scott Valley in the 1830s, at a time when beaver were so abundant that Scott Valley was referred to as "Beaver Valley" (SRWC 2005). The subsequent decline in beaver population resulted in the loss of beaver ponds and dams (SRWC 2005).The removal of beaver populations from the area represented the first major anthropogenic change to the Scott River stream system, likely altering the channel morphology and influencing timing and duration of groundwater recharge (Kennedy, Shilling, and Viers 2005).

Coinciding with the California Gold Rush, gold miners reached Scott Valley in the early 1850s (SRWC 2005). Mining methods, and corresponding impacts to streams and the surrounding landscape, changed over time. Placer gold mining in the 1850s took place in Shackleford Creek, Oro Fino Creek, French Creek, and in the East and South Forks of Scott River (Sommarstrom, Kellogg, and Kellogg 1990). Hydraulic and sluice mining were predominant in the 1880s; later dredging activities on the upper Scott River and Wildcat Creek in the 1930s to early 1950s resulted in extensive movement of material that resulted in tailings piles in the upper Scott River Floodplains (SRWC 2005; Sommarstrom, Kellogg, and Kellogg 1990). Hydraulic and dredge mining activities significantly increased sediment loads in the streams, increasing the susceptibility of the main channel to flooding (Kennedy, Shilling, and Viers 2005). Small-scale gold mining activity has continued since 1950 near Scott Bar, and mining of gravel and sand continued in the mainstem of Scott River and Kidder Creek (SRWC 2005).

Following influx of residents during the Gold Rush, farmers and ranchers cultivated Scott Valley to support the local population. Land was used for cattle ranching, pasture, and crop cultivation, primarily growing alfalfa hay and grain (SRWC 2005). In 1958, CDWR reported 29,000 acres to be irrigated in Scott Valley, not including 2,000 irrigated acres in the East Fork (CDWR 1963, Table 8). In 1964, CDWR provided a similar estimate and reported the actual irrigated acreage to be 27,500 acres (CDWR 1964, Table 58). A decade later, in 1970, irrigated acreage had increased by 9% from 31,000 acres around 1960 to 33,700 acres including the East Fork irrigated area (CDWR, 1976, Table II-14). In 1970, pasture (19,300 acres), alfalfa (9,000 acres), and grain (5,000 acres) already were the dominant crops. Acreage with irrigation equipment in CDWR's year 2000 landuse survey (not including the East Fork above Callahan) is 28,000 acres (Foglia et al., 2018). In addition, the survey reports 3,400 acres of "DRY" and 2,100 acres of "SUB"-irrigated land parcels (Foglia et al., 2013). Hence, irrigated acreage in Scott Valley has been relatively stable over the past 50-60 years.

Timber has historically been a major industry in Scott Valley. However, a decline in the timber industry, combined with increased regulations and protections resulted in reductions in timber harvests since the 1970s with the final two timber mills closing in 2002 (SRWC 2005; Charnley et al. 2006). In a 1990 watershed analysis, logging roads, skid trails, and other roads constructed on highly erosive granitic soils were found to contribute significant sources of sediment to the streambeds of the Scott River and certain tributaries. These human activities caused about a 60% increase in accelerated sediment yield to the streams. Resulting sedimentation in lower gradient reaches negatively impacted the quality of spawning gravels and egg survival for salmon and steelhead (Sommarstrom, Kelloggg, and Kelloggg 1990). In Scott Valley, the impacts from logging are particularly notable in the steeper western and northwestern sections of the Watershed with erosion and sediment loading to streams (California NCRWQCB 2005).

Natural events, specifically major floods, have contributed to altering the landscape and stream system in Scott Valley. Floods have been recorded in Scott Valley since the 1800s and large flooding events, such as the 1955 and 1964 floods, had profound effects on the Scott River, moving large quantities of sediment to the Valley floor (Sommarstrom, Kellogg, and Kellogg 1990). Following flooding that occurred in 1937–1938, the United States Army Corps of Engineers implemented flood control measures including construction of levees along the middle section of the Scott River, channel straightening, and removal of riparian vegetation and debris (SRWC 2005). Further flooding events that occurred from 1940 to 1974 caused increased erosion and widening of the channel, prompting application of riprap for bank stabilization and levee construction along Etna, Kidder, and Moffett Creeks (Kennedy, Shilling, and Viers 2005).

3.6.2 Irrigation Practices

Early agricultural activities, prior to the late 1960s, were supported mostly through surface water diversions from the mainstem of the Scott River and its tributaries. In 1953, irrigated acreage was reported to total around 30,370 acres (123 sq km), with approximately 15,000 acres (61 sq km) relying on surface water for irrigation, 15,000 (61 sq km) acres relying on natural sub-irrigation, and 370 acres (1.5 sq km) dependent on wells (Mack 1958). Very little groundwater pumping occurred until the 1960s. In the early 1960, groundwater reportedly supplied only 3,400 acre-feet of irrigation water (CDWR 1964 [Table 58])

During the 1960s and 1970s, efficient wheel-line irrigation with sprinkler systems were introduced to Scott Valley, necessitating pressurization. Water pumped from wells provided the necessary pressure, but also a more certain water supply, allowing to expand crop acreage and the cropping season for alfalfa, but at much higher irrigation efficiency than flood irrigation with surface water: Prior to the 1970s, growers typically obtained two cuttings, with irrigation in average and dry years seizing sometime in July. After the 1960s, groundwater-irrigated alfalfa produced three cuttings with irrigation extended into August and early September. Furthermore, well drilling increased following periods of drought, with the most wells drilled following the drought of 1976 to 1977 and increasing again in 1992 (ESA 2009). Reliance on groundwater has increased with more than 50% of water used for irrigation at turn of the 21st century coming from groundwater (Van Kirk and Naman 2008).

While the irrigated acreage has not significantly changed in Scott Valley since the late 1950s, crop types have transitioned with decreasing amounts of small grains and increasing alfalfa through the 1990s (Harter and Hines 2008). In the past two decades, the center pivot method has been applied for irrigation, a change from the traditionally used and less efficient wheel-line irrigation method (Harter and Hines 2008). Primary irrigation methods used in the Valley are flood, wheel-line, and center-pivot. One area of the Valley known as the "Discharge Zone" also uses sub-irrigation, or direct uptake of water from the aquifer, as groundwater levels are at or near the land surface. Low elevation spray application (LESA) systems on center pivots, which further reduce spray evaporation (consumptive water use), have recently been introduced but are not common.

3.6.3 Water Diversions

Stream diversions began during the early gold mining era of the 1850s to deliver water through mining ditches and flumes on almost every stream from the South Fork down to Scott Bar. Hydraulic and sluice mining in the 1880s diverted large volumes of water to wash hillsides for gold recovery. Some of these ditches were later converted for irrigation use to fields." (SRWC 2005). Diversions are currently used for stock watering and domestic purposes throughout the year and irrigation diversions generally occur in the spring, summer, and early fall (ESA 2009). The majority of the diversions in Scott Valley are not monitored or managed by a watermaster.

Under the Scott River Decree of 1980, water rights were determined for the Scott River, the South Fork and East Fork of the Scott River, Wildcat Creek, Oro Fino Creek, other tributaries and lakes, and a defined zone of interconnected surface and groundwater. Under this decree, water is diverted for irrigation from April through mid-October. Allocations to USFS land for instream uses for fish and wildlife are also included under this decree (CDWR 1991).

Two notable diversions are located on the mainstem of the Scott River. Farmers Ditch is allocated 36.0 cfs from the Scott River Decree and supplies water to 10 users for irrigated pasture, while the SVID Ditch diverts water at Young's point and has an allocation of 43 cfs (CDWR 1991).

3.7 Hydrology

The major surface water feature in Scott Valley is the Scott River. Contributing 5% of the Klamath's total annual runoff, the Scott River is one of the four main tributaries to the Klamath River, with the confluence at River Mile 143 (Harter and Hines 2008). Major tributaries to the Scott River, shown in Figure 9, include Shackleford/ Mill, Kidder, Etna, French, and Moffett Creeks, as well as the East and South Forks of Scott River (ESA 2009). The East Fork of the Scott River originates on China Mountain and the South Fork originates in the mountain lakes to the southwest of Callahan (ESA 2009). After the two forks converge at Callahan, the Scott River meanders through the flat lands of the valley and then descends into a canyon prior to joining the Klamath River. The Scott River is 58 mi (93 km) in length, 30 mi (48 km) of which are located in Scott Valley, from the convergence of the East and South Forks to the head of the canyon. The portion of Scott River that flows through Scott Valley is a lower grade area between the steeper headwaters and the canyon reach of the river (ESA 2009).

Precipitation stored in the snowpack is an important water source of both stream flows and groundwater recharge. The mountains to the west of Scott Valley are drained by perennial streams which tend to flow southwest-to-northeast (Figure 9). The most significant of these tributaries have formed alluvial fans, on which the stream channels become braided or anastomosing prior to joining the Scott River (ESA 2009). These alluvial fans are locations where groundwater recharge occurs. The mountains to the east of the Valley receive less precipitation than the higher elevation western mountains and many of the eastern streams are ephemeral for most of their length and do not reach the Scott River, with the notable exception of Moffett Creek (ESA 2009; NCRWQCB 2005).

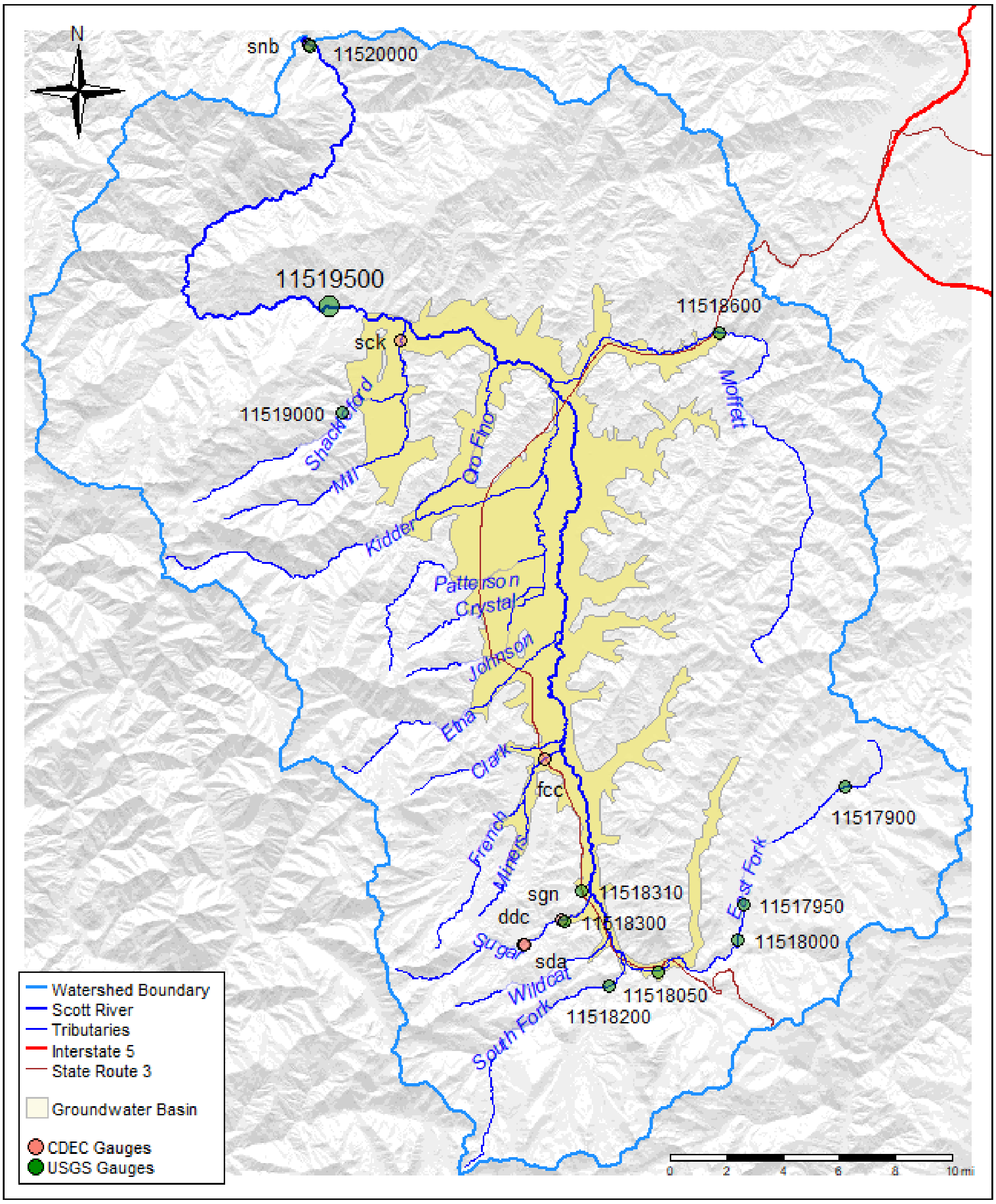


Figure 9: Main tributaries to the Scott River and locations of stream gauges.

Six subwatersheds, grouped by geographic region, have been defined in Scott Valley: the East Headwaters, West Headwaters, the Valley, Westside Mountains, the Eastside foothills and Moffett Creek, and the Canyon (SRWC 2005).

The East Headwaters encompass the East Fork of the Scott River above Callahan, which drains a 113.5 sq mi (294 sq km) area in the Scott Mountains and converges with the South Fork at River Mile 58. Elevations range from 8,540 ft (2603 m) on China Mountain to 3,120 ft (951 m) at Callahan; tributaries tend to be small and steep, flowing into low gradient channels at the base of valleys (SRWC 2005). Land uses in the surrounding areas are predominantly forest, rangeland, and irrigated agriculture.

The West Headwaters encompass the South Fork of the Scott River above Callahan, which drains a 39.3 sq mi (101.8 sq km) area with elevations from 7,400 ft (2,256 m) to 3,120 ft (951 m) at Callahan (SRWC 2005). Tributaries are generally small and steep and are impacted by snowpack and runoff. Land in this subwatershed is predominantly used for commercial forestland and wilderness areas.

The Valley encompasses the area from Callahan to the lower end of Scott Valley. Land in this area is predominantly used for agriculture. This subwatershed includes 60, 000 acres (243 sq km) and includes the alluvial deposits by tributaries to Scott Valley (SRWC 2005). Flood control and bank stabilization measures have been implemented along much of the channel in this subwatershed. Main tributaries include French, Etna, and Kidder Creeks. The mainstem of the Scott River in this subwatershed has a sinuous channel pattern, with a wide, flat floodplain and off-channel habitat. The average slope of the Scott River in this subwatershed is less than 0.1% (SRWC 2005). Streambed composition varies throughout this section from cobble-dominated in the steeper reaches near Callahan, sand-dominated in the low-slope reaches by Fort Jones and cobble-dominated in the rest of the channel (SRWC 2005; Sommarstrom, Kellogg, and Kellogg 1990).

The Westside Mountains are the source of some of the major tributary streams to Scott River including: Sugar Creek, French Creek, Etna Creek, Kidder/Patterson Creeks and Shackleford/Mill Creeks. Elevations fall in the range of 2,700 ft (823 m) in Quartz Valley to 8,200 ft (2,499 m) at Boulder Mountain. This subwatershed drains 181 sq mi, with precipitation at elevations above 5,000 ft (1,524 m) falling as snow (SRWC 2005). Headwater tributaries in this area are mostly steep, small, and low order with streamflows heavily influenced by snowfall. These high-gradient streams flow into lower gradient alluvial channels at valley bottoms. Most of the land in this area is wilderness and commercial forestland with some residences in the lower areas.

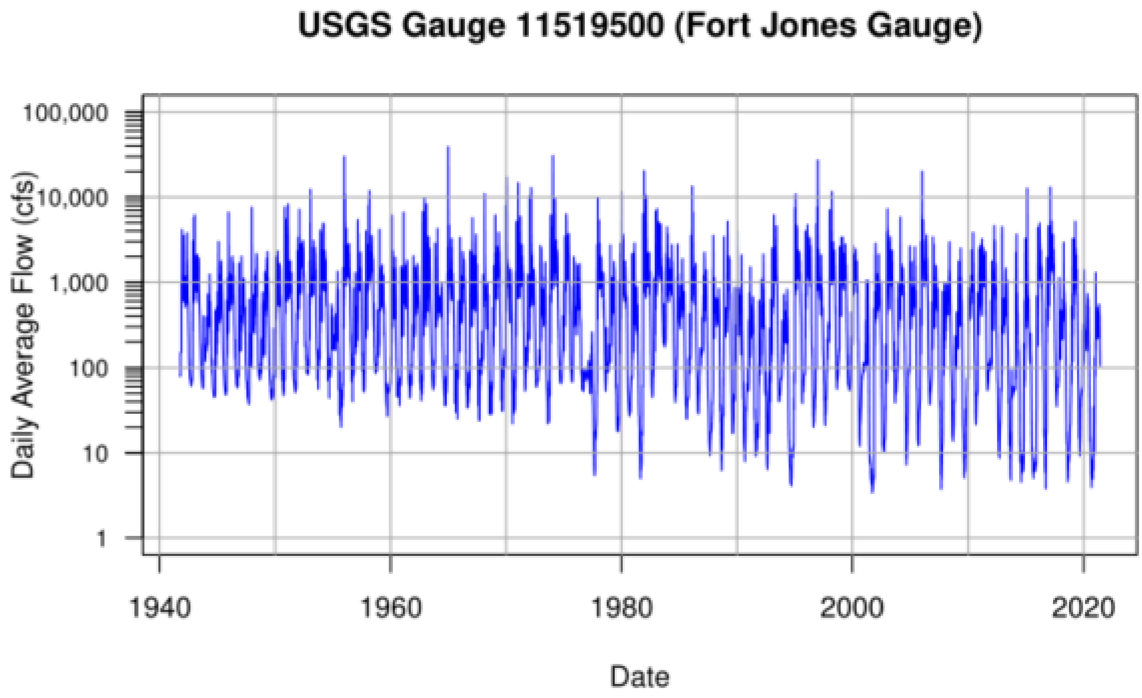
The largest watershed in the Eastside Foothills is Moffett Creek which drains 227.1 sq mi (588 sq km) with elevations ranging from 2,700 to 6,050 ft (823–1,844 m) (SRWC 2005). Other streams in the eastside foothills are ephemeral. The Canyon is a small subwatershed that includes 20 mi (32 km) of the Scott River that flows through a steep canyon, and is fed by perennial tributaries of Canyon, Kelsey, Middle, Tompkins, and Mill Creeks (SRWC 2005).

Within the recently developed functional flows framework for managing California rivers (Grantham et al. 2020), the Scott River system flows exhibit all five natural functional flow components: fall flush flow, winter storm flows, winter baseflow, spring recess, and summer baseflow. These five flow components characterize the strong seasonal variations in flows in the Scott River system. Fall flush flow in this Basin is the increasing discharge after the first significant period of fall precipitation, typically beginning sometime between September and November; winter storm discharge refers to peak discharge periods, typically in January or February, fed by winter storms, with intervening conditions of winter baseflow (typically several 100 cfs); spring recess is a period of mostly decreasing baseflow, as the snowpack melts off, from April to July;

summer baseflow (from less than 10 cfs to over 50 cfs) is a period of relatively steady flow conditions, fed mostly by groundwater discharge into the Scott River system, observed in August and September (USFS 2000).

Mean annual runoff from Scott Valley, measured at the Fort Jones USGS stream gauge (11519500) located in the Scott River Canyon just below the valley, is 440 thousand acre-ft (TAF). Discharge can be variable between different years, as illustrated in the Basin's history of floods and droughts. The total average annual Scott River flows range widely - from 54 to 1082 thousand acre-feet per year. For comparison, average annual applied water needs in Scott Valley are about 67 thousand acre-feet (with a range of 53-84 TAF).

Flows also vary widely within the same year. Winter and spring flows (December–May) average about 1,000 cubic feet per second (cfs) (28 cubic meters per second (cms)) but have peaked at 39,500 cfs (1,119 cms). Mean summer streamflow is 30 cfs (0.8 cms), but commonly drops below 20 cfs (0.6 cms) in the late summer and early fall. Most of the tributaries contributing to the Scott River come from the western side of the Valley, due to the eastern mountains experiencing a rain shadow effect as storms generally tend to track from west to east in the area. The streamflow record at the Fort Jones gauge from 1942 through 2019 is shown in Figure 10.



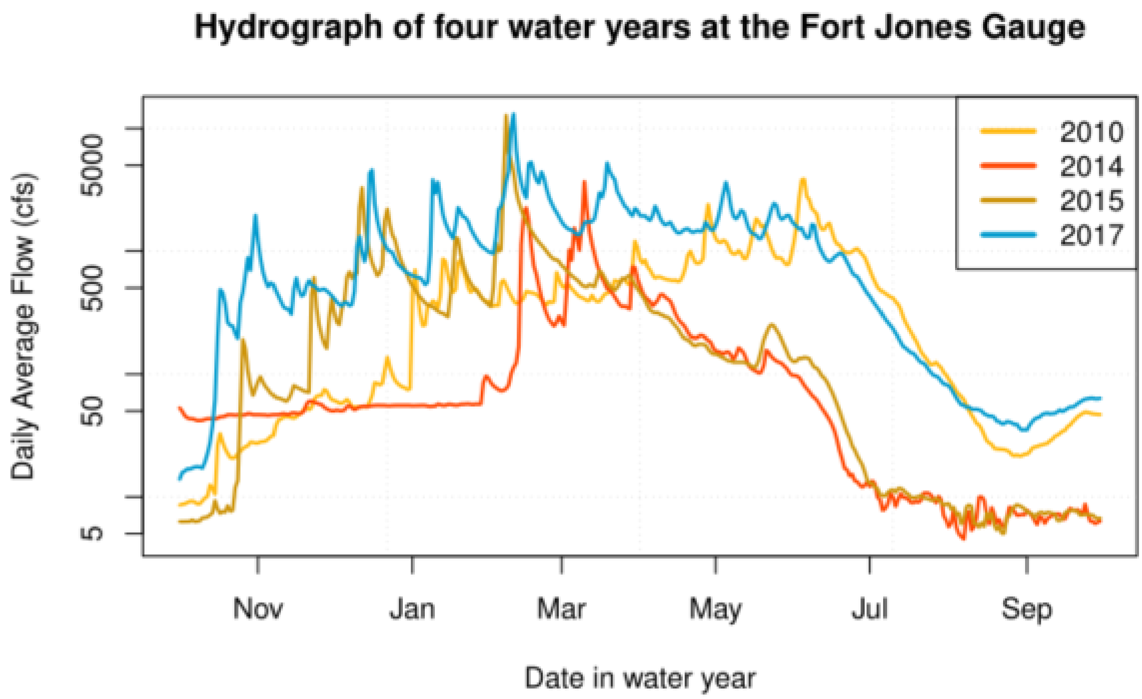


Figure 10: Streamflow record at the Fort Jones USGS Stream Gauge (11519500) from 1942 through 2019.

Much shorter stream flow records (one to few seasons) exist for the following tributaries:

- Shackleford Creek (1955-1960),
- Mill Creek (2004-2005),
- Moffett Creek (1958-1972),

- Kidder Creek (1972, 2002-2010),
- Patterson Creek (1972),
- Etna Creek (1955-1965, 1972),
- French Creek (2004-2016),
- Sugar Creek (1957-1972, 2009-2016),
- South Fork Scott River (1955-1972, 2001-2015), and
- East Fork Scott River (1955-1974, 2002-2015).

The magnitude of flows on these tributaries is strongly correlated to the magnitude of flow at the Fort Jones gage (Foglia et al, 2013, Deas and Tanaka, 2005).

The natural flow regime in the Basin determines the key ecosystem functions and supports aquatic species in the Basin (chapter 3.1). The five natural functional components of flows: the fall pulse flow, peak magnitude flow, wet-season baseflow, spring recession flow and dry season baseflow, are related to requirements of aquatic species at differing life stages. Each of these five flow regime components has key implications for the ecological functions of aquatic species in the Basin, particularly anadromous fish. The fall pulse flow is important for fall migrations, instream water quality and transportation of nutrients (California Environmental Flows Framework Technical Team 2020). The base flows during the wet season are vital to support migrations during this time period, peak magnitude flows transport sediment and influence channel geometry. Spring recession flows are vital for reproduction and migration and play a role in sediment redistribution. Finally, baseflows during the dry season support species through providing water quality and quantities during the dry season.

Of the five functional flow components, the timing of the spring recess, the amount of summer baseflow, and the timing of the fall pulse flow are particularly important to anadromous fish in the Scott River system. They are the most sensitive functional flow components with respect to depletion of surface water due to groundwater pumping.

Reaches of some major tributaries in the Scott Valley dry out every year (e.g., Kidder Creek between the Basin boundary and the confluence with Big Slough, or Moffett Creek from the Basin boundary to the confluence with the mainstem), and the duration of flow is highly dependent on precipitation timing and volume. During the summer baseflow season, most tributaries are dry or include dry sections (Figure 11). Only French and Shackleford Creek and the mainstem Scott River are largely perennial in average years. During dry years, all tributaries, and significant portions of the mainstem Scott River dry out. Flowing sections are entirely groundwater-fed.

Since the introduction of groundwater pumping in the 1970s (chapter 3.6.2), summer baseflow at the Fort Jones gauge has been measurably lower compared to gauge measurements from the 1940s to the 1960s, for comparable water year types. Dry year flows are typically less than 10-20 cfs with much of the Scott River and lower tributaries (within the GSA boundaries) falling dry until the first major fall precipitation events (fall pulse flow). Low stream flows have ecological implications, particularly for anadromous fish in the Basin that rely on sufficient flows for fall migrations and for suitable habitat. As shown in Figure 12, streamflow (as measured at the Fort Jones gauge) has often not been sufficient to meet the USFS water right and has generally been below the CDFW instream flow recommendation (CDFW 2017).

Lower baseflow conditions since the 1970s have also been attributed to climate change in addition to the onset of groundwater pumping after the 1960s, among others. Groundwater pumping has been shown to be the most significant factor causing the decline in base flow during July and August after the 1960s relative to the period prior to the 1970s (Van Kirk and Naman, 2008). In contrast, lower baseflow in September and October since the 1970s has been attributed to climate change as the dominant factor (ibid. Figure 6; Drake et al., 2000). Over the past 22 years, the relative frequency of below average and dry years has been much higher than during any period in the 20th century during which Scott River flows at Fort Jones have been measured (Figure 10). This has resulted in more frequent occurrence of baseflow conditions of less than 20 cfs, although low flows measured in recent years have not been lower than low flows measured prior to 2015 (Figure 10).

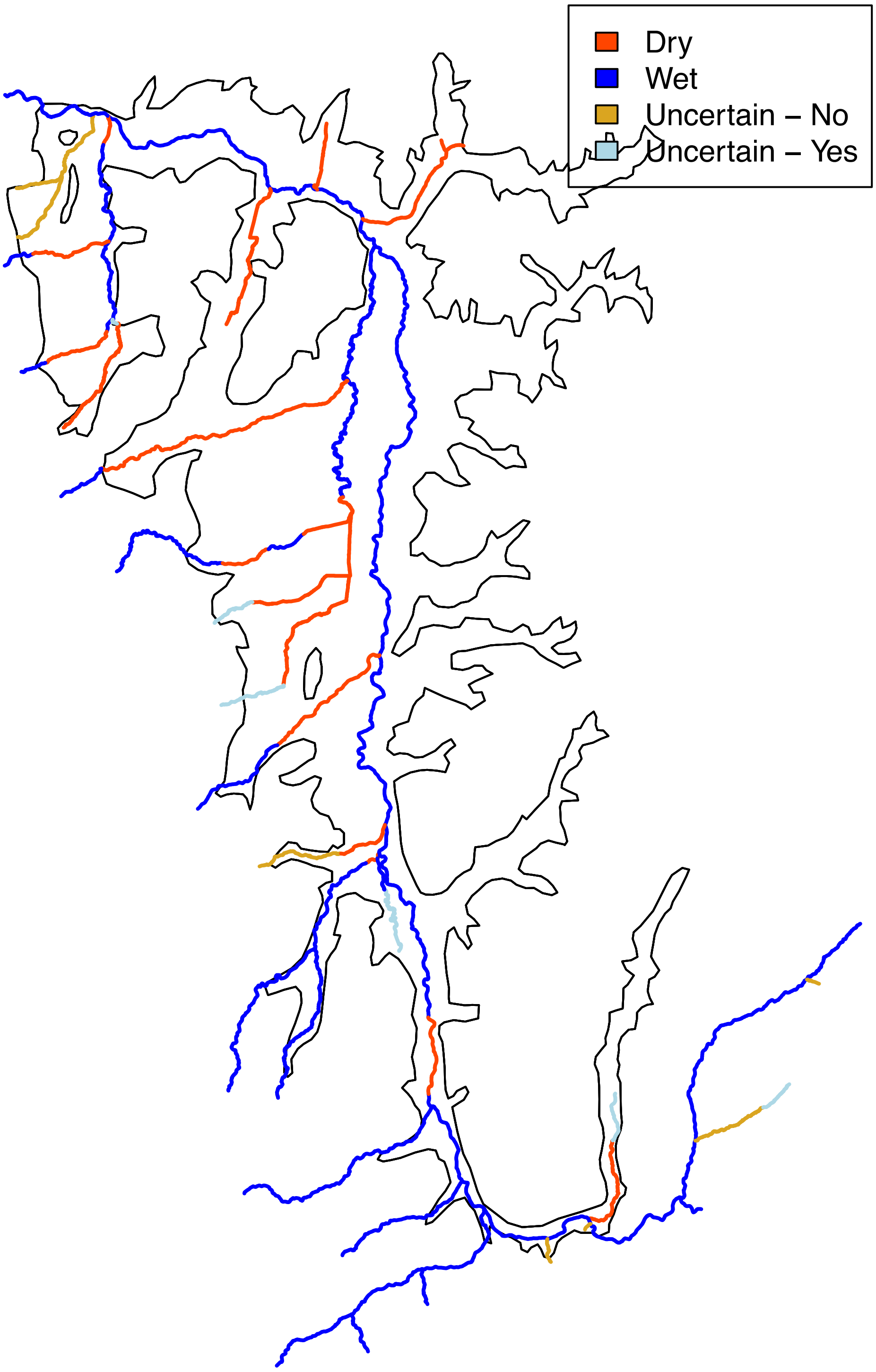


Figure 11: Baseflow (i.e., late summer and fall) conditions in the Scott River stream system during an average water year. Data from SRWC 2018.

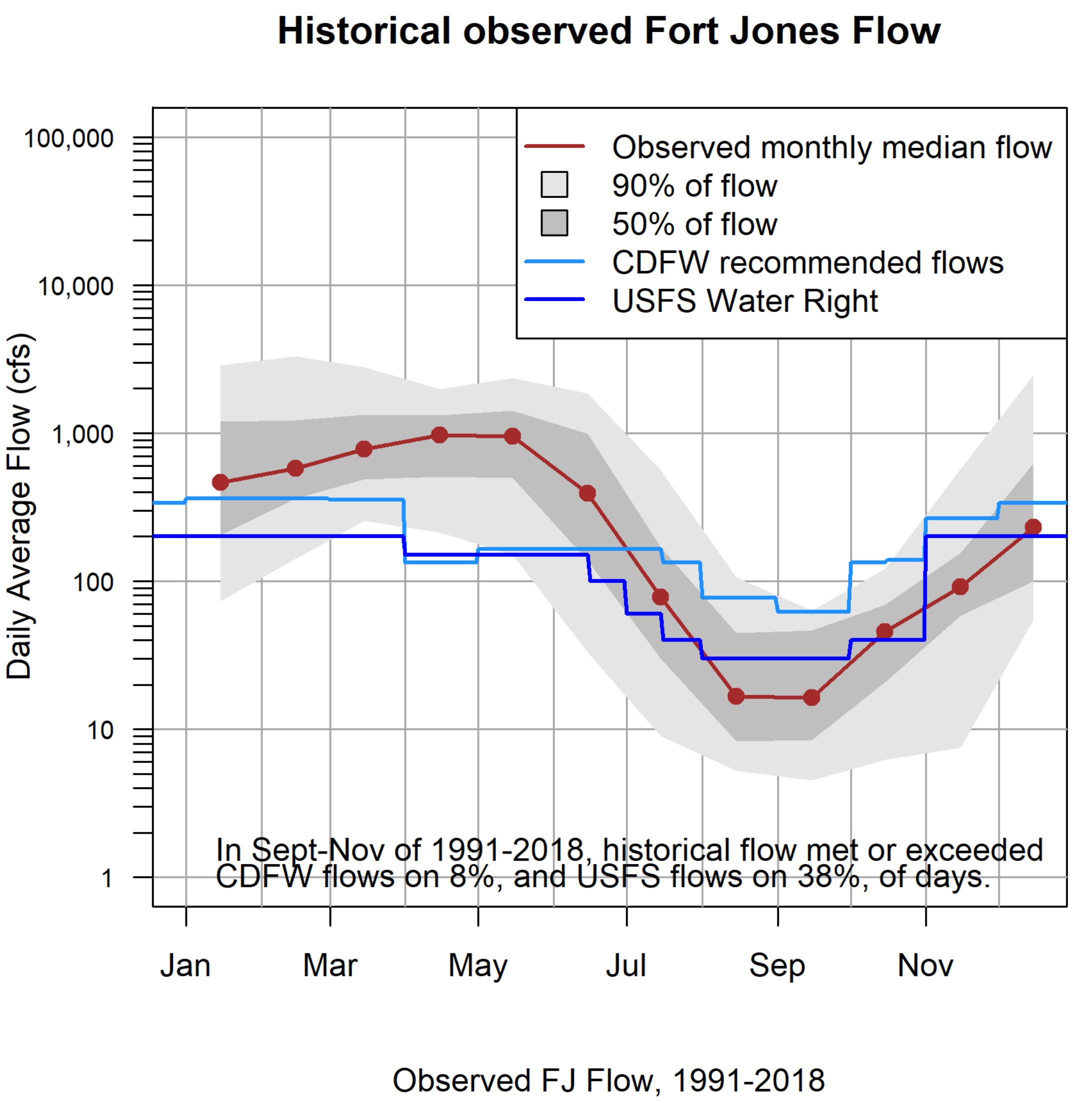


Figure 12: Range of historical monthly flows, January through December, as measured at the Fort Jones gauge, in comparison to CDFW recommended flows and the USFS water right. Monthly flows are the mean of daily average flow rates (measured in cubic-feet per second) over a given month. The observed median flow line indicates the flow that separates the wetter 14 months from the drier 14 months. In 14 of 28 years, flows fell within the dark grey shaded area. In 7 of 28 years, flows were within the lower light grey shaded area or just below that flow rate. Similarly, in 7 of 28 years, flows were within or just above the upper light grey shaded area.

3.8 Identification of interconnected surface water systems and stream depletion due to groundwater pumping

SGMA calls for the identification of interconnected surface waters (ISWs) in each GSP. ISWs are defined under SGMA as:

23 CCR § 351 (o): "Interconnected surface water" refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted."

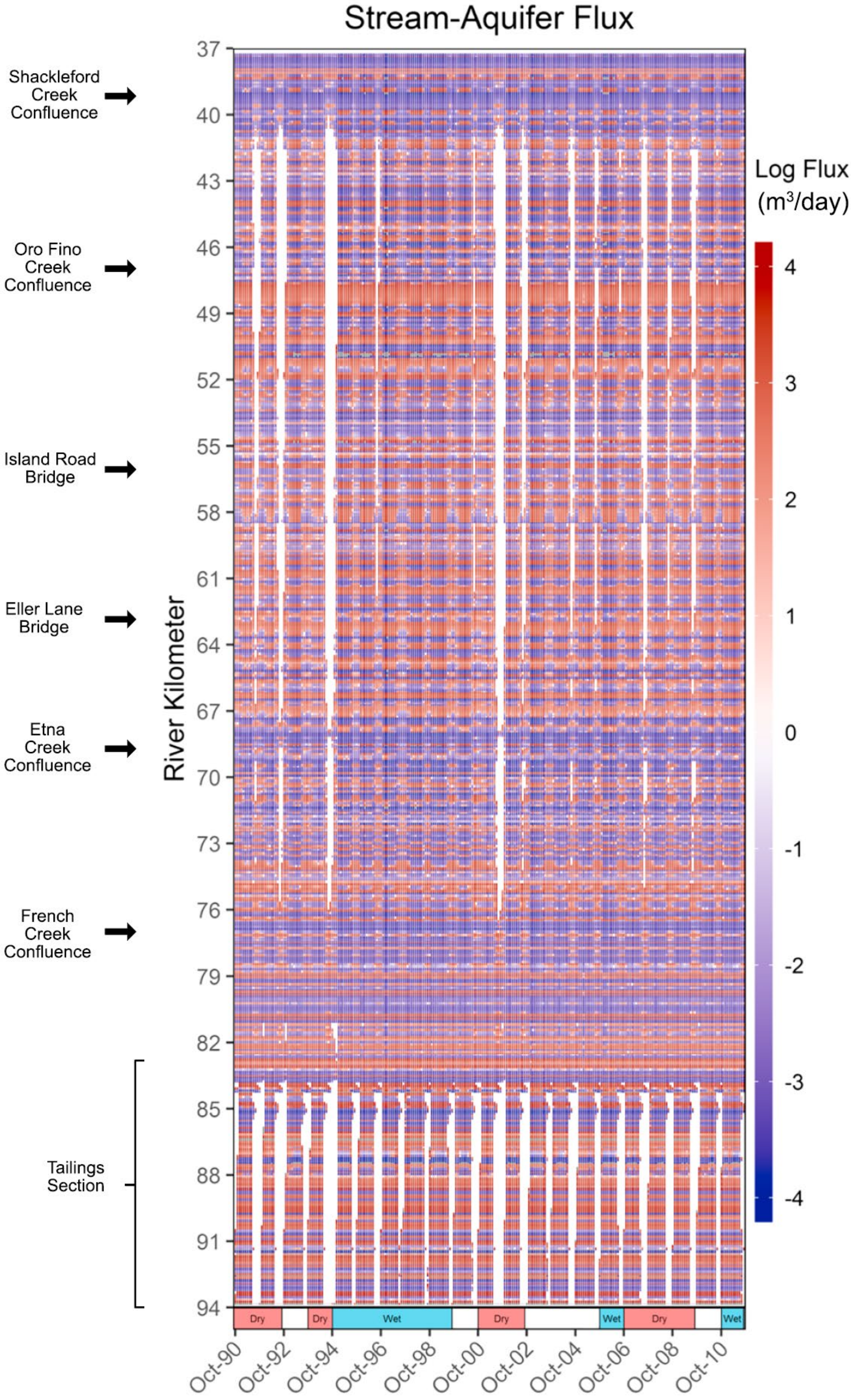
Because the water table in many parts of Scott Valley can be relatively shallow, the Scott River surface water network contains many miles of stream channel that are connected to groundwater. The direction of flow exchange (i.e., gaining vs losing stream reaches) varies over both space and time, and simulated rates of stream leakage or groundwater accretion to tributaries and the Scott River can vary by orders of magnitude.

Figure 13 illustrates the temporal and spatial variations in the direction of water exchange between groundwater and surface water. Losing sections are indicated by red colors and the positive value of the logarithm of the rate of stream leakage to groundwater. Gaining stream sections are indicated by blue colors and the negative value of the logarithm of the rate of stream accretion from groundwater. The vertical axis indicates the stream mileage location along the main stem of the Scott River with the lowest, most downstream location near the Fort Jones USGS stream gage at the top and the highest, most upstream location near Callahan at the bottom. The horizontal axis indicates the time, beginning with October 1990 and ending with September 2018 (Tolley, Foglia, and Harter 2019). White areas indicate locations and times when flow in the streambed is insignificant (effectively dry streambed conditions), although local, disconnected cold water pools may exist (not explicitly modeled).

This figure demonstrates that the stream and aquifer are highly connected in this system; water in the Scott River mainstem weaves in and out of the aquifer on its journey south to north. Long stretches of dry riverbed, both within the tailings and (less often) between the confluences of French and Shackleford Creeks, are common seasonal occurrences.

Similarly varying conditions exist along the tributaries of the Scott River where they flow over the groundwater basin. However, the uppermost section of tributaries, near the apex of their alluvial fans (e.g., near Etna and Greenview, close to the mountain front) are generally losing streams contributing significant recharge to the groundwater system.

Over the entirety of the basin, the streamflow system generally makes a net gain during wet years, but has a net loss to groundwater during dry years (see below, Figure 20). Gains and losses also fluctuate seasonally (see below, Figure 21) with most losses during the late rainy season (January through May) due to the large amount of recharge from tributaries when they first enter the basin, over the upper alluvial fans. Largest net accretion occurs during the dry season. During that period, recharge from the tributaries near the mountain front is small.



Stream-Aquifer Flux
Shackleford Creek Confluence
Oro Fino Creek Confluence
Island Road Bridge
Eller Lane Bridge
Etna Creek Confluence
French Creek Confluence
Tailings Section
River Kilometer
37
40
43
46
49
52
55
58
61
64
67
70
73
76
79
82
85
88
91
94
Log Flux (m3/day)
4
3
2
1
0
-1
-2
-3
-4
Dry
Dry
Wet
Dry
Wet
Dry
Wet
Oct-90
Oct-92
Oct-94
Oct-96
Oct-98
Oct-00
Oct-02
Oct-04
Oct-06
Oct-08
Oct-10

Figure 13. (Previous Page) Spatiotemporal heat map of fluxes between groundwater and surface water for the Scott River with geographic locations noted. Fluxes are highly spatially variable, despite relatively homogeneous parameterizationof the stream. White areas indicate dry reaches. Colors along the bottom of the plot indicate dry/critical (red) and wet (blue) water year types according to the Sacramento Valley water year hydrologic classification. The absolute value is the magnitude of the flux, while the sign indicates flux direction: Red and blue indicate losing and gaining reaches, respectively (reproduced from Tolley et al., 2019).

Across the stream system in Scott Valley (Figure 11), there are no known stream reaches that are flowing and also entirely and permanently disconnected from surface water, separated from the water table by thick unsaturated zones. For purposes of this plan, the Scott River and its major tributaries (Mill, Shackleford, Oro Fino, Moffett, Kidder, Patterson, Crystal, Johnson, Etna, French, Miners, Sugar, and Wildcat Creeks, South Fork and East Fork Scott River, Figure 9) are therefore all considered part of a single interconnected surface water system in the basin. The interconnected surface water system supports significant fish habitat and riparian vegetation.

The Scott Valley Integrated Hydrologic Model (Tolley et al., 2019) was used to compute the amount of stream depletion in interconnected surface water due to groundwater pumping within the basin as a whole, but also separately for both, the areas outside and within the adjudicated zone. The amount of stream depletion is computed for the location of the Fort Jones gage, by month, for the period 1990 – 2018 (see Chapter 6 for detailed description of methods and results). It is computed by comparing simulation of actual 1990 – 2018 conditions (basecase conditions) to hypothetical no-pumping scenarios, either outside or inside the adjudicated zone or across the entire basin (see Chapter 6).

In the no-pumping scenarios, individual fields that partly or fully depend on groundwater wells for irrigation are assumed to be covered by natural vegetation using rainfall and soil moisture only to meet its ET demand, with no access to groundwater. The potential ET of natural vegetation is assumed to be 60% of reference ET (well-watered grass). This potential ET rate is consistent with recent studies of natural vegetation (such as oak savannah and rainfed grasslands) transpiration (Maurer et al. 2006; Howes, Fox, and Hutton 2015). Actual ET is computed by SVIHM based on available soil moisture and may be lower than potential ET due to soils drying out during the summer and fall.

For the “no pumping” scenario and the basecase alike, only vegetation in the Discharge Zone is assumed to be able to consume groundwater for ET. The Discharge Zone is a known area of very shallow groundwater in the western central Basin, in a contiguous area of sub-irrigated pasture east of Highway 3 between Greenview and Etna (see below, Figure 22). The “no-pumping” scenario does not account for ET directly from groundwater due to groundwater-dependent ecosystems that would likely be in place in lieu of agricultural crops. It is therefore considered to provide a book-end, conservative maximum estimate of stream-depletion due to groundwater pumping. Truly unimpaired scenarios were developed separately at a late stage in the GSP process (see chapters 6 and 7).

Table 3: Estimated stream depletion, in September and October of 1991-2018, due to groundwater pumping in three geographic areas defined by the Adjudicated Zone (Superior Court of Siskiyou County 2018)**. "Days of Earlier Reconnection (FJ Flow > 20 cfs)" refers to the number of days between (a) the first fall date in the no-pumping scenario simulation when stream flow at the Fort Jones gage exceeds 20 cfs and (b) the date for the same event in the basecase simulation. The date is later in the basecase simulation due to groundwater pumping during the summer. We find that similar numbers of "Days of Earlier Reconnection" occur when flow thresholds of 10 cfs, 30 cfs, and 40 cfs are considered rather than 20 cfs.**

Well Area	Average Stream Depletion, Sep-Oct '91-'18, due to groundwater irrigation in this area (cfs)	Days of Earlier Reconnection (FJ Flow > 20 cfs) if no pumping occurred in this area
SGMA Wells (Wells outside Adjudicated Zone, OAZ)	25 – 29 cfs	22-23 days
Adjudicated Zone Wells (IAZ)	24 – 30 cfs	23-27 days
All pumping (all wells)	43 – 65 cfs	23-27 days

With simulation of these no-pumping scenarios it is possible to estimate the stream depletion attributable to groundwater irrigation inside the adjudicated zone (IAZ), outside the adjudicated zone (OAZ), and in the valley overall, by simple differencing:

$$FJ_{NPA1} - FJ_{Basecase} = \text{Depletion}_{\text{Pumping, A1}} \text{ (all in cfs)}$$

Where:

FJ_{NPA1} is the Flow at Fort Jones Gauge, No-Pumping in Area 1 Scenario;

$FJ_{Basecase}$ is the Flow at Fort Jones Gauge, Basecase; and

$\text{Depletion}_{\text{Pumping, A1}}$ is the Stream Depletion at Fort Jones Gauge due to groundwater irrigation in Area 1, where "Area 1" either corresponds to the entire basin, to the adjudicated zone, or to the area outside of the adjudicated zone.

The depletion is an important metric related to summer baseflow. But equally important from a functional ecological flows perspective (Figure 24) are changes in the timing of the spring recess and fall flush flow that may occur due to groundwater pumping. The same simulation scenarios used to compute stream depletion can also be used to compute the change in date, for a given year, at which flows first fall below (spring recess) or exceed (fall flush flow) various streamflow thresholds. Table 3 shows the difference, measured in number of days, of the fall date at which simulated streamflow at the Fort Jones gage first exceeds 20 cfs ("Days of Earlier Reconnection (FJ Flow > 20 cfs)"), between the no-pumping reference scenario described above and the calibrated basecase scenario (where the latter most closely simulates actual conditions over the 1991-2018 period). Table 3 provides both, the average September-October stream depletion and the range of days of earlier reconnection, between water years 1991 and 2018.

The annual September-October mean stream depletion varies between 25 and 29 cfs for wells regulated under the Scott Valley GSP. It is of similar magnitude (24-30 cfs) for wells in the adjudicated zone. Their combined mean September-October stream depletion effect (both areas not pumping simultaneously) varies from 43 cfs to 65 cfs across the 1991-2018 water years. In years when flows do not already exceed 20 cfs throughout August, flows climb above 20 cfs about 3 to 4 weeks earlier under the no-pumping scenario (Table 3).

4 SVIHM Update 1991-2018: "SVIHM-2018"

4.1 SVIHM Overview

The Scott Valley Integrated Hydrologic Model (SVIHM) is an integrated hydrologic model of the Scott Valley watershed above the Scott River canyon, that is, the catchment of the USGS Fort Jones gage on the Scott River (https://waterdata.usgs.gov/monitoring-location/11519500/). SVIHM consists of four separate conceptual models contained within three separate simulation tools:

1. An upper watershed model, based on statistical regression, representing daily runoff in the major tributaries at the locations where these enter the Scott Valley alluvial basin
2. A Soil Water Budget Model (SWBM) representing the landuse and vadose zone hydrology across the Scott Valley alluvial basin
3. A stream flow routing model representing the surface water system overlying the Scott Valley alluvial basin, using the MODFLOW 2005 Stream-Flow Routing (SFR) package
4. A groundwater model of the Scott Valley alluvial basin, using MODFLOW 2005 (Harbaugh et al., 2017)

SVIHM Model Structure. SVIHM simulations consist of a sequential execution of three software codes: the SVIHM tributary streamflow regression model (upper watershed model, written in the programming language R), the SVIHM SWBM (written in the programming language Fortran), and the SVIHM MODFLOW 2005 software (MS Windows executable code). The SVIHM tributary streamflow regression model provides streamflow estimates at the margin of the alluvial basin. These values are provided as input to SWBM and, subsequently, to the SFR package. The SWBM, which also uses climate, land use (including crop type, irrigation type, and irrigation water source), and soil data as input, computes soil moisture content, applied surface water amounts, applied groundwater amounts (groundwater pumping), evapotranspiration (ET), and recharge to groundwater. The streamflow routing model, using the tributary inflows computed by the upper watershed model, and subtracting the surface water diversions computed by SWBM, routes surface water through the Scott Valley stream systems, considering direct interactions with groundwater, through an integrated MODFLOW 2005 simulation with the groundwater model. The SFR model provides flow rates throughout the stream system. The groundwater model, using input from SWBM (recharge, pumping) and user-defined inputs (mountain front recharge, aquifer properties, aquifer structure), computes water levels and groundwater fluxes throughout the Scott Valley groundwater basin.

SVIHM Discretization in Time and Space. The streamflow regression model provides daily streamflow at 12 discrete tributaries entering the Scott Valley (Figure 9). The SWBM is a vertically one-dimensional tipping-bucket-type soil water routing model, applied to each of 2,119 landuse polygons, at daily time-steps (Figures 16 and 17). The SFR and groundwater model, simulated with MODFLOW-2005, is discretized into 328 ft x 328 ft (100 m x 100 m) grid cells, in two layers. The upper layer has uniform thickness of 50 ft (15.24 m). The thickness of the lower layer is variable depending on the depth to bedrock. Cell thickness in the lower layer is largest in the center of Scott Valley, with a maximum thickness of 201 ft (60.9 m) between Etna and Fort Jones. The model includes nearly 200 individually represented wells each associated with one or multiple land use polygons with groundwater irrigation needs. The model uses daily time-steps and monthly stress periods.

Previous SVIHM Documentation. The hydrologic conceptual model, the upper watershed model, and the SWBM model are described in detail in Foglia et al. (2013a, b). The SWBM model was subsequently updated with additional field information to adjust the irrigation rates, which is described in Foglia et al. (2018). An initial uncalibrated version of the Scott Valley groundwater and stream model using the MODFLOW "River" package, simulating the period for water years 1991-2011 is documented in Foglia et al. (2018). The final, calibrated version of that model uses the MODFLOW stream flow routing (SFR) package rather than the "River" package and is documented in Tolley et al. (2019). Here we refer to this latter model as "SVIHM-2011". A sensitivity and uncertainty analysis of a potential managed aquifer recharge project, and an application of SVIHM-2011 to develop stream depletion functions were published in the dissertation by Tolley (2019).

The SVIHM Update "1991-2018" extends the simulation period of SVIHM-2011 to and including the water year 2018 and is here referred to as "SVIHM-2018". SVIHM-2018 became the basis for multiple additional versions of SVIHM, representing numerous future scenarios as well as streamflow depletion scenarios, implemented for the 1991-2018 climate period. Scenario simulations are represented as specific, user-defined changes to the hydrologic "stresses" in the system. Therefore, they require changes in the input to the upper watershed model, the SWBM, the SFR, and the groundwater model. Some scenarios also require significant changes in the coding of the SWBM model.

Streamflow Regression Model: Though some flow monitoring exists for these locations, the stream gauge records do not cover the entire model period and are largely incomplete. Statistical analysis showed that existing daily flow records for tributary streams are best estimated using linear regression of the normalized, log-transformed daily flow data at the tributary stream gauge against the normalized, log-transformed daily flow data at the USGS Gauge 11519500 (Fort Jones Gauge). The Fort Jones gauge represents stream outflow from the Scott Valley. Two separate linear regressions were performed - one for the period period prior to water year 1973, prior to the occurrence of frequent summer flows below 30 cfs, and one for records falling into the period October 1, 1973, to September 30, 2011. Normalization with respect to mean and standard deviation of log-transformed daily flow data was performed separately for the time series records at each gauging station. The streamflow regression model is used to estimate a continuous daily flow record for the model period at each of the 12 inflow points from the upper watershed.

Soil water budget model (SWBM). SWBM is a FORTRAN-based calculator used to simulate water fluxes into and out of the soil zone, on a field-by-field basis, for 2,119 fields in the Scott Valley. It is described in more detail in Section 6 of Foglia et al. (2013a) and Section 3 of Tolley et al. (2019). In the SWBM, agricultural irrigation is calculated based on daily crop demand. Perfect farmer foresight of daily irrigation demand is assumed, and the water volume is attributed to either diverted surface water (i.e., Surface Water Irrigation in Figure 20) or pumped groundwater (i.e., Groundwater Irrigation/Wells in Figure 20) depending on which source(s) is (are) available for each field. Irrigation technologies associated with each field (i.e., flood irrigation, wheel line or center pivot) are used to calculate irrigation efficiencies. The soil root zone of each field is treated as a "tipping bucket" object: at the end of each day, any water remaining in the soil zone beyond its field capacity is assumed to recharge to groundwater. A small number of fields in the so-called "discharge zone" between Greenview and Etna, east of Highway 3, are sub-irrigated; ET in these fields is assumed to come not only from soil water storage but also directly from shallow groundwater (rather than applied irrigation), where the latter is simulated by the groundwater model. Additionally, all precipitation falling on cultivated fields or native vegetation is assumed to infiltrate into the soil column (i.e., runoff is neglected).

MODFLOW Model. The finite difference groundwater-surface-water model is built using MODFLOW-NWT (Niswonger et al., 2011), a version of MODFLOW-2005 (Harbaugh et al., 2017) that solves for unconfined flow using the Newton-Raphson solver. The packages used in the MODFLOW-NWT model include:

* SFR, streamflow routing package (Prudic, Konikow, and Banta 2004)

* WEL, well package (Harbaugh 2005)

* RCH, recharge package (Harbaugh et al. 2000; Harbaugh 2005)

* ETS, evapotranspiration segments package (Banta 2000)

* DRN, drain package (Harbaugh et al. 2000)

The integrated SVIHM is weakly coupled in that calculated fluxes are passed from the upper watershed streamflow regression model and from the SWBM to the MODFLOW model, but there are no direct feedbacks from the MODFLOW model back to the streamflow regression model or the SWBM (Tolley et al., 2019). The exception is direct uptake of evapotranspiration from groundwater in the "discharge zone". An explicit iterative process between MODFLOW and SWBM ensures appropriate allocation of the ET demand to the unsaturated (soil) zone and to groundwater.

A description of the structure of the MODFLOW groundwater-surface water model can be found in section 3.4 of Tolley et al. (2019). Key model construction information is summarized below. The model domain (i.e. the extent of active cells) is shown in Figure 22:

- 440 rows
- 210 columns
- 100-m (328 ft) gridcell lateral resolution
- cell depths of 0-61 m (0-200ft) thick
- 46,618 total acres within model domain (Figures 16 and 17)

    - 17,232 acres alfalfa in rotation with wheat
    - 16,362 acres pasture
    - 11,246 acres natural vegetation (ET, no irrigation)
    - 1,626 acres of pavement or cobbles (no ET, no irrigation)
    - 152 acres of water surface
- 164 irrigation wells and 55 monitoring wells (Figure 14)
- Nine hydrogeologic zones and three surface water channel zones (Figure 15)

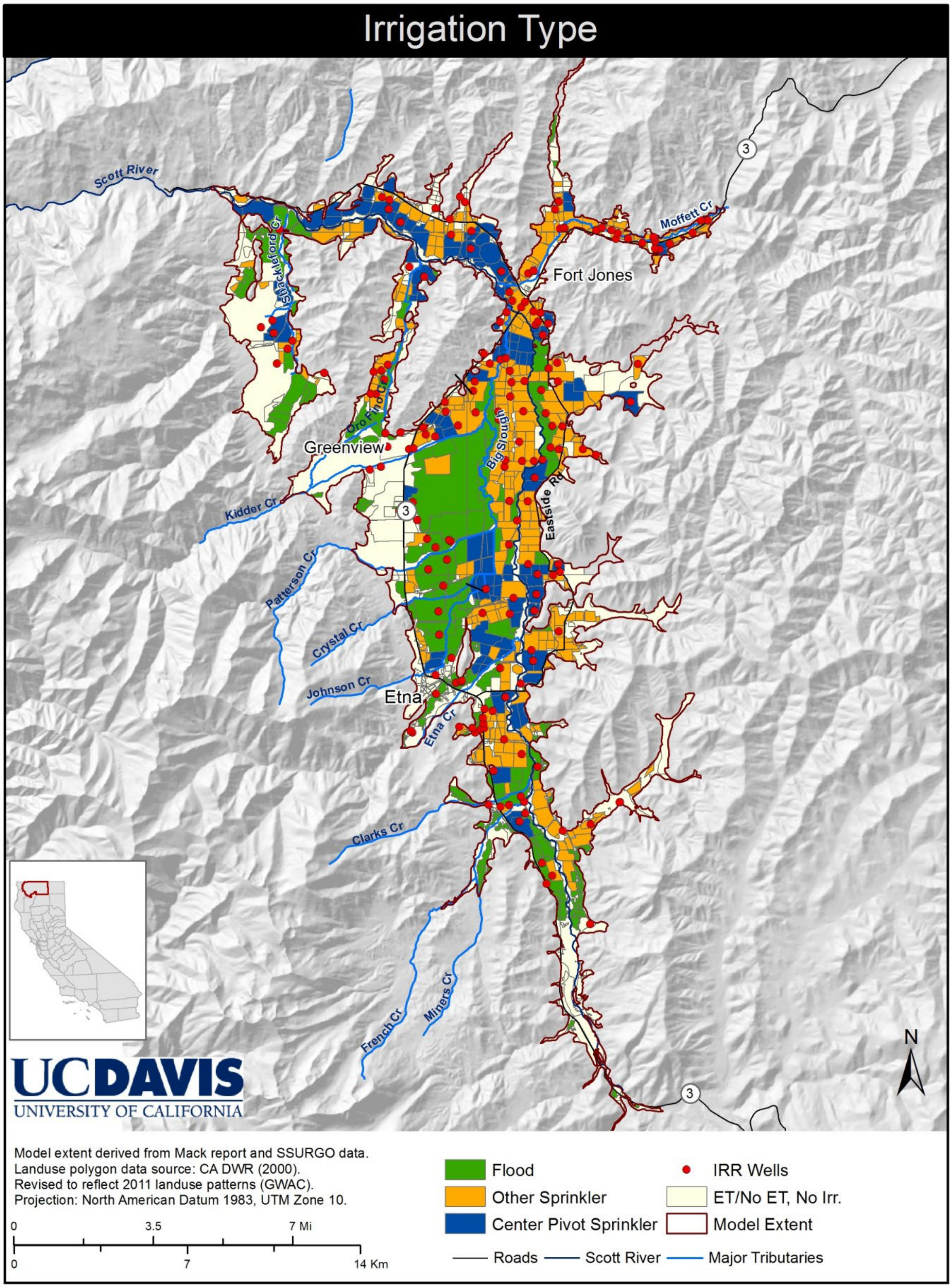


Figure 14. Map of the irrigation type and of the available irrigation wells for Version 2 of the integrated hydrologic model. Locations have been refined by inspection (see text) and may not coincide with those reported by the California Department of Water Resources. The irrigation type reflects recent (2011) conditions. The year of conversion from "Other Sprinkler" (typically wheelline) to "Center Pivot" is an attribute of the "Center Pivot Sprinkler" polygons, if the conversion occurred after 1990, and is taken into account in the soil water budget model.

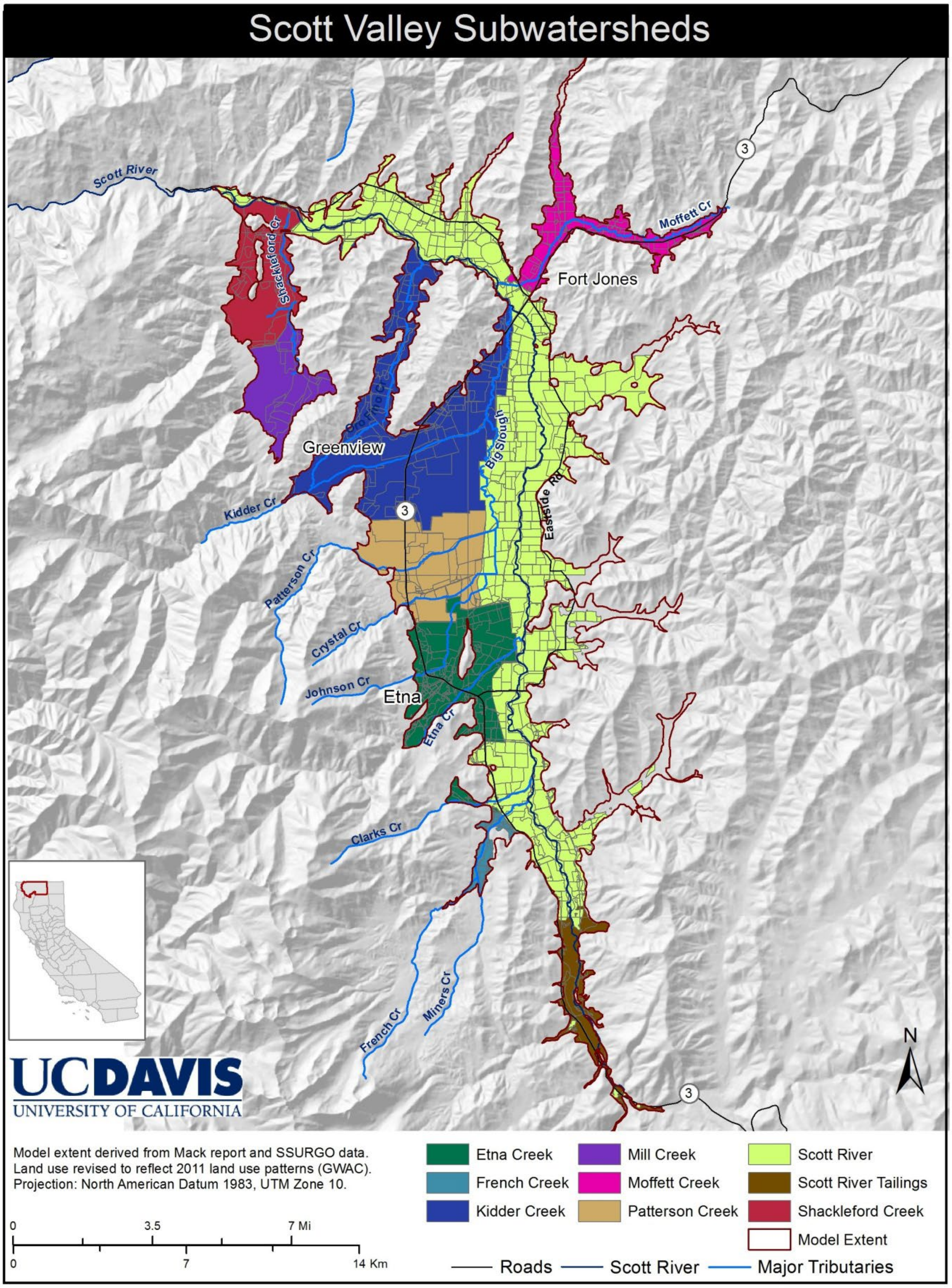


Figure 15. Map of the Scott Valley with the boundaries of the integrated hydrologic model study and the nine subwatersheds.

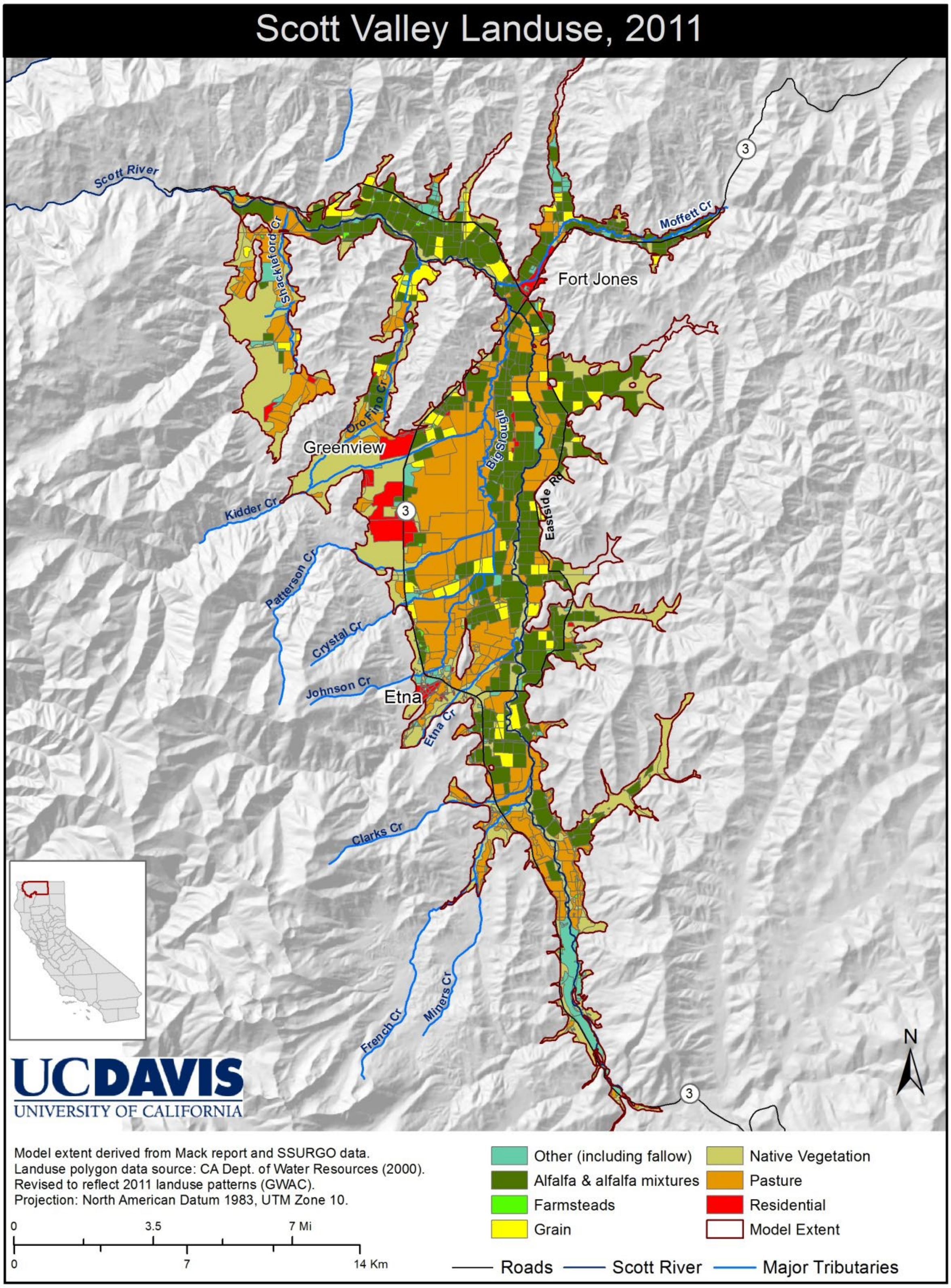


Figure 16. Land use categories based on CDWR 2000 map and updated for 2011 using suggestions from GWAC and local landowners.

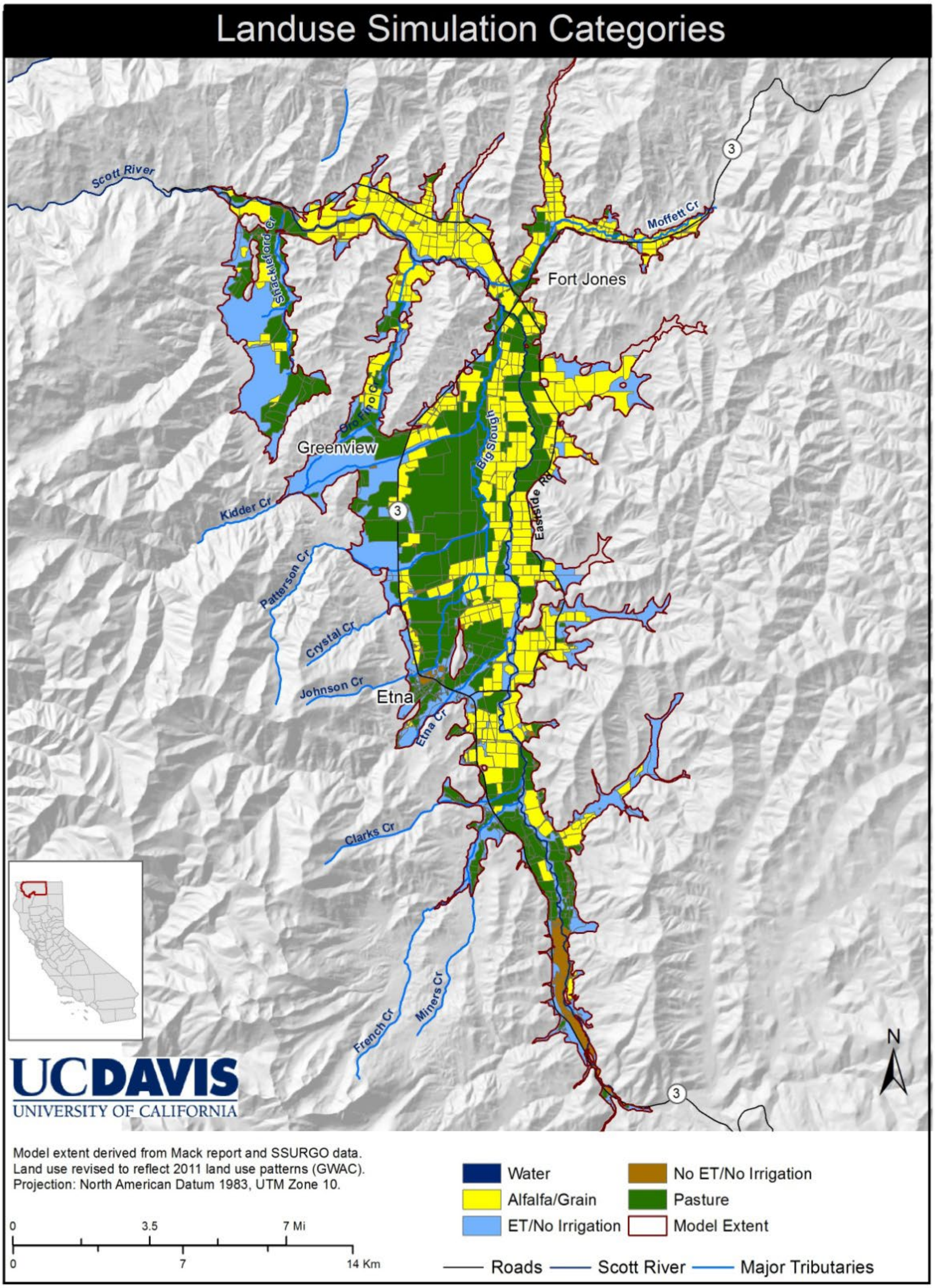


Figure 17. Aggregated five land use categories developed for the new conceptual soil water budget model from the landuse map shown in Figure 16.

4.2 Summary of Model Calibration and Sensitivity Analysis

Model calibration is a process for estimating parameter values that are unavailable or difficult to measure, such as the hydraulic conductivity of a geologic formation. The goal of calibration is to select parameter values that minimize the error in the model output (e.g., minimizing the difference between simulated and observed values for surface flow rates and groundwater elevations). Typically, this involves building the model using initial "best-guess" values for the difficult-to-measure parameters, then running the model many times using different parameter values, and recording the output to evaluate which parameter set generates the minimum error. "Gradient-based" methods use the information from past runs to select the next set of parameters.

Sensitivity analysis is used to calculate an overall index of how sensitive a desired model output (such as a flowrate in a single location, or the aggregate error in simulated groundwater elevation) is to a change in the value of a given parameter, such as the infiltration rate of a soil type. Sensitivity analyses can be "global" (covering the full range of possible values for all parameters) or "local" (starting with an initial parameter and deviating from it by set "perturbation" values).

In the calibration analysis, the end point of the analysis is typically determined by: 1) the convergence of the error function on an assumed irreducible value or 2) limitations imposed by computational resources. For a model like the SVIHM, which takes 4-5 hours to complete one simulation, global sensitivity analysis methods are commonly too expensive.

SVIHM Calibration Results. Calibration and sensitivity analysis of the 1991-2011 version of SVIHM was performed using the inverse modeling software suite UCODE_2014 (Poeter and Hill 1998; Poeter et al. 2014) and is described in more detail Section 3.5 of (Tolley, Foglia, and Harter 2019).

UCODE_2014 was used to automate the model calibration process, which included the following steps:

Sensitivity Analysis:

1. Select initial values for 61 parameters, including hydraulic properties of nine hydrogeologic zones, the amount of mountain front recharge, canal seepage, stream channel properties, and values in the SWBM related to deep soil moisture depletion, irrigation efficiency, and crop evapotranspiration.
2. Run the model forward to simulate groundwater heads and daily stream flowrates for the 1991-2011 model period.
3. Vary each of the 61 parameters by a small amount to determine sensitivity of simulated water levels and flow rates at monitored locations. Select the parameters for which model outcomes are significantly sensitive (14 parameters).

Calibration:

1. Run the model forward to simulate groundwater heads and daily stream flowrates for the 1991-2011 model period.

2. Compare the observed groundwater elevations and flowrates with corresponding simulated values. Record the difference; summarize the differences as the result of a weighted objective function. (Lower flow rates, for example, were weighted higher in the SVIHM calibration than higher flowrates to prioritize minimizing errors in low flows.)
3. Select a new set of 14 calibration parameters based on the results of past calibration runs and repeat steps 1-3 until parameters or the objective function no longer change significantly between calibration runs.

To account for the potential nonlinear effects of the initial parameter values, calibration of SVIHM was performed five times, using five sets of initial values for each of the 14 calibration variables (Table 2 in Tolley et al. 2019). Sections 4 and 5 of (Tolley, Foglia, and Harter 2019) describe the SVIHM calibration results in detail; key summary quotations are included below for convenience:

- The largest variations were observed in Kx1, Kx3, and Sy1, which ranged over an order of magnitude for hydraulic conductivity and varied up to 50% for specific yield. Parameters contained within SWBM showed similar variations across runs but with much less variability due to tighter imposed constraints. None of the parameters were calibrated to unreasonable values, with only a few limited by upper or lower calibration bounds.
- Values of DFBETAS and Cook's D show that timing of the most influential observations occurs during or immediately following the lowest period of streamflow during the year.
- The most sensitive parameters in SVIHM are crop coefficients for alfalfa and pasture, which control water demand (ET), and the SMDF for alfalfa/grain fields, which affects how much irrigation water is applied and therefore recharge rates for that land use type.

4.3 Model Extension and Validation

SVIHM development began nearly a decade ago in 2011, and the initial data summary and model input production was documented in Foglia et al. 2013 and Foglia et al. 2018. The calibrated version of SVIHM documented in Tolley et al. 2019 simulated conditions in the 21-year period between Oct. 1990 and Sept. 2011. Here, this SVIHM version is referred to as SVIHM-2011.

SGMA requires water budgets to include the 20 years prior to 2015, so an extension of SVIHM was necessary in order to use it for the Scott GSP. Work on this model extension began in 2019, so the extension period was 7 years, ending in Sept. 2018. Here, this version of SVIHM is referred to as SVIHM-2018.

While not re-calibrated, model results for this extended period version of SVIHM are an opportunity for an important model validation experiment, which analyzes how closely the parameter values, calibrated on observations in water years 1991-2011, can replicate observations from Oct. 2011 - Sept. 2018.

4.3.1 Methods for Extending Precipitation, Tributary Inflow, and ET

Extending the model period consists of extending key climate records that drive model behavior: valley floor precipitation, tributary inflow, and ET.

Precipitation. The precipitation record consists of a daily depth value and is calculated as the average of the rainfall values for the Callahan and Fort Jones weather stations. On days with missing values in these two rain records, the value is calculated based on data at other stations. More details are included in Section 4 of Foglia et al. 2013 and below.

Though evidence exists of higher rainfall on the western side of the valley, the location of existing gauges did not allow estimation of a rainfall gradient at the time, so a single daily value was used. In a future version of the model, it may be possible to develop a spatially-explicit rainfall record that reflects this rainfall gradient, using the data from several new private rain gauges installed during monitoring efforts for the GSP in 2019-2021.

Based on methodology described in Foglia et al. 2013, the original rainfall record was generated in Excel. To extend the model, a researcher implemented the same methodology in R (R Core Team 2020), the statistical programming language. The steps in the method are:

1. Align all available precipitation data by date in one table. For this extension, the records used were from the following weather stations (with their NOAA identification code):
   - Callahan (USC00041316)
   - Fort Jones (USC00043182)
   - Etna (USC00042899)
   - Greenview (USC00043614)
   - Yreka (USC00049866), long-term record
   - Yreka (US1CASK0005), more recent record

   The original precipitation record relied only on the first four stations in this list, but for this extension, it was necessary to add the two Yreka stations (which, notably, are outside the Scott River watershed) to fill in gaps with no records at the other stations in the 2012-2018 period.

2. Make a table of relevant values (slope and R^2^) for the set of 0-intercept linear regressions in which the Callahan and Fort Jones stations' precipitation record is predicted using each other station's record, segregated by month. The total set of linear models calculated is [2 predicted values] * [6 predictors] * [12 months] - [24 combinations where x = y] = 120 total linear regressions.
3. For each missing value in the daily Callahan and Fort Jones records, estimate the precipitation on that day using the linear regression model for the relevant month with the highest R^2^ value.
4. Once all gaps have been filled in this manner, average the values for each day for Callahan and Fort Jones.

Due possibly to corrections in the online databases from which records were obtained, this method was unable to exactly reproduce the original 1991-2011 precipitation record in the 2019 version of SVIHM. Therefore, the daily rainfall values produced using the R software were used only for water years 2012-2018 (and for five leap days, which were not included in SVIHM-2011).

Tributary Inflow. The daily flow records for tributary inflow to the model domain were extended using the Fort Jones record, Oct. 2011 - Sept. 2018, and the existing Streamflow Regression Model script in R. Although at least one tributary flow gauge has recorded additional observations since 2011, the tributary flow records used to build regression models with the Fort Jones record were kept consistent between the 2019 SVIHM version and the extended version. In future work, expanding the tributary datasets may improve the Fort Jones Gauge-tributary flow predictions.

Evapotranspiration. The evapotranspiration data that drives irrigation demand in SVIHM is denoted as ET_{ref}, or the ET measured over a reference short grass crop. Crop coefficients are used to convert this daily value into irrigation demand for different crops. The ET_{ref} model input for the 2019 version of SVIHM was calculated using the NWSETO program (Snyder, Orang, and Matyac 2002). Additional details are in Section 6 of Foglia et al. 2013.

For this extension, two data sources were used. CIMIS Station 225 was installed in northeastern Scott Valley in 2015, and this ET_{ref} record is used for the days in which it is available (CDWR 2021). The second source, used to bridge the gap between the end of the 2019 ET_{ref} record in Sept. 2011 and the start of the CIMIS Station 225 record in 2015, was interpolated Spatial CIMIS data products (CDWR 2007). The location used to generate the Spatial CIMIS output was the location of the current CIMIS Station 225.

4.3.2 Flow Matching

Methods of validating the quality of flow-matching include:

- Visual comparison on time series plots (Figure 18, Panel A)
- Exceedance plots to compare overall abundance of high and low values (Figure 18, Panel B)
- Calculations of flow-matching indices, such as the Nash-Sutcliffe Efficiency (NSE) (Nash and Sutcliffe 1970) and, to account for high variability in flow, a modified NSE (Tolley, Foglia, and Harter 2019) (Table 4).

These results indicate that SVIHM flow-matching performance in the 2012-2018 period is about the same, or slightly better, than in the 1991-2011 period (Table 4). This might simply be a consequence of the fact that SVIHM generally performs better at low flows, and that the 2012-2018 period (18.4 average annual inches of rainfall) was drier than 1991-2011 (21.8 inches).

A known limitation of the model is that it does not capture large storm flow peaks, because these happen in a matter of days, while the MODFLOW stress periods in SVIHM are monthly (Figure 18, Panel A). This is reflected in the seasonal difference in NSE values: SVIHM matches dry season flows better than wet season flows. The season in which flow-matching performance is highest is during the spring recession and early growing season. This probably reflects the fact that longer-term processes control streamflow during this time, such as snowmelt or the draining of the subsurface, rather than short-term storm events.

Due to the aforementioned limitation, SVIHM tends to underpredict flows >1,000 cfs (Figure 18, Panel B). Conversely, it tends to overpredict flows <10 cfs. This overprediction may be due to the high sensitivity of the low-flow hydrologic system to small deviations from simulated conditions or behaviors (e.g., irrigation behavior not captured by the logical statements in the SWBM). However, overpredictions during low-flow conditions tend to be small, on the order of 1-5 cfs. The middle area of discrepancy in the exceedance plots ranges from 10-70 cfs; SVIHM simulates fewer of these daily flowrates than are observed. This may reflect a lag in the fall, i.e., the model is slower to respond to fall rain events than the physical watershed (Figure 18).

Table 4: Nash-Sutcliffe Efficiencies (NSE) and modified NSE values for various SVIHM-2018 time periods.

Time Period	NSE	MNSE
Water years 1991-2011	0.472	0.929
water years 2012-2018	0.529	0.935
All water years 1991-2018	0.485	0.931
Wet Season (Dec-Mar)	0.334	0.790
Spring Recession (Apr-Jul)	0.641	0.912
Dry Season (Aug-Nov)	0.449	0.840

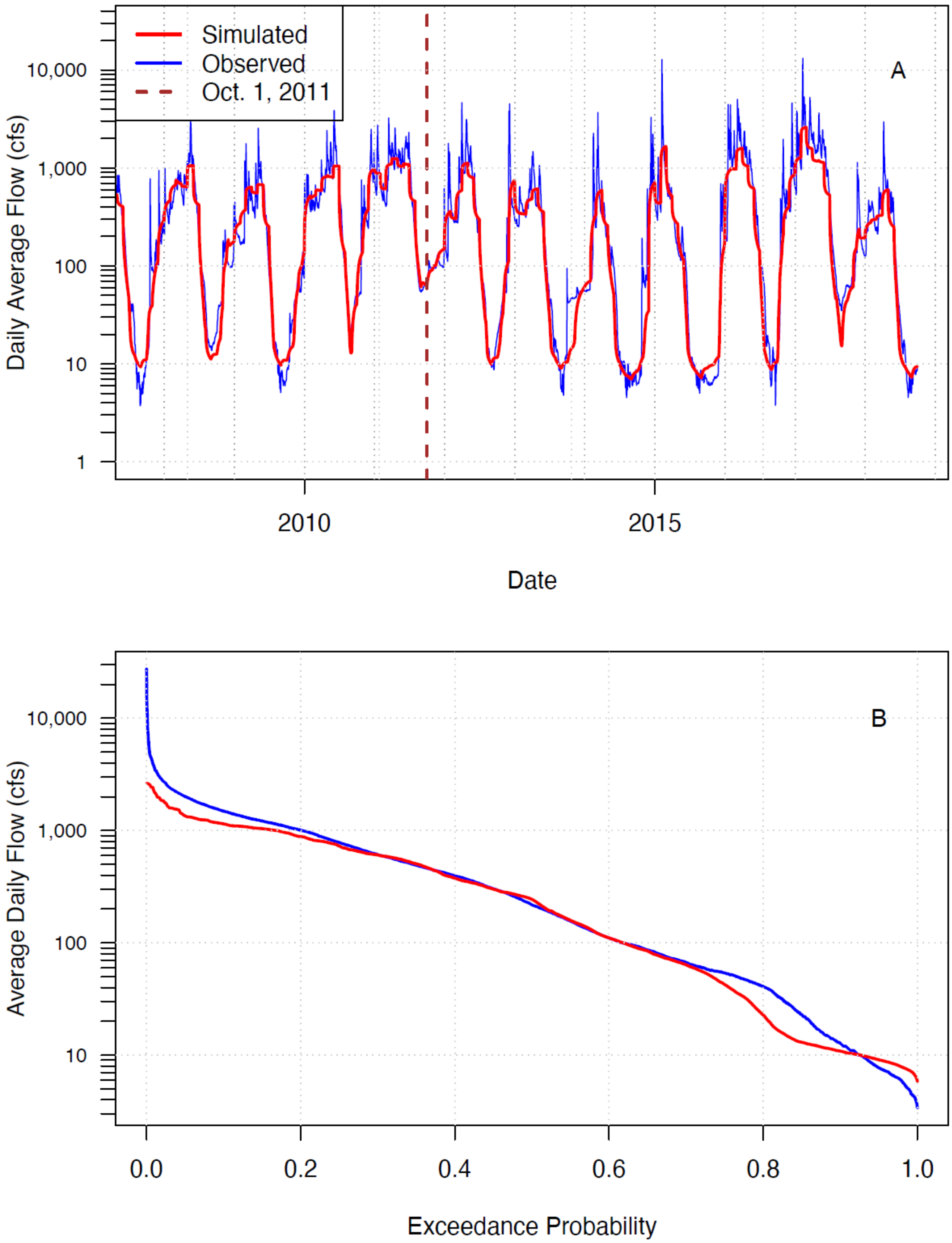


Figure 18: Daily flow at the Fort Jones Gauge, simulated vs. observed. Furthest extent of SVIHM-2018 model version is indicated as a brown dashed line.

4.3.3 Groundwater Head Matching

The model performance regarding groundwater head (elevation) matching can be evaluated using several methods or indices:

- Visual inspection of scatter plots
- The R^2 of the correlation between simulated and observed values
- The root mean squared error (RMSE) of simulated and observed values
- The percentage of groundwater elevation residuals less than a given number of feet or meters

Based on these results, the extended version of SVIHM performs about the same, or slightly worse, than the original 1991-2011 version at matching groundwater heads.

Observed and simulated groundwater head values show a strong correlation (Figure 19, Panel A; R^2 value of 0.98). The RMSE for the 1991-2018 period is 9.31 feet, compared with 7.48-9.12 feet in the 1991-2011 version (Tolley, Foglia, and Harter 2019).

Residuals range from -38 to 72 feet (Figure 19, Panel B). The proportion of residuals less than 3.3, 6.7, or 10 ft (1, 2, or 3 m) is 48%, 67%, and 78%, respectively, compared with 50%, 70%, and 80% in the 1991-2011 version.

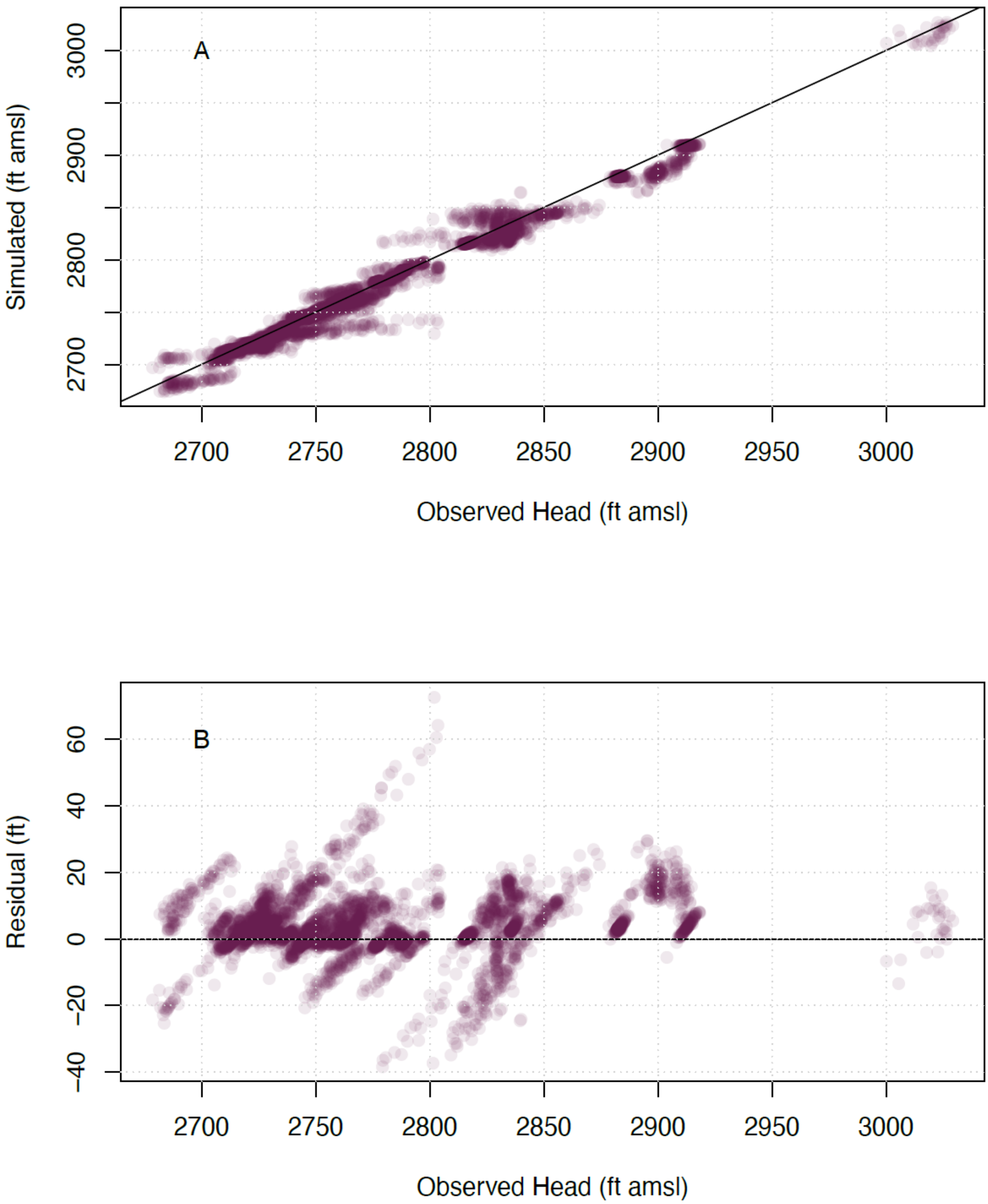


Figure 19: Groundwater elevations or heads, observed vs. simulated and observed vs. residuals (calculated as [simulated] - [observed]).

5 SVIHM-2018 Water Budget

5.1 Water Budget Overview

The historical water budget for the Basin was estimated for the period October 1991 through September 2018, using the Scott Valley Integrated Hydrologic Model (SVIHM). This 28-year model period includes water years ranging from very dry (e.g., 2001 and 2014) to very wet (e.g., 2006 and 2017). On an interannual scale, this period includes one multi-year wet period in the late 1990s and two multi-year dry periods in the late 2000s and mid-2010s. The CDWR SGMA Water Year Type dataset for Scott Valley was used to identify water year types within the water budget analyses.

Because surface water conditions and the potential occurrence of undesirable outcomes are heavily dependent on water year type, this section will include water budget quantities during example wet (2017), dry (2014) and average rainfall years, as well as in the overall 28-year model period. Two years with near-average annual rainfall (2010 and 2015) are used to illustrate the effect of temporal distribution of rainfall within a water year. In 2015 the rainy season ended earlier and rain fell in a smaller number of larger storms than in 2010.

Annual water budgets for the full model period are shown in Figure 20 and monthly values of selected budget components are shown in Figure 21 for each of the four example water years. Tables 5-7 show a summary of these budgets, and details are provided below. The following two sections provide an overview of the Scott Valley Integrated Hydrologic Model, which is used to determine the full water budget for the three hydrologic subsystems of the Basin: the surface water subsystem, the land subsystem, and the groundwater subsystem. The budget also includes the total water budget of the Basin. The second section provides a description of the water budget shown in the Figures and Tables below and explains the water budget dynamics in the context of the basin hydrogeology and hydrology described in previous sections.

Table 5: Annual values (TAF) for water budget components simulated in the Surface Water (SW) subsystem of the SVIHM. Positive values are water entering the stream network as inflows from tributary streams and overland flow entering streams; negative values are water leaving the stream network as diversions to the Farmers and SVID ditches and outflow from the valley through the Scott River. The net direction of stream leakage and the overall change in water stored in the stream system can be both negative and positive in different water years. Inflows to the SW represent the outflows from the upper watershed subsystem.

	Inflow	Overland	Farmers Div.	SVID Div.	Stream Leakage	Outflow	Storage
Minimum	91	1	-2	-4	-8	-689	0
25th %ile	192	2	-2	-4	0	-488	0
Median	276	3	-2	-4	9	-292	0
75th %ile	461	6	-2	-4	27	-188	1
Maximum	640	10	-2	-4	44	-85	2

Table 6: Annual values (TAF) for water budget components simulated in the Land and soil subsystem (L) of the SVIHM. Positive values are water entering the soil volume as precipitation and surface water (SW) or groundwater (GW) irrigation; negative values are water leaving the soil volume as evapotranspiration (ET) and recharge to the aquifer. The overall change in storage in the soil volume can be both negative and positive in different water years.

Statistic	Precip.	SW Irrigation	GW Irrigation	ET	Recharge	Storage
Minimum	49	21	41	-102	-9	-1
25th %ile	53	24	48	-112	-13	0
Median	90	31	36	-121	-31	-5
Mean	34	21	54	-107	-9	7
75th %ile	117	29	34	-118	-57	-6
Maximum	97	32	45	-121	-55	1

Table 7: Annual values (TAF) for water budget components simulated in the Groundwater (GW) subsystem of the SVIHM. Positive values are water entering the aquifer as recharge from the soil zone, canal seepage, and mountain front recharge (MFR); negative values are water leaving the aquifer as evapotranspiration (ET), discharge to overland flow, and pumped water from wells. The net direction of stream leakage and the overall change in water stored in the aquifer can be both negative and positive in different water years.

Statistic	Recharge	ET	Storage	Overland	Stream Leakage	Wells	Canal and MFR
Minimum	9	-1	19	-1	-5	-39	18
25th %ile	13	-1	8	-1	8	-45	18
Median	31	-0	-18	-3	7	-34	18
Mean	9	-1	24	-1	2	-51	18
75th %ile	56	-1	-29	-5	-8	-32	18
Maximum	54	-1	5	-6	-27	-43	18

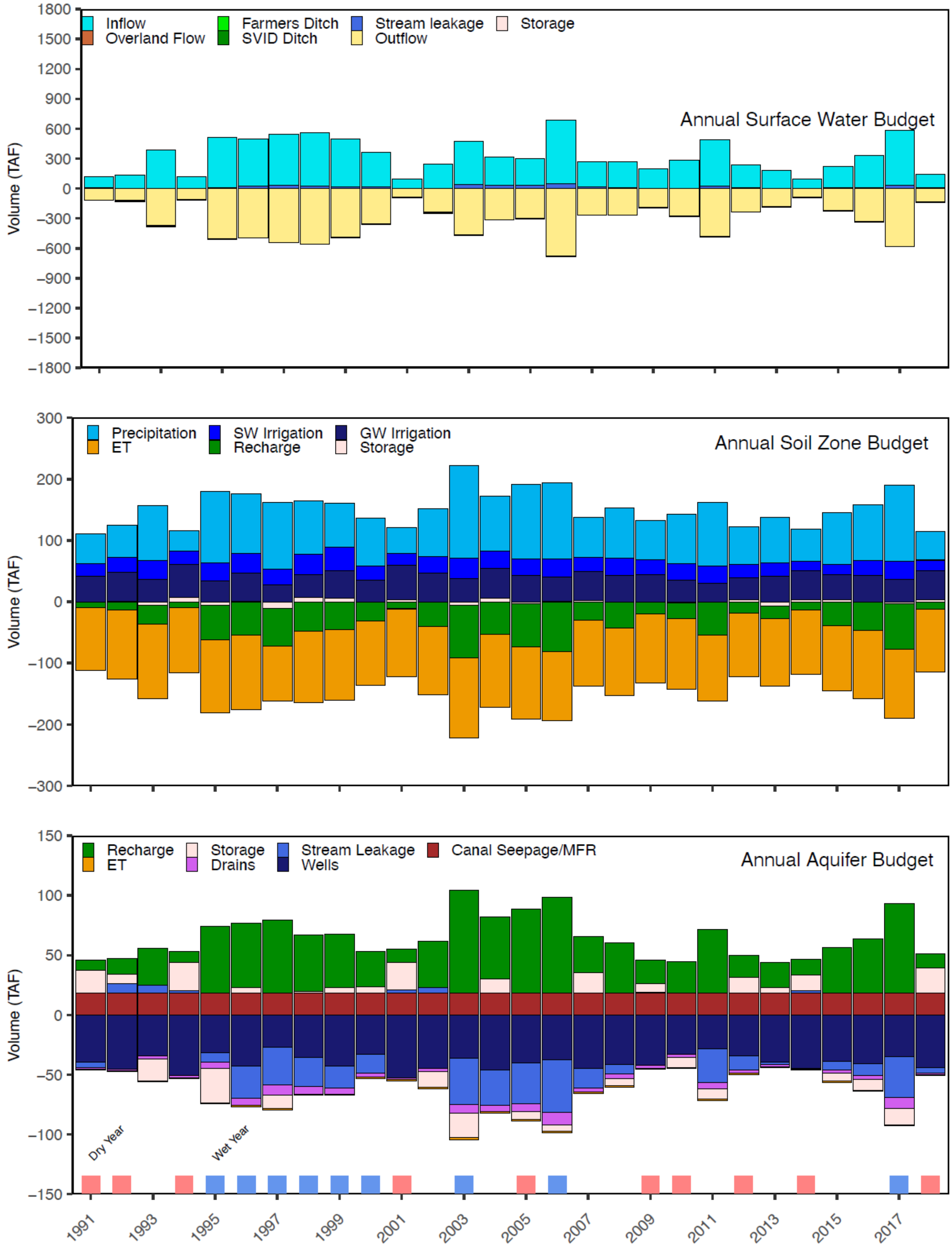


Figure 20: Annual water budgets for the three conceptual subsystems used to represent the hydrology of the Basin: the surface water system, the soil zone, and the aquifer.

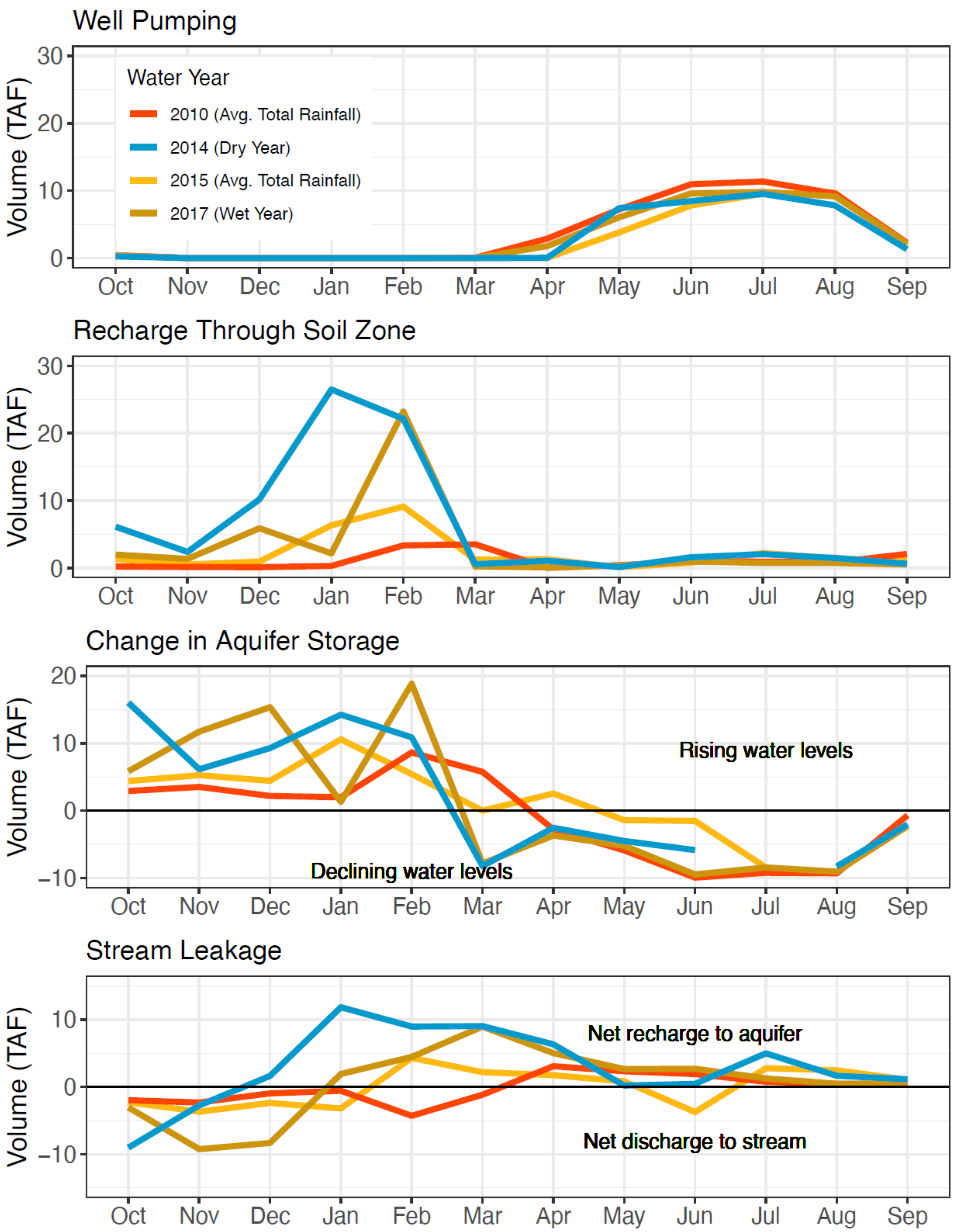


Figure 21: Monthly values of selected water budget components in four example water years: 2010, 2014, 2015, and 2017.

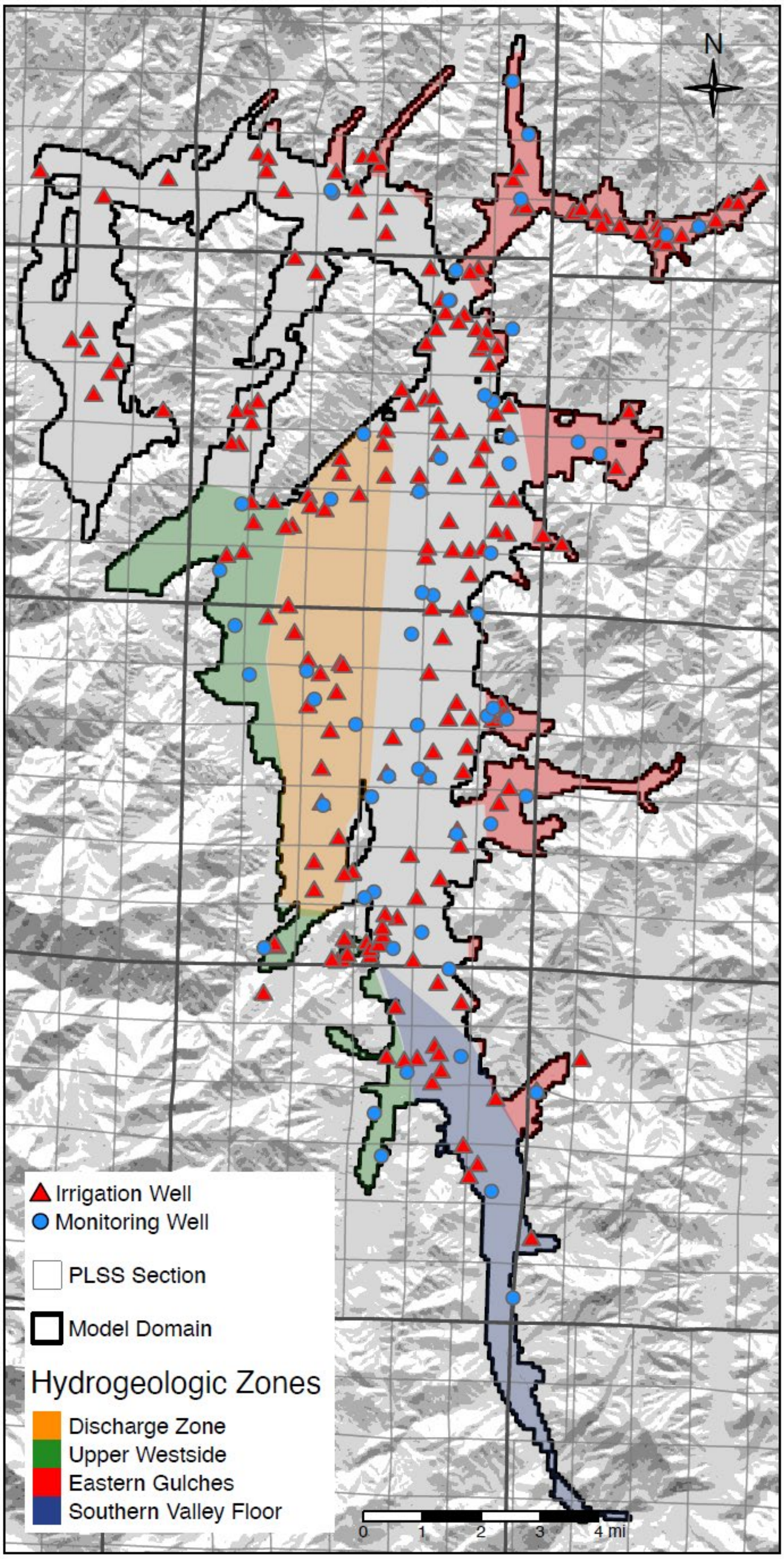


Figure 22: The SVIHM-2011 and SVIHM-2018 model domain boundary, pumping wells explicitly embedded in each of the two models and monitoring wells used to calibrate SVIHM-2011 and for validation of SVIHM-2018. Water level observations are grouped into four generalized hydrogeologic zones, adapted from Mack (1958) and are documented by UC Davis (https://groundwater.ucanr.edu/Research/ScottValley/).

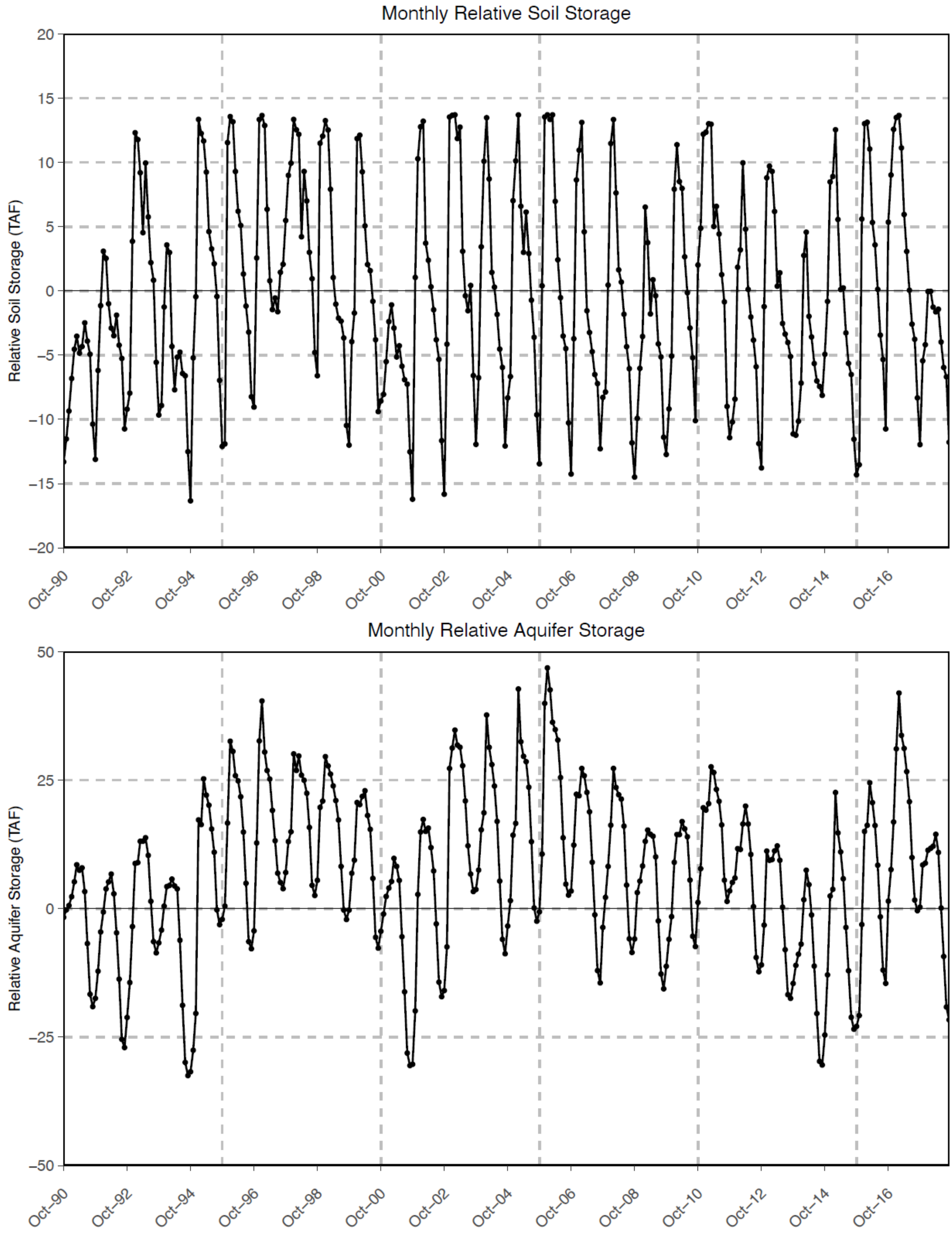


Figure 23: Monthly change in volume of water stored in the soil zone (top panel) and groundwater aquifer (bottom panel). Total storage volume and interannual variability are both greater of the aquifer than for the soil zone.

5.2 Description of Historical Water Budget Components

The section describes the full water budget of the Basin including inflows to the Basin, outflows from the Basin, and the internal fluxes between the three hydrologic subsystems of the Basin: the surface water subsystem, SW, the land-soil/vadose zone subsystem, L, and the groundwater subsystem, GW (CDWR 2020b). The subsystems into, out of, or between which the fluxes occur are explicitly identified using the SW, L, and GW notation.

Water budget components are described in the following categories:

1. basin inflows
2. basin outflows
3. flows between surface water and land-soil zone (SW and L)
4. flows between surface water and groundwater (SW and GW)
5. flows between land-soil zone and groundwater (L and GW)
6. change in storage in the land-soil zone and in groundwater (L, GW)

Figure 20 shows the water budgets of each of those three subsystems. Fluxes between subsystems are shown twice: in the subsystem from where the flux originates as output (negative flux, analogous to an account withdrawal at a bank), and in the subsystem into which the flux occurs as input (positive flux, analogous to an account deposit at a bank).

This section also describes storage changes in the subsystems. An increase in storage over a period of time occurs when fluxes into a subsystem exceed fluxes out of the subsystem over that period of time (similar to deposits exceeding the amount of withdrawals in a bank account: the account balance increases). In Figure 20, a storage increase is depicted as additional negative bar length needed to balance the negative bar length (fluxes out of the subsystem) with the positive bar length (fluxes into the subsystem). In other words, storage increase is depicted as if it were a negative flux. This is consistent with accounting principles in hydrologic modeling.

Similarly, a decrease in storage over a period of time occurs when fluxes into a subsystem are less than the fluxes out of the subsystem over that period of time (similar to withdrawals from a bank account exceeding the deposits into the bank account: the account balance decreases). In Figure 20, a storage decrease is depicted as additional positive bar length needed to balance the positive bar length (fluxes into the subsystem) with the negative bar length (fluxes out of the subsystem). In other words, storage decrease is depicted as if it were a positive flux, consistent with hydrologic modeling practice.

5.2.1 Basin Inflows

There are three inflows in the historic water budget: precipitation on the valley floor (to L), surface water inflow to the Basin from the upper watershed (to SW), and subsurface inflow or mountain front recharge from the surrounding bedrock underlying the upper watershed (to GW).

5.2.1.1 Precipitation

Rainfall on the valley floor is a key input in the SWBM. SVIHM assumes that all precipitation falling on cultivated fields or native vegetation infiltrates into the soil column (i.e., runoff is neglected) (Tolley et al., 2019).

Although a west-to-east decreasing rainfall gradient has been observed by Scott Valley residents, the locations of weather stations in the Scott Valley does not allow for robust calculation of this gradient. As a result, uniform daily precipitation value for the entire model domain is assumed (Foglia et al. 2013). That uniform daily value is the mean of the values observed or estimated at the Fort Jones and Callahan stations.

Missing days exist in the rainfall record for the Fort Jones and Callahan stations over the model period. On days with missing data, the value at the Fort Jones or Callahan station was estimated using data from six NOAA weather stations in the Scott Valley and immediate vicinity (see Table 1). On days where precipitation is less than 20% of the atmospheric water demand (reference ET), it is assumed that the water evaporates before it infiltrates below the surface of the soil, so no infiltration is simulated (Tolley, Foglia, and Harter 2019b)

5.2.1.2 Surface Water Inflow

The surface water inflows are derived from monthly tributary flow volumes that are calculated using the streamflow regression model (Foglia et al. 2013). These values are passed to the SWBM (L budget) as the monthly volume of surface water available for irrigation. Surface water diversions are computed as a function of irrigation demand. The conceptual diversion points from tributary flows are just outside the Basin boundary, except for two internal diversions (6 TAF, see below), which is consistent with most diversions occurring near the Basin margin. The remaining inflow from the upper watershed (streamflow regression model) is passed to the MODFLOW model domain as stream inflows (SW budget) (Tolley, Foglia, and Harter 2019b). In the water budget shown in Figure 20, the total surface water inflow is the sum of “Inflow” into the SW budget and “SW Irrigation” in the L budget, minus 6 TAF that are diverted from the mainstem Scott River to “SW Irrigation” from within the Basin.

5.2.1.3 Subsurface Inflow or Mountain Front Recharge (MFR)

Mountain Front Recharge, the phenomenon of diffuse water flow through mountain soil or fractured bedrock into the alluvial sediments of an aquifer along a valley margin, is simulated along the western edge of the model domain. It is estimated to be a volume that changes month-to-month (i.e., greater recharge during the wet season) but which is identical year over year (see Appendix 2-C for more details).

5.2.1.4 Discussion

Among the three inflows, canal and mountain front recharge is a relatively small amount, estimated to average 18 TAF. Stream inflow (Inflow plus SW Irrigation) is the largest source of water for the Basin, with a median inflow of 295 TAF, nearly 4 times larger than median precipitation of 81 TAF. Both of these sources of water vary widely between years. Precipitation varies, from less than half the median to nearly twice the median value (34 TAF to 151 TAF).

Stream inflow varies even more widely from 100 TAF to 664 TAF. Water year 2006 had the highest combined inflow and precipitation (788 TAF). Water year 2001 was the driest year, with a combined upper watershed stream inflow and valley precipitation of 149 TAF. The variability in precipitation and upper watershed inflows is entirely driven by climate variability.

5.2.2 Basin Outflows

The three outflows in the historic water budget component are the surface water outflow, subsurface outflow, and evapotranspiration.

5.2.2.1 Surface Water Outflow

The surface outlet of the Scott Valley is near the USGS Gauge 11519500 (Fort Jones Gauge). The record of flow at this location dates back to the 1940s and continues to the present day.

5.2.2.2 Subsurface Outflow

Subsurface outflow is assumed to be negligible, and all water leaving the Scott Valley in liquid phase does so through the Scott River.

5.2.2.3 Evapotranspiration

Evaporative demand, or evapotranspiration by crops and native vegetation (ET), is the primary driver of the model. Reference ET (ET_0) is measured at CIMIS Station 225 and was modeled for the period prior to CIMIS station installation in 2015 (Foglia et al. 2013; Snyder, Orang, and Matyac 2002). ET0 is multiplied by crop coefficients on each day of their growth cycle to calculate daily water demand for each crop or vegetation type (Foglia et al. 2013). ET is primarily simulated in the SWBM, but a small amount of ET is also simulated as direct plant uptake from groundwater in the MODFLOW model, within the Discharge Zone (section 2.2.1.5).

5.2.2.4 Discussion

Among the two Basin outflows, surface water outflow is the largest over the long term: median surface water outflow is 292 TAF, slightly more than median inflow after surface water diversions are subtracted (276 TAF). Median evapotranspiration is 112 TAF, mostly – but not exclusively – from agricultural crops grown in the Basin.

The magnitude of stream outflow closely follows the magnitude of stream inflows from the upper watershed, after subtracting surface water diversions. In 19 of 28 years, stream outflows exceed stream inflows in the SW budget (Figure 20). The largest differences between inflow and outflow occur in the wettest years (2006, 2017), when outflow exceeds inflow by nearly 50 TAF. In 9 of 28 years, mostly among the driest years (1992-1994, 2001-2002, 2009-2010, 2013-2014), stream outflow is slightly less than stream inflow, with the largest difference being 12 TAF in 1992 (Figure 20). Except in some of the driest years, the Scott Valley therefore is a net contributor to stream outflow from the Scott Valley.

Like surface water inflows, surface water outflows are highly variable between years, ranging from 85 and 89 TAF (in 2014 and in 2001) to 689 TAF (in 2006). In contrast, evapotranspiration is much less variable from year to year, ranging from 90 TAF (in 1997) to 130 TAF (in 2003). In half of years, evapotranspiration lies within the narrow range of 107 TAF to 116 TAF. The existing variability in evapotranspiration largely reflects year-over-year differences in average temperature and in the number of days with precipitation and significant cloud cover. The lack of larger variability in evapotranspiration reflects the land use in Scott Valley. Perennial crops (alfalfa and pasture) and perennial natural vegetation in the Basin make up most of the land surface.

Even in the driest year (2001), stream outflow is only about 5% (5 TAF) less than stream inflow. Since the net stream contribution even in 2001 (5 TAF) to valley evapotranspiration in that year (110 TAF) is minimal, the remaining contributions to ET come from surface water irrigations (19 TAF), mountain front recharge (18 TAF), precipitation (42 TAF), and the depletion of groundwater and soil storage (23 TAF and 3 TAF, respectively).

5.2.3 Flows Between Surface Water and Land (Soil) Zone

5.2.3.1 Surface Water Diversion for Irrigation

SVIHM simulates the diversion of surface water and the application of that water to fields as irrigation. The number and type of available water sources varies between fields; in fields with access to both surface and groundwater, it is assumed that irrigators will use surface water whenever it is available. In the water budget figures and tables, surface water diversion for irrigation is considered an inflow to the Basin, not a diversion from streams within the Basin. It is therefore separate from the inflow to the stream channels ("Inflow" in the SW budget), as most diversions occur near the Basin margins (see discussion above). In SVIHM, the diversions are conceptually located at or just outside the Basin boundary. In the water budget, these appear as surface water irrigation, which also include 6 TAF from the Farmers Ditch and Scott Valley Irrigation District diversion (see below).

5.2.3.2 Farmers Ditch and Scott Valley Irrigation District Diversion

These are the largest diversions within Scott Valley, located along the mainstem of the Scott River. The amount is assumed constant each year, 2 TAF to Farmers Ditch and 4 TAF to the Scott Valley Irrigation District. In SVIHM, these diversions are explicitly represented at the actual diversion location. This is an outflow from the SW budget and an inflow to the L budget, where it is counted as part of surface water irrigation.

5.2.4 Flows Between Surface Water and Groundwater

5.2.4.1 Stream Leakage and Groundwater Discharge to Stream

The flux of water between the surface water system and the aquifer is simulated in the MODFLOW model using the SFR (Streamflow Routing) package (Prudic 2004; Tolley, Foglia, and Harter 2019b). When this flux is net positive into the aquifer (negative in the SW budget), it is commonly referred to as stream leakage; when it is net positive into the stream (negative in the GW budget), it is often referred to as groundwater discharge or baseflow.

The annual net exchange between groundwater and streams across the basin varies from 8 TAF of groundwater discharge into the stream (1992) to 44 TAF of stream losses to groundwater (2006). A net groundwater discharge to the stream system occurs only in 1992-1994, 2001-2002, 2009, 2014, which are among the driest years. The largest net groundwater replenishment from streams occurs in wet years, with 1997, 2004-2006, and 2017 exceeding 30 TAF. The majority of the replenishment occurs along the upper alluvial fans of the tributaries. Most of the groundwater contribution occurs along the valley trough (main-stem Scott River).

5.2.4.2 Drains / Overland Flow

To simulate groundwater seepage to the surface and into open ditches in a region known to have an elevated water table, "drains" were placed at the land surface in the Discharge Zone on the western side of the Basin (Figure 22). Groundwater entering these drains is routed to a nearby stream segment (Tolley, Foglia, and Harter 2019b). "Overland" flow appears as a negative term in the GW budget and as a positive term in the SW budget. It ranges from 1 to 10 TAF with a median value of 3 TAF.

5.2.4.3 Canal Seepage from Farmers Ditch and SVID Ditch

Two unlined canals are used to transport surface water from the Scott River to diversion points along the eastern side of the Basin margin (Figure 22). Seepage from these canals into the aquifer is estimated to be a volume that changes month-to-month (i.e., greater seepage during the growing season) but which is identical year over year. Together with mountain front recharge (an inflow to the Basin), this amounts to 18 TAF of inflow to the GW budget.

5.2.5 Flows Between Land (Soil) Zone and Groundwater

5.2.5.1 Recharge to Aquifer

Each day, a field-by-field tipping-bucket method in the SWBM sub-model of SVIHM is used to calculate recharge through the soil zone to the aquifer. Soil zone inputs are infiltrating precipitation and irrigation water, and the driving output is ET. The "bucket" is the assumed water storage capacity in the soil rooting zone, which is dependent on the soil type of the field. Any soil moisture in excess of the field capacity (the amount retained in gravity-drained soil through capillary forces) at the end of each day is assumed to recharge to groundwater.

Recharge from the land surface occurs primarily in winter months but is limited – except under flood irrigation – during the summer months. Like precipitation, recharge from the landscape is highly variable, ranging from 9 TAF to 87 TAF with a median of 39 TAF.

5.2.5.2 Groundwater Pumping

Groundwater pumping is computed by the SWBM sub-model of SVIHM to meet ET demand in irrigated crops that is not met by precipitation, surface water irrigation, or – prior to the beginning of the irrigation season - by soil water storage. Groundwater pumping is limited to fields with groundwater as the source of irrigation water. Pumping also occurs in fields designated as having access to surface water and groundwater, after streamflow inflow from the upper watershed is insufficient to meet irrigation demands. The pumping amount varies as a function of soil type, crop, and irrigation type, which in turn determine soil moisture, irrigation efficiency, ET, among others. Groundwater pumping only occurs during the irrigation season, which is a function of the crop type and the dynamics of spring soil moisture depletion (see Foglia et al., 2013 for details).

Annual groundwater pumping varies in response to available precipitation and ET demand, from 27 TAF to 53 TAF, with a median of 40 TAF. The largest amount of pumping occurs in 2001 (53 TAF) and other dry years (at or above 45 TAF: 1992, 1994, 2001-2002, 2004, 2007, 2014). The least amount of pumping is observed in years with exceptionally wet springs (1997 and 2011).

5.2.5.3 Groundwater Uptake by Crops

In the Discharge Zone of the western Scott Valley, water table is sufficiently shallow that sub-irrigation (direct crop uptake of water from the water table) is used to grow pasture. In SVIHM, the use of groundwater by crops is explicitly simulated to supplement soil moisture contribution to ET, which is accounted for in SWBM (Tolley, Foglia, and Harter 2019b). Annually, this flux term is 2 TAF or less.

5.2.6 Change in Storage

5.2.6.1 Surface Water Storage

Change in storage in the surface water system is calculated, but at an annual timescale; this budget component, less than 2 TAF within the stream system, is nearly negligible (Figure 20).

5.2.6.2 Soil Zone Storage

The inter-annual change in the water stored in the soil zone (defined as the top of the soil to the bottom of the rooting zone, or 8 ft (2.4 m) below ground, in SVIHM) ranges from annual net loss as high as 7 TAF to an annual net gain as high as 10 TAF (Figure 23). Storage gains are typically associated with wet and near average years, storage losses occur during near average and dry years.

5.2.6.3 Aquifer Storage

Groundwater is the largest storage component in the Basin. Annual changes in groundwater storage range from as much as 29 TAF increase to as much as 24 TAF in decrease over a 12 month period. There is no significant long-term trend indicating groundwater depletion. On September 30, 2018, total groundwater storage was 23 TAF lower than at the beginning of the simulation period (October 1, 1991) due to 2018 being a dry year. One year earlier, total groundwater storage was 2 TAF lower than at the beginning of the simulation period (Figure 23).

5.3 Groundwater Dynamics in the Scott Valley Aquifer System: Key Insights

The Scott Valley groundwater basin is an intermontane alluvial basin surrounded by an upper watershed that has highly variable natural runoff, but no surface storage reservoirs. The Basin itself generates additional discharge to the stream system that exits the basin and larger upper Scott River watershed just above the Fort Jones gage on the Scott River. The groundwater system receives recharge from both, the stream system, especially along the upper alluvial fans of the tributaries, and from the landscape. Groundwater discharges into the main-stem of the Scott River, and into the lower sections of the tributaries, but also emerges in springs and drainages within the Discharge Zone. Riparian vegetation along the tributaries and the main-stem Scott River taps into shallow groundwater.

Precipitation occurs predominantly in the winter months, from October through April. Irrigation with surface water and groundwater between April and September is used to grow perennial crops (alfalfa, in occasional rotation with grains, and pasture). Groundwater has been used for irrigation since the 1970s and has allowed for an extended irrigation season, especially on alfalfa. Groundwater pumping significantly affects baseflow conditions during the summer.

Winter rains and winter/spring runoff fill the aquifer system between October and April (Figure 21). Groundwater discharge to streams along the thalweg drains the aquifer system year-round. Groundwater pumping further enhances the natural lowering of water levels during the dry season, leading to less baseflow.

Water levels are highest near the valley margin and slope from both sides of the valley toward the valley thalweg, along the main-stem Scott River. Higher recharge during the winter months increases the slope of the water table from the valley margins toward the thalweg. The lack of recharge for most of the dry period lowers the slope of the water table toward the thalweg over the summer months, decreasing discharge from groundwater into the Scott River system. Because the water table slopes toward the main-stem Scott River, seasonal water level fluctuations are largest near the valley margin and least near the Scott River (see Section 2.2.2.1).

Seasonal variability of recharge is accentuated by year-to-year climate variability: Years with low precipitation led to a smaller snowpack and lower runoff from the surrounding watershed, hence less recharge from the tributaries into the alluvial fans, less recharge across the landscape of the Basin, and therefore less winter groundwater storage increase in the aquifer system. This in turn leads to a reduced slope of the water table to the Scott River at the beginning of the irrigation season when compared to wetter years, and lower winter and spring water levels, particularly near the margins of the Basin.

Any significant long-term decrease or increase of long-term precipitation totals over the watershed will lead to commensurate lowering or raising, respectively in the average slope of the water table from the valley margins toward the Scott River thalweg, leading to a dynamic adjustment of water levels, even under otherwise identical land use and land use management conditions. These climate-induced adjustments will be relatively small near the main-stem Scott River, but larger near the valley margins. Such changes, however, are unlikely to lead to groundwater overdraft. However, they will affect baseflow conditions, the timing of the spring recess in Scott River flows and the arrival of the first fall flush flows in the river system.

Similarly, any increase or reduction in groundwater pumping leads to an equal decrease or increase in groundwater discharge to the stream systems. Any managed increase in recharge will also lead to an equal increase in groundwater discharge to the stream system within the Basin. The response of the groundwater discharge to the stream system will be delayed relative to the timing of the changes in pumping or recharge – by a few days if changes occur within a few tens or hundreds of feet of a stream, by weeks to months if they occur at larger distances from the stream. But when these changes occur permanently (even if only seasonally each year), the annual total change to groundwater discharge into the stream system will be approximately the same as the change in pumping (leading to less discharge) or in recharge (leading to more discharge).

This delay in timing can be taken advantage of with managed aquifer recharge or in-lieu recharge during periods of excess flows in the stream system, used for recharge or irrigation (in lieu of pumping), but creating additional discharge of groundwater to the stream during the critical low flow period in the summer and (early) fall.

Table 8: Annual and summarized annual values (TAF) for water budget components simulated in the surface water (SW) subsystem of the SVIHM. Positive values are water entering the stream network as inflows from tributary streams and overland flow entering streams; negative values are water leaving the stream network as diversions to the Farmers and SVID ditches and outflow from the valley through the Scott River. The net direction of stream leakage and the overall change in water stored in the stream system can be both negative and positive in different water years.

Water Year	Inflow	Overland	Farmers Div.	SVID Div.	Stream Leakage	Outflow	Storage
1991	115	0	-2	-4	5	-115	0
1992	133	0	-2	-4	-8	-120	1
1993	384	0	-2	-4	-7	-371	0
1994	118	0	-2	-4	-2	-111	1
1995	504	0	-2	-4	8	-506	0
1996	472	0	-2	-4	27	-494	0
1997	515	0	-2	-4	31	-541	0
1998	537	0	-2	-4	24	-555	0
1999	478	0	-2	-4	18	-491	0
2000	345	0	-2	-4	16	-355	0
2001	94	0	-2	-4	-3	-87	1
2002	249	0	-2	-4	-5	-238	0
2003	431	0	-2	-4	39	-464	0
2004	287	0	-2	-4	30	-311	0
2005	269	0	-2	-4	34	-297	0
2006	640	0	-2	-4	44	-679	0
2007	253	0	-2	-4	16	-264	1
2008	262	0	-2	-4	8	-265	0
2009	195	0	-2	-4	-1	-188	0
2010	283	0	-2	-4	0	-277	-0
2011	458	0	-2	-4	28	-480	-0
2012	227	0	-2	-4	12	-233	0
2013	183	0	-2	-4	2	-180	1
2014	91	0	-2	-4	-2	-84	2
2015	216	0	-2	-4	7	-219	1
2016	326	0	-2	-4	9	-330	0
2017	550	0	-2	-4	34	-579	0
2018	135	0	-2	-4	4	-134	1
Minimum	91	0	-2	-4	-8	-679	-0
25th %ile	192	0	-2	-4	-0	-483	0
Median	276	0	-2	-4	9	-287	0
Mean	312	0	-2	-4	13	-320	0
75th %ile	461	0	-2	-4	27	-186	1
Maximum	640	0	-2	-4	44	-84	2

Table 9: Annual and summarized annual values (TAF) for water budget components simulated in the land-soil/vadose zone water (L) subsystem of the SVIHM. Positive values are water entering the landscape or soil system via precipitation, surface water irrigation, or groundwater irrigation; negative values are water leaving the landscape or soil system via ET or recharge to groundwater. The overall change in water stored in the soil/vadose zone can be both negative and positive in different water years.

Water Year	Precip	SW Irrig.	GW Irrig.	ET	Recharge	Storage
1991	49	21	41	-102	-9	-1
1992	53	24	48	-112	-13	0
1993	90	31	36	-121	-31	-5
1994	34	21	54	-107	-9	7
1995	117	29	34	-118	-57	-6
1996	97	32	45	-121	-55	1
1997	109	25	28	-90	-62	-10
1998	87	33	37	-117	-48	7
1999	71	39	45	-116	-45	6
2000	78	23	35	-105	-30	-1
2001	42	19	56	-110	-11	3
2002	78	26	47	-112	-39	-1
2003	151	32	38	-130	-87	-5
2004	90	28	49	-120	-52	5
2005	122	27	42	-118	-71	-2
2006	124	30	39	-113	-81	1
2007	64	24	47	-107	-31	2
2008	82	27	43	-110	-42	-0
2009	64	23	45	-112	-19	-0
2010	81	27	35	-115	-27	-1
2011	104	28	30	-107	-54	-1
2012	61	22	36	-104	-18	3
2013	74	21	42	-109	-21	-7
2014	53	15	48	-106	-13	3
2015	84	17	41	-107	-39	3
2016	91	24	43	-111	-46	-1
2017	124	30	36	-112	-75	-2
2018	47	18	47	-103	-12	3
Minimum	34	15	28	-130	-87	-10
25th %ile	63	21	36	-116	-54	-2
Median	81	25	42	-112	-39	-0
Mean	83	26	42	-111	-39	0
75th %ile	99	29	47	-107	-19	3
Maximum	151	39	56	-90	-9	7

Table 10: Annual and summarized annual values (TAF) for water budget components simulated in the groundwater (GW) subsystem of the SVIHM. Positive values are water entering the aquifer via recharge from the soil subsystem or as mountain front recharge and due to canal leakage; negative values are water leaving the aquifer via ET directly from the water table (in the "Discharge Zone" of Scott Valley), in drains, or via well pumping. Net basin wide recharge from streams (stream leakage) may be positive or negative. The overall change in water stored in the grounndwater system can be both negative and positive in different water years.

Water Year	Recharge	ET	STorage	Drains	Stream Leakge	Wells	Canals, MFR
1991	9	-1	19	-1	-5	-39	18
1992	13	-1	8	-1	8	-45	18
1993	31	-0	-18	-3	7	-34	18
1994	9	-1	24	-1	2	-51	18
1995	56	-1	-29	-5	-8	-32	18
1996	54	-1	5	-6	-27	-43	18
1997	61	-1	-12	-8	-31	-27	18
1998	48	-1	1	-7	-24	-35	18
1999	45	-1	5	-5	-18	-43	18
2000	29	-1	6	-4	-16	-33	18
2001	11	-1	23	-1	3	-53	18
2002	39	-1	-13	-3	5	-45	18
2003	86	-2	-20	-7	-39	-36	18
2004	52	-2	12	-5	-30	-46	18
2005	70	-1	-6	-7	-34	-40	18
2006	81	-2	-5	-10	-44	-37	18
2007	30	-1	17	-3	-16	-45	18
2008	42	-1	-6	-4	-8	-41	18
2009	19	-1	7	-2	1	-42	18
2010	27	-1	-8	-3	-0	-33	18
2011	53	-1	-9	-6	-28	-28	18
2012	18	-1	14	-3	-12	-34	18
2013	21	-1	5	-2	-2	-40	18
2014	13	-1	13	-1	2	-45	18
2015	38	-1	-7	-2	-7	-39	18
2016	46	-1	-9	-4	-9	-41	18
2017	75	-1	-14	-9	-34	-35	18
2018	12	-1	21	-2	-4	-44	18
Minimum	9	-2	-29	-10	-44	-53	18
25th %ile	19	-1	-9	-6	-27	-44	18
Median	38	-1	3	-3	-9	-40	18
Mean	39	-1	1	-4	-13	-40	18
75th %ile	54	-1	12	-2	0	-35	18
Maximum	86	-0	24	-1	8	-27	18

6 SVIHM Scenario Development: Attribution of Stream Depletion

6.1 Overview

SVIHM-18 was developed as a decision-support tool to guide stakeholders, and local and state agencies in understanding the relationship between land use, groundwater use, and projects and management actions on one hand and streamflow conditions in the Scott Valley stream system on the other hand (Figure 9). As a simulation tool, the assessment of these interdependencies is achieved by simulating so-called "scenario" simulations that are then compared to the original SVIHM-18, which – in the context of scenario simulations – is referred to as the "basecase". In the interaction with stakeholders and the development of the Groundwater Sustainability Plan (GSP), it has been shown to be helpful to distinguish the following categories of scenarios:

- Stream depletion attribution scenarios
- Project and management action scenarios
- Future climate scenarios

Stream depletion attribution scenarios are simulations that are prepared to determine the total stream depletion resulting from modern day (1991-2018) land use and water use. SVIHM-18 is used to attribute stream depletion to various combinations of water users: groundwater users inside and outside the adjudicated zone, and surface water users inside and outside the adjudicated zone. Stream depletion attribution scenarios are also prepared to understand how sensitive the computed stream depletion is to the simulated design of the "unimpaired" reference landscape, representing pre-historic land use under modern day climate and stream-geomorphology conditions. These scenarios are explained and discussed in this chapter.

Project and management action scenarios are developed to understand how much of the existing stream depletion, as defined by the stream depletion attribution scenarios, can be reversed, at what locations it can be reversed and at what time periods it can be reversed with (future) implementation of projects and management actions. Projects and management actions may include those designed specifically to improve streamflow conditions. For purposes of this report, projects and management actions may also include other changes in land use and water use (either groundwater or surface water) that may positively or negatively impact stream depletion. These scenarios are further explained and discussed in chapter 7.

Future climate scenarios are simulations that are prepared to simulate representative conditions under various future climate conditions, with land use and water use conditions corresponding to those over the recent historic period. These scenarios are implemented to better understand potential threats to groundwater and stream conditions due to climate change. These scenarios are explained and discussed in chapter 8.

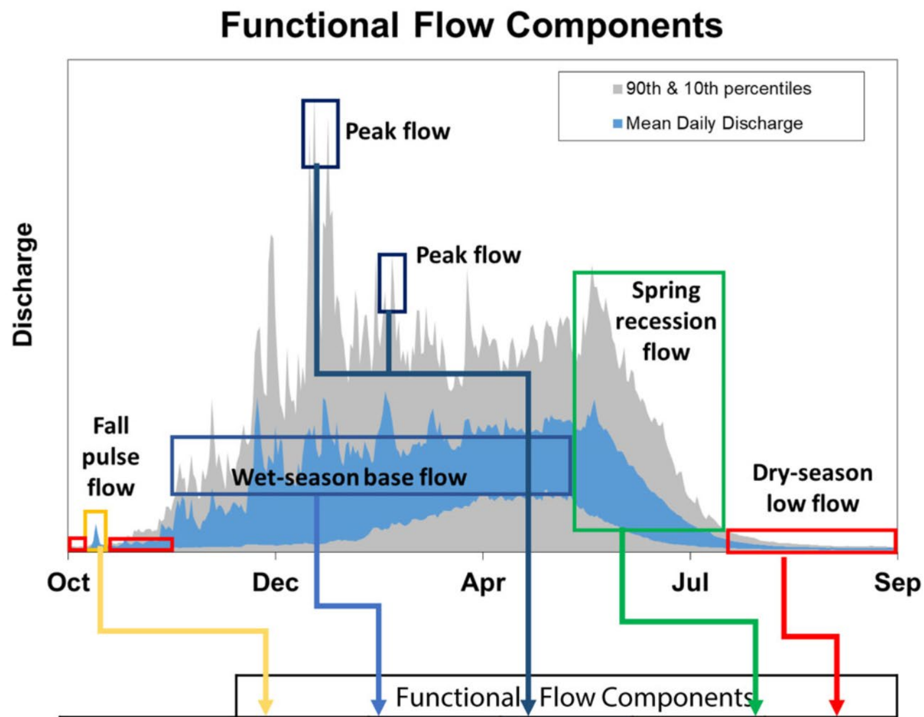
Common to all scenario simulations in chapters 6 through 8 is that they are employed in the context of the 1991-2018 basecase: the informative value of those simulations arises from comparisons to the simulation outcomes under basecase conditions, since the only difference between a scenario simulation and the basecase simulation is a named set of differences in model boundary conditions that represents the conceptual scenario. Specifically, the purpose of the scenario simulations is to understand the quantitative *difference* in outcomes relative to 1991-2018 basecase conditions, whether that is depth to groundwater or streamflow conditions, at any location in the Scott Valley, and in any month of any year in the 1991-2018 period.

Common to all scenario simulations in these three chapters is also that their outcome (and the difference in outcomes relative to the basecase) is measured as hydraulic head (for groundwater), groundwater flow, and streamflow (in the surface water system) at any location within the Scott Valley basin, on each day of the 28-year simulation period. The active groundwater simulation grid has 19,869 active cells in layer 1 and 14,054 active cells in layer 2 (33,923 total active cells), all with hydraulic head and three-dimensional groundwater flow data, 1,835 active stream cells across 30 stream tributaries or segments, each with stream stage, streamflow and groundwater-surface water exchange data, and 2,869 active drain cells (mostly underneath the Discharge Zone between Greenview and Etna) with drainage data (from groundwater). These 130,000 simulation data records can be recorded at each of 10,227 days in the 28 year simulation period, yielding over 1.3 billion data points per scenario. For each of these datapoints, the difference to the basecase can be computed.

Here, our interest is focused on the flows in the Scott River at the USGS Fort Jones gage, against which SVIHM-2018 was validated. The simulated location of the gaging station is the most downstream Scott River stream system SFR cell in the model domain. Flows at that location are used here to represent the overall status of the stream system. Each scenario yields 10,227 data points, chronicling the daily flows over a 28-year period at the USGS Fort Jones gage. These data are further summarized here to obtain a more comprehensive understanding of stream flow properties that are possibly relevant to ecosystem function, especially the life-cycle of salmonids in the Scott River watershed. Yarnell et al. (2020), building on concepts developed by Escobar and Pasternak (2010) and by others, proposed quantitative metrics that can be obtained from long duration streamflow records, to describe ecosystem-relevant functioning of a river. In a mixed rainfall-snowmelt runoff stream system such as the Scott River, the annual hydrograph obtained at a stream gage is characterized by five functional flow components (Figure 24):

- Fall pulse flows
- Wet season baseflow
- Wet season peak flow
- Spring recession
- Dry season baseflow

Each of these functional flow components can be quantified by two to four of the following five flow characteristics: flow magnitude, flow timing, duration, frequency, and/or rate of change. In total, Yarnell et al. (2020) propose 17 quantitative metrics to describe the functional flow components of river systems like the Scott River.



	Functional Flow Components				
Flow Characteristics	Fall Pulse	Wet Baseflow	Peak Flow	Spring Recession	Dry Low Flow
Magnitude	X	X	X	X	X
Timing	X	X	X	X	X
Duration		X	X	X	X
Frequency			X		
Rate of Change				X	X

Figure 24: Functional flow components (colored boxes) of the Scott River, California, with their respective quantitative flow characteristics (table). The flow behavior shown is schematic and not specific to the Scott River. *Copy of Figure 2 in Yarnell et al. (2020).*

Groundwater use and management does not necessarily impact all 17 of these quantitative metrics. The impacts from groundwater use are mostly felt in three of the five functional flow components: spring recess, dry season low flow, and fall pulse. Wet season baseflow and peak flow are largely driven by winter precipitation dynamics and snowpack accumulation. In this study, we therefore focus on three quantitative metrics of functional flows in the Scott River system:

- the magnitude of dry season baseflow,
- the timing of spring recess,
- the timing of fall pulse flow.

The magnitude of dry season baseflow and particularly the contribution of groundwater to dry season baseflow affects stream temperature, which in turn has been shown to affect the suitability of the stream habitat for juvenile coho and for steelhead trout that over-summer in some portions of the Scott River stream system and also in tributaries upstream of the Scott Valley basin. The magnitude of dry season baseflow at the USGS Fort Jones gage is also related to the connectivity of flows within the Scott Valley stream system. At flows below 10 - 40 cfs, significant portions of the stream system across the basin are dry (see chapter 3.7). At flows above 100 cfs, major tributaries and the mainstem of the Scott River are flowing and well connected, including the Scott River reach through the mine tailings north of the town of Callahan. Dry season baseflow is well below 100 cfs (Figure 24).

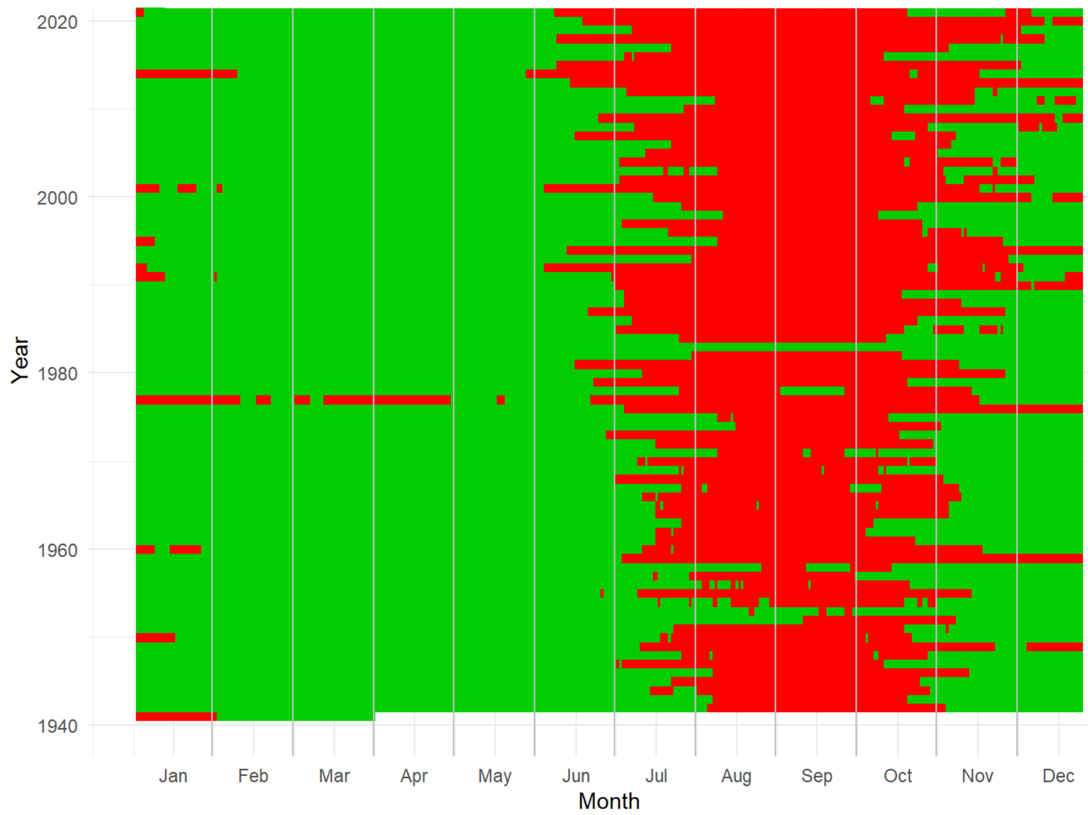


Figure 25: Heat map that is indicating, in red, days (x-axis) of each calendar year (y-axis) during which historical flows measured at the USGS Fort Jones gage on the Scott River were less than 100 cfs.

The magnitude of dry season baseflow is visualized and compared between scenario and basecase through several graphs:

- The average streamflow difference and the standard deviation of that difference for each month in the water year.
- Difference in monthly stream flow between the scenario and the basecase simulation, in a dry year (2014), average year (2010), and wet year (2017).
- For reference: average and standard deviation of monthly streamflow in the basecase, for each month in the water year (log-scale for flows).
- The scenario and basecase monthly stream flow, in a dry year (2014), average year (2010), and wet year (2017), with differences shaded for illustration, for each month in the water year (log-scale for flows).
- A graph comparing the monthly median, 25th – 75th percentile range, and 5th – 95th percentile range in a water year, measured over the 28 simulated water years with the instream flows recommended by the California Department of Fish and Wildlife (CDFW,

2017) and with the emergency flow table associated with the 2021/2022 SWRCB Emergency Regulations.

The timing of spring recess and fall pulse flow is measured for four different stream flow thresholds: 10 cfs, 20 cfs, 30 cfs, and 40 cfs. For each of these thresholds, a cumulative distribution is plotted of the first day on which USGS Fort Jones gage Scott River flows fall below (spring recess) or above (fall pulse) the threshold flow value. Cumulative distributions are obtained for the basecase and for scenarios.

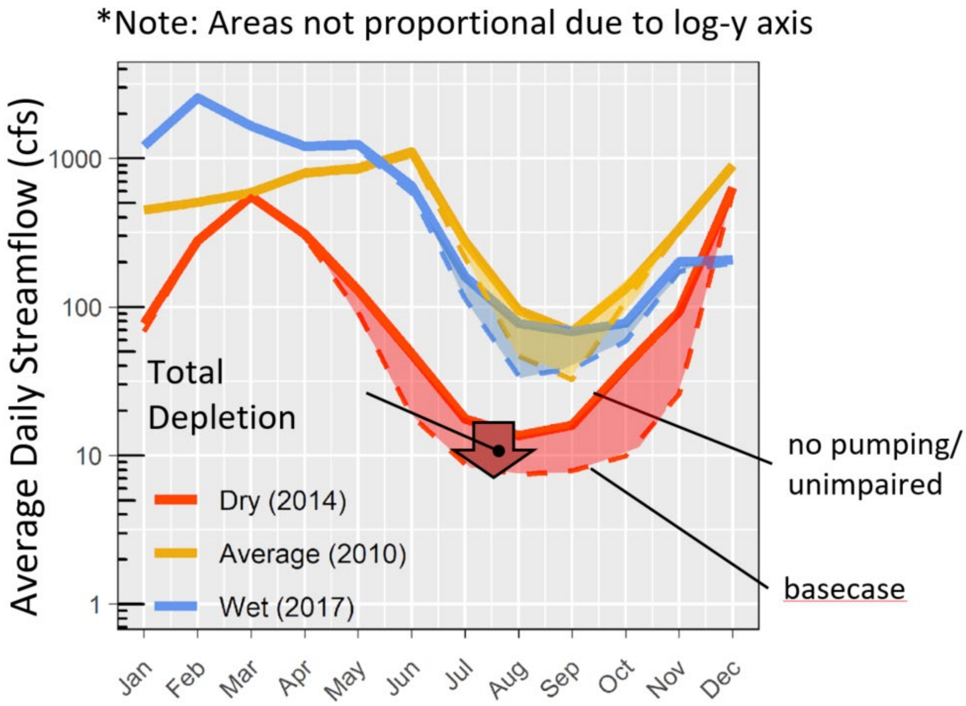


Figure 26: Example figure illustrating the basecase and a stream depletion scenario case for dry, average, and wet water year. Daily streamflows shown are averaged for each month in the water year indicated. Shaded areas indicate the magnitude of the difference between basecase and scenario. Note that the y-axis (stream flow [cfs]) is plotted on a logarithmic (order of magnitude) scale.

6.2 Attribution Analysis: Developing "Unimpaired" Landuse Scenarios

6.2.1 Overview

For groundwater management in Scott Valley, knowledge of the overall magnitude of stream depletion due to anthropogenic land use activities provides an important baseline against which future projects and management actions (chapter 7) and climate change impacts (chapter 8) can be evaluated.

We consider two design categories in crafting unimpaired land use and water use scenarios:

1. Selection of specific geographic areas and/or water sources for which unimpaired scenarios are developed.

2. Design of the unimpaired landscape and how it participates in the hydrologic cycle of the basin.

6.2.2 Geographic Areas and Water Sources

The purpose of the first design category is to create scenarios that allow for an evaluation of stream depletion due to water use in various geographic areas or due to different water sources. From a water rights perspective, we consider three major groups of water rights holders in the Scott Valley: surface water users, groundwater users within the adjudicated zone, and groundwater users outside the adjudicated zone.

In this analysis, only irrigation water users are considered. SVIHM (i.e., both, SVIHM-2011 and SVIHM-2018) does not simulate domestic or urban water extraction, septic system recharge, or urban wastewater recharge, nor does it simulate stockwater use, all of which are considered very minor consumptive water users. Within SVIHM, “water users” are individual agricultural land use polygons (Figure 16). For each water user, Foglia et al. (2013a) provides the water source, which was obtained from the year 2000 CDWR land use survey and reviewed in 2011 by the Scott Valley groundwater advisory committee. The irrigation water source is one of the following (Foglia et al., 2013a):

- Surface water (i.e., diversion from streams)
- Groundwater (i.e., pumping from groundwater via wells)
- Mixed source water (i.e., surface water while stream flows are available at sufficient quantity, then groundwater use)
- Subflows (typically in pasture land use, i.e., shallow groundwater directly available to pasture without pumping)

Surface water irrigation, groundwater irrigation, and mixed source irrigation occur in the adjudicated zone as well as outside the adjudicated zone. Subflow irrigation occurs in a small area within the “Discharge Zone” of Mack (1958, see chapter 3) between Greenview and Etna, east of Highway 3 and west of Big Slough. The assigned water source category does not change during the simulation period.

Subflow irrigation is considered incidental to the natural setting of the landscape and cannot be terminated. Water users with subflow irrigation are therefore not considered to cause stream depletion.

With three active water sources (**s**urface, **m**ixed, and **g**roundwater) in two geographic areas (inside and outside the adjudicated zone), stream depletion could be calculated separately for 7 combinations (s, m, g, s-m, s-g, m-g, s-m-g) of water sources outside the adjudicated zone, 7 combinations of water sources inside the adjudicated zone, and seven combinations of water sources for both areas combined (21 scenarios). Instead, we here focus on water users that depend on groundwater, including water users with mixed water source. Only the following combinations of water source and geographic area water users are created as scenarios under unimpaired conditions, for the purpose of computing stream depletion due to these users:

- Groundwater and mixed source water users (“no pumping”) within the adjudicated zone
- Groundwater and mixed source water users (“no pumping”) outside the adjudicated zone
- Groundwater, mixed source water, and surface water users (“no irrigation”) within the adjudicated zone
- Groundwater, mixed source water, and surface water users (“no irrigation”) outside the adjudicated zone
- Groundwater and mixed source water users (“no pumping”) within *and* outside the adjudicated zone
- Groundwater, mixed source water, and surface water users (“no irrigation”) within *and* outside the adjudicated zone

For the stream depletion attribution analysis, the respective water users (i.e., field polygons) do not use any irrigation water application at any time during the 1991-2018 simulation period. This includes mixed source water users, which – in attribution scenarios that include those – are not considered to irrigate at any time, including no irrigation from surface water.

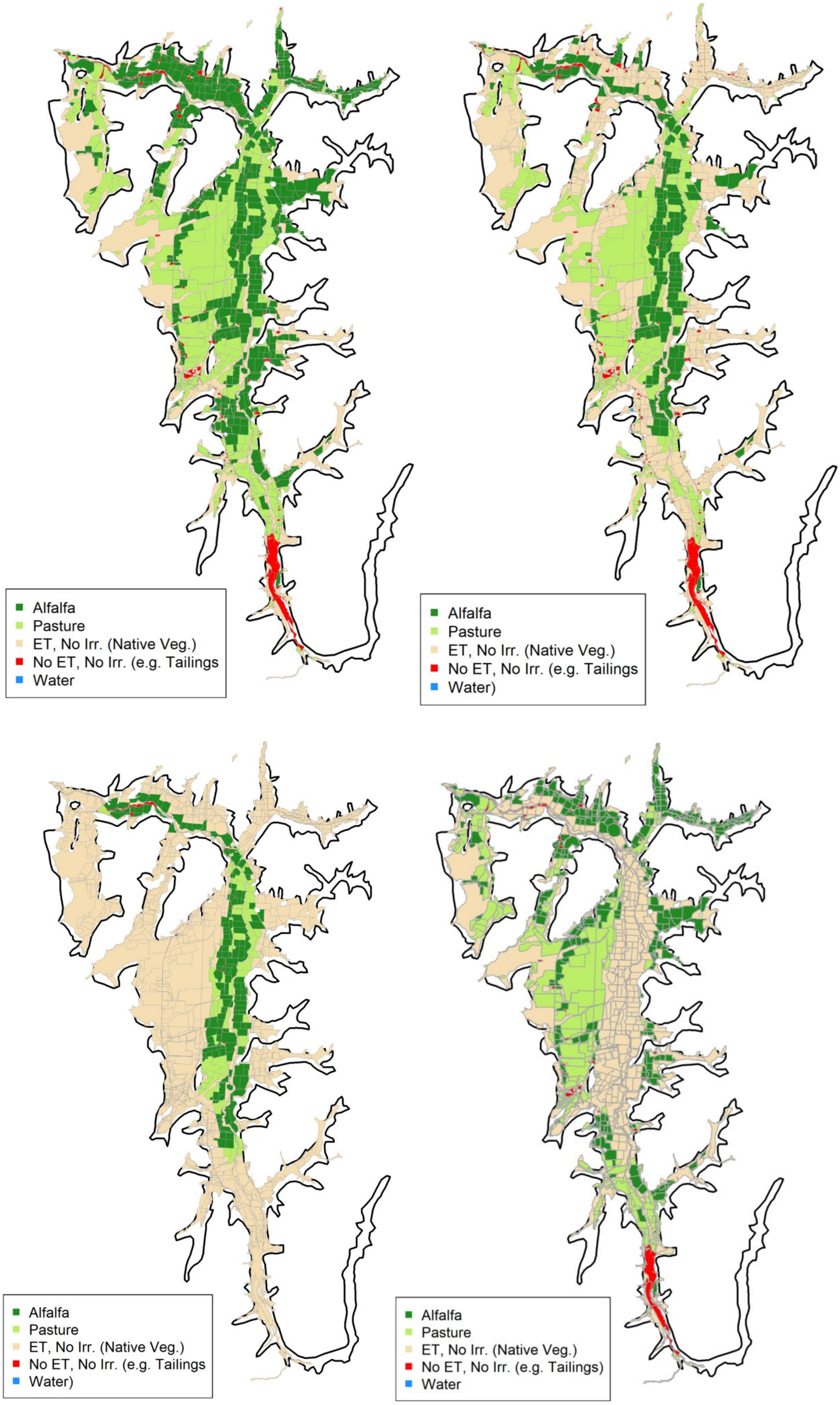


Figure 27: Simulated land use under 1991-2018 basecase conditions (top left) and the following stream depletion attribution scenarios: no pumping by groundwater and mixed source water users outside the adjudicated zone (top right), no groundwater or surface water irrigation outside the adjudicated zone (bottom left), no groundwater or surface water irrigation inside the adjudicated zone (bottom right).

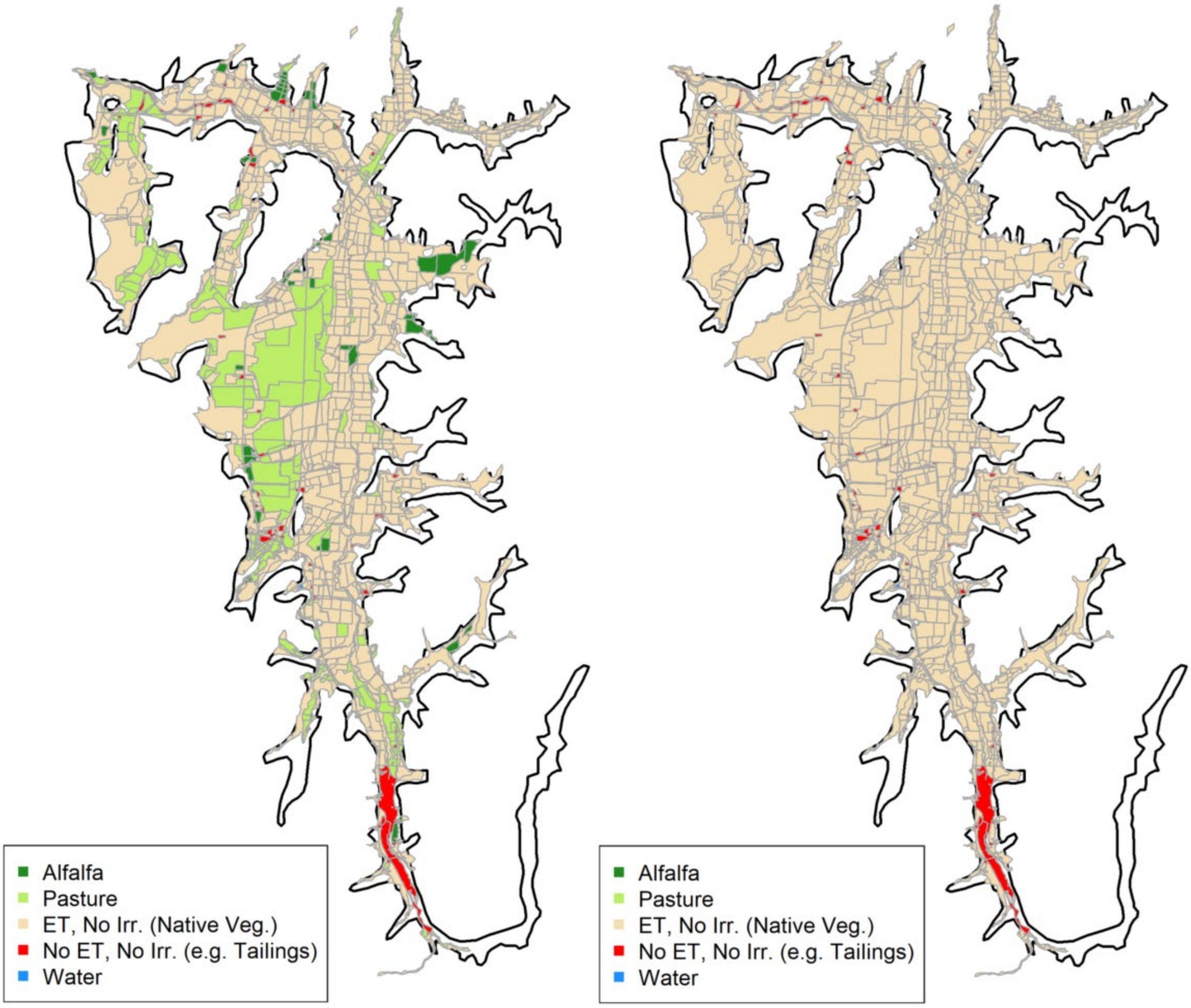


Figure 28: Simulated land use for the following stream depletion attribution scenarios: no pumping by groundwater and mixed source water users inside *and* outside the adjudicated zone (left), no pumping or surface water use by all water users inside *and* outside the adjudicated zone (right).

6.2.3 Ecohydrologic Design of the Unimpaired Landscape

A second important aspect of designing attribution scenarios to understand stream depletion is the ecohydrologic condition of the unimpaired, native vegetation. Unimpaired conditions cannot be designed without considering these ecohydrologic conditions. Native vegetation of a hypothetical landscape generating unimpaired stream flows would be adapted to the hydrologic conditions in Scott Valley, including its climate (temperature and precipitation patterns), soil conditions (soil water storage potential, drainage), and the depth to groundwater in case of groundwater-dependent ecosystems.

We used three SVIHM scenario design parameters to represent the ecohydrologic conditions of native vegetation under unimpaired conditions:

- Crop coefficient, K_c,, of native vegetation, where K_c is here defined as the ratio of the potential evapotranspiration of native vegetation (i.e., its actual transpiration under conditions of full water availability) and the reference evapotranspiration used to compute crop ET in the SWBM: $K_c = ET_p / ET_{REF}$
- Whether or not native vegetation is a groundwater-dependent ecosystem (GDE)
    - For GDEs only: maximum depth of groundwater extraction

<u>"No pumping" scenarios</u>: Native vegetation is already a land use option in the SVIHM basecase simulations, representing land use polygons within the Scott Valley that are currently occupied by native vegetation. In land use polygons with native vegetation, the same algorithm is used to route water through the unsaturated zone as for irrigated agricultural crops, using the SWBM. In contrast to irrigated agricultural crops, however, no irrigation is applied and the K_c value used to simulate evapotranspiration from those areas is set to 0.6 (chapter 6 in Foglia et al., 2013b). Much, albeit not all of this native vegetation is located on the upper alluvial fans, away from the lowest areas in Scott Valley, in areas where water levels are generally deeper. Hence, SVIHM does not account for any direct groundwater uptake from these native vegetation land use polygons (classified as "ET/no irrigation" land use in Figure 16).

For the attribution scenarios, the "ET/no irrigation" approach to simulating native vegetation was used as the default ecohydrologic design of the unimpaired landscape (K_c = 0.6 with ET limited to available soil moisture storage, but no groundwater uptake, see chapter 3).

The default ecohydrologic parameter design in SVIHM ("no-pumping" scenario) represents a shallow-rooted grass vegetation. The rationale for choosing this design as the default was driven by the need to quickly develop attribution scenarios for the GSP development process that is also a "book-end" scenario representing the highest conceivable stream depletion. The default scenario was developed within the SWBM, but did not require changes in the MODFLOW parameter set.

<u>"Native vegetation" scenarios</u>: Besides the default ecohydrologic design, four other ecohydrologic designs of the unimpaired landscape were considered, all of which considered that native vegetation may be groundwater-dependent. For those four GDE-like unimpaired native vegetation scenarios, SWBM computes the daily ET-deficit as the difference between the potential ET of native vegetation and actual, soil-water limited ET of native vegetation in an unimpaired land use polygon. This time-series of daily ET-deficit is passed as an input for the ET-demand to the ET package in MODFLOW. The ET package in MODFLOW accounts for GDE water uptake as a head-dependent flux boundary condition. Specifically, ET package will attempt to extract the ET-demand (maximum ET) from groundwater as long as groundwater levels are at or above a reference level (typically the land surface). On the other hand, the ET package sets ET to zero, if groundwater levels are below the maximum depth from which vegetation can tap into groundwater.

With the MODFLOW ET package, the actual ET extract by crops when water levels are above the maximum ET extraction depth but below the land surface is less than the ET-demand. The actual

ET varies linearly with water level depth, from zero at the maximum ET extraction depth to the full ET-demand when water level rises to the land surface. In Scott Valley, the depth to water table, outside of the Discharge Zone, is typically well below the land surface. Hence, the actual ET of native vegetation, without considering ET from groundwater, in most locations of Scott Valley is simulated as much lower than the ET-demand during summer and fall, after soil water storage has been depleted.

Depth to groundwater is only one factor determining the composition of a native vegetation. Other factors include daily and seasonal temperature ranges, occurrence of frost, precipitation patterns, occurrence and duration of inundation during the rainy season, and soil characteristics (e.g., Hammersmark et al., 2009; Noest, 1994). These factors are accounted for by the soil, climatic, and hydrologic characteristics embedded in SVIHM simulations.

Rationale for GDE design: The vegetation in the Scott Valley, in the region overlying the groundwater basin, was first described in the 1851 by George Gibbs and characterized as "suited to pasturage" with natural bunch grasses and an abundance of wild clover (Heizer, 1972), possibly with disperse stands of oak and pine. Rich soils were found along "the river, and the two or three small branches which continue to flow during the dry season" (*ibid.*) and likely occupied by riparian forests.

Perennial bunch grasses and clover are adopted to California's dry climate with deeper root distribution (Holmes and Rice, 1996). An extensive database of plant rooting depth was compiled for California, by The Nature Conservancy (TNC, https://www.groundwaterresourcehub.org/where-we-work/california/plant-rooting-depth-database/). The reported maximum rooting depth of bunch grasses ranges from 1 ft to nearly 10 ft, with most species' documented rooting depth ranging from 3 to 6 feet. Similarly, root depth of clover has been reported to range to 7 feet (https://doi.org/10.1071/EA9610150 reports root distribution for several Trifolium, ranging from 3 to 7 feet. https://doi.org/10.1071/EA04276 reports native grasses with roots to 2 m depth). The TNC plant rooting depth database reports many live oak studies showing their root depth ranges from 10 to over 50 feet.

Native vegetation GDE sensitivity analysis: For the sensitivity analysis, four ecohydrologic parameter design sets were developed, all of which allow for some of the ET demand from natural vegetation to be sourced from groundwater to the degree that soil moisture cannot provide that ET. Equivalent to the simulation for subflow irrigated crops in the basecase, groundwater ET for native vegetation (GDEs) utilizes the MODFLOW ET package with a user-defined maximum ET and a user-defined maximum ET extraction depth. The potential ET of the native vegetation is computed using the native vegetation crop-coefficient. The maximum ET in the MODFLOW ET package is set to the daily ET not obtained from within the soil system (simulated by SWBM), separately for each field (user). The actual ET is a function of water level depth, relative to the maximum depth of ET extraction.

For those additional GDE-like unimpaired native vegetation scenarios, two maximum depths from which water can be extracted by vegetation roots were considered, 15 ft and 33 feet (4.5 m and

10 m). Also, in addition to the K_c value of 0.6, a K_c value of 1.0 was considered, following studies of native vegetation in the Central Valley that were analyzed for their approximate K_c values in Howes et al., (2015), showing that K_c is approximately 1 for several wetland and perennial grassland ecosystem, when water levels are very close to the land surface.

In summary, five ecohydrologic design settings were considered for the unimpaired native vegetation:

- No GDE, K_c = 0.6 (default; used for all attribution scenarios)
- GDE, K_c = 0.6, maximum ET extraction depth = 15 ft (4.5 m)
- GDE, K_c = 0.6, maximum ET extraction depth = 33 ft (10 m)
- GDE, K_c = 1.0, maximum ET extraction depth = 15 ft (4.5 m)
- GDE, K_c = 1.0, maximum ET extraction depth = 33 ft (10 m)
- The latter four ecohydrologic design settings were compared to the default ecohydrologic design only used for the last attribution scenario listed in the previous sub-section ("no irrigation" within *and* outside the adjudicated zone)

Here, ET extraction depth represents the sum of rooting depth and unsaturated zone wicking height. All four alternative ecohydrologic parameter design sets were implemented for the unimpaired flow attribution scenario in which no irrigation occurs in Scott Valley. Only one GDE scenario, with a *Kc* of 1.0 and a maximum ET extraction depth of 15 ft (4.5 m), was also used for other attribution scenarios.

The following summarizes the natural vegetation scenarios ("no pumping") that assume native vegetation is ***not*** a GDE, with acronym used for this study:

- natveg_outside_adj – Cease irrigation serving all fields outside the Adjudicated Zone and convert affected acreage to native vegetation.
- natveg_gwmixed_outside_adj – Cease irrigation serving fields outside the Adjudicated Zone, which have a groundwater or mixed groundwater and surface water irrigation source and convert af- fected acreage to native vegetation.
- natveg_inside_adj – Cease irrigation serving all fields inside the Adjudicated Zone and convert affected acreage to native vegetation.
- natveg_gwmixed_inside_adj – Cease irrigation serving fields inside the Adjudicated Zone, which have a groundwater or mixed groundwater and surface water irrigation source and convert affected acreage to native vegetation.
- natveg_all – Cease irrigation serving all irrigated fields in the SVIHM model and convert affected acreage to native vegetation.
- natveg_gwmixed_all – Cease irrigation serving all irrigated fields in the SVIHM model, which have a groundwater or mixed groundwater and surface water irrigation source and convert affected acreage to native vegetation.

And the following list summarized the natural vegetation scenarios that assume native vegetation includes GDEs where water levels are sufficiently shallow, with acronyms used in this study:

- natveg_outside_adj_et_check_1.0nvkc_4.5m_ext – Cease irrigation serving all fields outside the Adjudicated Zone and convert affected acreage to native vegetation.
- natveg_gwmixed_outside_adj_et_check_1.0nvkc_4.5m_ext – Cease irrigation serving fields outside the Adjudicated Zone, which have a groundwater or mixed groundwater and surface water irrigation source and convert affected acreage to native vegetation.
- natveg_inside_adj_et_check_1.0nvkc_4.5m_ext – Cease irrigation serving all fields inside the Adjudicated Zone and convert affected acreage to native vegetation.
- natveg_gwmixed_inside_adj_et_check_1.0nvkc_4.5m_ext – Cease irrigation serving fields inside the Adjudicated Zone, which have a groundwater or mixed groundwater and surface water irri- gation source and convert affected acreage to native vegetation.
- natveg_all_et_check_1.0nvkc_4.5m_ext – Cease irrigation serving all irrigated fields in the SVIHM model and convert affected acreage to native vegetation.
- natveg_gwmixed_all_et_check_1.0nvkc_4.5m_ext – Cease irrigation serving all irrigated fields in the SVIHM model, which have a groundwater or mixed groundwater and surface water irriga- tion source and convert affected acreage to native vegetation.

6.3 Attribution Analysis: Total Stream Depletion for Various "Unimpaired" Landuse Scenarios

6.3.1 Stream Depletion due to Irrigation outside the Adjudicated Zone

Stream depletion, SD, is measured as the difference between the streamflow at the Fort Jones gage simulated with the attribution scenario, Q_{UI}, and the streamflow simulated with the basecase, Q_{bc} (no unimpaired landscape):

$$SD = Q_{UI} - Q_{BC} \quad \text{[in cubic feet per second, cfs]}$$

In this section we review all unimpaired land use scenarios that are based on the default ecohydrologic design of non-GDE native vegetation in unimpaired land use polygons: a native vegetation K_c of 0.6 with ET from the soil storage pool, but no extraction of water from the water table. Sensitivity to other ecohydrologic designs is presented in the subsequent section.

Groundwater and mixed source water fields outside the adjudicated zone, on average, create stream depletion from April through December, but a small amount of negative stream depletion in the winter months, January through March (Figure 29). On average, the largest amount of stream depletion occurs in June, at over 50 cfs, declining to less than 40 cfs by August, but remaining at that level through November, before further declining in December (less than 20 cfs). Negative stream depletion is strongest in February, reaching about -10 cfs. Between April and December, stream depletion due to groundwater and mixed water source use outside the adjudicated zone averages well over 30 cfs, totaling about 18,000 acft. The negative stream depletion between January and March averages -5 cfs, totaling about -1,000 acft.

The negative stream depletion in January through March is an insignificant fraction of the average flows during this period, which exceed 500 cfs. But it can be attributed to a delayed impact from the lack of irrigation recharge during the spring and summer months in the unimpaired native vegetation areas. That impact is likely to be there year-round, dampening the actual stream depletion by similar amounts, particularly in the later summer months and fall.

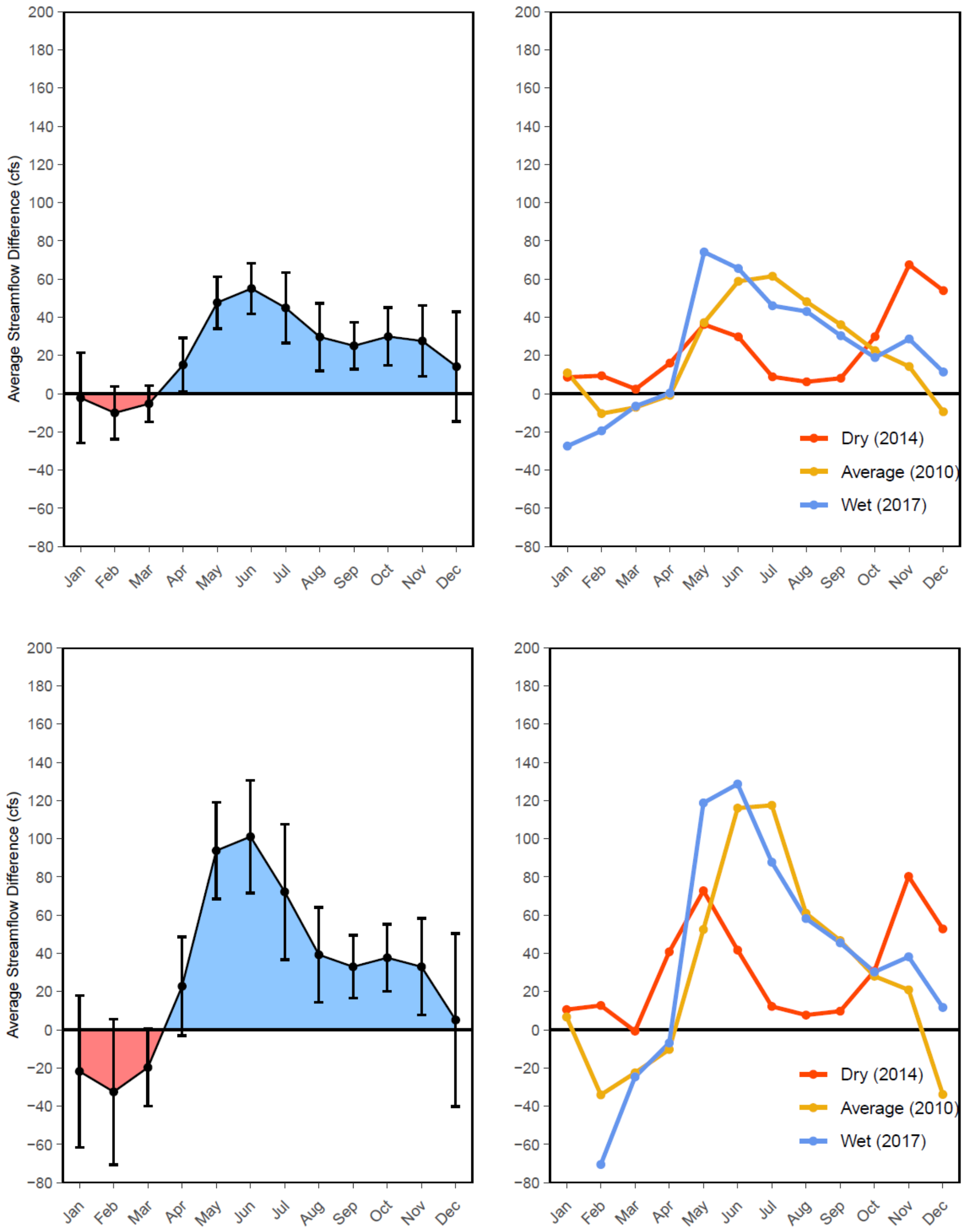


Figure 29: Simulated stream depletion (i.e., difference in streamflow under unimpaired conditions and basecase conditions) [in cfs]. Left: Average stream depletion (y-axis) by calendar month (x-axis). Whiskers indicate standard deviation across years. Right: Monthly stream depletion [cfs] for three example years, each being a different water year type (dry, average, wet). Stream depletion shown is due to

groundwater and mixed source water uses (top) or due to all water uses (bottom) outside the adjudicated zone.

Between years, especially between different water year types, large differences can be seen in stream depletion. In average and wet years, stream depletion is highest early in the summer and persists throughout the summer, gradually declining in the fall. In dry years, such as 2014, stream depletion becomes very small (less than 10 cfs) in July, August, and September. Simulated basecase flows during those months, in 2014, were between 8 and 9 cfs, while unimpaired flows were about twice as large. The limited stream depletion is is due to the stream network drying out even under unimpaired conditions in such dry years.

Stream depletion in a dry year has a rebound effect after the stream network reconnects with fall flush flows: In 2014, the largest stream depletion observed were in October, November and December. Stream depletions can be thought of as "accumulating" in the subsurface while the stream network is strongly disconnected (dry). The accumulated stream depletion is transferred to the stream network after that network has reconnected. In October, November, and December 2014, unimpaired (vs. basecase) flows averaged 40 cfs (vs. 10 cfs), 90 cfs (vs. 25 cfs), and over 600 cfs (vs. just under 600 cfs).

The combined impact of groundwater and surface water irrigation outside of the adjudicated zone is nearly twice as high in the early summer (May and June), at nearly 100 cfs. Average stream depletion over the April – December period is nearly 50 cfs, totaling over 25,000 acft. The much larger stream depletion of all irrigation water uses outside of the adjudicated zone versus groundwater and mixed source water users only reflects the fact that a large fraction of surface water users are located outside of the adjudicated zone, with diversions off the tributaries near the margins of the valley. Negative stream depletion in the winter months increases to an average of -25 cfs, totaling almost -5000 acft. The much larger negative stream depletion is due to the fact that flood irrigated pasture is the major water user among those depending on surface water as irrigation water. Flood irrigation has much lower irrigation efficiency and leads to more groundwater recharge during the irrigation season (Foglia et al, 2013b). That recharge from flood irrigated fields reverses some of the stream depletion effects both, during and until well after the actual irrigation season.

6.3.2 Stream Depletion due to Irrigation Inside the Adjudicated Zone

The pattern of stream depletion due to irrigation inside the adjudicated zone is overall similar to that for irrigation outside the adjudicated zone. Groundwater and mixed source water fields inside the adjudicated zone, on average, create stream depletion from April through November, but negative stream depletion in the winter months, December through March. On average, the largest amount of stream depletion occurs in June, at just over 70 cfs, declining to less than 40 cfs by September. Negative stream depletion is strongest in January and February, reaching nearly -30 cfs in February. Between April and November, stream depletion due to pumping in the adjudicated zone averages over 40 cfs, totaling about 20,000 acft. The negative stream depletion between December and March averages under -15 cfs, totaling about -4,000 acft.

In comparison, all irrigation combined (groundwater and surface water) in the adjudicated zone is causing about 10% higher stream depletion, but 20% more negative stream depletion in the winter months, than water use on groundwater and mixed water source irrigated fields. The smaller contribution to stream depletion from fields irrigated with surface water reflects the much smaller fraction of surface water users within the adjudicated zone, when compare with the area outside of the adjudicated zone. Like outside of the adjudicated zone, those surface water users are mostly irrigating pasture, with flood irrigation at low irrigation efficiencies. Hence, the relatively small number of surface water users achieve a disproportionally larger dampening effect on streamflow depletion, seen as negative stream depletion during the winter months.

6.3.3 Stream Depletion due to Irrigation throughout Scott Valley (inside *and* outside the adjudicated zone)

The magnitude of stream depletion due either to groundwater and mixed source water users (top row, Figure 29) or due to all irrigation in Scott Valley, including diversions for surface water users (bottom row, Figure 30) is approximately the sum of the depletion caused by respective users inside or outside the adjudicated zone, shown above. Stream depletion from all groundwater and mixed source water users peaks at nearly 130 cfs in June, then steadily declines to zero in December. Average stream depletion from April to December is nearly 70 cfs, totaling nearly 40,000 acft. Negative stream depletion during winter averages -30 cfs, totaling over 5,000 acft. Stream depletion from all irrigation water uses (including surface water) averages over 90 cfs, totaling 50,000 acft. Negative stream depletion during winter is averages -60 cfs, for all irrigation, totaling well over 10,000 acft.

6.3.4 Spring Recess and Fall Pulse Flow Conditions

Under unimpaired conditions, using the default ecohydrologic parameters for non-GDE native vegetation land use, spring recess flows would fall below 30 cfs later than under basecase conditions. Similarly, fall flows would exceed 30 cfs earlier than under basecase conditions. The contribution of irrigation outside the adjudicated zone to that shift in flows is significantly less than the contribution from the adjudicated zone, whether or not surface water diversions are considered.

Under unimpaired conditions on groundwater or mixed water source fields, about two to four weeks and six to eight weeks are gained in the spring recess flow period, for the area outside and inside the adjudicated zone, respectively (Figure 31). Outside the adjudicated zone, unimpaired conditions for all fields (including those irrigated by surface water) gain approximately one week relative to unimpaired conditions on groundwater and mixed source water fields only. Only a couple of additional days are gained inside the adjudicated zone, for unimpaired conditions on all fields, relative to unimpaired conditions on groundwater and mixed source water fields.

Conversely, about 6 – 8 weeks are gained in the period with flows above 30 cfs during the fall, with slightly more gains when considering unimpaired conditions on all fields and for the area inside the adjudicated zone than outside the adjudicated zone (Figure 31).

The 30 cfs threshold is not exceeded in 5 of 28 years under current conditions. Unimpaired conditions on groundwater and mixed source water fields outside the adjudicated zone would lead to 10 of 28 years not having flows below 30 cfs before September, and to 21 of 28 years not having flow below 30 cfs in September or later. Unimpaired conditions for all of Scott Valley would avoid flow below 30 cfs in any year during the 1991-2018 simulation period (Summary Table)

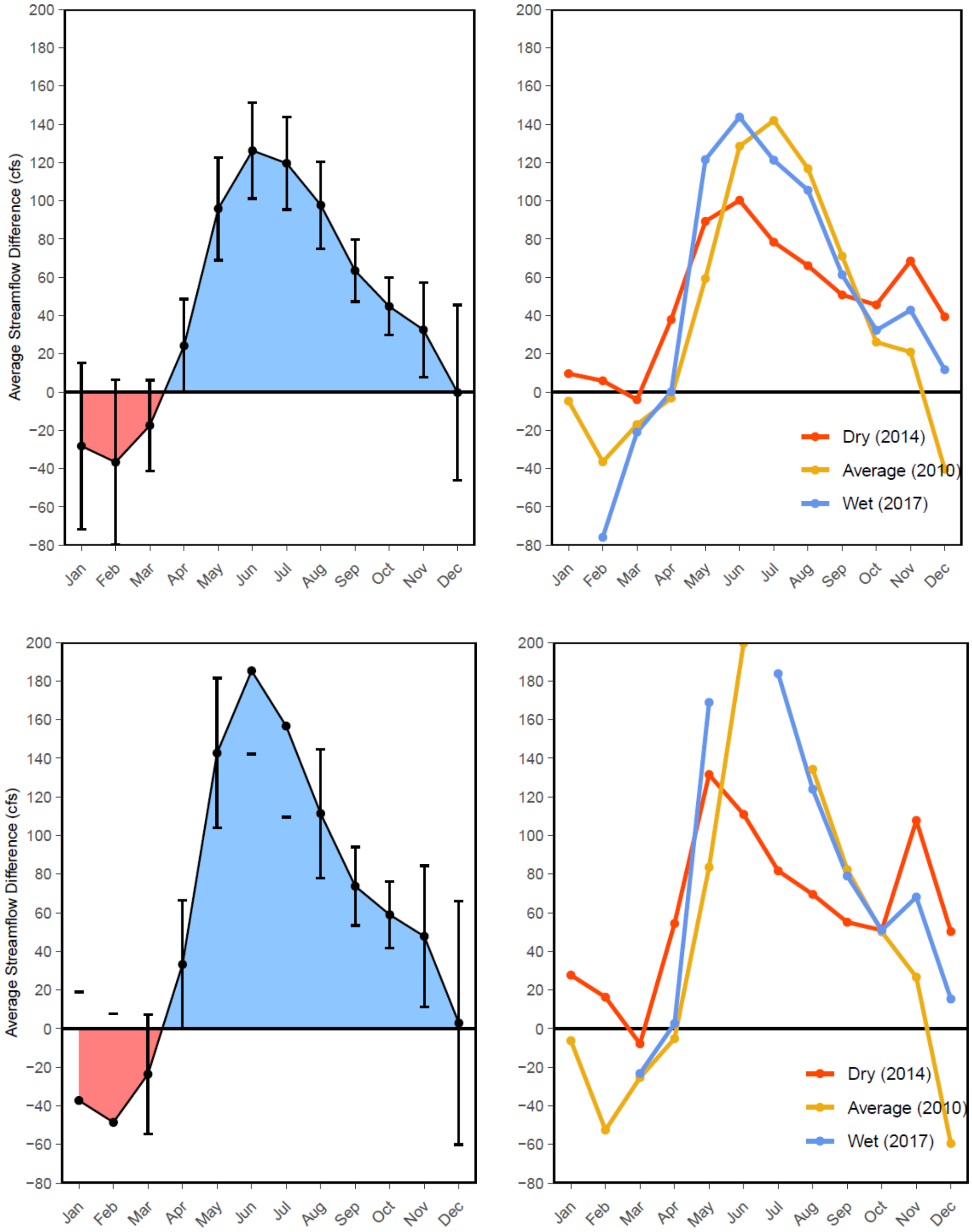


Figure 30: Simulated stream depletion (i.e., difference in streamflow under unimpaired conditions and basecase conditions) [in cfs]. Left: Average stream depletion (y-axis) by calendar month (x-axis). Whiskers indicate standard deviation across years. Right: Monthly stream depletion [cfs] for three example years, each being a different water year type (dry, average, wet). Stream depletion shown is due to groundwater and mixed source water uses (top) or due to all water uses (bottom) within *and* outside of the adjudicated zone (i.e., all of Scott Valley).

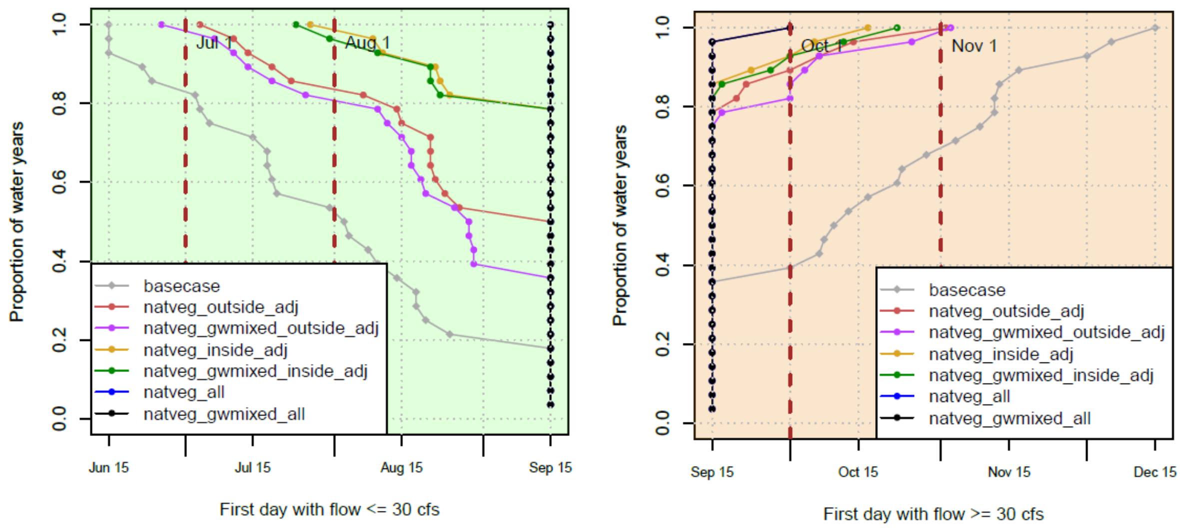


Figure 31: Cumulative distribution of the first day of simulated Scott River flows (at the USGS Fort Jones gage) when, during the spring recess (left), flows are 30 cfs or less and when, during the fall pulse flow (right), flows are 30 cfs or more, for various attribution scenarios. The cumulative distributions for the basecase are shown in grey. All stream depletion attribution scenarios use the default ecohydrologic design parameters for native vegetation: K_c = 0.6, but with ET limited by moisture in the soil root zone (no GDE), except in areas of the Discharge Zone identified in the basecase as subflow irrigated.

6.4 Sensitivity Analysis: Differences in Total Stream Depletion between Ecohydrologic Designs of Native Vegetation

6.4.1 Alternative Ecohydrologic Parameter Design

The unimpaired land use conditions described in the previous section represent ecohydrologic conditions that do not rely on groundwater as a source of ET, except in a small region in the Discharge Zone (about 2,300 acres or 900 ha) that has "subflow" as the designated water source in the CDWR land use survey for the year 2000. The ET of the native vegetation is assumed to rely on soil moisture storage. It does not exceed 60% of reference ET, even when the soil moisture pool is full, since K_c = 0.6. When the soil moisture pool is depleted, no ET occurs from native vegetation

The ecohydrologic parameter design of the native vegetation has significant influence on the amount of ET that native vegetation may extract from groundwater. Stream depletion is largest with the default non-GDE ecohydrologic parameter design set and least with the GDE native vegetation that represents ET using a K_c of 1.0 and a maximum ET extraction depth of 33 ft. Relative to the default, stream depletion for the entire Scott Valley (all water sources) also begins in April, but ends in August. Over those five months, the average depletion is about 60 cfs, totaling less than 20,000 acft, instead of 50,000 acft in the default case. Stream depletion is negative during the remaining seven months, averaging under -30 cfs, totaling nearly -15,000 acft. Dry season baseflow during drought would be insignificantly different from, e.g., conditions during the last drought. In average and wet years, streamflow depletion is largest in May through August, but negative during most of the remainder of the year. Other ecohydrologic parameter designs used for simulating this attribution scenario yield intermediate results between those described for the default parameter design set in the previous section and that for the GDE native vegetation scenario with *Kc* = 1.0, ET depth = 33 ft (Figure 32).

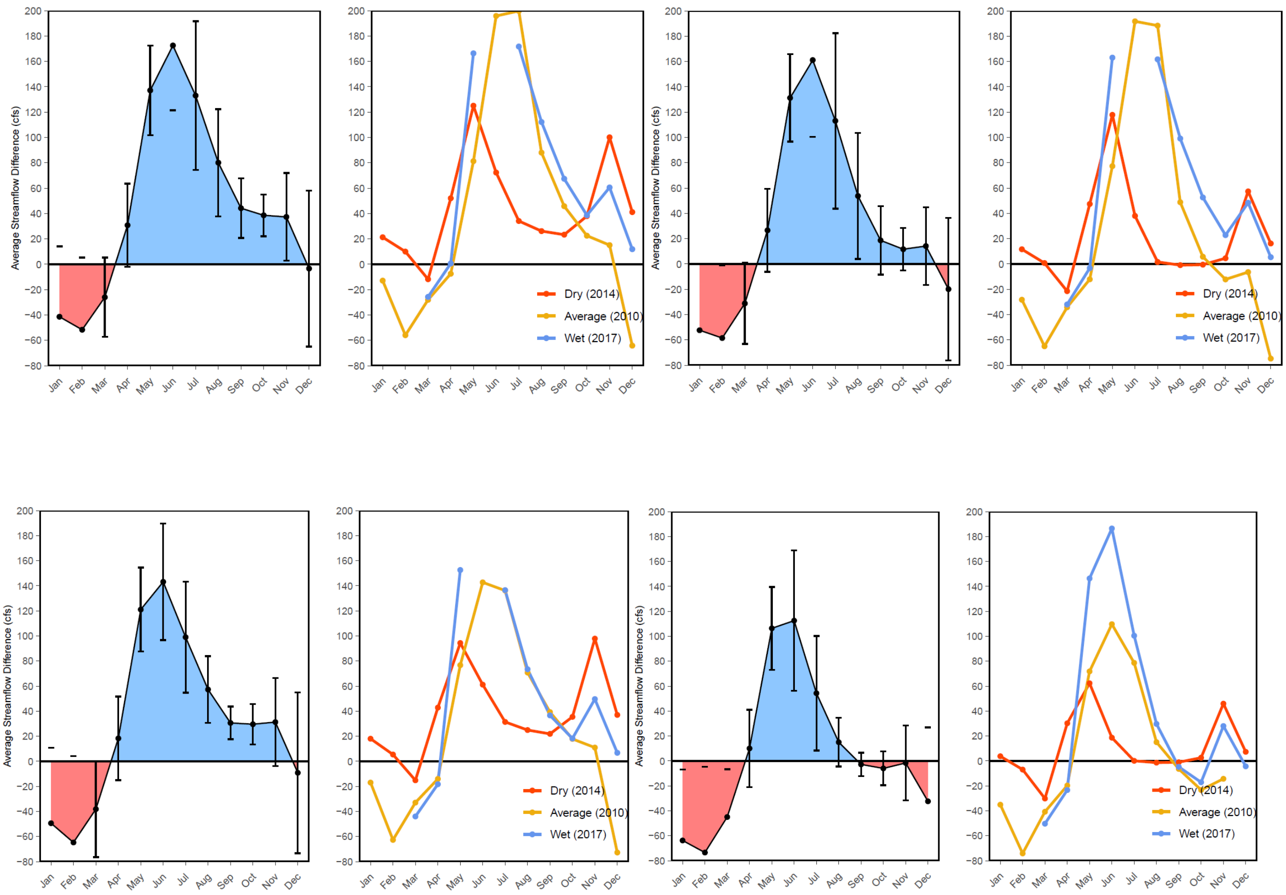


Figure 32: Simulated stream depletion (i.e., difference in streamflow under unimpaired conditions and basecase conditions) [in cfs]. Left: Average stream depletion (y-axis) by calendar month (x-axis). Whiskers indicate standard deviation across years. Right: Monthly stream depletion [cfs] for three example years, each being a different water year type (dry, average, wet). Stream depletion shown is due to groundwater and mixed source water uses (top) or due to all water uses (bottom) within *and* outside of the adjudicated zone (i.e., all of Scott Valley). The four panels represent four alternative ecohydrologic parameter designs: Kc = 0.6, ET depth = 15 ft (top left), Kc = 0.6, ET depth = 33 ft (top right), Kc = 1.0, ET depth = 15 ft (bottom left), and Kc = 1.0, ET depth = 33 feet (bottom right).

The selection of the ecohydrologic design parameters for native vegetation therefore has significant impact on attributing the impact of agriculture on spring recess duration and fall pulse flow. Only those for the default non-GDE ecohydrologic design and for the GDE design with Kc = 0.6 or 1.0 and ET depth = 4.5 m are nearly identical, with few years when the flow threshold of 30 cfs is not met (Figure 33). The occurrence of spring recess flows dipping below 30 cfs, and fall pulse flows reaching 30 cfs after September 15 is most sensitive to the maximum ET depth, and, at the larger ET depth, it is also sensitive to the K_c value. This is due to a much larger area having water table that is shallower than 33 feet over long periods of time than the area where water table is shallower than 15 feet deep. For the most ET-consuming native vegetation design (K_c = 1.0, ET depth = 33 ft), fall reconnection is worse than under current basecase conditions, but spring recess declines below 30 cfs about 2 weeks later (better) than under the current basecase.

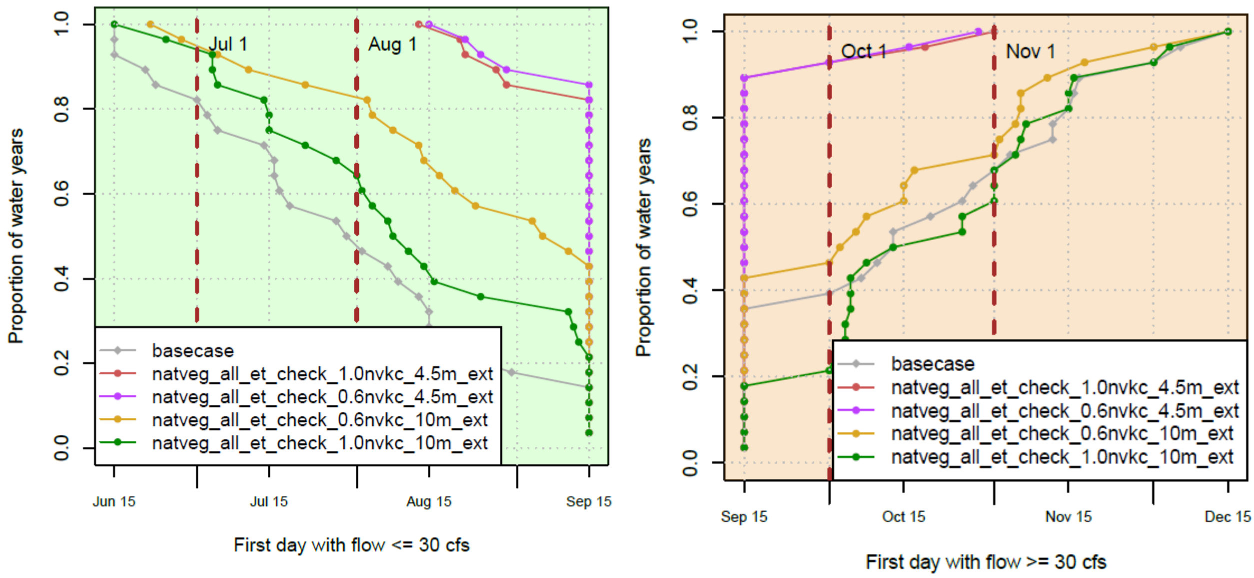


Figure 33: Cumulative distribution of the first day of simulated Scott River flows (at the USGS Fort Jones gage) when, during the spring recess (left), flows are 30 cfs or less and when, during the fall pulse flow (right), flows are 30 cfs or more, for various attribution scenarios. The cumulative distributions for the basecase are shown in grey. The selected stream depletion attribution here considers the effect of all irrigation water uses across Scott Valley. The default ecohydrologic design parameters for native vegetation: K_c = 0.6, but with ET limited by moisture in the soil root zone (no GDE), except in areas of the Discharge Zone identified in the basecase as subflow irrigated. Other ecohydrologic parameter design sensitivity cases include those with ET from groundwater, across Scott Valley, where water table depth allows: K_c = 0.6, ET depth = 15 ft (4.5 m); K_c = 0.6, ET depth = 33 ft (10 m); K_c = 1.0, ET depth = 33 ft (10 m).

Given what is known about native vegetation prior to the agricultural development of Scott Valley, a likely ecohydrologic design parameter set considers a Kc value of 1.0 and an ET depth of 15 ft (4.5 m). This provides the high ET for riparian vegetation and wetlands with very shallow water table, but also accounts for some groundwater-derived ET, at much lower rate for the bunch grass – clover grassland with disperse oak woodland. All stream depletion attribution scenarios were re-simulated with this alternative ecohydrologic parameter set. Differences between attribution scenarios are qualitatively similar to those under the default ecohydrologic parameter design. However, the magnitude of stream depletion is lower and the duration of dry season base flow in spring and fall is longer, with differences to the basecase significantly less, particularly in the fall.

In summary, the ecohydrologic design parameters of native vegetation in unimpaired scenario simulations have significant impact on the magnitude of estimated total stream depletion. Further research into appropriate ecohydrologic parameter selection for unimpaired land use conditions is therefore warranted.

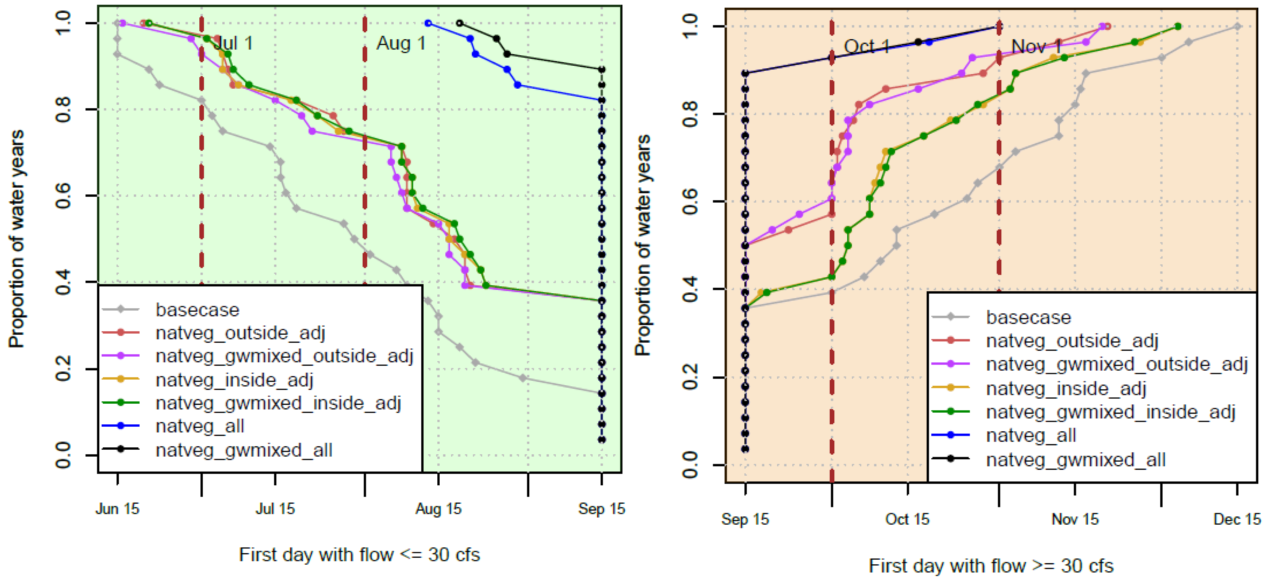


Figure 34: Cumulative distribution of the first day of simulated Scott River flows (at the USGS Fort Jones gage) when, during the spring recess (left), flows are 30 cfs or less and when, during the fall pulse flow (right), flows are 30 cfs or more, for various attribution scenarios. The cumulative distributions for the basecase are shown in grey. All stream depletion attribution scenarios use the an ecohydrologic design parameters for native vegetation representing a mix of riparian forest, deep rooted native grasses (bunch grasses, wild clover) and disperse oak-woodland: K_c = 0.6, ET depth = 15 ft.

7 SVIHM Scenario Development: Projects and Management Actions, Regulatory Actions

7.1 Overview

This section presents results developed for decision-support in the Scott Valley GSP development process and developed to provide some preliminary insights on potential curtailments under the 2021 Scott Valley Drought Emergency Order. During the GSP development process, stakeholders asked, among other questions, how much beneficial impact certain projects and management actions may have on instream flow conditions in the Scott River. The projects and management action scenarios presented here were developed in collaboration with the GSA advisory committee for Scott Valley, staff at the North Coast Regional Board, GSA staff, State Water Board staff and board members, and the GSP technical team. The results shown here were the foundation for setting the sustainable management criteria in the Scott Valley Groundwater Sustainability Plan and partially informed expectations of fall 2021 outcomes under the 2021 drought emergency order.

As with the attribution scenarios, these scenarios provide a large dataset of daily stream flows and groundwater levels throughout the groundwater basin, and their differences to the basecase. Results are presented in a series of figures.

A scenario to estimate the effects of beaver dam analogs on streamflow (one of the original project objectives) was considered but never completed. Our assessment was that significant changes to the simulation code were needed to properly accomplish that task. Hence, this particular management action remains on the list of needed SVIHM scenario developments.

7.2 Description of the Scenarios

7.2.1 Infrastructure scenarios

7.2.1.1 Enhanced Recharge (EnhRch) and Expanded Enhanced Recharge (EnhRchEx)

The enhanced recharge scenarios were developed to estimate the dry season streamflow increases that could be engineered by banking surface water in the aquifer, or using surface water to delay the use of groundwater pumping.

Managed Aquifer Recharge (MAR) involves the diversion of winter surface flow for purposes of applying it to a land area and allowing it to infiltrate into the aquifer. MAR diversions are designed to take place December-March, when surface flow is generally abundant, on a set of fields selected using two criteria: a potentially-willing landowner (as of the scenario design period, 2013-2017) and ease of water application (red and orange areas, Figure 35, Panel A). Each MAR field was assigned an infiltration rate based on the SSURGO soil properties database (Tolley et al., in prep).

In Lieu Recharge (ILR) involves using surface water for irrigation in lieu of groundwater, starting in the early growing season (March-April) and for as long as surface water is available. This practice both delays extracting groundwater and contributes some additional recharge to the aquifer as infiltration through the crop rooting zone. Fields on which this kind of irrigation flexibility is possible by definition have access to both surface water and groundwater irrigation sources (yellow and orange areas, Figure 35, Panel A). Some fields were considered candidates for both enhanced recharge techniques (orange areas, Figure 35, Panel A).

The Expanded Enhanced Recharge scenario design assumed that, with additional infrastructure, any field that had access to a surface water irrigation source could be included in a combined MAR and ILR program (Figure 35, Panel B). However, the additional fields in the expanded set were not assigned an infiltration rate in the same way. Instead, a range of possible average infiltration rates was tested in three scenarios: 3, 19, and 35 cm/day.

The following list describes acronyms and specific scenario settings of the various MAR and ILR scenarios performed:

- mar – Divert surface water to over-irrigate fields and enhance groundwater recharge during the wet season (Dec-Mar). Allow diversions from tributaries to continue as long as water is available (on a monthly volume basis).
- ilr – Divert surface water to irrigate fields during the growing season (Apr-Jun or Jul) in lieu of pumping groundwater. Allow diversions from tributaries to continue as long as water is available (on a monthly volume basis).
- mar_ilr – Combination of MAR and ILR scenarios.
- mar_ilr_max_0.003 – MAR and ILR on all old MAR and ILR fields and all other fields with a surface water irrigation source. Assumed max infiltration rate of 0.003 m/day for all fields without specified infiltration rates.
- mar_ilr_max_0.019 – MAR and ILR on all old MAR and ILR fields and all other fields with a surface water irrigation source. Assumed max infiltration rate of 0.019 m/day for all fields without specified infiltration rates.
- mar_ilr_max_0.035 – MAR and ILR on all old MAR and ILR fields and all other fields with a surface water irrigation source. Assumed max infiltration rate of 0.035 m/day for all fields without specified infiltration rates.

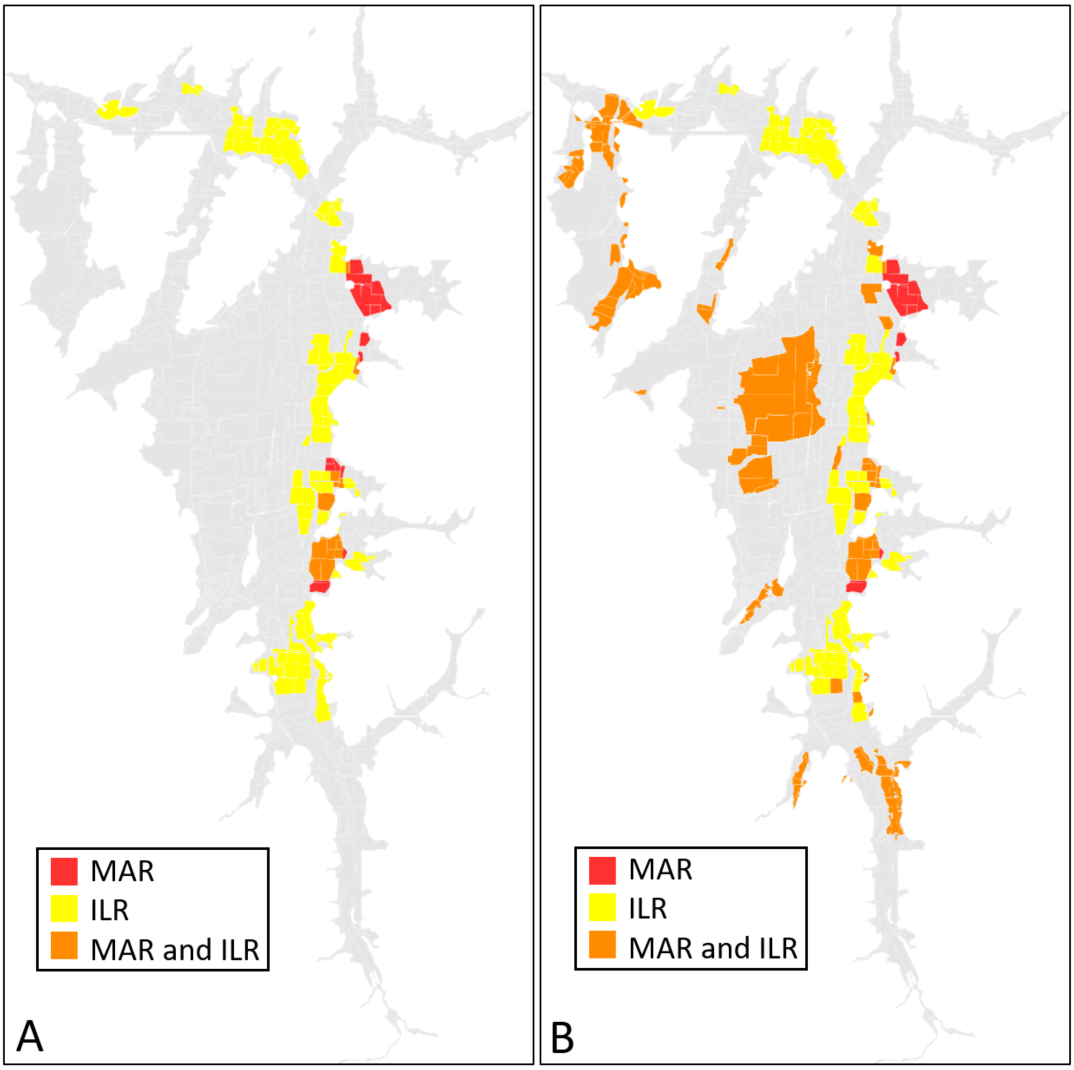


Figure 35: Fields selected for implementation of MAR and ILR enhanced recharge practices (after Tolley et al., in prep) (A), and the expanded version, which assumes that all fields with a surface water source participate in the MAR and ILR program (B).

7.2.1.2 *Crop Change (decreased irrigation demand; CropCh)*

The Crop Change scenarios were developed to assess hydrologic impacts of replacing all existing irrigated crops with an unspecified different crop that consumed 90% or 80% of the historical crop cover (two separate scenarios). To simulate this, a 0.8 or 0.9 multiplier was applied to the daily crop ET value for each field in the model domain.

Crops with potentially lower annual ET that have been mentioned during stakeholder meetings as possibly suited to the climate of Scott Valley or have been cultivated in a trial setting include potatoes, sunflowers, and carrots for seed, though notably, to the authors' knowledge no local grower has cultivated any of these commercially.

The following two acronyms are used for the two scenarios:

- irrig_0.8 – Assumes unspecified irrigated crop change, reducing all irrigated acreage water demand by 20%.
- irrig_0.9 – Assumes unspecified irrigated crop change, reducing all irrigated acreage water demand by 10%.

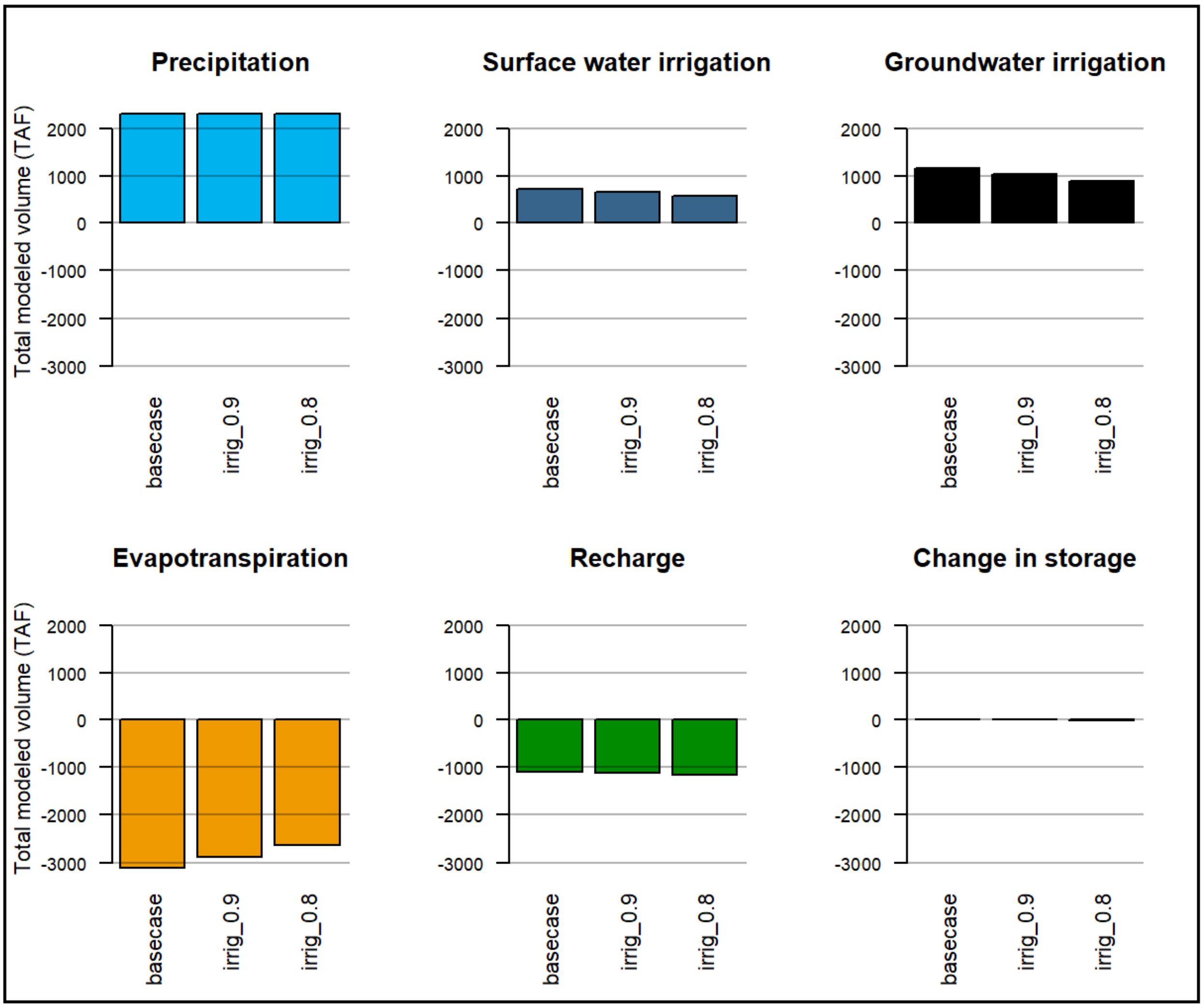


Figure 36: Comparison of six key water budget terms (precipitation, surface water irrigation, groundwater irrigation, ET, recharge, and change in storage), averaged over the 28-year simulation period. Shown are results for the basecase, irrig_0.9, and irrig_0.8 (left to right, respectively).

7.2.1.3 Irrigation Efficiency (IrrEff)

The Irrigation Efficiency scenarios were developed to test the hydrologic impact of widespread deployment of higher-efficiency irrigation technologies. The exact technology is unspecified; in this scenario design, a multiplier of 1.1 or 1.2 was applied to the irrigation efficiency parameter associated with each field in the model domain.

Existing irrigation techniques in Scott Valley include flood irrigation, sub-irrigation (in areas with known shallow groundwater), wheel line, and center pivot (Harter and Hines 2008). In recent years some agricultural operations have installed higher-efficiency technology like Mid- or Low-Elevation Spray Application, and Low Energy Precision Application has been tested in some areas (Galdi 2021). The following two acronyms are used for these two scenarios:

- irr_eff_improve_0.1 – Effective irrigation efficiency of wheel line and center pivot on alfalfa and pasture improves by 0.1 (10%).
- irr_eff_improve_0.2 – Effective irrigation efficiency of wheel line and center pivot on alfalfa and pasture improves by 0.2 (20%).

7.2.1.4 Reservoirs (Res)

The Reservoir scenarios were developed to assess whether a small reservoir, located on one of the main tributary streams, could significantly enhance dry season flows. Four tributary locations were tested (from north to south): Shackleford, Etna, and French Creeks, and the South Fork of the Scott River (Figure 37). In each scenario the daily flow of one tributary is altered to simulate storage and release of flow. This alteration occurs upstream of the SVIHM model domain, such that from the perspective of the SVIHM, the only change from basecase is to replace one tributary's inflow to the model (i.e., the daily tributary flow estimated in the Streamflow Regression Model; Foglia et al. 2013; Tolley, Foglia, and Harter 2019) with the outflow record of the reservoir.

In four of the scenarios, the capacity of the reservoir was set at 9 thousand acre-feet (TAF, or 11.1 million m3). This was calculated by multiplying a desired outflow, 30 cubic feet per second (cfs; 0.85 cms or 73 thousand m3 per day), for 150 days of a potential dry season (August-December). It also accounted for stakeholder input (as discussed during GSP development) that in the Scott Valley topographic context, a reservoir of greater than 10 TAF would probably be infeasible. However, in some multi-year drought periods, the 9 TAF reservoir runs dry and cannot meet the desired dry season outflow. To extend the analysis, an additional scenario was designed to furnish a 30 cfs dry season release with 100% reliability for the climate record 1991-2018, by ignoring the reservoir capacity constraints. The minimum reservoir capacity that accomplished this was a 29 TAF reservoir. It was sited on Etna creek to allow comparison with an existing 9 TAF reservoir scenario.

For the Reservoir scenarios, a series of operating rules dictates the following:

- Hold all water except 30 cfs back in the wet season (Dec. 1-Mar. 31), until the reservoir is full.
- Allow water to pass through during the growing season (Apr. 1-June 31), to make sure enough surface water was available for irrigation, but retains water in storage.
- Release 30 cfs in the dry season (July 1-Nov. 30), unless the reservoir runs dry.

Additionally, no feasibility or risk factors were evaluated, some of which could completely preclude actual reservoir construction. For example, stakeholder feedback regarding the Etna Creek reservoir indicated that any reservoir upstream of the community of Etna would create an unacceptable potential flood risk. Further- more some stakeholders conveyed strenuous objections to on-stream storage solutions, due to unacceptable impacts to aquatic habitat, though off-stream storage options generated less opposition.

The following acronyms are used for the specific scenarios involving reservoirs:

- reservoir_shackleford Simulates a 9 TAF reservoir on the Shackleford Creek tributary by withhold- ing wet-season flow and releasing it during the dry season according to set operations rules.
- reservoir_etna Simulates a 9 TAF reservoir on the Etna Creek tributary by withholding wet-season flow and releasing it during the dry season according to set operations rules.
- reservoir_french Simulates a 9 TAF reservoir on the French Creek tributary by withholding wet- season flow and releasing it during the dry season according to set operations rules.
- reservoir_sfork Simulates a 9 TAF reservoir on the South Fork tributary by withholding wet-season flow and releasing it during the dry season according to set operations rules.
- reservoir_etna_29kAF Simulates a 29 TAF reservoir on the Etna Creek tributary by withholding wet-season flow and releasing it during the dry season according to set operations rules.

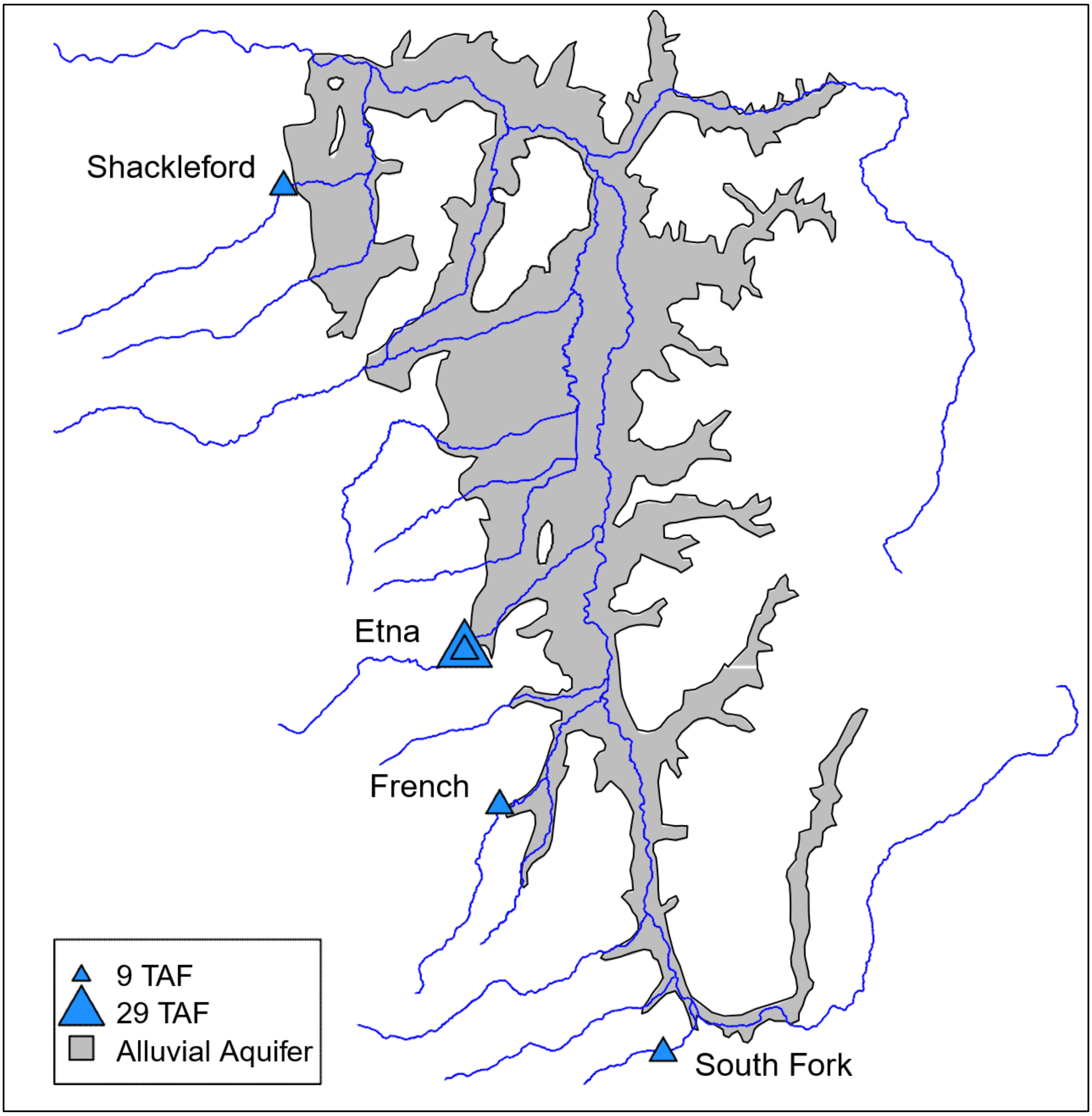


Figure 37: Schematic location of hypothetical reservoirs in the Scott River watershed, on South Fork Scott River, French Creek, Etna Creek, and Shackleford Creek. Note that scenario simulations neither account for actual reservoir location or construction, nor for any delivery infrastructure. The scenario simulations only add water from the hypothetical reservoirs, at prescribesd rates, to the tributaries at the upstream boundary of the SVIHM domain (grey area), for instream flow purposes. The scenario simulations also track filling and emptying of the reservoir. Reservoir inflow are equal to the estimated tributary flows at the upstream boundary of the SVIHM domain.

7.2.2 Regulatory scenarios

7.2.2.1 Early cessation of alfalfa irrigation (AlfIrr)

The Alfalfa Irrigation scenarios were developed to assess the potential for increased dry season flows in the event of a reduced alfalfa harvest.

The basecase default cessation date for alfalfa irrigation in the SVIHM is August 31st. Alfalfa is a perennial crop, but is harvested periodically during "cuttings." The most common schedule in Scott Valley involves three cuttings per growing season. One scenario explored during GSP development was a proposition that alfalfa growers reduce the number of cuttings to two and then ceasing to irrigate the alfalfa crop; this would still generate some revenue for the grower but would avoid irrigation and crop ET during the critical part of the dry season. Depending on the year and growing conditions, in the two-cutting scenario, the date of the final irrigation may range from as early as mid-July to mid-August, so SVIHM was used to simulate a range of three cessation dates. A variation on this tested the impact of implementing early cessation in dry years only, which in the model period were designated as water years 1991, '92, '94, 2001, '09, '13, '14, '18. In this scenario it is assumed that a dry year can be identified before the onset of the growing season (e.g. depending on wet season precipitation and snowpack accumulation.)

The following acronyms are used for the scenarios simulating early cessation of alfalfa irrigation. Cessation of alfalfa irrigation includes all sources of irrigation water, surface water diversions and groundwater.

- alf_irr_stop_jul10 Alfalfa irrigation ceases on July 10th of every growing season
- alf_irr_stop_aug01 Alfalfa irrigation ceases on August 1st of every growing season.
- alf_irr_stop_aug15 Alfalfa irrigation ceases on August 15th of every growing season.
- alf_irr_stop_aug01_dry_yrs_only Alfalfa irrigation ceases on August 1st in designated dry years only.
- alf_irr_stop_aug15_dry_yrs_only Alfalfa irrigation ceases on August 15th in designated dry years only.

Most alfalfa acreage is irrigated with groundwater (Foglia et al., 2013a). As a result, these management scenarios yield negligible reductions in surface water diversions, but as much as one-third cut-back in groundwater pumping (alf_irr_stop_jul10 scenario, Figure 38). Evapotranspiration is reduced by less than 10%, even in the earliest cessation scenario. Earlier cessation of irrigation on alfalfa, which occupies nearly half of the irrigated acreage in the basin, also leads to a reduction in recharge (Figure 38).

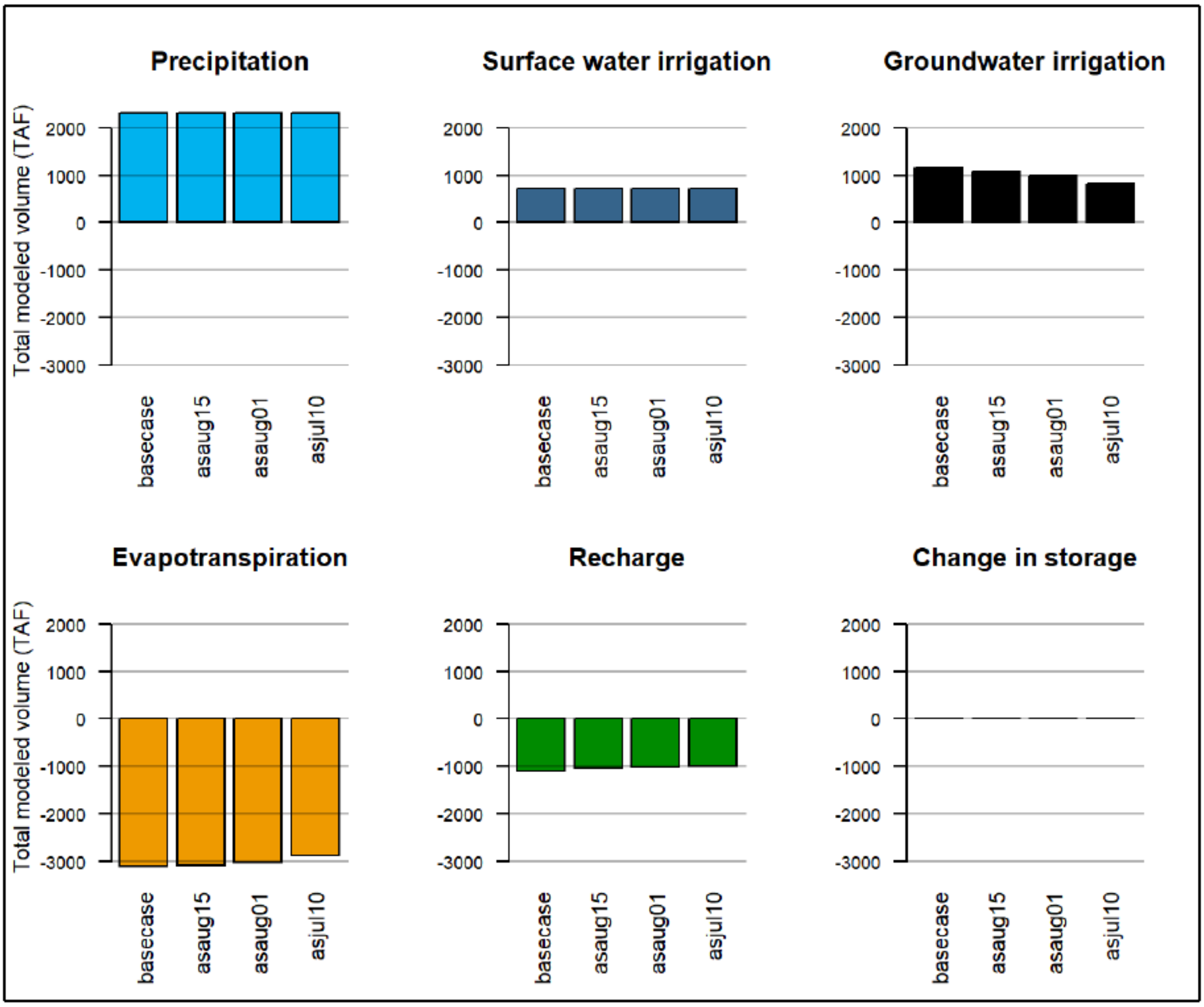


Figure 38: Comparison of six key water budget terms (precipitation, surface water irrigation, groundwater irrigation, ET, recharge, and change in storage), averaged over the 28-year simulation period. Shown are results for the basecase, alf_irr_stop_aug15, alf_irr_stop_aug01, and alf_irr_stop_jul10 (left to right, respectively).

7.2.2.2 Curtailment of all irrigation mid-growing season (Curtail)

The Curtailment scenarios were developed to assess the potential for increased dry season flows in the event of a total irrigation cut-off, i.e., curtailment of all groundwater pumping and surface water diversions, on all crops, sometime during the growing season.

The basecase default cessation date for alfalfa irrigation in the SVIHM is August 31st, while grain is irrigated through late July and pasture irrigation continues through October. Emergency drought orders by the California State Water Resources Control Board (SWRCB) in water years 2021 and 2022 (SWRCB 2021b, SWRCB 2021a) prompted a stepwise analysis, by date of initiation of curtailment, of the impact of total irrigation curtailment.

In the six Curtailment scenarios, implemented during all water years, all irrigation proceeds normal until the following curtailment dates, when all irrigation ceases (first term indicates the scenario acronym):

- curtail_start_jun01 – June 1st
- curtail_start_jun15 – June 15th
- curtail_start_jul01 – July 1st
- curtail_start_jul15 – July 15th
- curtail_start_aug01 – August 1st
- curtail_start_aug15 – August 15th

7.2.2.3 Limits on diversion of surface water during low-flow periods at the Fort Jones Gauge (FlowLims)

The Low Flow Diversion Limits scenario was simulated to assess the hydrologic impact of restricting surface water diversions during periods when the Fort Jones Gauge falls below a proscribed desired flow regime.

In this scenario, available water is defined as the proportion of total flow at the FJ gauge in excess of CDFW 2017 recommended instream flow values (CDFW 2017); alternative flow regimes could be substituted in future analyses. The "available" percentage is applied to the flow in each tributary and used to limit surface flow diversions, but not groundwater pumping. Surface water rights are not accounted for in this scenario. It was included in GSP development as a book-end scenario to explore the outcome of management actions such as surface water leases or potential expanded implementation of the existing water master programs on some tributary streams.

- flow_lims – Surface water diversions limited based on FJ flow and CDFW Recommended Instream Flows (CDFW 2017), in all years.

Figure 39 illustrates, how days at which no irrigation can occur, are determined by comparing actually measured flow at the Fort Jones with the CDFW (2017) minimum instream flow recommendation. On days when flows at the Fort Jones gage historically were below the recommended instream flows, (red colored periods in Figure 39), the scenario simulation would not allow for surface water diversions. Fields that have been identified as having a "mixed" irrigation source, i.e., access to both surface water and groundwater, switch to groundwater pumping during those periods. Fields that have been identified as only surface water irrigated do not receive any irrigation during those periods. The SWBM module in SVIHM tracks the ensuing reduction in ET and recharge. The SWBM model, however, does not track reduced ET after crops have been under extended water stress, a limitation of SVIHM.

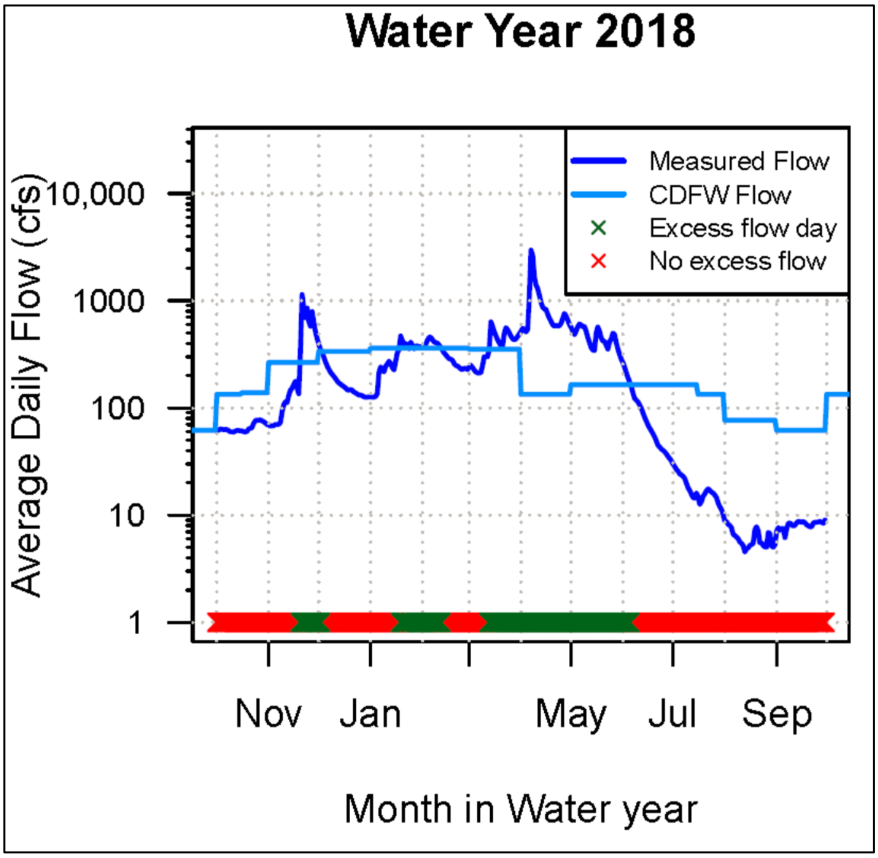


Figure 39: Days on which, in the Low Flow Diversion Limits scenario, tributary surface water diversions for irrigation would be allowed (green x) and not allowed (red x) in an example water year.

7.3 Interpretive Summary of Outcomes under GSP Projects and Management Actions and Potential SWRCB Regulatory Actions

7.3.1 Scenario Simulation Outcomes

Like the natural vegetation scenarios described in chapter 6, each of the project/management action scenarios yields a 28-year, day-by-day comparison between the scenario outcome and the basecase outcome. Simulation outcomes include groundwater levels and streamflows in tributaries and the main-stem Scott River, throughout the entire basin, at the spatial resolution of SVIHM (328 ft or 100 m). For the GSP development and for the 2021 Scott Valley Drought Emergency Order, the focus of stakeholder considerations has been flows at the Fort Jones gage.

This report presents presents a summary of the stream depletion reversal outcomes of the various scenarios considered in the development of the GSP (Section 7.3.2) with details of stream depletion reversal, spring recess timing, and fall reconnection timing provided in Appendix 1. A short discussion of the Fort Jones gage flow outcomes of the regulatory scenarios (Early Cessation of Alfalfa Irrigation, Curtailment), focusing on the drought year 2015, which followed drought year 2014 is presented in Section 7.3.3.

7.3.2 Projects and Management Actions Scenarios: Effects on Stream Depletion Reversal

Consistent with the attribution analysis (Section 6), stream depletion reversal is defined as the difference in daily simulated Scott River Fort Jones gage flow between the scenario case and the basecase:

stream depletion reversal [cfs] = scenario flow rate [cfs] – basecase flow rate [cfs]

Stream depletion reversal is measured for each day of the 28-year simulation period. Stream depletion reversal is positive, when the Scott River flow rate is higher in the scenario case than in the basecase. Streamflow depletion reversal is negative when the Scott River flow rate is less in the scenario case than in the basecase. For example, under the MAR scenario, stream depletion reversal is negative during the period of additional surface water diversions for operating the MAR project during the winter months. But it is positive during the period following the MAR diversions. The amount of negative stream depletion reversal during the winter months is a small fraction of the total flow. Hence, on a logarithmic scale of flow rates, the small amount of negative stream depletion reversal is not noticeable, while both, stream depletion and stream depletion reversal are significant during the low flow summer months, and therefore emphasized (Figure 340).

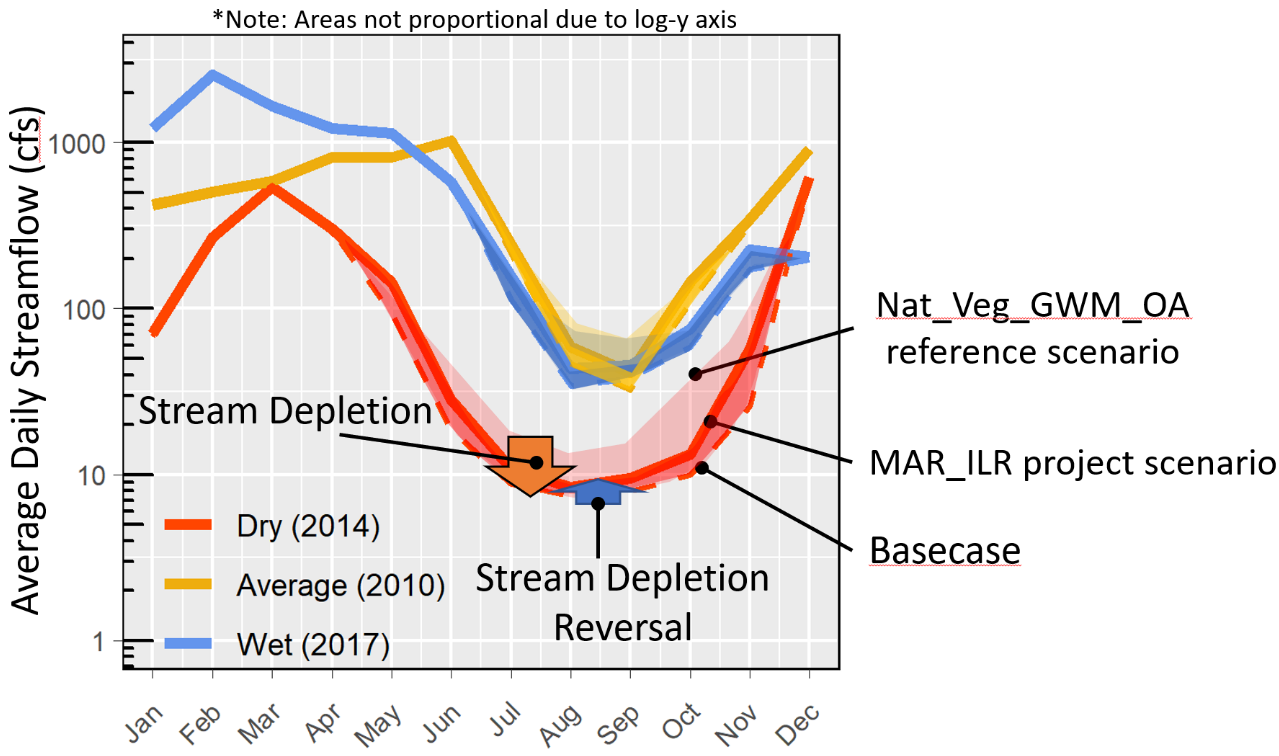


Figure 40: Simulated Scott River flows at the Fort Jones gage in a wet year (2017, blue), average year (2010, yellow), and dry year (2014, red). For each of these examples of the three water year types, simulated flow for the basecase (dashed line), for the project scenario (here: MAR and ILR, solid line), and for the natural vegetation scenario (attribution scenario, here Nat_Veg_GWM_OA, top of light-shaded area) are shown. The combined shaded area indicates the daily amount of stream depletion (see definition of stream depletion in Section 6). The dark-shaded area indicates the daily amount of stream depletion reversal (see above). The y-axis is plotted on a logarithmic scale to emphasize differences when flows are relatively low.

To more precisely illustrate the amount of stream depletion and stream depletion reversal (the magnitude of the total shaded and dark shaded areas, respectively, in Figure 40 above), these are plotted separately, with a linear flow scale (y-axis) in the following figure (Figure 41). Note that stream depletion and stream depletion reversal are not to be confused with the amount of (simulated) streamflow. Both of these terms are differences in flow between scenarios and the basecase, but also computed daily, in [cfs].

For the development of the GSP, only one of the attribution scenarios presented in Section 6 was used to compute stream depletion: the Nat_Veg_GWM_OA, a scenario simulating natural vegetation (Nat_Veg) in those locations that are groundwater-irrigated (GW) or mixed-irrigated (M) and located outside the adjudicated zone (OA). These fields are under the jurisdiction of the Groundwater Sustainability Agency. The GSA does not have regulatory oversight of the adjudicated zone. For the development of the sustainable management criteria, the GSA needed to consider the stream depletion due to groundwater pumping within the jurisdictional area of the GSA. Hence, this attribution scenario was the selected reference scenario during GSP preparation.

A particular focus of the GSP development was the effect of projects and management actions on the amount and duration of dry season baseflow during the critical ecologic period from September to November, when Chinook salmon are migrating into Scott Valley for spawning. For ease of comparison, an indicator was created, computed from the total amount of stream depletion reversal observed during this critical September-November period between October 1991 and September 2018 (Figure 41). The indicator is the relative stream depletion reversal during September to November, computed as the ratio of the stream depletion reversal to the stream depletion for the same period:

relative stream depletion reversal [%] = 100% • stream depletion reversal / stream depletion

Daily amounts for both, stream depletion reversal and stream depletion in September, October, and November over the simulation period were added. Hence the indicator represents an average relative stream depletion reversal over the simulation period.

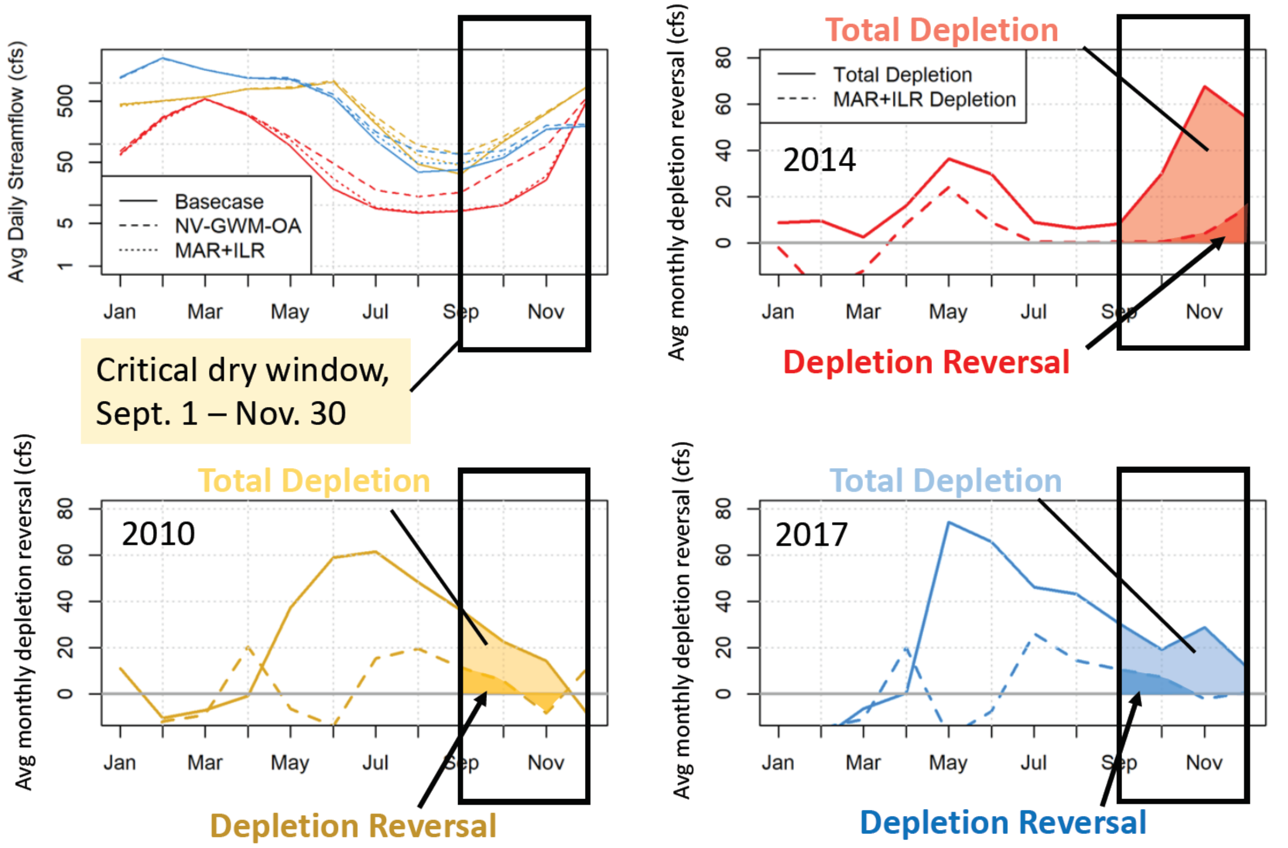


Figure 41: Daily amounts of stream depletion (solid line) and stream depletion reversal (dashed line), corresponding to the height of the total shaded and dark shaded areas, respectively, in the previous figure. Stream depletion and stream depletion reversal are here plotted on a linear flow scale ([cfs]). As in the previous figure, results are shown for a dry year (2014), average year (2010), and wet year (2017). One focus of the GSP advisory committee discussion was the stream depletion during the critical fall low flow period between September and November (black box). The figure illustrates the computation of the totalized 1991-2018 stream depletion reversal and relative stream depletion reversal, shown in the following table.

Enhanced recharge scenarios generated 9% to 44% of stream depletion reversal, with the highest reversal generated by the Expanded MAR_ILR scenario. Surface water diversion limits that curtail surface water use according to the recommended CDFW (2017) instream flows, generate 38% in stream flow depletion reversal. When combined with the MAR_ILR, 57% stream depletion reversal were achieved. The Crop Change scenario, reducing basin-wide ET by 20%, achieved similarly large reversal, at 61%. Irrigation efficiency improvements yielded smaller reversals, from 4% to 12%.

Among the regulatory scenarios, cessation of alfalfa irrigation achieved the largest reversal when implemented consistently over all years, especially when effectively foregoing a third cutting (July 15 or August 1 cessation dates). Implementation of these scenarios in dry years only resulted in much less average stream depletion reversal, although they may be significant in those years. The reservoir options also generated significant stream depletion reversals, ranging from 26% to 184% (Table 11).

The stream depletion and relative stream depletion reversal tabulated in Table 11 are specific to the choice of Nat-Veg_GWM_OA as the attribution or reference scenario. Some of the other attribution scenarios generate more stream depletion (>100% in Table 11) and, hence, less relative stream depletion reversal under any of the project and management scenarios; some attribution scenarios generate less stream depletion (<100% in Table 11) and, hence, more relative stream depletion reversal under the project and management scenarios. The largest stream depletion occurs when assuming all currently irrigated areas are in unirrigated natural vegetation with no groundwater-dependent ecosystems outside the Discharge Zone: Were that reference scenario selected, stream depletion of project and management scenarios would be 212% of that listed in Table 11, about twice as large. Hence, the relative stream depletion reversal, relative to that reference scenario, would only be half as large. The choice of reference scenario would, however, not change the total amount of stream depletion reversal listed in Table 11.

Scenario Type	Scenario ID	Scenario Depletion Reversal, Sep-Nov '91-'18 (TAF)	Relative Depletion Reversal, Sep-Nov '91-'18
Enhanced Recharge	MAR (Managed Aquifer Recharge) in Jan-Mar	13	10%
	ILR (In-Lieu Recharge) in the early growing season	12	9%
	MAR + ILR	25	19%
	Expanded MAR + ILR *(assumed max infiltration rate of 0.019 m/d)*	60	44%
Diversion Limits	All surface water diversions limited at low FJ flows	51	38%
	MAR + ILR, with all surface water diversions limited at low FJ flows	77	57%
Crop change	80% Irrigation demand	82	61%
	90% Irrigation demand	40	29%
Irrigation Efficiency	Improve irrigation efficiency by 0.1	5.8	4%
	Improve irrigation efficiency by 0.2	16	12%
	Reduce irrigation efficiency by 0.1	-3.2	-2%
Irrigation schedule change	Alfalfa irrigation schedule - July 10 end date	117	86%
	Alfalfa irrigation schedule - Aug 01 end date	82	60%
	Aug 01 end date, *dry years only ('91, '92, '94, '01, '09, '13, '14, '18)*	19	14%
	Alfalfa irrigation schedule - Aug 15 end date	45	33%
	Aug 15 end date, *dry years only ('91, '92, '94, '01, '09, '13, '14, '18)*	9	7%
Attribution - adjudicated area impacts	Natural Vegetation Outside Adjudicated area (NVOA)	171	126%
	Natural Vegetation, on Groundwater- or Mixed-source fields, Outside Adjudicated area (NV-GWM-OA)	**136**	100%
	Natural Vegetation Inside Adjudicated area (NVIA)	126	93%
	Natural Vegetation, on Groundwater- or Mixed-source fields, Inside Adjudicated area (NV-GWM-IA)	116	85%
	Natural Vegetation (NV)	287	212%
	Natural Vegetation on all Groundwater- or Mixed-source fields (NV-GWM)	233	171%
Reservoir	9 TAF Reservoir, 30 cfs release, Shackleford	46	34%
	9 TAF Reservoir, 30 cfs release, Etna	65	48%
	9 TAF Reservoir, 30 cfs release, French	78	58%
	9 TAF Reservoir, 30 cfs release, S. Fork	35	26%
100% reliable reservoir	29 TAF Reservoir, 100% reliability 30 cfs release	72	53%
	134 TAF Reservoir, 100% reliability 60 cfs release	250	184%

Table 11: Stream depletion reversal and relative stream depletion reversal (right-most column) for the critical flow period from September to November, totalized over the simulation period, October 1991 – September 2018 (second-right-most column). The relative stream depletion reversal represents an average over all days in the critical flow period of all years simulated.

7.3.3 Regulatory Scenarios: Scott River Fort Jones Gage Flow Outcomes

Next, we consider the entire water year hydrograph during 2015, which had near-average rainfall, but very early in the winter, rapid snow-pack melt-off and a long dry-season baseflow period, following another very dry year 2014. Measured and simulated basecase flows at the Scott River Fort Jones gage are shown both, in Figures 42 and 43.

Among the alfalfa early irrigation cessation scenarios, two scenarios yield practically no improvements over basecase conditions before October 1 (Figure 42): the alf_irr_stop_aug15_dry_yrs_only and the alf_irr_stop_aug01_dry_yrs_only scenarios. In the late fall of 2014, following a very dry preceding winter, those two scenarios produced significant stream depletion reversal not until well after the first large fall "flush flows", which also achieved reconnection of the partially dried out streamflow system.

Other early cessation scenarios yield some stream depletion reversal (a few cfs) within a few weeks of pumping cessation. Only the alf_irr_stop_jul10, implemented every year regardless of water year type, provided more than 20 cfs of stream depletion reversal. Under none of those scenarios did streamflow reach recommended drought emergency instream flows (CDFW, 2021) until well after the fall flush flows and stream reconnection occurred in November.

Curtailments of all irrigation – surface and groundwater, inside and outside the adjudicated zone, regardless of crop – yields much larger stream depletion reversals, with flows generally above the drought emergency instream flow recommendations (CDFW, 2021), within 1 to 2 months after curtailment, but not instantaneously (Figure 43). These scenarios are not strictly drought curtailment scenarios, since they are implemented every year. The curtailment scenarios, in the design presented here, are more optimistic in their outcome than curtailment scenarios, implemented in dry years only, would be (compare, e.g., alf_irr_stop_aug01 and alf_irr_stop_aug01_dry_yrs_only in Figure 42).

From a practical management perspective, the scenarios depicted in Figures 42 and 43 also suggest that the stream depletion reversal begins within days to few weeks after pumping cessation or complete curtailment occurs. Under dry conditions, such as 2014 and 2015, some of the stream depletion reversal is "banked" until the reconnection of the stream system during fall flush flows, after which these regulatory scenarios yield further stream depletion reversal.

The Appendix provides detailed graphical, quantitative metrics that have been computed from the scenario and reference simulations.

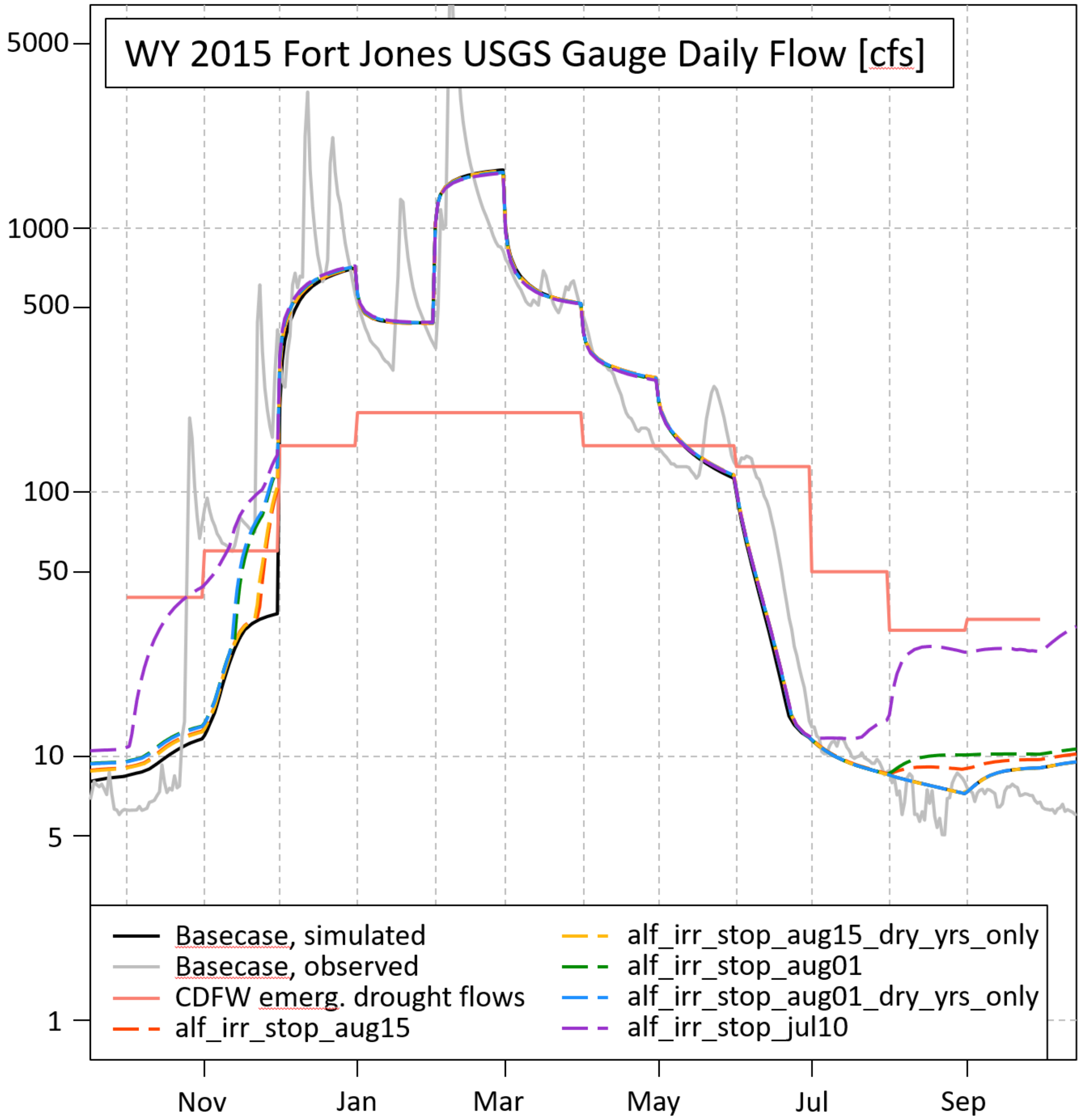


Figure 42: Effect of alfalfa irrigation scenarios on Fort Jones flow in an example water year. Because 2015 was not a dry-type year, no differences from basecase flow are seen in the two dry-year-only scenarios.

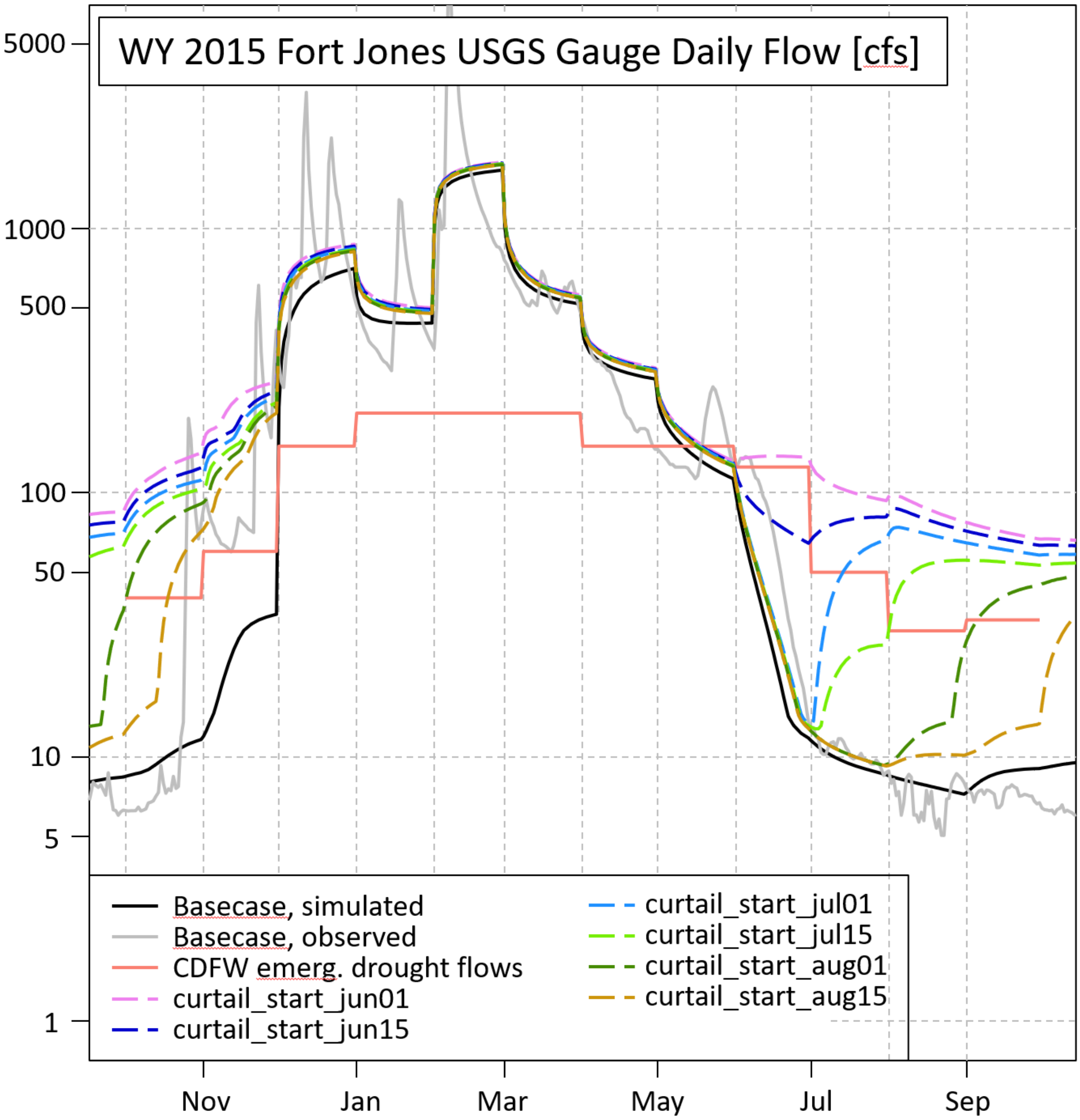


Figure 43: Effect of irrigation curtailment scenarios on Fort Jones flow in an example water year.

8 SVIHM Application to Climate Change: Future Water Budgets

8.1 Overview

The future projected water budget contains all of the same components as the historical water budget; for a description of those terms, see Section 2.2.3.

To inform long-term hydrologic planning, the future projected water budget was developed using the following method:

1. Observed weather and streamflow parameters from water years 1991-2011 were used multiple times to make a 50-year "Basecase" climate record (see Table 12 for details). The Basecase projection represents a hypothetical future period in which climate conditions are the same as conditions from 1991-2011.
2. The climate-influenced variables Precipitation (as rain), Reference Evapotranspiration (ET_{ref}), and tributary stream inflow were altered to represent four climate change scenarios:
    a. Near-future climate, representing conditions in the year 2030 (held over the entire 50-year projection)
    b. Far-future climate, representing central tendency of projected conditions in the year 2070 (held over the entire 50-year projection)
    c. Far-future climate, Wet with Moderate Warming (WMW), representing the wetter extreme of projected conditions in the year 2070 (held over the entire 50-year projection)
    d. Far-future climate, Dry with Extreme Warming (DEW), representing the drier extreme of projected conditions in the year 2070 (held over the entire 50-year projection)
3. The SVIHM was run for the 50-year period of water years 2022-2071 for the Basecase and all four projected climate change scenarios.

For convenience, the scenarios described in points 2a-2d above will be referenced as the Near, Far, Wet and Dry future climate scenarios.

8.2 Method Details

The climate record for the projected 50-year period of water years 2022-2071 (October 2021-September 2071) was constructed from model inputs for the years 1991-2011. The minimum bound of 1991 was imposed by ET_{ref} data, which is not available prior to the SVIHM historical model period; the maximum bound of 2011 was imposed by CDWR change factors, which are only available through 2011 (Table 12).

Under their SGMA climate change guidance, CDWR provided a dataset of "change factors" which each GSA can use to convert local historical weather data into 4 different climate change scenarios (CDWR 2018b). Change factors are geographically and temporally explicit. Geographically, a grid of

1/16-degree resolution cells covers the extent of California; for each of these cells, one change factors applies to each month, 1911-2011.

The change factor concept is intended to convert all past years to a single near or far future year; for example, imagining that in a hypothetical grid cell, the 2030 (Near) scenario change factor for ET_{ref} in March 2001 was 5%. This would imply that, under the local results of the global climate change scenario used to inform this guidance, if March 2001 had occurred in the year 2030, there would be 5% more ET in that grid cell than historically observed.

8.3 Future Climate Simulation Outcomes

The 2030 (Near) and 2070 central tendency (Far) scenarios predict similar rainfall conditions to the Basecase, while the 2070 DEW (Dry) and 2070 WMW (Wet) scenarios show less and more cumulative rain, respectively. Conversely, all scenarios predict higher future ET than the Basecase (Figure 44).

Historical rainfall for three selected periods (1936-2020, 2000-2020, and 2010-2020, with 20.8, 19.8 and 19.3 inches respectively) demonstrate that conditions in the last 10 years have been drier than the last 20, which have been drier than the full record period since 1936. The Basecase and three of the four future scenarios exceed the historic averages, while the DEW (Dry) future scenario (19.2 inches) is on par with the average of the last 10 years (19.3 inches) (Figure 45).

More groundwater is held in aquifer storage in the Wet scenario, and less in the Dry scenario (Figure 46). However, interannual variability is a greater driver of storage change than which climate change scenario is selected i.e., in future year 2045 the difference between the Wet and Dry scenarios was ~5 TAF, but the range in overall interannual variability in each scenario is greater than 40 TAF (Figure 46). Importantly for sustainable groundwater management, none of the future climate scenarios indicate that the lowest groundwater storage points decrease over time, even though repeated decadal wet-dry cycles (Figure 46). This suggests that long-term overdraft and subsidence are unlikely in an aquifer system as seasonally dynamic as the Scott River watershed, at least under climate conditions as extreme as the Dry scenario. However, the lowest point in the cumulative aquifer storage curve for the Dry scenario is typically several TAF below the lowest point in the Far or Basecase scenarios, suggesting that deeper seasonal deficits of groundwater storage under some climate change scenarios may lead to lower dry-season flows.

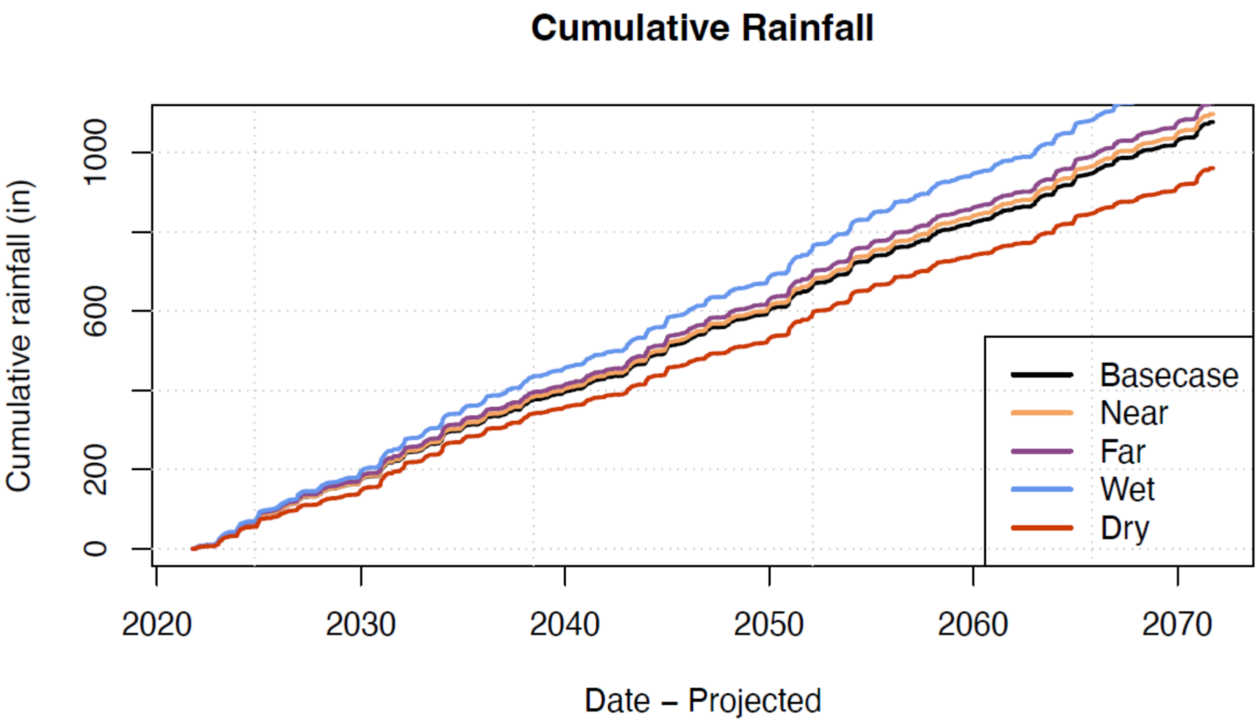
Overall, the effects of all four climate change scenarios on groundwater appear to be somewhat moderate and a matter of degree; conversely, the impact of future climate conditions on surface flows is highly variable depending on which scenario is selected (Figure 47). Near and Far scenarios show minimal differences from historical basecase flow conditions. The Dry scenario shows some periods of notably reduced flow, while the Wet scenario shows some years with much higher flow than historical basecase flow conditions.

While this initial climate analysis is a GSP requirement, it does not provide substantial information to inform sustainable management, in part because the “Dry” scenario more or less matches the climate of the most recent historic decade, while the "Wet" scenario seems unlikely based on the past 20 years of climate patterns.

8.4 Limitations and Future Improvements

The primary limitation of the future water budget analysis is that it likely does not explicitly simulate expected future changes in snow melt dynamics. The tributary inflows have been altered by the application of streamflow change factors provided by CDWR. Even in the Dry with Extreme Warming (DEW) scenario, the most significant change in the overall hydrograph of Shackleford, a major tributary, is a lengthening of the dry season later into the fall (Figure 48). The timing of the spring recession remains extremely similar between the basecase and DEW.

This does not reflect known and recently observed changes in spring recession timing; namely, that higher temperatures will cause snow melt to occur earlier in the year. In future model developments, additional climate change analysis is warranted that would explicitly model regional snow pack dynamics and associated altered tributary inflows.



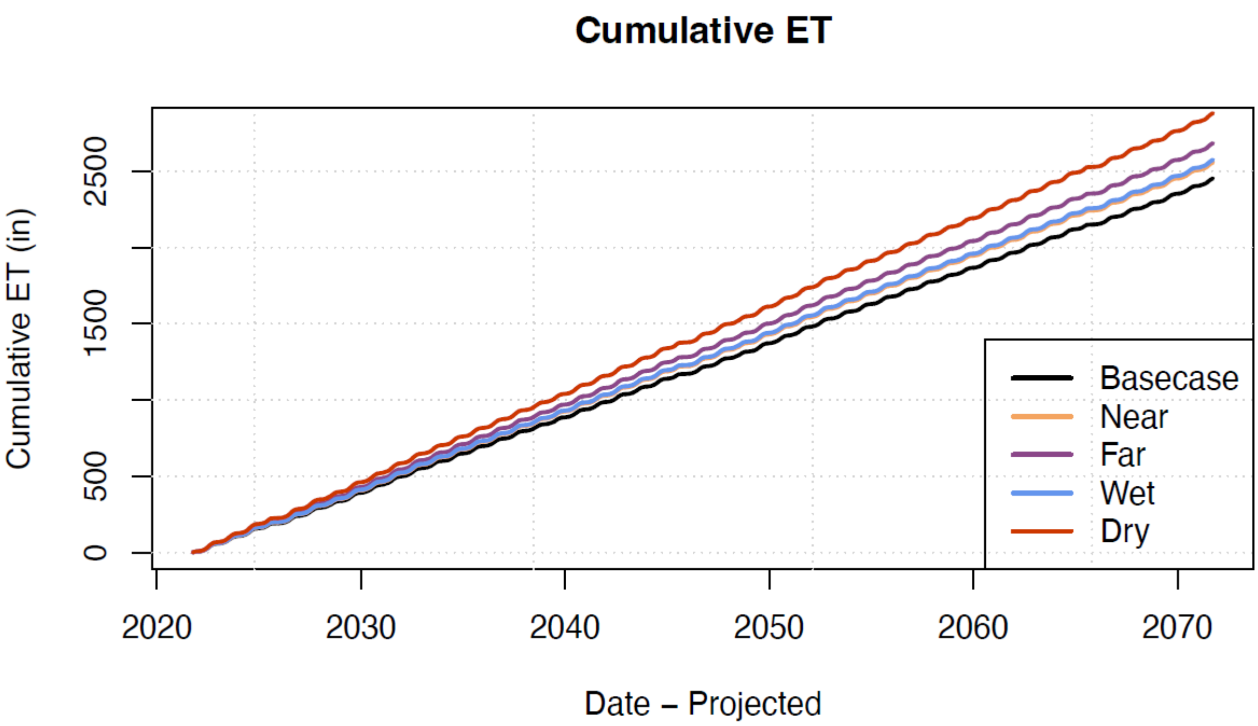


Figure 44: Cumulative precipitation and reference ET for the future projected climate conditions, with basecase and four CDWR climate scenarios. The 2030 (Near) and 2070 central tendency (Far) scenarios predict similar rainfall conditions to the Basecase, while the 2070 DEW (Dry) and 2070 WMW (Wet) scenarios show less and more cumulative rain, respectively. Conversely, all scenarios predict higher future ET than the Basecase.

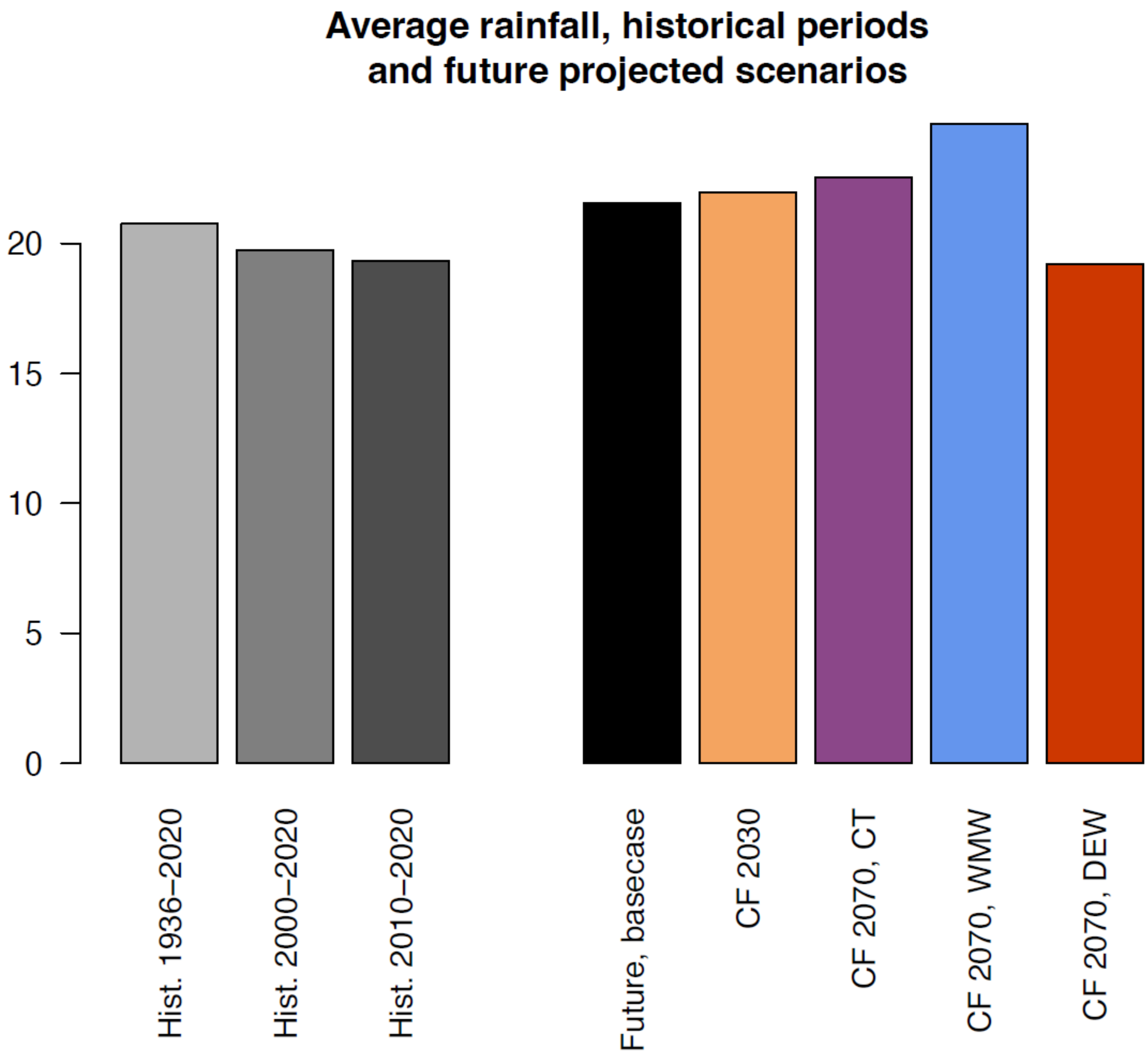


Figure 45: Historical rainfall for three selected periods (1936-2020, 2000-2020, and 2010-2020, with 20.8, 19.8 and 19.3 inches respectively) demonstrate that conditions in the last 10 years have been drier than the last 20, which have been drier than the full record period since 1936. The basecase and three of the four future scenarios exceed the historic averages, while the DEW (Dry) future scenario (19.2 inches) is on par with the average of the last 10 years (19.3 inches).

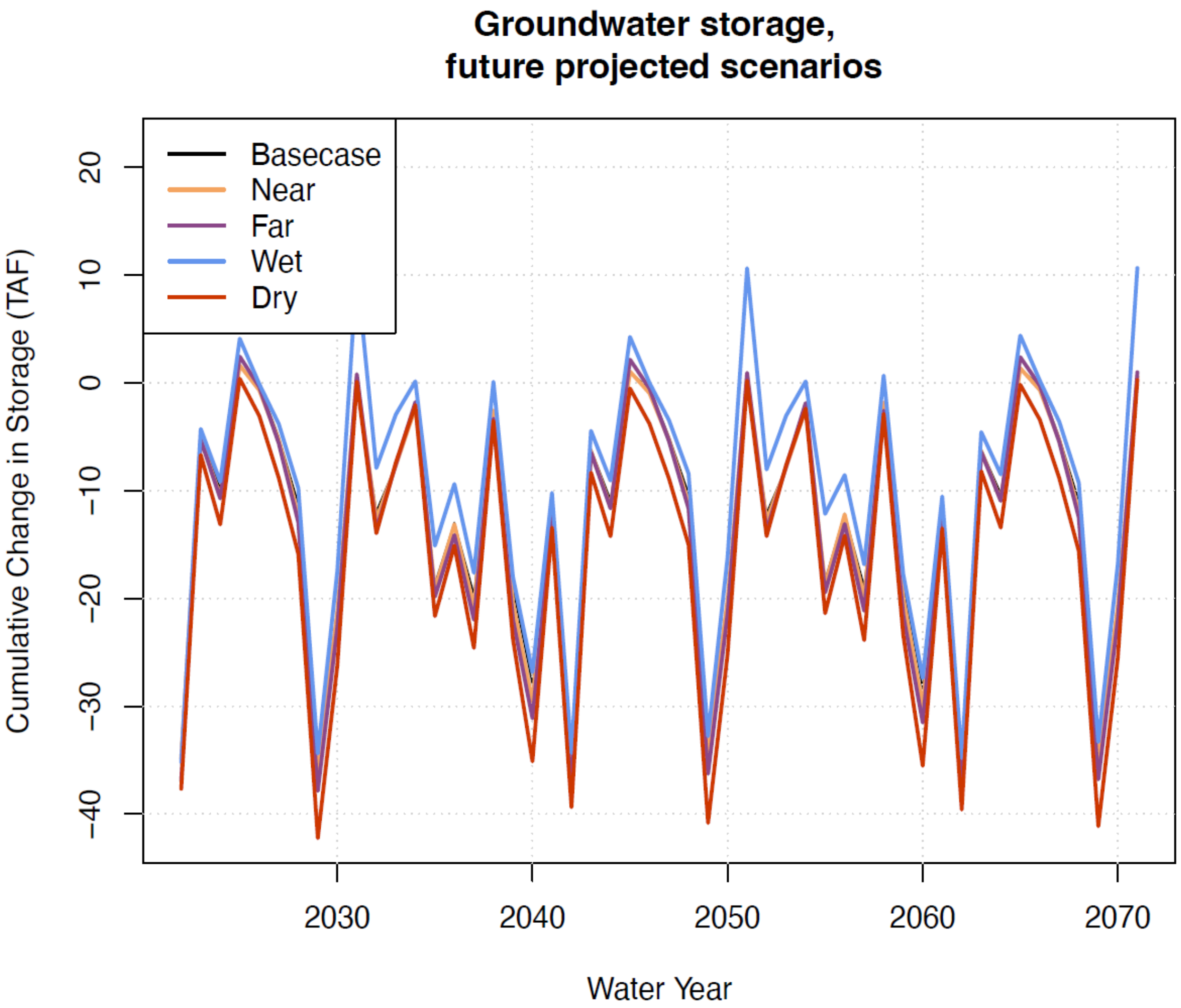


Figure 46:Cumulative annual change in groundwater storage in the Basecase and four climate change scenarios for the future projected water budget.

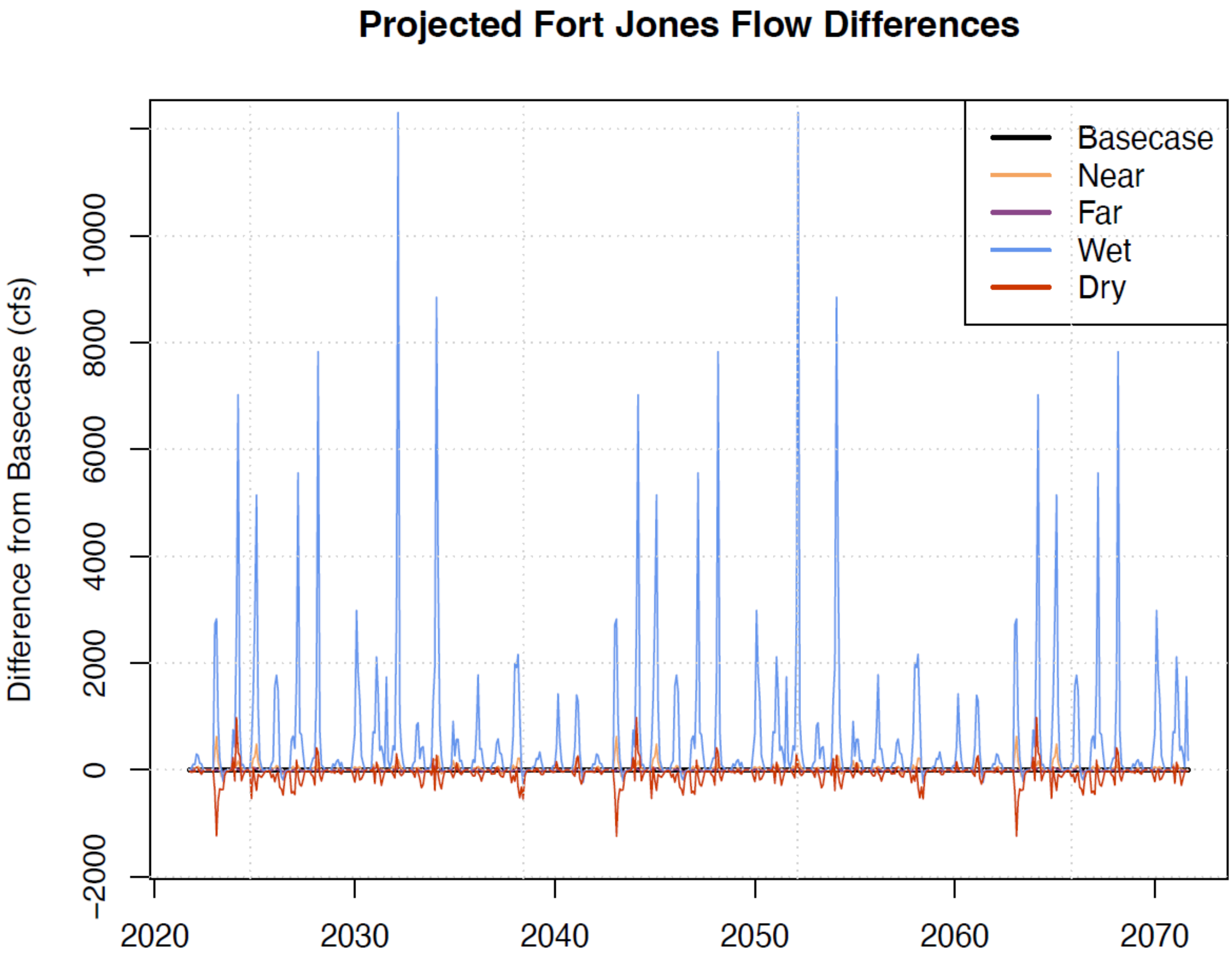
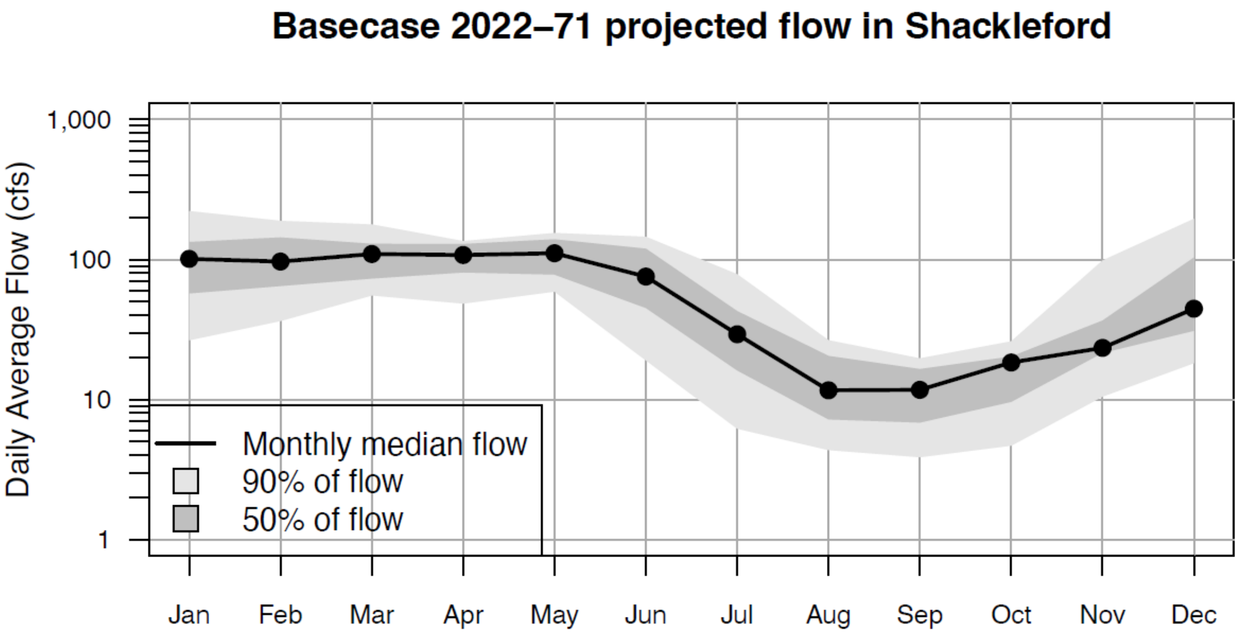


Figure 47: Projected flow at the Fort Jones Gauge, in difference (cfs) from Basecase, for four future projected climate change scenarios. Near and Far scenarios show minimal differences from historical basecase flow conditions. The Dry scenario shows some periods of notably reduced flow, while the Wet scenario shows some years with much higher flow than historical basecase flow conditions.



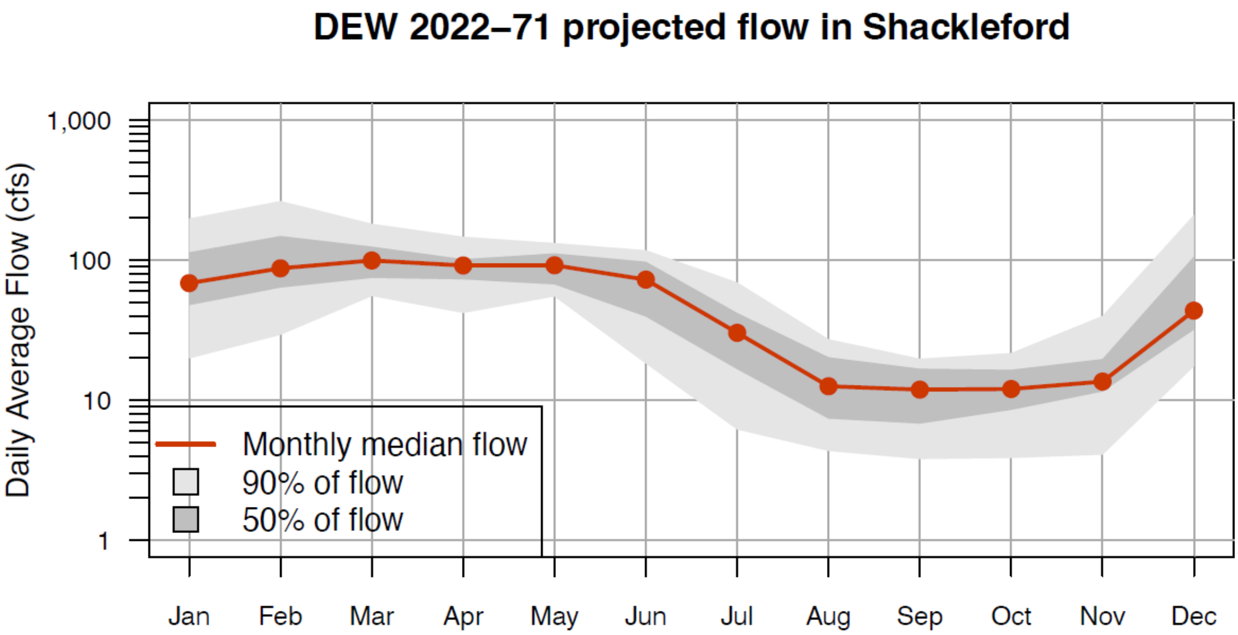


Figure 48: Median flow values for Shackleford tributary inflow with shaded areas covering the 25th-75th and 5th – 95th percentiles, for each month in the 50-year projected model period.

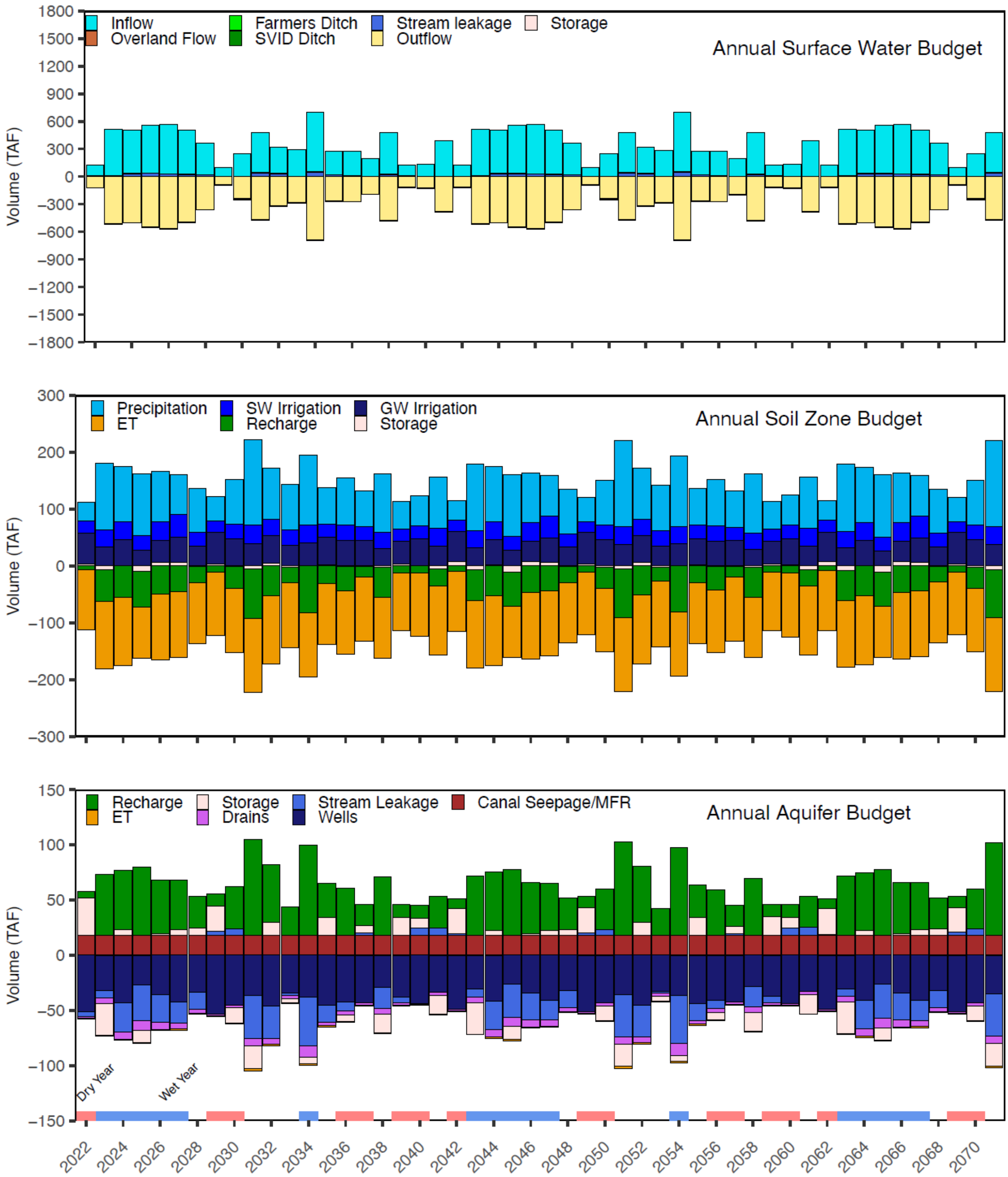


Figure 49: Future Basecase. Annual water budgets for the three conceptual subsystems used to represent the hydrology of the Basin (the surface water system, the soil zone, and the aquifer) for 50 potential future years, with future climate data constructed from the past climate data of water years 1991-2011.

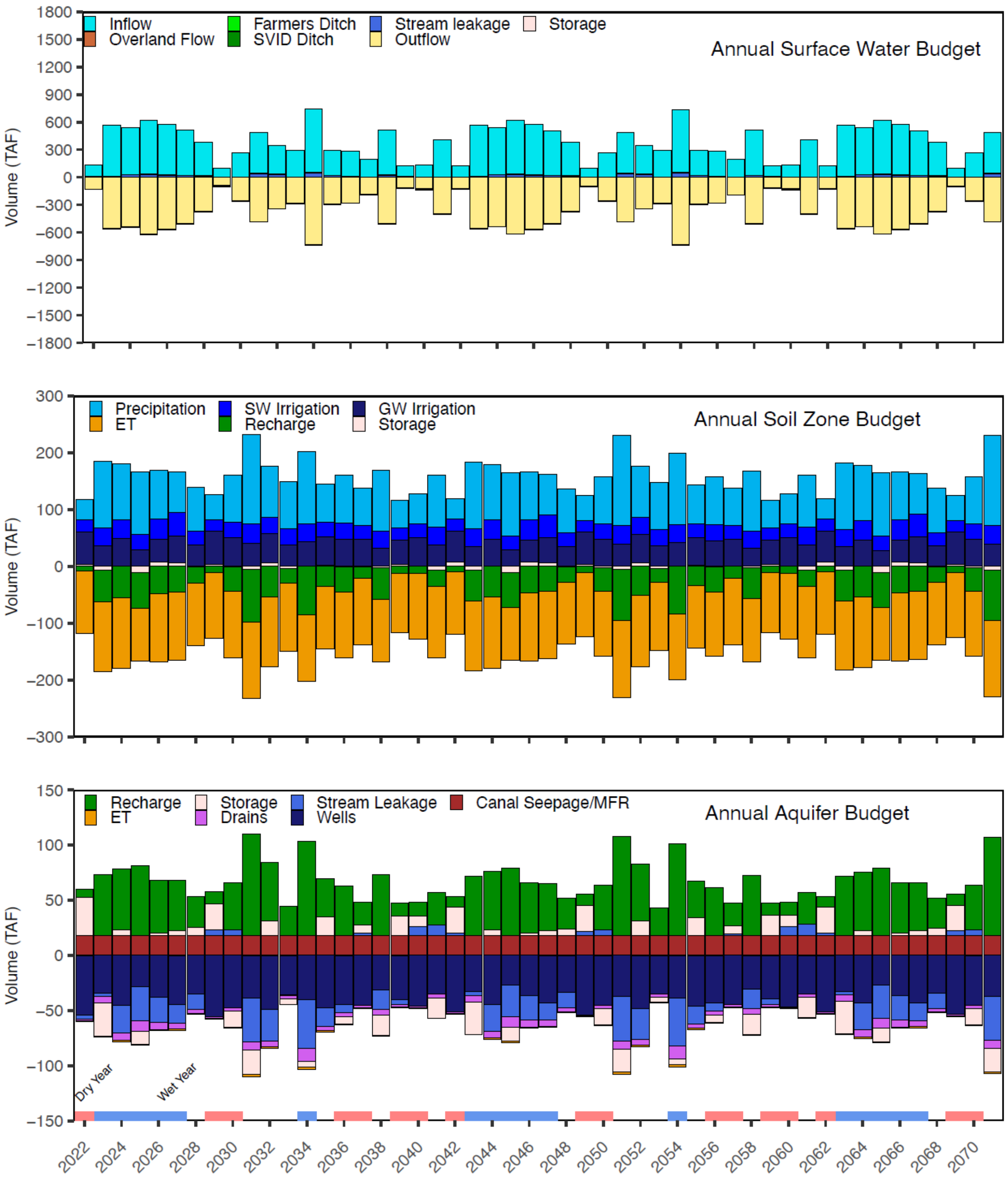


Figure 50: Near Future (2030) Climate Change Scenario. Annual water budgets for the three conceptual subsystems used to represent the hydrology of the Basin (the surface water system, the soil zone, and the aquifer) for 50 potential future years, with basecase future input data multiplied by change factors for the 2030 (Near) future climate scenario.

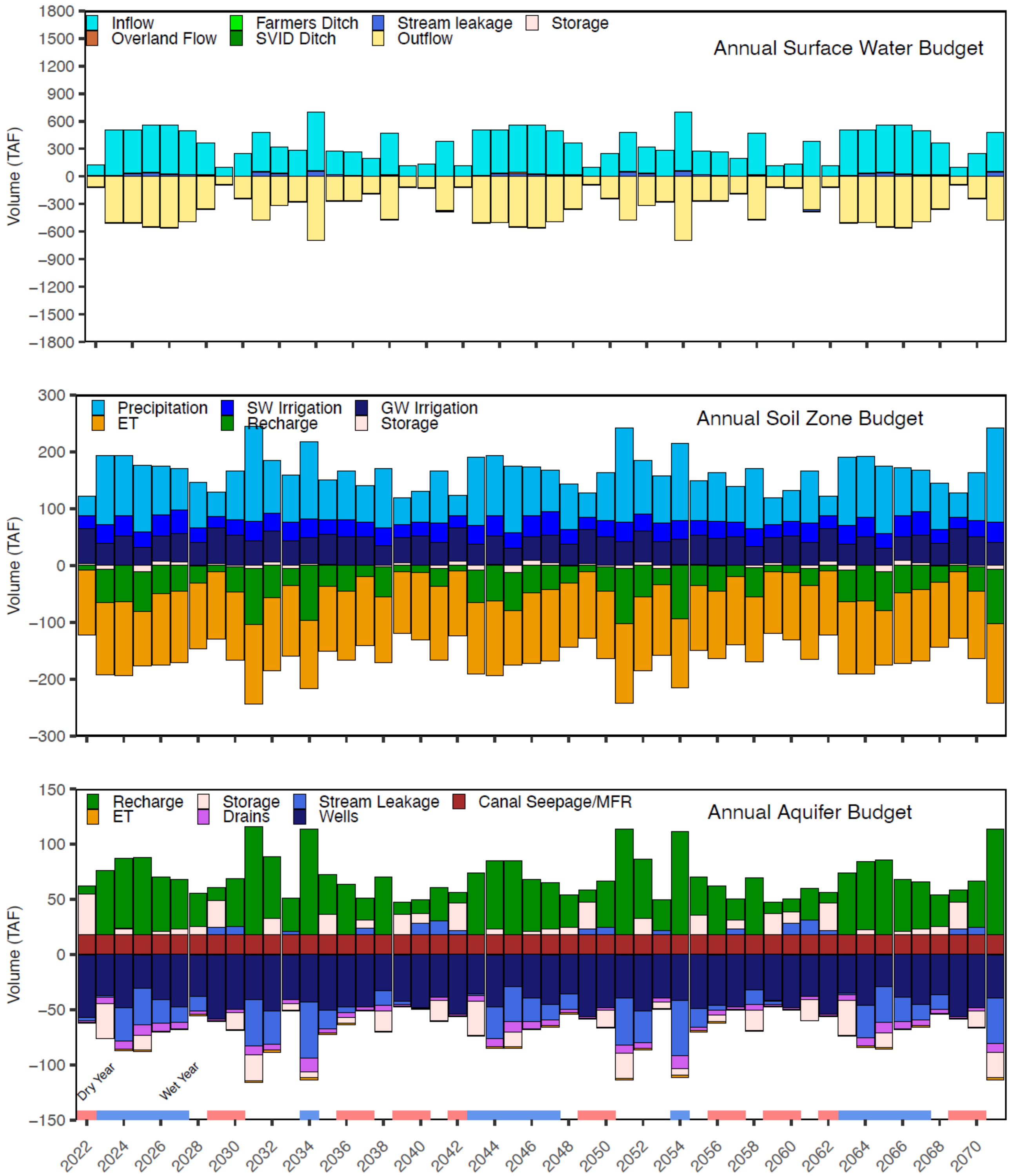


Figure 51: Far Future (2070) with Central Tendency Climate Change Scenario. Annual water budgets for the three conceptual subsystems used to represent the hydrology of the Basin (the surface water system, the soil zone, and the aquifer) for 50 potential future years, with basecsae future input data multiplied by change factors for the 2070 Central Tendency (Far) future climate scenario.

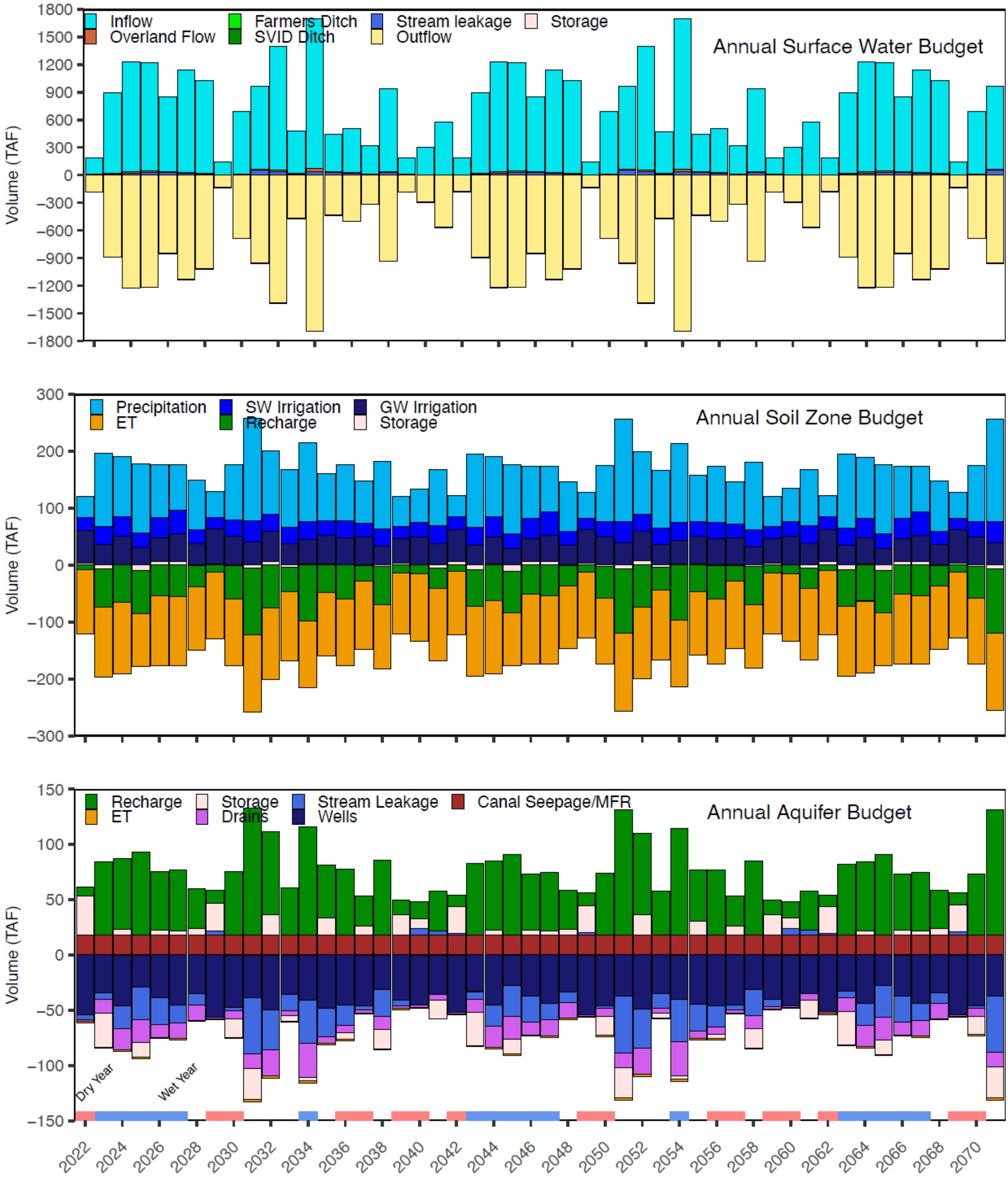


Figure 52: Far Future (2070) Wet Scenario. Annual water budgets for the three conceptual subsystems used to represent the hydrology of the Basin (the surface water system, the soil zone, and the aquifer) for 50 potential future years, with basecsae future input data multiplied by change factors for the 2070 Wet with Moderate Warming (Wet) future climate scenario.

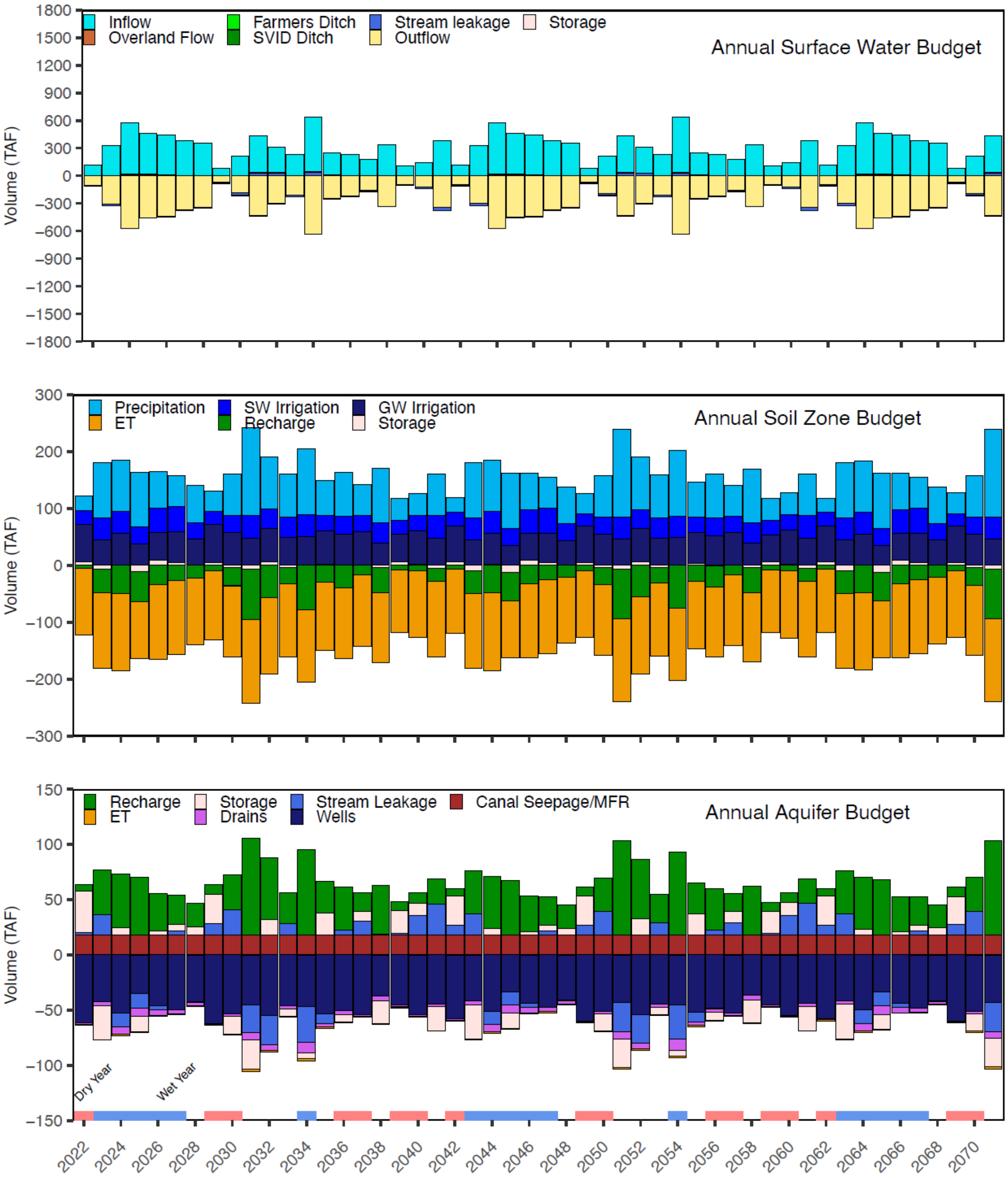


Figure 53: Far Future (2070) Dry Scenario. Annual water budgets for the three conceptual subsystems used to represent the hydrology of the Basin (the surface water system, the soil zone, and the aquifer) for 50 potential future years, with basecase future input data multiplied by change factors for the 2070 Dry with Extreme Warming (Dry) future climate scenario.

Table 12: The data used to build the 50-year future projected climate record is specified below, including the historical water year type. To account for leap days, some years were transposed.

Historical Year	Future Year	Water Year Type
1994	2022	Critical
1995	2023	Wet
1996	2024	Wet
1997	2025	Wet
1998	2026	Wet
1999	2027	Wet
2000	2028	Below Normal
2001	2029	Critical
2002	2030	Dry
2003	2031	Above Normal
2004	2032	Above Normal
2010	2033	Below Normal
2006	2034	Wet
2007	2035	Below Normal
2008	2036	Dry
2009	2037	Dry
2011	2038	Above Normal
1991	2039	Critical
1992	2040	Critical
1993	2041	Above Normal
1994	2042	Critical
1995	2043	Wet
1996	2044	Wet
1997	2045	Wet
1998	2046	Wet
1999	2047	Wet
2000	2048	Below Normal
2001	2049	Critical
2002	2050	Dry
2003	2051	Above Normal
2004	2052	Above Normal
2010	2053	Below Normal
2006	2054	Wet
2007	2055	Below Normal
2008	2056	Dry
2009	2057	Dry
2011	2058	Above Normal
1991	2059	Critical
1992	2060	Critical
1993	2061	Above Normal
1994	2062	Critical
1995	2063	Wet
1996	2064	Wet
1997	2065	Wet
1998	2066	Wet
1999	2067	Wet
2000	2068	Below Normal
2001	2069	Critical
2002	2070	Dry
2003	2071	Above Normal

Table 13: Annual water budget components [TAF] for the Future Basecase scenario surface water (S) subsystem.

Water Year	Inflow	Overland	Farmers Div.	SVID Div.	Stream Leakage	Outflow	Storage
2022	118	2	-2	-4	4	-119	1
2023	504	5	-2	-4	7	-510	0
2024	472	6	-2	-4	27	-500	0
2025	515	9	-2	-4	32	-550	0
2026	537	7	-2	-4	25	-563	-0
2027	478	5	-2	-4	19	-497	0
2028	345	4	-2	-4	16	-358	0
2029	94	1	-2	-4	-3	-88	1
2030	249	3	-2	-4	-6	-240	0
2031	431	7	-2	-4	38	-470	-0
2032	287	5	-2	-4	30	-316	0
2033	283	3	-2	-4	2	-282	0
2034	640	10	-2	-4	44	-689	0
2035	253	3	-2	-4	16	-267	1
2036	262	4	-2	-4	8	-268	0
2037	195	2	-2	-4	-2	-189	0
2038	457	5	-2	-4	19	-476	-0
2039	115	2	-2	-4	5	-117	0
2040	133	1	-2	-4	-6	-123	1
2041	384	3	-2	-4	-6	-375	-0
2042	118	1	-2	-4	-1	-114	1
2043	504	5	-2	-4	8	-511	0
2044	472	6	-2	-4	26	-499	0
2045	515	8	-2	-4	30	-548	0
2046	537	7	-2	-4	24	-562	0
2047	479	5	-2	-4	18	-497	-0
2048	345	4	-2	-4	16	-358	0
2049	94	1	-2	-4	-2	-89	1
2050	249	3	-2	-4	-5	-241	0
2051	431	7	-2	-4	38	-471	-0
2052	287	5	-2	-4	29	-316	0
2053	283	3	-2	-4	2	-282	0
2054	640	10	-2	-4	43	-688	0
2055	253	3	-2	-4	15	-266	1
2056	262	4	-2	-4	8	-268	0
2057	195	2	-2	-4	-2	-190	0
2058	458	5	-2	-4	19	-476	0
2059	115	2	-2	-4	6	-118	0
2060	133	1	-2	-4	-6	-123	1
2061	384	3	-2	-4	-7	-374	0
2062	118	1	-2	-4	-1	-114	1
2063	504	5	-2	-4	7	-510	-0
2064	472	6	-2	-4	26	-499	0
2065	515	8	-2	-4	31	-549	0
2066	537	7	-2	-4	25	-563	-0
2067	479	5	-2	-4	18	-497	0
2068	345	4	-2	-4	16	-359	0
2069	94	1	-2	-4	-3	-89	1
2070	249	3	-2	-4	-6	-241	0
2071	431	7	-2	-4	38	-470	0
Minimum	94	1	-2	-4	-7	-689	-0
25th %ile	249	3	-2	-4	-1	-499	0
Median	345	4	-2	-4	15	-358	0
Mean	345	4	-2	-4	14	-358	0
75th %ile	479	6	-2	-4	26	-240	0
Maximum	640	10	-2	-4	44	-88	1

Table 14: Annual water budget components [TAF] for the Future Basecase scenario land-soil/vadose zone (L) subsystem.

Water Year	Precip	SW Irrig.	GW Irrig.	ET	Recharge	Storage
2022	34	21	55	-106	-6	3
2023	117	29	34	-118	-55	-7
2024	97	32	45	-120	-55	1
2025	109	25	28	-90	-62	-10
2026	87	34	38	-117	-49	7
2027	71	39	45	-116	-45	6
2028	78	23	35	-106	-29	-1
2029	42	19	57	-111	-11	3
2030	78	26	48	-112	-38	-1
2031	151	32	39	-130	-87	-5
2032	90	28	49	-119	-53	6
2033	81	27	36	-115	-26	-3
2034	124	30	40	-113	-82	1
2035	64	24	48	-107	-31	2
2036	82	27	45	-111	-43	-0
2037	64	23	45	-113	-19	-1
2038	104	28	30	-107	-53	-2
2039	49	21	40	-102	-12	4
2040	53	24	46	-112	-12	1
2041	90	31	35	-121	-29	-6
2042	34	21	52	-106	-9	8
2043	117	29	33	-118	-54	-7
2044	97	32	44	-122	-53	2
2045	109	24	27	-90	-60	-11
2046	87	33	36	-117	-47	7
2047	71	39	43	-115	-43	6
2048	78	23	33	-105	-29	-1
2049	42	19	55	-110	-11	4
2050	78	26	46	-111	-37	-2
2051	151	32	37	-130	-85	-6
2052	90	28	48	-121	-51	6
2053	81	27	35	-115	-24	-3
2054	124	30	39	-113	-80	0
2055	64	24	46	-106	-30	2
2056	82	27	43	-110	-42	-1
2057	64	23	44	-112	-19	-0
2058	104	28	30	-107	-52	-3
2059	49	21	40	-102	-11	4
2060	53	24	47	-113	-12	1
2061	90	31	35	-121	-29	-6
2062	34	21	52	-106	-9	8
2063	117	29	32	-117	-54	-7
2064	97	32	43	-120	-53	1
2065	109	24	27	-89	-60	-11
2066	87	33	36	-117	-47	7
2067	71	39	43	-116	-43	6
2068	78	23	34	-106	-28	-0
2069	42	19	55	-110	-10	4
2070	78	26	46	-111	-37	-2
2071	151	32	37	-130	-85	-6
Minimum	34	19	27	-130	-87	-11
25th %ile	64	23	35	-117	-53	-3
Median	81	27	41	-113	-42	0
Mean	84	27	41	-112	-40	-0
75th %ile	102	31	46	-107	-25	4
Maximum	151	39	57	-89	-6	8

Table 15: Annual water budget components [TAF] for the Future Basecase scenario groundwater (GW) subsystem.

Water Year	Recharge	ET	STorage	Drains	Stream Leakge	Wells	Canals, MFR
2022	6	-1	34	-1	-4	-51	18
2023	55	-1	-29	-5	-7	-32	18
2024	54	-1	5	-6	-27	-43	18
2025	62	-1	-11	-9	-32	-27	18
2026	48	-1	2	-7	-25	-36	18
2027	45	-1	5	-5	-19	-42	18
2028	29	-1	6	-4	-16	-33	18
2029	11	-1	23	-1	3	-53	18
2030	38	-1	-13	-3	6	-45	18
2031	87	-2	-21	-7	-38	-37	18
2032	53	-2	12	-5	-30	-46	18
2033	26	-1	-4	-3	-2	-34	18
2034	82	-2	-5	-11	-44	-38	18
2035	31	-1	16	-3	-16	-45	18
2036	43	-1	-6	-4	-8	-42	18
2037	19	-1	7	-2	2	-43	18
2038	53	-1	-17	-5	-19	-29	18
2039	11	-1	16	-2	-5	-38	18
2040	12	-1	9	-1	6	-44	18
2041	29	-0	-17	-3	6	-33	18
2042	9	-1	23	-1	1	-49	18
2043	54	-1	-28	-5	-8	-31	18
2044	52	-1	5	-6	-26	-42	18
2045	59	-1	-12	-9	-30	-26	18
2046	47	-1	1	-7	-24	-34	18
2047	43	-1	4	-5	-18	-41	18
2048	28	-1	5	-4	-16	-32	18
2049	11	-1	23	-1	2	-51	18
2050	37	-1	-13	-3	5	-43	18
2051	84	-2	-20	-7	-38	-35	18
2052	51	-2	12	-5	-29	-45	18
2053	24	-1	-4	-3	-2	-33	18
2054	80	-2	-5	-11	-43	-37	18
2055	30	-1	16	-3	-15	-44	18
2056	41	-1	-6	-4	-8	-41	18
2057	19	-1	7	-2	2	-42	18
2058	52	-1	-17	-5	-19	-28	18
2059	11	-1	17	-2	-6	-37	18
2060	12	-1	10	-1	6	-44	18
2061	28	-0	-17	-3	7	-33	18
2062	9	-1	23	-1	1	-49	18
2063	53	-1	-28	-5	-7	-30	18
2064	52	-1	4	-6	-26	-41	18
2065	60	-1	-12	-9	-31	-26	18
2066	47	-1	1	-7	-25	-34	18
2067	43	-1	5	-5	-18	-41	18
2068	28	-1	6	-4	-16	-32	18
2069	10	-1	22	-1	3	-51	18
2070	36	-1	-13	-3	6	-43	18
2071	84	-2	-20	-7	-38	-35	18
Minimum	6	-2	-29	-11	-44	-53	18
25th %ile	25	-1	-13	-6	-26	-43	18
Median	42	-1	3	-4	-15	-39	18
Mean	40	-1	0	-4	-14	-39	18
75th %ile	53	-1	9	-3	1	-33	18
Maximum	87	-0	34	-1	7	-26	18

Table 16: Annual water budget components [TAF] for the Near Future (2030) scenario surface water (S) subsystem.

Water Year	Inflow	Overland	Farmers Div.	SVID Div.	Stream Leakage	Outflow	Storage
2022	126	2	-2	-4	4	-127	1
2023	555	6	-2	-4	3	-558	0
2024	510	7	-2	-4	25	-536	0
2025	581	9	-2	-4	30	-615	0
2026	543	7	-2	-4	22	-566	0
2027	487	5	-2	-4	17	-503	0
2028	359	3	-2	-4	14	-371	0
2029	99	1	-2	-4	-5	-91	2
2030	260	3	-2	-4	-5	-252	0
2031	439	7	-2	-4	40	-481	-0
2032	313	5	-2	-4	29	-341	0
2033	288	3	-2	-4	0	-285	0
2034	683	11	-2	-4	45	-733	0
2035	274	4	-2	-4	17	-289	1
2036	272	4	-2	-4	7	-278	0
2037	193	2	-2	-4	-2	-188	0
2038	488	6	-2	-4	18	-505	-0
2039	116	2	-2	-4	5	-117	0
2040	135	1	-2	-4	-8	-123	1
2041	405	3	-2	-4	-10	-393	0
2042	126	1	-2	-4	-2	-121	1
2043	555	6	-2	-4	3	-559	-0
2044	510	6	-2	-4	24	-536	0
2045	581	9	-2	-4	29	-614	0
2046	544	7	-2	-4	22	-566	0
2047	487	5	-2	-4	16	-502	0
2048	359	3	-2	-4	14	-371	0
2049	99	1	-2	-4	-4	-92	1
2050	260	3	-2	-4	-5	-252	0
2051	440	7	-2	-4	41	-482	0
2052	313	5	-2	-4	28	-341	0
2053	288	3	-2	-4	-0	-285	-0
2054	683	11	-2	-4	44	-732	0
2055	274	4	-2	-4	16	-289	1
2056	272	4	-2	-4	7	-278	0
2057	193	2	-2	-4	-1	-189	0
2058	488	5	-2	-4	18	-505	-0
2059	116	2	-2	-4	5	-118	0
2060	135	1	-2	-4	-8	-123	1
2061	405	3	-2	-4	-10	-392	0
2062	126	1	-2	-4	-2	-121	1
2063	555	6	-2	-4	3	-558	-0
2064	510	7	-2	-4	24	-536	0
2065	582	9	-2	-4	30	-615	0
2066	544	7	-2	-4	22	-566	-0
2067	487	5	-2	-4	16	-503	0
2068	359	3	-2	-4	14	-371	0
2069	99	1	-2	-4	-4	-92	2
2070	260	3	-2	-4	-5	-252	0
2071	440	7	-2	-4	40	-481	0
Minimum	99	1	-2	-4	-10	-733	-0
25th %ile	260	3	-2	-4	-2	-536	0
Median	359	4	-2	-4	14	-371	0
Mean	364	5	-2	-4	12	-376	0
75th %ile	510	7	-2	-4	24	-252	0
Maximum	683	11	-2	-4	45	-91	2

Table 17: Annual water budget components [TAF] for the Near Future (2030) scenario land-soil/vadose zone (L) subsystem.

Water Year	Precip	SW Irrig.	GW Irrig.	ET	Recharge	Storage
2022	36	21	58	-111	-7	3
2023	117	31	36	-122	-56	-7
2024	98	34	48	-125	-55	0
2025	111	26	30	-93	-64	-10
2026	85	35	41	-121	-48	7
2027	71	41	48	-120	-45	6
2028	78	24	37	-110	-28	-1
2029	43	20	60	-115	-11	3
2030	83	27	50	-116	-43	-1
2031	158	34	40	-134	-92	-5
2032	90	30	51	-124	-53	6
2033	83	29	38	-119	-27	-3
2034	127	32	42	-117	-85	1
2035	68	25	50	-110	-35	2
2036	84	28	48	-115	-45	-0
2037	66	24	48	-117	-21	-0
2038	106	30	32	-111	-55	-2
2039	49	22	42	-105	-12	4
2040	53	24	49	-115	-13	1
2041	91	32	37	-125	-30	-6
2042	36	21	55	-110	-9	7
2043	117	31	35	-122	-54	-7
2044	98	33	47	-126	-53	1
2045	111	26	29	-93	-61	-11
2046	85	35	39	-121	-46	8
2047	71	40	45	-120	-43	6
2048	78	24	35	-108	-28	-1
2049	43	20	57	-113	-11	4
2050	83	27	48	-115	-41	-2
2051	158	33	39	-134	-90	-6
2052	90	29	51	-125	-51	6
2053	83	28	37	-120	-25	-3
2054	127	32	41	-116	-83	0
2055	68	24	49	-110	-33	2
2056	84	28	45	-113	-44	-1
2057	66	24	47	-116	-21	0
2058	106	30	32	-110	-54	-3
2059	49	22	42	-105	-11	4
2060	53	24	50	-116	-12	1
2061	91	32	37	-126	-29	-6
2062	36	21	55	-110	-9	7
2063	117	31	34	-121	-54	-7
2064	98	34	46	-124	-53	1
2065	111	25	28	-92	-62	-11
2066	85	35	39	-121	-46	8
2067	71	40	46	-120	-43	6
2068	78	24	36	-109	-28	-0
2069	43	20	57	-114	-11	4
2070	83	27	48	-115	-41	-2
2071	158	33	39	-134	-90	-6
Minimum	36	20	28	-134	-92	-11
25th %ile	68	24	37	-121	-54	-3
Median	84	28	44	-116	-43	0
Mean	85	28	43	-116	-41	-0
75th %ile	104	32	49	-111	-26	4
Maximum	158	41	60	-92	-7	8

Table 18: Annual water budget components [TAF] for the Near Future (2030) scenario groundwater (GW) subsystem.

Water Year	Recharge	ET	STorage	Drains	Stream Leakge	Wells	Canals, MFR
2022	7	-1	35	-1	-4	-54	18
2023	56	-1	-30	-6	-3	-34	18
2024	55	-1	5	-7	-25	-45	18
2025	64	-1	-12	-10	-30	-29	18
2026	48	-1	2	-7	-22	-38	18
2027	45	-1	5	-5	-17	-45	18
2028	28	-1	7	-3	-14	-35	18
2029	11	-1	24	-1	5	-56	18
2030	42	-1	-15	-3	5	-47	18
2031	92	-2	-22	-7	-40	-38	18
2032	53	-2	13	-5	-29	-49	18
2033	27	-1	-5	-3	-0	-36	18
2034	85	-2	-5	-11	-45	-40	18
2035	34	-1	17	-4	-17	-48	18
2036	45	-1	-6	-4	-7	-45	18
2037	21	-1	8	-2	2	-45	18
2038	55	-1	-18	-6	-18	-31	18
2039	12	-1	18	-2	-5	-40	18
2040	13	-1	9	-1	8	-46	18
2041	29	-0	-18	-3	10	-35	18
2042	9	-1	24	-1	2	-51	18
2043	54	-1	-29	-6	-3	-33	18
2044	53	-1	5	-7	-24	-44	18
2045	61	-1	-13	-9	-29	-27	18
2046	46	-1	2	-7	-22	-37	18
2047	43	-1	4	-5	-16	-43	18
2048	28	-1	6	-3	-14	-33	18
2049	11	-1	23	-1	4	-54	18
2050	41	-1	-14	-3	5	-45	18
2051	89	-2	-21	-7	-41	-37	18
2052	51	-2	13	-5	-28	-48	18
2053	25	-1	-5	-3	0	-35	18
2054	83	-2	-5	-11	-44	-39	18
2055	33	-1	16	-4	-16	-46	18
2056	44	-1	-7	-4	-7	-43	18
2057	21	-1	8	-2	1	-44	18
2058	54	-1	-18	-5	-18	-30	18
2059	11	-1	18	-2	-5	-40	18
2060	12	-1	10	-1	8	-47	18
2061	29	-0	-18	-3	10	-35	18
2062	9	-1	24	-1	2	-51	18
2063	53	-1	-29	-6	-3	-33	18
2064	53	-1	5	-7	-24	-43	18
2065	61	-1	-12	-9	-30	-27	18
2066	46	-1	2	-7	-22	-36	18
2067	43	-1	5	-5	-16	-43	18
2068	27	-1	7	-3	-14	-34	18
2069	11	-1	23	-1	4	-54	18
2070	41	-1	-14	-3	5	-46	18
2071	89	-2	-21	-7	-40	-37	18
Minimum	7	-2	-30	-11	-45	-56	18
25th %ile	25	-1	-14	-7	-24	-46	18
Median	43	-1	3	-4	-14	-41	18
Mean	41	-1	-0	-5	-12	-41	18
75th %ile	54	-1	10	-3	2	-35	18
Maximum	92	-0	35	-1	10	-27	18

Table 19: Annual water budget components [TAF] for the Far Future (2070) scenario surface water (S) subsystem.

Water Year	Inflow	Overland	Farmers Div.	SVID Div.	Stream Leakage	Outflow	Storage
2022	116	1	-2	-4	3	-116	1
2023	500	5	-2	-4	2	-502	-0
2024	469	7	-2	-4	30	-501	0
2025	512	9	-2	-4	34	-550	0
2026	533	7	-2	-4	22	-555	0
2027	475	5	-2	-4	15	-489	0
2028	342	3	-2	-4	13	-354	0
2029	93	1	-2	-4	-6	-84	2
2030	247	3	-2	-4	-7	-237	0
2031	428	8	-2	-4	42	-472	-0
2032	284	5	-2	-4	30	-314	0
2033	278	3	-2	-4	-3	-272	0
2034	637	12	-2	-4	51	-694	0
2035	251	3	-2	-4	17	-267	1
2036	259	4	-2	-4	5	-263	0
2037	193	2	-2	-4	-6	-184	0
2038	454	5	-2	-4	13	-466	-0
2039	113	2	-2	-4	3	-112	0
2040	132	1	-2	-4	-10	-118	1
2041	380	3	-2	-4	-12	-366	0
2042	116	1	-2	-4	-4	-110	1
2043	501	5	-2	-4	2	-502	0
2044	470	7	-2	-4	29	-500	0
2045	512	9	-2	-4	32	-548	0
2046	533	7	-2	-4	21	-556	-0
2047	475	5	-2	-4	14	-489	0
2048	342	3	-2	-4	14	-354	0
2049	93	1	-2	-4	-5	-85	2
2050	247	3	-2	-4	-7	-238	0
2051	428	8	-2	-4	43	-473	-0
2052	285	5	-2	-4	29	-314	0
2053	278	3	-2	-4	-4	-272	0
2054	637	12	-2	-4	50	-693	0
2055	251	4	-2	-4	17	-267	1
2056	259	4	-2	-4	5	-263	0
2057	193	2	-2	-4	-5	-185	0
2058	454	5	-2	-4	13	-466	0
2059	113	2	-2	-4	3	-113	0
2060	132	1	-2	-4	-10	-118	1
2061	381	3	-2	-4	-13	-365	0
2062	116	1	-2	-4	-3	-110	1
2063	501	5	-2	-4	1	-501	0
2064	469	7	-2	-4	29	-500	0
2065	512	9	-2	-4	33	-549	0
2066	533	7	-2	-4	21	-556	0
2067	476	5	-2	-4	14	-489	0
2068	343	3	-2	-4	13	-354	0
2069	93	1	-2	-4	-5	-85	2
2070	247	3	-2	-4	-7	-238	0
2071	428	8	-2	-4	42	-472	-0
Minimum	93	1	-2	-4	-13	-694	-0
25th %ile	247	3	-2	-4	-4	-500	0
Median	342	4	-2	-4	13	-354	0
Mean	342	5	-2	-4	12	-354	0
75th %ile	475	7	-2	-4	27	-237	0
Maximum	637	12	-2	-4	51	-84	2

Table 20: Annual water budget components [TAF] for the Far Future (2070) scenario land-soil/vadose zone (L) subsystem.

Water Year	Precip	SW Irrig.	GW Irrig.	ET	Recharge	Storage
2022	35	22	61	-115	-7	4
2023	120	33	39	-127	-59	-7
2024	106	35	51	-130	-64	1
2025	118	27	32	-96	-70	-11
2026	85	37	43	-125	-49	8
2027	72	42	50	-125	-45	6
2028	80	26	40	-115	-30	-1
2029	43	21	63	-118	-11	3
2030	85	28	53	-120	-44	-2
2031	166	35	43	-140	-99	-5
2032	93	31	54	-129	-56	6
2033	83	33	43	-123	-30	-5
2034	135	34	46	-121	-96	3
2035	70	26	53	-114	-36	2
2036	85	30	51	-120	-46	0
2037	64	25	51	-121	-19	0
2038	104	32	35	-115	-53	-3
2039	47	23	45	-108	-11	5
2040	54	25	51	-118	-12	1
2041	91	35	41	-130	-30	-5
2042	35	22	59	-113	-9	7
2043	120	33	38	-126	-57	-8
2044	106	35	50	-131	-62	2
2045	118	27	30	-96	-67	-12
2046	85	37	41	-125	-47	9
2047	72	42	48	-124	-43	5
2048	80	26	38	-113	-30	-1
2049	43	20	60	-117	-11	4
2050	85	28	51	-119	-42	-2
2051	166	35	41	-140	-97	-6
2052	93	31	54	-130	-54	7
2053	83	32	42	-124	-28	-5
2054	135	34	44	-121	-94	2
2055	70	25	52	-114	-35	2
2056	85	30	48	-118	-44	-0
2057	64	25	50	-120	-20	1
2058	104	31	34	-115	-52	-3
2059	47	23	44	-108	-11	5
2060	54	25	52	-119	-12	1
2061	91	34	40	-131	-29	-6
2062	35	22	58	-113	-9	7
2063	120	33	37	-126	-56	-8
2064	106	35	49	-129	-62	1
2065	118	27	30	-95	-68	-11
2066	85	37	41	-125	-47	9
2067	72	42	48	-125	-43	5
2068	80	25	38	-114	-29	-0
2069	43	20	60	-117	-11	4
2070	85	28	51	-119	-42	-3
2071	166	35	41	-140	-96	-6
Minimum	35	20	30	-140	-99	-12
25th %ile	70	25	41	-126	-56	-5
Median	85	30	47	-120	-43	1
Mean	88	30	46	-120	-44	-0
75th %ile	106	35	51	-115	-29	4
Maximum	166	42	63	-95	-7	9

Table 21: Annual water budget components [TAF] for the Far Future (2070) scenario groundwater (GW) subsystem.

Water Year	Recharge	ET	STorage	Drains	Stream Leakge	Wells	Canals, MFR
2022	7	-1	37	-1	-3	-57	18
2023	58	-1	-32	-5	-2	-37	18
2024	64	-2	5	-7	-30	-49	18
2025	70	-1	-13	-10	-34	-30	18
2026	49	-1	3	-7	-22	-41	18
2027	45	-1	5	-5	-15	-47	18
2028	30	-1	7	-3	-13	-38	18
2029	11	-1	25	-1	6	-58	18
2030	44	-1	-15	-3	7	-50	18
2031	98	-2	-23	-8	-42	-41	18
2032	56	-2	14	-5	-30	-52	18
2033	30	-1	-6	-3	3	-41	18
2034	96	-2	-6	-12	-51	-43	18
2035	36	-1	18	-4	-17	-50	18
2036	45	-1	-6	-4	-5	-48	18
2037	19	-1	8	-2	6	-48	18
2038	52	-1	-19	-5	-13	-33	18
2039	11	-1	19	-2	-3	-42	18
2040	12	-1	9	-1	10	-48	18
2041	30	-0	-19	-3	12	-38	18
2042	9	-1	25	-1	4	-54	18
2043	56	-1	-31	-5	-2	-36	18
2044	62	-2	5	-7	-29	-47	18
2045	67	-1	-14	-9	-32	-29	18
2046	47	-1	3	-7	-21	-39	18
2047	43	-1	5	-5	-14	-45	18
2048	30	-1	6	-3	-14	-36	18
2049	11	-1	25	-1	5	-56	18
2050	42	-1	-15	-3	7	-48	18
2051	96	-2	-22	-8	-43	-39	18
2052	54	-2	15	-5	-29	-51	18
2053	28	-1	-6	-3	4	-40	18
2054	93	-2	-6	-12	-50	-42	18
2055	35	-1	18	-4	-17	-49	18
2056	44	-1	-6	-4	-5	-46	18
2057	19	-1	8	-2	5	-47	18
2058	51	-1	-19	-5	-13	-32	18
2059	11	-1	19	-2	-3	-42	18
2060	12	-1	10	-1	10	-48	18
2061	29	-0	-19	-3	13	-38	18
2062	9	-1	25	-1	3	-54	18
2063	56	-1	-32	-5	-1	-35	18
2064	62	-2	5	-7	-29	-46	18
2065	67	-1	-13	-10	-33	-29	18
2066	47	-1	3	-7	-21	-39	18
2067	42	-1	5	-5	-14	-45	18
2068	29	-1	7	-3	-13	-36	18
2069	10	-1	24	-1	5	-56	18
2070	42	-1	-15	-3	7	-48	18
2071	96	-2	-23	-8	-42	-39	18
Minimum	7	-2	-32	-12	-51	-58	18
25th %ile	28	-1	-15	-7	-27	-48	18
Median	43	-1	4	-4	-13	-44	18
Mean	43	-1	-0	-5	-12	-44	18
75th %ile	56	-1	10	-3	4	-38	18
Maximum	98	-0	37	-1	13	-29	18

Table 22: Annual water budget components [TAF] for the Far Future (2070) Wet scenario surface water (S) subsystem.

Water Year	Inflow	Overland	Farmers Div.	SVID Div.	Stream Leakage	Outflow	Storage
2022	180	2	-2	-4	5	-182	1
2023	877	12	-2	-4	6	-889	-0
2024	1188	18	-2	-4	20	-1221	0
2025	1171	19	-2	-4	29	-1214	0
2026	817	11	-2	-4	24	-846	-0
2027	1109	14	-2	-4	16	-1132	-0
2028	1000	13	-2	-4	10	-1017	0
2029	139	1	-2	-4	-4	-132	1
2030	681	7	-2	-4	2	-684	0
2031	895	13	-2	-4	51	-953	0
2032	1334	22	-2	-4	36	-1387	0
2033	455	5	-2	-4	14	-468	-0
2034	1628	29	-2	-4	39	-1690	0
2035	406	6	-2	-4	26	-433	1
2036	480	7	-2	-4	18	-499	0
2037	311	3	-2	-4	3	-312	0
2038	902	11	-2	-4	24	-931	0
2039	179	2	-2	-4	6	-181	0
2040	298	2	-2	-4	-6	-289	1
2041	571	5	-2	-4	-4	-567	0
2042	180	1	-2	-4	-2	-175	1
2043	877	12	-2	-4	7	-889	0
2044	1189	18	-2	-4	19	-1221	0
2045	1171	19	-2	-4	28	-1213	0
2046	817	11	-2	-4	24	-846	-0
2047	1109	14	-2	-4	15	-1132	0
2048	1000	13	-2	-4	10	-1017	0
2049	139	2	-2	-4	-2	-134	1
2050	681	7	-2	-4	3	-685	0
2051	896	13	-2	-4	52	-954	0
2052	1334	22	-2	-4	35	-1386	0
2053	455	4	-2	-4	13	-467	-0
2054	1628	29	-2	-4	38	-1690	0
2055	406	6	-2	-4	25	-433	1
2056	480	7	-2	-4	19	-499	-0
2057	311	3	-2	-4	4	-313	0
2058	902	11	-2	-4	24	-931	-0
2059	179	2	-2	-4	6	-182	0
2060	298	2	-2	-4	-6	-289	1
2061	571	5	-2	-4	-5	-566	0
2062	180	1	-2	-4	-2	-176	1
2063	877	12	-2	-4	6	-889	-0
2064	1189	18	-2	-4	20	-1221	0
2065	1171	19	-2	-4	29	-1214	0
2066	817	11	-2	-4	24	-846	0
2067	1109	14	-2	-4	15	-1132	-0
2068	1000	13	-2	-4	10	-1017	0
2069	139	1	-2	-4	-3	-133	1
2070	681	7	-2	-4	2	-685	0
2071	896	13	-2	-4	51	-954	-0
Minimum	139	1	-2	-4	-6	-1690	-0
25th %ile	406	4	-2	-4	4	-1103	0
Median	817	11	-2	-4	15	-846	0
Mean	746	10	-2	-4	15	-766	0
75th %ile	1082	13	-2	-4	24	-433	0
Maximum	1628	29	-2	-4	52	-132	1

Table 23: Annual water budget components [TAF] for the Far Future (2070) Wet scenario land-soil/vadose zone (L) subsystem.

Water Year	Precip	SW Irrig.	GW Irrig.	ET	Recharge	Storage
2022	37	22	58	-113	-8	3
2023	129	31	36	-123	-67	-7
2024	106	35	49	-126	-65	1
2025	122	26	30	-93	-76	-9
2026	92	35	41	-122	-53	6
2027	81	41	48	-121	-55	6
2028	87	24	37	-111	-36	-1
2029	46	21	60	-117	-12	2
2030	98	28	51	-117	-58	-1
2031	180	37	40	-136	-116	-6
2032	111	31	52	-125	-75	7
2033	101	29	38	-121	-43	-3
2034	138	32	43	-117	-98	1
2035	82	25	51	-111	-49	2
2036	99	29	48	-116	-60	-0
2037	74	25	49	-119	-27	-1
2038	118	31	33	-112	-68	-2
2039	52	23	43	-107	-13	3
2040	58	26	48	-118	-15	1
2041	98	32	38	-126	-36	-5
2042	37	22	55	-112	-10	7
2043	129	31	35	-122	-65	-7
2044	106	35	48	-128	-63	2
2045	122	26	29	-93	-73	-10
2046	92	35	39	-123	-51	7
2047	81	41	46	-121	-53	6
2048	87	24	35	-110	-35	-1
2049	46	21	58	-116	-12	4
2050	98	27	49	-116	-56	-2
2051	180	37	39	-136	-114	-6
2052	111	30	52	-126	-73	7
2053	101	29	36	-122	-40	-4
2054	138	32	42	-117	-97	1
2055	82	25	49	-111	-47	2
2056	99	29	46	-115	-58	-1
2057	74	25	48	-118	-27	-0
2058	118	30	32	-111	-67	-2
2059	52	22	43	-107	-13	3
2060	58	25	49	-119	-15	1
2061	98	32	37	-127	-35	-5
2062	37	22	55	-112	-10	7
2063	129	31	35	-122	-65	-8
2064	106	35	47	-126	-63	1
2065	122	26	29	-92	-74	-10
2066	92	35	39	-122	-51	7
2067	81	41	47	-121	-53	6
2068	87	24	36	-111	-35	-1
2069	46	21	58	-116	-12	4
2070	98	27	49	-116	-56	-2
2071	180	37	39	-136	-114	-6
Minimum	37	21	29	-136	-116	-10
25th %ile	81	25	37	-122	-66	-3
Median	98	29	45	-118	-53	0
Mean	96	29	44	-117	-51	-0
75th %ile	116	32	49	-112	-35	3
Maximum	180	41	60	-92	-8	7

Table 24: Annual water budget components [TAF] for the Far Future (2070) Wet scenario groundwater (GW) subsystem.

Water Year	Recharge	ET	STorage	Drains	Stream Leakge	Wells	Canals, MFR
2022	8	-1	35	-1	-5	-54	18
2023	66	-1	-31	-12	-6	-34	18
2024	64	-2	5	-19	-20	-46	18
2025	75	-1	-13	-21	-29	-29	18
2026	53	-1	4	-12	-24	-39	18
2027	55	-1	4	-14	-16	-46	18
2028	36	-1	6	-14	-10	-35	18
2029	12	-1	25	-1	4	-56	18
2030	58	-1	-17	-7	-2	-48	18
2031	115	-2	-28	-13	-51	-38	18
2032	75	-2	18	-24	-36	-50	18
2033	42	-1	-5	-5	-14	-36	18
2034	98	-2	-3	-31	-39	-41	18
2035	48	-1	15	-6	-26	-48	18
2036	59	-1	-6	-7	-18	-45	18
2037	27	-1	8	-3	-3	-46	18
2038	68	-1	-18	-12	-24	-32	18
2039	13	-1	18	-2	-6	-41	18
2040	15	-1	9	-2	6	-46	18
2041	36	-0	-17	-5	4	-36	18
2042	10	-1	24	-1	2	-52	18
2043	65	-1	-30	-12	-7	-33	18
2044	63	-1	5	-19	-19	-45	18
2045	73	-1	-13	-21	-28	-28	18
2046	51	-1	4	-12	-24	-37	18
2047	53	-1	3	-15	-15	-44	18
2048	35	-1	5	-14	-10	-33	18
2049	12	-1	24	-2	2	-54	18
2050	56	-1	-17	-7	-3	-46	18
2051	113	-2	-27	-13	-52	-37	18
2052	73	-2	19	-24	-35	-49	18
2053	40	-1	-5	-4	-13	-35	18
2054	96	-2	-3	-31	-38	-40	18
2055	46	-1	12	-6	-25	-44	18
2056	59	-1	-4	-7	-19	-46	18
2057	27	-1	8	-3	-4	-45	18
2058	67	-1	-18	-12	-24	-31	18
2059	13	-1	18	-2	-6	-40	18
2060	15	-1	10	-2	6	-46	18
2061	35	-0	-17	-5	5	-35	18
2062	10	-1	24	-1	2	-52	18
2063	64	-1	-30	-12	-6	-33	18
2064	63	-2	4	-19	-20	-44	18
2065	73	-1	-13	-21	-29	-28	18
2066	51	-1	4	-12	-24	-37	18
2067	53	-1	4	-14	-15	-44	18
2068	35	-1	6	-14	-10	-34	18
2069	12	-1	24	-1	3	-54	18
2070	55	-1	-17	-7	-2	-46	18
2071	113	-2	-27	-13	-51	-37	18
Minimum	8	-2	-31	-31	-52	-56	18
25th %ile	35	-1	-16	-14	-24	-46	18
Median	53	-1	4	-12	-15	-42	18
Mean	51	-1	-0	-11	-15	-41	18
75th %ile	66	-1	9	-4	-4	-35	18
Maximum	115	-0	35	-1	6	-28	18

Table 25: Annual water budget components [TAF] for the Far Future (2070) Dry scenario surface water (S) subsystem.

Water Year	Inflow	Overland	Farmers Div.	SVID Div.	Stream Leakage	Outflow	Storage
2022	109	1	-2	-4	-2	-104	2
2023	325	3	-2	-4	-19	-304	-0
2024	556	7	-2	-4	13	-570	0
2025	439	7	-2	-4	13	-455	1
2026	437	5	-2	-4	4	-440	0
2027	373	4	-2	-4	-4	-368	0
2028	347	3	-2	-4	1	-345	0
2029	80	1	-2	-4	-10	-67	2
2030	213	2	-2	-4	-22	-188	0
2031	403	6	-2	-4	26	-430	0
2032	276	5	-2	-4	27	-303	0
2033	227	3	-2	-4	-10	-214	-0
2034	596	9	-2	-4	32	-632	0
2035	238	3	-2	-4	9	-245	1
2036	227	3	-2	-4	-4	-220	0
2037	171	2	-2	-4	-12	-156	0
2038	332	4	-2	-4	-0	-330	0
2039	104	2	-2	-4	-2	-99	0
2040	142	1	-2	-4	-17	-120	1
2041	377	3	-2	-4	-28	-347	0
2042	109	1	-2	-4	-9	-97	2
2043	324	3	-2	-4	-19	-303	-0
2044	556	7	-2	-4	12	-569	0
2045	439	7	-2	-4	12	-453	1
2046	438	5	-2	-4	3	-440	0
2047	374	4	-2	-4	-4	-368	0
2048	347	3	-2	-4	1	-345	0
2049	80	1	-2	-4	-9	-68	2
2050	214	2	-2	-4	-21	-189	0
2051	404	6	-2	-4	26	-431	0
2052	277	5	-2	-4	26	-303	0
2053	227	3	-2	-4	-11	-214	-0
2054	596	9	-2	-4	31	-631	0
2055	238	3	-2	-4	9	-245	1
2056	227	3	-2	-4	-4	-220	0
2057	171	2	-2	-4	-11	-157	0
2058	332	4	-2	-4	-0	-330	-0
2059	105	2	-2	-4	-1	-100	0
2060	142	1	-2	-4	-17	-121	1
2061	378	3	-2	-4	-28	-346	0
2062	109	1	-2	-4	-9	-97	2
2063	324	3	-2	-4	-19	-303	-0
2064	556	7	-2	-4	12	-570	0
2065	439	7	-2	-4	13	-454	1
2066	438	5	-2	-4	3	-440	-0
2067	374	4	-2	-4	-3	-369	0
2068	347	3	-2	-4	1	-345	0
2069	80	1	-2	-4	-9	-68	2
2070	214	2	-2	-4	-21	-189	0
2071	404	6	-2	-4	26	-431	0
Minimum	80	1	-2	-4	-28	-632	-0
25th %ile	214	2	-2	-4	-11	-430	0
Median	325	3	-2	-4	-2	-303	0
Mean	305	4	-2	-4	-1	-303	1
75th %ile	404	5	-2	-4	11	-188	1
Maximum	596	9	-2	-4	32	-67	2

Table 26: Annual water budget components [TAF] for the Far Future (2070) Dry scenario land-soil/vadose zone (L) subsystem.

Water Year	Precip	SW Irrig.	GW Irrig.	ET	Recharge	Storage
2022	25	24	66	-116	-5	6
2023	98	38	45	-133	-41	-7
2024	90	39	56	-136	-49	0
2025	97	30	37	-100	-53	-11
2026	65	42	49	-130	-34	9
2027	54	45	54	-130	-27	5
2028	64	30	45	-118	-22	0
2029	36	22	68	-121	-9	5
2030	73	30	58	-125	-32	-4
2031	154	40	48	-146	-88	-7
2032	93	34	58	-135	-56	7
2033	76	36	49	-128	-28	-4
2034	117	37	50	-127	-78	1
2035	61	27	57	-119	-29	3
2036	77	32	54	-124	-39	1
2037	55	28	58	-125	-17	1
2038	95	36	39	-122	-45	-4
2039	38	25	48	-110	-8	6
2040	39	27	59	-117	-9	2
2041	73	40	48	-133	-23	-5
2042	25	24	63	-112	-7	6
2043	98	38	45	-132	-40	-10
2044	90	38	55	-137	-48	2
2045	97	30	35	-100	-50	-12
2046	65	41	47	-131	-32	9
2047	54	44	51	-129	-26	5
2048	64	30	43	-116	-21	0
2049	36	22	65	-118	-9	4
2050	73	30	55	-124	-31	-3
2051	154	39	46	-146	-86	-7
2052	93	33	57	-136	-54	7
2053	76	36	47	-129	-26	-4
2054	117	37	48	-127	-76	0
2055	61	27	55	-119	-28	3
2056	77	32	52	-122	-38	-0
2057	55	28	56	-124	-17	1
2058	95	36	39	-121	-44	-4
2059	38	25	48	-109	-8	6
2060	39	27	59	-118	-9	2
2061	73	39	48	-133	-23	-5
2062	25	24	63	-112	-7	6
2063	98	38	44	-131	-40	-10
2064	90	38	53	-135	-48	1
2065	97	30	35	-100	-50	-12
2066	65	41	47	-130	-32	9
2067	54	44	52	-129	-26	5
2068	64	30	44	-117	-21	0
2069	36	22	65	-118	-9	4
2070	73	30	55	-123	-31	-3
2071	154	39	46	-146	-86	-7
Minimum	25	22	35	-146	-88	-12
25th %ile	54	28	47	-131	-47	-4
Median	73	33	50	-124	-31	1
Mean	74	33	51	-124	-34	-0
75th %ile	94	38	57	-118	-21	5
Maximum	154	45	68	-100	-5	9

Table 27: Annual water budget components [TAF] for the Far Future (2070) Dry scenario groundwater (GW) subsystem.

Water Year	Recharge	ET	STorage	Drains	Stream Leakge	Wells	Canals, MFR
2022	5	-1	38	-1	2	-62	18
2023	41	-1	-31	-3	19	-42	18
2024	49	-2	6	-7	-13	-53	18
2025	52	-1	-14	-7	-13	-35	18
2026	34	-1	3	-5	-4	-46	18
2027	27	-1	6	-4	4	-50	18
2028	21	-1	7	-3	-1	-43	18
2029	9	-1	26	-1	10	-62	18
2030	32	-1	-16	-2	22	-53	18
2031	87	-2	-26	-6	-26	-45	18
2032	56	-2	14	-5	-27	-55	18
2033	28	-1	-7	-3	10	-46	18
2034	78	-2	-5	-10	-32	-47	18
2035	29	-1	20	-3	-9	-54	18
2036	39	-1	-7	-3	4	-51	18
2037	17	-1	10	-2	12	-54	18
2038	45	-1	-21	-4	0	-37	18
2039	8	-1	20	-2	2	-46	18
2040	9	-1	11	-1	17	-54	18
2041	23	-0	-22	-3	28	-44	18
2042	7	-1	26	-1	9	-58	18
2043	39	-1	-31	-3	19	-42	18
2044	47	-2	6	-7	-12	-51	18
2045	49	-1	-14	-7	-12	-33	18
2046	32	-1	3	-5	-3	-44	18
2047	26	-1	5	-4	4	-48	18
2048	21	-1	6	-3	-1	-41	18
2049	9	-1	26	-1	9	-60	18
2050	31	-1	-16	-2	21	-51	18
2051	86	-2	-25	-6	-26	-43	18
2052	54	-2	14	-5	-26	-54	18
2053	26	-1	-7	-3	11	-44	18
2054	75	-2	-5	-10	-31	-45	18
2055	28	-1	19	-3	-9	-52	18
2056	38	-1	-7	-3	4	-49	18
2057	17	-1	10	-2	11	-53	18
2058	44	-1	-21	-4	0	-36	18
2059	8	-1	20	-2	1	-45	18
2060	9	-1	12	-1	17	-55	18
2061	23	-0	-22	-3	28	-44	18
2062	6	-1	26	-1	9	-58	18
2063	39	-1	-31	-3	19	-41	18
2064	47	-2	5	-7	-12	-50	18
2065	50	-1	-13	-7	-13	-33	18
2066	32	-1	3	-5	-3	-44	18
2067	26	-1	5	-4	3	-48	18
2068	21	-1	7	-3	-1	-41	18
2069	9	-1	26	-1	9	-60	18
2070	31	-1	-16	-2	21	-51	18
2071	86	-2	-26	-6	-26	-43	18
Minimum	5	-2	-31	-10	-32	-62	18
25th %ile	21	-1	-15	-5	-11	-53	18
Median	31	-1	4	-3	2	-47	18
Mean	34	-1	-0	-4	1	-48	18
75th %ile	47	-1	12	-2	11	-44	18
Maximum	87	-0	38	-1	28	-33	18

9 SVIHM Application to Developing Sustainable Management Criteria

9.1 Overview

The Groundwater Sustainability Plan (GSP) Regulations provide that the monitoring network for Depletions of Interconnected Surface Water should include "[m]onitor[ing] surface water and groundwater where interconnected surface water conditions exist, to characterize spatial and temporal exchanges between surface water and groundwater and to calibrate and apply the tools and methods necessary to calculate depletions of surface water caused by groundwater extractions". (23 CCR 354.34(c)(6).)

9.2 Groundwater Levels as Proxy for Stream Depletion Monitoring – not suitable

Water levels are not a suitable proxy for surface water depletion in the Scott Valley, although they have been proposed in other groundwater basins (e.g., in the GSP adopted recently by the Santa Cruz Mid-County Groundwater Agency). This is because in the Scott Valley system (1) groundwater levels are affected by many factors including, but not limited to groundwater use, and (2) the typical variability induced by seasonal climate, recharge, and pumping changes is greater than the change in head that would correspond to a significant change in outflow to the stream system. In other words, the head data currently available are too noisy to be useful for assessing stream depletion due to groundwater pumping or stream depletion reversal due to specific projects and management actions (PMAs).

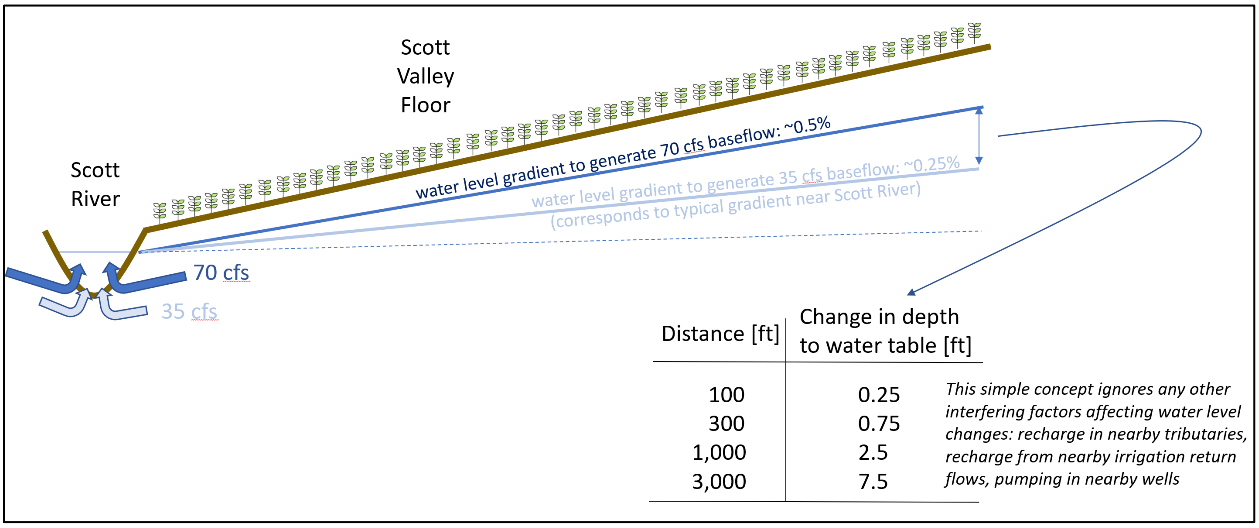


Figure 54: Conceptual cross-section across the valley floor near the Scott River (left), showing the land surface (brown, with crop cover) and two hypothetical water tables: at a gradient of about 0.5%, corresponding to a baseflow of about 70 cfs, and at a gradient of about 0.25%, corresponding to a baseflow of about 35 cfs. Gradients are approximate. The inserted table shows the resulting difference in water table depth between these two hypothetical water table locations, at different distances from the Scott River. The conceptual cross-section does not account for water table influences from nearby pumping, irrigation return flows, or tributaries.

Specifically, the average decrease in summer streamflow before and after the 1970s (69.9 and 35.0 cfs, respectively [1.98 and 0.99 cms, respectively]), is approximately 35 cfs (0.85 cms) in baseflow. This difference in baseflow is caused by a Basin average decline in water table gradient toward the Scott River (GSP Section 2.2.3.3) of approximately 3/10ths of one percent (see Figure 54). At 100 ft (30.5 m) from Scott River, this is a 3 in (7.6 cm) difference in water level if the water table next to the Scott River remains the same. This is much smaller than the typical transient variations induced by pumping wells and seasonal climate variability in water levels measured in monitoring wells near the river (see GSP Chapter 2). Additionally, water levels near the stream – and more so away from the stream - are influenced by factors other than groundwater pumping outside of the Adjudicated Zone, including proximity to tributaries and their recharge history, proximity to wells and their pumping history, irrigation methods and agricultural return flows in nearby fields, and aquifer heterogeneity.

For example, monthly water table depth in 2006 – 2018 in "valley floor" wells varied across wells and time, from less than 5 feet to over 20 feet (Harter n.d.). The median summer water table elevation in dry years is only about 2 feet lower than the median elevation in average or wet years. Between dry years with similarly low stream flows (less than 10 cfs at the USGS Fort Jones gauge, e.g., 2009, 2013, 2014), differences in median water level of "valley floor" observation wells were on the order of 1 to 2 feet (Harter n.d.).As a result of the magnitude of these fluctuations, partly due to the interference from hydrologic inputs/stresses other than PMAs, water level monitoring is not a suitable tool to measure whether groundwater users' PMAs have effectively decreased stream depletion.

However, the GSP recognizes that groundwater levels are fundamentally linked with groundwater-stream flux rates, and these measurements can be useful when judiciously used in combination with the SVIHM. In addition, use of observing long-term trends in the hydraulic gradient between the aquifer and stream has been suggested as a tool to comply with SGMA requirements for depletion of interconnected surface water (Hall et al. 2018). While groundwater levels as a proxy for stream depletion monitoring are by themselves not suitable for the Basin, these measurements will be collected and used to assess long-term trends in water level gradients and to avoid long-term, Basin scale water level declines (see GSP Sections 3.3.1 and 3.4.1). These data, among many others, are also used to calibrate and improve SVIHM. SVIHM in turn accounts for and processes a much wider range of relevant land use, hydrologic, and geologic data that would not be reflected in water level data alone. Using more appropriate, comprehensive information, including measured water level dynamics, SVIHM computes water level changes due to PMAs and estimates stream depletion reversal occurring specifically due to PMAs in ways that cannot be achieved with water level measurements alone (see below).

9.3 Streamflow as Proxy for Stream Depletion Monitoring – not suitable

Direct measurement of streamflow at the Fort Jones gauge is also not a suitable proxy for surface water depletion in the Scott Valley because it is affected by several factors other than groundwater use outside the Adjudicated Zone. The Fort Jones gauge streamflow during the summer baseflow season is a direct measure of the total groundwater contribution from the Scott River Valley Basin to the stream. That groundwater contribution to streamflow is a function of groundwater use inside and outside the Adjudicated Zone, of winter and spring recharge from precipitation and irrigation on the valley floor, of winter and spring recharge from tributaries on the upper alluvial fans, of mountain front recharge, and of surface water diversions (see GSP Section 2.2.3.3.). It is a function of both, their total amounts and the temporal dynamics of these amounts (pumping, recharge, diversions, etc.).

9.4 Legal Requirements for Quantifying Stream depletion due to Groundwater Pumping

Per 23 CCR Section 354.28(c), minimum thresholds for depletions of interconnected surface water shall be a rate or volume of surface water depletion caused by groundwater use that has adverse impacts on beneficial uses of the surface water. Minimum thresholds represent the threshold, above/below which undesirable results may occur. The legal requirements for the minimum threshold allow for the use of a numerical groundwater and surface water model to quantify ("monitor" or "measure") the amount of surface water depletion due to groundwater pumping and to set the minimum threshold using the model.

9.5 Quantifying Stream Depletion due to Groundwater Pumping with SVIHM

The Scott Valley Integrated Hydrogeological Model (SVIHM) is the best available tool to evaluate surface water depletion SMC conditions in Scott Valley and to quantify the amount of depletion attributable to groundwater use outside of the Adjudicated Zone. The current version of SVIHM simulates Scott Valley conditions for 1991–2018 climate conditions based on the best available information, including numerous climate, production well, geographic, geologic, and land use monitoring data from Scott Valley and calibrated against hundreds of streamflow and water level measurements. A SGMA-compliant software (MODFLOW 2005) is used for SVIHM.

After GSP adoption in 2022, the process for computing ("measuring") stream depletion in a given month, season, or water year with SVIHM is defined through the following specific modeling process:

1. "**Current**" is defined as a recently completed water year at the time new simulations are implemented. For example, if this modeling exercise is implemented in 2029, "current" may be the water year 2027 or 2028.
2. There are two operating modes for SVIHM:
    a. The **calibrated timeline mode**. The calibrated SVIHM version is implemented for a simulation period from 1991 to current, representing actual climate and stream inflow conditions to the Basin for the period of 1991 to current and representing

the actual historical evolution of PMAs and other land use and land management changes in the Basin. This mode is used to update and re-calibrate SVIHM using three types of datasets (target data, conceptual and input data, and PMA data, see GSP Section 3.3.5.2).

   b. The **scenario mode**. The scenario mode can be thought of as a future time period of the same length as 1991 to current (at the writing of this GSP, a 28-year period from 1991 to 2018) over which a specific scenario is implemented, for "measurement" purposes: For all scenario simulations described below (PMA Model, BAU Model, No Pumping Reference Model), the monthly (or daily) time series of climate conditions (precipitation, evapotranspiration (ET), inflow from tributaries, etc.) is that from 1991 to current. But the scenarios represented (PMA, BAU, No Pumping) are static over the entire simulation period, where "static" means that the set of PMAs (PMA portfolio), BAU, or No Pumping conditions does not change its pattern or land use and land management rule set over time. The PMA portfolio may be structured dynamically; for example, it may include projects that only occur in dry years or run only from July to September each year, but the structure of the PMA portfolio rule set does not change. This characteristic of the scenario mode allows it to be used to "measure" stream depletion and the reversal of stream depletion due to specific PMAs or PMA portfolios over a representative period of time.

3. "**Measuring**" or "monitoring" the impacts on streamflow from projects and management actions (PMAs) or under any No Pumping Reference Model is implemented by using the model in "scenario" mode. Specifically, the computation ("measurement") is implemented by first simulating two scenarios and then computing the difference in outcomes (streamflow), e.g., between the BAU simulation and the PMA or between the BAU simulation and the No Pumping Reference Model simulation. In other words, the impact of an action (PMA, No Pumping Reference) is measured by running two SVIHM scenario simulations: one simulation without the action and one simulation with the action. Each simulation provides a time series of monthly streamflow information for the 28-year (or longer) simulation period. For each month in the 28-year simulation period (336 months) the impact of the action is computed as the difference in streamflow (measured in cfs) between the two scenario simulations. Because the model runs over at least 28 years (1991-current), the approach allows for computing ("measuring") the stream depletion reversal (and remaining stream depletion) under a wide range of wet, average, and dry year conditions with monthly (or daily) varying, real climate characteristics as observed over the period 1991 to current. Some important characteristics of these computations ("measurements") are summarized here:
   - Changes can be computed ("measured") for any specific date (month) in the simulation period (1991-current)
   - Changes can be computed ("measured") at any location within the stream network in the Basin. The stream network has a resolution of 330 ft (100 m).

- In addition to changes in flow, the two simulations (with and without an action) can be used to assess temporal changes in the characteristics of key "functional flow" elements (see GSP Section 2.2.1.6), particularly the acceleration or delay in spring recess flow timing and the delay or acceleration in the onset of the fall pulse flow in any given year.
- The two simulations can also be used to assess the changes in the length of dry stream sections within the stream network resulting from PMAs, e.g., as a function of water year type.
- SVIHM currently uses monthly "stress periods" (time-varying model inputs such as precipitation are provided month-by-month, reflecting the average condition over each month), but computes daily flows (and groundwater level changes). Flows can be aggregated by month, season, year, or water-year type. Future versions of SVIHM may use daily stress periods.
- Numerous statistics can be obtained from the model with respect to
  - absolute flow differences between two scenarios,
  - relative flow differences (a PMA scenario change relative to a No Pumping Reference Model change),
  - changes in the timing of flows,
  - and other characteristics.

4. **Business as Usual Model (BAU Model)** scenario: SVIHM is used to compute daily streamflow at the same times and locations as the PMA model, explicitly excluding all PMA implementation over the entire simulation period. This simulation represents the "Business as Usual Model (BAU)", a scenario in which no PMAs are implemented that would make water use more sustainable than during the baseline period (1991-2018). This version includes representative land use and land management conditions without PMAs.
5. **Project and Management Action (PMA Model) scenario**: SVIHM is used to compute daily streamflow at the Fort Jones gauge (and other locations) under assumed (future) conditions with a static implementation of a specific PMA of interest, a PMA portfolio of interest (see GSP Chapter 4), or the specific PMA portfolio representing current (post-2021) conditions. The latter is the "**Current PMA Portfolio Model**". The PMA models are simulated as if the set of PMAs, as is, were to continue throughout the simulation period. The PMA Model allows for evaluation of desired or current PMA effects over a variety of climate conditions. The Current PMA Portfolio Model is the model used for compliance purposes and to "measure" the stream depletion reversal (and remaining stream depletion) under the current portfolio of PMAs.
6. **No Pumping Reference (NP Model) scenario**: For the NP Model, SVIHM is used to compute daily streamflow at the same times and locations as the PMA Model, but for conditions of no pumping outside the Adjudicated Zone and no implementation of PMAs. Various no pumping scenarios have been and can be constructed (see GSP Appendix 4-A)
7. The total surface water depletion due to groundwater use outside of the Adjudicated Zone ("**Total Depletion**") is calculated by taking the difference in simulated streamflow at the Fort Jones gauge between the BAU Model and the NP Reference Model. The total

depletion is a time-series with daily values over the simulation period. It is measured in the same units as average daily streamflow (cubic-feet per second, cfs), but can be summed as a cumulative volume over a month, season, or water-year (thousand acre-feet, TAF), and it can be averaged over the entire simulation period, by water-year type, and for specific seasons.

8. The surface water depletion that was avoided by the implementation of PMAs ("**PMA Depletion Reversal**") is calculated by taking the difference in simulated streamflow at the Fort Jones gauge between the PMA Model and the Business as Usual Model, and comparing that difference to Total Depletion:

Total Depletion [cfs] = NP – BAU

PMA Depletion Reversal [cfs] = PMA - BAU

Relative PMA Depletion Reversal [%] = 100 · PMA Depletion Reversal / Total Depletion

A visual schematic of this framework is included as Figures 30 and 36.

With this framework, the GSA can estimate streamflow changes (including numerous statistics of those changes for any period of interest) caused by the implementation of PMAs over the range of observed, actual climate conditions. It can assess the changes relative to a scenario in which no management actions were taken and calculate the fraction of total depletion due to pumping outside the Adjudicated Zone that was reversed by PMAs. All of this can be calculated under the specific weather conditions experienced. The amount [cfs] and fraction [%] of total depletion reversed for the Current PMA Portfolio Model will be reported in annual GSA reports.

This is designed to be an adaptive management process that evolves as new knowledge is gained. The monitoring network assessment section below (see GSP Section 3.3.5.2) describes in more detail the relationship between the numerous data collection efforts and the updating process of SVIHM as a measurement tool of stream depletion due to groundwater pumping outside of the Adjudicated Zone.

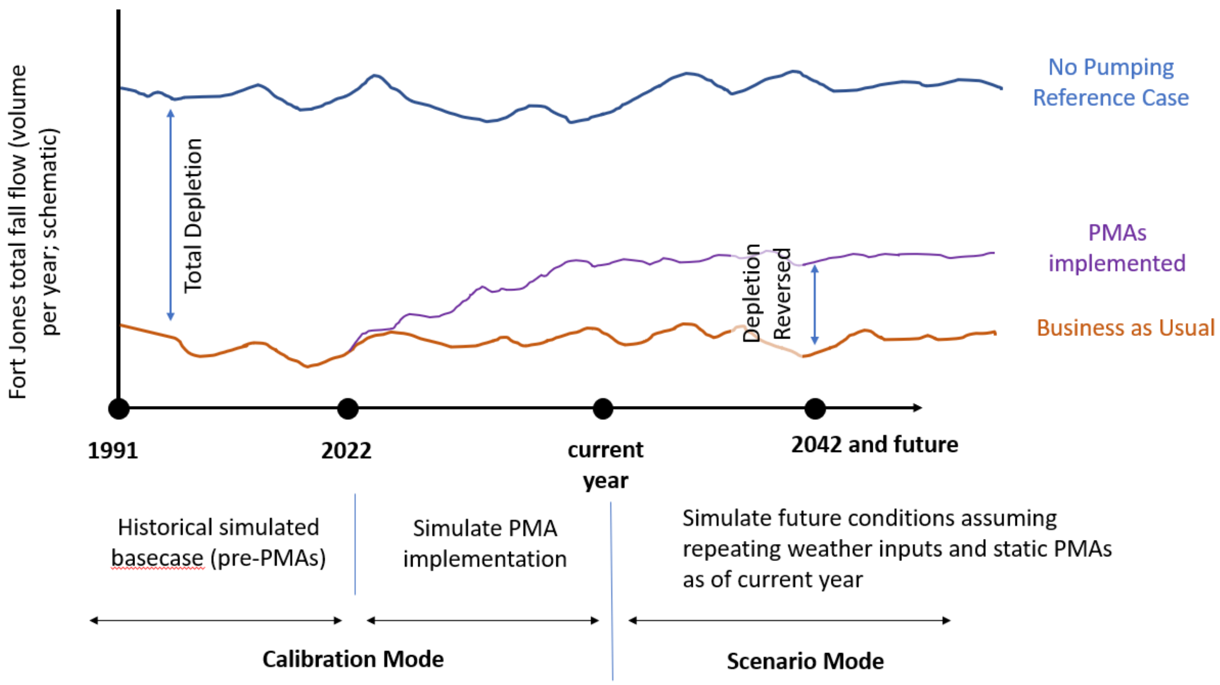


Figure 55. Visual schematic of simulations used to calculate Relative Depletion Reversal in future sustainable groundwater management reports.

9.6 Additional Monitoring Related to Interconnected Surface Water

To monitor for sustainable rates of surface flow depletion, the GSA will also rely on existing monitoring programs. The GSA plans to collaborate with other entities to add verified data and additional monitoring locations to fill data gaps.

9.6.1 Surface water monitoring

The GSA will continue to rely on the longstanding flow record of the Scott River monitored at the Fort Jones Gauge (USGS; Station ID 11519500).

The flows in tributary streams to the Scott River constitute a data gap. Currently, records of flowrates in tributary streams are limited, and for the SVIHM simulations, the temporal gaps in tributary records are filled using statistical correlations between each tributary's record and the record at the USGS Fort Jones gauge (see GSP Chapter 2). Additional monitoring on tributaries would provide more information on specific water year type conditions and inflows to interconnected stream reaches. Such tributary data would generate critical target data (see GSP Section 3.3.3.2) to improve the reliability of SVIHM.

9.6.2 Biological monitoring

Existing biological monitoring that will be used to assess the condition of aquatic and other groundwater-dependent ecosystems includes the CDFW camera trap program and biological surveys conducted by the Siskiyou County RCD (RCD), and juvenile salmonid outmigrant monitoring conducted by CDFW.

Since 2008, CDFW has operated a camera trap on the Scott River, near the bottom of the Scott Valley stream system. It is located downstream of the Fort Jones gauge at river mile 18.2 (041º 38' 10.93" N; 123º 04' 3.08"W). The camera trap records the passage of migrating salmonids (Knechtle and Guidice 2021).

Since 2001, the RCD has collected data on the location and abundance of salmon redds (gravel nests where eggs are laid) in the late fall and early winter. These surveys include recording of redd locations, occurrence of adult spawning salmon (both live and as carcasses), and stream connectivity and flow conditions.

Annual juvenile salmonid monitoring has been occurring since 2001, following the installation of the Scott River rotary trap; the Scott River Juvenile Salmonid Outmigrant study in 2020 monitored emigrating Chinook salmon, coho salmon and steelhead trout (Massie and Morrow 2020). Annual monitoring of juvenile salmonids is part of work conducted by CDFW and the Shasta Valley Resource Conservation District on Shasta and Scott Rivers.

Additional biological monitoring data may be used as it becomes available through other organizations and agencies. For GSP and groundwater sustainability monitoring purposes, no data gaps in biological monitoring have been identified at this time.

9.7 Assessing and Improving SVIHM

The SVIHM, as a "monitoring" instrument of surface water depletion due to groundwater pumping, will be assessed and updated every 5 to 10 years, utilizing the data and knowledge used for the original/previous model development update plus any additional monitoring data collected since the last model update. New data that will be considered in the assessment and update of SVIHM fall into three general categories:

- *Validation and re-calibration data ("target" data)*. These are independently collected field data, typically collected on a daily, monthly, or seasonal basis, that are also simulation outcomes by SVIHM: groundwater level monitoring data and streamflow measurements within Scott Valley and at the Fort Jones gauge. They are commonly used as calibration targets during model (re-)calibration. In other words, real monitoring data are used to compare model simulation results to reality and to adjust the model (within the limits of the conceptual model) to closely simulate measured and monitored real hydrologic outcomes (groundwater levels, streamflow).
- *Conceptual model data – hydrologic and hydrogeologic conditions (concept and "input" data)*. These are data that the model uses as input and data that are used to parametrize or conceptually design the model. These types of data include, but are not limited to precipitation data, tributary inflow data to the basin, hydrogeologic data obtained from well logs and pump tests, and research insights obtained from projects to further understand any hydrologic sub-systems within Scott Valley (e.g., groundwater-surface

water interaction measured with distributed temperature sensing tools or a local network of piezometers, see Groundwater Study Plan 2008).

- *Data about projects and management action implementation ("PMA" data)*. These are (monitoring) data collected specifically to characterize the implementation of PMAs to inform the GSA, stakeholders, and the design of future model scenario updates. The specific datasets collected are a function of the PMA and are described in GSP Chapter 4. Examples include monthly volume and location of water recharged (MAR PMA); acreage, location, and irrigation efficiency of improved irrigation systems (irrigation efficiency PMA); acreage, crop/land use, and pumping/diversion restriction conditions associated with conservation easements (voluntary land repurposing PMA).

The data collected will be used to update the calibrated timeline mode of SVIHM in three ways:

- *Conceptual Data* to update SVIHM simulation period: Precipitation and streamflow data measured at weather stations and the USGS Fort Jones gauge (from which tributary inflows are estimated using an existing statistical regression model) will be used to extend the simulation time horizon of SVIHM without any parameter, boundary condition, or scenario adjustments to the original time horizon of the model. This is a relatively inexpensive SVIHM application that allows for updated comparison of SVIHM water level and streamflow predictions against measured data under baseline and (existing) scenario conditions through the most current time period for which data are available. This type of SVIHM application is anticipated to occur at least once in every five-year reporting period, or possibly annually.
- *PMA Data* to update SVIHM simulation period: In addition to (1), data about PMA implementation will be used to update the model to include new, actual PMA implementation on the correct timeline within SVIHM. This provides a model update that appropriately represents recent changes in PMA implementation. This allows for a more consistent evaluation of simulated versus measured water level and streamflow data. This type of SVIHM application is anticipated to occur at least once in every five-year reporting period.
- *Conceptual, PMA, and Target Data* to update SVIHM and re-calibrate: In addition to (1) and (2), conceptual model data are used to update model parameters and model boundary conditions unrelated to PMAs to improve the conceptual model underlying SVIHM based on new insights and data. This will typically (but not automatically) require a re-calibration of the model against measured validation and re-calibration target data. After the re-calibration, all scenarios of interest and the timeline of stream depletion reversal associated with each scenario of interest and any new scenario of interest will be updated using the re-calibrated model to allow for consistent comparison of stream depletion and depletion reversal that has resulted or will result from PMAs. This type of SVIHM application is anticipated to occur at least every ten years.

For example, the version of SVIHM used in GSP Chapter 2 was calibrated for the period 1991-2011 (step 3 above), then extended using step 1 above to cover the period 1991-2018.

The above protocol ensures tight integration between monitoring programs, projects and management action implementation, and SVIHM as a monitoring tool for surface water depletion due to groundwater use. It provides the most accurate estimation not only of stream depletion, but also numerous associated information about water level dynamics, streamflow dynamics and their spatial, seasonal, interannual, and water-year-type-dependent behavior. Examples of future field monitoring data used to assess and improve SVIHM are listed below:

- Validation and re-calibration data (“target” data):
  - Water level in the water level monitoring network.
  - Daily streamflow measured at the Fort Jones gauge of the Scott River.
  - Data documenting dates and locations of dry sections in the stream network.
  - Last date on which certain low flow triggers are exceeded in the spring recession (e.g., date at which flow at the Fort Jones gauge falls below 40 cfs [1.1 cms]).
  - First date on which certain low flow triggers are reached as flow increases in the fall (e.g., date at which flow at the Fort Jones gauge exceeds 40 cfs [1.1 cms]).
- Hydrologic and hydrogeologic conditions (concept and “input” data):
  - Precipitation data from existing climate stations.
  - Potential ET data computed form existing climate stations.
  - Daily streamflow measured at locations near tributary stream inflow to Scott Valley (e.g., French Creek gauge at Hwy. 3).
  - Pump test data that contain information about hydrogeologic properties in the vicinity of a well.
  - Geologic information obtained from new well drilling logs.
  - Data collected in conjunction with research and pilot projects characterizing hydrologic and hydrogeologic conditions in Scott Valley.
  - Improved estimates of unimpaired tributary inflows from the upper watershed to the Basin accounting, e.g., for the location of existing/historic gauges relative to diversion locations.
  - Assess the need to incorporate fall/winter stockwater diversions
  - Refine stress-period setup in MODFLOW (e.g., daily instead of monthly)
- Data about projects and management actions (“PMA” data); see Chapter 4:
  - Date when certain PMA phases begin.
  - Location of PMA implementation:
    - The location of all fields participating in MAR activities during a given water year.
    - The location of conservation easements with altered diversion or pumping patterns during a given water year.
    - The location of improved irrigation systems with higher irrigation efficiencies.
  - Timing and volumes of water associated with PMA implementation:

- The total volume of water recharged in MAR activities during a given month of a given water year.
- The amount of streamflow diversion dedicated to instream flow in a given month of a given water year.
- The amount of pumping curtailment implemented in a given month of a given water year.
- The reduction in ET over the total growing season in a conservation easement.
- First installation date of improved irrigation systems with higher irrigation efficiencies and estimated improvements in irrigation efficiency.
- Perform additional sensitivity analysis on conceptual model inputs and PMA data inputs.

9.8 Assessing and Improving Related Monitoring Networks

As discussed above, one major data gap identified is flows in tributary streams. Though some active gauges exist on tributary streams (notably on Sugar, French and Shackleford Creeks; see table in GSP Chapter 2 Section 2.2.1.6), other major tributaries do not appear to be actively gauged based on publicly available data. Data gaps in tributary flows will be addressed through prioritization of streams for measurement and GSA coordination with other agencies for addition of stream gauges. Repeated evaluations of the network will occur on a five-year basis. Additional stream gauges may be implemented throughout the GSP implementation period. Streams should be prioritized according to how much flow each stream contributes to the Basin. According to estimated flow volumes in SVIHM, the five highest-priority tributaries for installation of flow gauges would be East and South Forks of the Scott River (possibly immediately below their confluence) and Kidder, Etna and Shackleford Creeks (Table 28). French Creek is also a priority location for installation of a flow gauge due to its value as habitat for coho salmon, a priority GDE in the Basin. If possible, these gauges should be located near the Basin boundary to capture flow conditions before streams interact with the alluvial aquifer underlying the flat valley floor.

Tributary Name	Proportion of total inflow to SVIHM
East Fork	18%
Kidder Creek	18%
Etna Creek	15%
Shackleford Creek	12%
South Fork	11%
French Creek	8%
Patterson Creek	5%
Sugar Creek	4%
Mill Creek	4%
Moffett Creek	3%
Johnson Creek	1%
Crystal Creek	1%

Table 28: Major tributary streams to the Scott River and the proportion of total flow inputs to the model domain simulated in SVIHM. The source for this data is the available tributary inflow records, with missing daily values interpolated using a streamflow regression model (see GSP Chapter 2, Section 2.2.1.6, and GSP Appendix 2-F for more information).

9.9 Information and Methodology Used to Establish Minimum Thresholds and Measurable Objectives for the Interconnected Surface Water Criteria

The minimum threshold is defined in terms of modeled monthly stream depletion reversal for climate period 1991-2018 conditions under proposed PMAs. This is measured with the SVIHM, simultaneously in percent of Total Depletion reversed, in cubic-feet-per-second (cfs), and in year-specific number of days gained in the spring recess flow and fall pulse flow for specific flow thresholds (e.g., 10 cfs, 20 cfs, 30 cfs, or 40 cfs) at the simulated Fort Jones gauge. In establishing minimum thresholds for depletions of interconnected surface water, the following information was considered:

- Feedback on concerns about depletions of interconnected surface water and feasibility of PMAs from stakeholders.
- An assessment of interconnected surface water in the Basin.
- Results of the numerical groundwater model, which was used to calculate surface water depletion under a variety of scenarios.
- Input from stakeholders resulting from the consideration of the above information in the form of recommendations regarding minimum thresholds and associated management actions.

The minimum thresholds were selected based on results of scenarios, modelled using SVIHM, used to identify a realistic and reasonable amount of surface water depletion that can be achieved through the proposed PMAs. The proposed PMAs included in the scenarios to improve the decline in spring flow recession, summer and fall baseflow conditions, and the onset of the fall flush flow in dry and some average years, individually and in combination were:

- Winter and spring managed aquifer recharge.
- Beaver dam analogues and other fish-friendly structures.
- Changes in irrigation technology or crop type.
- Surface water storage.
- Seasonal pumping restrictions in the non-Adjudicated Zone.
- Voluntary pumping restrictions in the Adjudicated Zone.
- Conservation easements that would limit irrigation in some or all water years.
- An expanded surface water leasing program.

Along with Depletion Reversal for specific scenarios of PMAs, other output of SVIHM was also used to compute and present other relevant project outcome metrics important to understanding and assessing the project and management action benefits to streamflow. Information considered by the Advisory Committee include:

- The ratio of Depletion Reversal and Total Depletion, which is the "**Relative Depletion Reversal**", measured in percent. The computation of this value is shown in Figure 56.
- Streamflow on any given day and location, a metric relevant to measure environmental outcomes.
- The number of days gained in stream connectivity in dry and some average years, both in the summer after the end of the spring flow recession, and in the fall when streamflow increases for the fall flush.
- Other relevant metrics including the timeseries of relative streamflow increase and simulated streamflow.
- Evaluation under Future Climate Conditions: The Total Depletion under future climate conditions, as well as the Depletion Reversal under future climate conditions, can be modeled in the same way as for the 1991-2018 models, using future climate data and CDWR's protocol for simulating climate change conditions.
- Uncertainty Analysis: SVIHM also allows for uncertainty analysis in predicting Total Depletion, as well as Depletion Reversal for specific projects and management actions under current or future climate conditions.
- For each group of projects and management actions that are implemented, the Depletion Reversal is a measure of the amount of surface water depletion that is reversed relative to business as usual (BAU0 conditions. PMAs are therefore – through SVIHM – inextricably, deterministically, and directly linked to specific "measured" outcomes: streamflow, streamflow gains, Depletion Reversal, Relative Depletion Reversal, number of days gained in stream connectivity, etc.

A full portfolio of the scenarios and results are described in Chapters 6 and 7 and in the Appendix to this Report.

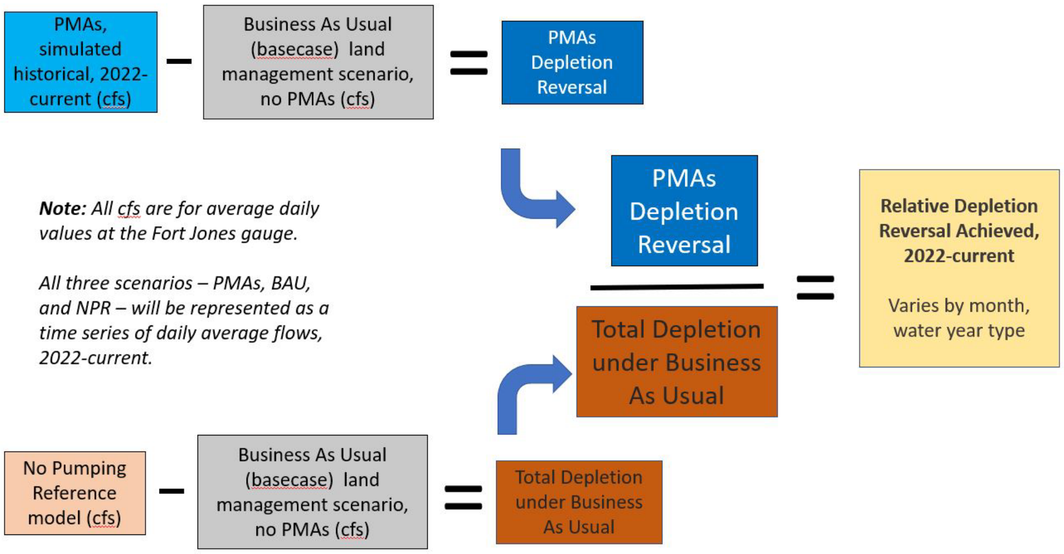


Figure 56: Computation of the Relative Depletion Reversal as the ratio of Depletion Reversal (due to PMAs) and Total Depletion. The graphic also shows the computation of the Total Depletion and the Depletion Reversal as defined above. The Relative Depletion Reversal is a unitless fraction. Multiplied by 100, it has units of percent [%]. PMAs may lead to less than 100% Relative Depletion Reversal, or even more than 100% Relative Depletion Reversal. Just like Total Depletion and project or management action-specific Depletion Reversal, the Relative Depletion Reversal varies from day to day.

10 Conclusions

This project began as and continues to be a key element to the implementation of the Scott River Temperature TMDL and to achieving the water quality objective for temperature in the Scott River. The initial SVIHM model development followed recommendations of the Scott Valley Groundwater Study Plan (http://groundwater.ucdavis.edu/files/136426.pdf). It has since critically informed groundwater management planning efforts, and specifically, as documented in this report, the 2019 – 2022 development of the Scott Valley Groundwater Sustainability Plan, through:

- Updating the simulation period (originally ending in 2011) to extend through 2018.
- Updated water budget analysis.
- The development of reference scenarios
    - for computation and attribution of streamflow depletion due to groundwater pumping, data that are required by SGMA regulations, and
    - for unimpaired streamflow estimation through no-pumping and no-irrigation (i.e., no-pumping *and* no surface water diversion) scenarios with and without natural vegetation in lieu of agricultural land uses, and spatially distinguishing between the adjudicated zone, the region outside the adjudicated zone regulated under the GSP, but also the entire Scott Valley region.
- The development of a large number of project and management action scenarios that provide information about anticipated future water level and streamflow benefits derived from such projects.
- A preliminary climate change impact assessment by simulating several future climate conditions with SVIHM and quantifying associated changes in groundwater levels, storage, and interconnected streamflow.
- Providing critical scientific tools and associated information in the development of the groundwater-surface water sustainability indicator including the development of a minimum threshold and as monitoring tool to quantify the reversal of streamflow depletion resulting from specific project implementation.
- Extensive and continuous communications (meetings, presentations, meeting minutes, written comments and comment responses, draft GSP reports and final GSP) with local, regional and state agencies and interested parties.

This project has been a cornerstone to better integrate technical assistance with regulatory efforts and local management of groundwater and surface water resources under Porter-Cologne, SGMA, existing adjudications, and surface water rights management. Follow-on projects will support further development of SVIHM to support the ongoing implementation of groundwater related projects and management actions by the GSA and other entities, and to inform policy and decision-making efforts on instream flow requirements in the Scott River system.

An overarching insight from SVIHM-18 and the scenarios developed for the GSP may be this: water users collectively have a meaningful degree of control over the flow in the Scott River, but significant increases in environmental flows would probably require water use changes with significant economic consequences. In addition, SGMA mandated “reasonable” management of water resources, but the reasonableness of any given management action can only be determined in relation to all other options. Quantitative summaries of management actions, such as those developed here in collaboration with the GSA advisory committee during the GSP development, are critical for comparing multiple scenarios that can help inform decision-making processes.

SVIHM integrates our understanding of hydrologic, geologic, soils, geographic, and land use processes into a scientifically comprehensive and consistent framework. While SVIHM cannot solve political disputes between diverse stakeholders, it provides a critical and important scientific footing for resource management decisions in Scott Valley.

11 References

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M., 1998, Crop evapotranspiration-Guidelines for computing water requirements-FAO Irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations, Rome, Italy: FAO.

Banta, Edward R. 2000. "MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model - Documentation Of Package For Simulating Evapotranspiration With A Segmented Function (ETS1) And Drains With Return Flow (DRT1). Open-File Report 00–466." U.S. Geological Survey Open-File Report 00-466.

California Department of Water Resources (CDWR). 1963, Land and Water Use in Shasta-Scott Valleys Hydrographic Unit. Volume I: Text, Bulletin No. 94-5, 232 p.

———. 1964. Klamath River Basin Investigation, Bulletin No. 83, July 1964, 198 p.

———. 1976. Siskiyou County Land Uses and Water Demands, March 1976, 88 p.

———. 2000, Land Use Survey, Siskiyou County. Available online at http://www.water.ca.gov/landwateruse/lusrvymain.cfm. Accessed May 14, 2009.

———. 2007. "Spatial CIMIS Dataset." California Irrigation Management Information System. Online Dataset. 2007. https://cimis.water.ca.gov/SpatialData.aspx.

———. 2021. "CIMIS Station Reports." California Irrigation Management Information System. Online Dataset. 2021. https://cimis.water.ca.gov/WSNReportCriteria.aspx.

California State Water Resources Control Board (SWRCB). 2021a. "ORDER IMPOSING WATER RIGHT CURTAILMENT AND REPORTING REQUIREMENTS FOR ADJUDICATED GROUNDWATER RIGHTS IN THE SCOTT RIVER WATERSHED (ORDER WR 2021-0083-DWR)." https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2015/rs2015_0002.pdf.

———. 2021b. "ORDER IMPOSING WATER RIGHT CURTAILMENT AND REPORTING REQUIRE- MENTS FOR REPORTED WATER RIGHTS IN THE SCOTT RIVER WATERSHED." Sacramento, CA. https://www.waterboards.ca.gov/drought/scott_shasta_rivers/.

———. 2022a. "Guidance on Groundwater Reduction Local Cooperative Solution for the Scott River Watershed." Sacramento, CA. https://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/scott_shasta_rivers/docs/groundwater-reduction-lcs-guidance.pdf

———. 2022b. "Establishment of Minimum Instream Flow Requirements, Curtailment Authority and Information Order Authority in the Klamath Watershed." Sacramento, CA. https://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/scott_shasta_rivers/docs/groundwater-reduction-lcs-guidance.pdf

Carle, S., and Fogg, G., 1996, Modeling Spatial Variability with One and Multidimensional Continuous-Lag Markov Chains Mathematical Geology Volume 29, Number 7, 891-918, DOI: 10.1023/A:1022303706942.

CDFW. 2017. “Interim Instream Flow Criteria for the Protection of Fishery Resources in the Scott River Watershed, Siskiyou County.” https://wildlife.ca.gov/Conservation/Watersheds/Instream-Flow/Studies/Scott- Shasta-Study.

Deas, M.L., and S.K. Tanaka, 2003, Scott River Water Balance Study: Data Analysis and Model Review. Prepared for the Scott River Watershed Council.

Deas, M.L., and S.K. Tanaka, 2004, Scott River Water Balance Study: Data Analysis and Model Review, Watercourse Engineering, June 2004.

Deas, M.L., and S.K. Tanaka, 2005, Scott River Runoff Forecast Model: Investigation of Potential Formulation, Watercourse Engineering, December 2005.

Deas, M.L., and S.K. Tanaka, 2006, Scott River Water Supply Indices: Year Types for the Scott River Basin, prepared for the Siskiyou RCD.

Deas, M.L., and S.K. Tanaka, 2008, Scott River Water Balance-Streamflow and Precipitation Gauging, prepared for the Siskiyou RCD.

Doherty, J., 2010, Methodologies and Software for PEST-Based Model Predictive Uncertainty Analysis, Watermark Numerical Computing, Australia.

Drake, D., Tate, K., and Carlson, H., 2000, Analysis shows climate-caused decreases in Scott River Fall Flows, California Agriculture, Vol. 54 n. 6, pp. 46-49.

Foglia, Laura, Alison McNally, Courtney Hall, Lauren Ledesma, Ryan Hines, and Thomas Harter. 2013a. “Scott Valley Integrated Hydrologic Model: Data Collection, Analysis, and Water Budget.” April 2013. University of California, Davis. http://groundwater.ucdavis.edu/files/165395.pdf.

Foglia, L., McNally, A., & Harter, T. 2013b. Coupling a spatiotemporally distributed soil water budget with stream-depletion functions to

inform stakeholder-driven management of groundwater-dependent ecosystems. Water Resources Research, 49, 7292–7310. https://doi.

org/10.1002/wrcr.20555

Foglia, Laura, Jakob Neumann, Douglas G. Tolley, Steve B. Orloff, Richard L. Snyder, and Thomas Harter. 2018. “Modeling Guides Groundwater Management in a Basin with River–Aquifer Interactions.” California Agriculture 72 (1): 84–95.

Galdi, Giuliano. 2021. “Personal communication, phone conversation with Giuliano Galdi, Siskiyou UC Cooperative Extension specialist.”

Gesch, D.B., 2007, The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.

Gesch, D., et al., 2002, The National Elevation Dataset: Photogrammetric Engineering and Remote Sensing, v. 68, no. 1, p. 5-11.

Hanson, B., Orloff, S., Bali, K., Sanden, B., Putnam, D., 2011a, Evapotranspiration of Fully-Irrigated Alfalfa in Commercial Fields, 2011 Conference Proceedings, Agricultural Certification Programs-Opportunities and Challenges.

Hanson, B., Orloff, S., Bali, K., Sanden, B., Putnam, D., 2011b, Mid-summer Deficit Irrigation of Alfalfa in Commercial Fields, 2011 Conference Proceedings, Agricultural Certification Programs-Opportunities and Challenges.

Harbaugh, A.W., Langevin, C.D., Hughes, J.D., Niswonger, R.N., and Konikow, L. F., 2017, MODFLOW-2005 version 1.12.00, the U.S. Geological Survey modular groundwater model: U.S. Geological Survey Software Release, 03 February 2017, http://dx.doi.org/10.5066/F7RF5S7G

Harbaugh, A.W., Banta, E.R., Hill, M.C. and McDonald, M.G., 2000, MODFLOW-2000, The U.S. Geological Survey modular ground-water model – users guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Hargreaves, G. H., and Z. A. Samani, 1982, Estimating potential evapotranspiration, J. Irrig. Drain. Eng., 108(3), 225-230.

Hargreaves, G.H., and J.P. Riley, 1985, Irrigation water requirements for the Senegal river basin. Journal of Irrigation and Drainage Engineering 111(3): 265-275.

Harter, Thomas, and Ryan Hines. 2008. "Scott Valley Community Groundwater Study Plan." Davis. CA: Groundwater Cooperative Extension Program University of California, Davis. http://groundwater.ucdavis. edu/files/136426.pdf.

Heizer, R.F., 1972, George Gibbs' Journal of Redick McKee's Expedition Through Northwestern California in 1851 (edited and with annotations). Archeological Research Facility, Department of Anthropology, Univ. of California Berkeley, pages 62-63.

Hines, Ryan. "MS Thesis Draft." October 2010.

Howes, D., P. Fox, and P. Hutton, 2015, Evaportranspiration from natural vegetation in the Central Valley of California: Monthly grass reference-based vegetation coefficients and the dual crop coefficient approach. J. Hydrol. Eng. 20(10), 17 pages, DOI: 10.1061/(ASCE)HE.1943-5584.0001162.

Mack, S., 1958, Geology and Ground-Water Features of Scott Valley Siskiyou County, California: U.S. Geological Survey Water-Supply Paper 1462. Washington D.C.

Monteith, J.L. , 1965, Evaporation and environment. Symp. Soc. Exp. Biol. 19, 205-224.

Nash, J. E., and J. V. Sutcliffe. 1970. "River Flow Forecasting through Conceptual Models Part I - A Discussion of Principles." Journal of Hydrology 10 (3): 282–90. https://doi.org/10.1016/0022-1694(70)90255-6.

Noest, V, 1994, A hydrology-vegetation interaction model for predicting the occurrence of plant species in dune slacks. J. Env. Mgmt 40:119-128. https://doi.org/10.1006/jema.1994.1008

North Coast Regional Water Board, 2006, Action Plan for the Scott River Sediment and Temperature Total Maximum Daily Loads, September 2006.

North Coast Regional Water Board, Staff report for the action plan for the Scott River Watershed Sediments and Temperature TMDLs, 2005, https://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/scott_river/092005/sr/01titlepageandtableofcontents.pdf.

Orang, M.N., Snyder, R.L., Matyac, J.S., 2008, Consumptive Use Program +, California Department of Water Resources, http://www.water.ca.gov/landwateruse/models.cfm.

Poeter, Eileen P., and Mary C. Hill. 1998. "Documentation of UCODE, a Computer Code for Universal Inverse Modeling. U.S. Geological Survey Water-Resources Investigations Report 98-4080."

Poeter, E.P., Hill, M.C., Banta, E.R., Mehl, S.W., and Christensen, S., 2005, UCODE-2005 and six other computer codes for universal sensitivity analysis, inverse modeling, and uncertainty evaluation, U.S. Geological Survey Techniques and Methods, 6-A11.

Prudic, David E., Leonard F. Konikow, and Edward R. Banta. 2004. "A New Streamflow-Routing (SFR1) Package to Simulate Stream-Aquifer Interaction with MODFLOW-2000." U.S. Geological Survey Open-File Report 2004-1042.

Quigley, D., S. Farber, K. Conner, J. Power, and L. Bundy, 2001, Water Temperatures in the Scott River Watershed in Northern California." Prepared for U.S. Fish and Wildlife Service.

R Core Team. 2020. "R: A Language and Environment for Statistical Computing." Vienna, Austria. https://www.r-project.org/.

Siskiyou County Flood Control and Water Conservation District. 2021. "Scott Valley Groundwater Sustain- ability Plan." https://www.co.siskiyou.ca.us/naturalresources/page/scott-valley-gsp-chapters.

Snyder, R.L., M. Orang and S. Matyac, 2002, A long-term water use planning model for California. Proceedings of the Sixth International Symposium on Computer Modelling in Fruit Research and Orchard Management. Acta Hort., 584: 115-121.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, 1975, Soil Survey Geographic (SSURGO) Database for [Survey Area, State]. Available online athttp://soildatamart.nrcs.usda.gov . State of California, State Water Resources Control Board, 1975.

S.S. Papadopulos & Associates, 2012, Groundwater conditions in Scott Valley, Report prepared for the Karuk Tribe, March 2012.

Swenson, M. 1947. Report on Scott River Watershed Basic Data Pertinent to Development of a Watershed Management Plan for the Klamath National Forest. Region 5. U.S. Forest Service.

Superior Court of Siskiyou County. 1980. "Scott River Adjudication, Decree No. 30662. Scott River stream system, Siskiyou County. California State Water Resources Control Board." Sacramento, CA. https://www. waterboards.ca.gov/waterrights/board_decisions/adopted_orders/judgments/docs/scottriver_jd.pdf.

Superior Court of Siskiyou County. 2018. "Notice of Reduction of Scott River Watermaster Service Area." https://www.sswatermaster.org/scottmaps.

Tanaka, S.K., and M.L. Deas, 2008, Scott River Water Balance: Streamflow and Precipitation Gauging." Watercourse Engineering, May 2008.

Tolley, Douglas G., Laura Foglia, and Thomas Harter. 2019. "Sensitivity Analysis and Calibration of an Integrated Hydrologic Model in an Irrigated Agricultural Basin with a Groundwater-Dependent Ecosystem." Water Resources Research 55 (8). https://doi.org/10.1029/2018WR024209.

UCCE Leaflet 21427, Using Reference Evapotranspiration (ET0) and Crop Coefficients to estimate Crop Evapotranspiration (Etc) for agronomic crops, grasses, and vegetable crops, http://lawr.ucdavis.edu/irrigation/irrigation_leaflets/L21427.html

Van Kirk, R. W. and S. W. Naman, 2008, Relative Effects of Climate and Water Use on Base-Flow Trends in the Lower Klamath Basin. Journal of the American Water Resources Association (JAWRA) 44(4):1035-1052. DOI: 10.1111/j.1752-1688.2008.00212.x

Watershed Sciences, 2010, LiDAR Remote Sensing Data Collection: Scott Valley California. November 11, 2010. Watershed Sciences, 529 SW 3rd Avenue, Suite 300, Portland, OR 97204. 24 pages. Accessed through the California State Water Resources Control Board.

12 Appendix: SVIHM Scenario Results Catalog

Scott Valley Management Scenario Results

Claire Kouba

11/14/2023

Table of Contents

Scott Valley Management Scenario Results

Summary Table

Scenario Type	Scenario ID	Scenario Depletion Reversal, Sep-Nov '91-'18 (TAF)	Relative Depletion Reversal, Sep-Nov '91-'18
Enhanced Recharge	MAR (Managed Aquifer Recharge) in Jan-Mar	13	10%
	ILR (In-Lieu Recharge) in the early growing season	12	9%
	MAR + ILR	25	19%
	Expanded MAR + ILR *(assumed max infiltration rate of 0.019 m/d)*	60	44%
Diversion Limits	All surface water diversions limited at low FJ flows	51	38%
	MAR + ILR, with all surface water diversions limited at low FJ flows	77	57%
Crop change	80% Irrigation demand	82	61%
	90% Irrigation demand	40	29%
Irrigation Efficiency	Improve irrigation efficiency by 0.1	5.8	4%
	Improve irrigation efficiency by 0.2	16	12%
	Reduce irrigation efficiency by 0.1	-3.2	-2%
Irrigation schedule change	Alfalfa irrigation schedule - July 10 end date	117	86%
	Alfalfa irrigation schedule - Aug 01 end date	82	60%
	Aug 01 end date, *dry years only ('91, '92, '94, '01, '09, '13, '14, '18)*	19	14%
	Alfalfa irrigation schedule - Aug 15 end date	45	33%
	Aug 15 end date, *dry years only ('91, '92, '94, '01, '09, '13, '14, '18)*	9	7%
Attribution - adjudicated area impacts	Natural Vegetation Outside Adjudicated area (NVOA)	171	126%
	Natural Vegetation, on Groundwater- or Mixed-source fields, Outside Adjudicated area (NV-GWM-OA)	**136**	100%
	Natural Vegetation Inside Adjudicated area (NVIA)	126	93%
	Natural Vegetation, on Groundwater- or Mixed-source fields, Inside Adjudicated area (NV-GWM-IA)	116	85%
	Natural Vegetation (NV)	287	212%
	Natural Vegetation on all Groundwater- or Mixed-source fields (NV-GWM)	233	171%
Reservoir	9 TAF Reservoir, 30 cfs release, Shackleford	46	34%
	9 TAF Reservoir, 30 cfs release, Etna	65	48%
	9 TAF Reservoir, 30 cfs release, French	78	58%
	9 TAF Reservoir, 30 cfs release, S. Fork	35	26%
100% reliable reservoir	29 TAF Reservoir, 100% reliability 30 cfs release	72	53%
	134 TAF Reservoir, 100% reliability 60 cfs release	250	184%

Summary of scenarios

- Supply-side scenarios
  - Enhanced Recharge
  - Reservoirs
- Demand-side scenarios
  - Crop change
  - Irrigation efficiency
  - Irrigation schedule change
- Attribution
  - Impact of pumping inside and outside adjudicated zone
- Range of depletion reversal: 4% - 114%
  - Not including Attribution scenarios

Explanatory Material

The following information is intended to help a reader understand the scenario results plots and interpret them in the context of setting the surface water SMC for the Scott Valley Groundwater Sustainability Plan.

Acronyms:

UR – Undesirable Result

- Informed by Sustainability Goal, but must be tied to metric(s)

MT – Minimum (or Maximum) Threshold.

- The MT is the boundary beyond which a UR occurs.
- *Note*: MT and UR definitions are **linked.**

MO – Measurable Objective

- Ideal operating range

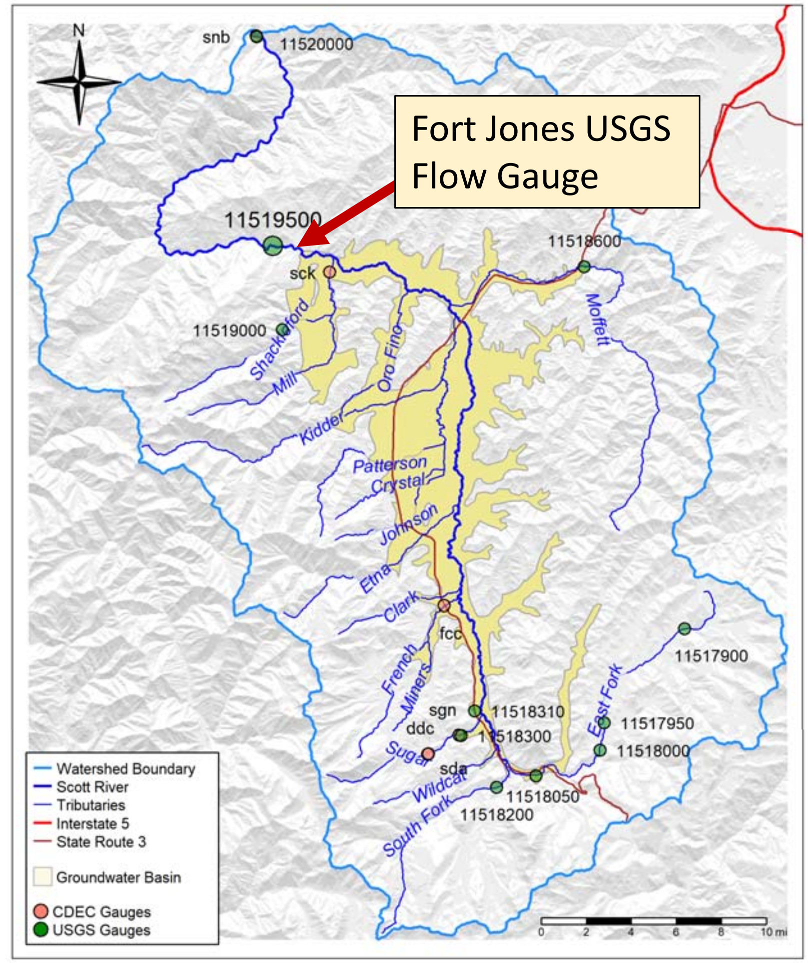
SMC – Sustainable Management Criteria (includes URs, MO and MTs)

PMAs – Projects and Management Actions

Quantifying the SMC

Streamflow Depletion is quantified as:

- the **difference in flow** at the Fort Jones Gauge…
- over the model period of 1991-2018…
- between the Basecase (estimated historical) conditions and a management scenario.

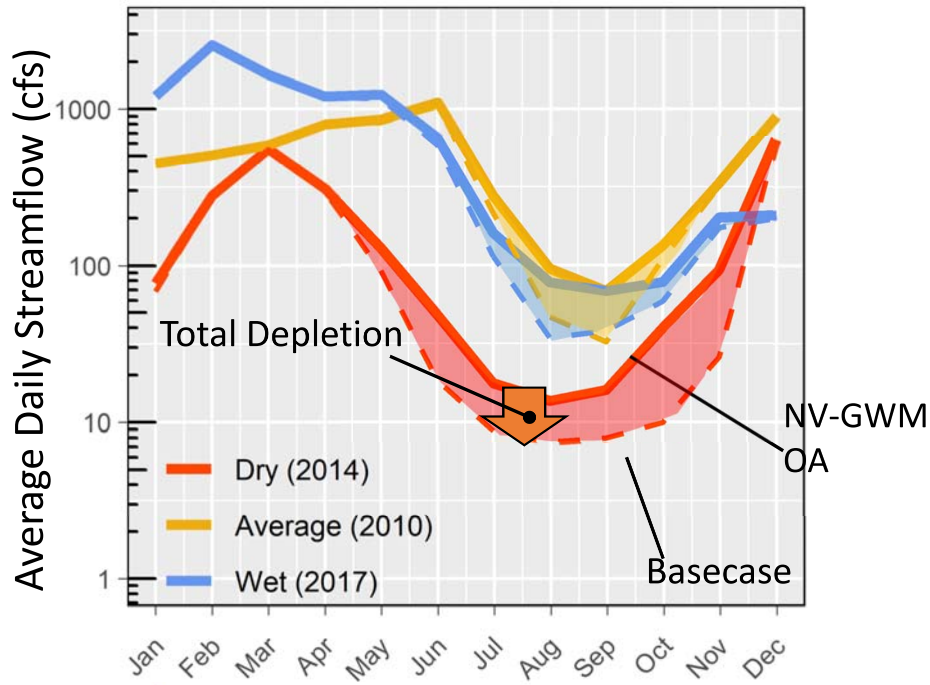


Quantifying the SMC

Total Streamflow Depletion* is quantified as:

- the **difference in flow** at the Fort Jones Gauge…
- over the model period of 1991-2018…
- between the Basecase (estimated historical/current) conditions and the No Pumping** Reference case.

*Note: Areas not proportional due to log-y axis



Total Depletion, 2010

Total Depletion, 2017

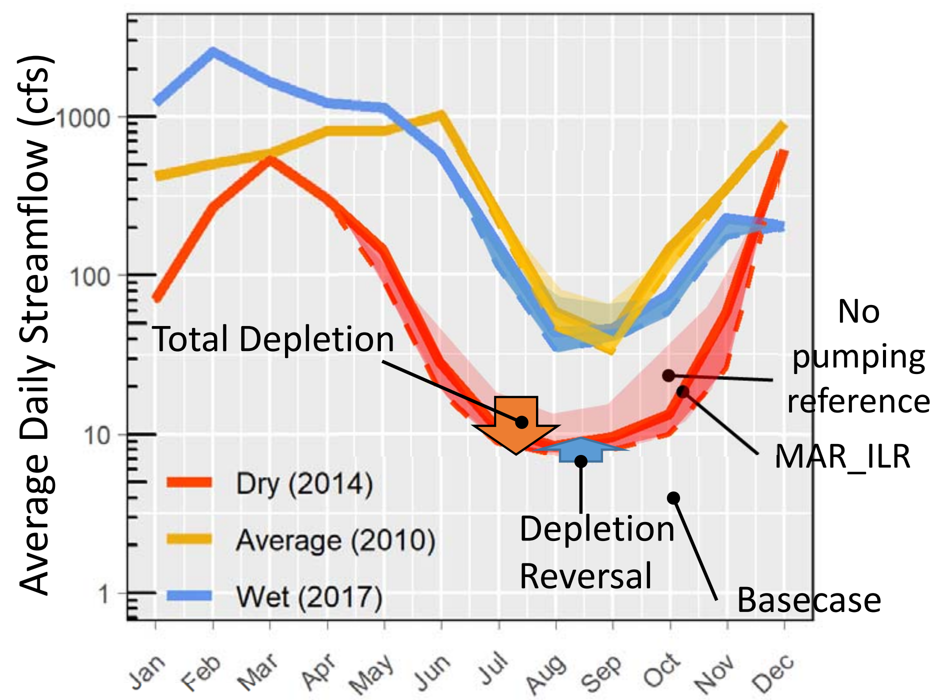
Total Depletion, 2014

* Due to pumping in SGMA wells
** Also referred to as "Natural Vegetation on GW and Mixed-source fields Outside the Adjudicated Zone", or NV-GWM-OA

Quantifying the SMC

Depletion Reversal is quantified for **each** scenario as the difference between the Basecase (simulated historical & current) conditions and the relevant scenario (for example, MAR+ILR).

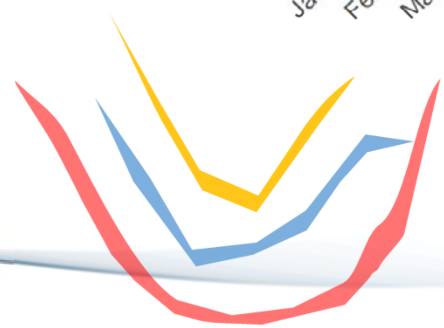
*Note: Areas not proportional due to log-y axis



Total Depletion, 2010

Total Depletion, 2017

Total Depletion, 2014



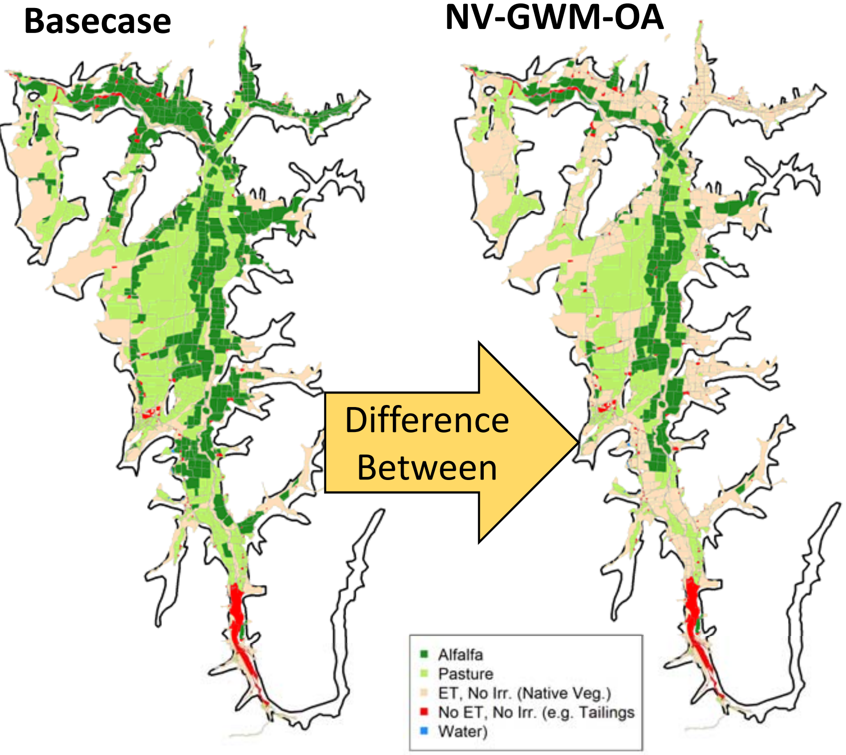
MAR+ILR Depletion Reversal, 2010

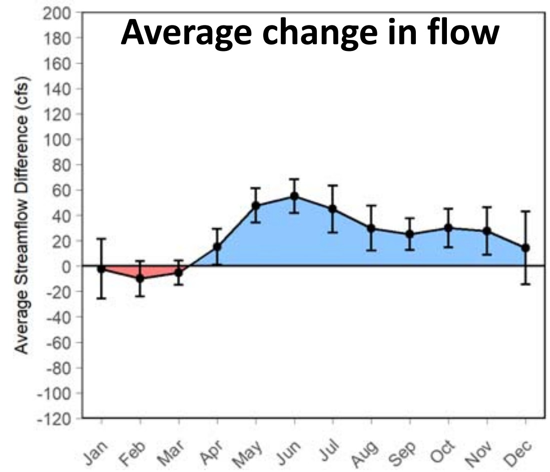
MAR+ILR Depletion Reversal, 2017

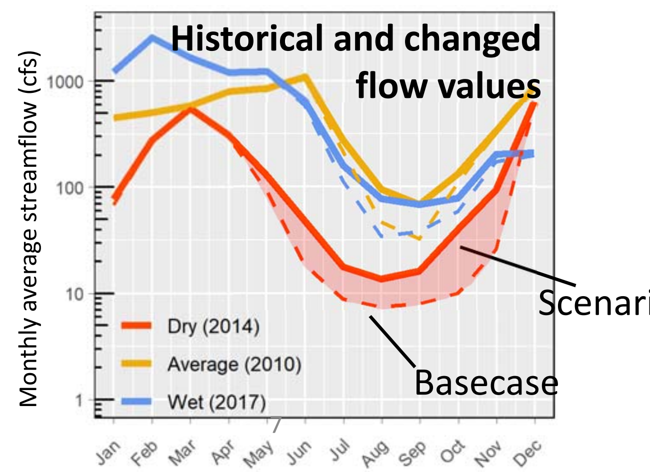
MAR+ILR Depletion Reversal, 2014

Total Depletion: no-pumping reference case maps

Basecase **NV-GWM-OA**



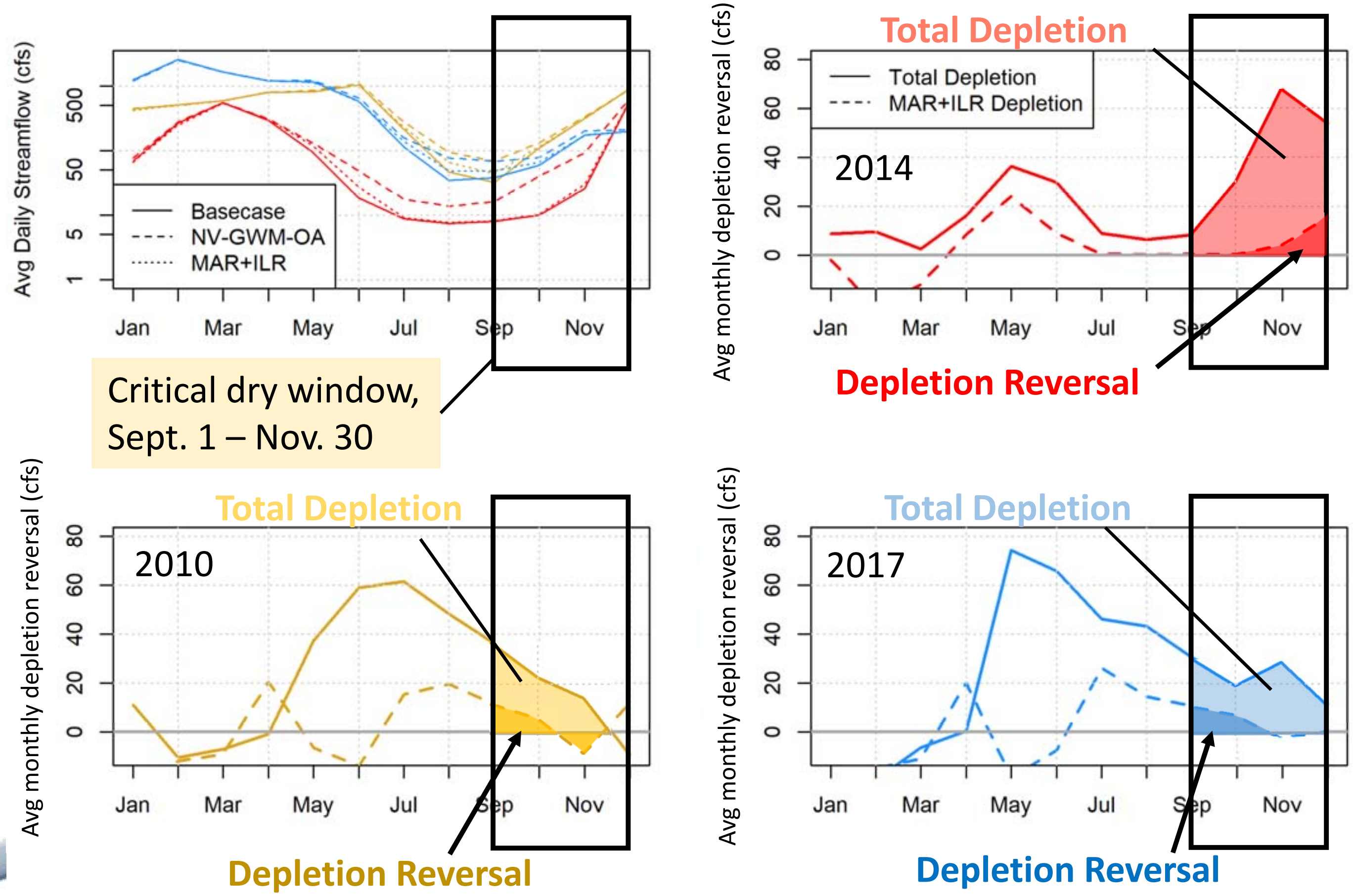




Basecase Landuse

Native Vegetation on *GW and Mixed Water Source Fields* Outside Adjudication

Quantifying Depletion Reversal



To calculate relative depletion reversal, sum the darker areas for each year and divide by the sum of the lighter areas in the Sept-Nov window.

Relative Depletion Reversal for MAR+ILR:

19%

of Total Depletion, Sept.-Nov. for 1991-2018.

Setting the SMC – Minimum Threshold (MT)

- The MT selected will define the "significant and unreasonable" undesirable result.

- The MT will be set as the amount of stream depletion reversal achieved by the minimum required PMA (expressed as % of depletion reversed *relative* to the No-Pumping Reference Case).

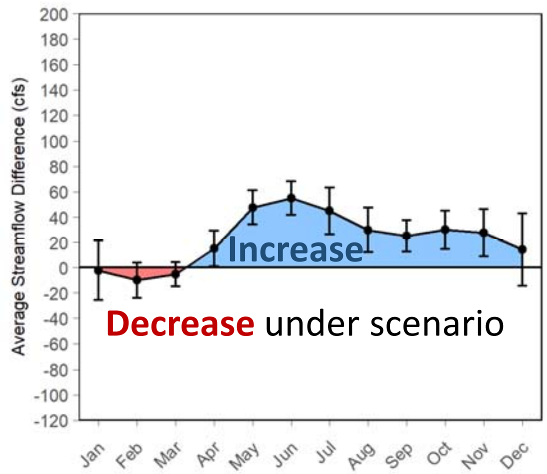
- The PMA(s) selected to define the MT should be realistic, feasible, and fair.

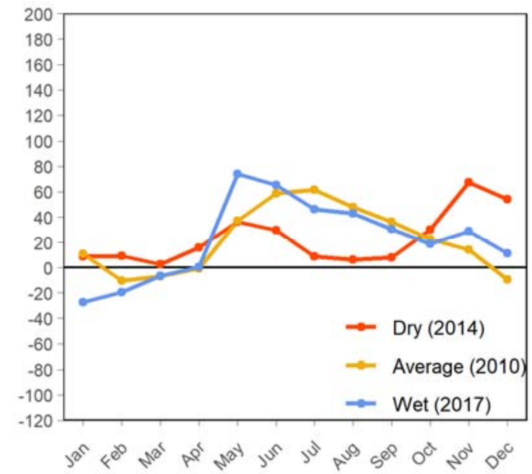
How to read and interpret graphs of scenario results

All flows and flow changes plotted are for the Fort Jones Gauge location

Flow Change Results

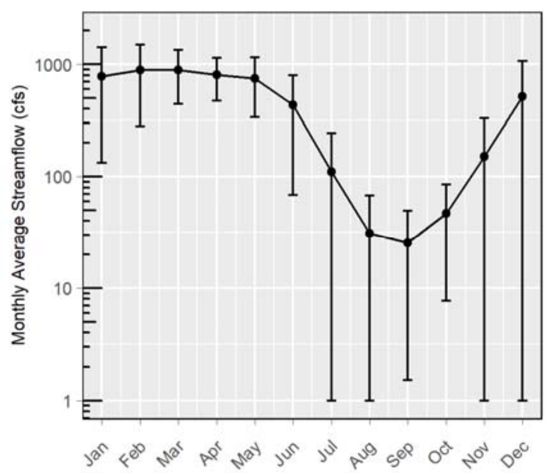
Change in flow, scenario minus basecase - 28 years, averaged monthly

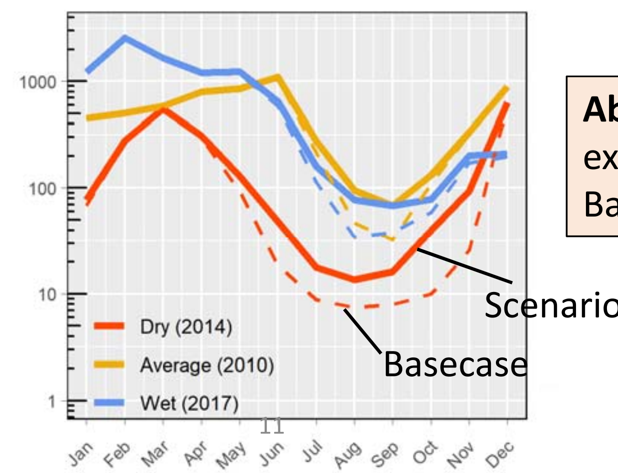




Change in flow, scenario minus basecase – 3 example years

Absolute flow value (simulated historical basecase) – 28 years, averaged monthly



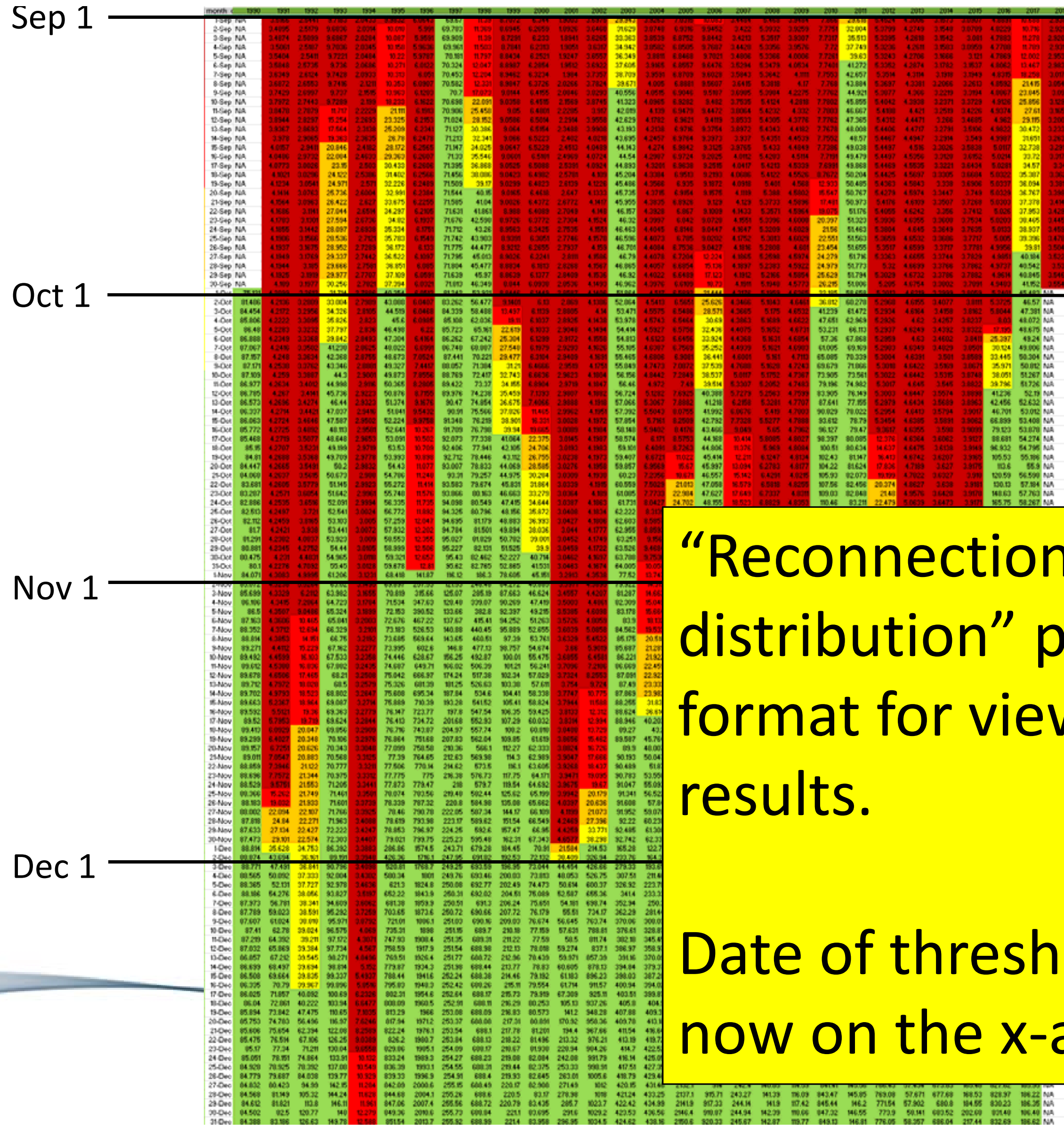


Absolute flow value – 3 example years, Basecase and Scenario

Threshold-passing or “reconnection” date distribution graphs

Basecase

(Simulated historical period)



“Reconnection date distribution” plots are a new format for viewing these results.

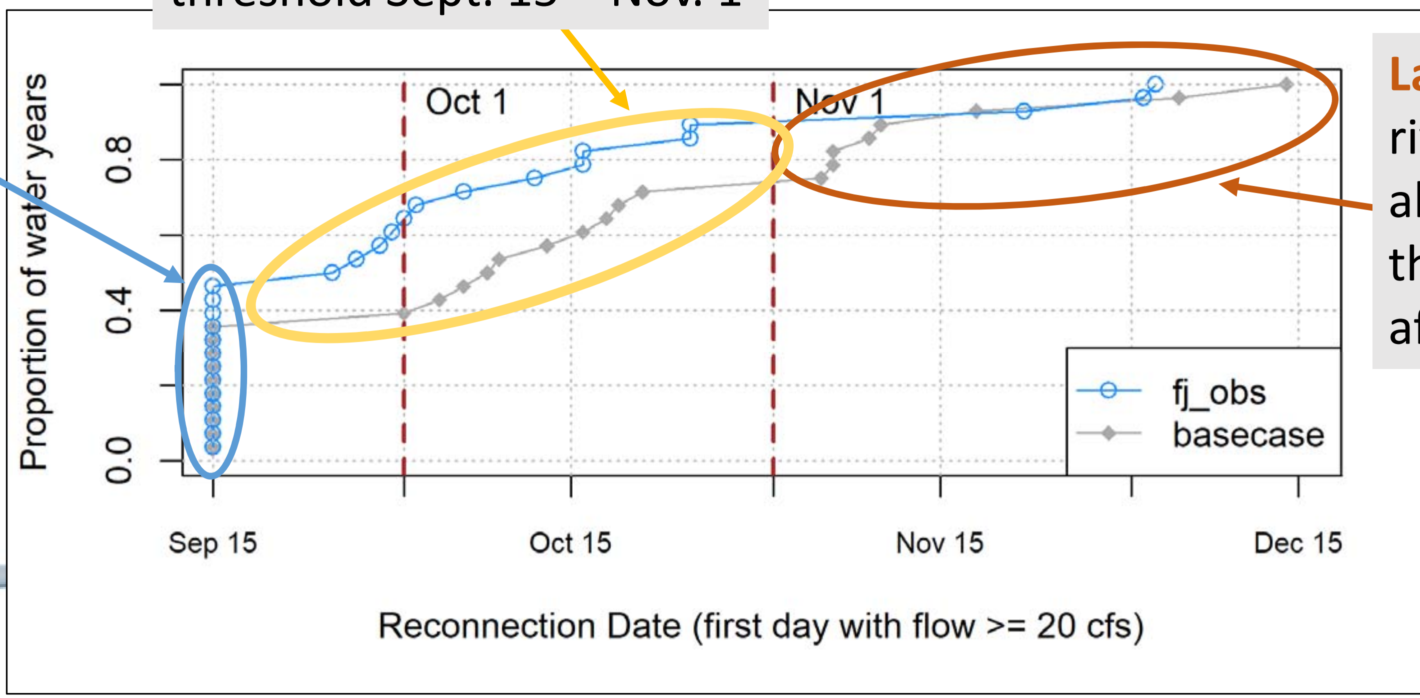
Date of threshold-passing is now on the x-axis.

Below 10 cfs
10-20 cfs
20-30 cfs
30-40 cfs
Above 40 cfs

Threshold-passing or "reconnection" date distribution graphs

Intermediate years – river flow rose above the threshold Sept. 15 – Nov. 1

Early years – river passed this threshold on or before Sept. 15, or never fell below it

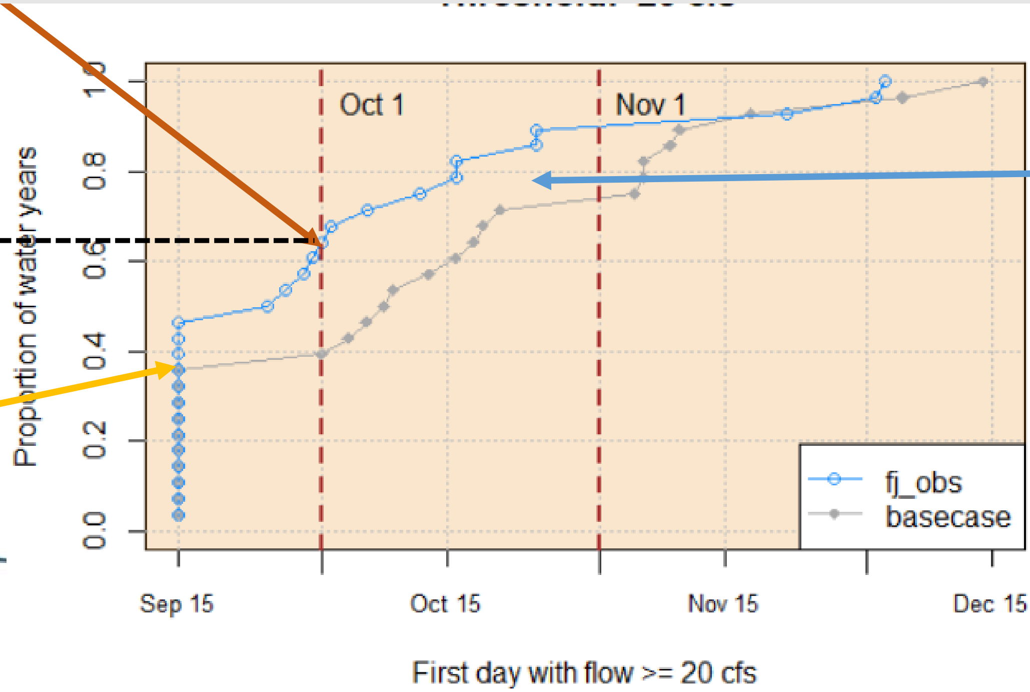


Late years – river flow rose above the threshold after Nov 1

Threshold-passing or "reconnection" date distribution graphs

How to read this graph: From 1991-2018, the FJ gauge measured flow >20 cfs **on or before Oct. 1** in ~**63%** of years.

Y-intercept of ~0.63, or ~63%

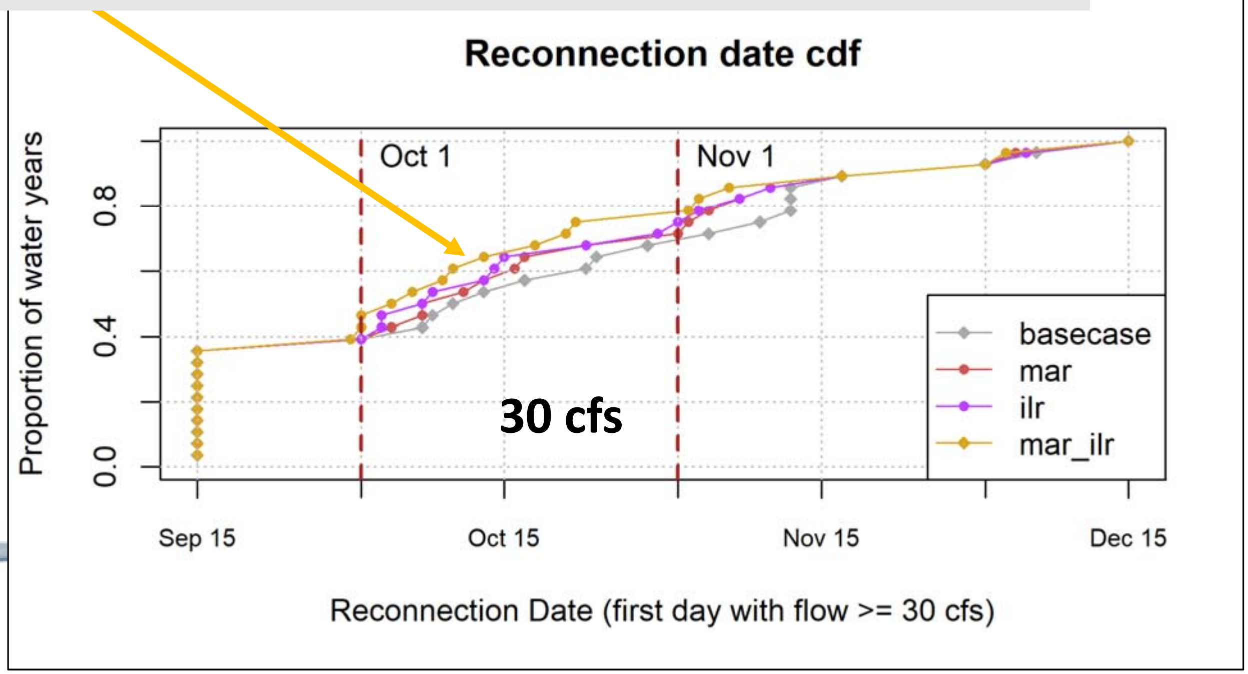


Notes on model performance: The basecase simulates 10 years with flow >20 cfs before Sept 15, or not dropping below 20 cfs at all **(early years)**; in the observed record it's 13 years.

Notes on model performance: The discrepancies between the observed and simulated basecase distributions are another reason to think of scenario results as "relative change" rather than a prediction of future conditions.

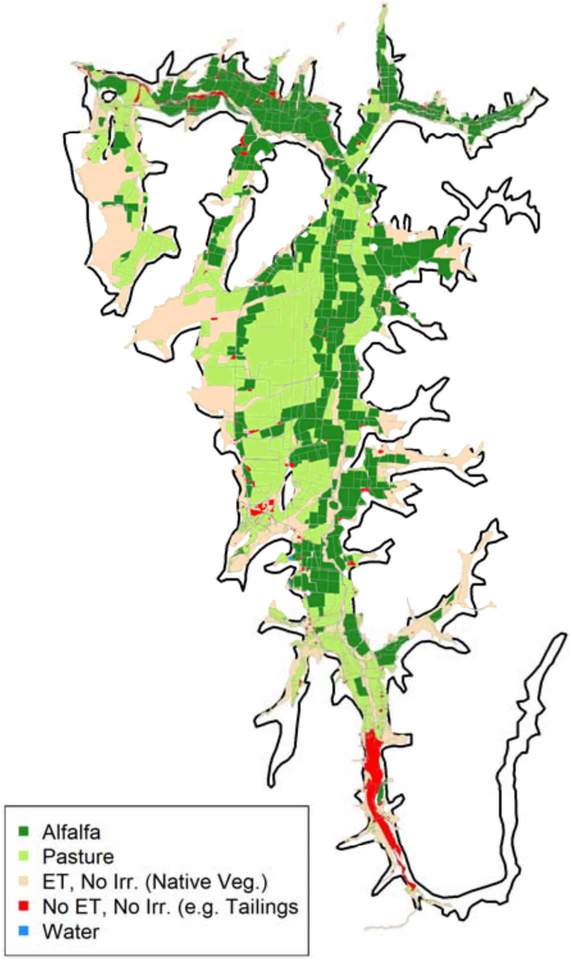
Threshold-passing or “reconnection” date distribution graphs

MAR+ILR: Generates a gain of ~7 days in higher-flow dais intermediate and some late years

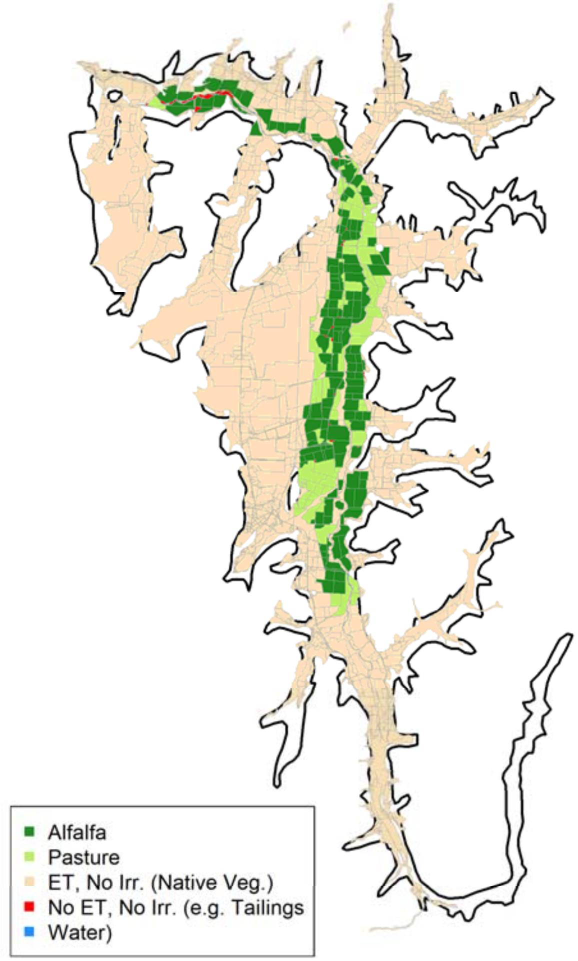


Scenario descriptions and visual references

Land Use / Crop Type: Basecase

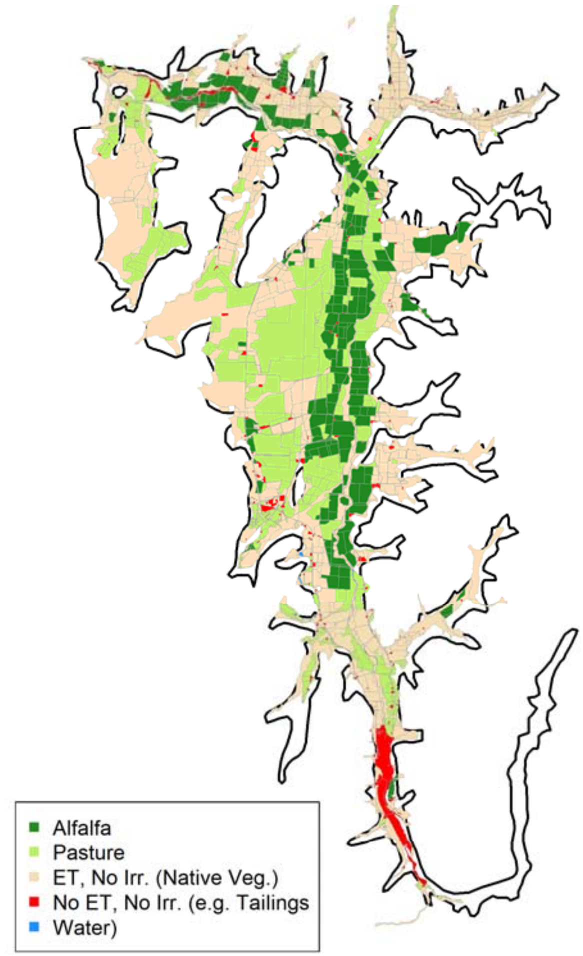


Native Vegetation Outside Adjudication



"NVOA"

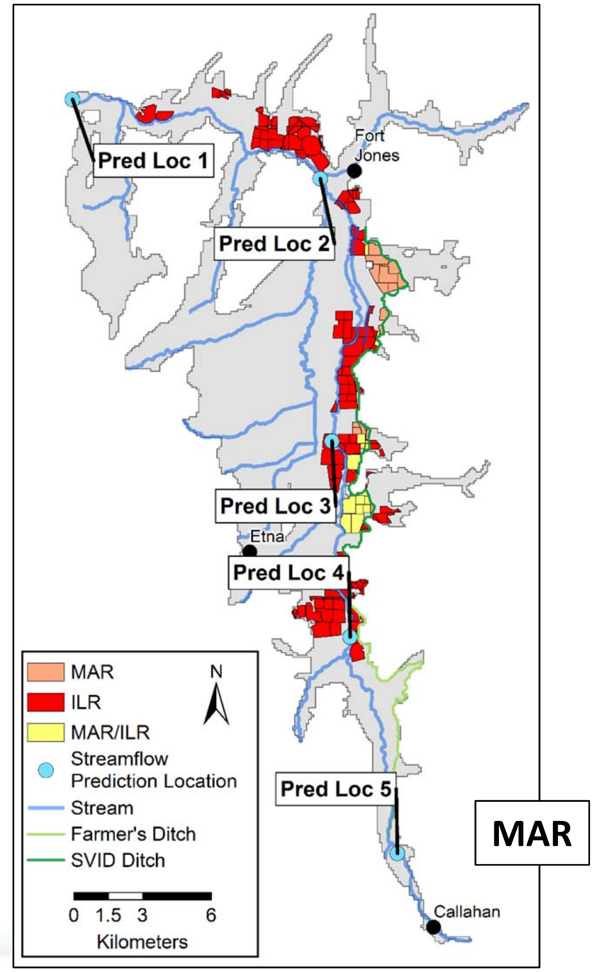
Native Vegetation on *GW and Mixed Water Source Fields* Outside Adjudication



"NV-GWM-OA"

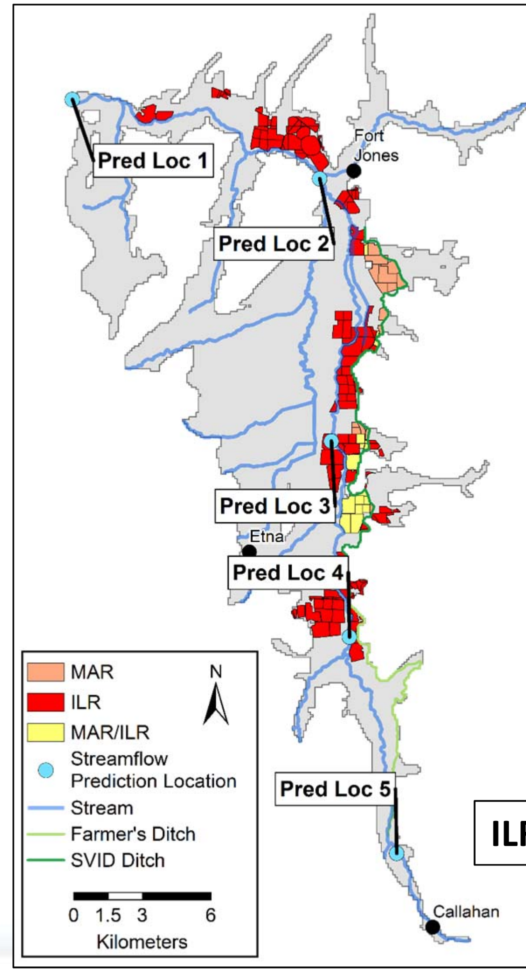
MAR (Managed Aquifer Recharge)

- 1,390 acres
- Surface water applied to orange and yellow fields, Jan-Mar.
- Water delivered through SVID Ditch



ILR (In-Lieu Recharge)

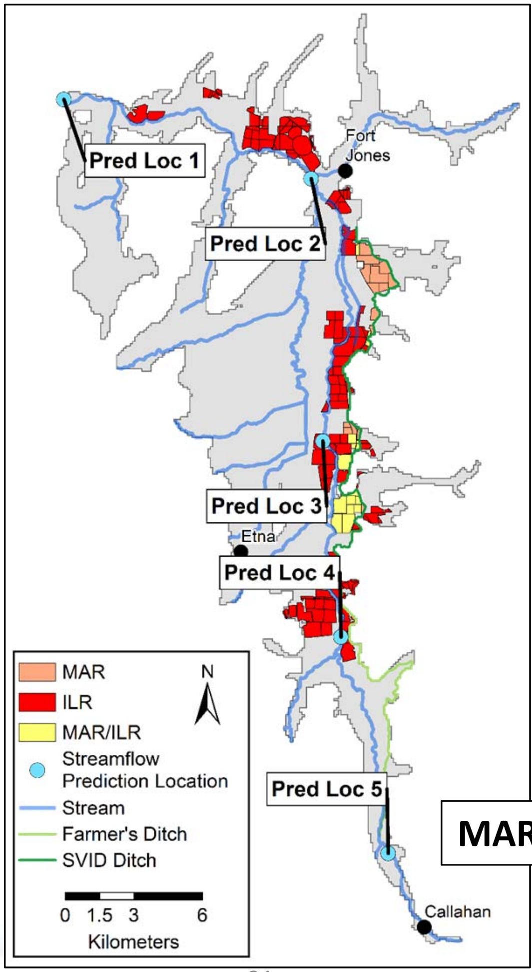
- 5,490 acres
- Operator applies surface water to yellow and red fields instead of pumping groundwater in the early growing season, as long as surface water is available.
- Water delivered through SVID Ditch



ILR

MAR+ILR

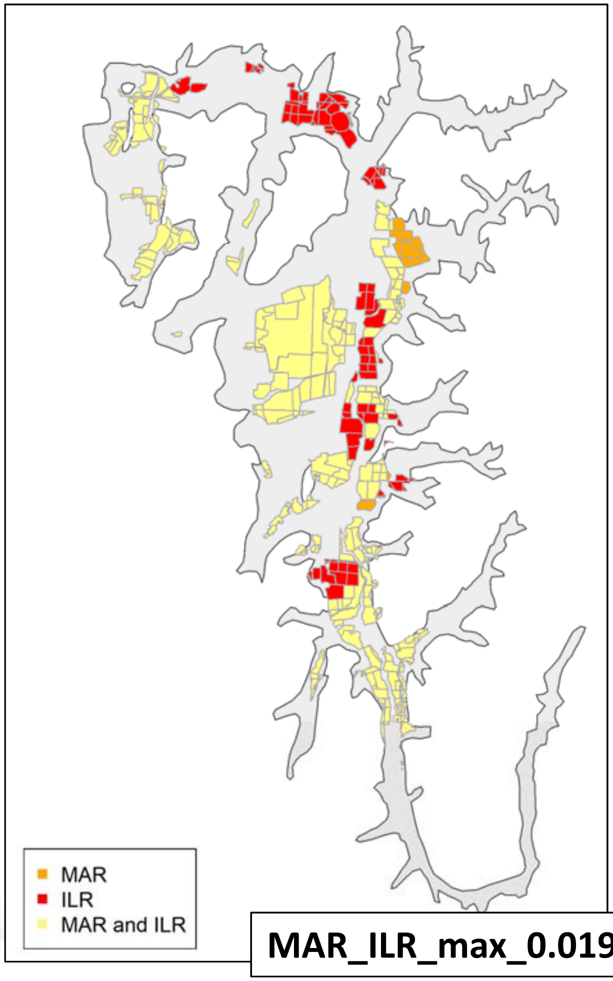
- 6,250 combined acres
- Both MAR (January-March) and ILR (early growing season) practices used.



MAR_ILR

MAR+ILR expanded, 0.019 m/day, diversion limits on MAR

- 16,450 combined acres
- In this expanded scenario, MAR and ILR irrigation practices were assumed to be practicable on all fields with a surface water irrigation source.
  - MAR surface water diversions limited on days with FJ flow near or below the CDFW recommended instream flows.
  - Current known range of infiltration capacities is 0.003-0.035 m/day. In fields with unknown infiltration capacities, 0.019 m/day infiltration rate is assumed.

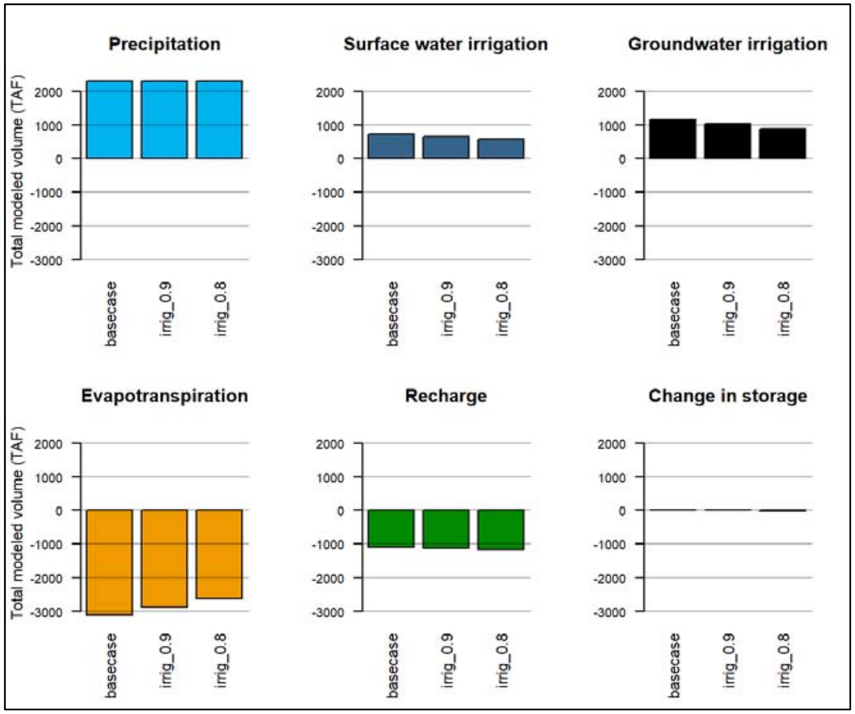


MAR_ILR_max_0.019

Irrigation demand change

- Two scenarios in which an unspecified crop change results in:
  - 90%
  - 80%

of the historical irrigation demand on all cultivated acres (a 10% or 20 reduction in ET on irrigated fields).



irrig_0.8
irrig_0.9

Irrigation efficiency scenarios

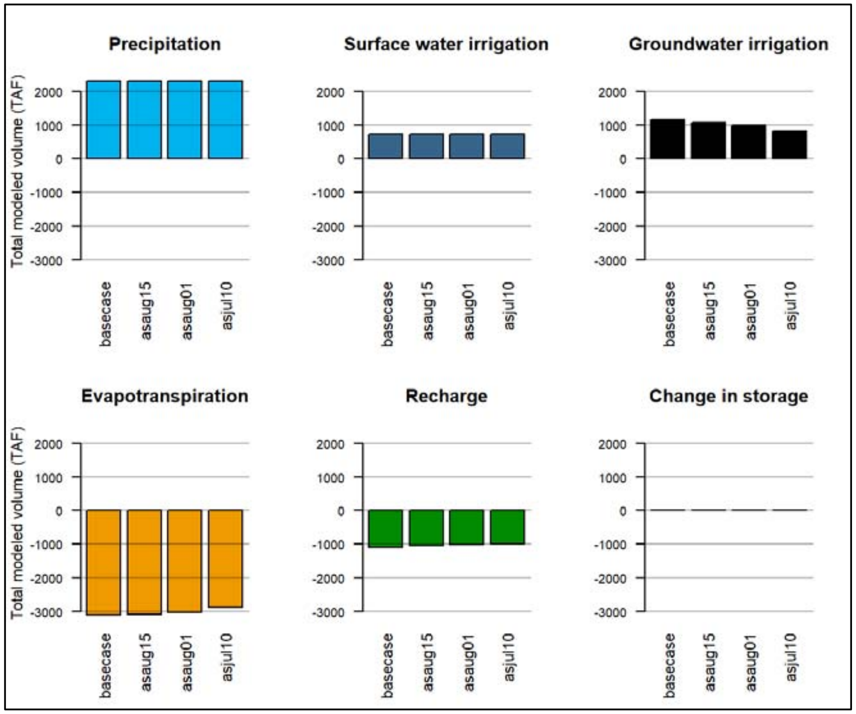
- Three scenarios:
  - Improve by 10%
  - Improve by 20%
  - Reduced (worsen) by 10%

- These scenarios assume an unspecified change in irrigation equipment that results in either an increase or decrease in irrigation efficiency on all irrigated fields.

irr_eff_improve_0.1
irr_eff_improve_0.2
irr_eff_worse_0.1

Alfalfa irrigation schedule change

- Three scenarios, in which irrigation on all alfalfa fields ceases, in all water years, on:
  - July 10
  - August 1
  - August 15
- Would presumably involve an incentive or compensation program (a back-of-the-envelope estimate of the value of the 3rd cutting of alfalfa is approximately $7.5 million).



alf_irr_stop_jul10
alf_irr_stop_aug01
alf_irr_stop_aug15

Alfalfa irrigation schedule change, dry years only

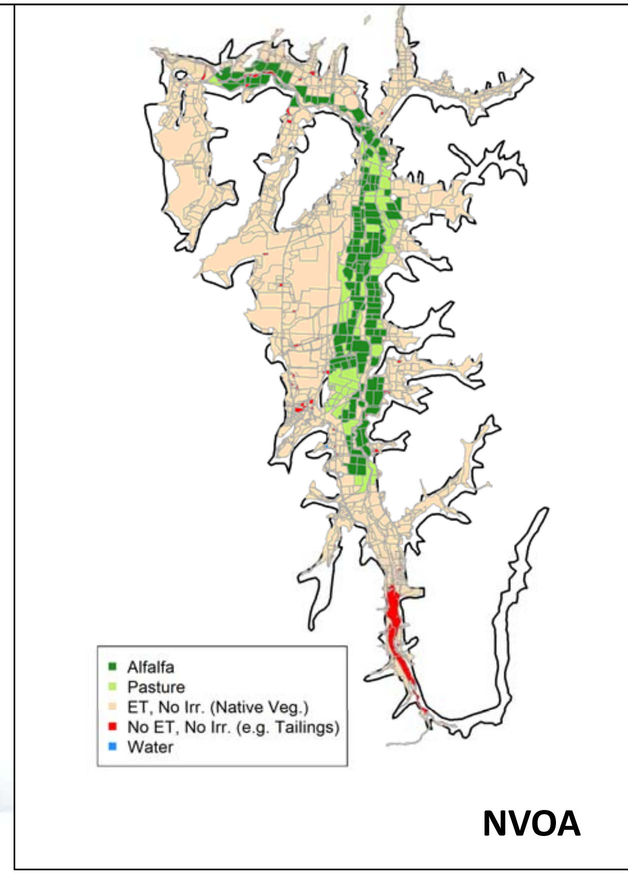
- Two scenarios, in which irrigation on all alfalfa fields ceases, in dry water years only, on:
  - August 1
  - August 15
  - Dry water years in this simulation: ’91, ’92, ’94, ’01, ’09, ’13, ’14, ’18.
- Would presumably involve an incentive or compensation program (a back-of-the-envelope estimate of the value of the 3rd cutting of alfalfa is approximately $7.5 million).

alf_irr_stop_aug01_dry_yrs_only
alf_irr_stop_aug15_dry_yrs_only

Turn off *all irrigation* outside adjudicated area

- 23,070 acres of cultivated crops converted to native vegetation.

Native Vegetation on All Fields Outside Adjudication

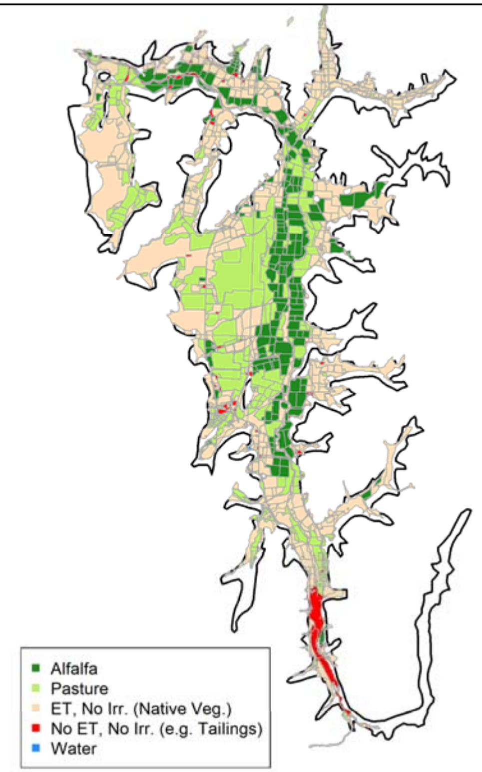


Used as no-pumping reference case in SMC definition

Turn off *pumping* outside adjudicated area

- 11,630 acres of cultivated crops converted to native vegetation.

Native Vegetation on *GW and Mixed Water Source Fields* Outside Adjudication

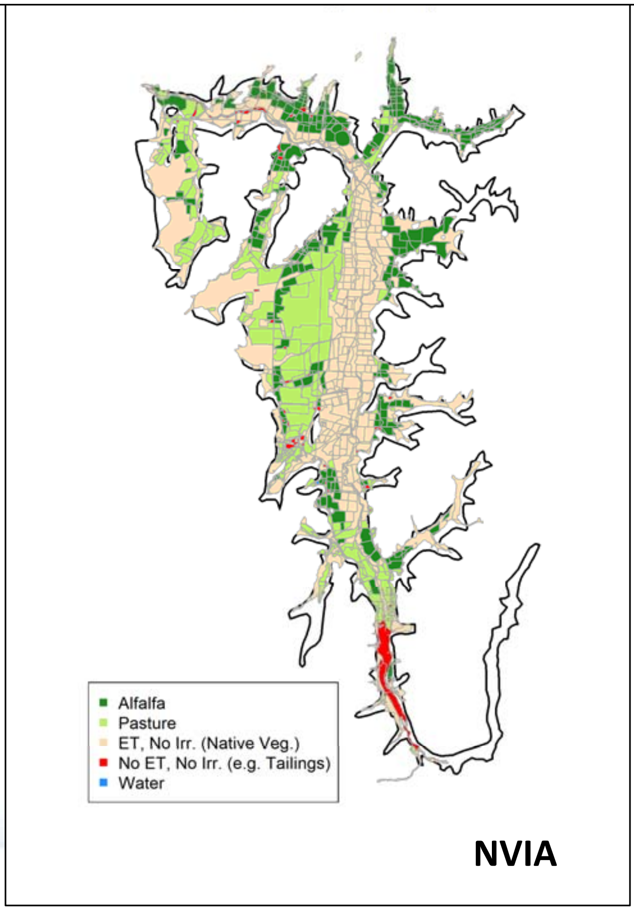


NV-GWM-OA

Turn off *all irrigation* **inside** adjudicated area

- 10,980 acres of cultivated crops converted to native vegetation.

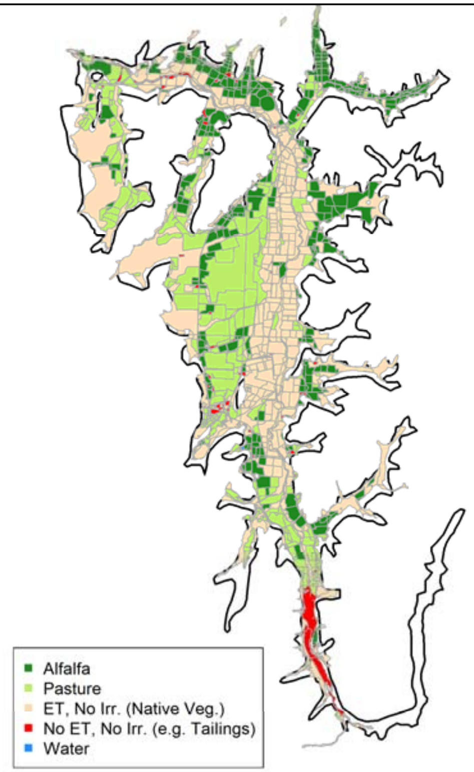
Native Vegetation Inside Adjudication



Turn off *pumping* **inside** adjudicated area

- 9,900 acres of cultivated crops converted to native vegetation.

Native Vegetation on *GW and Mixed Water Source Fields* Inside Adjudication

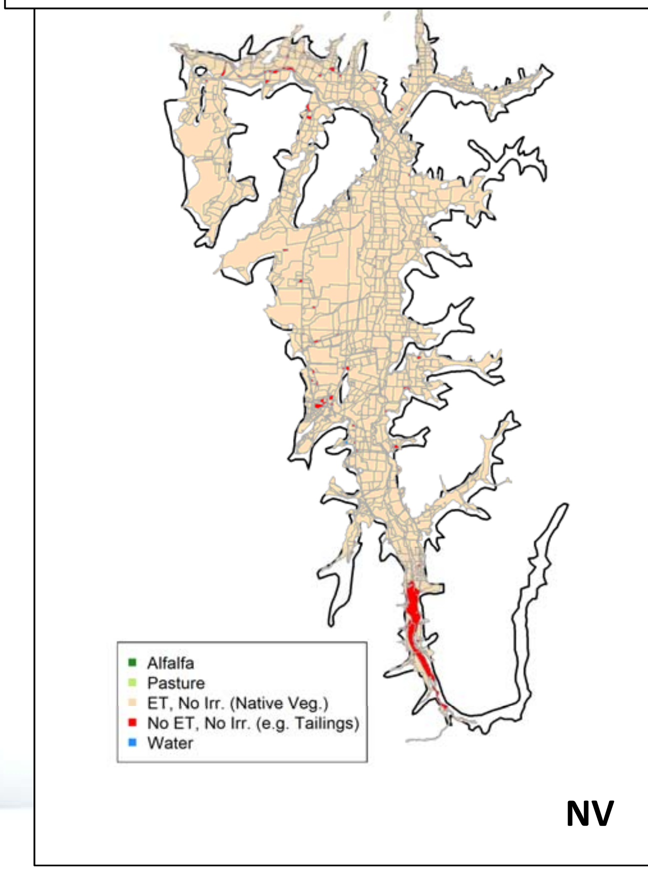


NV-GWM-IA

Turn off *all irrigation* in Scott Valley

- 34,040 acres of cultivated crops converted to native vegetation.

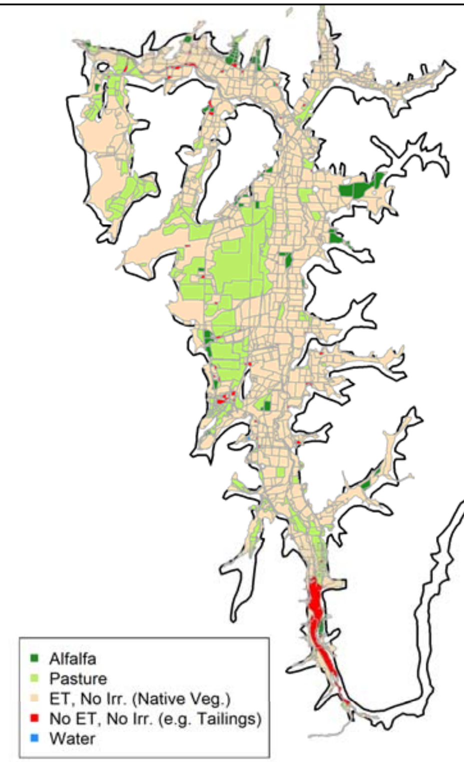
Native Vegetation on all non-urban fields/parcels



Turn off *all pumping* in Scott Valley

- 21,530 acres of cultivated crops converted to native vegetation.

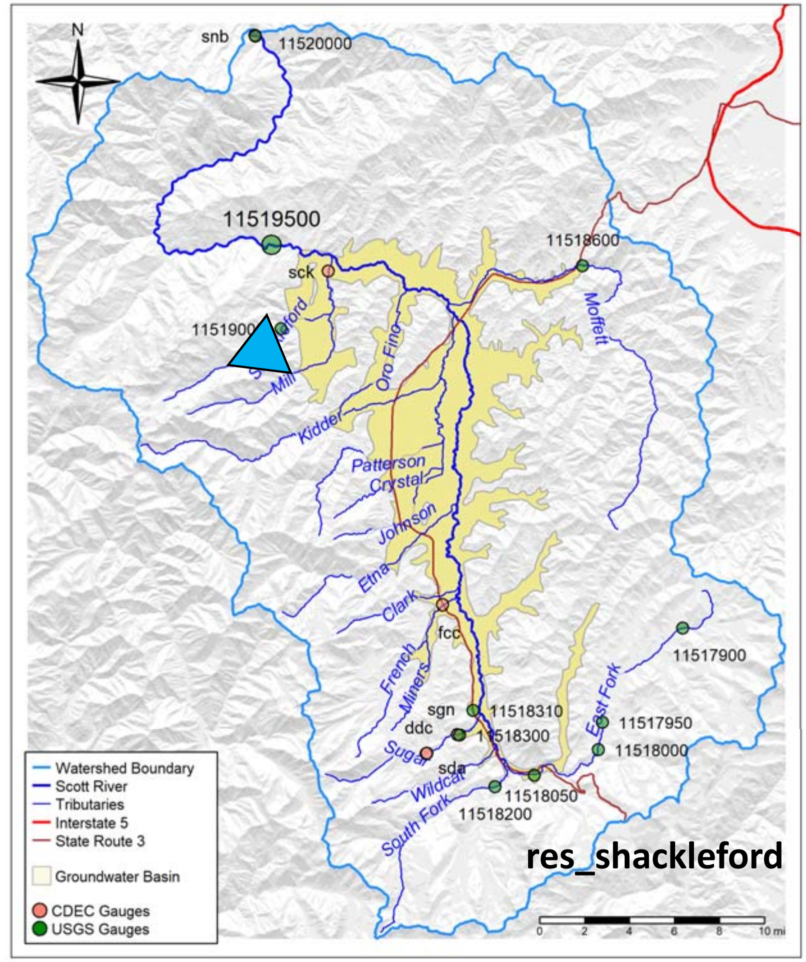
Native Vegetation on all *GW and Mixed Water Source Fields*



NV-GWM

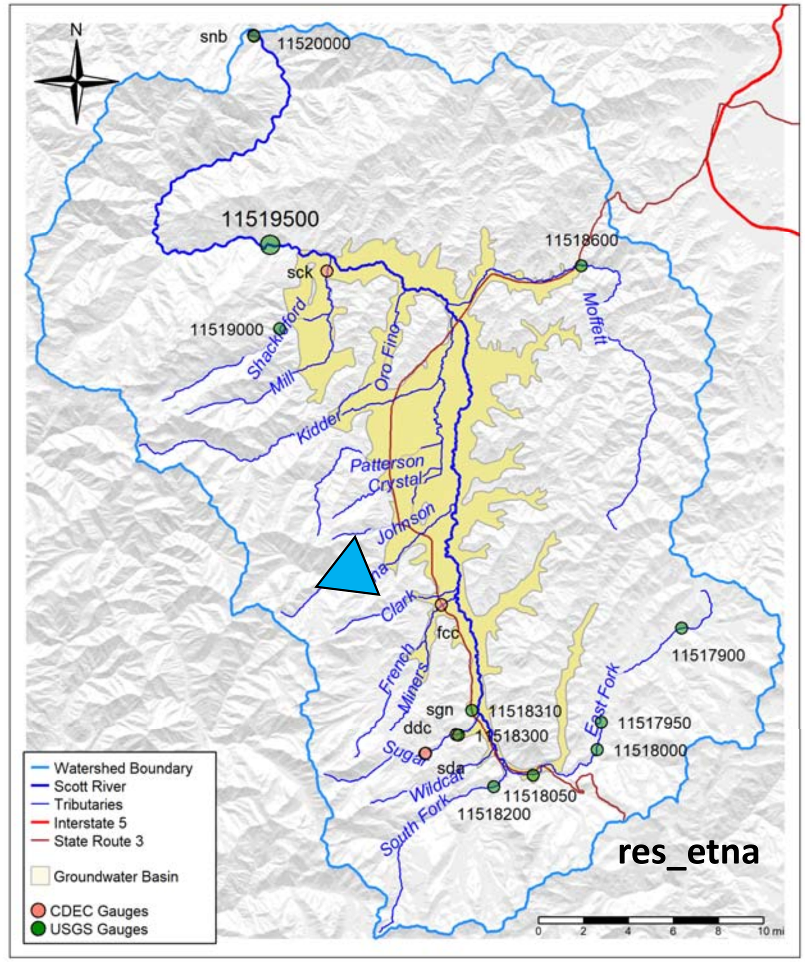
Reservoir, 30 cfs dry season release, Shackleford

- Alters the flow of Shackleford creek to simulate a 9 TAF reservoir storing and releasing flow.
- Holds all water except 30 cfs back in the wet season (Dec. 1-Mar. 31), until the reservoir is full.
- Allows water to pass through during the growing season (Apr. 1-June 31), but retains water in storage.
- Releases 30 cfs in the dry season (July 1-Nov. 30), unless the reservoir runs dry.



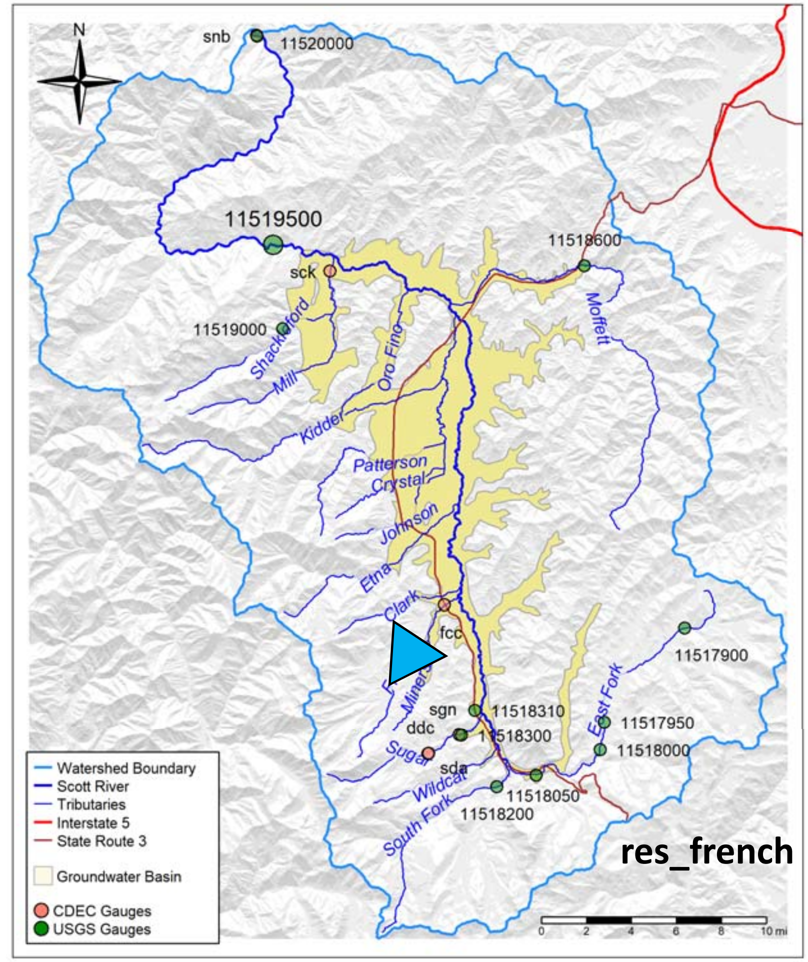
Reservoir, 30 cfs dry season release, Etna Creek

- Alters the flow of Etna creek to simulate a 9 TAF reservoir storing and releasing flow.
- Holds all water except 30 cfs back in the wet season (Dec. 1-Mar. 31), until the reservoir is full.
- Allows water to pass through during the growing season (Apr. 1-June 31), but retains water in storage.
- Releases 30 cfs in the dry season (July 1-Nov. 30), unless the reservoir runs dry.



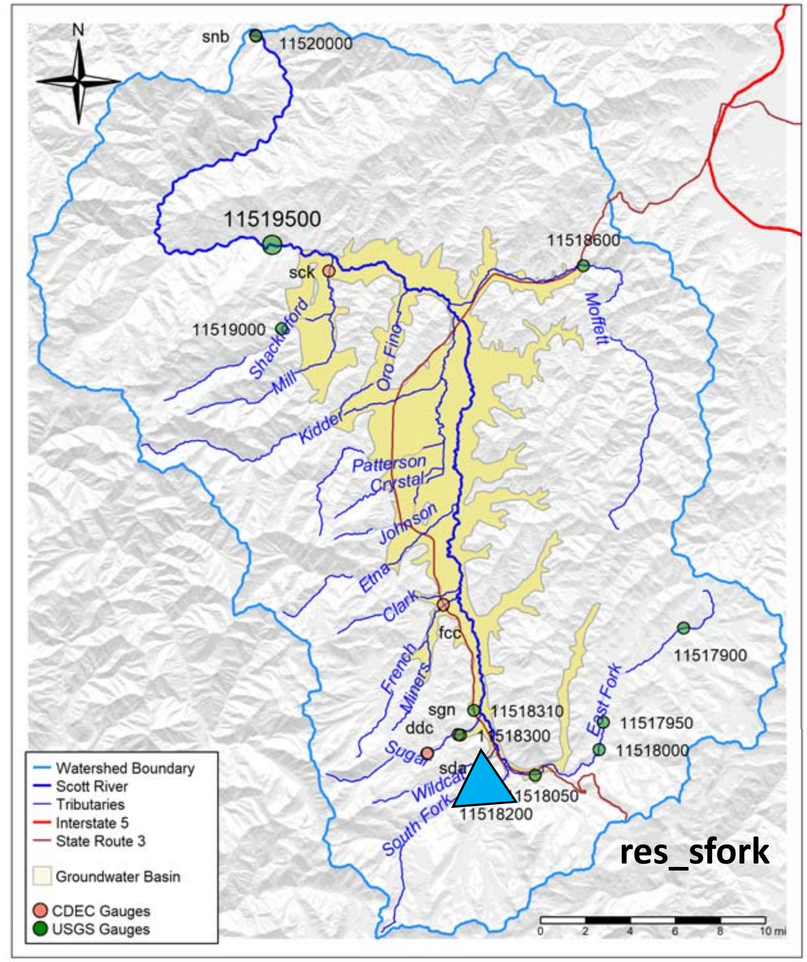
Reservoir, 30 cfs dry season release, French Creek

- Alters the flow of French creek to simulate a 9 TAF reservoir storing and releasing flow.
- Holds all water except 30 cfs back in the wet season (Dec. 1-Mar. 31), until the reservoir is full.
- Allows water to pass through during the growing season (Apr. 1-June 31), but retains water in storage.
- Releases 30 cfs in the dry season (July 1-Nov. 30), unless the reservoir runs dry.



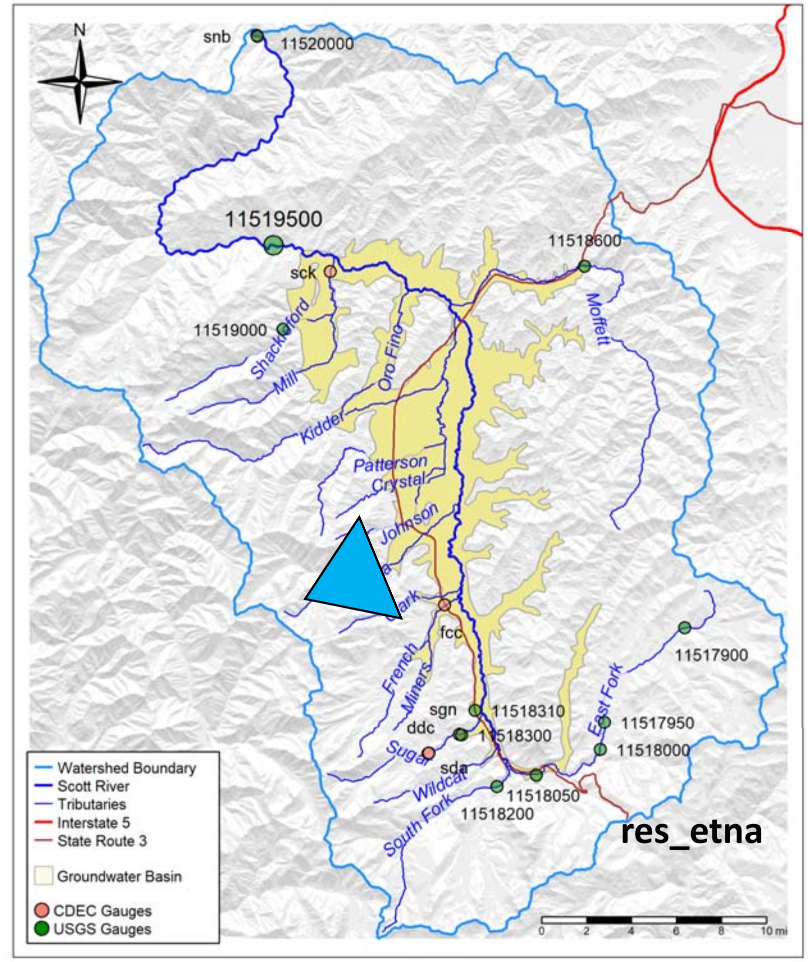
Reservoir, 30 cfs dry season release, South Fork

- Alters the flow of South Fork to simulate a 9 TAF reservoir storing and releasing flow.
- Holds all water except 30 cfs back in the wet season (Dec. 1-Mar. 31), until the reservoir is full.
- Allows water to pass through during the growing season (Apr. 1-June 31), but retains water in storage.
- Releases 30 cfs in the dry season (July 1-Nov. 30), unless the reservoir runs dry.



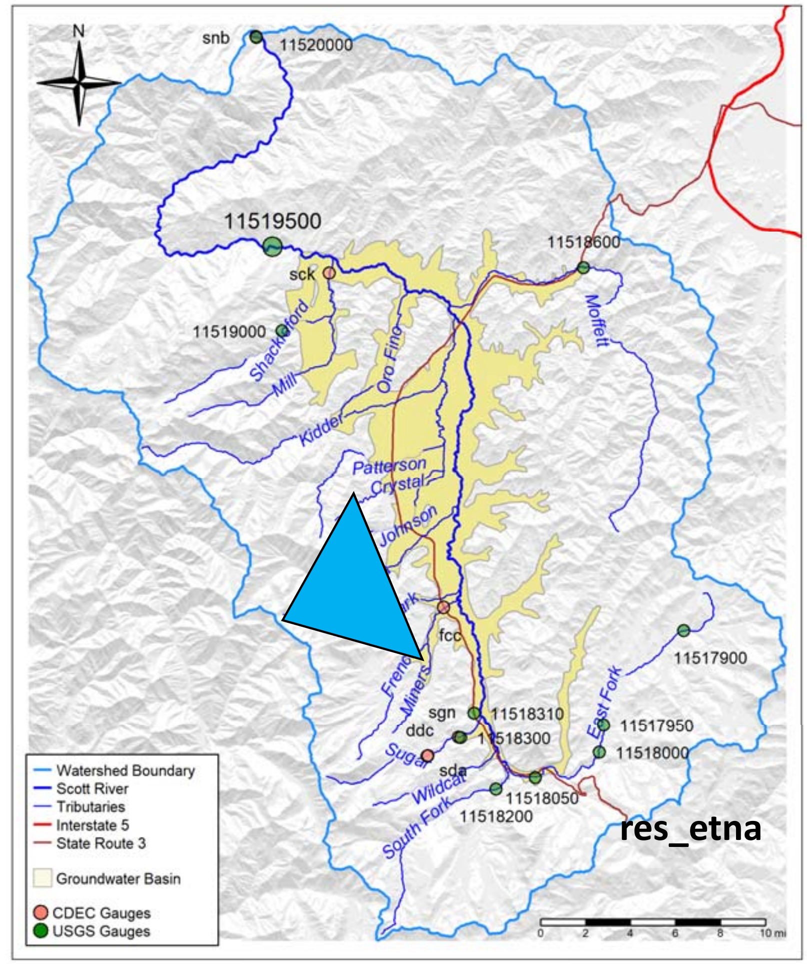
Large reservoir, 100% reliable 30 cfs dry season release, Etna Creek

- Alters the flow of Etna creek to simulate a 29 TAF reservoir storing and releasing flow.
- Holds all water except 30 cfs back in the wet season (Dec. 1-Mar. 31), until the reservoir is full.
- Allows water to pass through during the growing season (Apr. 1-June 31), but retains water in storage.
- Releases 30 cfs in every dry season (July 1-Nov. 30). This reservoir does not run dry during the 1991-2018 period.



Very large reservoir, 100% reliable 60 cfs dry season release, Etna Creek

- Alters the flow of Etna creek to simulate a 134 TAF reservoir storing and releasing flow.
- Holds all water except 30 cfs back in the wet season (Dec. 1-Mar. 31), until the reservoir is full.
- Allows water to pass through during the growing season (Apr. 1-June 31), but retains water in storage.
- Releases 60 cfs in every dry season (July 1-Nov. 30). This reservoir does not run dry during the 1991-2018 period.



Flow change results (Fort Jones Gauge)

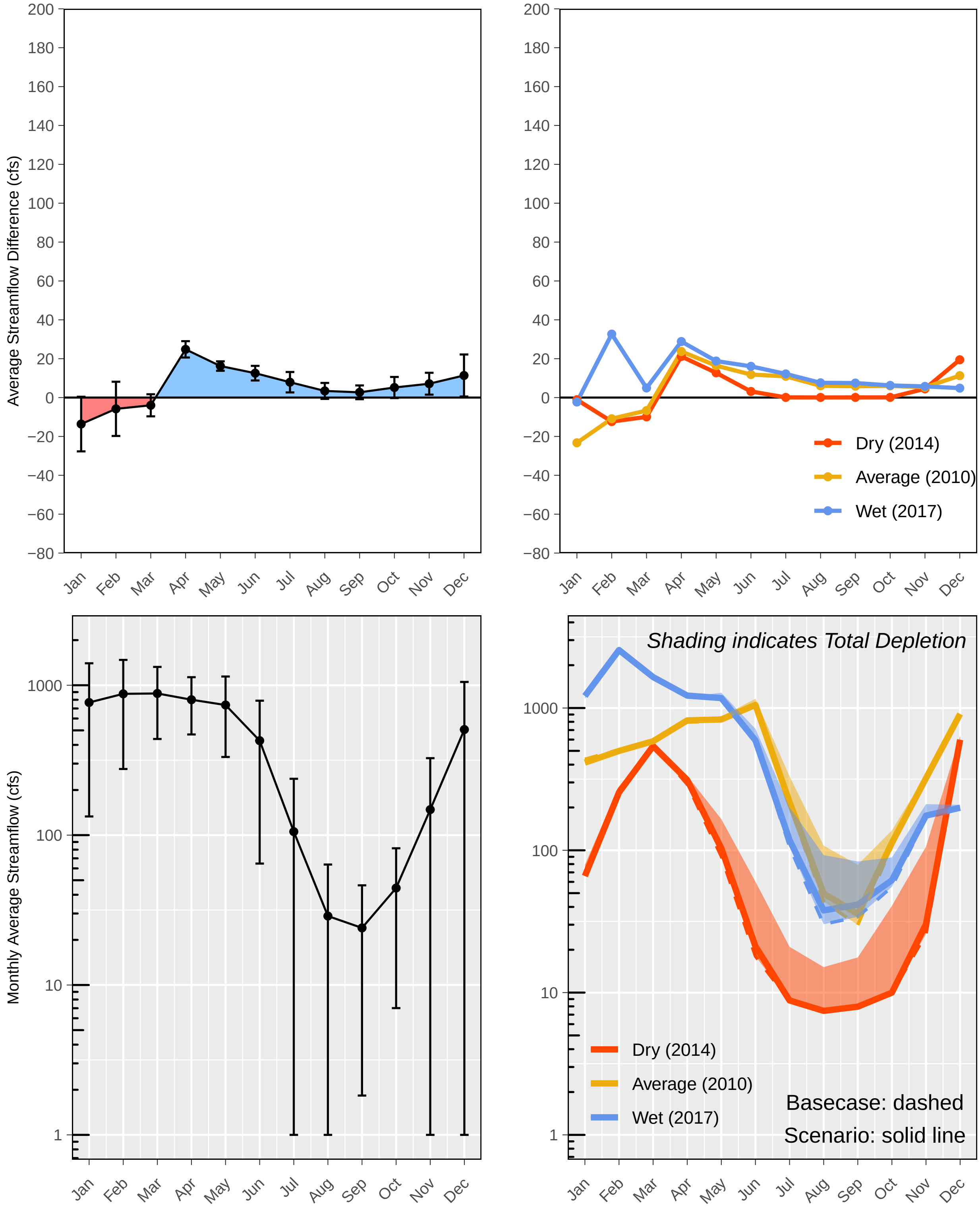
Changes in the simulated flow at the Fort Jones USGS flow gauge (number 11519500) are an indicator of the effect of a project or management action (PMA) on the Scott River stream system. Interpretation details are below; see explanatory plots at the beginning of this appendix for more information.

- Upper left plot: Black dots show the average change in flow (scenario minus basecase) in each month (e.g., all Januaries averaged over the 28-year model period). Whiskers indicate the standard deviation of flow values for each month. Blue areas show that on average, the scenario flow in those months is higher than the historical basecase, indicating that the project or management action would have increased flow in that month. Red areas indicate months with lower flow under the specified scenario.
- Upper right plot: Red, yellow and blue dots and lines indicate the monthly average change in flow in three example water years: 2014 (Dry), 2010 (Average), and 2017 (Wet). Some dots may be missing for some months - this indicates they are beyond the bounds of the figure axes. These example years are included to show deviations from average system behavior due to water year type and year-to-year variability.
- Lower left plot: Black dots show the monthly streamflow (averaged over the 28 year model period) in the historical basecase simulation. Whiskers show the standard deviation of those monthly flows. This is included for reference and is the same on every page of this appendix.
- Lower right plot: Dashed lines indicate the monthly hydrograph in the basecase (in dotted lines) and in the specified scenario (in solid lines) for the three example water years specified above. Shading has been added to each plot to indicate "Total Depletion" used to define the SMC.

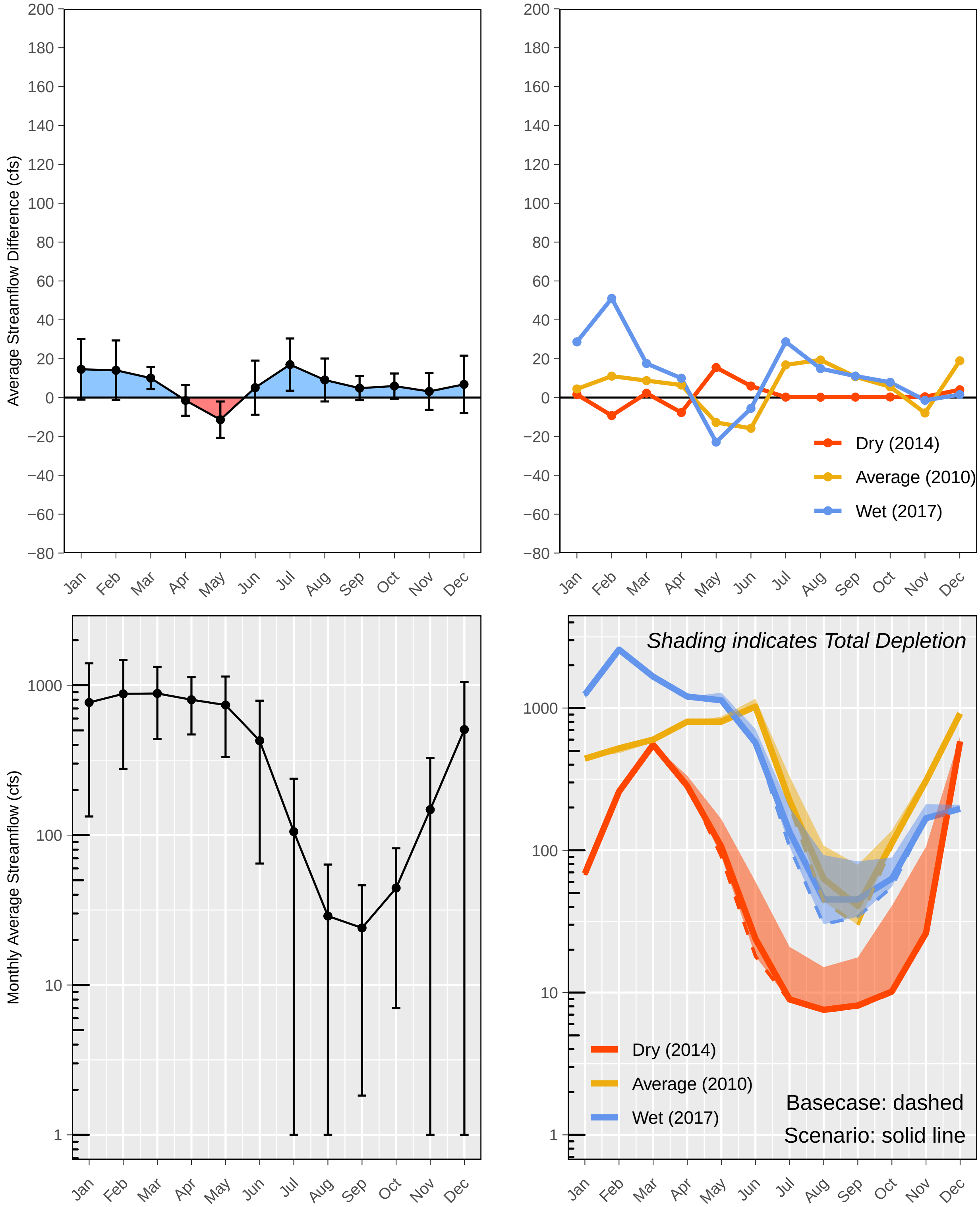
Total Depletion is defined as the difference in simulated Fort Jones flow between the basecase and the No-Pumping Reference Case, in which pumping is turned off outside the adjudicated zone and a reversion to natural vegetation is assumed on all fields serviced by groundwater or mixed groundwater-surface water sources. The No-Pumping Reference Case has also been referred to with these names: "No Pumping Outside Adjudicated Zone" or "Natural Vegetation, Groundwater and Mixed-source fields, Outside Adjudicated Zone [NV-GWM-OA]".

In all graphs, the Total Depletion is indicated by the shaded area. The top of the shaded area is the unmarked hydrograph for the No-Pumping Reference case. The bottom of the shaded area, marked by the dashed line, is the hydrograph of the Basecase. Hydrographs for the scenarios are shown with solid lines. The relative position of the solid line within the shaded area shows how much a PMA can increase streamflow (reverse stream depletion) relative to the Basecase (dashed line) and relative to the Total Depletion (shaded area).

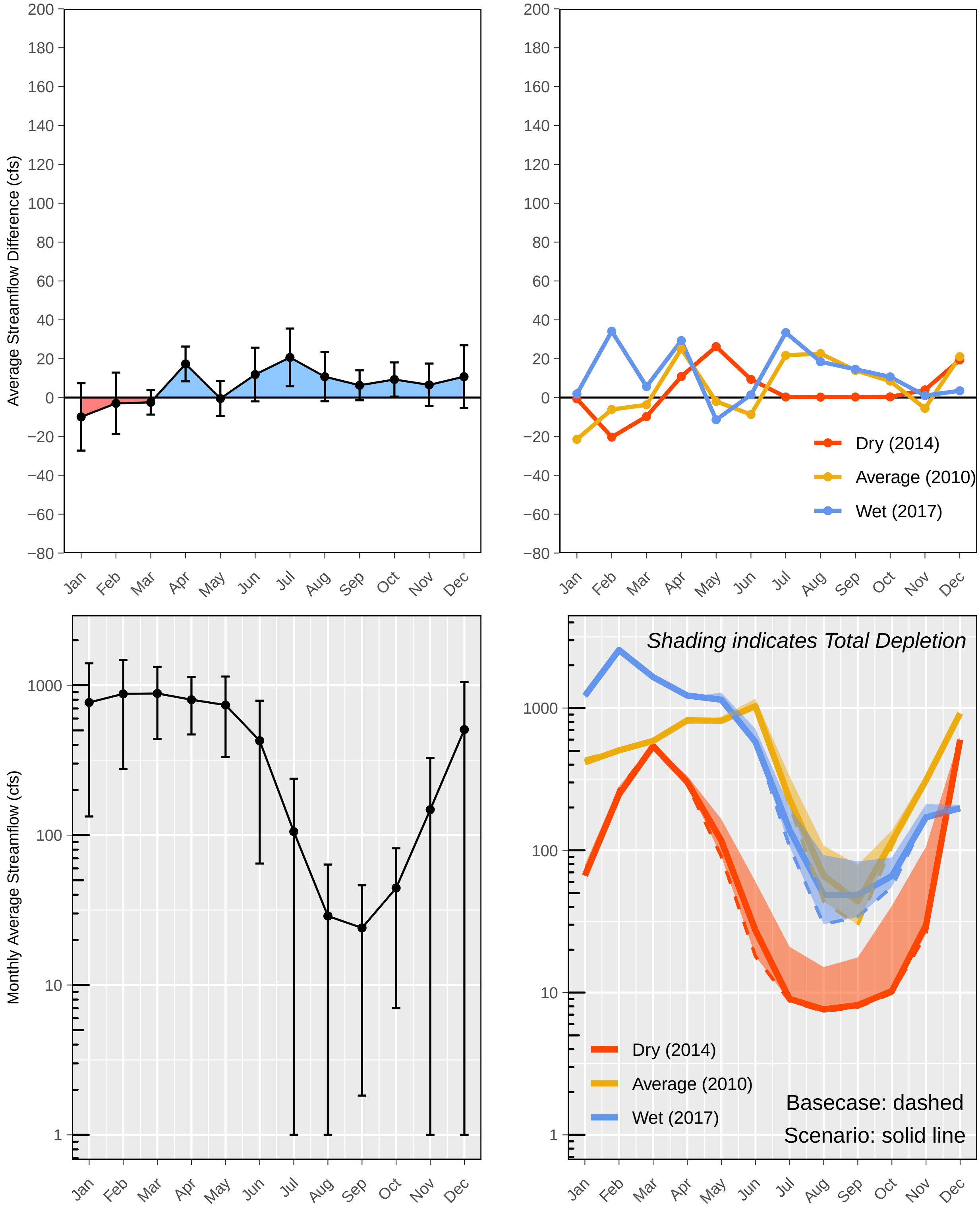
MAR (Managed Aquifer Recharge)



ILR (In−Lieu Recharge)

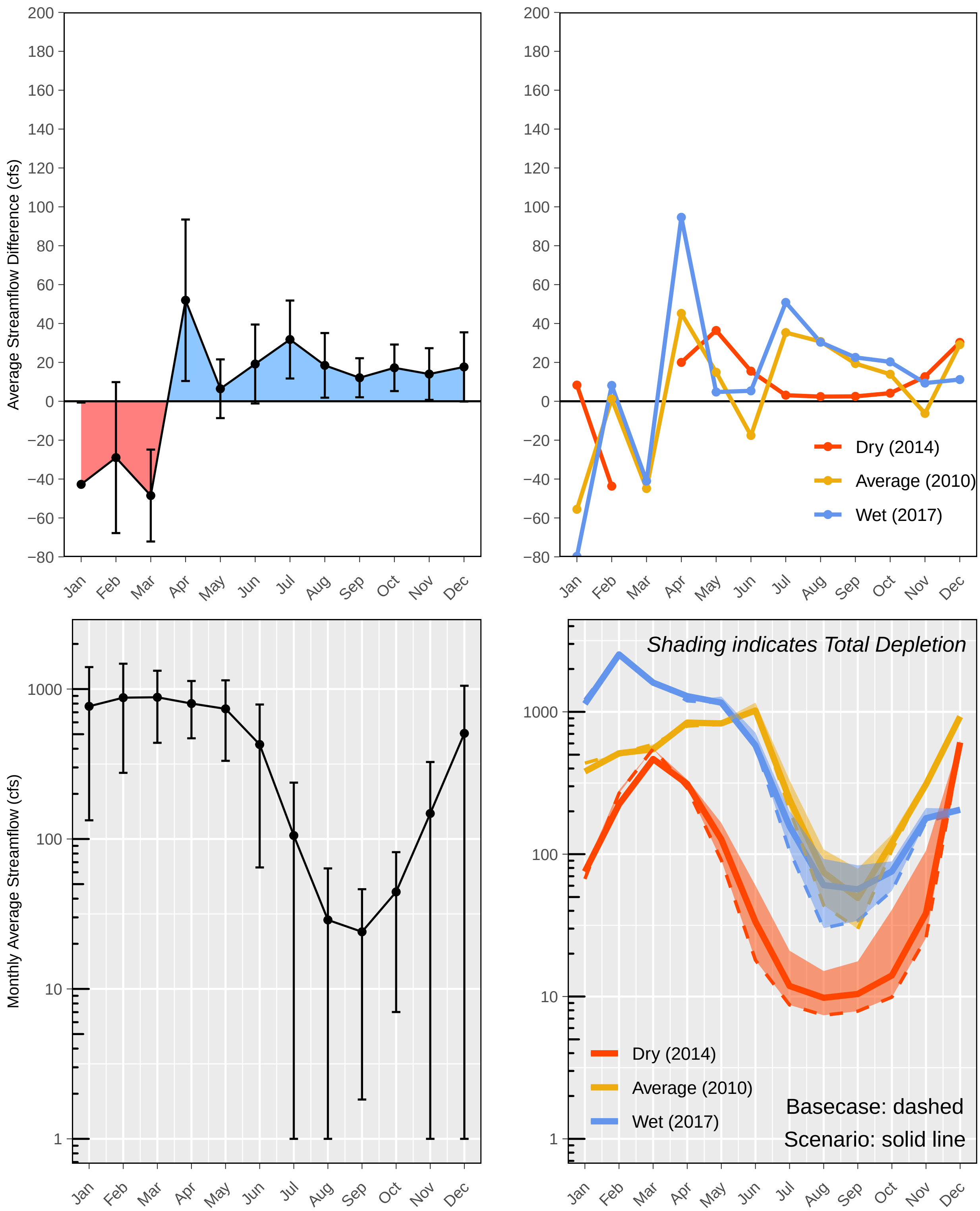


MAR and ILR

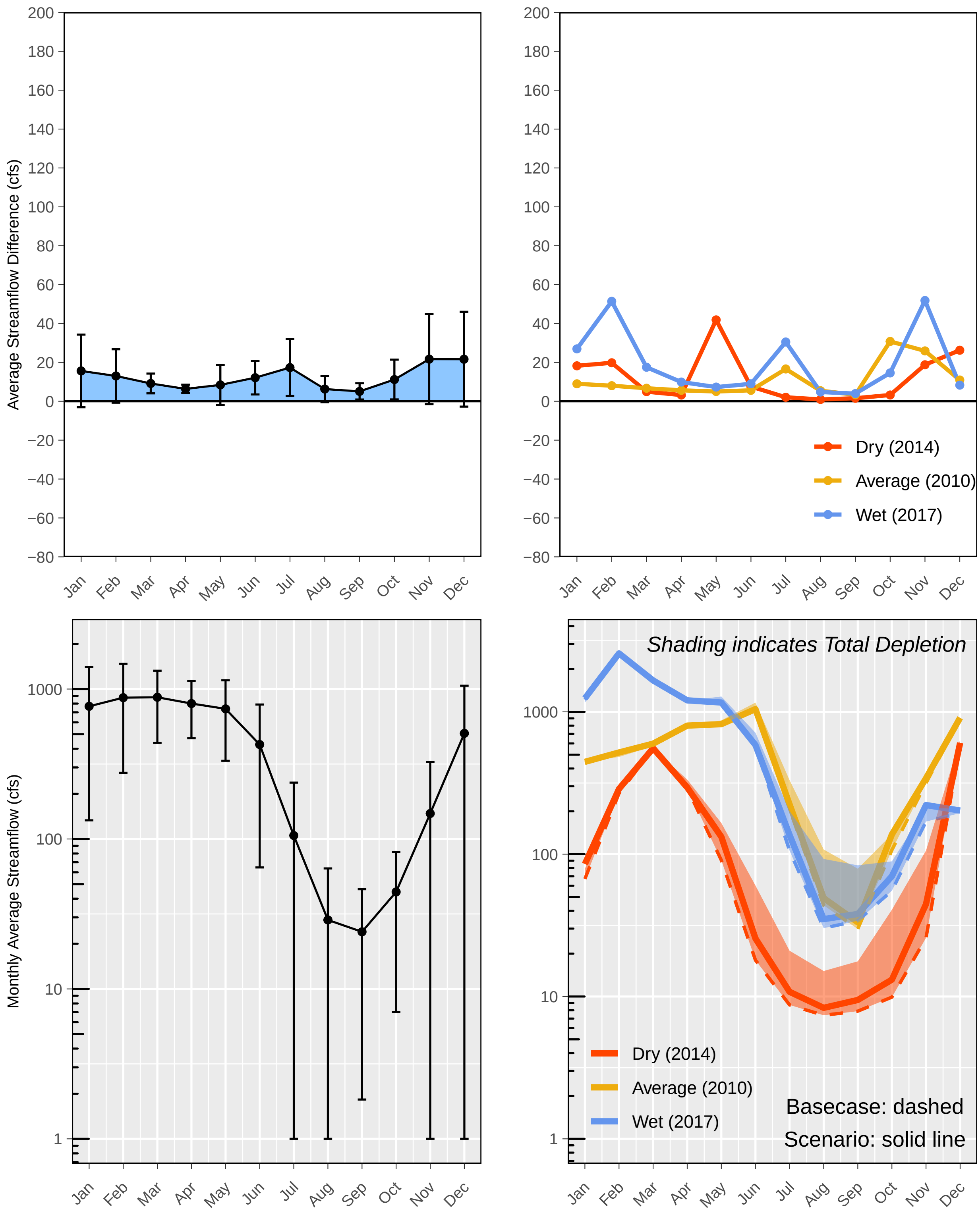


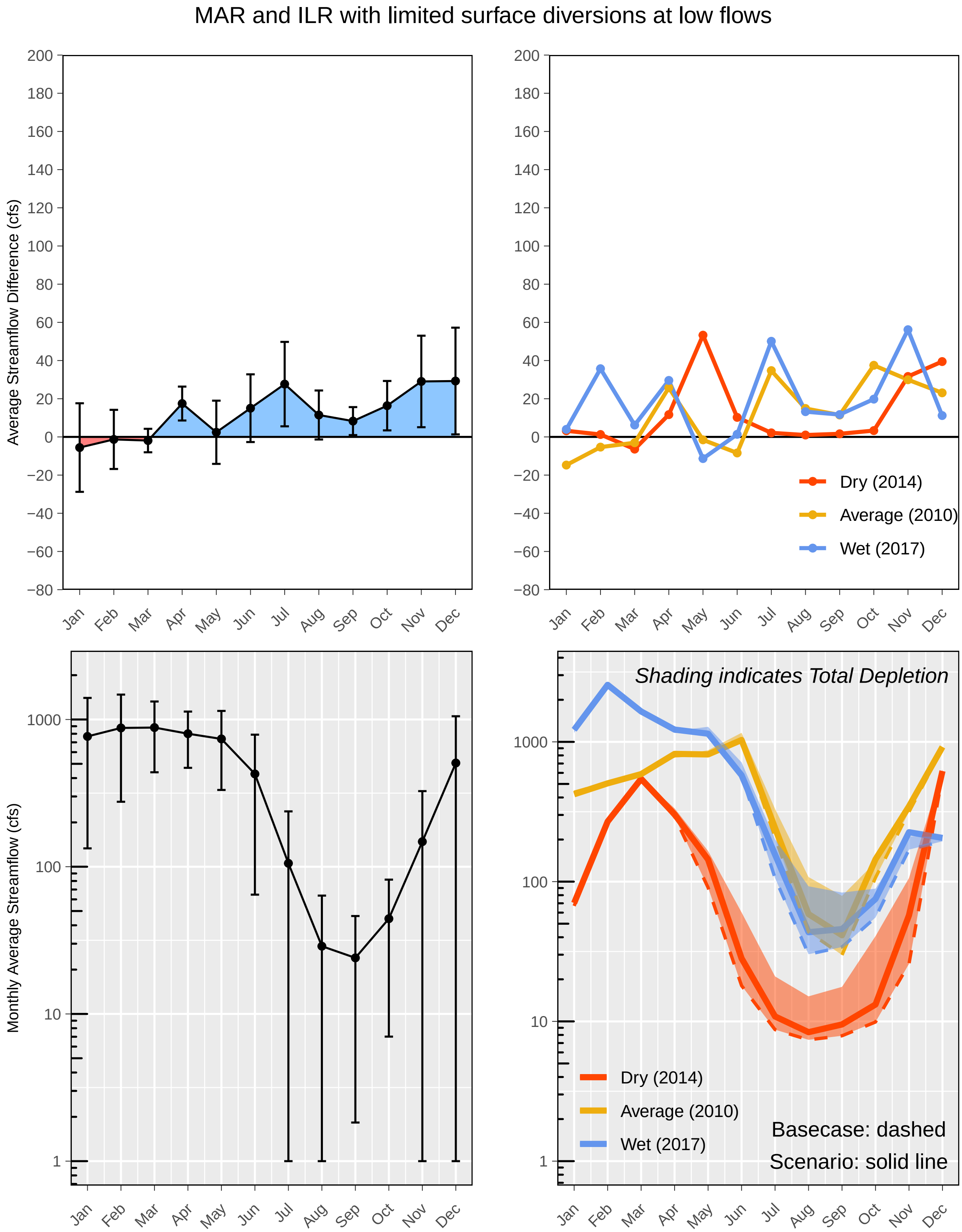
Average Streamflow Difference (cfs)
Monthly Average Streamflow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Dry (2014)
Average (2010)
Wet (2017)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line

Expanded MAR and ILR, assumed infiltration rate of 0.019 m/d

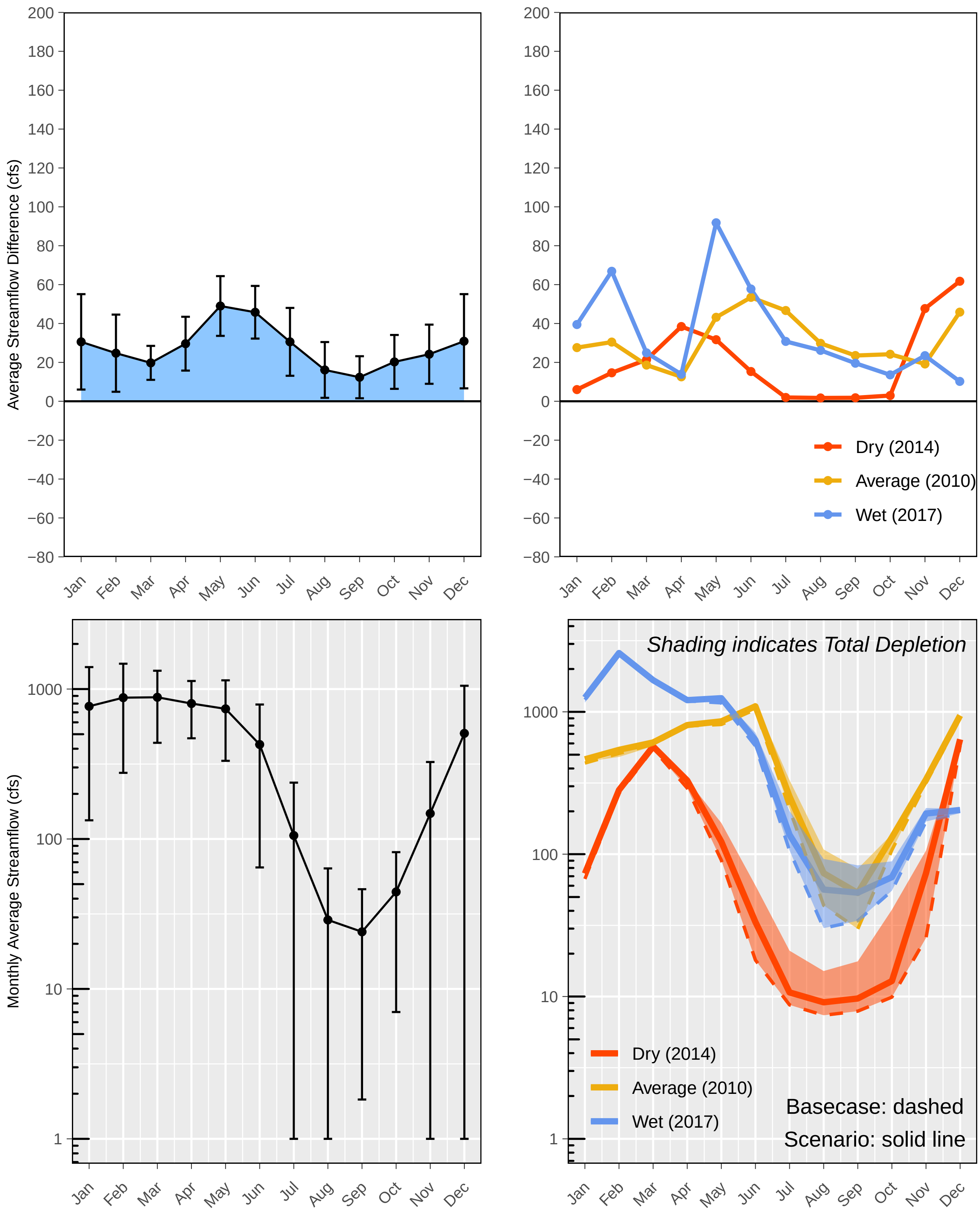


Limited surface diversions at low flows

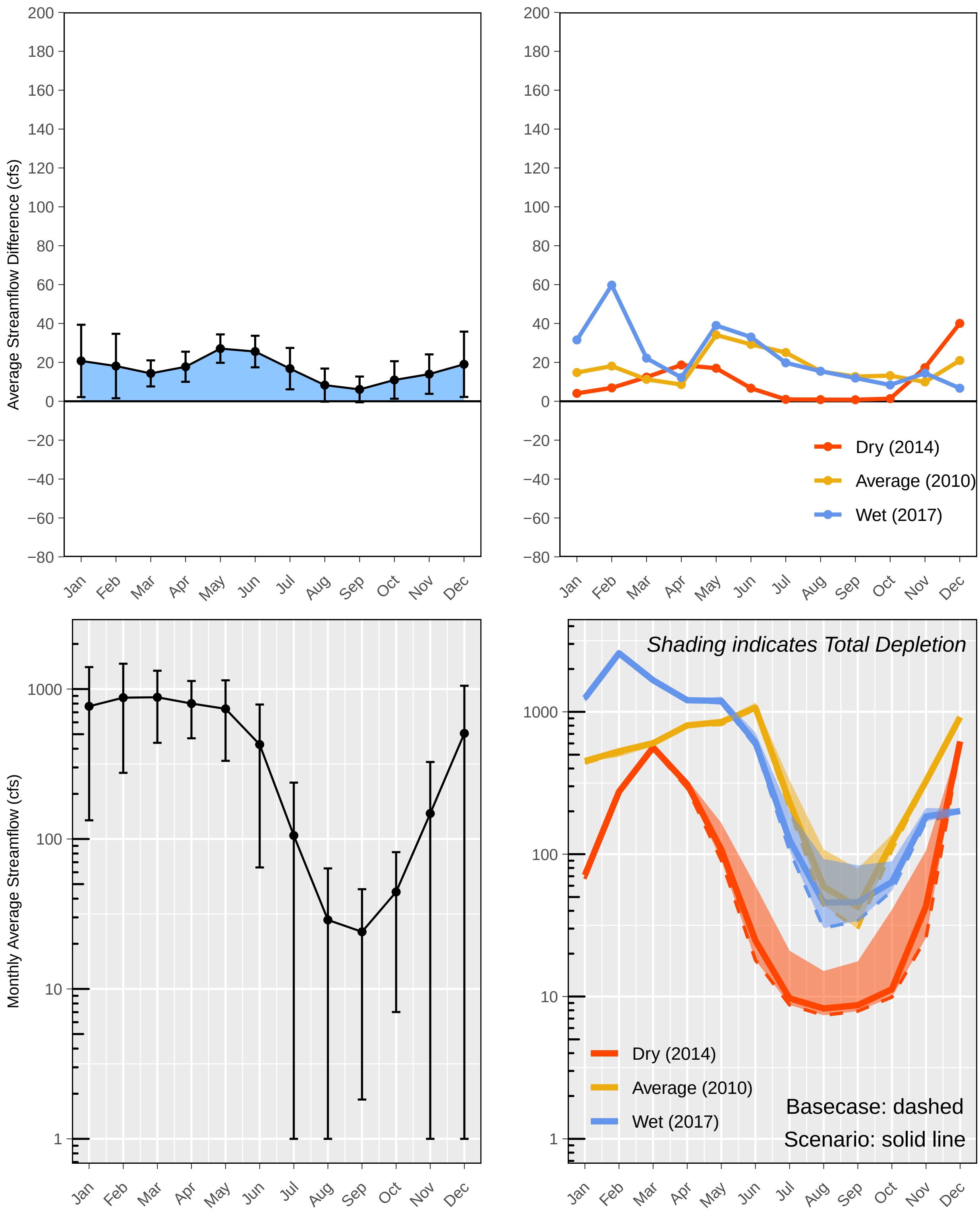



MAR and ILR with limited surface diversions at low flows
Average Streamflow Difference (cfs)
Monthly Average Streamflow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Dry (2014)
Average (2010)
Wet (2017)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line

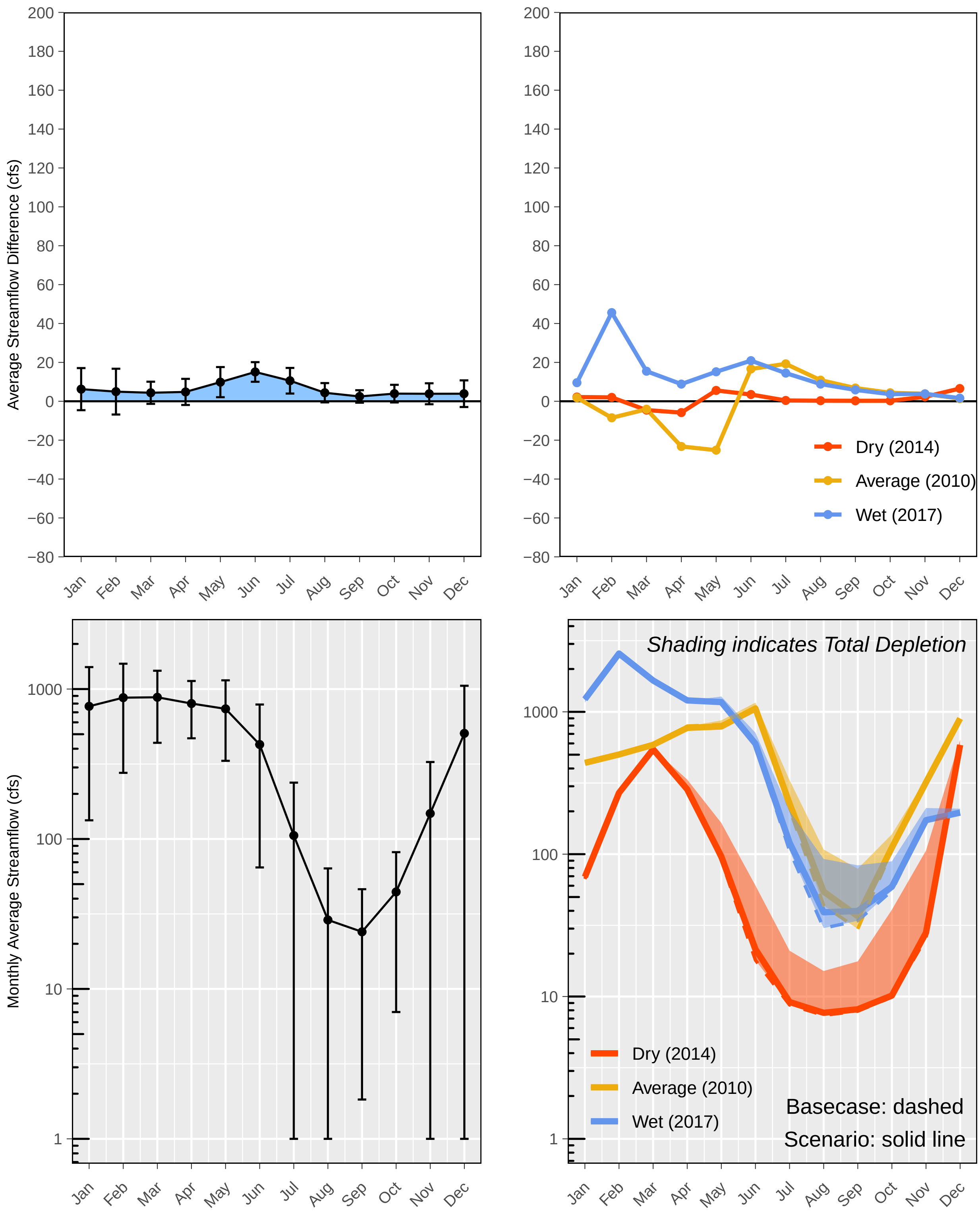
80% of Historical Irrigation Demand



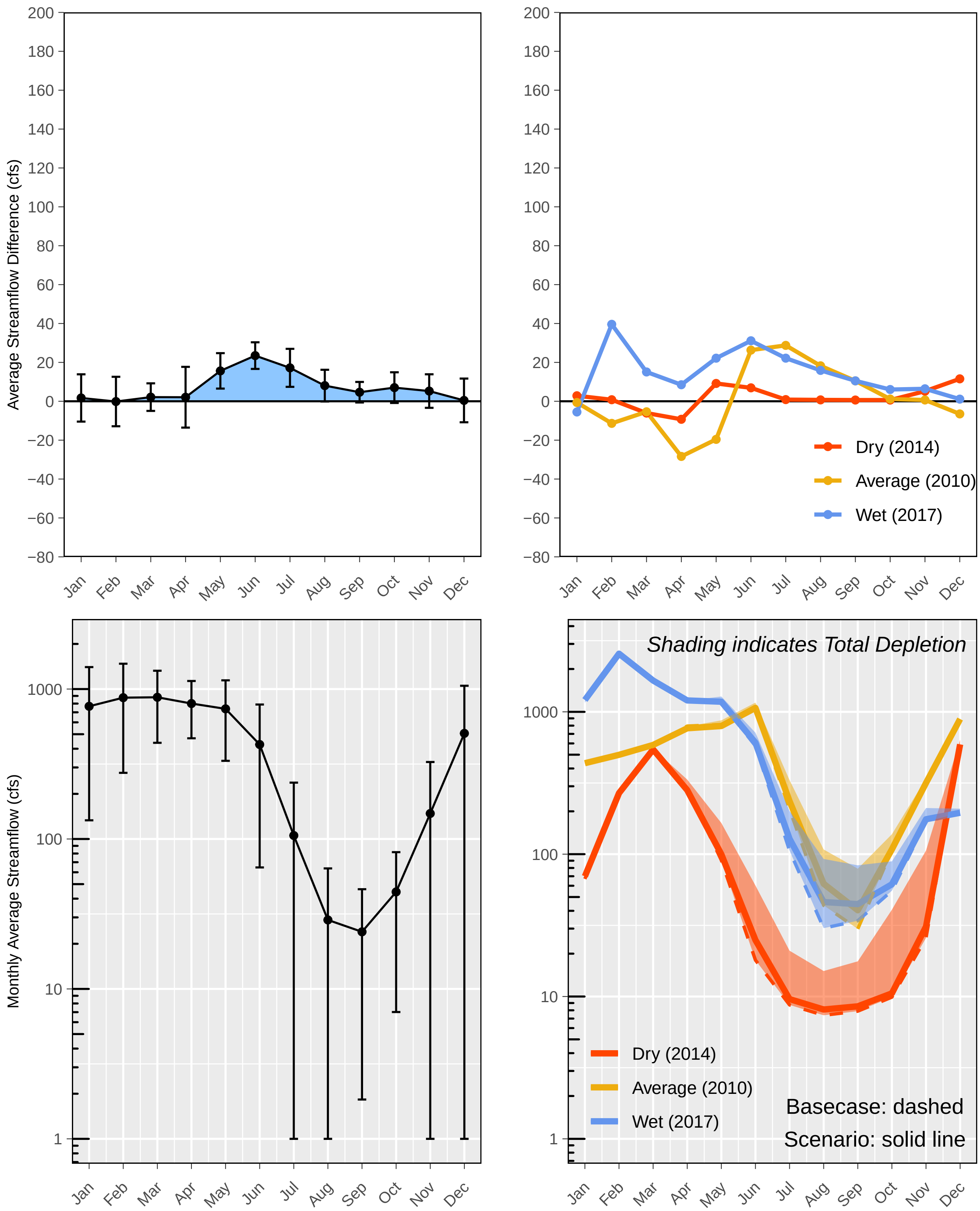
90% of Historical Irrigation Demand

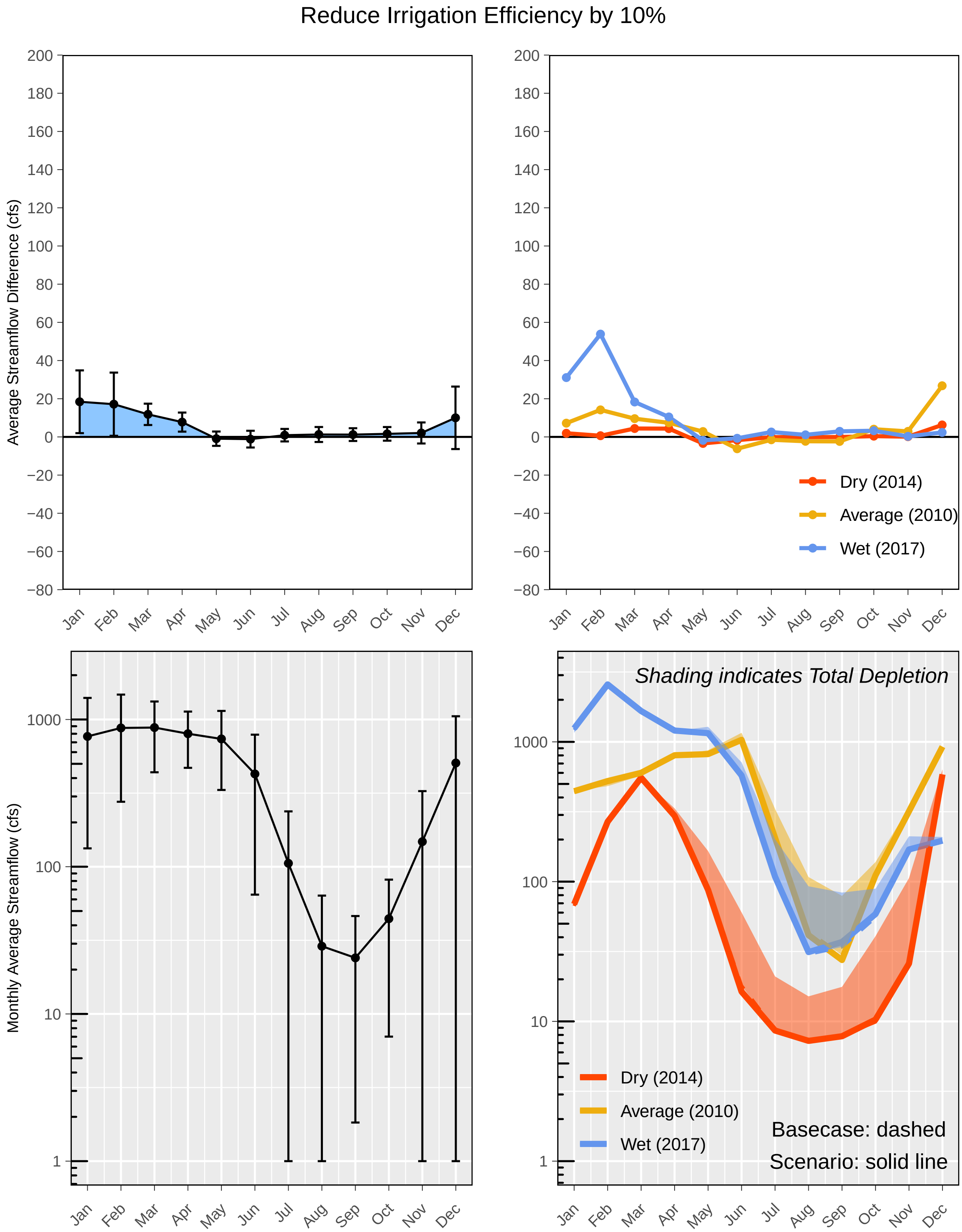


Improve Irrigation Efficiency by 10%

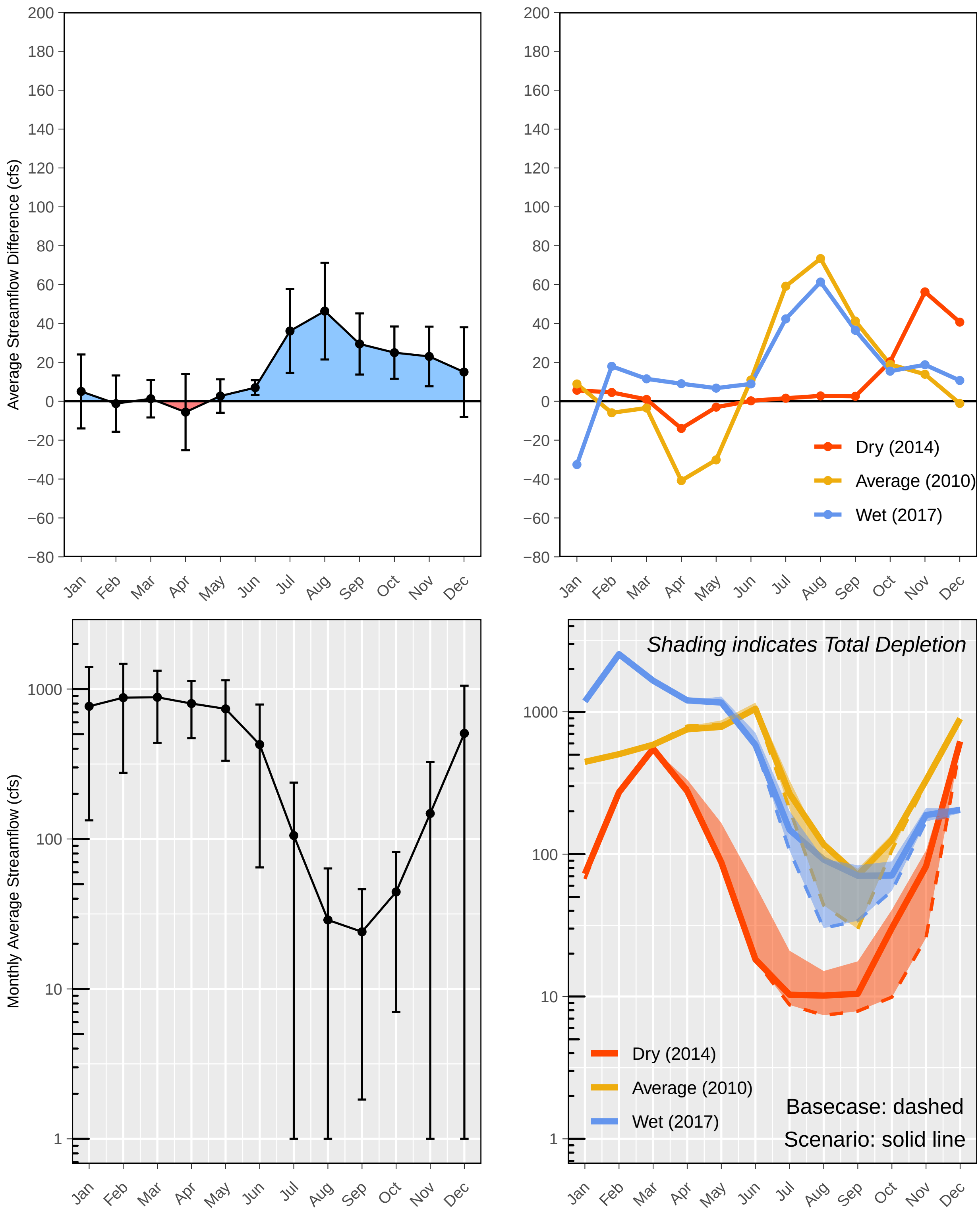


Improve Irrigation Efficiency by 20%

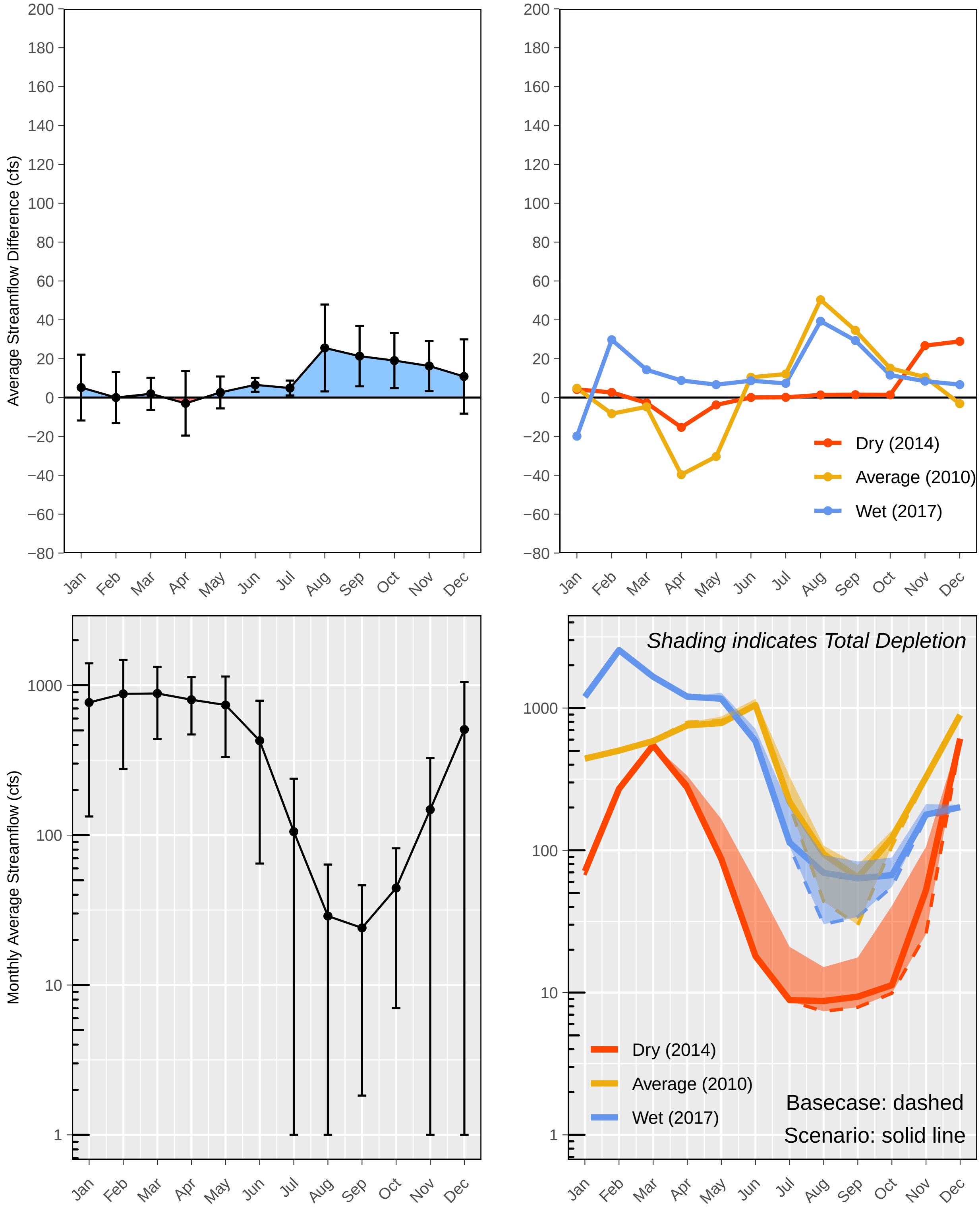


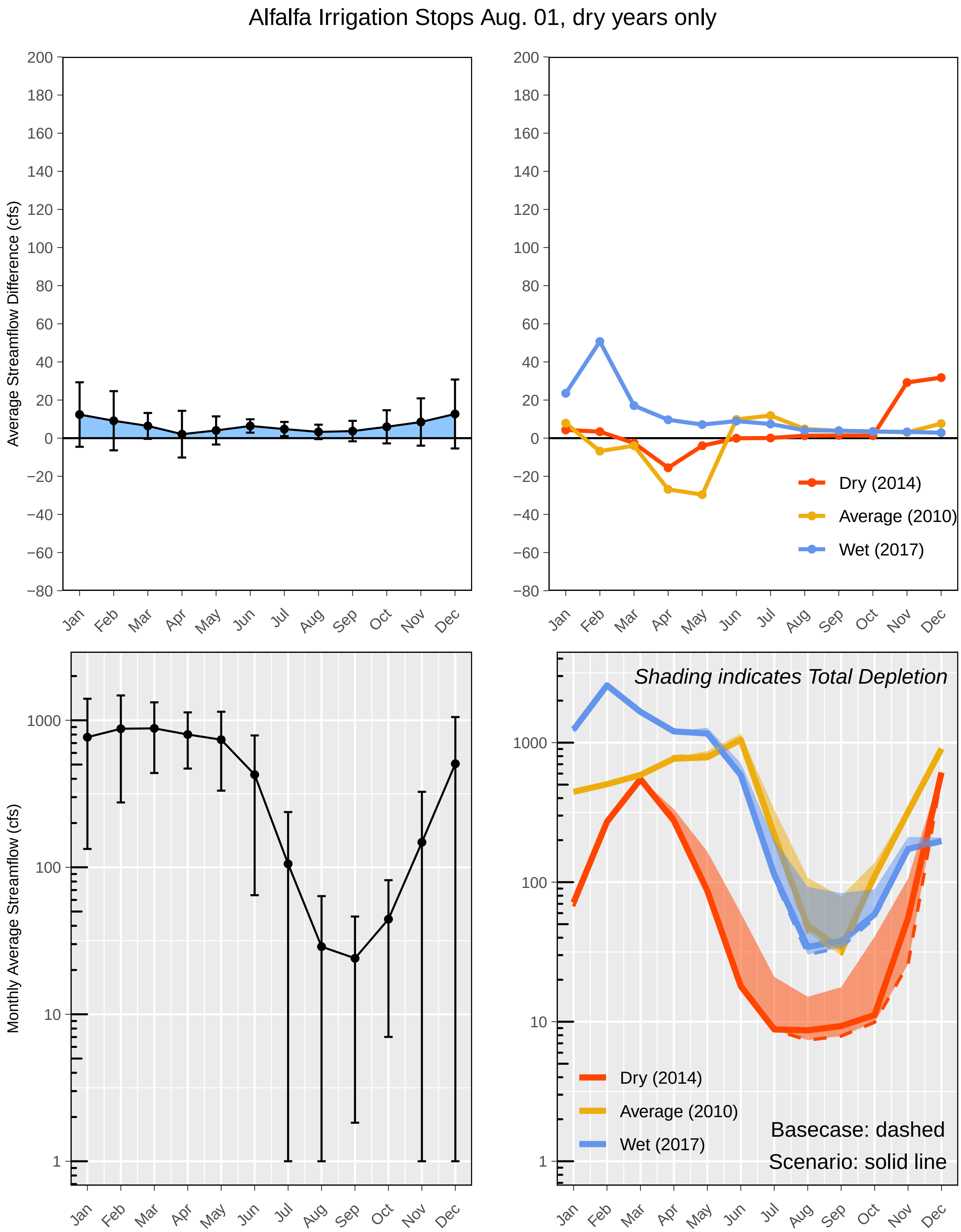

Reduce Irrigation Efficiency by 10%
Average Streamflow Difference (cfs)
200
180
160
140
120
100
80
60
40
20
0
−20
−40
−60
−80
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Dry (2014)
Average (2010)
Wet (2017)
Monthly Average Streamflow (cfs)
1000
100
10
1
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line

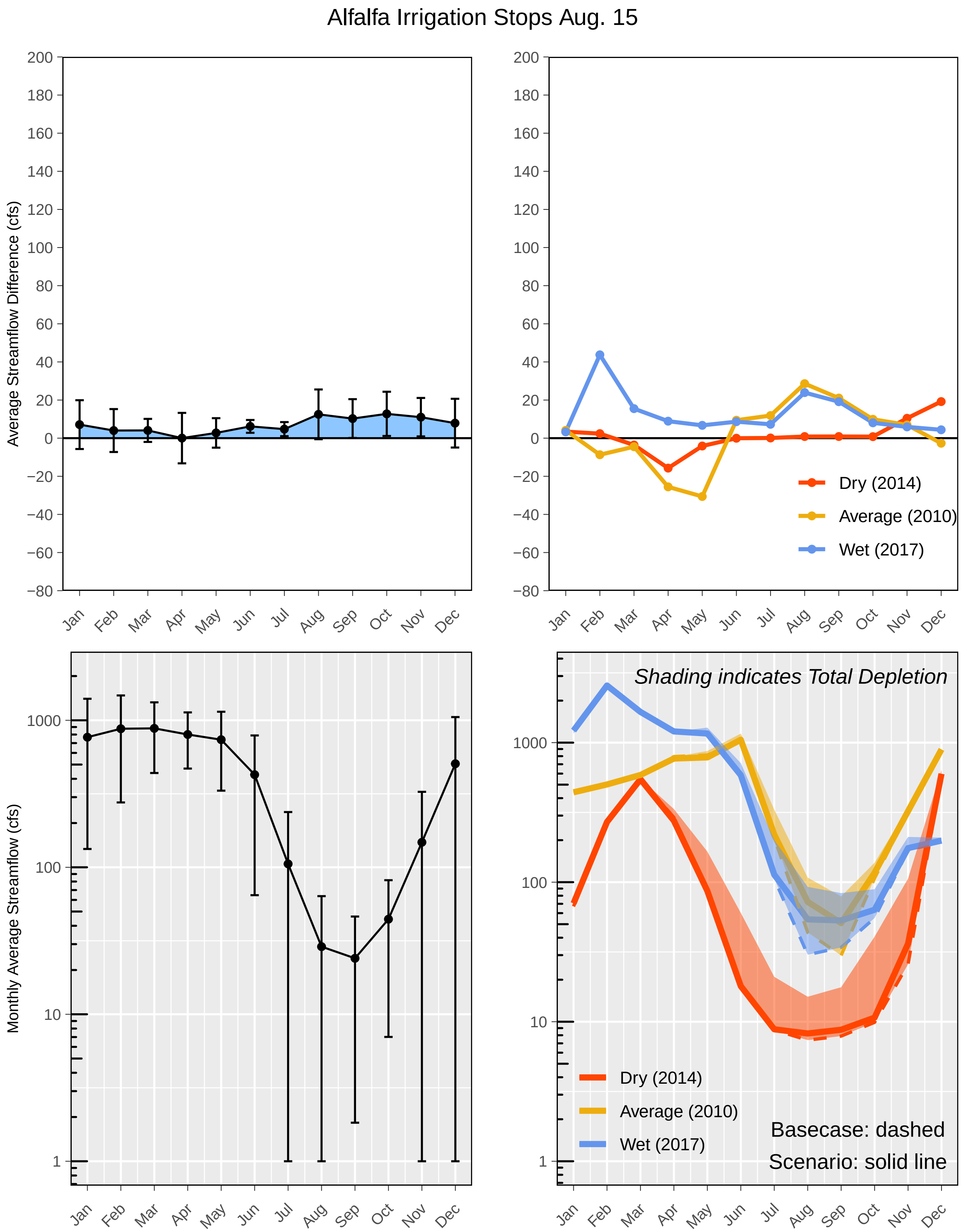
Alfalfa Irrigation Stops July 10



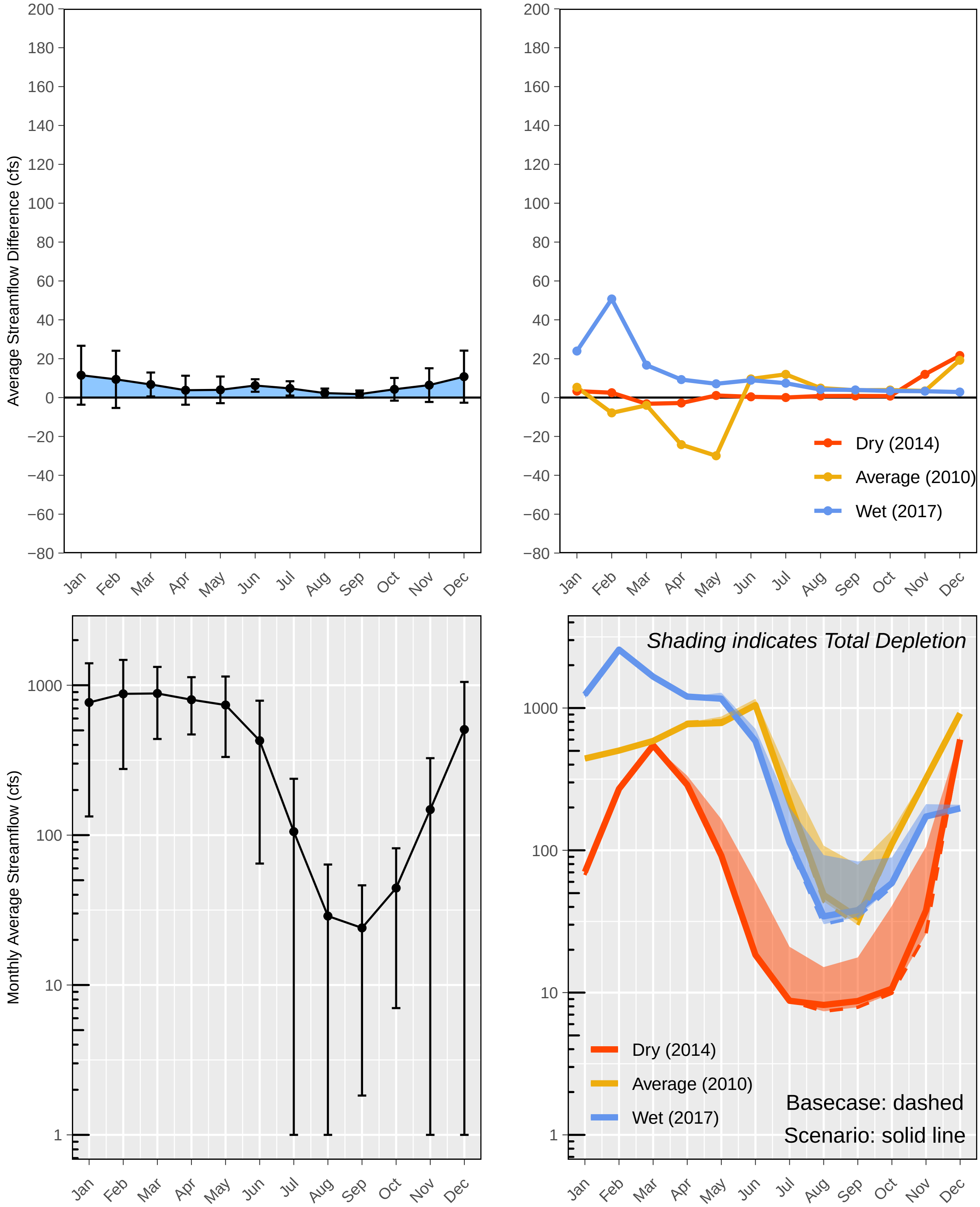
Alfalfa Irrigation Stops Aug. 01



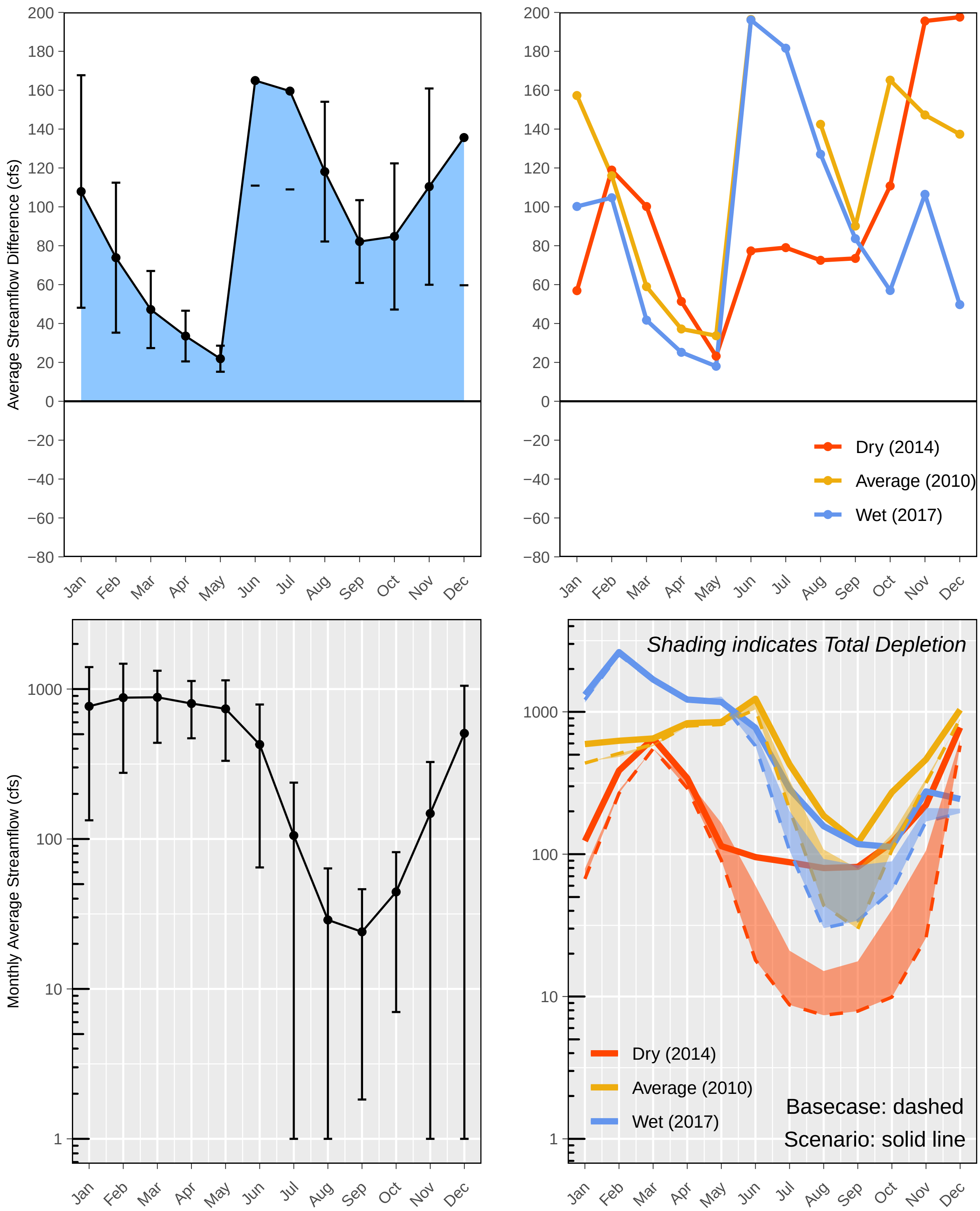

Alfalfa Irrigation Stops Aug. 01, dry years only
Average Streamflow Difference (cfs)
Dry (2014)
Average (2010)
Wet (2017)
Monthly Average Streamflow (cfs)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

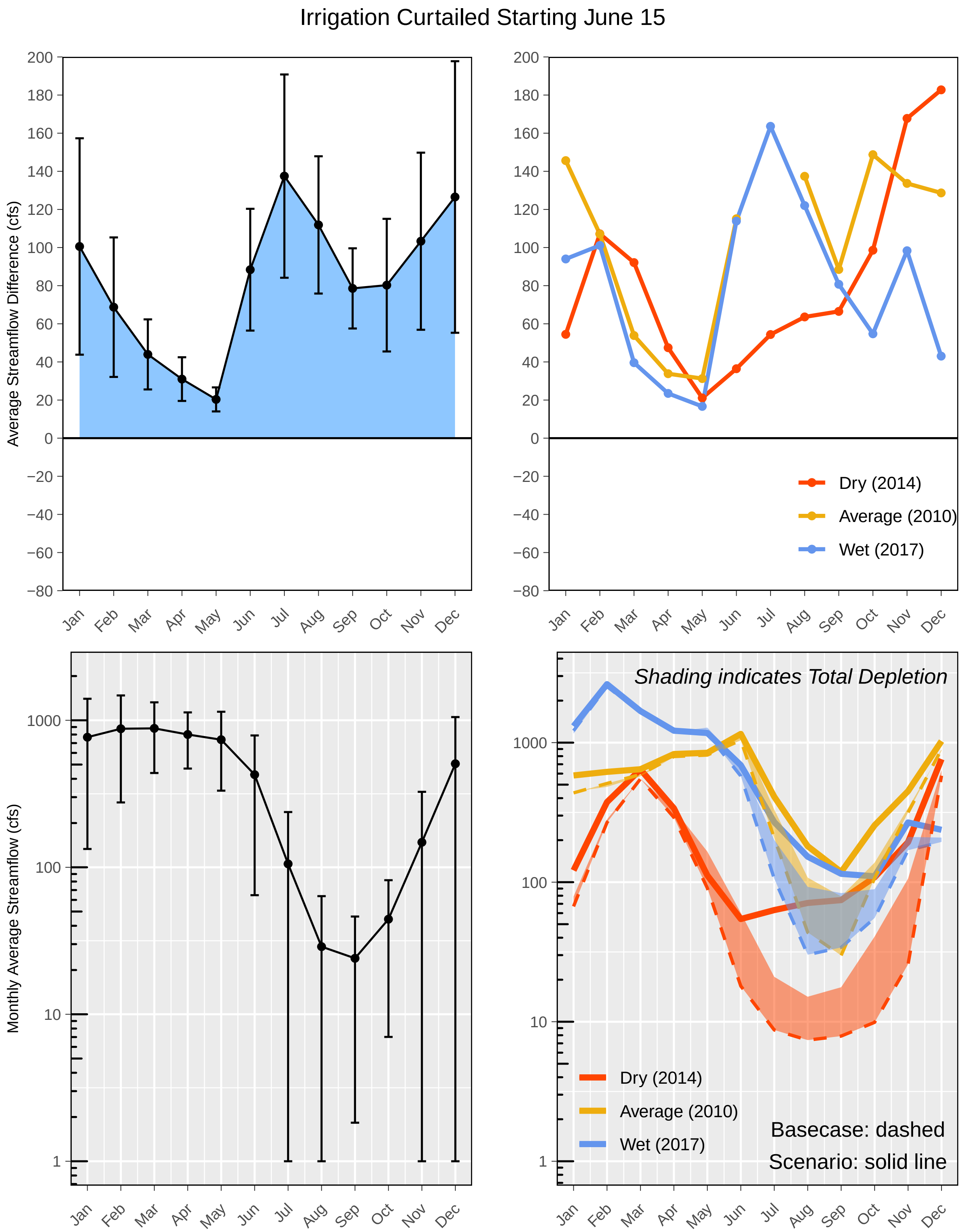

Alfalfa Irrigation Stops Aug. 15
Average Streamflow Difference (cfs)
Monthly Average Streamflow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Dry (2014)
Average (2010)
Wet (2017)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line

Alfalfa Irrigation Stops Aug. 15, dry years only

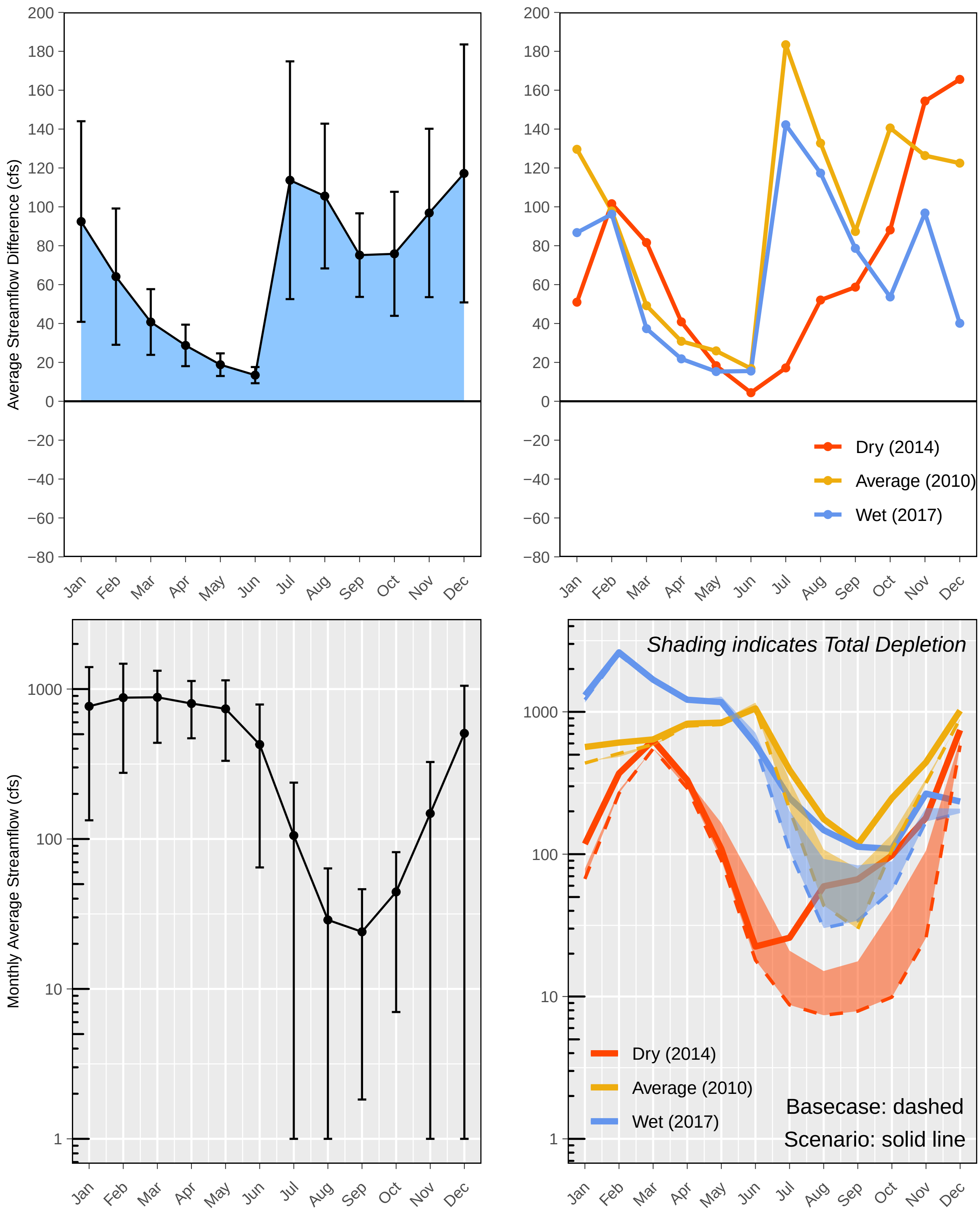


Irrigation Curtailed Starting June 01

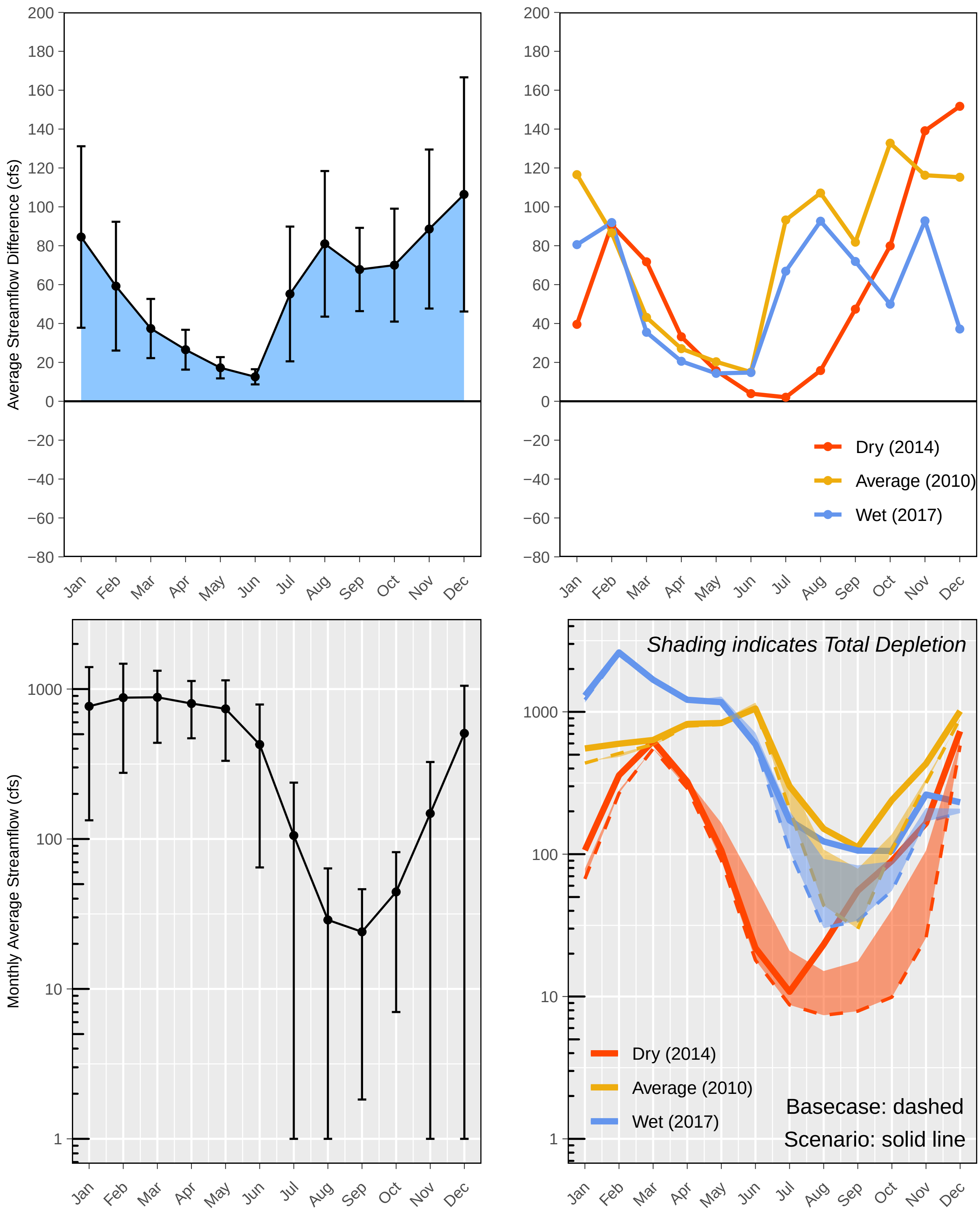



Irrigation Curtailed Starting June 15
Average Streamflow Difference (cfs)
Monthly Average Streamflow (cfs)
Dry (2014)
Average (2010)
Wet (2017)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

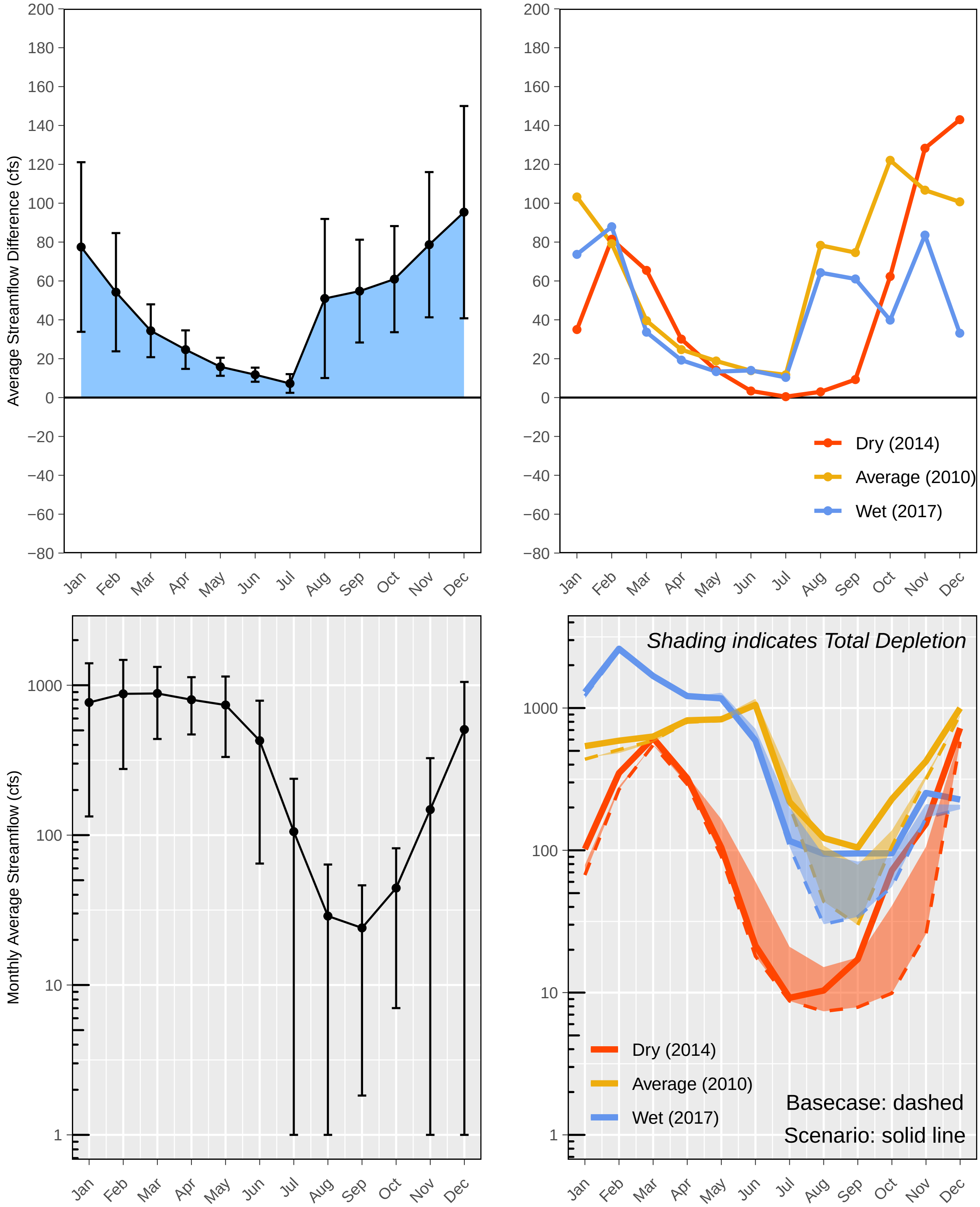
Irrigation Curtailed Starting July 01



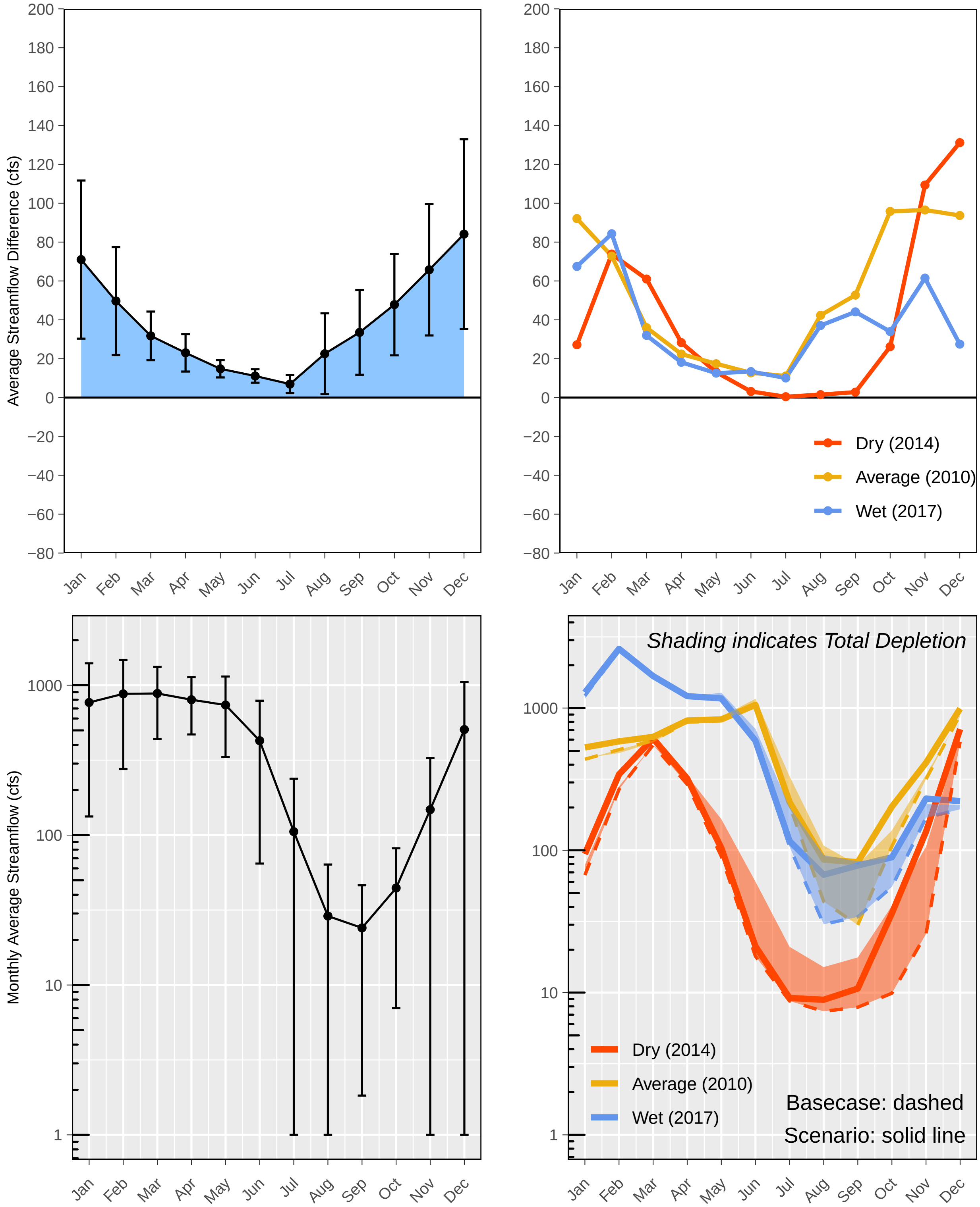
Irrigation Curtailed Starting July 15

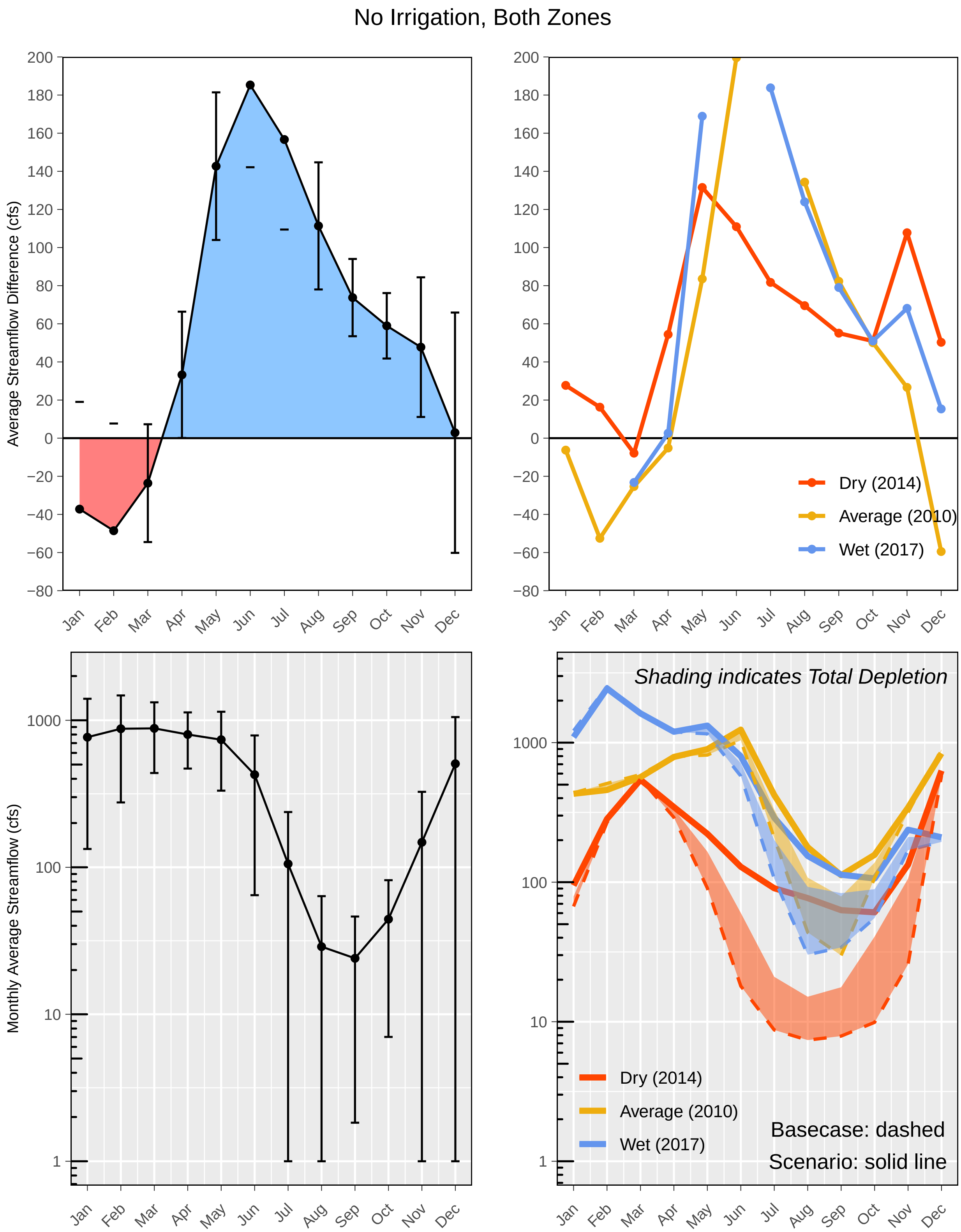


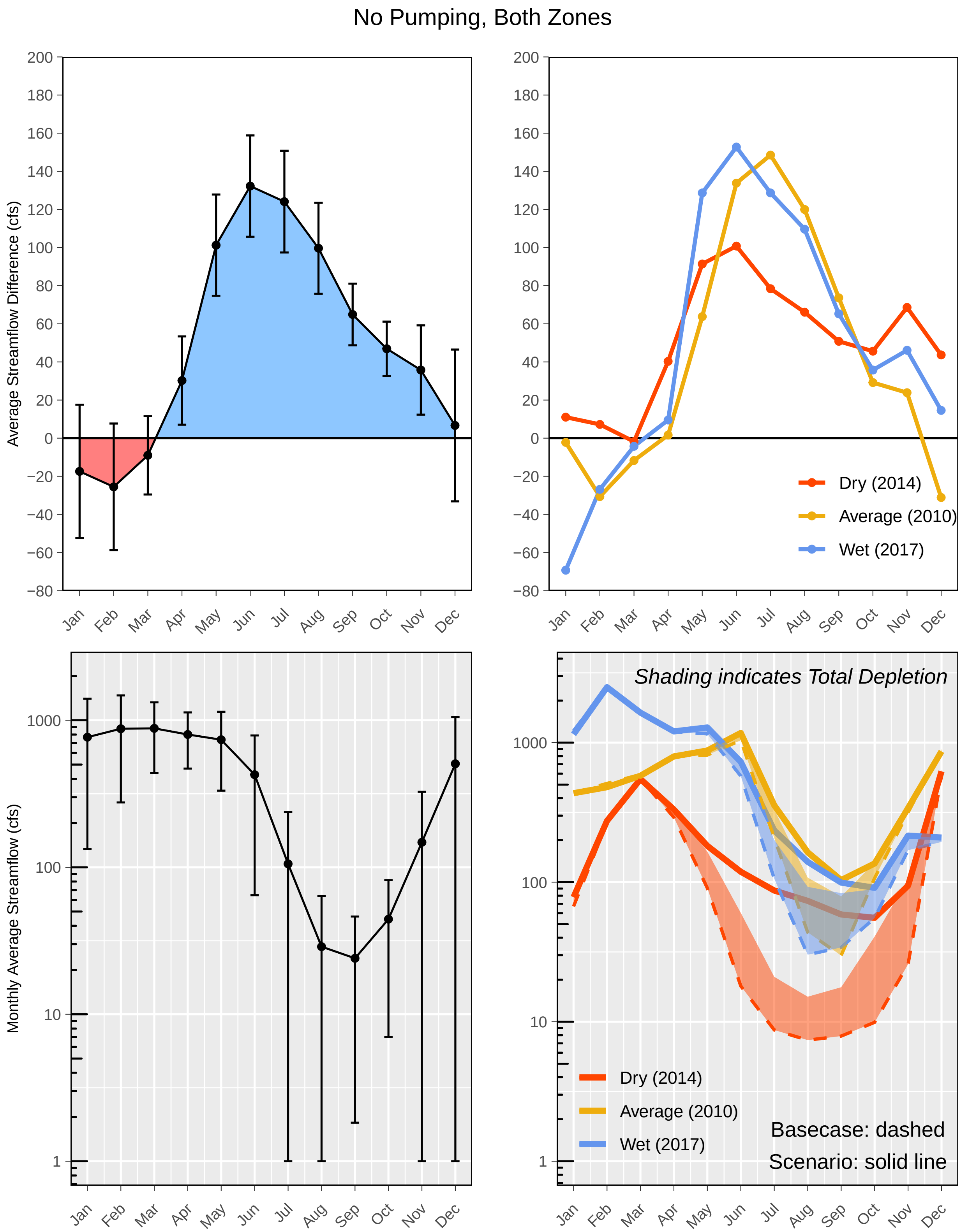
Irrigation Curtailed Starting Aug. 01



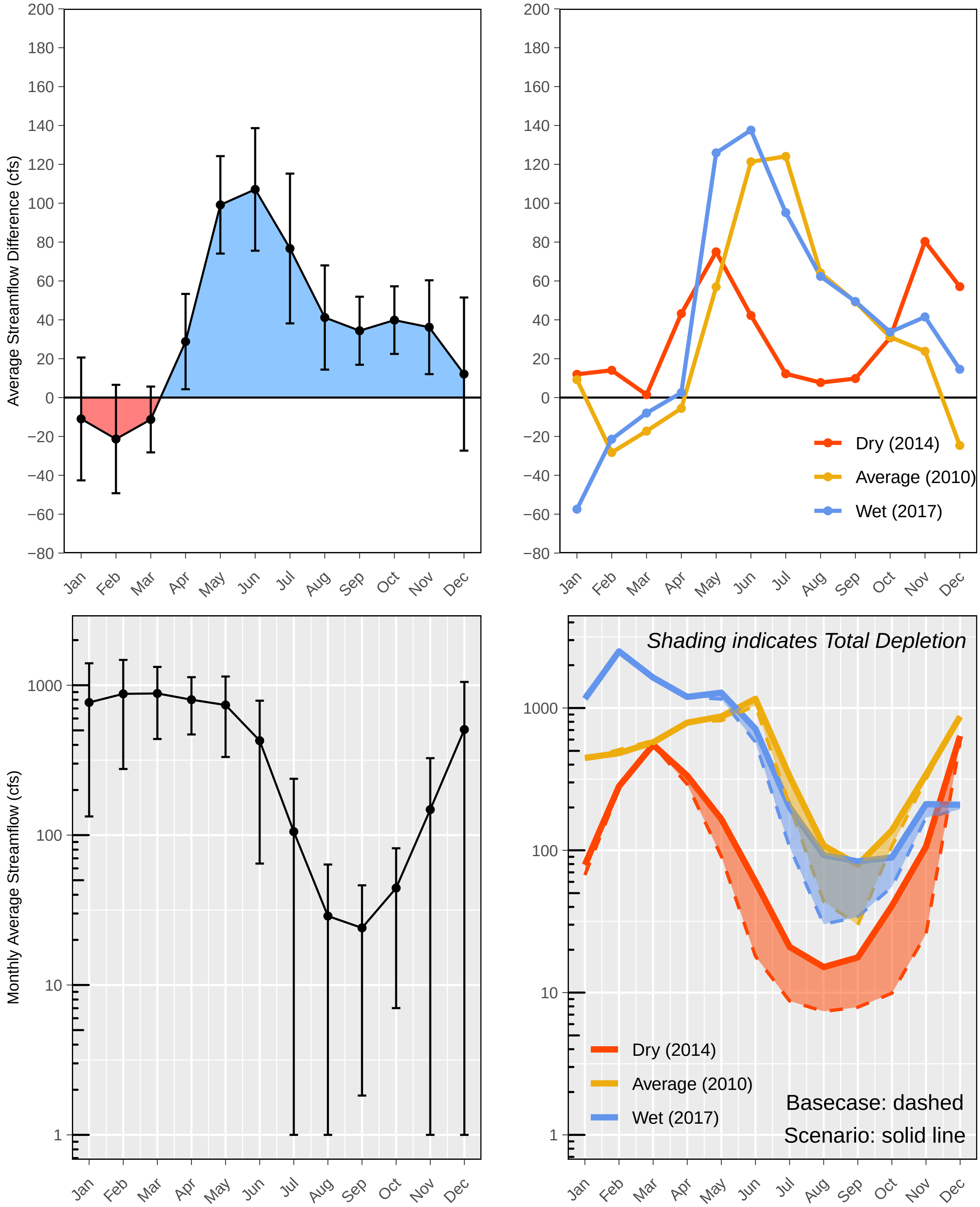
Irrigation Curtailed Starting Aug. 15

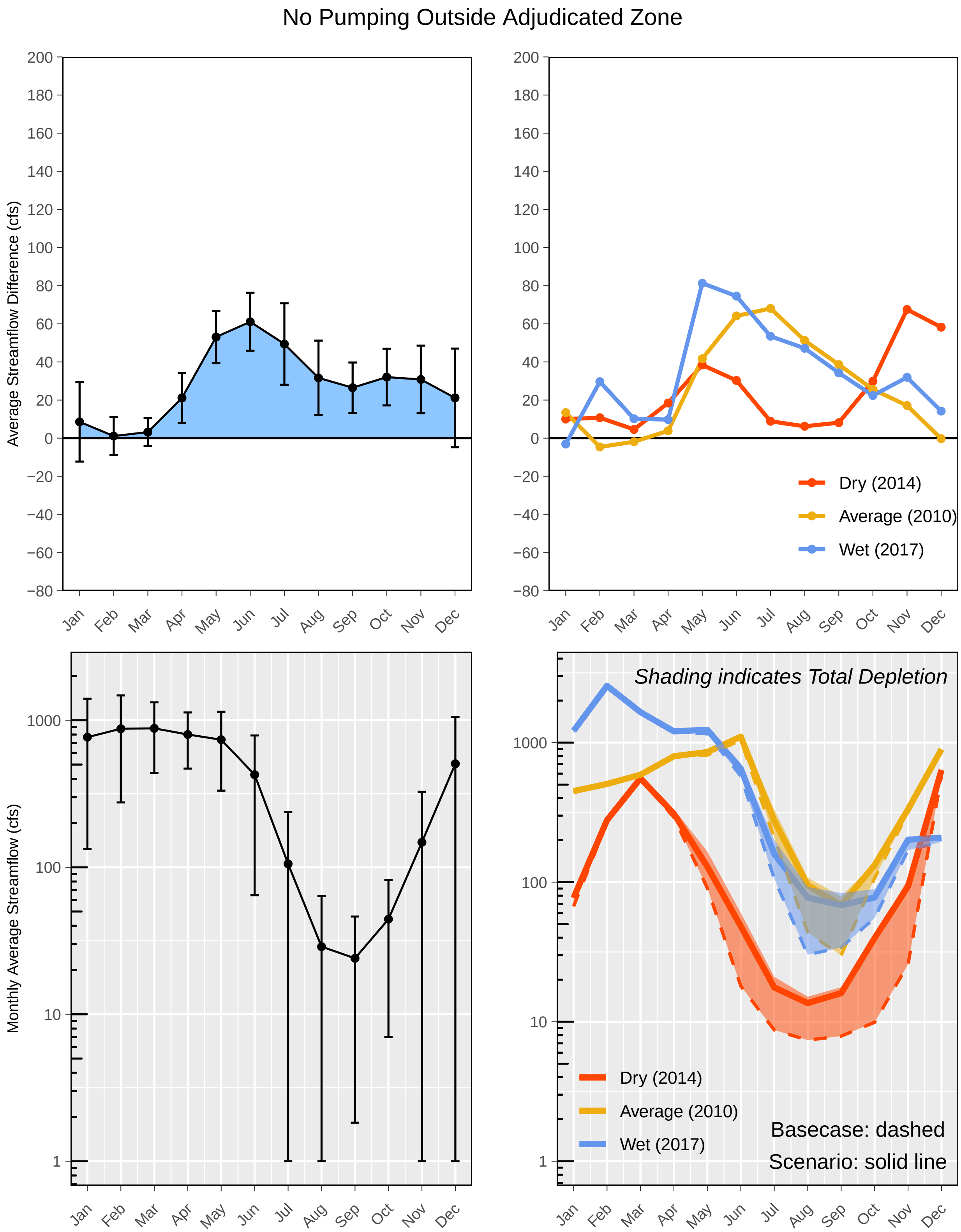



No Irrigation, Both Zones
Average Streamflow Difference (cfs)
Monthly Average Streamflow (cfs)
Dry (2014)
Average (2010)
Wet (2017)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

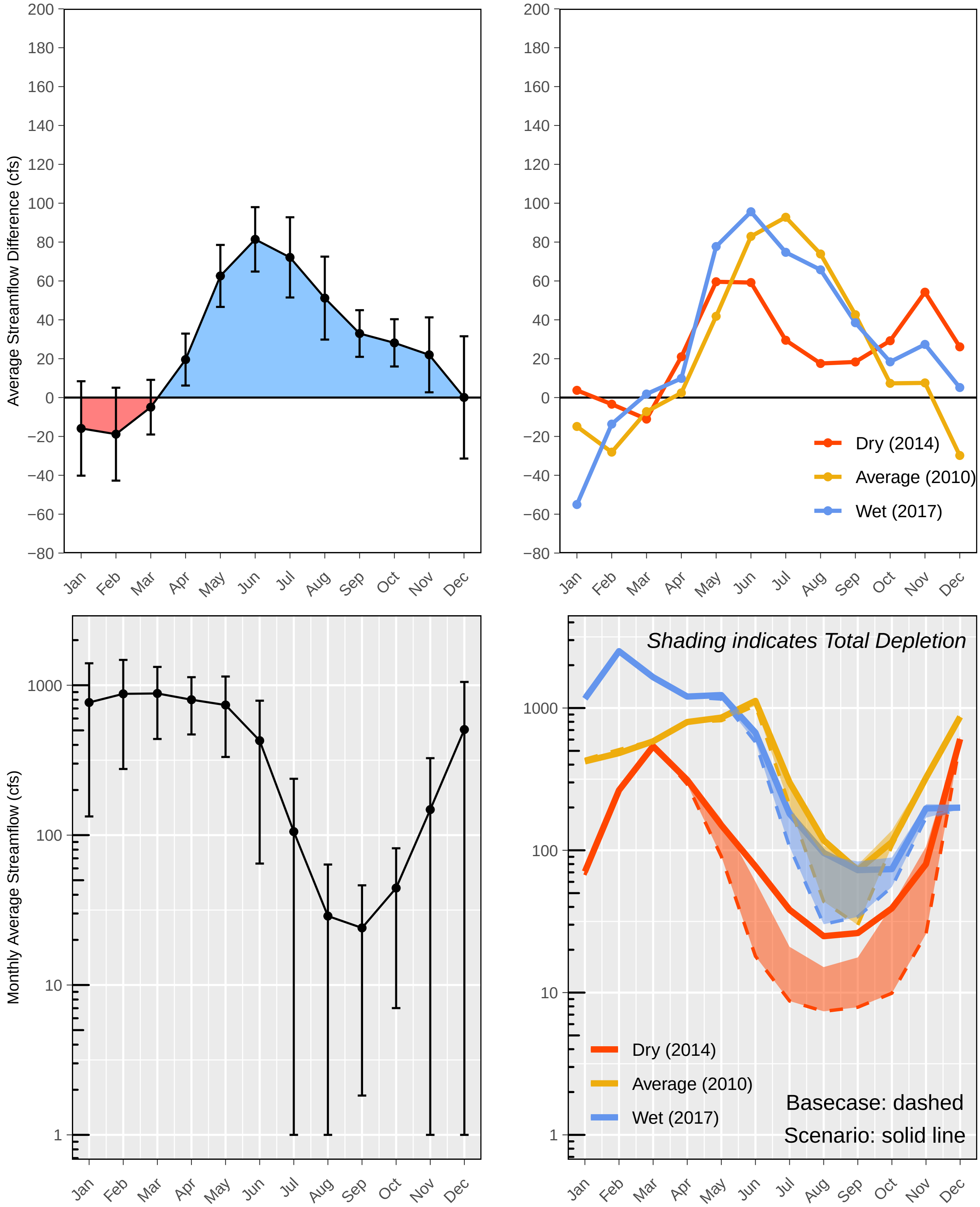

No Pumping, Both Zones
Average Streamflow Difference (cfs)
Dry (2014)
Average (2010)
Wet (2017)
Monthly Average Streamflow (cfs)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

No Irrigation Outside Adjudicated Zone

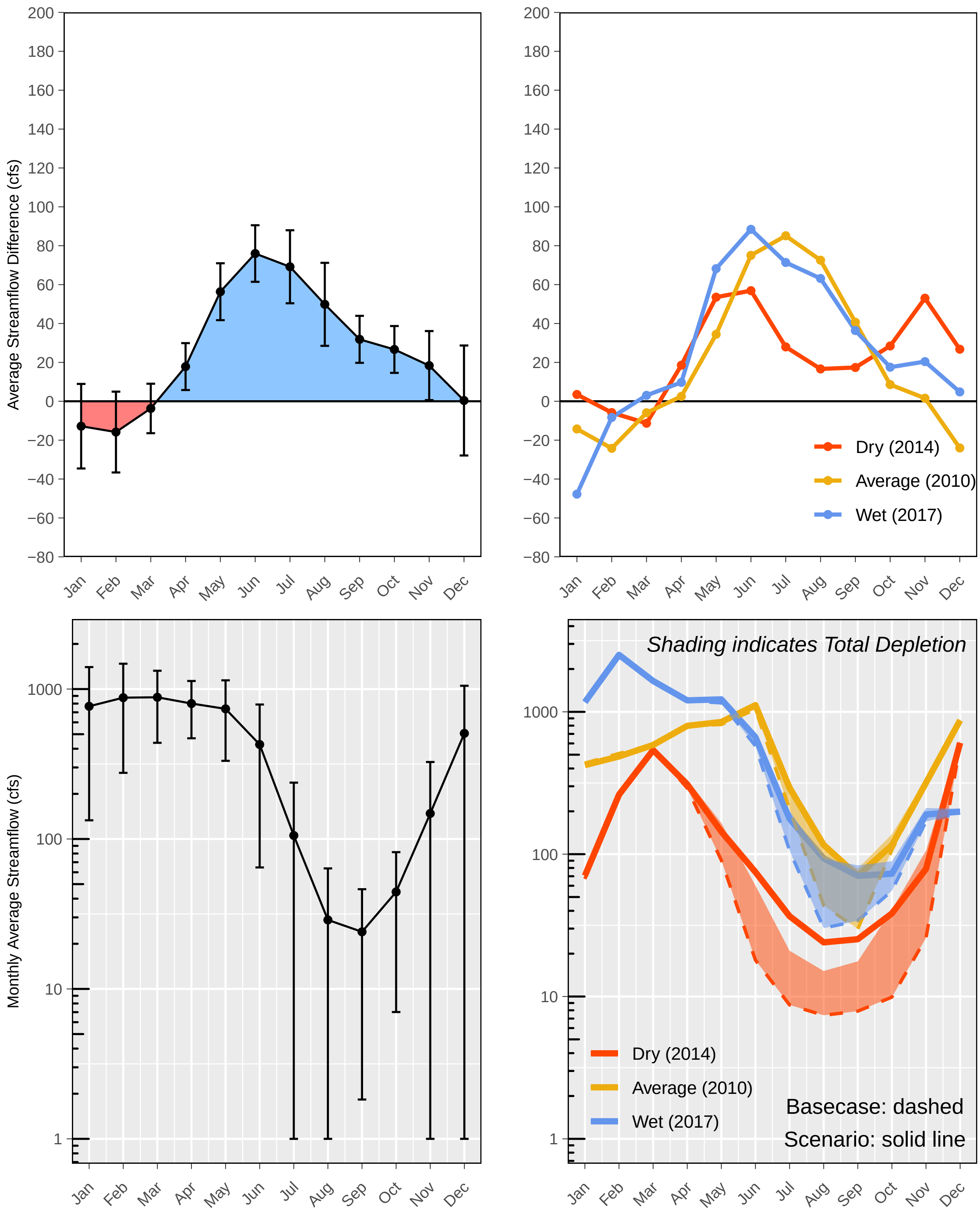



No Pumping Outside Adjudicated Zone
Average Streamflow Difference (cfs)
Monthly Average Streamflow (cfs)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Dry (2014)
Average (2010)
Wet (2017)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line

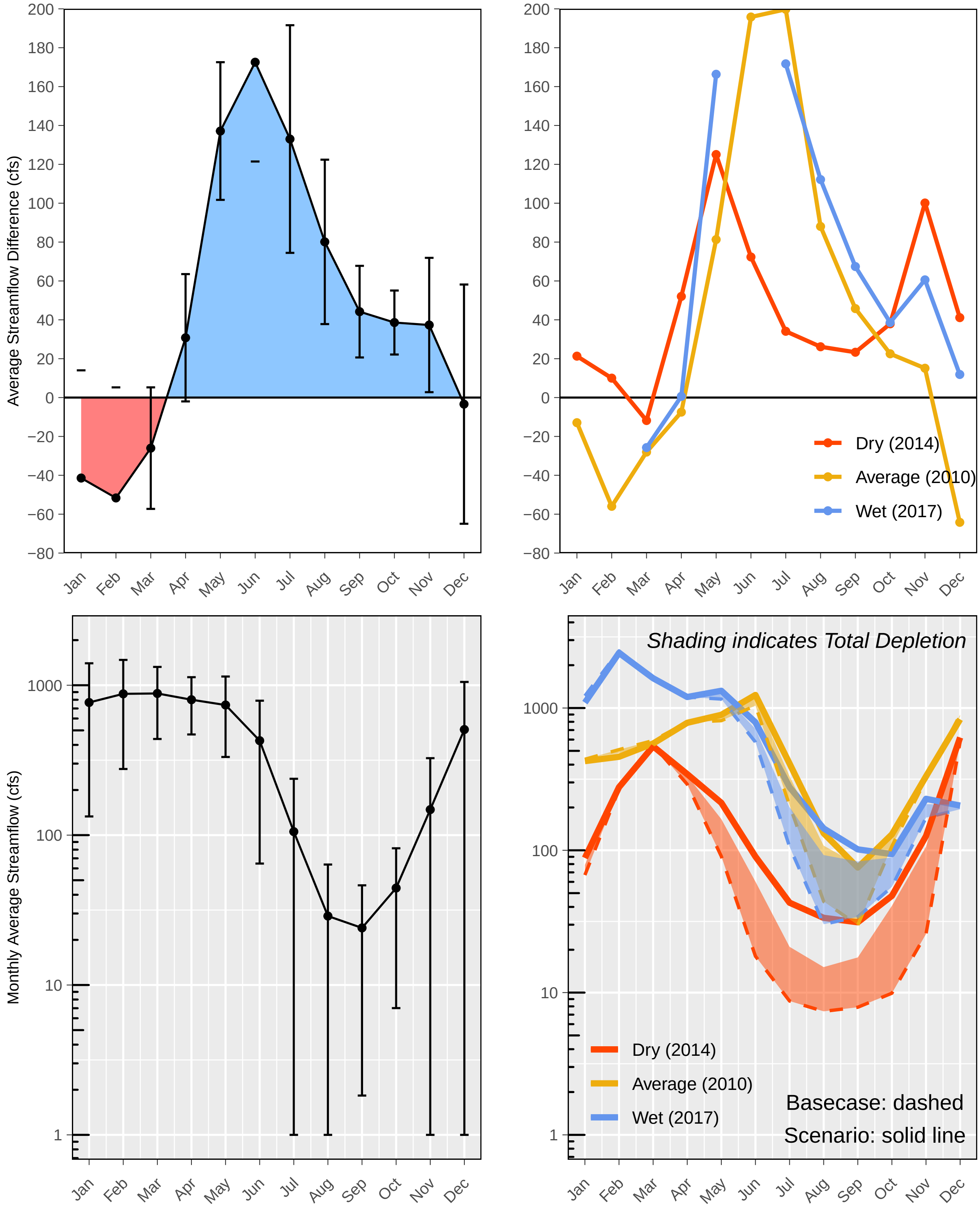
No Irrigation Inside Adjudicated Zone

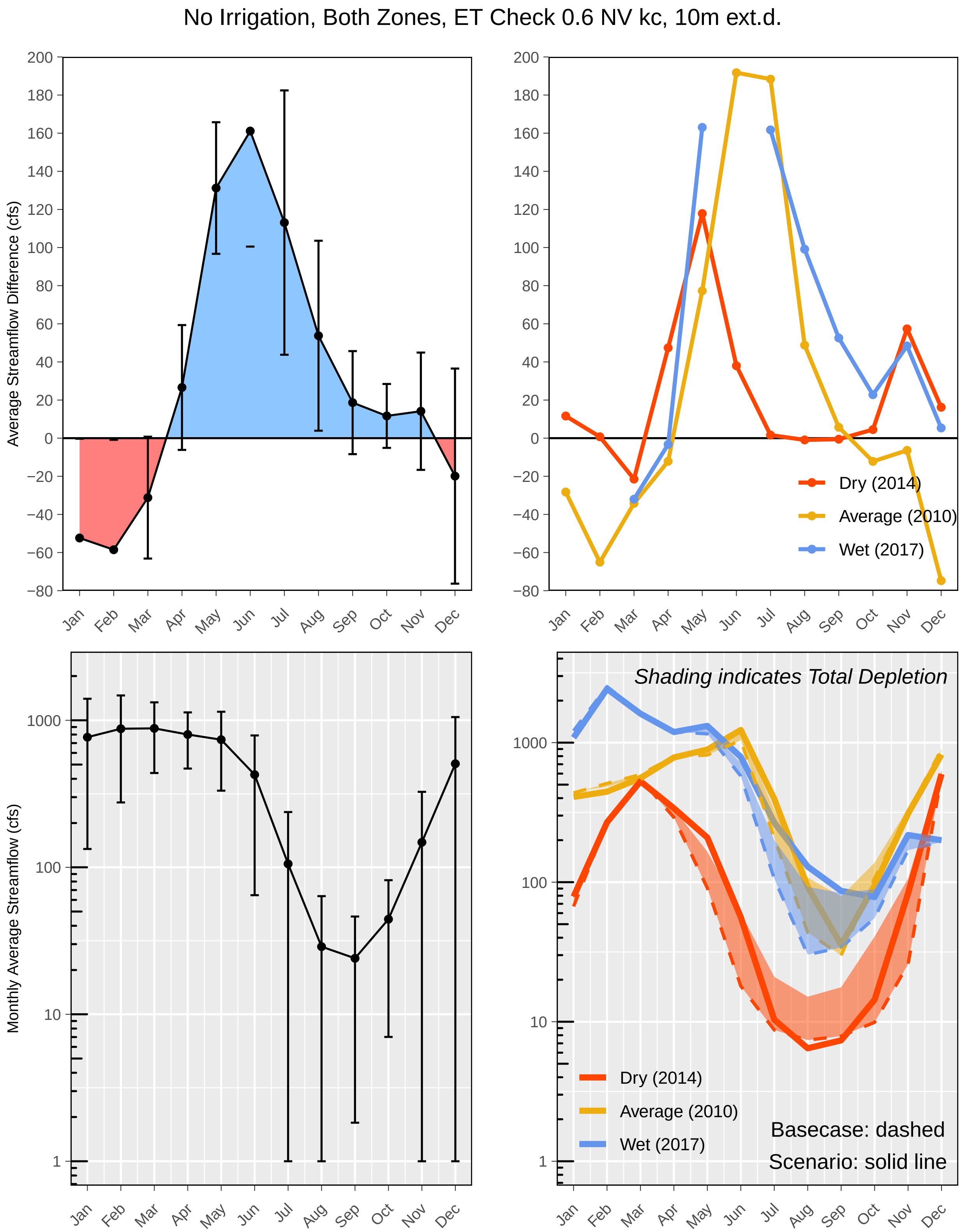


No Pumping Inside Adjudicated Zone

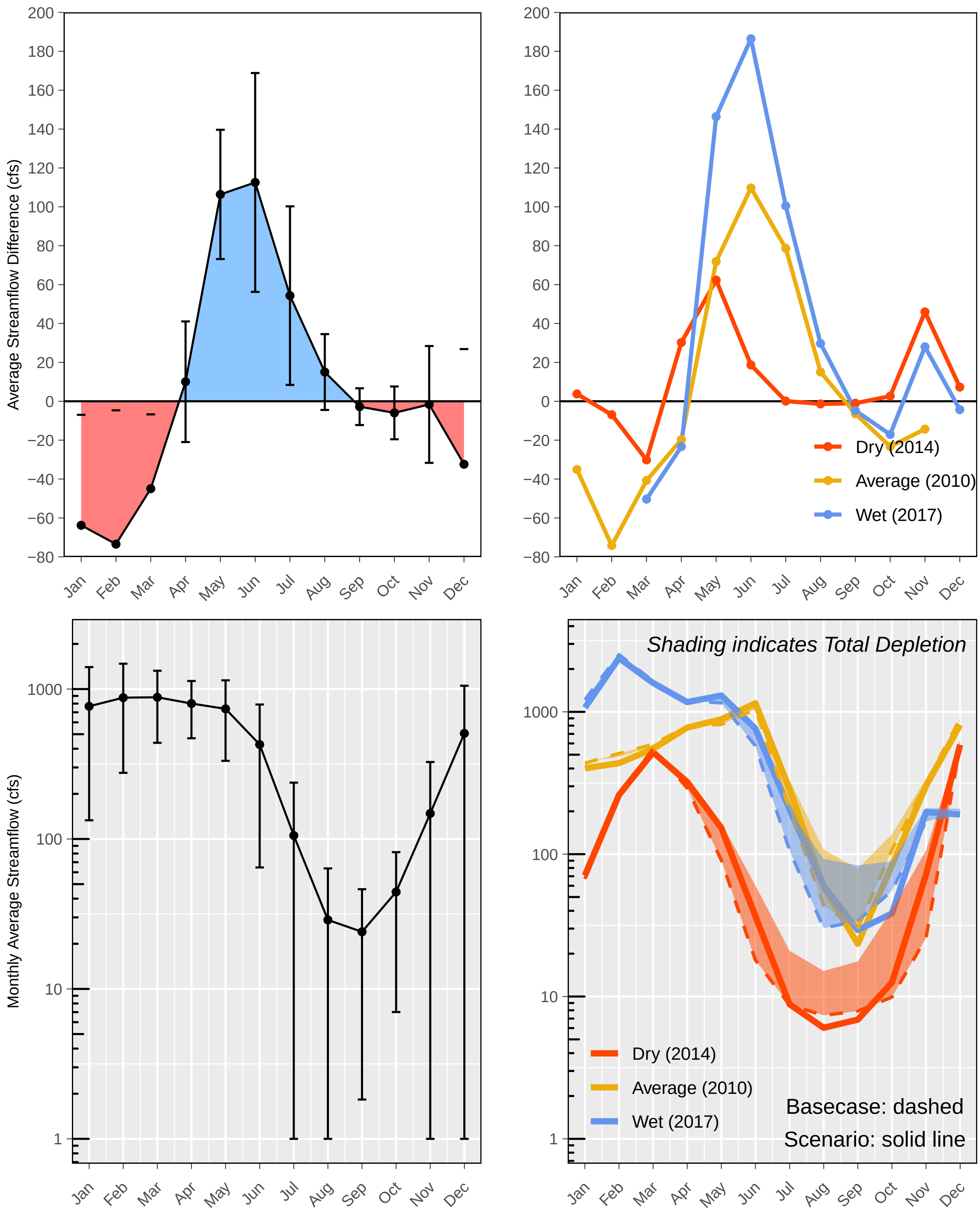


No Irrigation, Both Zones, ET Check 0.6 NV kc, 4.5m ext.d.

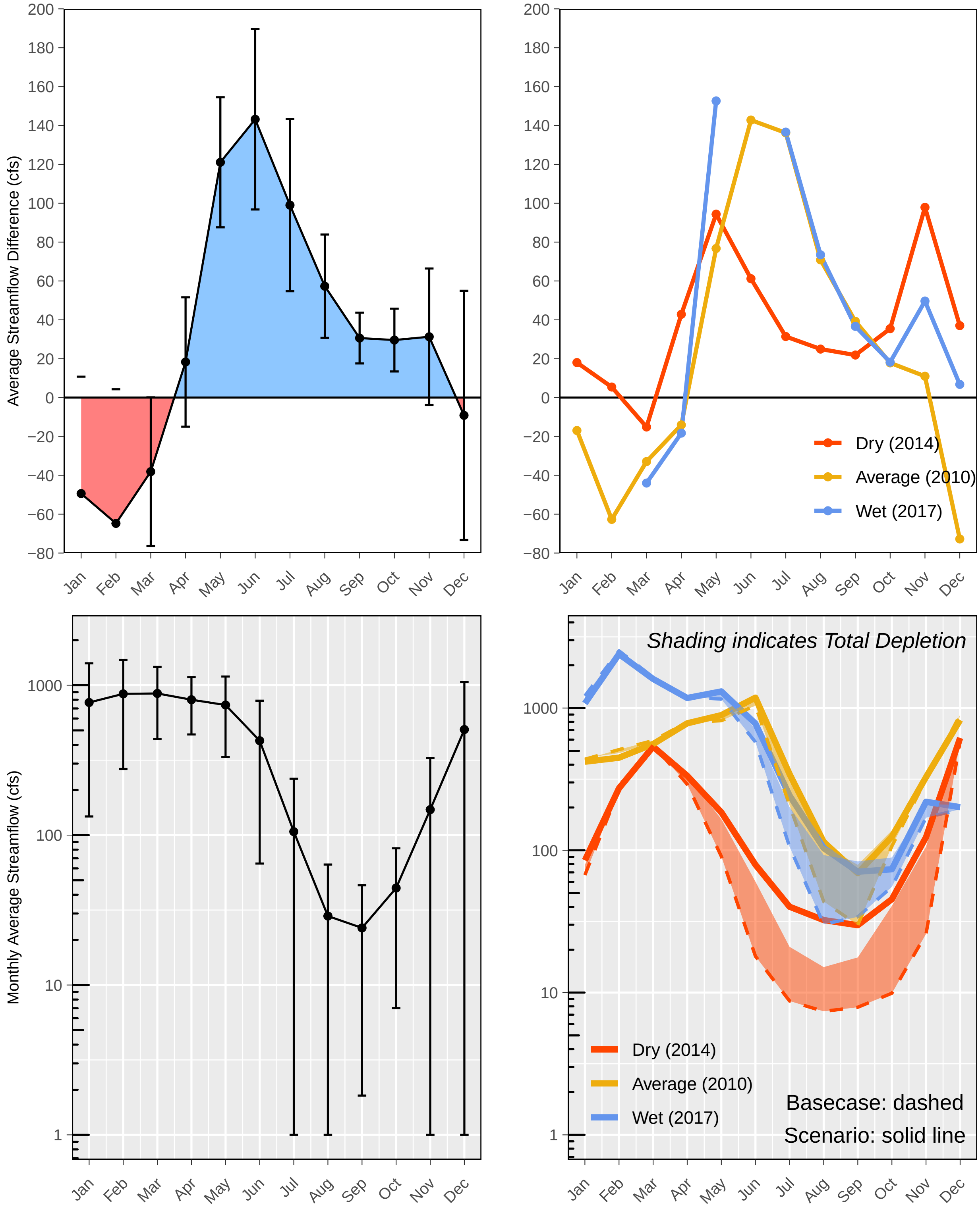


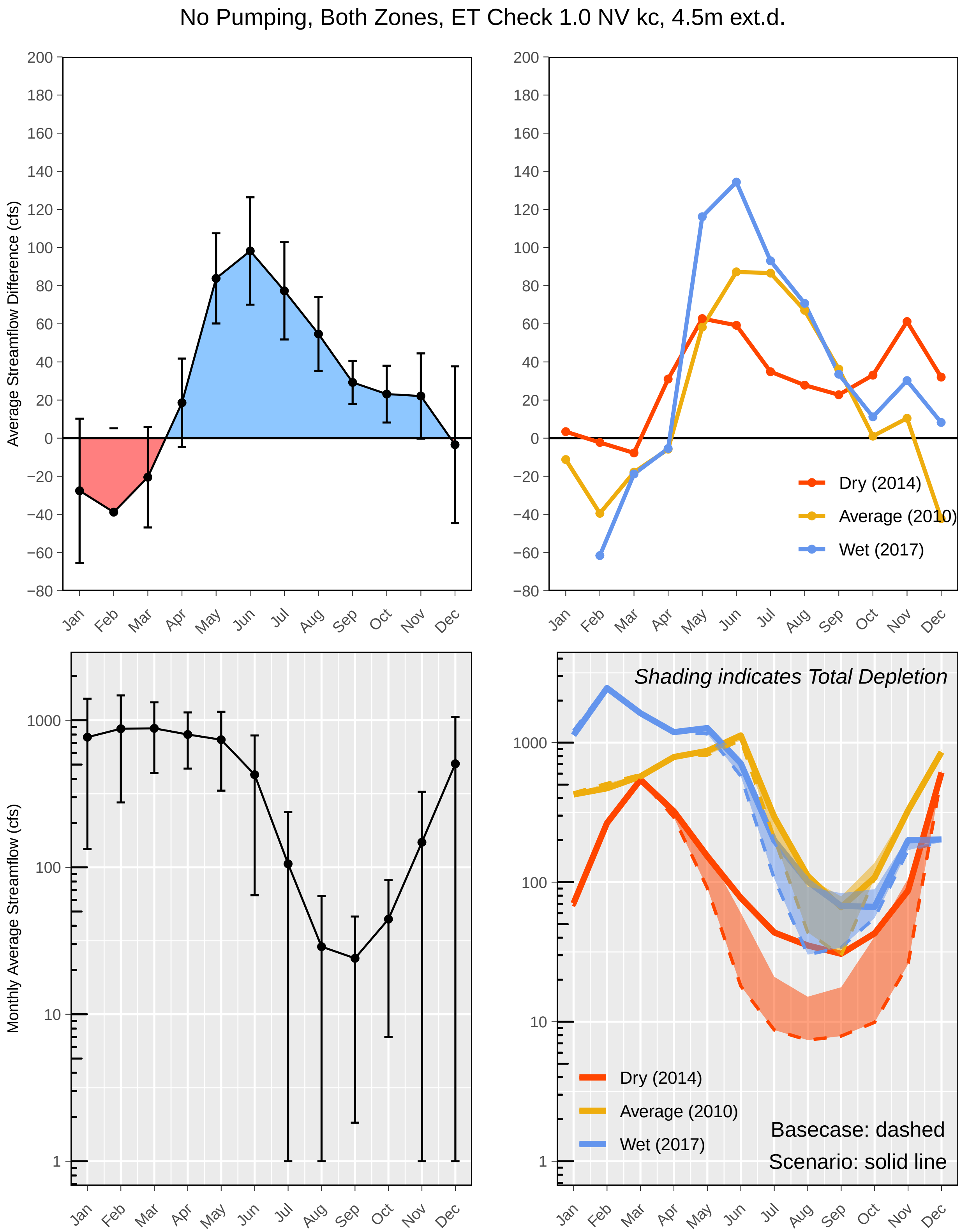

No Irrigation, Both Zones, ET Check 0.6 NV kc, 10m ext.d.
Average Streamflow Difference (cfs)
Monthly Average Streamflow (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Dry (2014)
Average (2010)
Wet (2017)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line

No Irrigation, Both Zones, ET Check 1.0 NV kc, 10m ext.d.

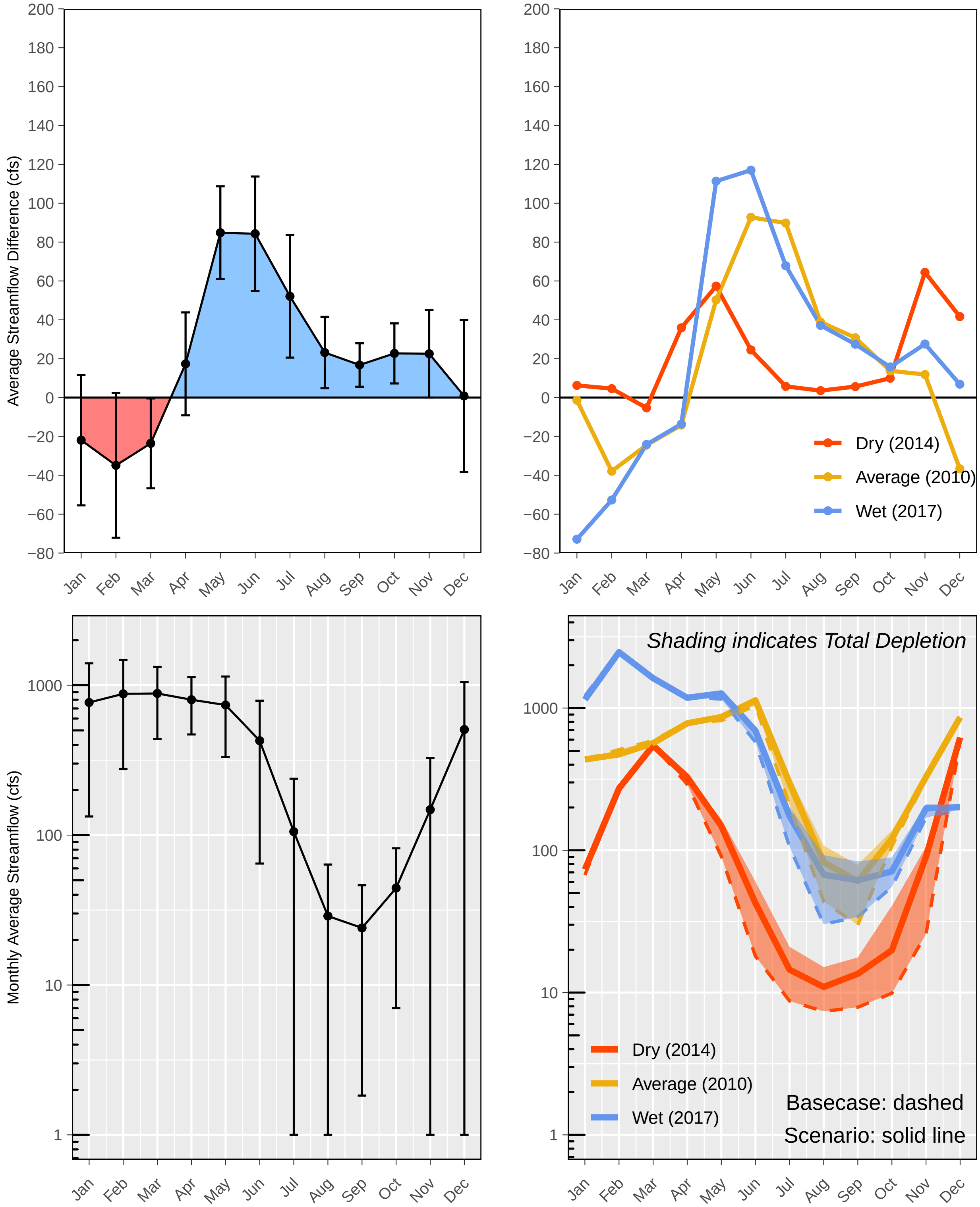


No Irrigation, Both Zones, ET Check 1.0 NV kc, 4.5m ext.d.

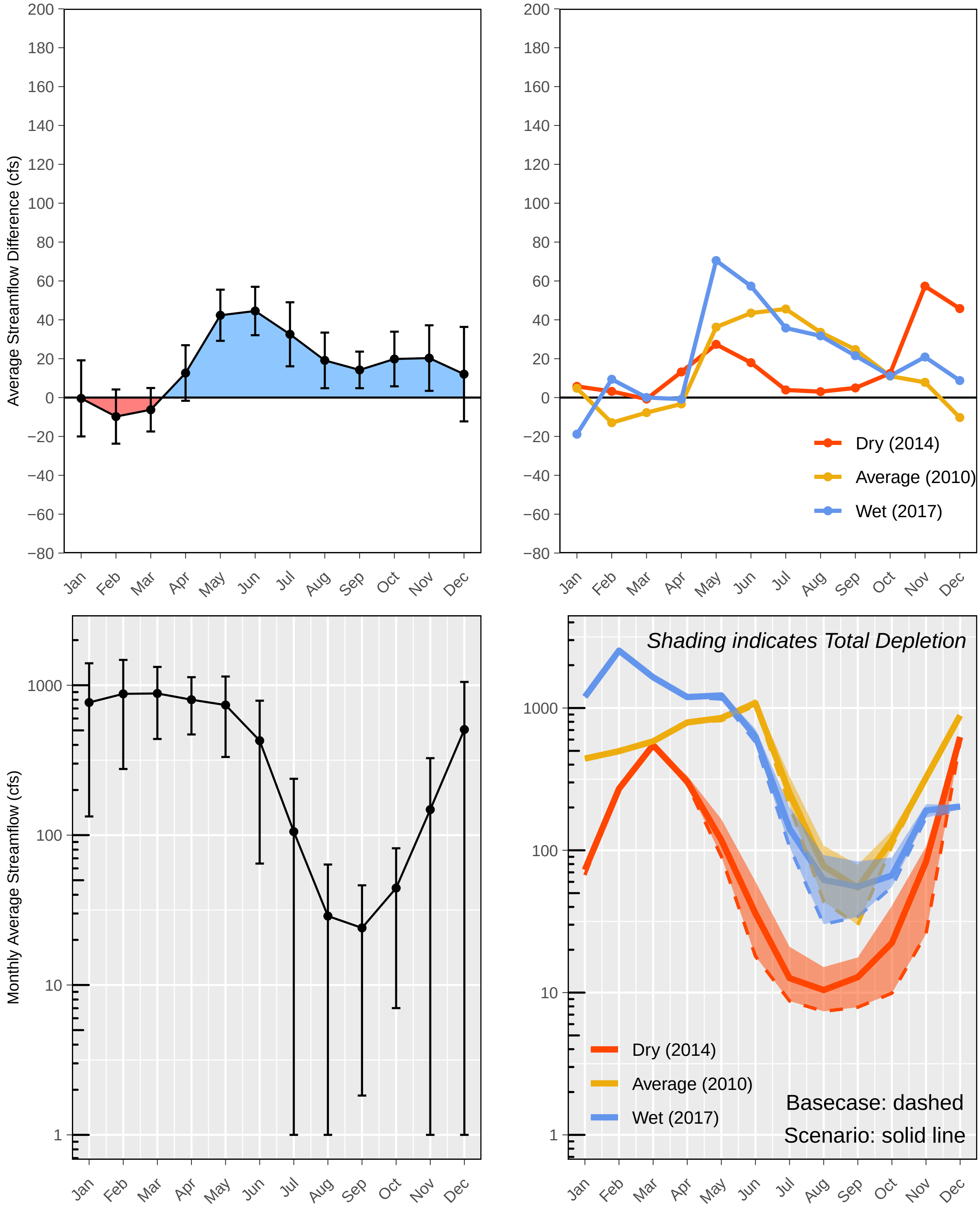



No Pumping, Both Zones, ET Check 1.0 NV kc, 4.5m ext.d.
Average Streamflow Difference (cfs)
Dry (2014)
Average (2010)
Wet (2017)
Monthly Average Streamflow (cfs)
Shading indicates Total Depletion
Basecase: dashed
Scenario: solid line
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

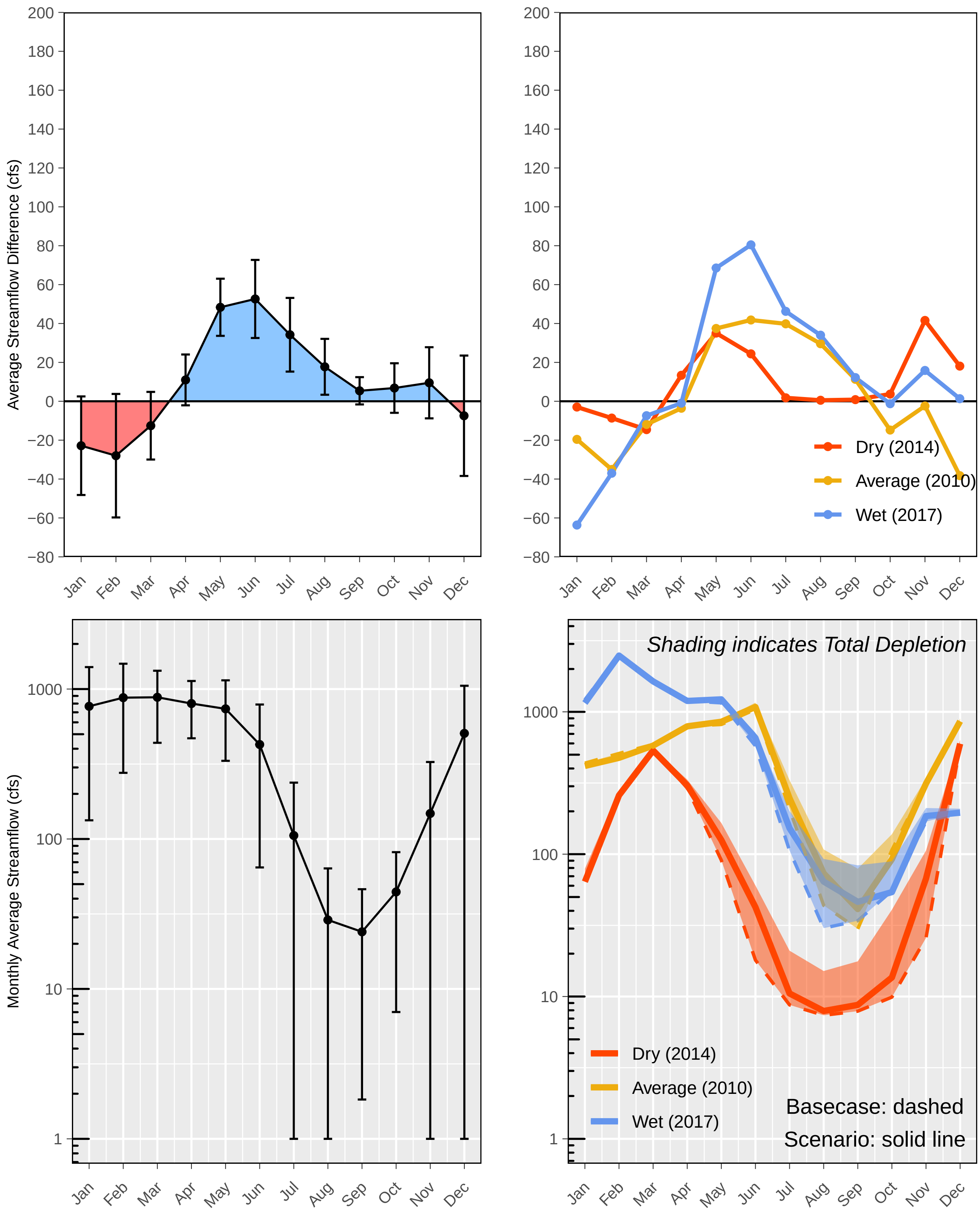
No Irrigation Outside Adjudicated Zone, ET Check 1.0 NV kc, 4.5m ext.d.



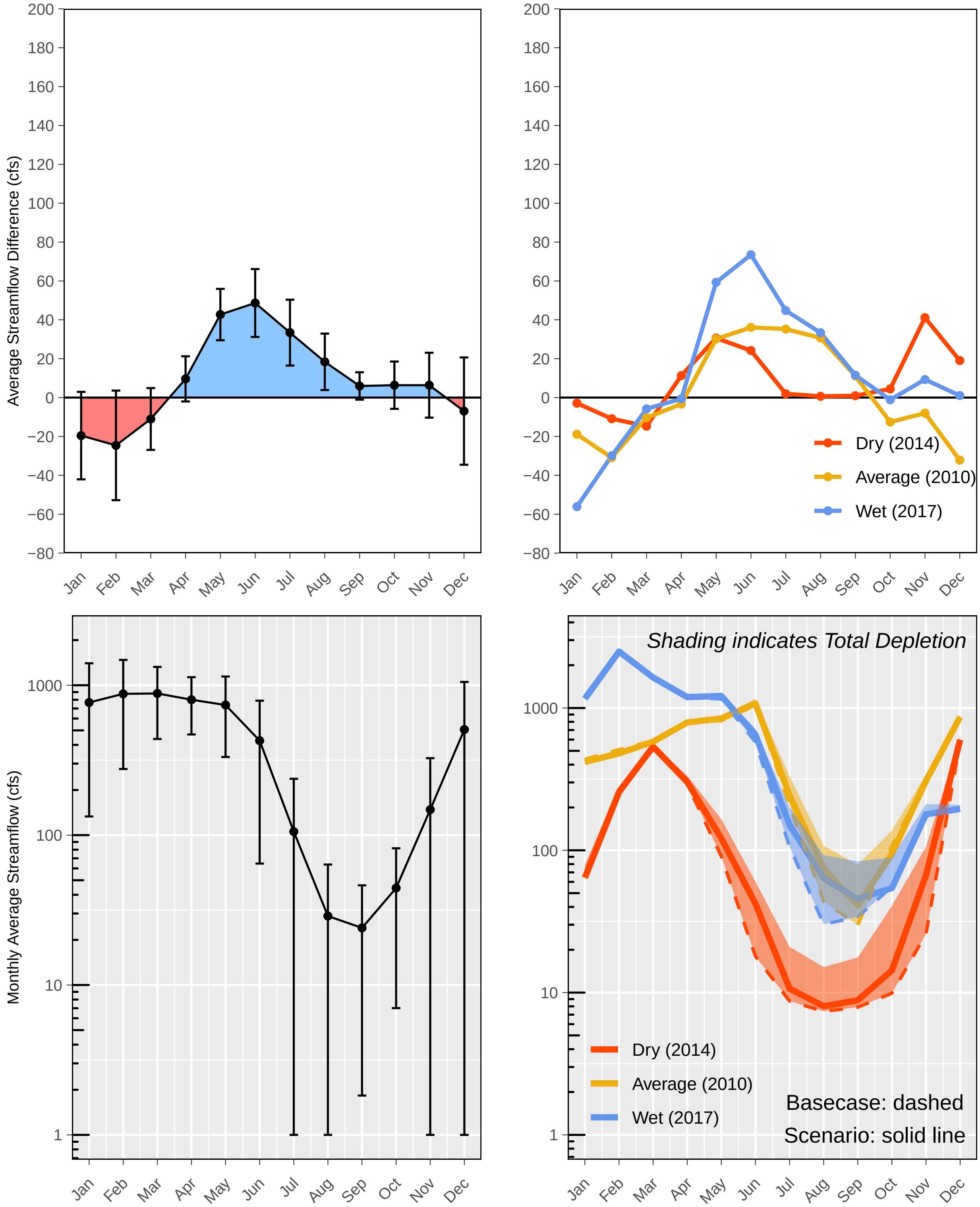
No Pumping Outside Adjudicated Zone, ET Check 1.0 NV kc, 4.5m ext.d.



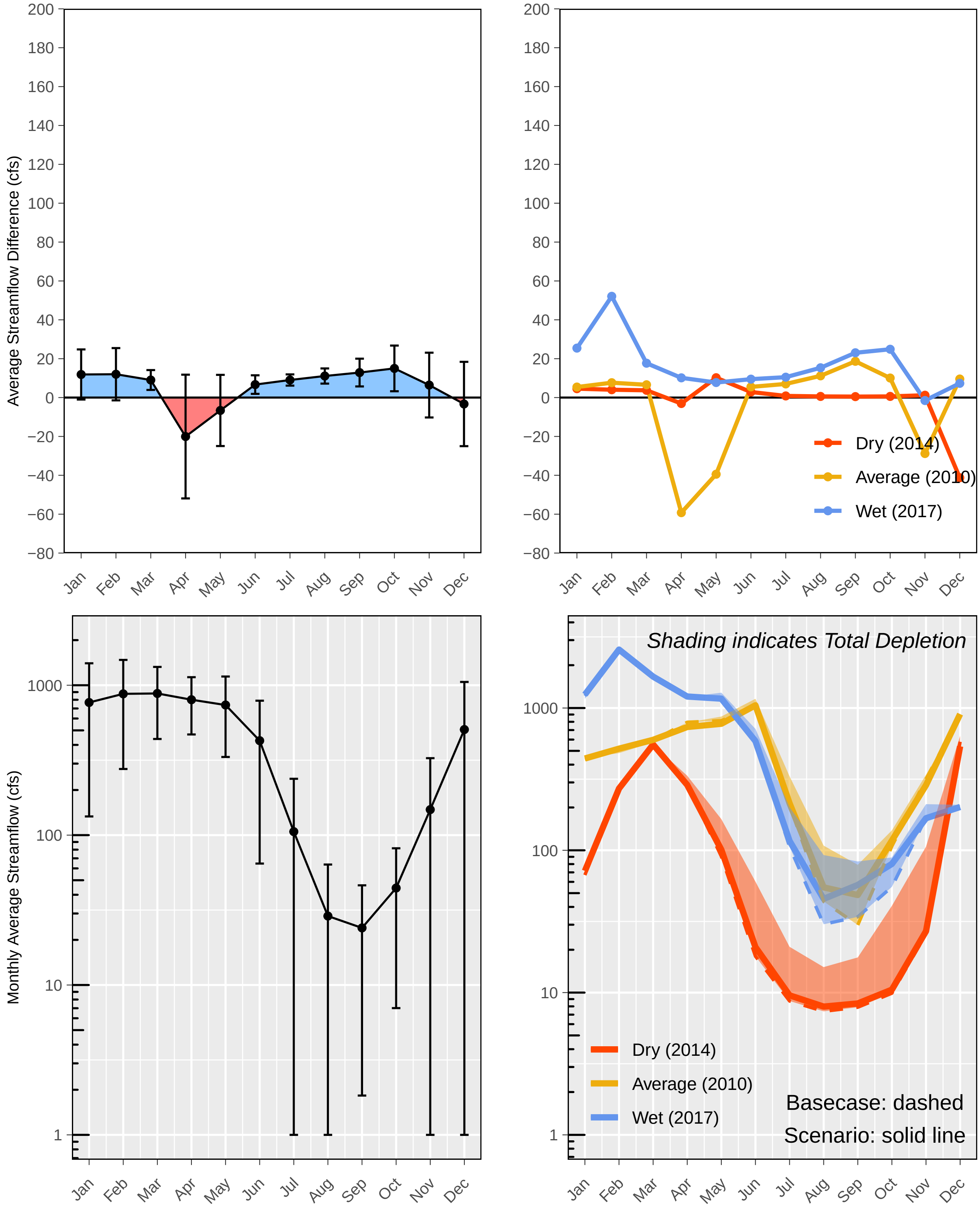
No Irrigation Inside Adjudicated Zone, ET Check 1.0 NV kc, 4.5m ext.d.



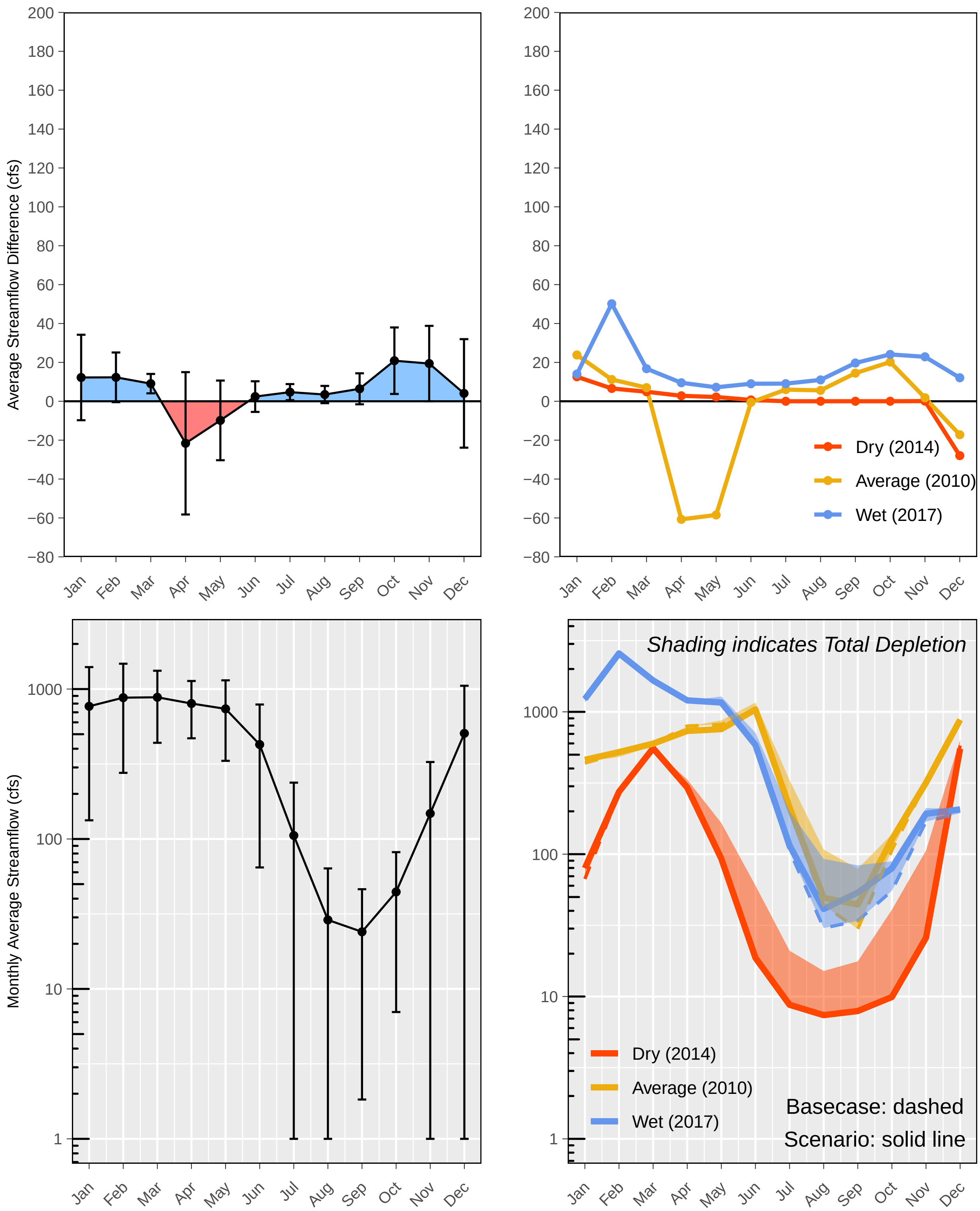
No Pumping Inside Adjudicated Zone, ET Check 1.0 NV kc, 4.5m ext.d.



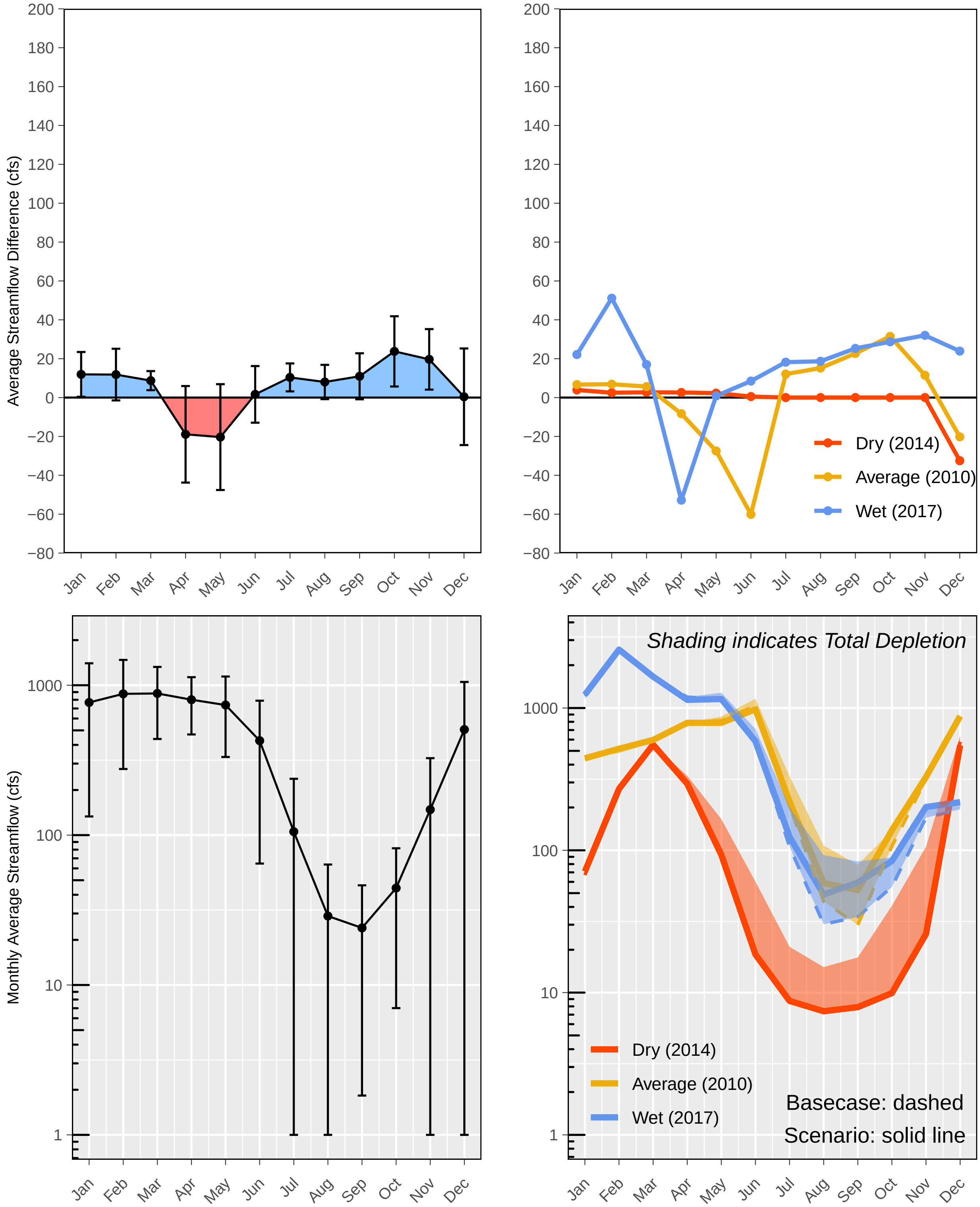
9 TAF Reservoir, Shackleford Creek



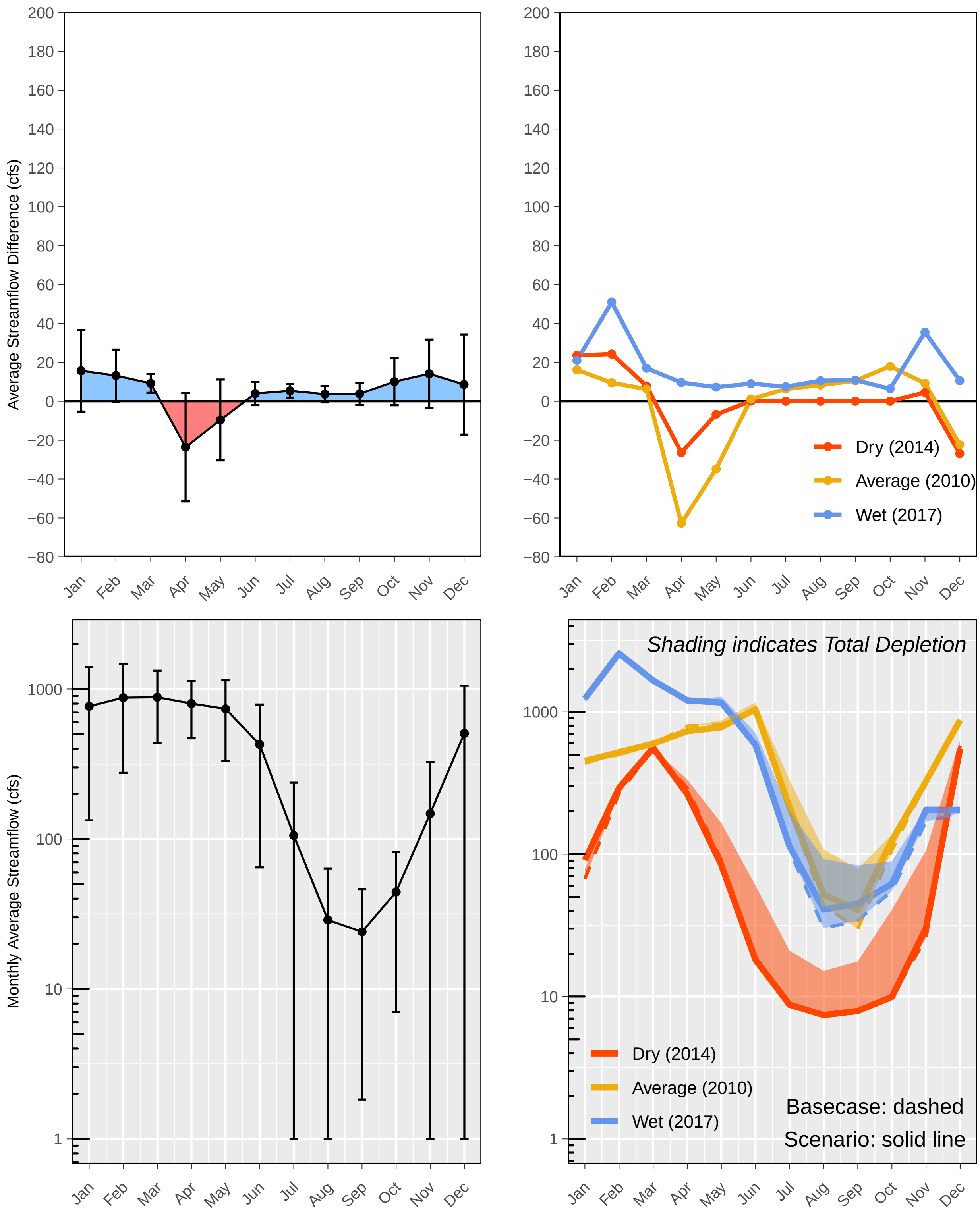
9 TAF Reservoir, Etna Creek



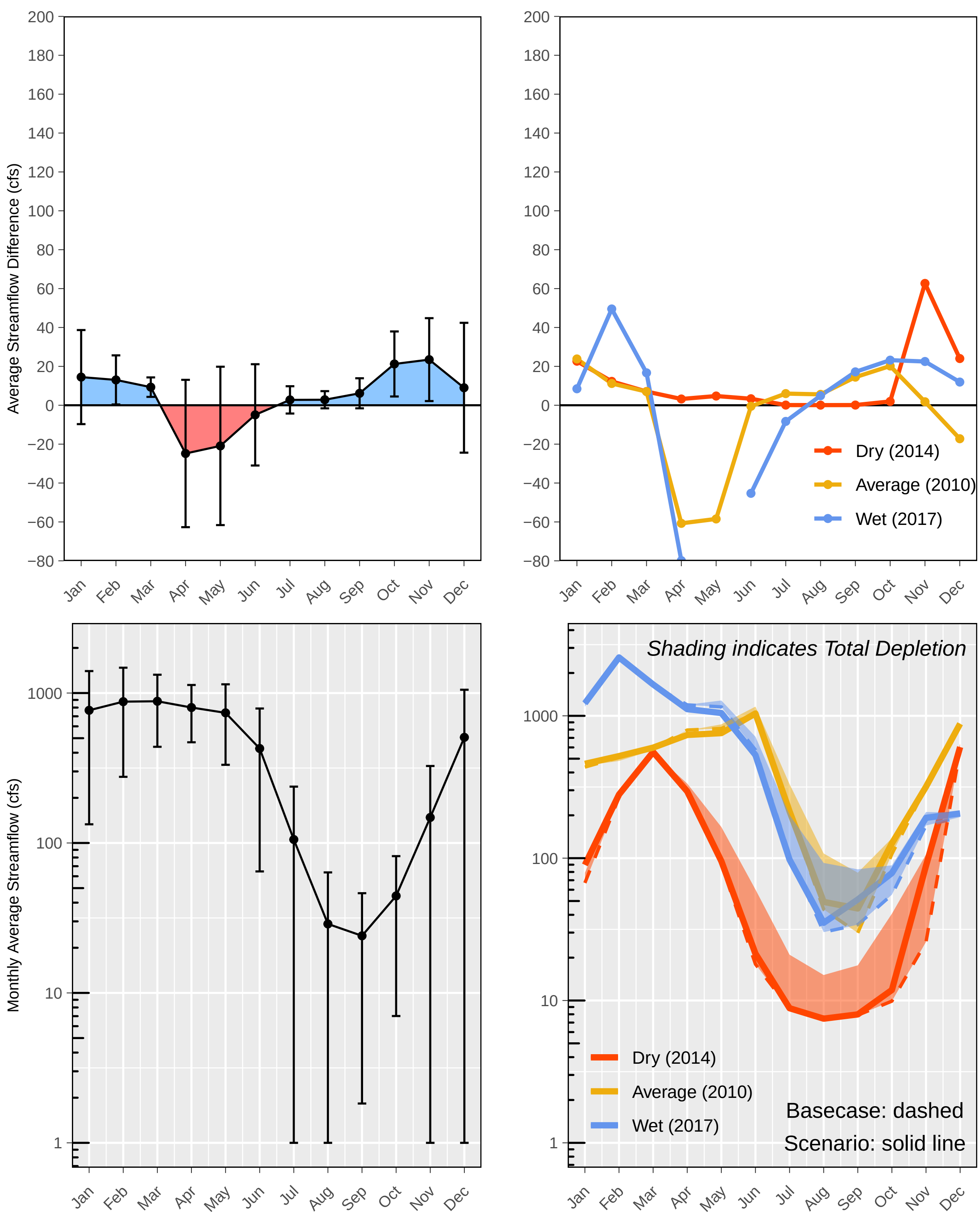
9 TAF Reservoir, French Creek



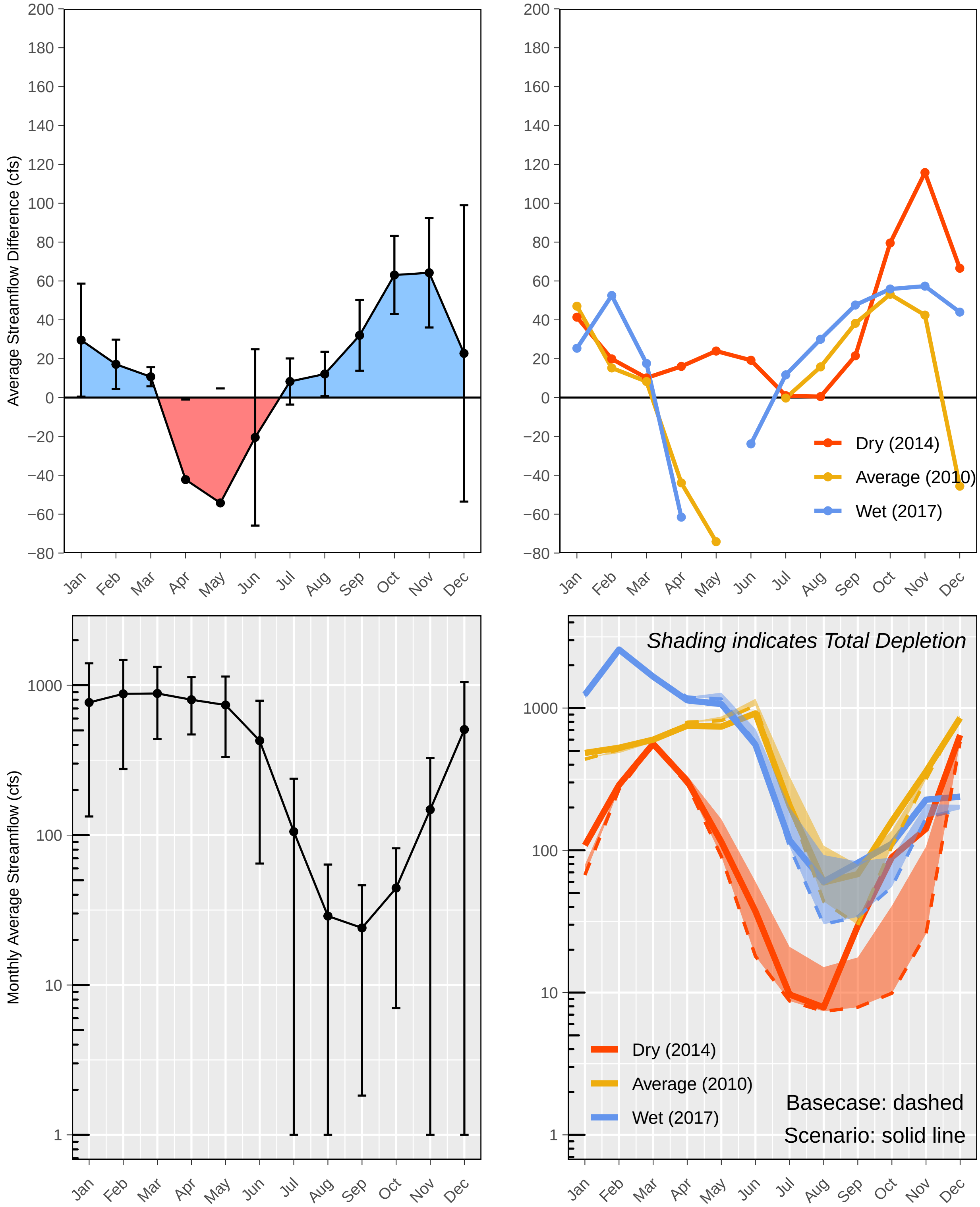
9 TAF Reservoir, South Fork



Reservoir, Etna Creek, 100% dry season 30 cfs release



Reservoir, Etna Creek, 100% dry season 60 cfs release



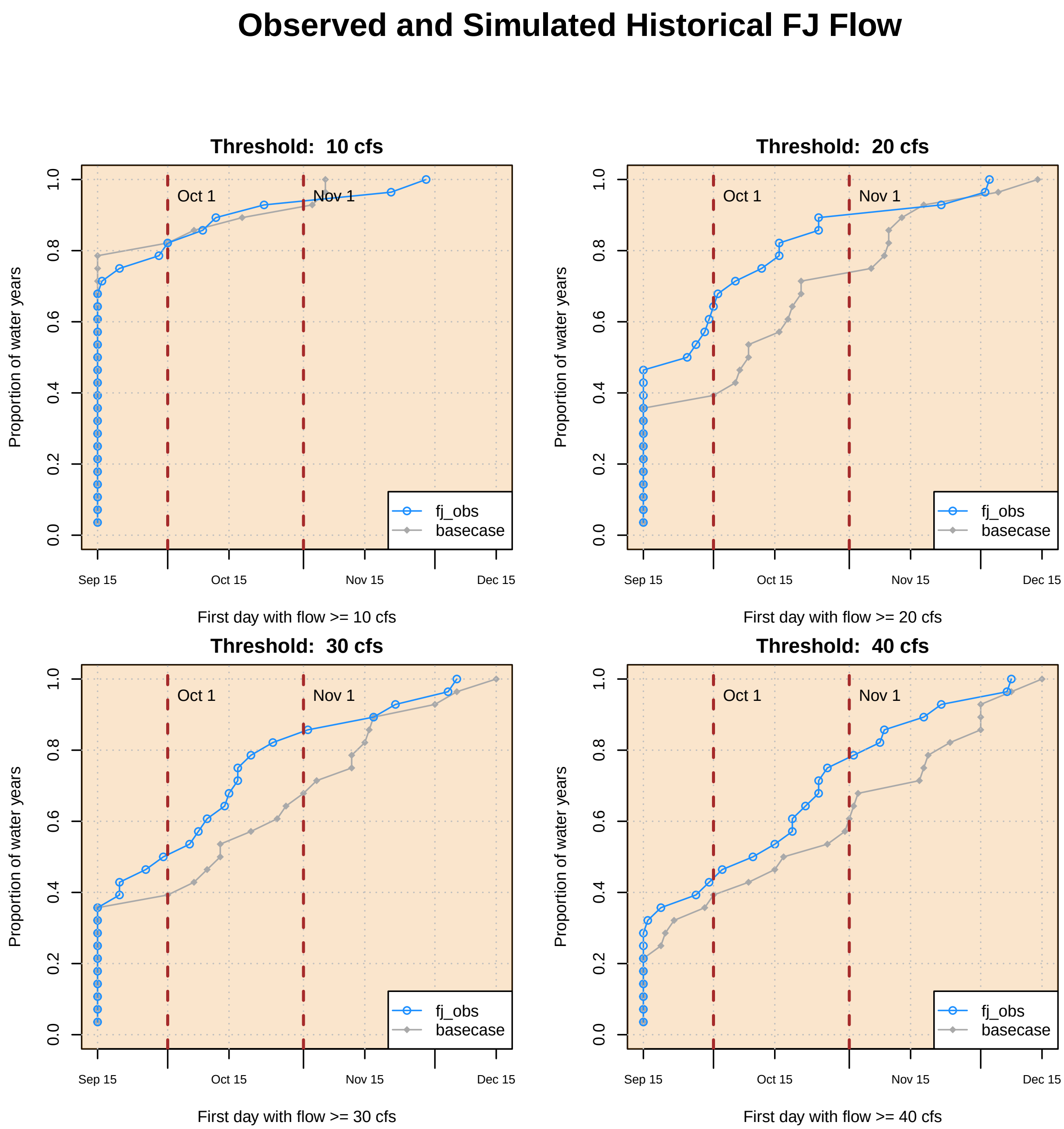
•

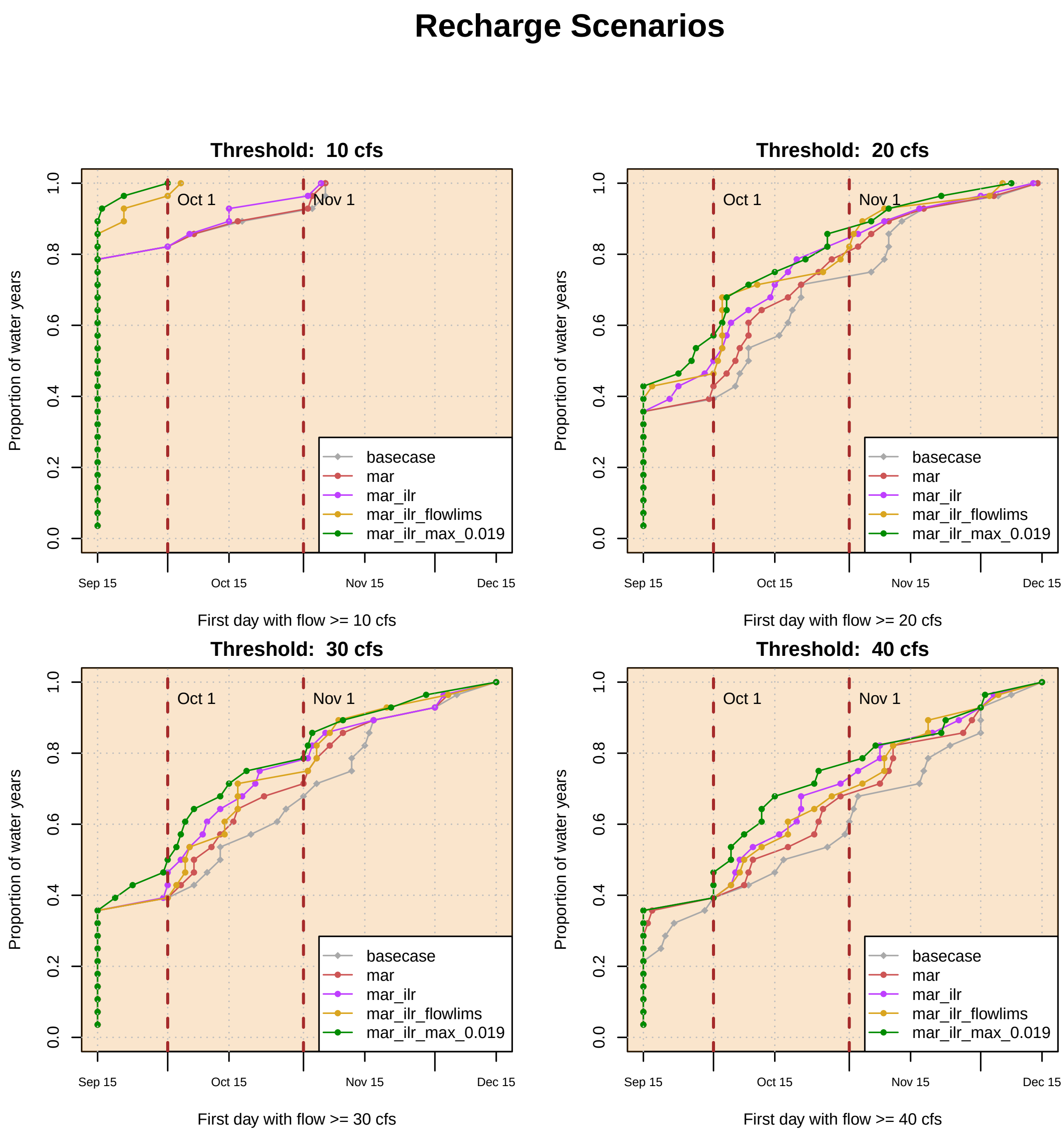
Rising flows in the fall (“reconnection” date distribution)

In the late summer and early fall, the Scott River can be dry, or running so low as to be impassable for spawning salmon. In these years, the “reconnection date” of the river is an important metric of ecosystem services: did the river become passable for salmon early enough in the spawning season?

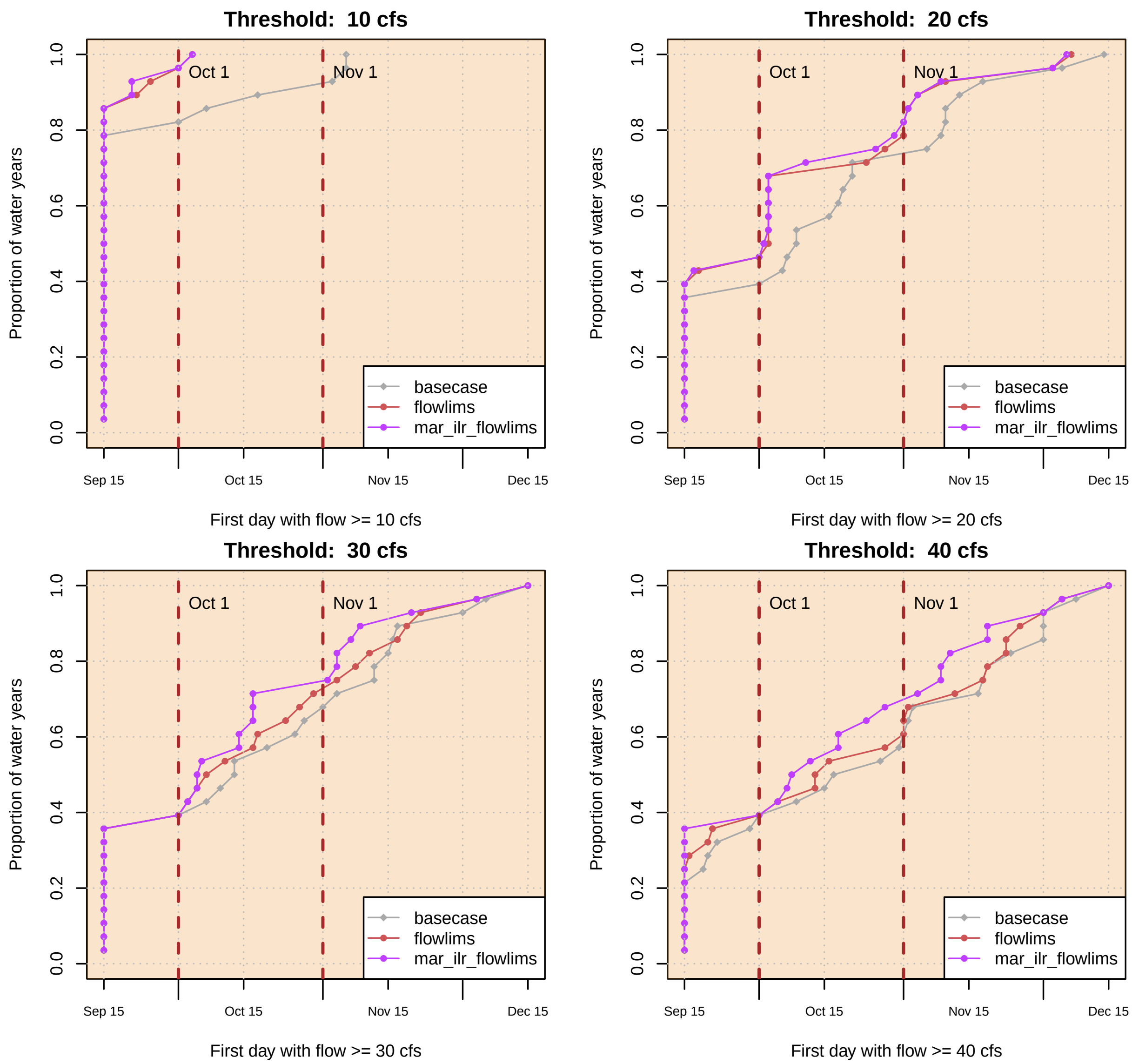
These results show the distribution of threshold-crossing dates of flow at the Fort Jones Gauge, or the first date in the fall season on which the flow exceeded a threshold. This threshold-crossing metric is assumed to be a proxy for reconnection dates. Multiple thresholds are depicted (10, 20, 30 and 40 cfs) to indicate uncertainty in the exact threshold of “reconnection” of different parts of the lower Scott River stream system.

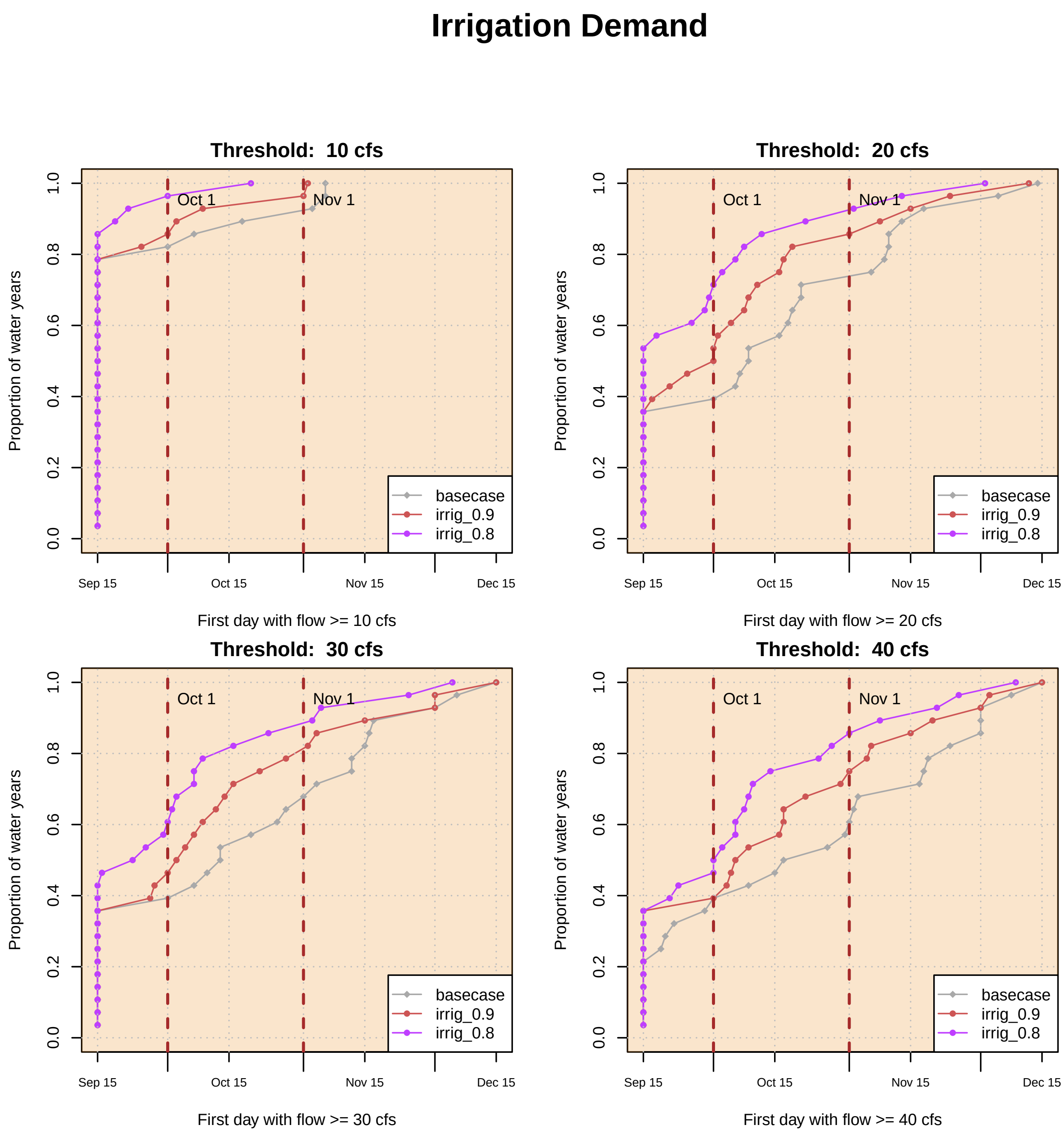
In general, scenarios in which more water years rise above the threshold earlier indicate more favorable hydrologic conditions (or, more dots on the left side of the plots is better). See explanatory graphs at the beginning of this appendix for more information.


Observed and Simulated Historical FJ Flow
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Oct 1
Nov 1
fj_obs
basecase
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Sep 15
Oct 15
Nov 15
Dec 15
First day with flow >= 10 cfs
First day with flow >= 20 cfs
First day with flow >= 30 cfs
First day with flow >= 40 cfs

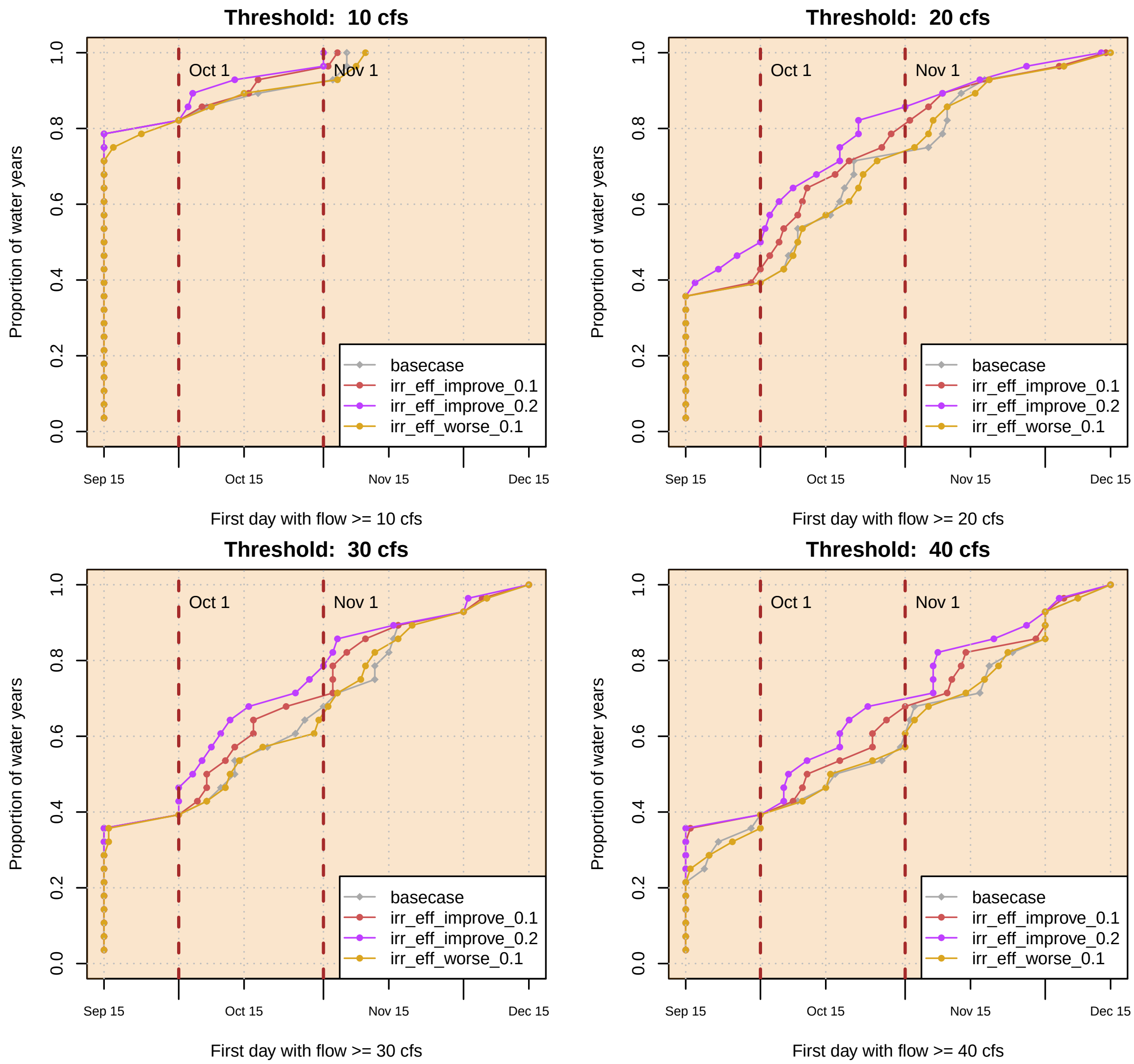

Recharge Scenarios
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Oct 1
Nov 1
Sep 15
Oct 15
Nov 15
Dec 15
basecase
mar
mar_ilr
mar_ilr_flowlims
mar_ilr_max_0.019
First day with flow >= 10 cfs
First day with flow >= 20 cfs
First day with flow >= 30 cfs
First day with flow >= 40 cfs

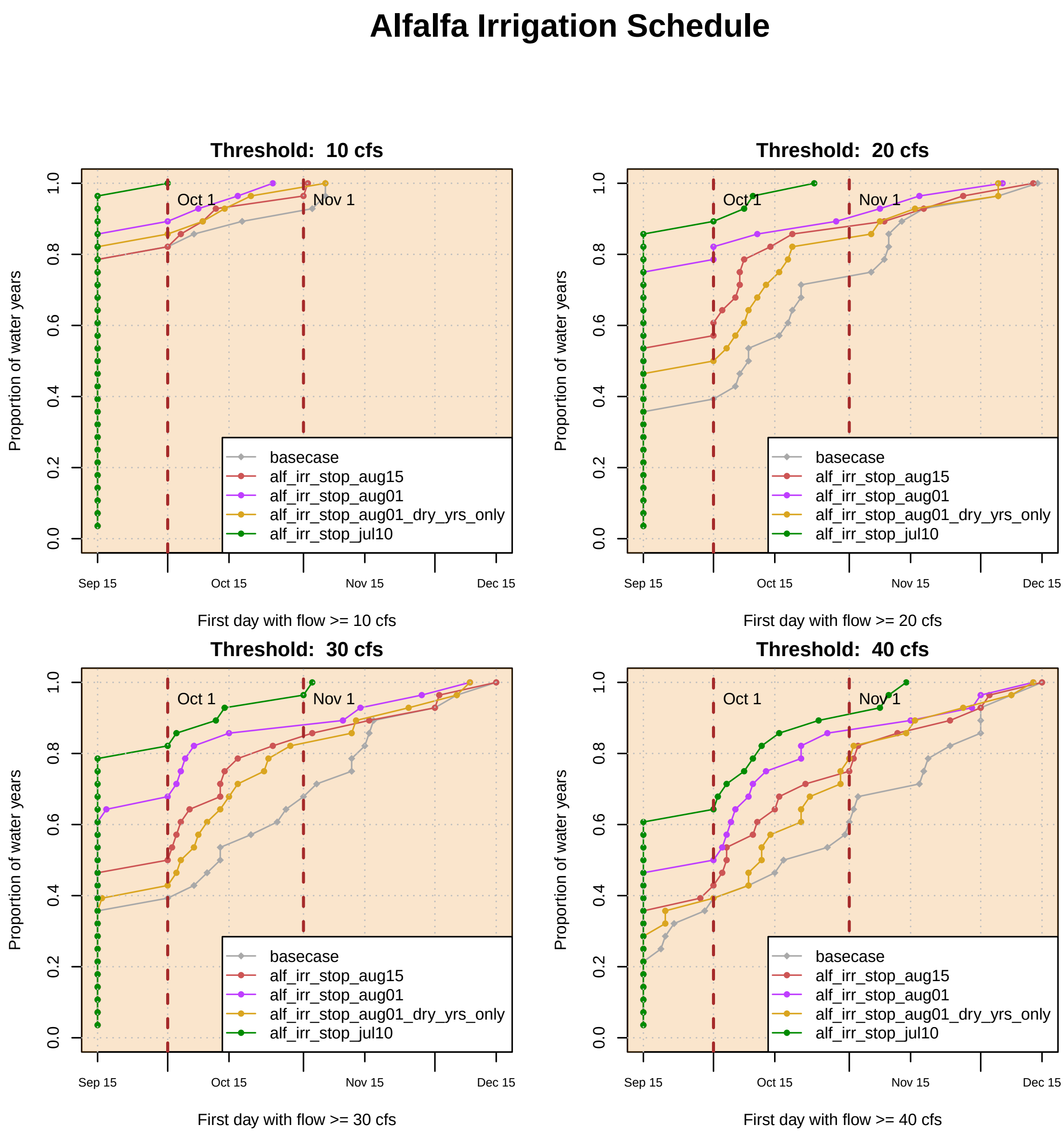
Tributary Diversion Limits at Low FLows

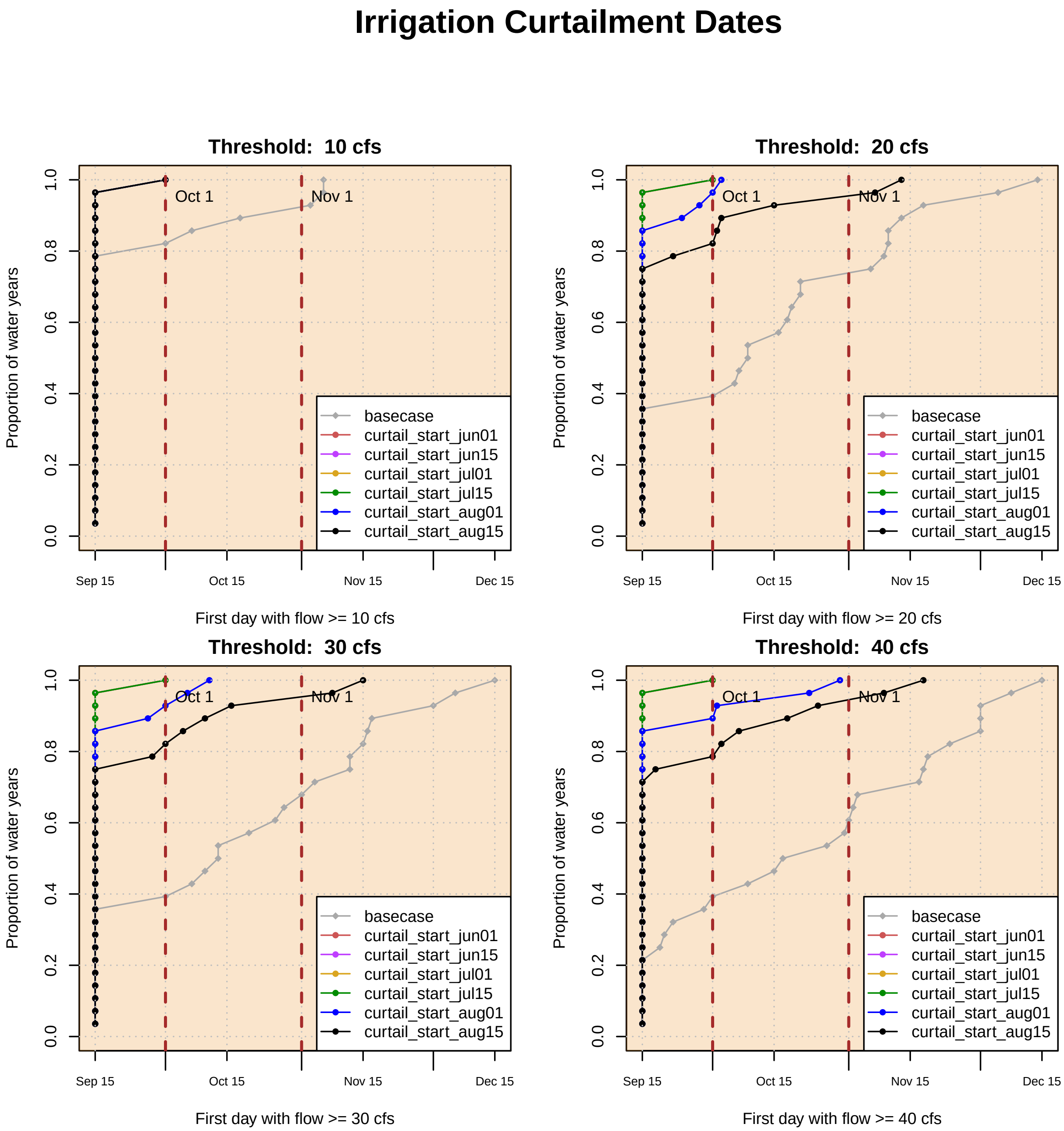



Irrigation Demand
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Oct 1
Nov 1
Sep 15
Oct 15
Nov 15
Dec 15
basecase
irrig_0.9
irrig_0.8
First day with flow >= 10 cfs
First day with flow >= 20 cfs
First day with flow >= 30 cfs
First day with flow >= 40 cfs

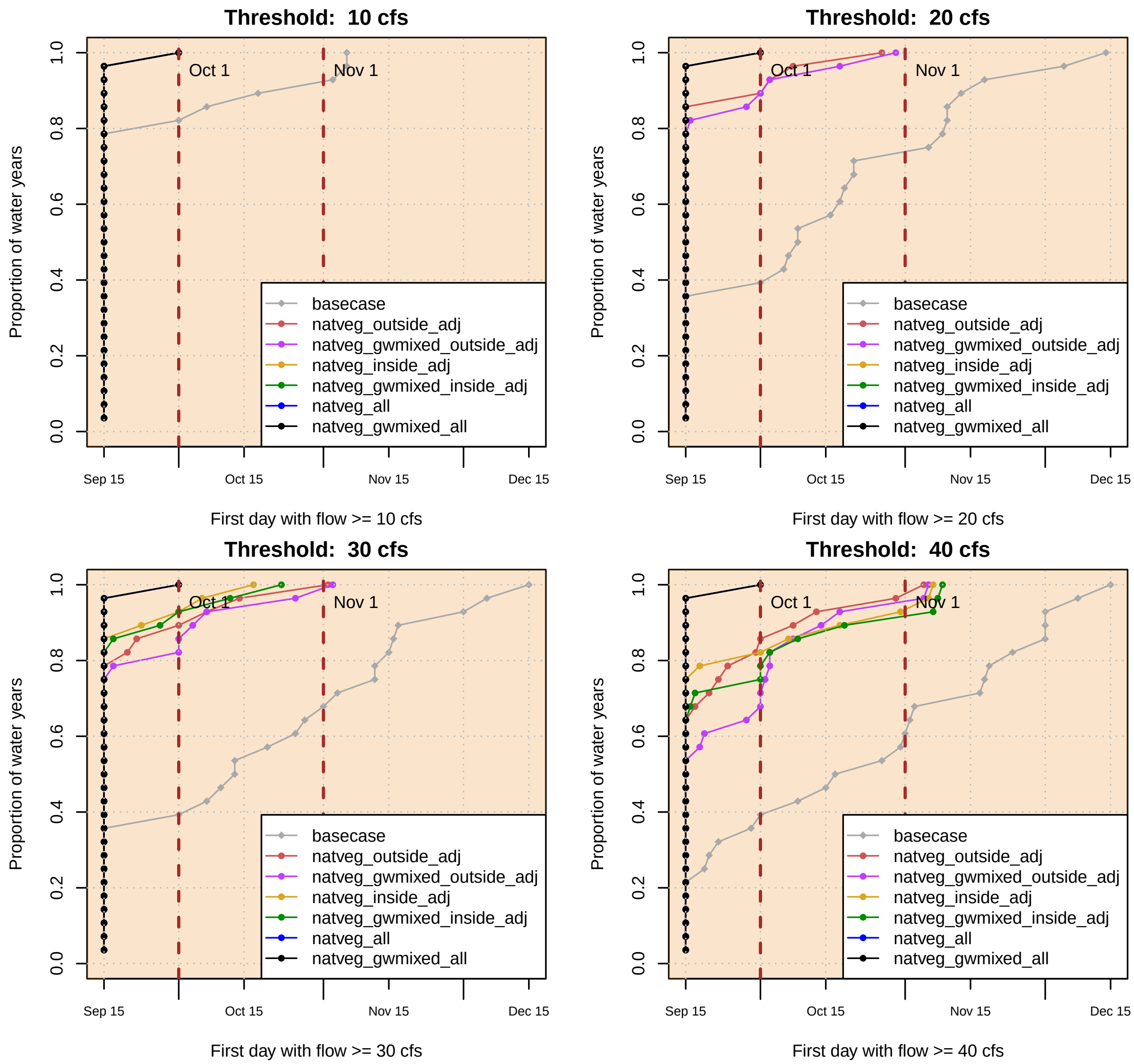
Irrigation Efficiency



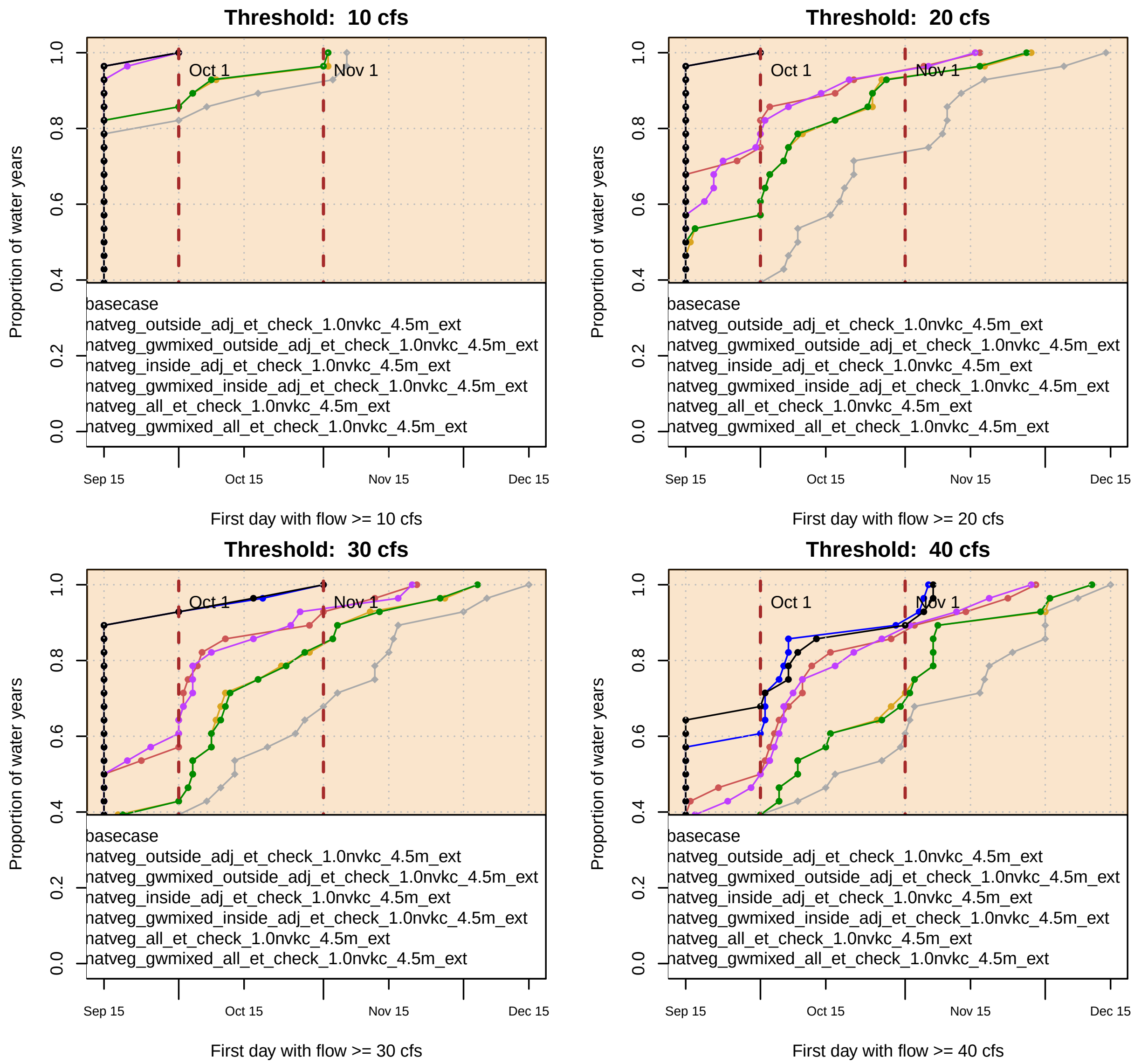

Alfalfa Irrigation Schedule
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Oct 1
Nov 1
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Sep 15
Oct 15
Nov 15
Dec 15
basecase
alf_irr_stop_aug15
alf_irr_stop_aug01
alf_irr_stop_aug01_dry_yrs_only
alf_irr_stop_jul10
First day with flow >= 10 cfs
First day with flow >= 20 cfs
First day with flow >= 30 cfs
First day with flow >= 40 cfs

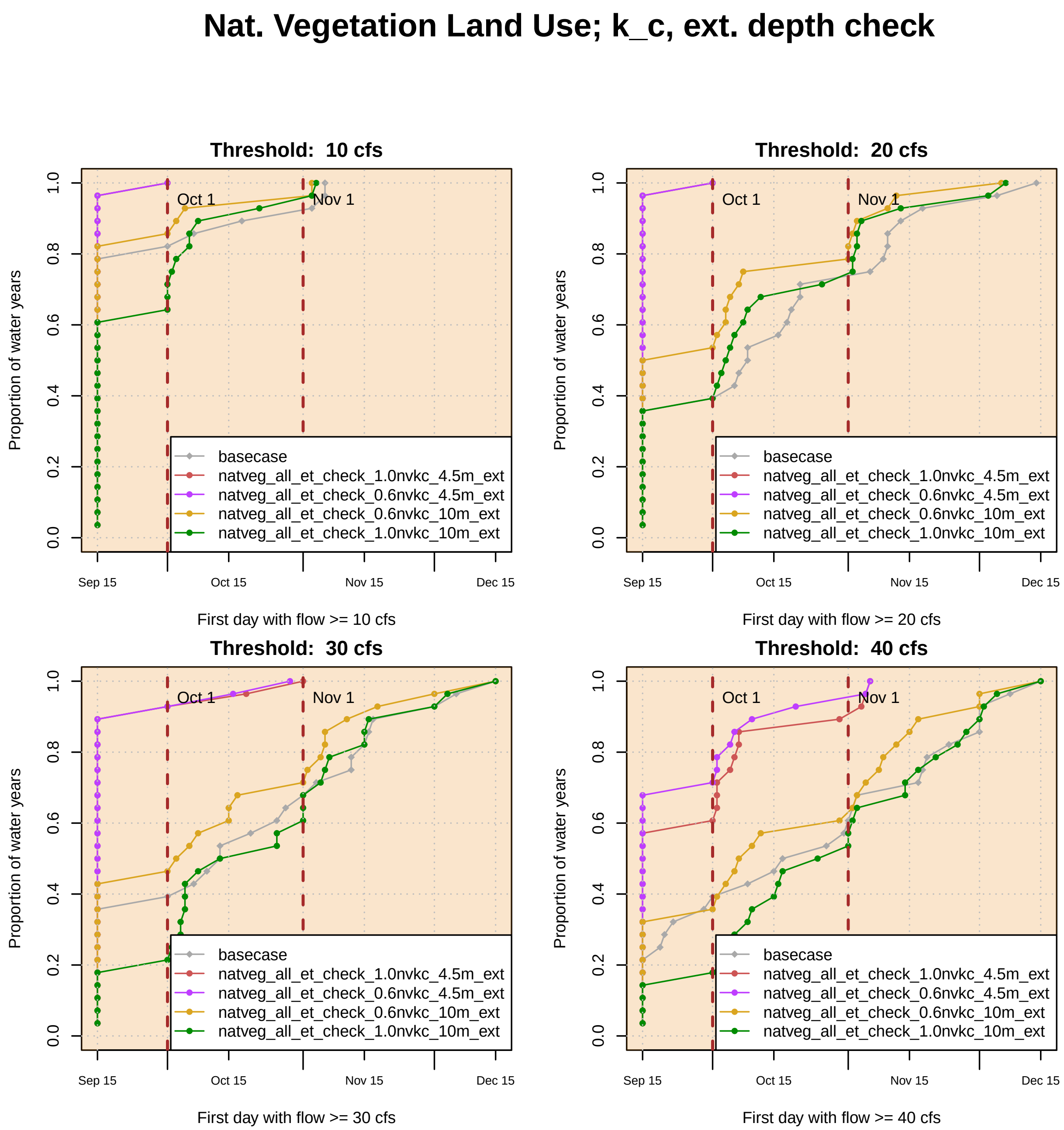

Irrigation Curtailment Dates
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Oct 1
Nov 1
Sep 15
Oct 15
Nov 15
Dec 15
basecase
curtail_start_jun01
curtail_start_jun15
curtail_start_jul01
curtail_start_jul15
curtail_start_aug01
curtail_start_aug15
First day with flow >= 10 cfs
First day with flow >= 20 cfs
First day with flow >= 30 cfs
First day with flow >= 40 cfs

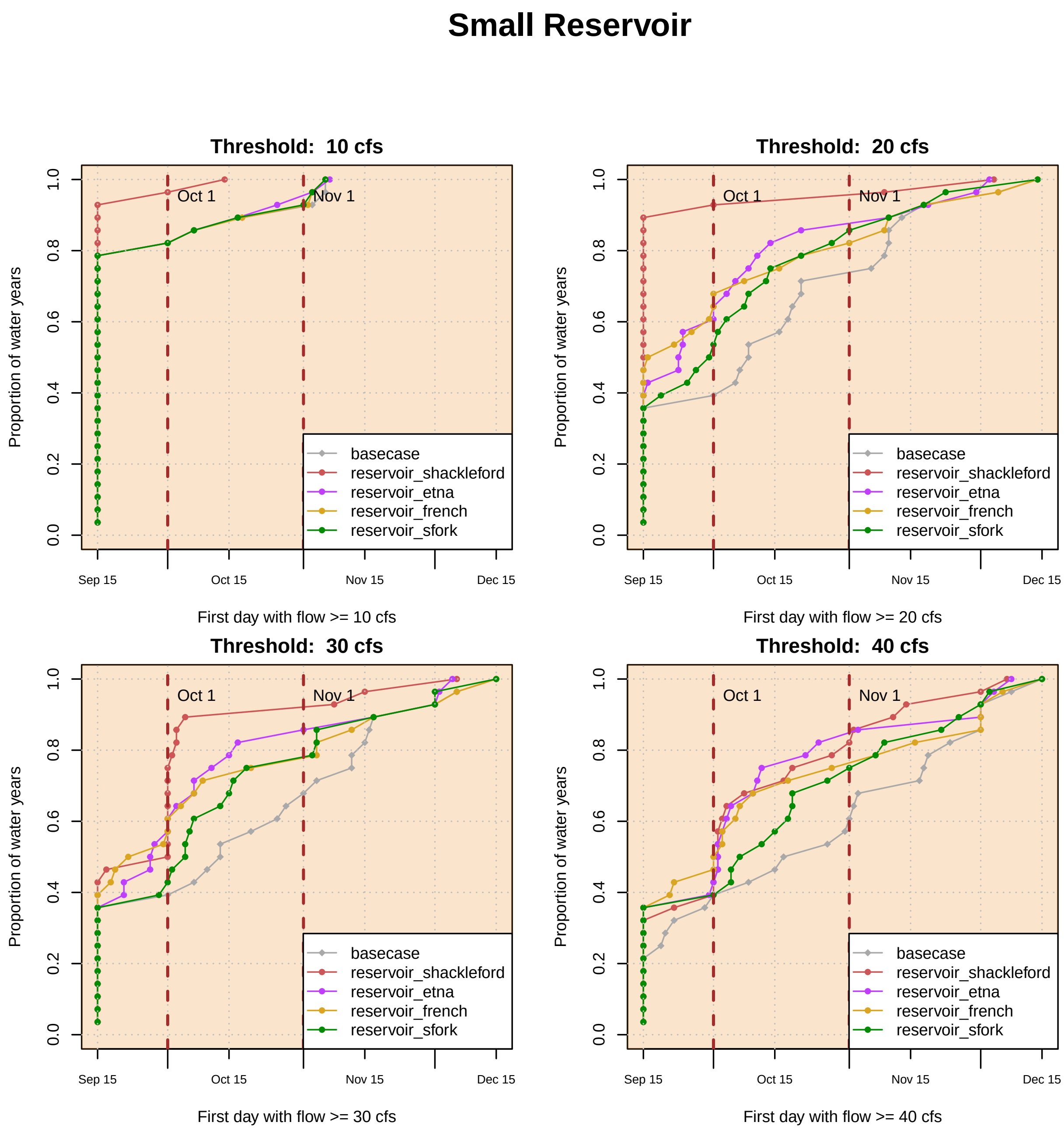
Nat. Vegetation Land Use, 0.6 kc, ET from GW in DZ only



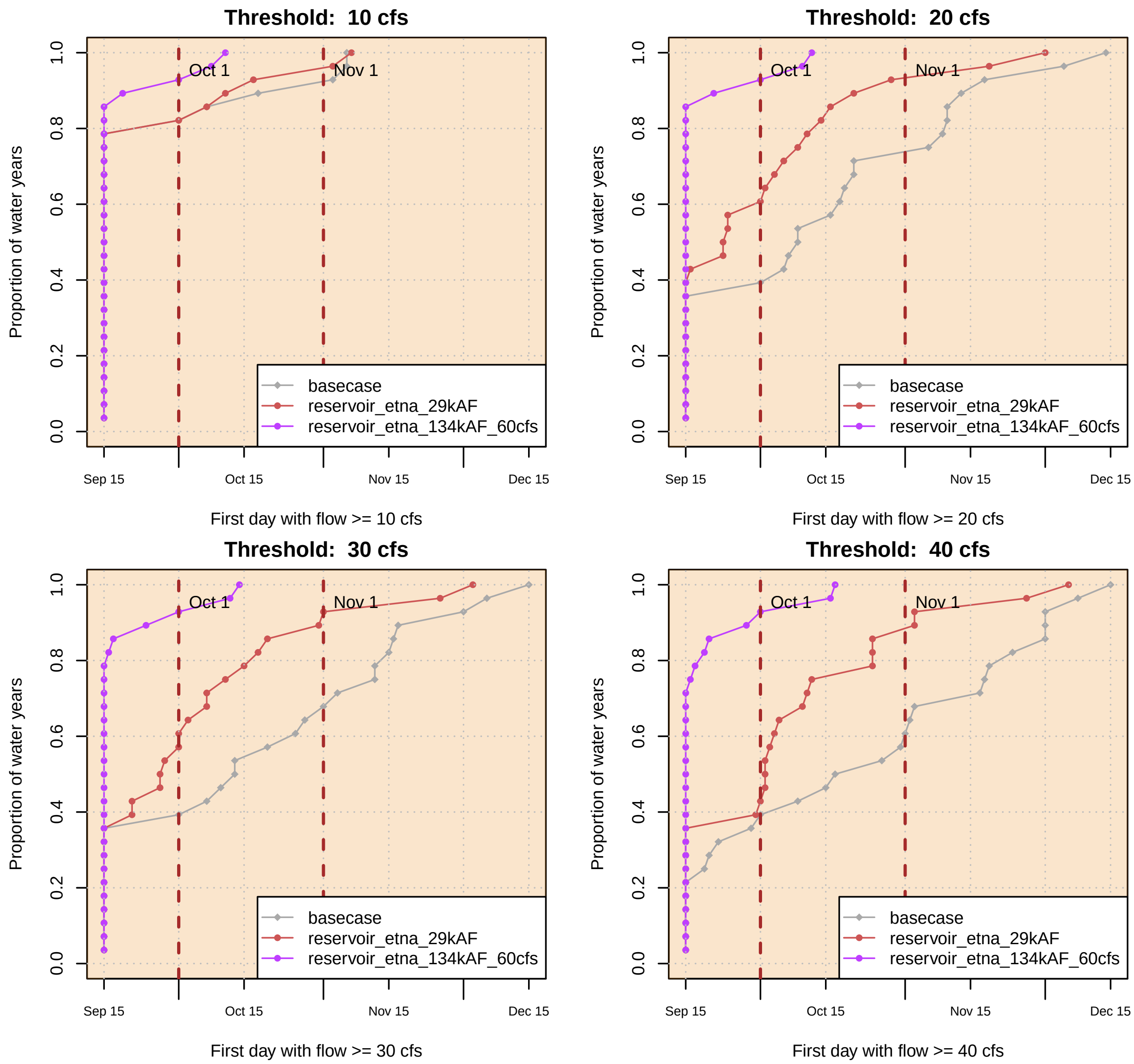
Natural Vegetation Land Use (1.0 kc, 4.5m)




Nat. Vegetation Land Use; k_c, ext. depth check
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Oct 1
Nov 1
Sep 15
Oct 15
Nov 15
Dec 15
basecase
natveg_all_et_check_1.0nvkc_4.5m_ext
natveg_all_et_check_0.6nvkc_4.5m_ext
natveg_all_et_check_0.6nvkc_10m_ext
natveg_all_et_check_1.0nvkc_10m_ext
First day with flow >= 10 cfs
First day with flow >= 20 cfs
First day with flow >= 30 cfs
First day with flow >= 40 cfs


Small Reservoir
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Oct 1
Nov 1
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Sep 15
Oct 15
Nov 15
Dec 15
basecase
reservoir_shackleford
reservoir_etna
reservoir_french
reservoir_sfork
First day with flow >= 10 cfs
First day with flow >= 20 cfs
First day with flow >= 30 cfs
First day with flow >= 40 cfs

100% Reliable Reservoir (30 or 60 cfs release)



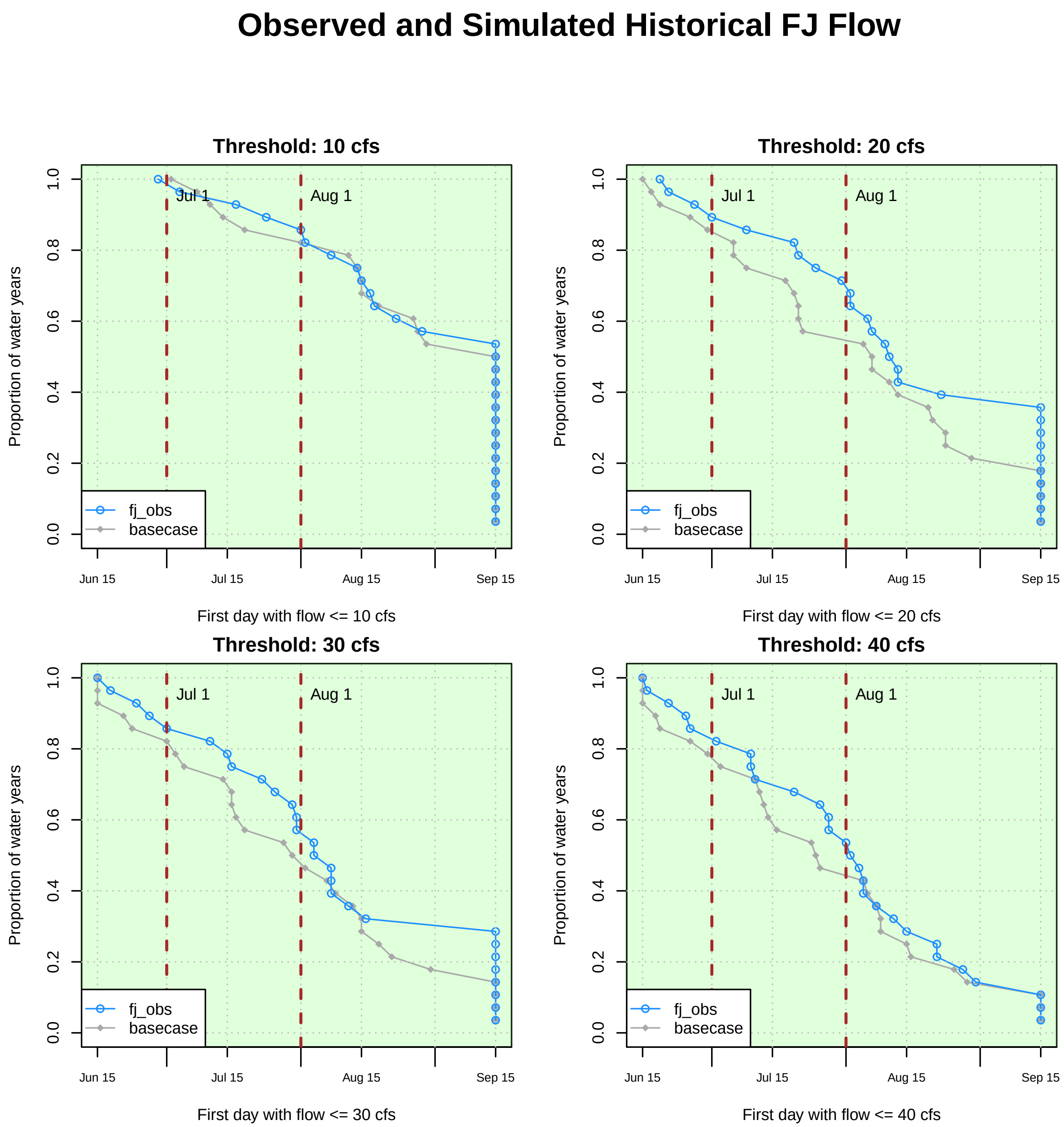
Declining flows in the summer ("disconnection" date distribution)

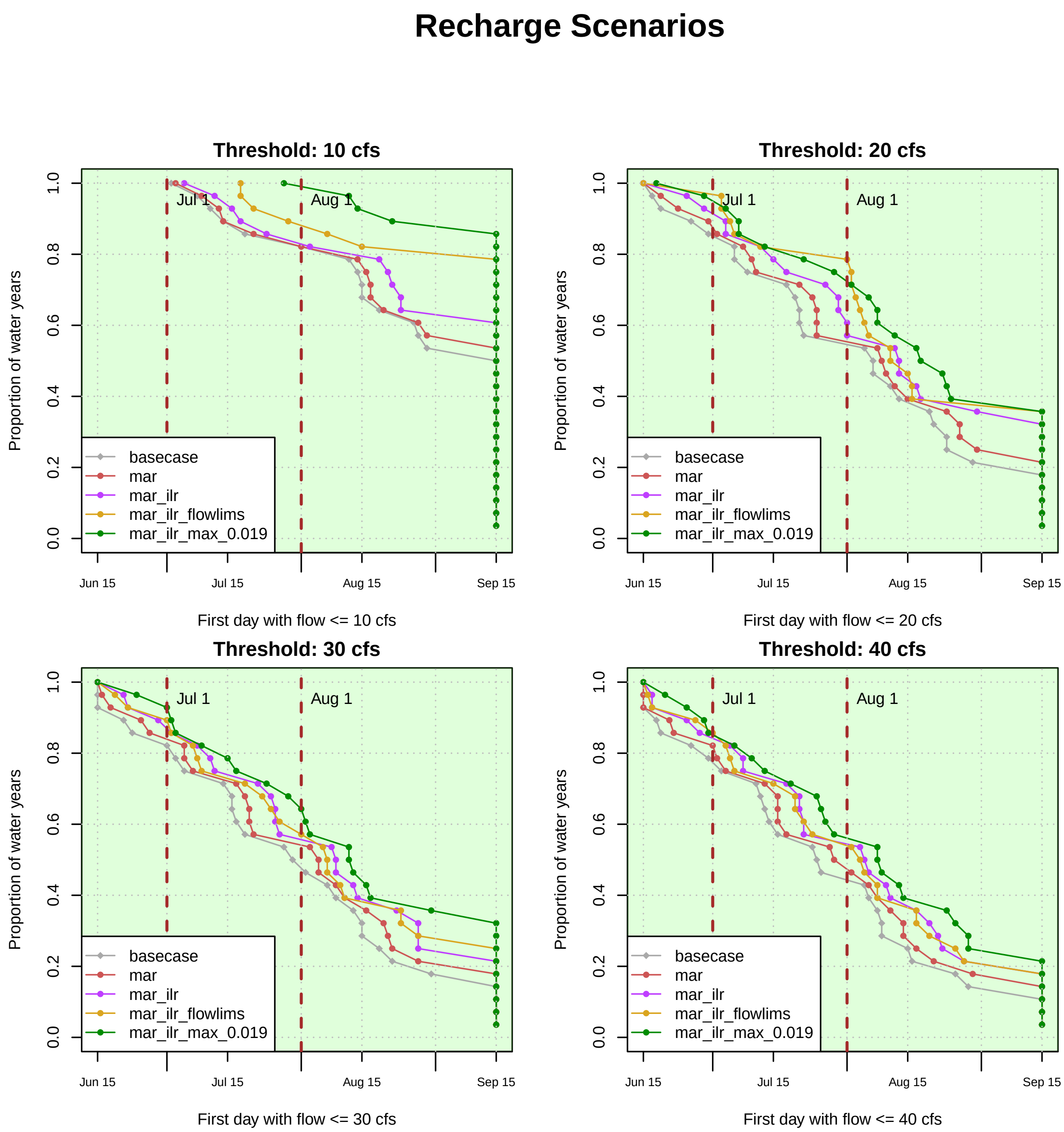
Over the course of the late spring and summer, the Scott River decreases gradually from snowmelt-influenced high flows to summer baseflow. Earlier decline in summer flows is believed to correspond to poorer habitat conditions for juvenile salmonids.

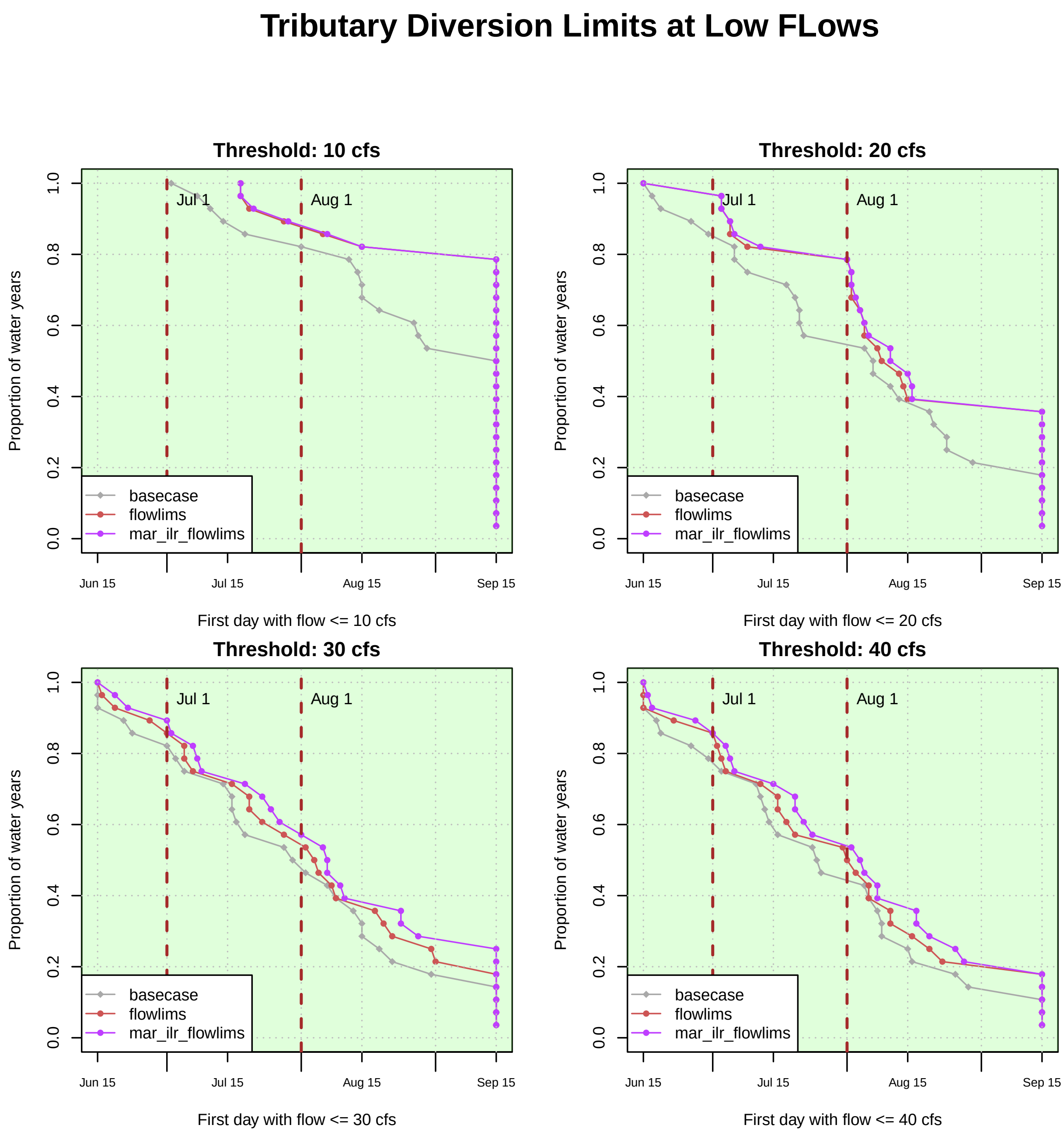
In particular, the "disconnection date" of the river is an important metric of ecosystem services: was the river flow high enough for long enough to allow juvenile salmonids to migrate out of the watershed towards the ocean?

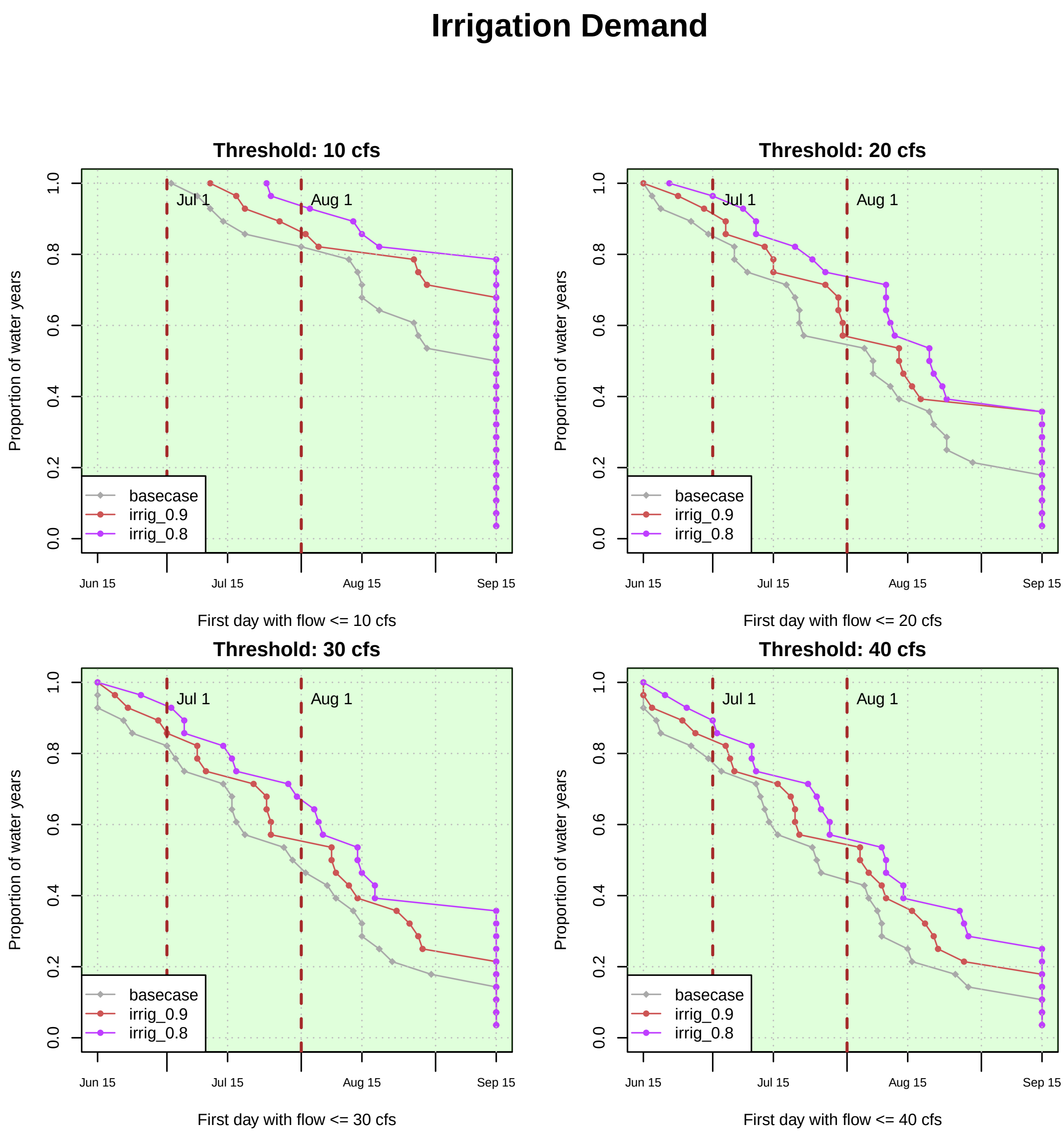
These results show the distribution of threshold-crossing dates of flow at the Fort Jones Gauge, or the first date in the summer season on which the flow fell below a threshold. This threshold-crossing metric is assumed to be a proxy for disconnection dates. Multiple thresholds are depicted (10, 20, 30 and 40 cfs) to indicate uncertainty in the exact threshold of "disconnection" of different parts of the lower Scott River stream system.

In general, scenarios in which more water years fall below the threshold later indicate more favorable hydrologic conditions (or, more dots on the right side of the plots is better). See explanatory graphs at the beginning of this appendix for more information.

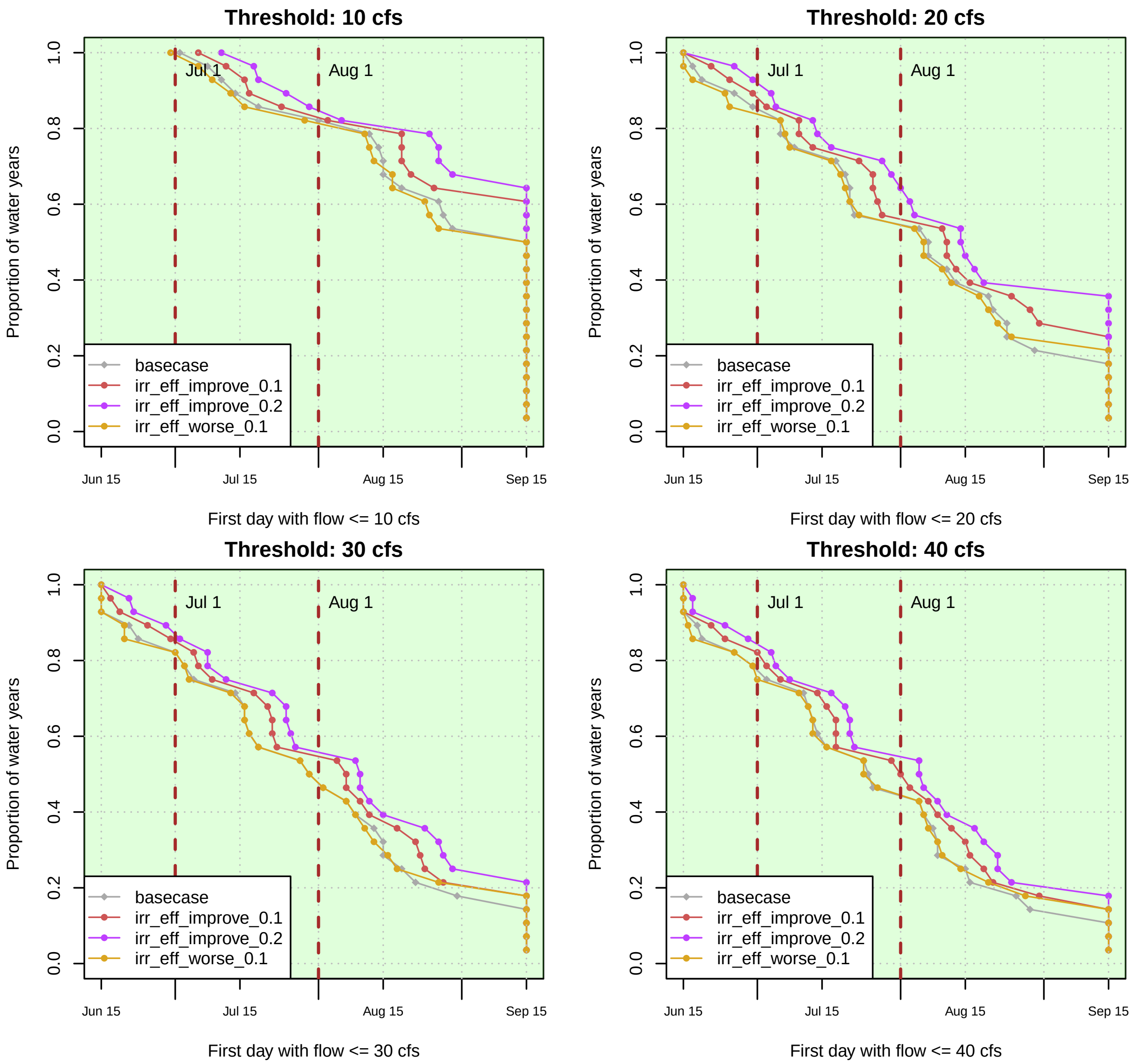

Observed and Simulated Historical FJ Flow
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Jul 1
Aug 1
fj_obs
basecase
Jun 15
Jul 15
Aug 15
Sep 15
First day with flow <= 10 cfs
First day with flow <= 20 cfs
First day with flow <= 30 cfs
First day with flow <= 40 cfs


Recharge Scenarios
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
Jul 1
Aug 1
Jun 15
Jul 15
Aug 15
Sep 15
basecase
mar
mar_ilr
mar_ilr_flowlims
mar_ilr_max_0.019
First day with flow <= 10 cfs
First day with flow <= 20 cfs
First day with flow <= 30 cfs
First day with flow <= 40 cfs

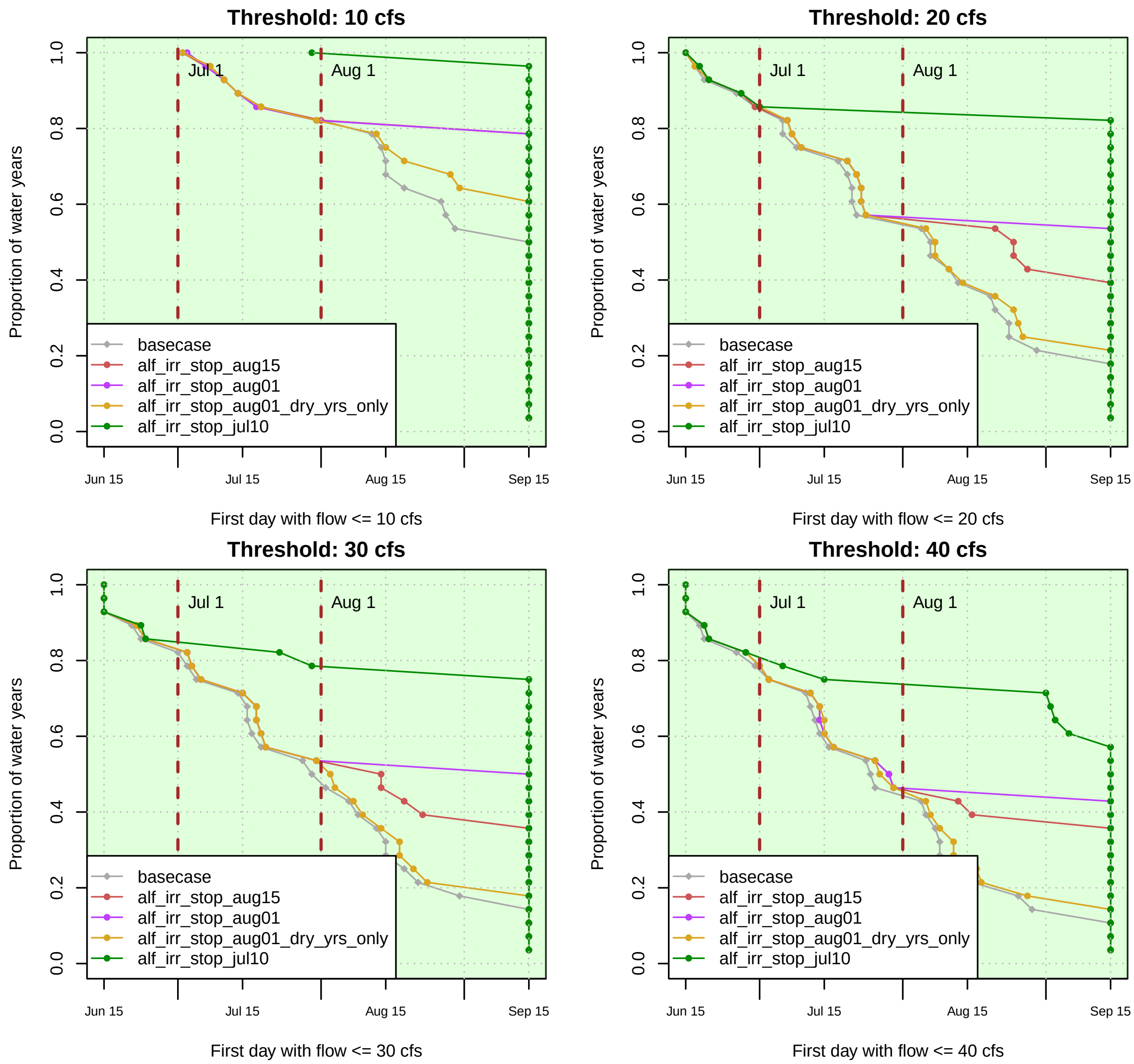

Tributary Diversion Limits at Low FLows
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Jul 1
Aug 1
Jun 15
Jul 15
Aug 15
Sep 15
basecase
flowlims
mar_ilr_flowlims
First day with flow <= 10 cfs
First day with flow <= 20 cfs
First day with flow <= 30 cfs
First day with flow <= 40 cfs

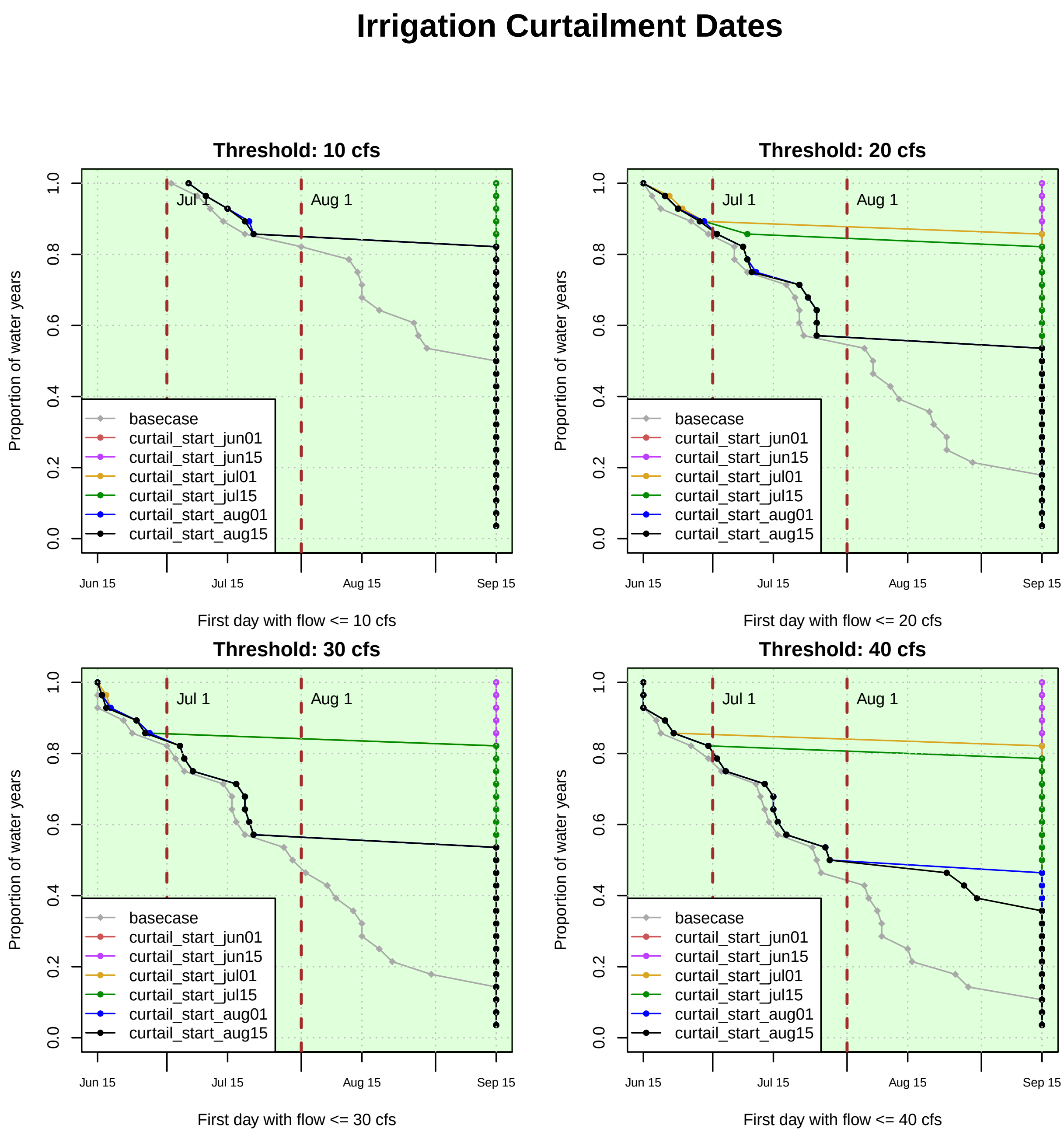

Irrigation Demand
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Jul 1
Aug 1
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Jun 15
Jul 15
Aug 15
Sep 15
basecase
irrig_0.9
irrig_0.8
First day with flow <= 10 cfs
First day with flow <= 20 cfs
First day with flow <= 30 cfs
First day with flow <= 40 cfs

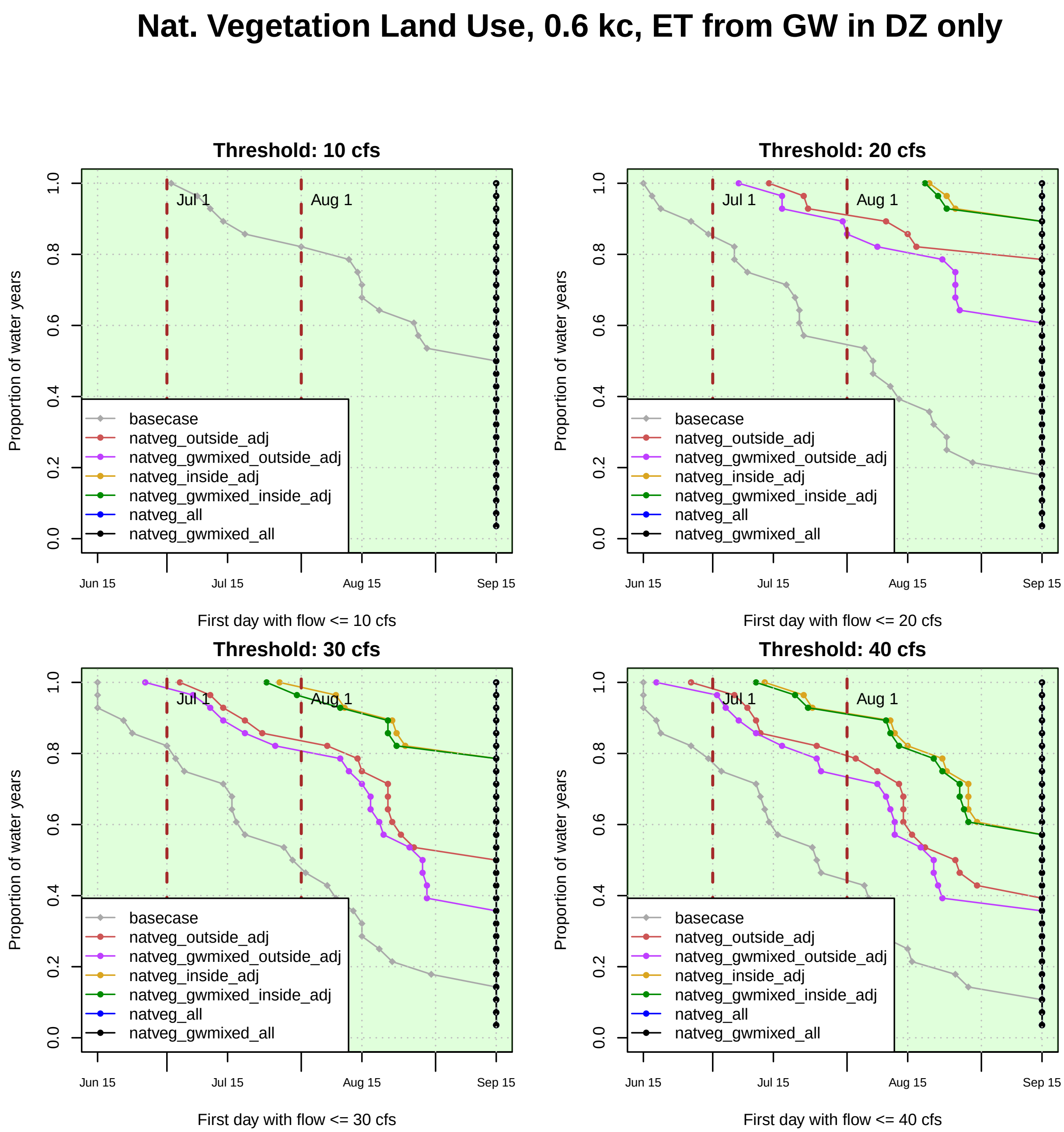
Irrigation Efficiency

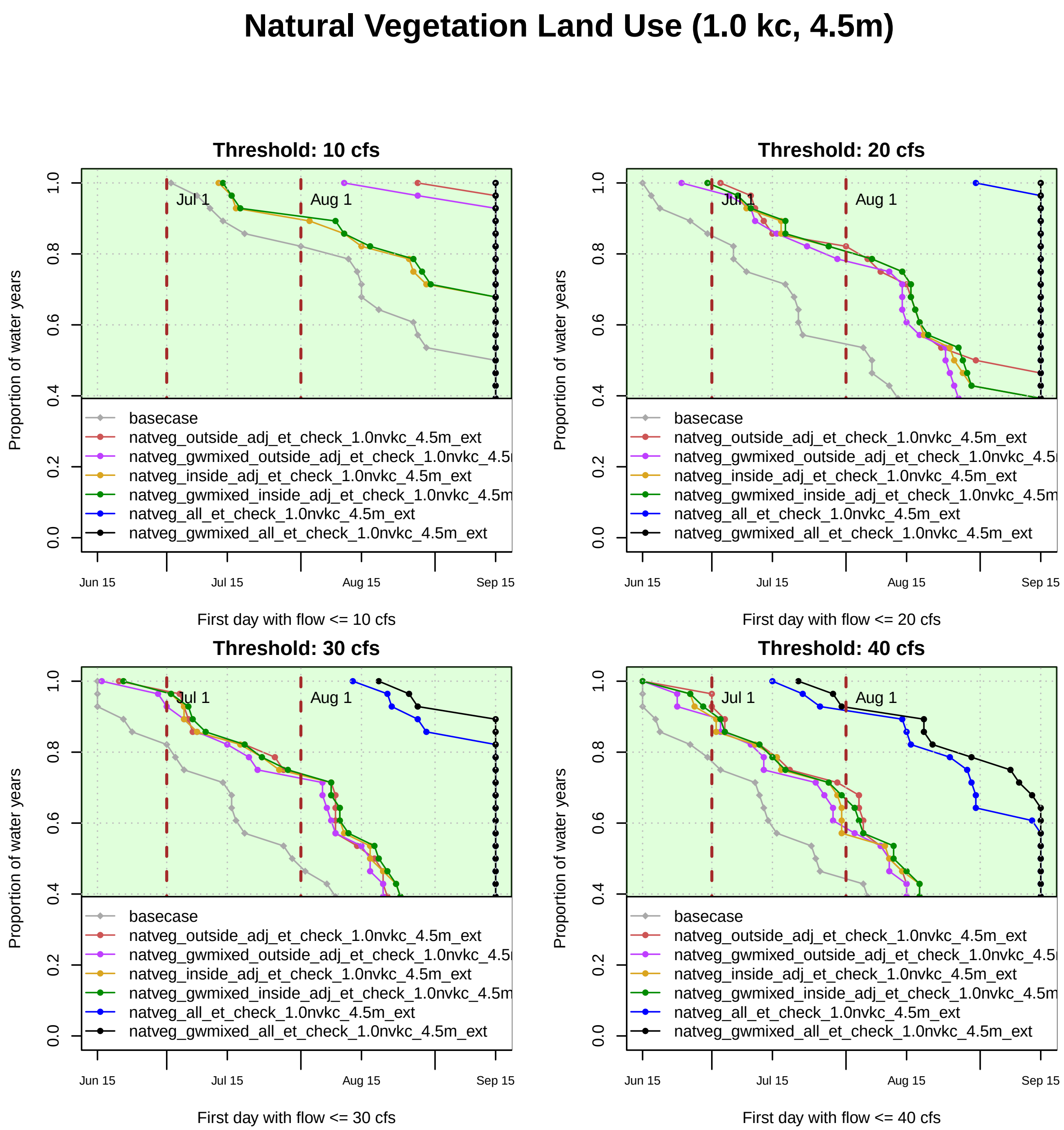


Alfalfa Irrigation Schedule

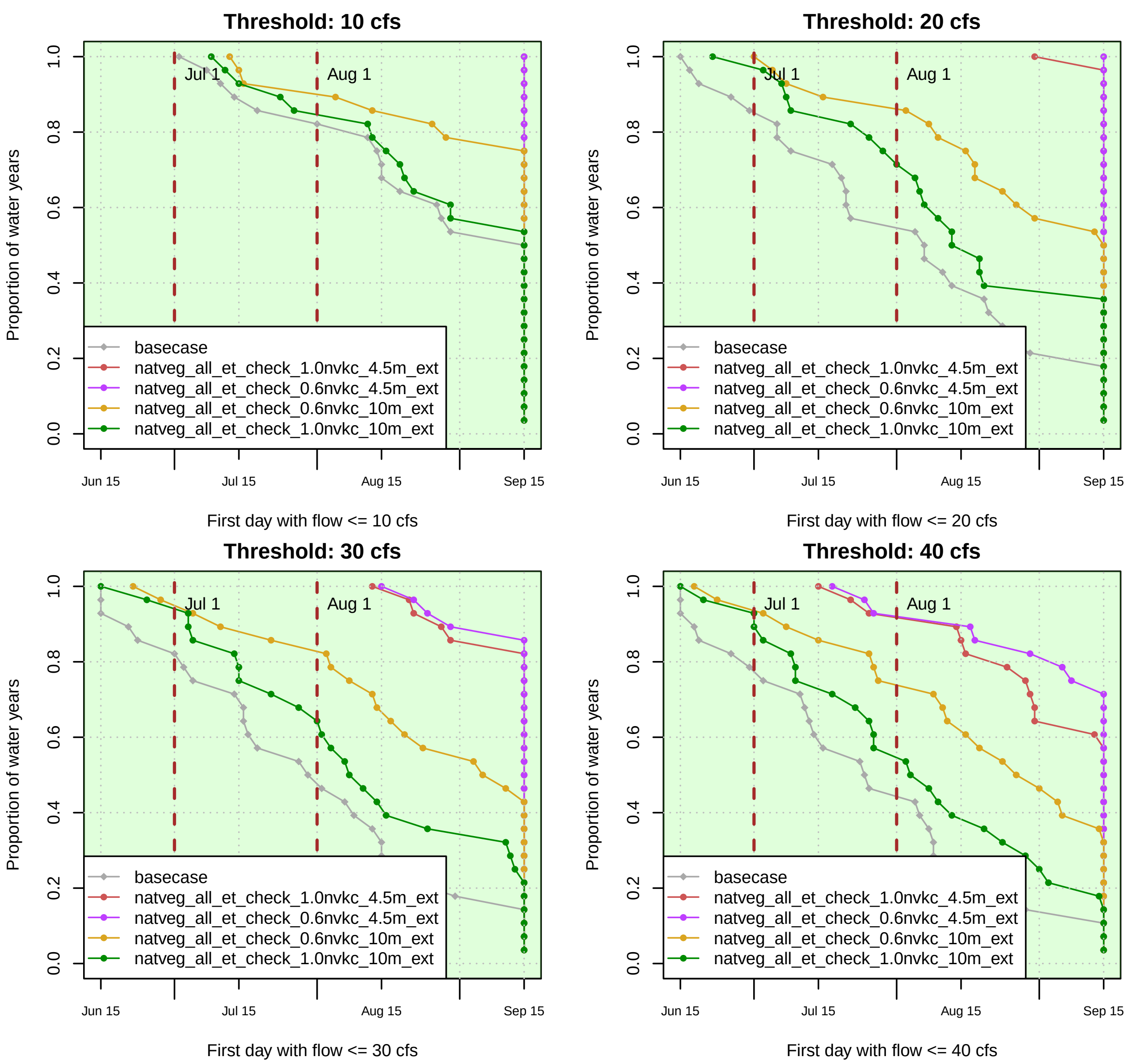


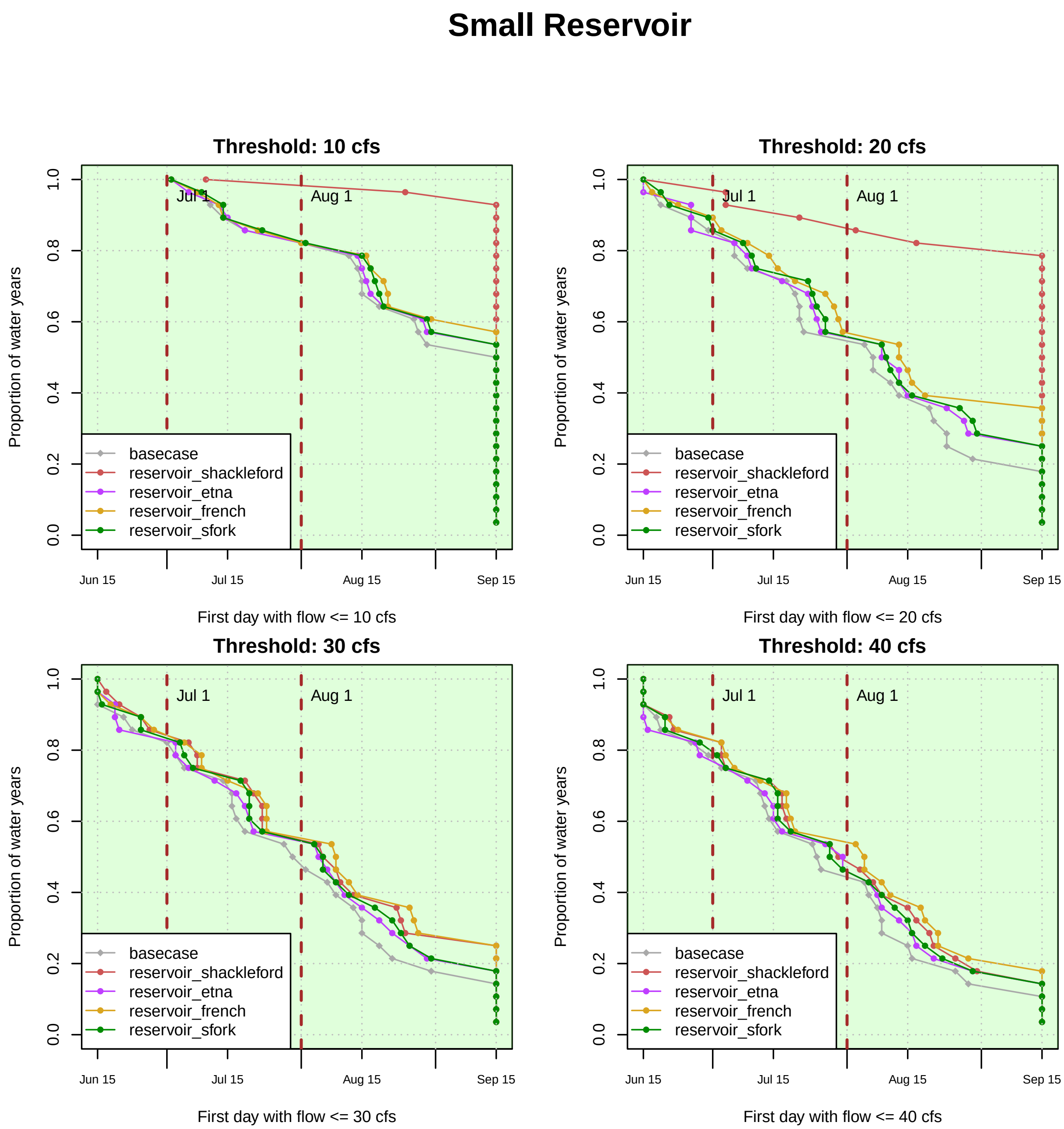

Irrigation Curtailment Dates
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
1.0
0.8
0.6
0.4
0.2
0.0
Jul 1
Aug 1
Jun 15
Jul 15
Aug 15
Sep 15
basecase
curtail_start_jun01
curtail_start_jun15
curtail_start_jul01
curtail_start_jul15
curtail_start_aug01
curtail_start_aug15
First day with flow <= 10 cfs
First day with flow <= 20 cfs
First day with flow <= 30 cfs
First day with flow <= 40 cfs


Nat. Vegetation Land Use, 0.6 kc, ET from GW in DZ only
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Jul 1
Aug 1
Jun 15
Jul 15
Aug 15
Sep 15
First day with flow <= 10 cfs
First day with flow <= 20 cfs
First day with flow <= 30 cfs
First day with flow <= 40 cfs
basecase
natveg_outside_adj
natveg_gwmixed_outside_adj
natveg_inside_adj
natveg_gwmixed_inside_adj
natveg_all
natveg_gwmixed_all

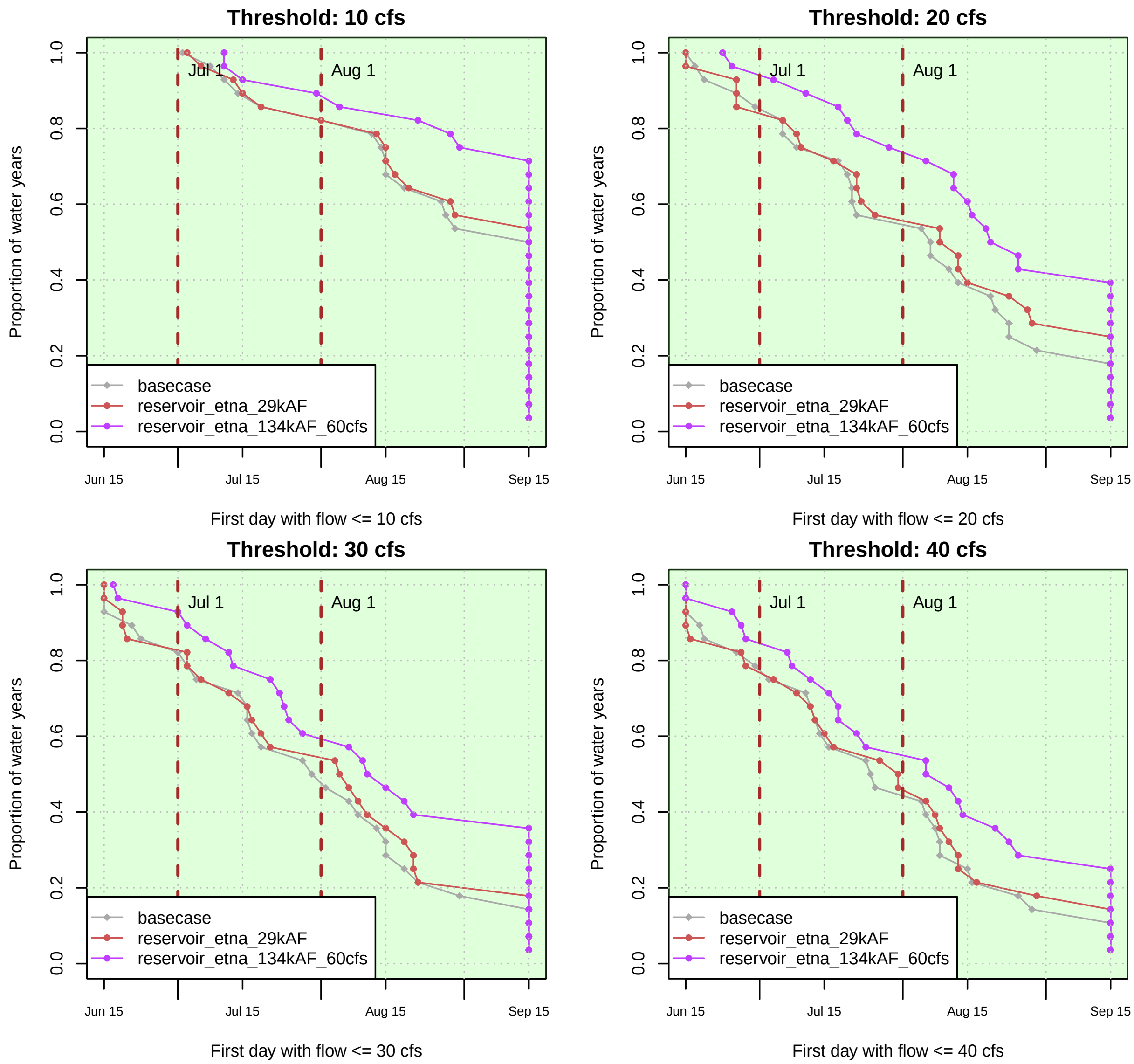

Natural Vegetation Land Use (1.0 kc, 4.5m)
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Jul 1
Aug 1
Jun 15
Jul 15
Aug 15
Sep 15
basecase
natveg_outside_adj_et_check_1.0nvkc_4.5m_ext
natveg_gwmixed_outside_adj_et_check_1.0nvkc_4.5
natveg_inside_adj_et_check_1.0nvkc_4.5m_ext
natveg_gwmixed_inside_adj_et_check_1.0nvkc_4.5m
natveg_all_et_check_1.0nvkc_4.5m_ext
natveg_gwmixed_all_et_check_1.0nvkc_4.5m_ext
First day with flow <= 10 cfs
First day with flow <= 20 cfs
First day with flow <= 30 cfs
First day with flow <= 40 cfs

Nat. Vegetation Land Use; k_c, ext. depth check




Small Reservoir
Threshold: 10 cfs
Threshold: 20 cfs
Threshold: 30 cfs
Threshold: 40 cfs
Proportion of water years
0.0
0.2
0.4
0.6
0.8
1.0
Jul 1
Aug 1
Jun 15
Jul 15
Aug 15
Sep 15
basecase
reservoir_shackleford
reservoir_etna
reservoir_french
reservoir_sfork
First day with flow <= 10 cfs
First day with flow <= 20 cfs
First day with flow <= 30 cfs
First day with flow <= 40 cfs

100% Reliable Reservoir (30 or 60 cfs release)

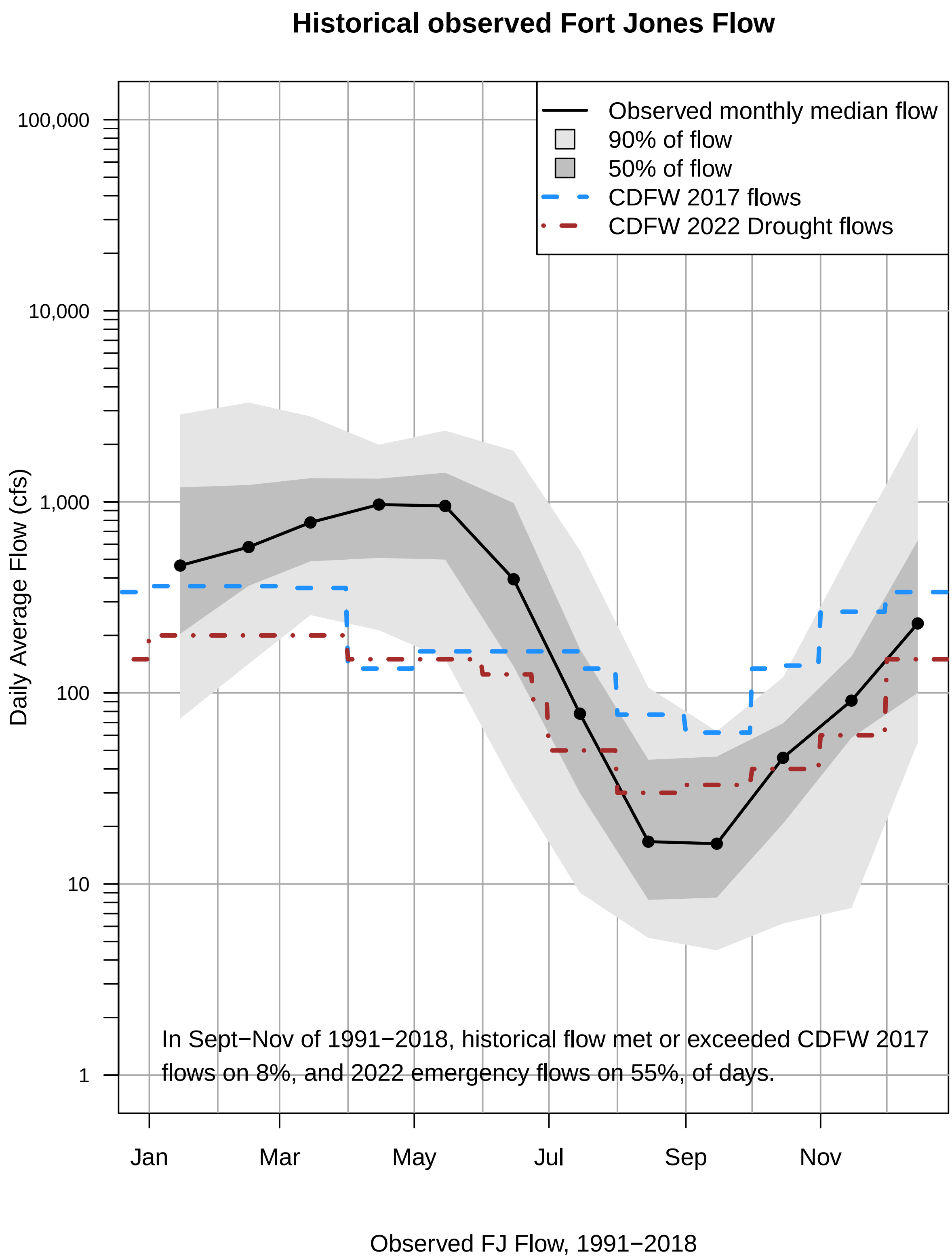


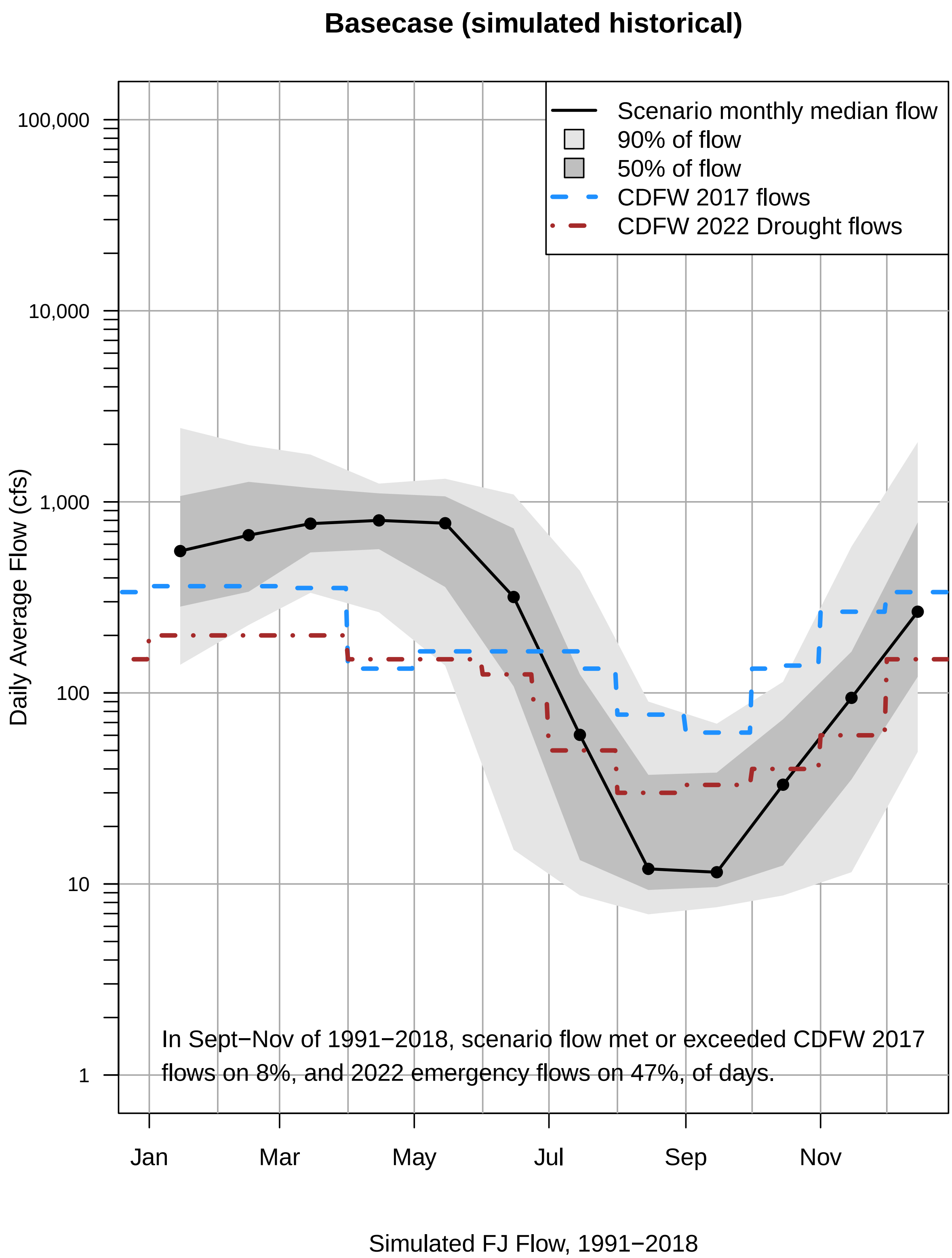
Percentile Flows and Flow Regime Comparison

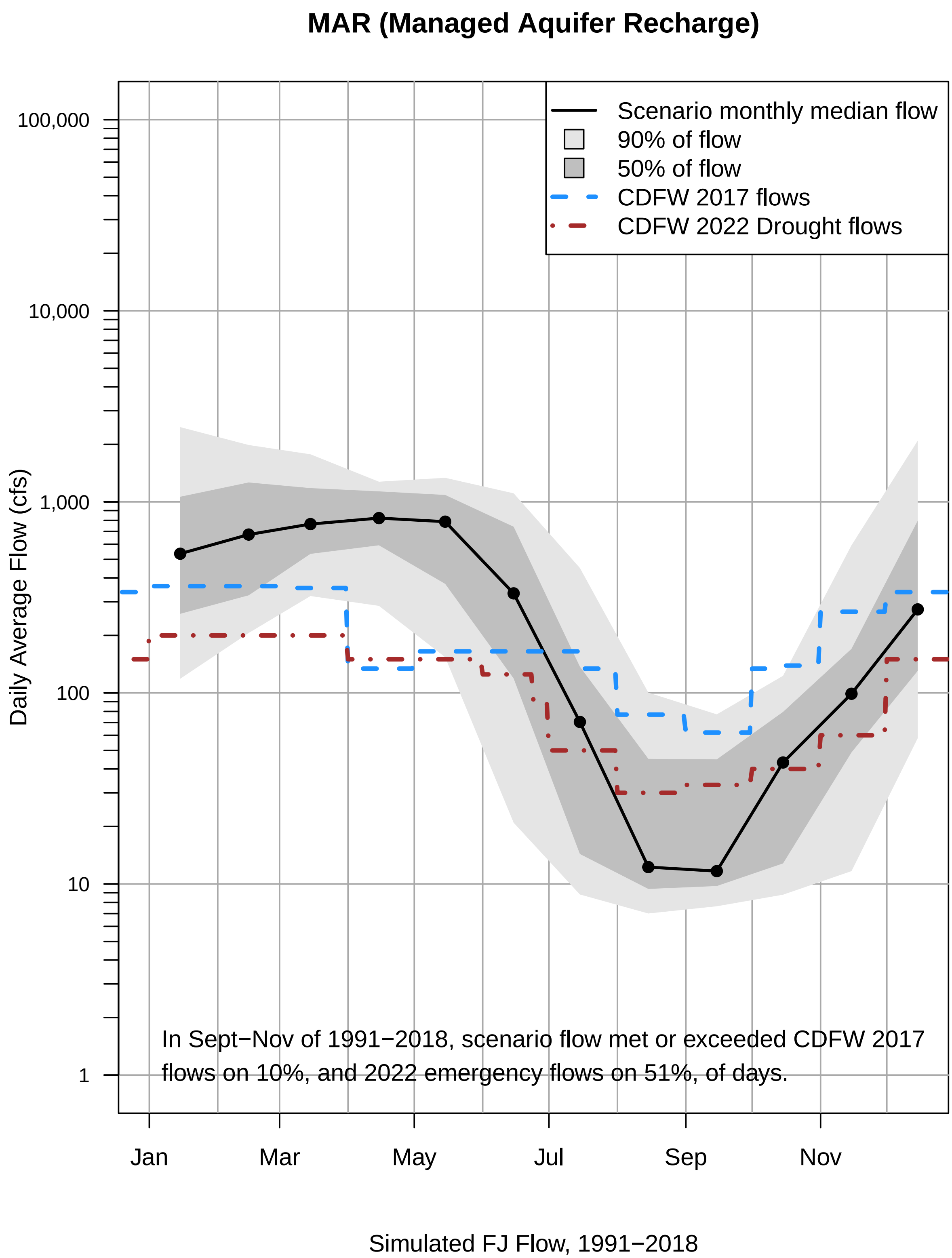
The goal of these plots is to 1) visualize the variability in Fort Jones flow in each model scenario, and 2) compare the flow to two proscribed flow regimes.

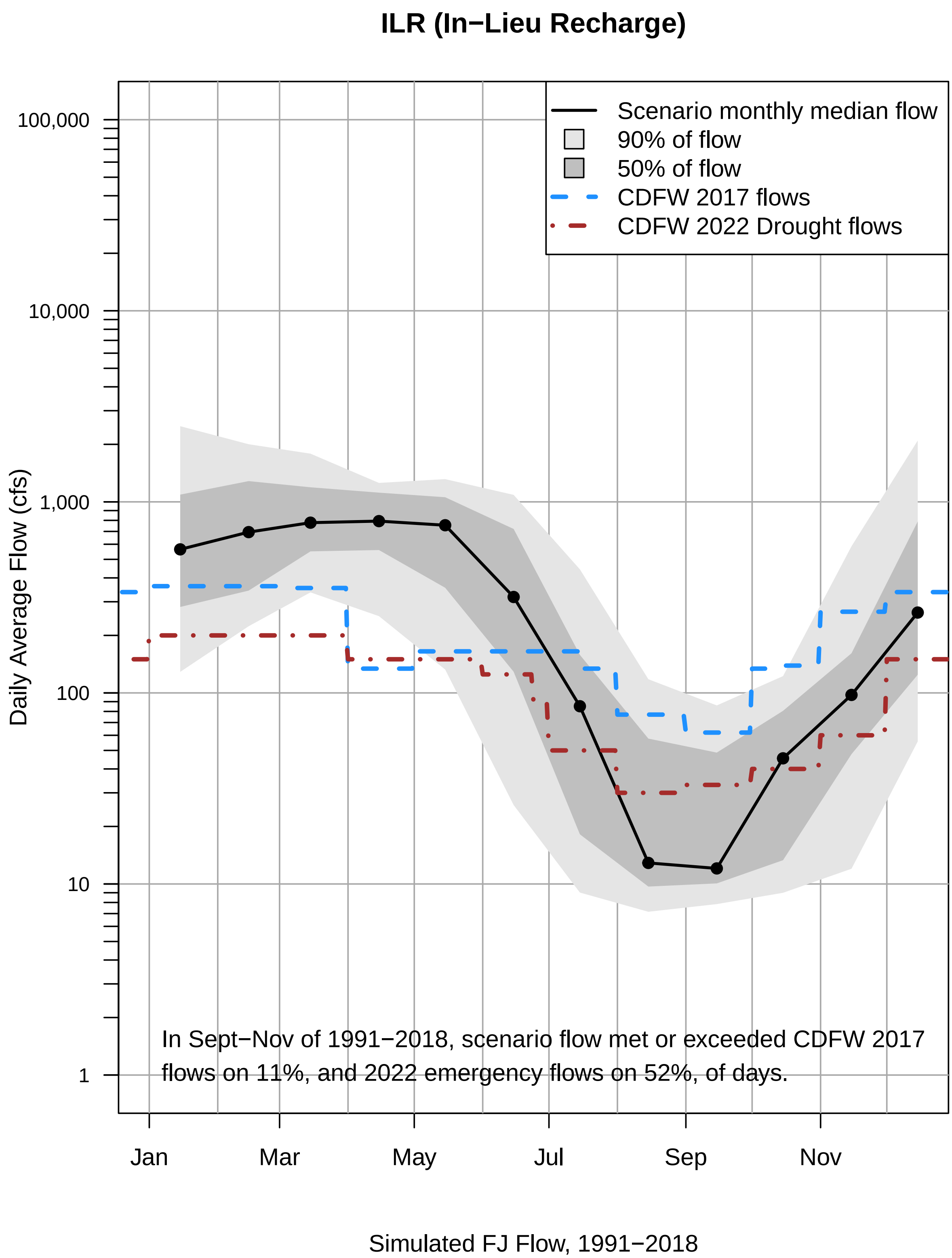
- Brown dots and line: The brown dots indicate the median flow recorded on all days falling in a given month in the 28-year model period (e.g., the median flow of all days of all the Januaries 1991-2018). That means that flow exceeds this brown line on approximately 50% of days in a given scenario.
- Gray shading: The dark gray shading captures the area from the 25th to the 75th percentiles of flow in a given month, and the light gray shading encompasses the 5th to the 95th percentiles. This means that that flow in a given scenario falls within the dark gray area on 50%, and within the light gray area on 90%, of days.
- Blue lines: The light blue line shows the flow regime published in the 2017 California Department of Fish and Wildlife (CDFW) report "Interim Instream Flow Criteria for the Protection of Fishery Resources in the Scott River Watershed, Siskiyou County". The dark blue line shows the flow regime for the United States Forest Service (USFS) water right as quantified in the Scott River Adjudication of 1980 (Decree No. 30662).

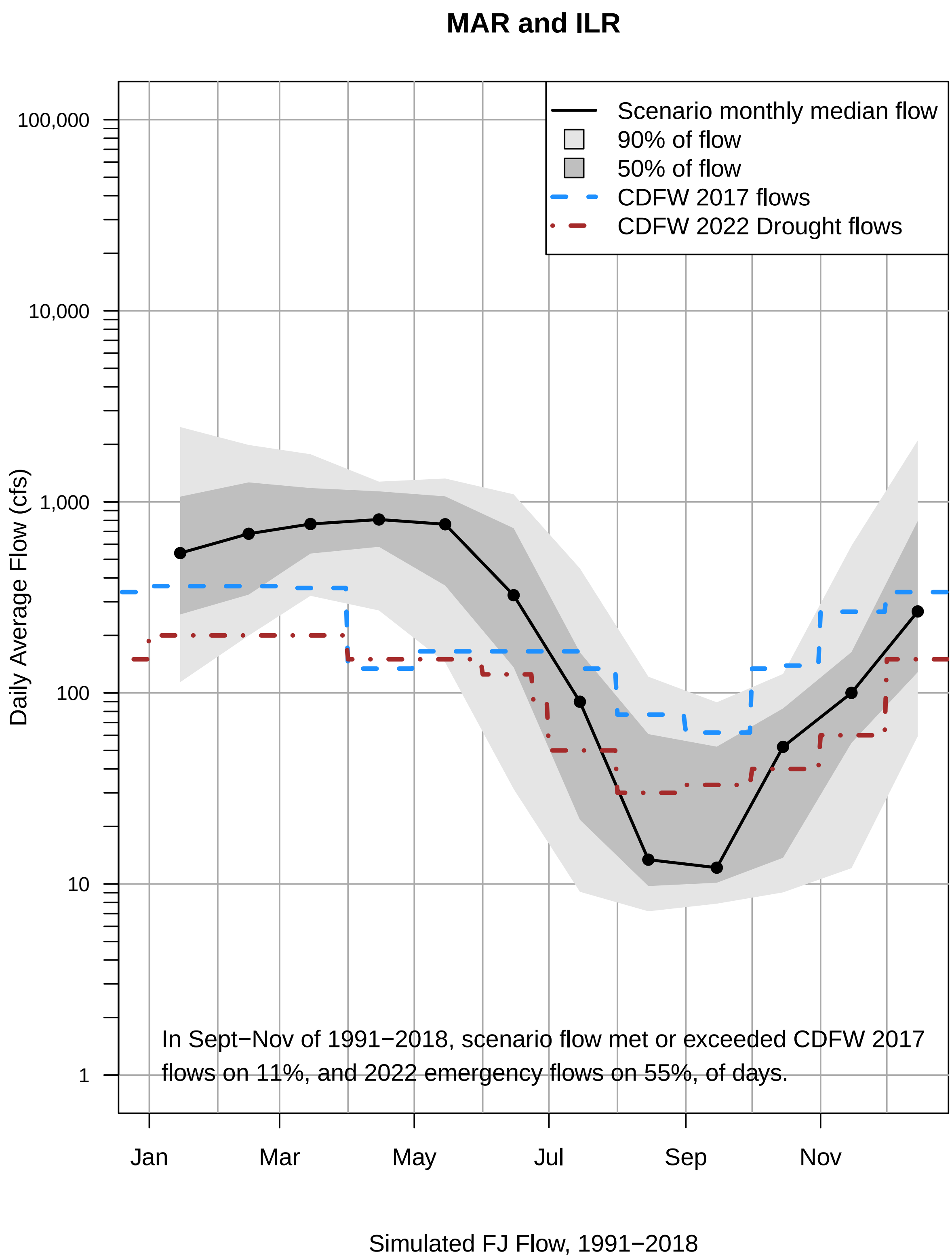
At the bottom of each plot, a note indicates the percentage of days in the critical low flow window (Sept. 1-Nov. 30, for all water years 1991-2018) on which each threshold was met.

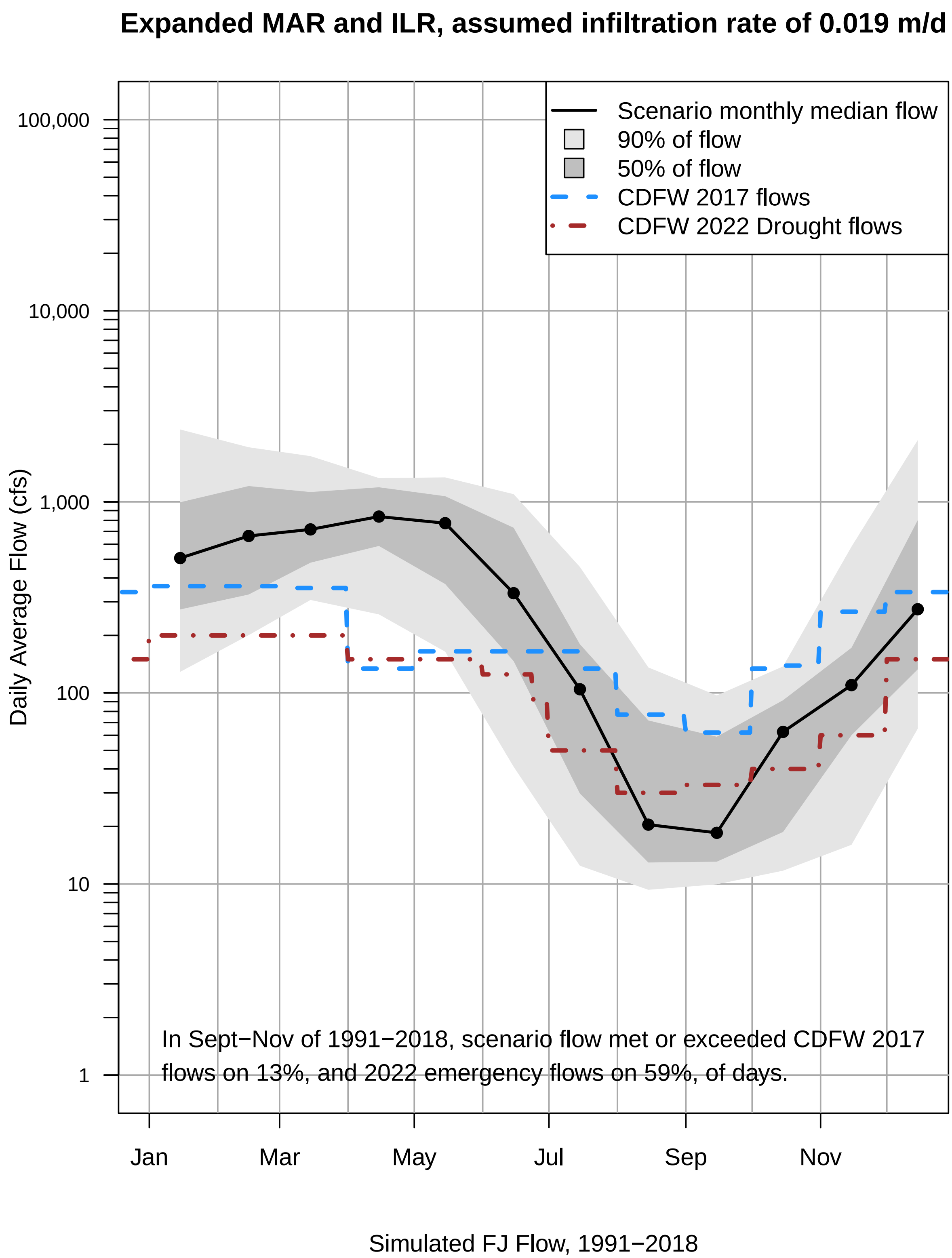

Historical observed Fort Jones Flow
Observed monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
In Sept−Nov of 1991−2018, historical flow met or exceeded CDFW 2017 flows on 8%, and 2022 emergency flows on 55%, of days.
Jan
Mar
May
Jul
Sep
Nov
Observed FJ Flow, 1991−2018

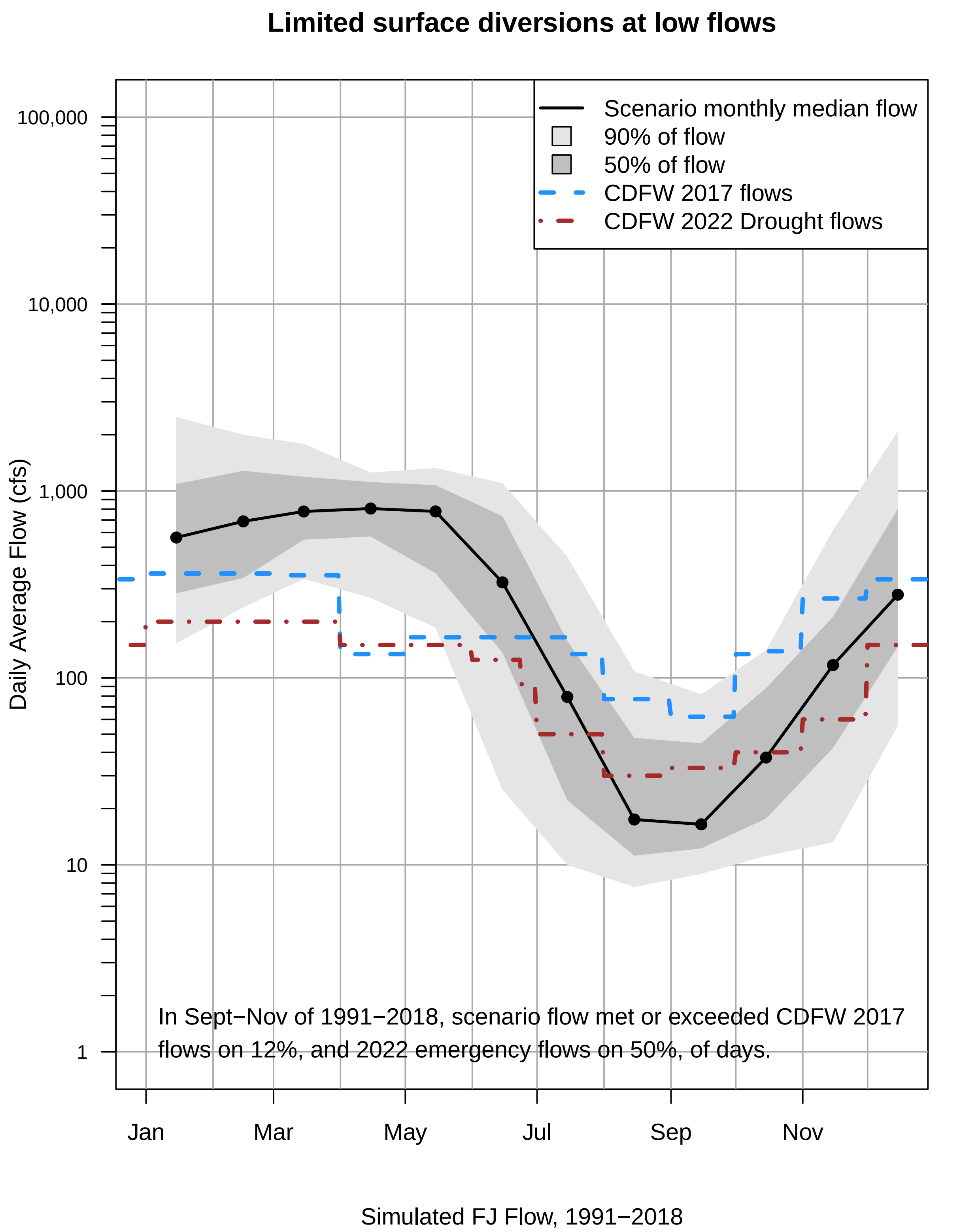

Basecase (simulated historical)
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 8%, and 2022 emergency flows on 47%, of days.
Simulated FJ Flow, 1991−2018

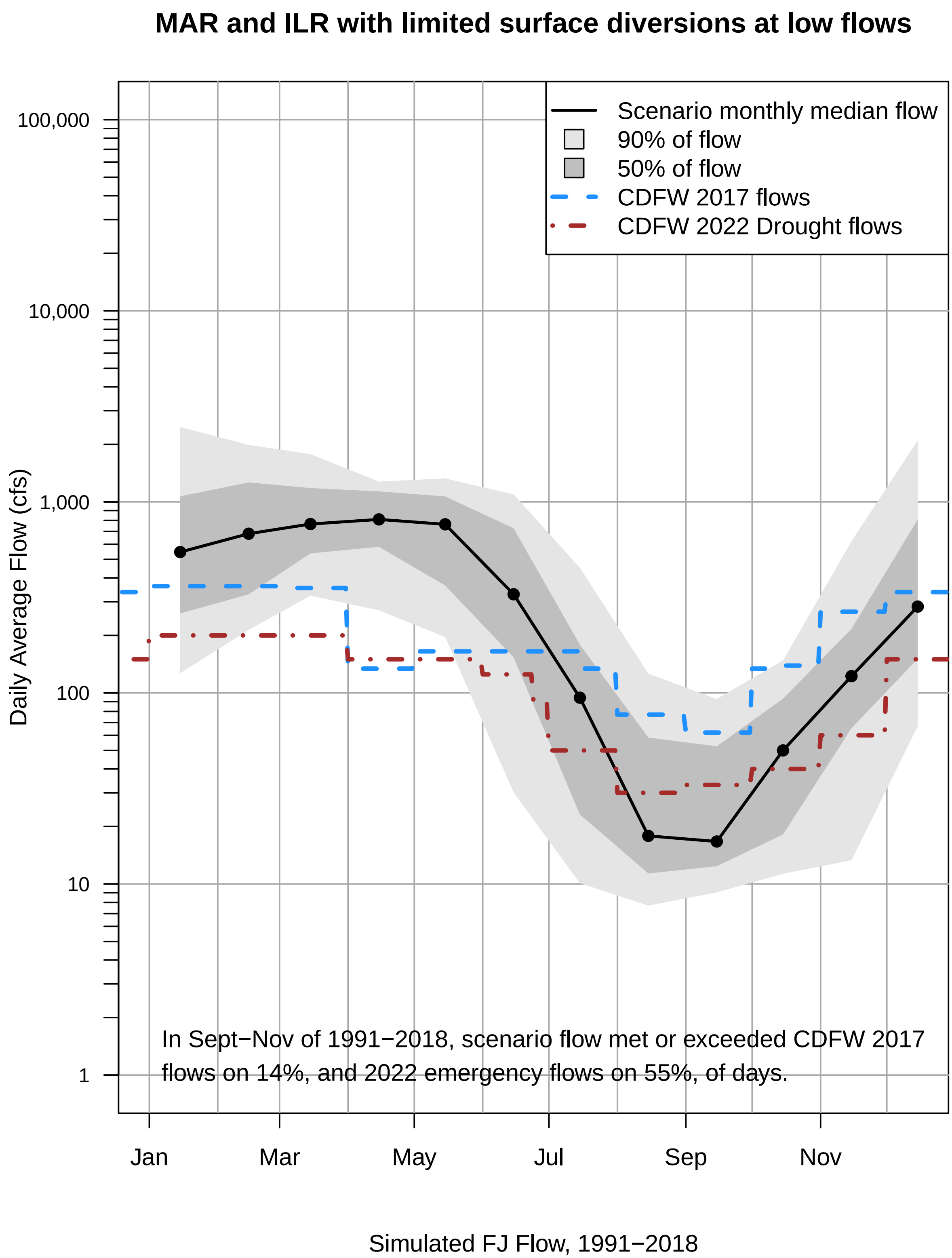

MAR (Managed Aquifer Recharge)
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017
flows on 10%, and 2022 emergency flows on 51%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

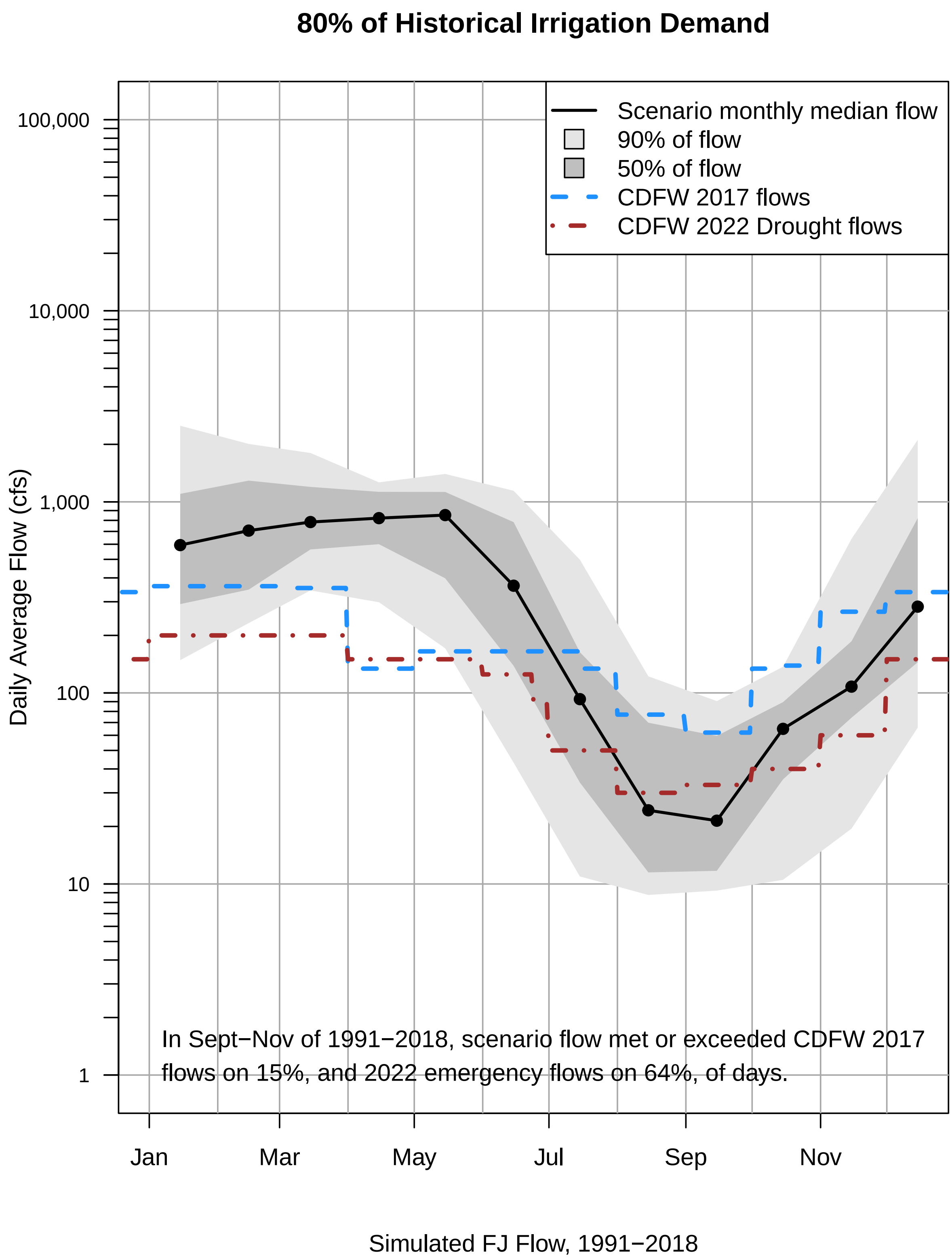

ILR (In−Lieu Recharge)
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 11%, and 2022 emergency flows on 52%, of days.
Simulated FJ Flow, 1991−2018

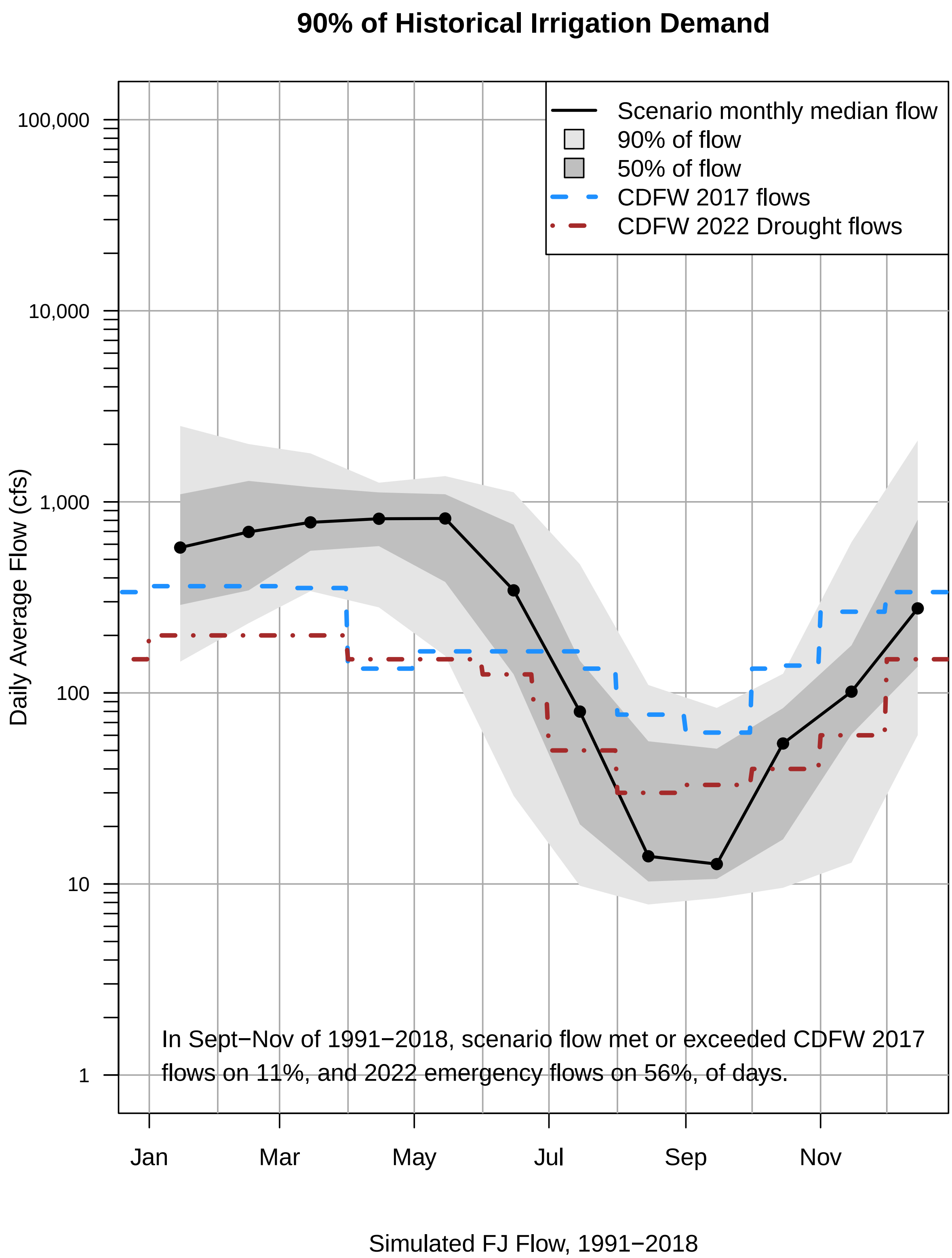

MAR and ILR
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 11%, and 2022 emergency flows on 55%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

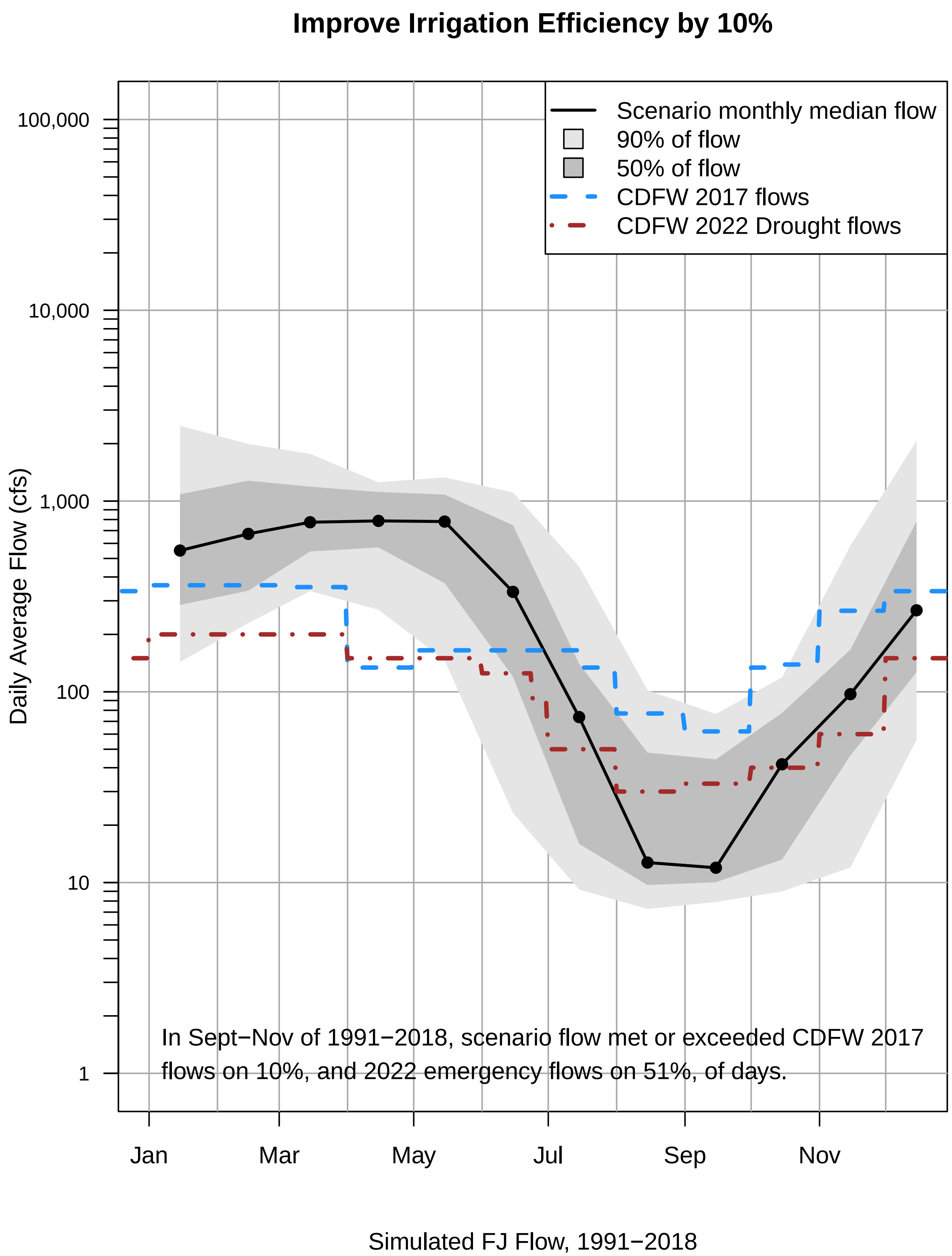

Expanded MAR and ILR, assumed infiltration rate of 0.019 m/d
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 13%, and 2022 emergency flows on 59%, of days.
Simulated FJ Flow, 1991−2018

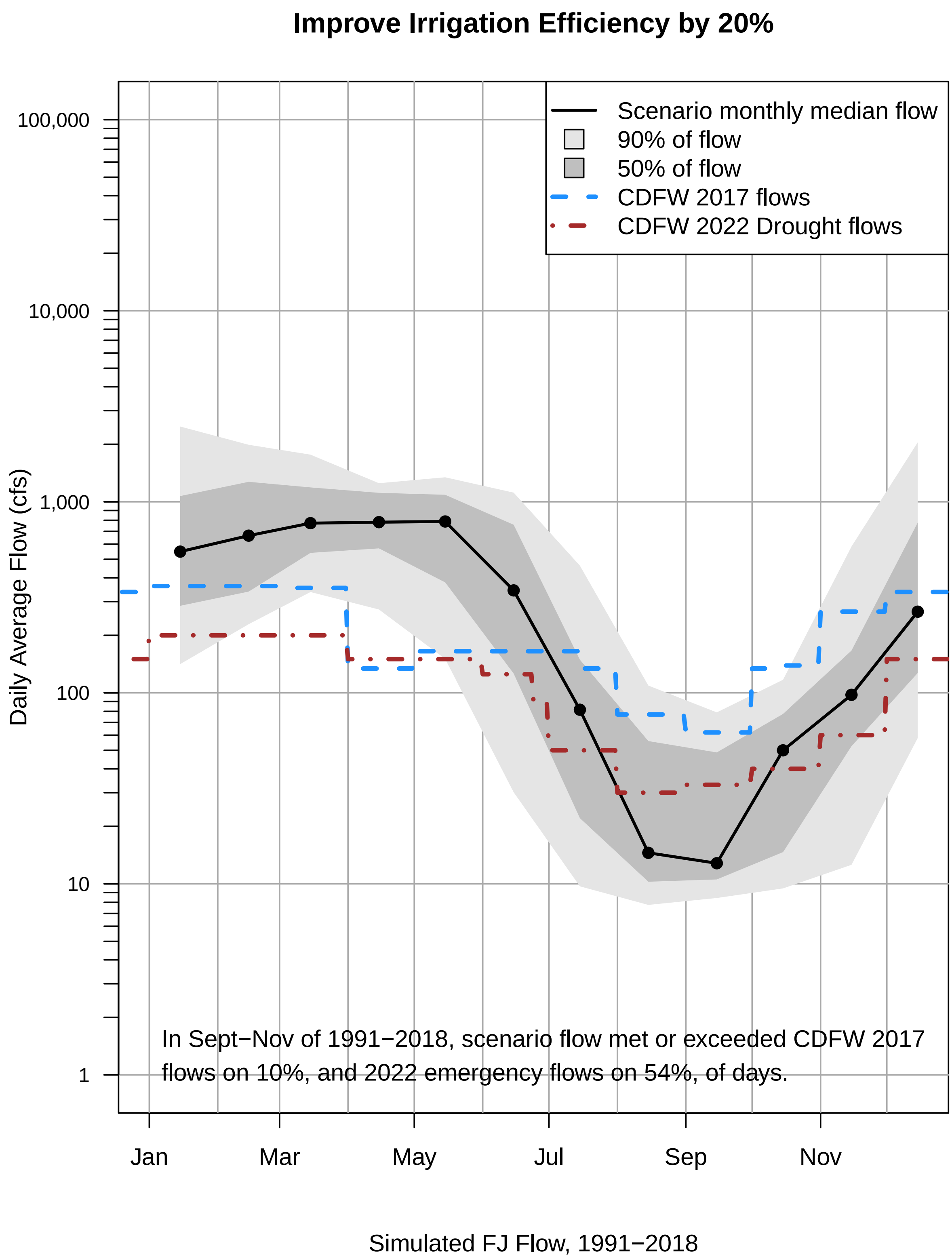

Limited surface diversions at low flows
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 12%, and 2022 emergency flows on 50%, of days.
Simulated FJ Flow, 1991−2018

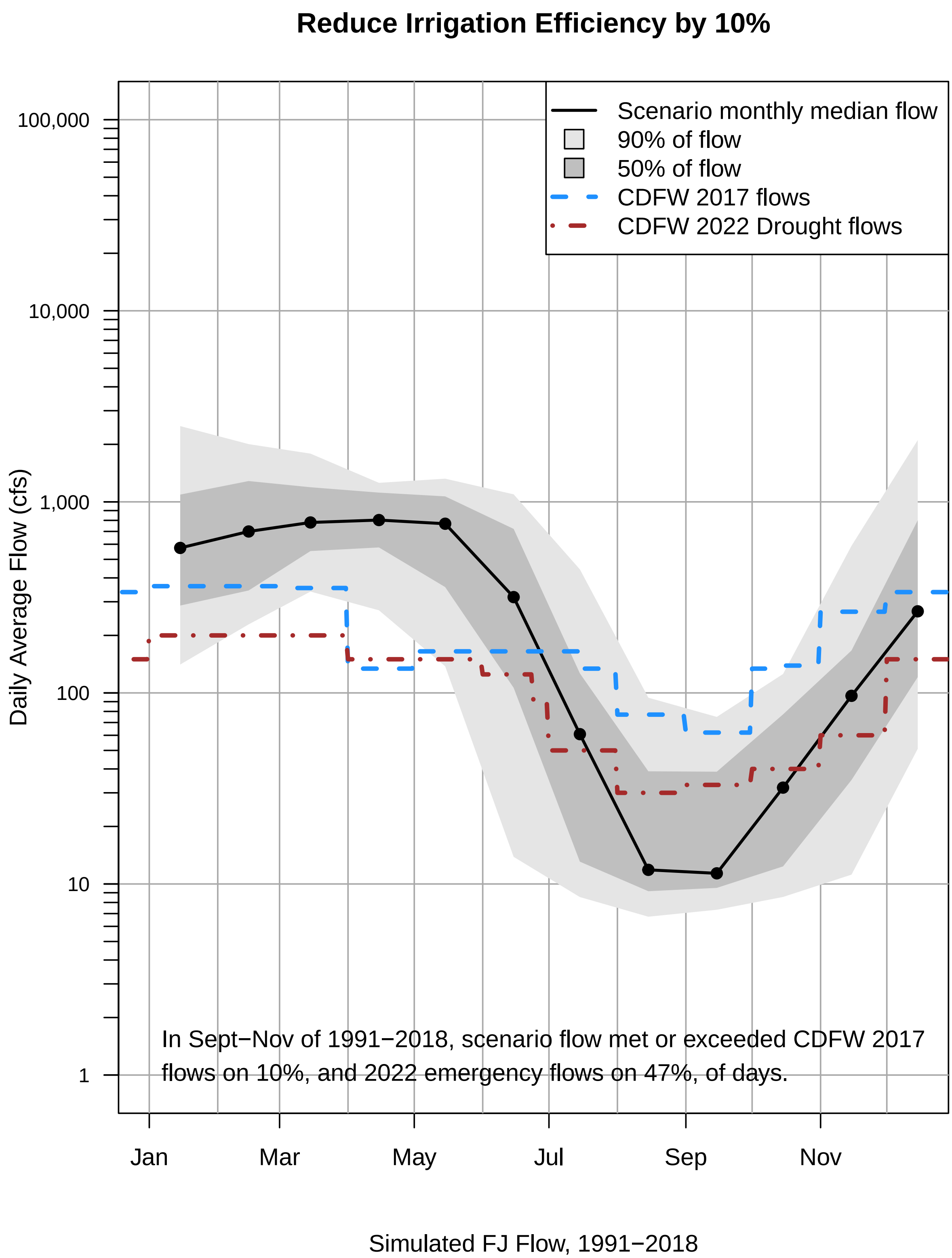

MAR and ILR with limited surface diversions at low flows
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 14%, and 2022 emergency flows on 55%, of days.
Simulated FJ Flow, 1991−2018

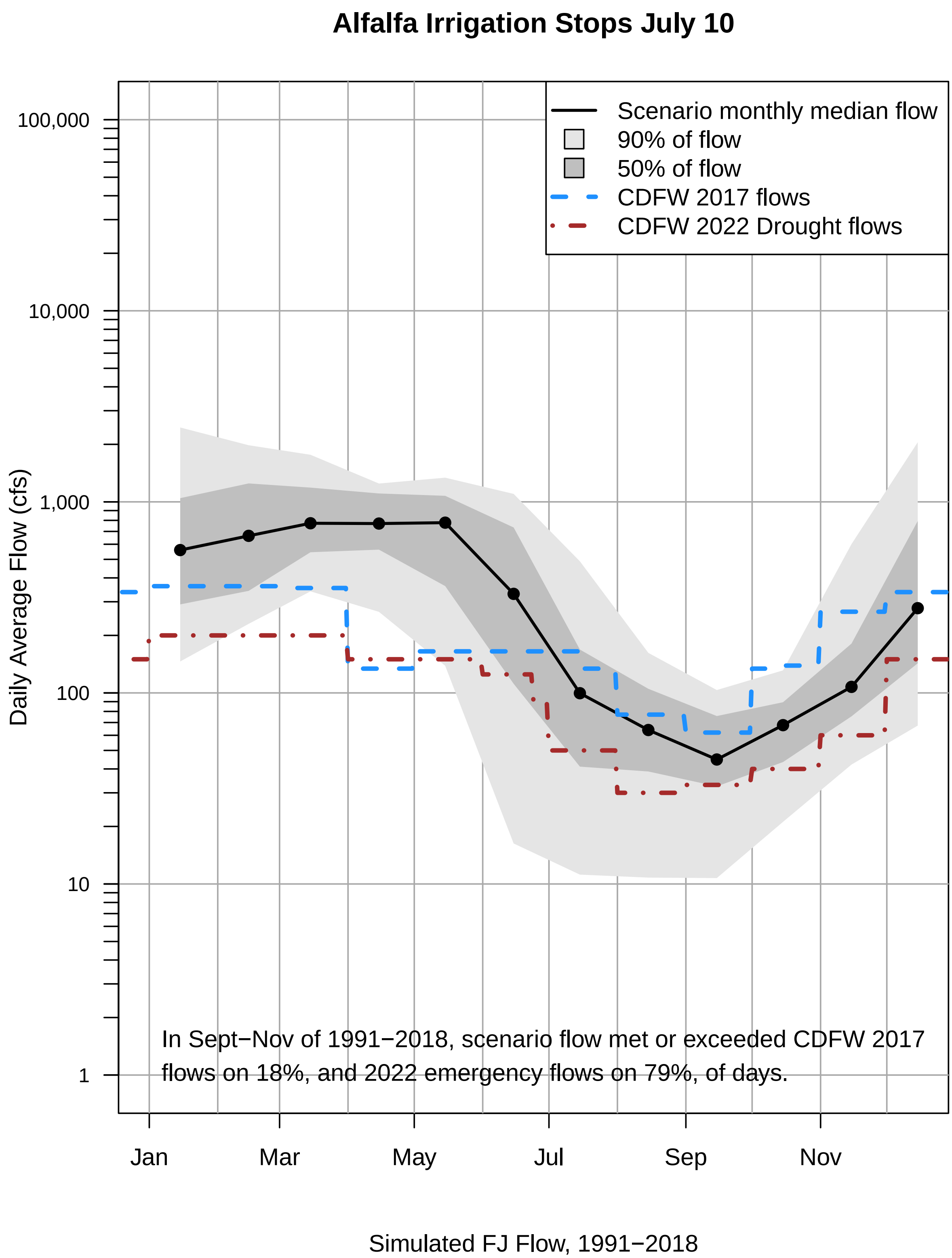

80% of Historical Irrigation Demand
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 15%, and 2022 emergency flows on 64%, of days.
Simulated FJ Flow, 1991−2018

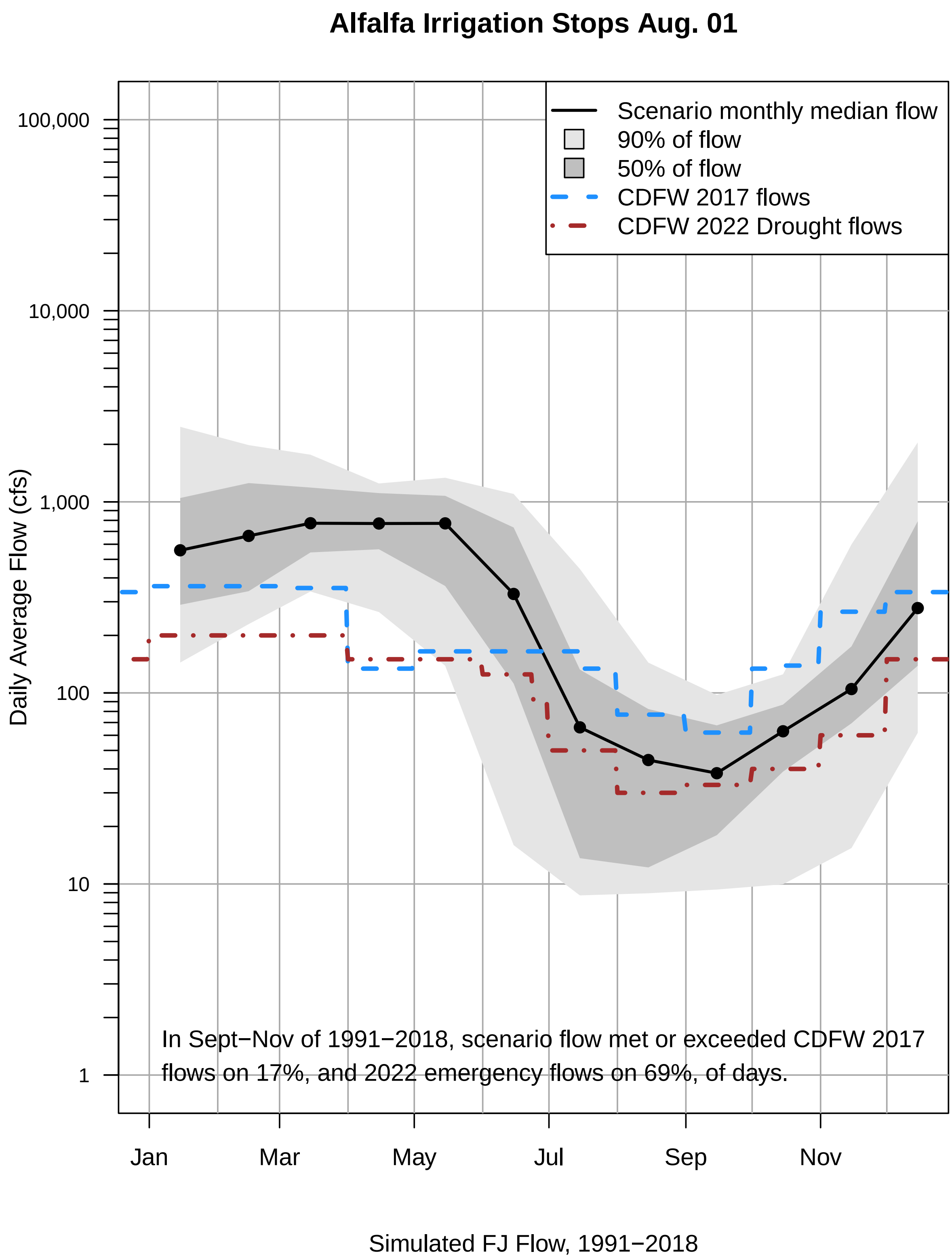

90% of Historical Irrigation Demand
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 11%, and 2022 emergency flows on 56%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

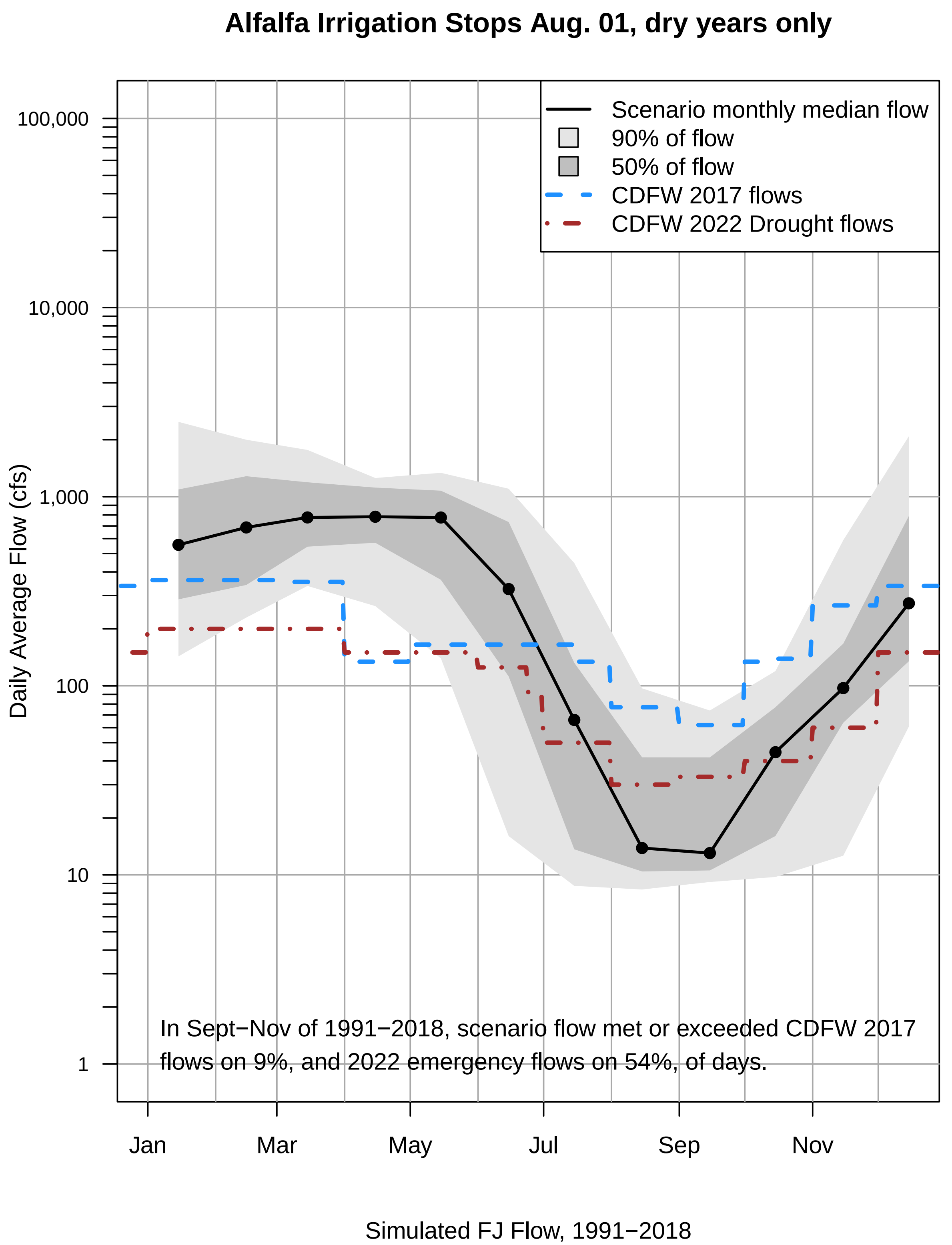

Improve Irrigation Efficiency by 10%
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 10%, and 2022 emergency flows on 51%, of days.
Simulated FJ Flow, 1991−2018

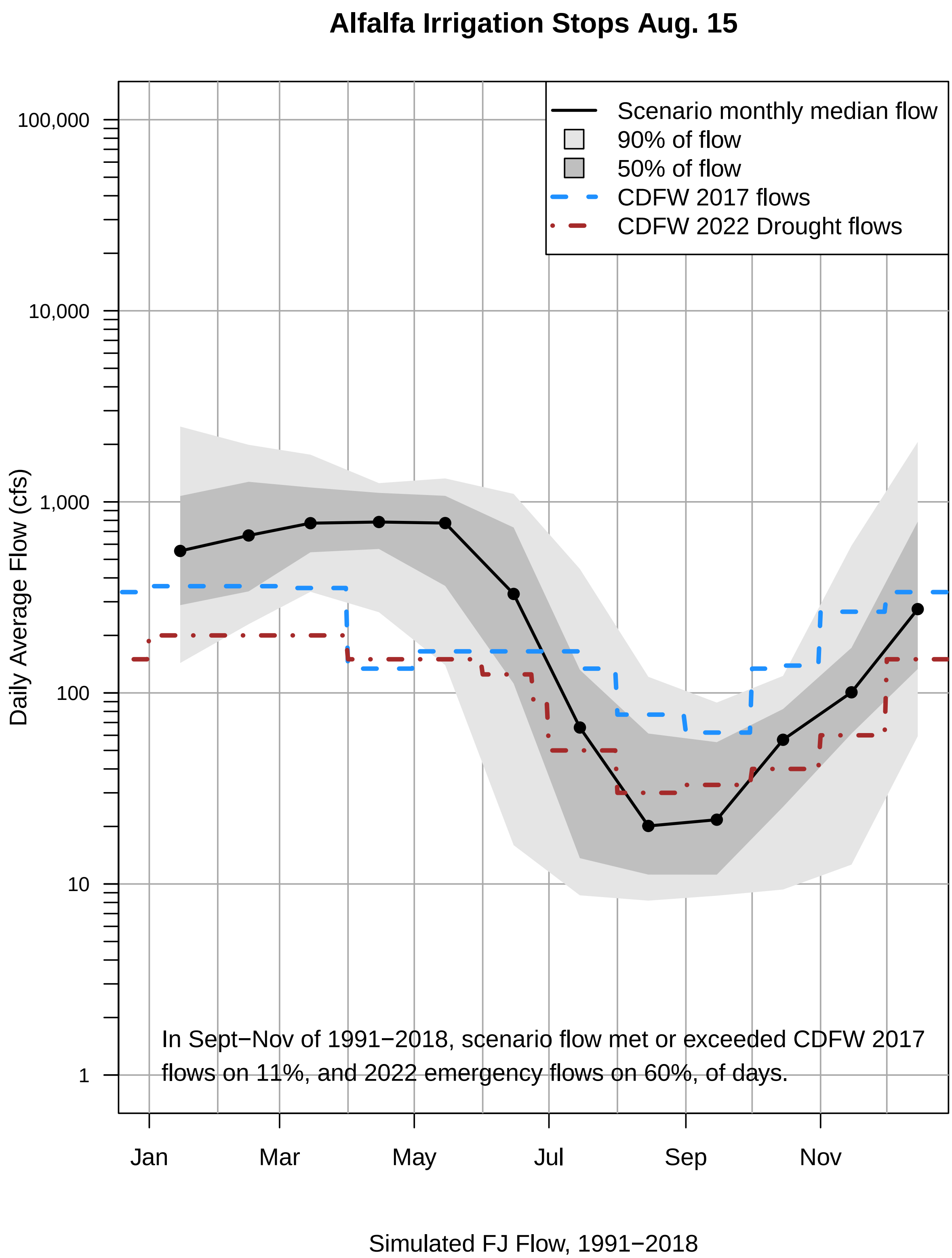

Improve Irrigation Efficiency by 20%
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 10%, and 2022 emergency flows on 54%, of days.
Simulated FJ Flow, 1991−2018

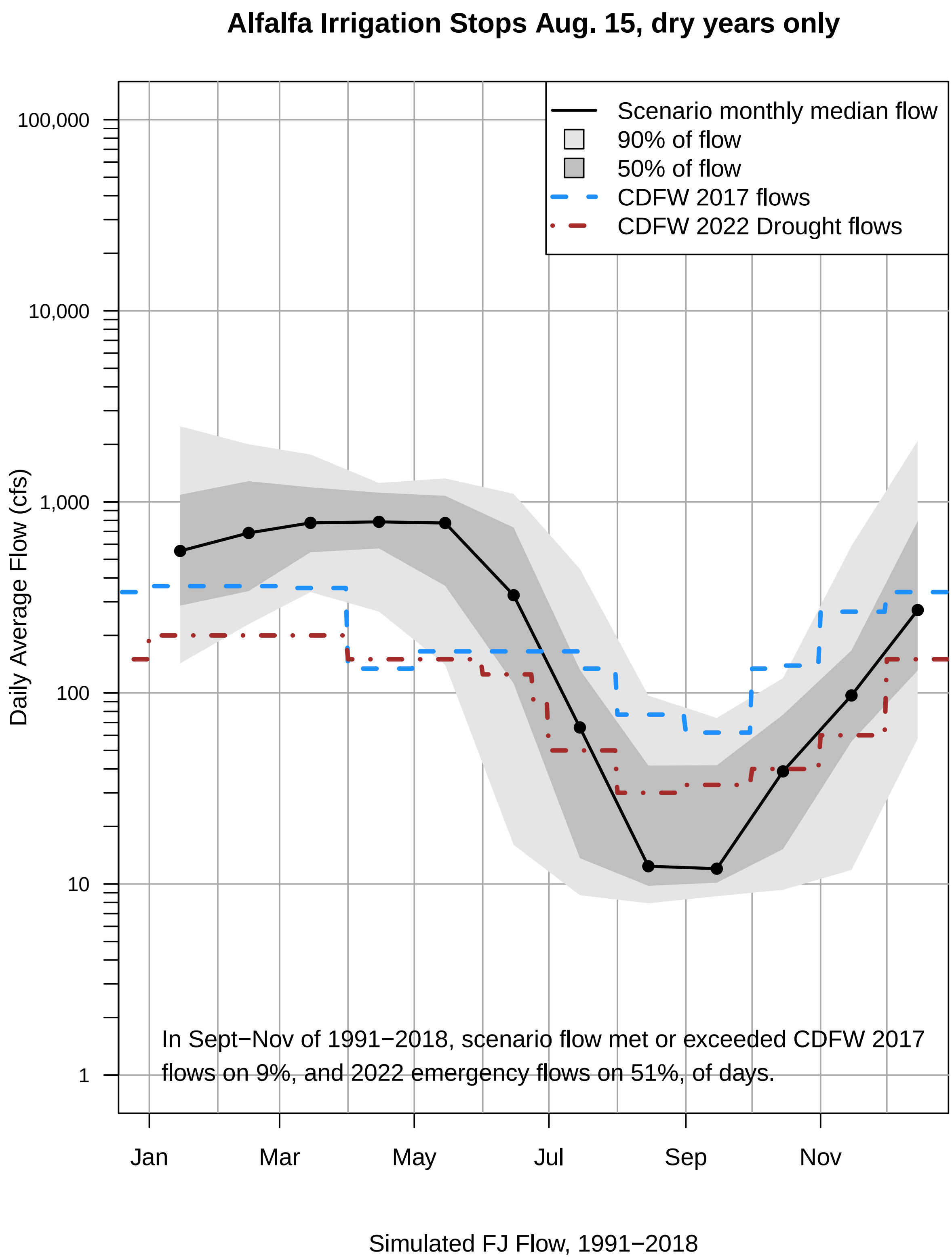

Reduce Irrigation Efficiency by 10%
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 10%, and 2022 emergency flows on 47%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

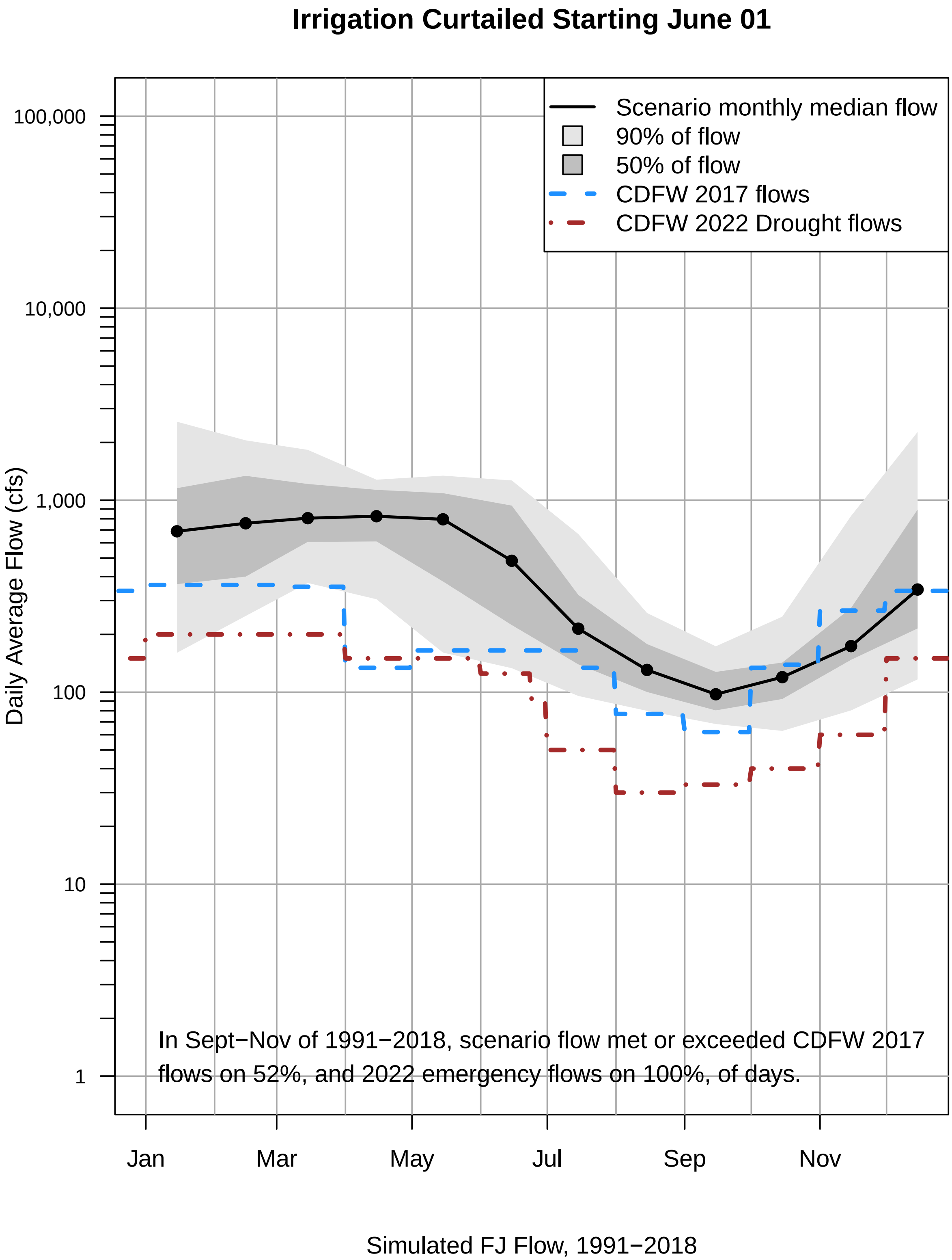

Alfalfa Irrigation Stops July 10
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 18%, and 2022 emergency flows on 79%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

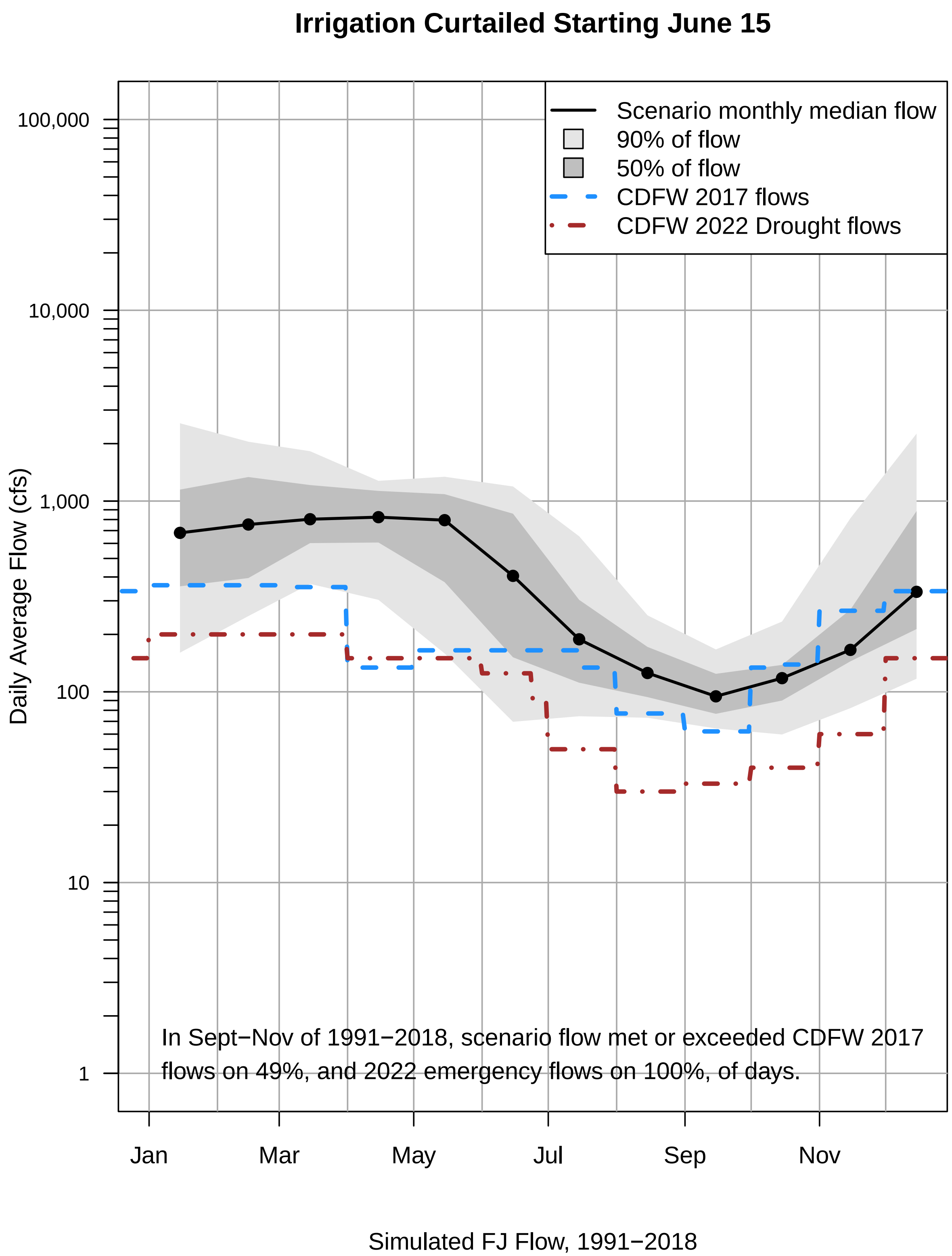

Alfalfa Irrigation Stops Aug. 01
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 17%, and 2022 emergency flows on 69%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

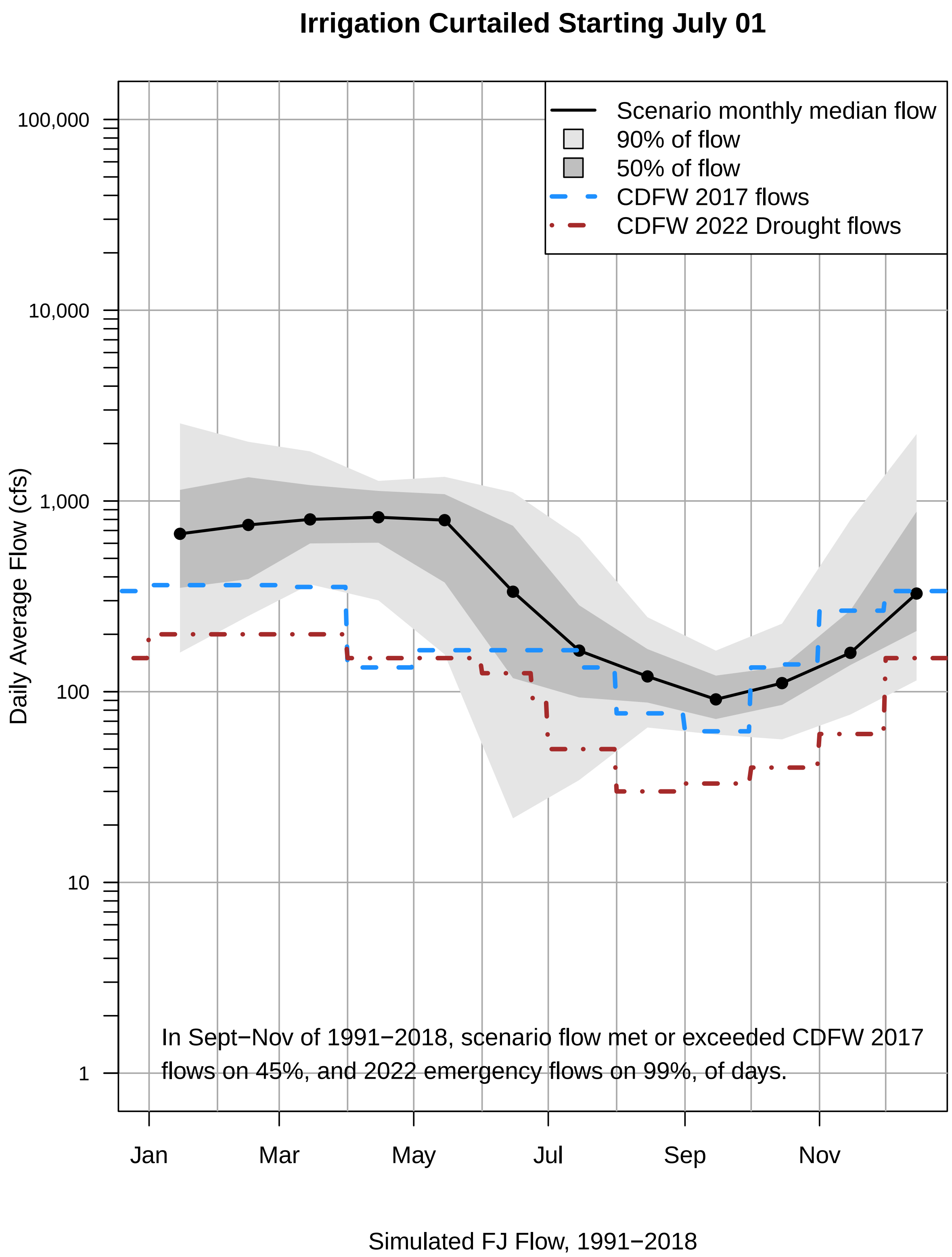

Alfalfa Irrigation Stops Aug. 01, dry years only
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 9%, and 2022 emergency flows on 54%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

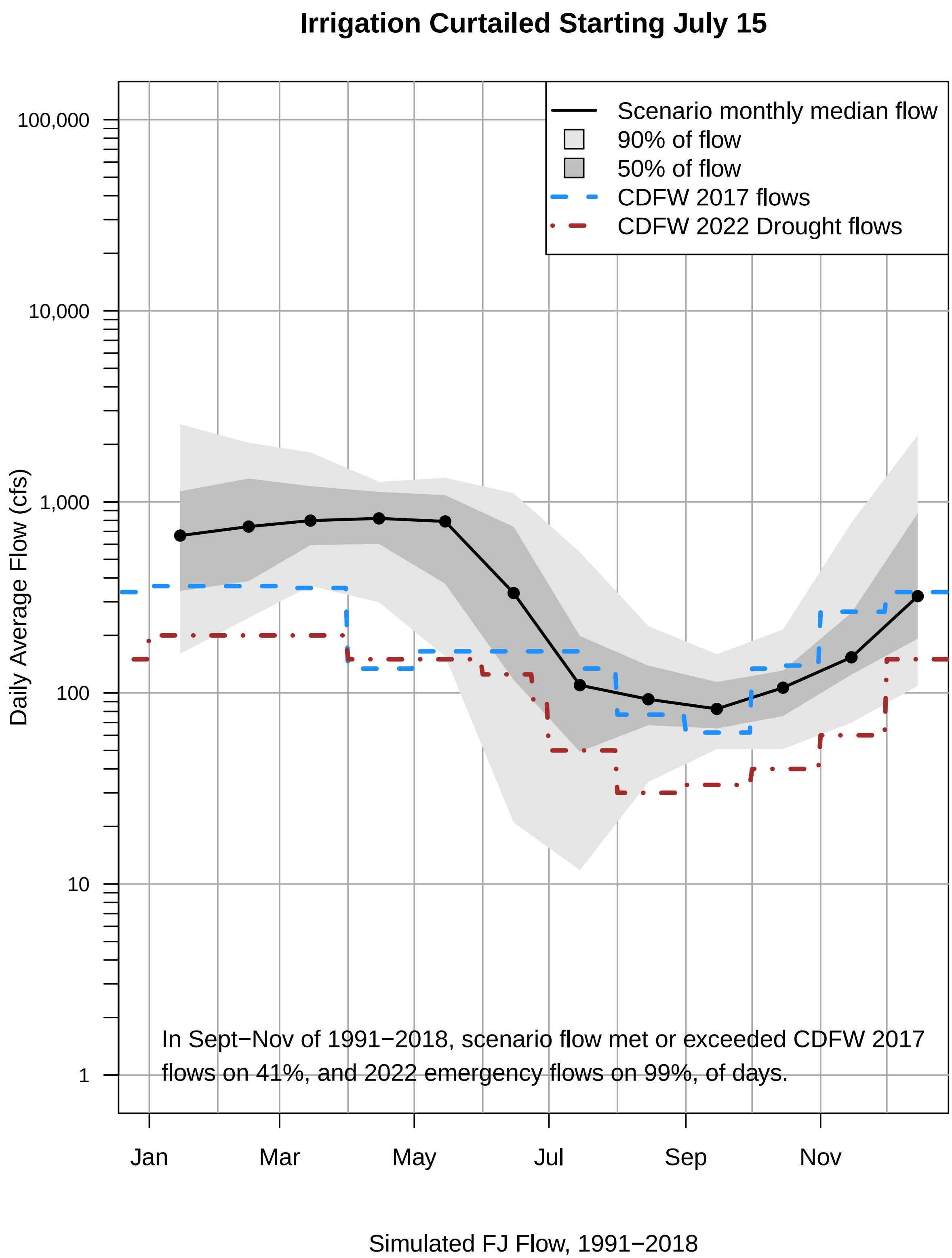

Alfalfa Irrigation Stops Aug. 15
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 11%, and 2022 emergency flows on 60%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

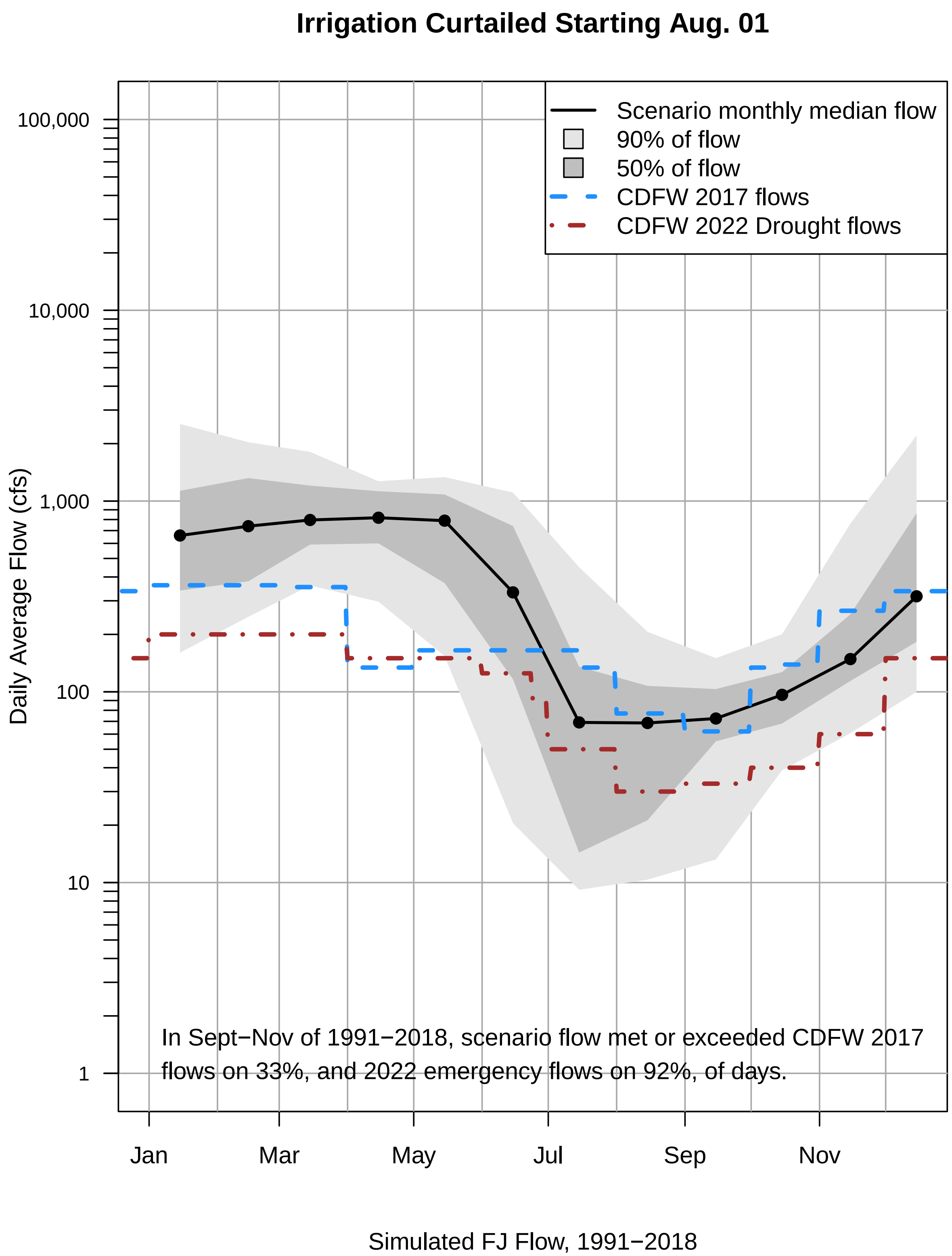

Alfalfa Irrigation Stops Aug. 15, dry years only
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 9%, and 2022 emergency flows on 51%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

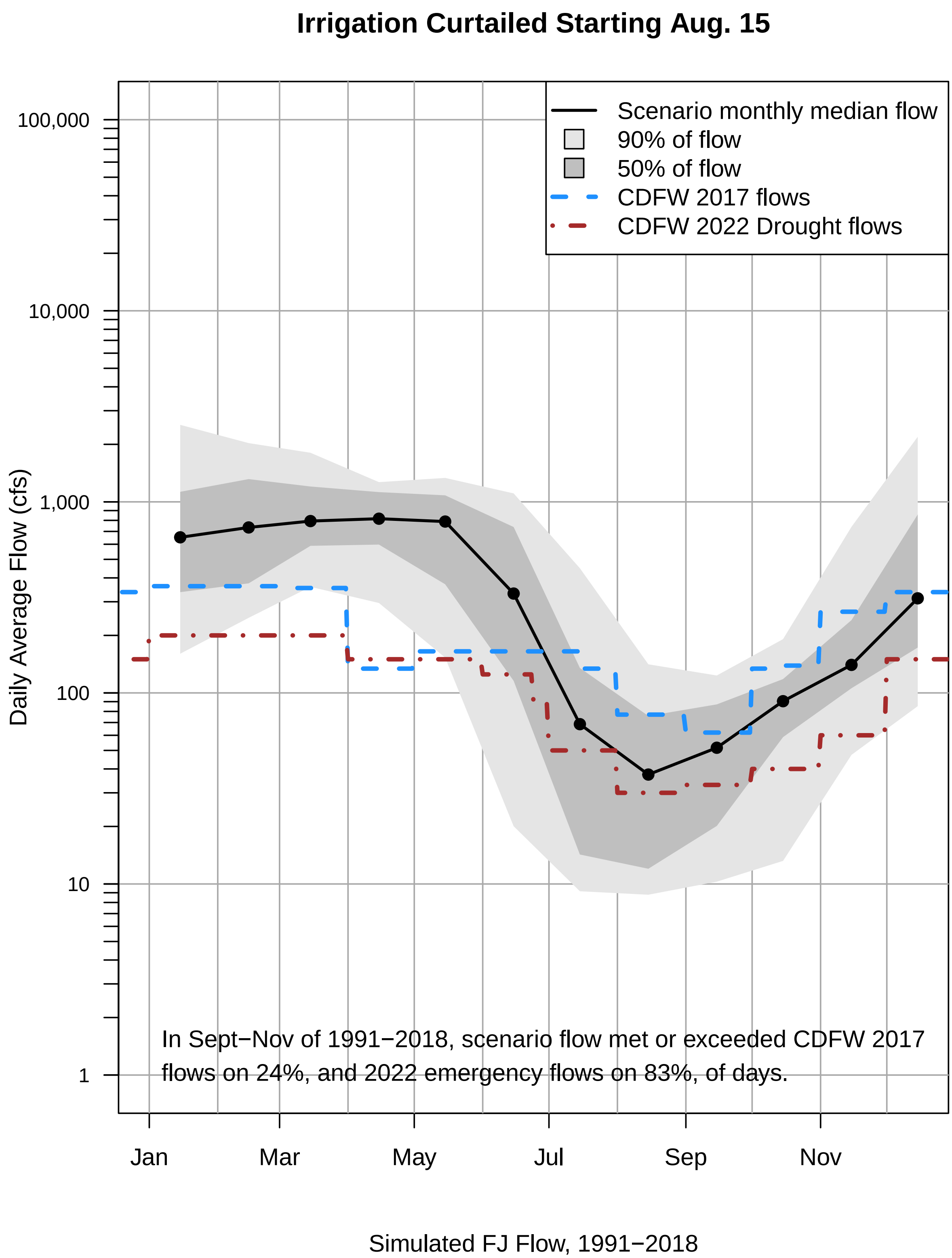

Irrigation Curtailed Starting June 01
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 52%, and 2022 emergency flows on 100%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

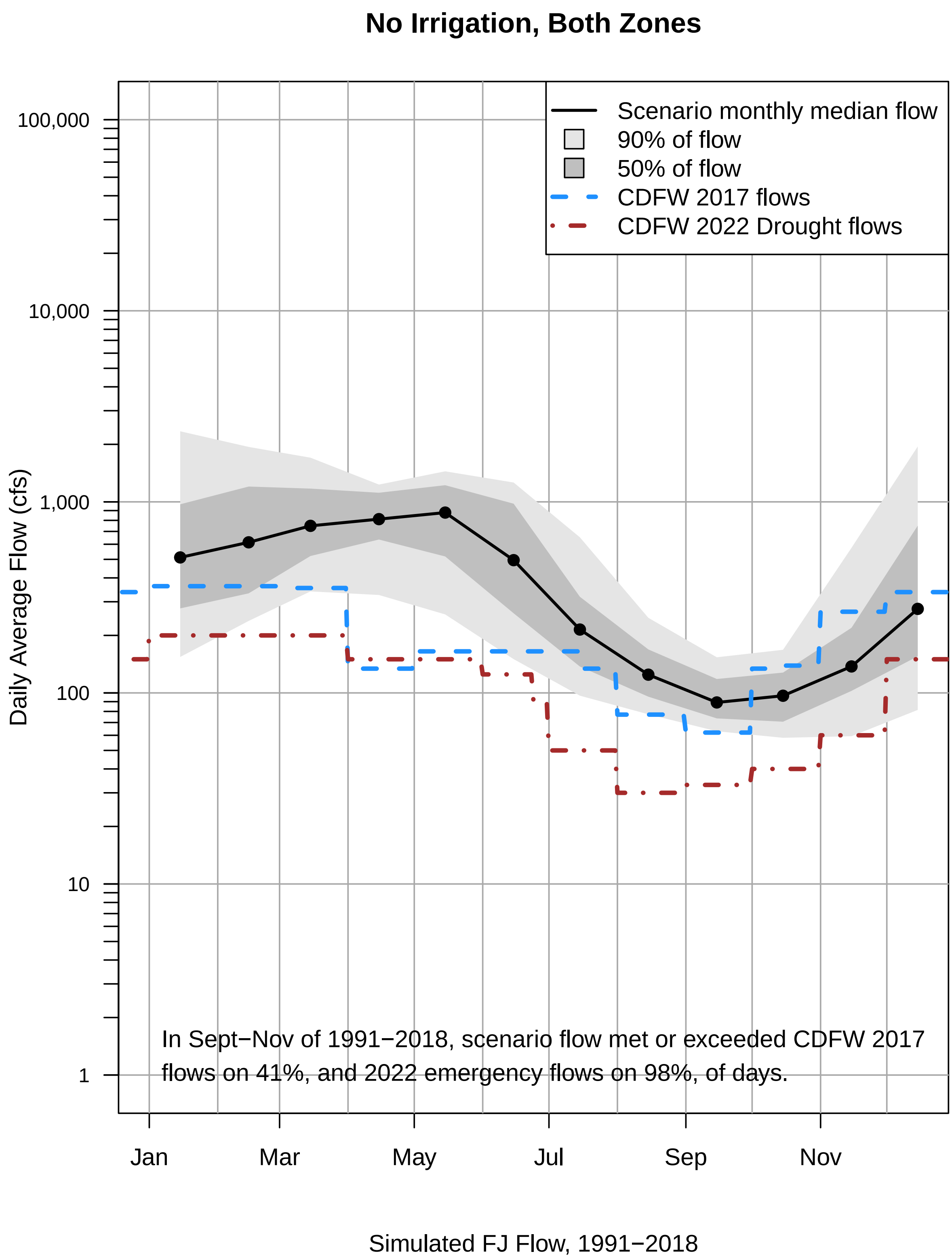

Irrigation Curtailed Starting June 15
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 49%, and 2022 emergency flows on 100%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

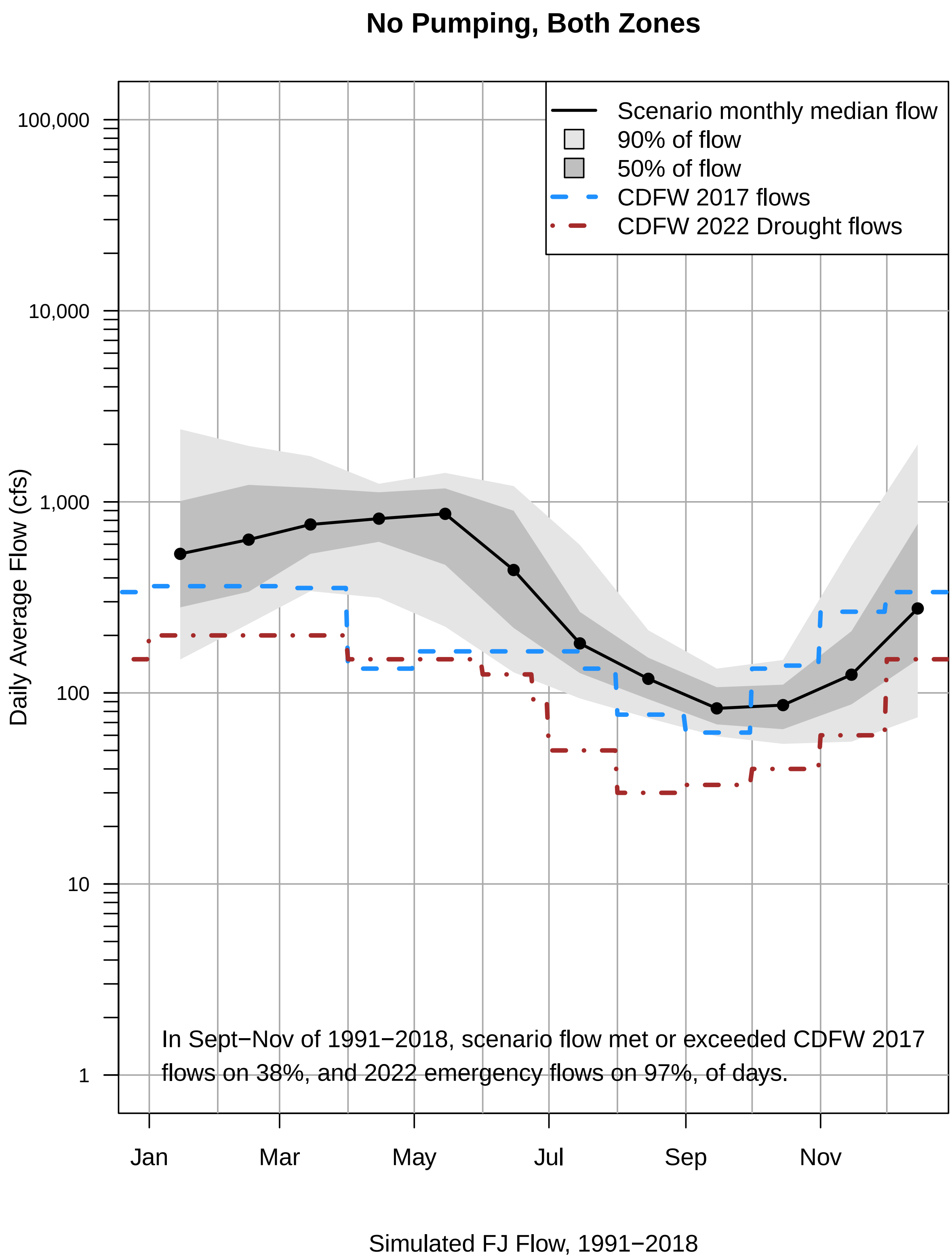

Irrigation Curtailed Starting July 01
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 45%, and 2022 emergency flows on 99%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

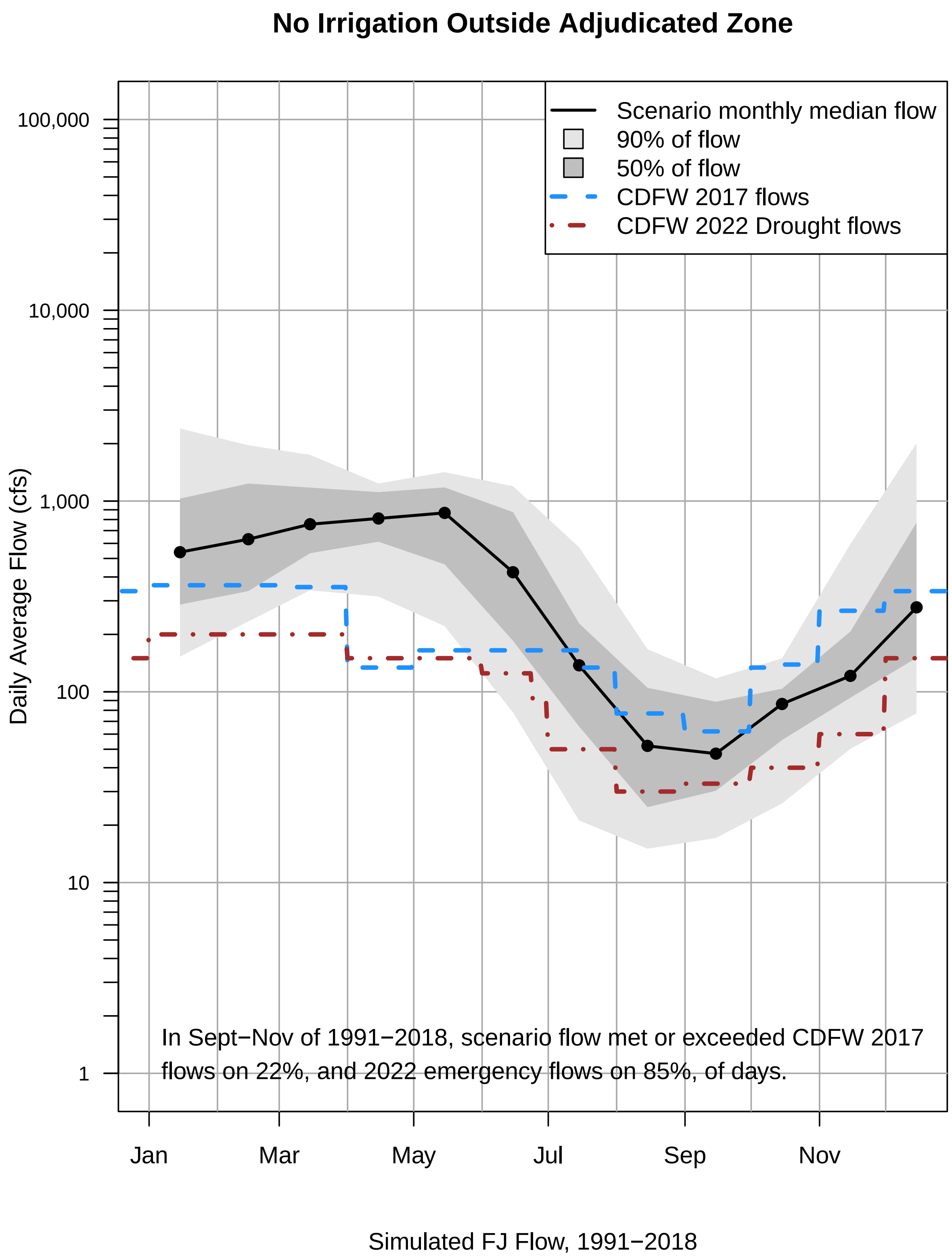

Irrigation Curtailed Starting July 15
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 41%, and 2022 emergency flows on 99%, of days.
Simulated FJ Flow, 1991−2018

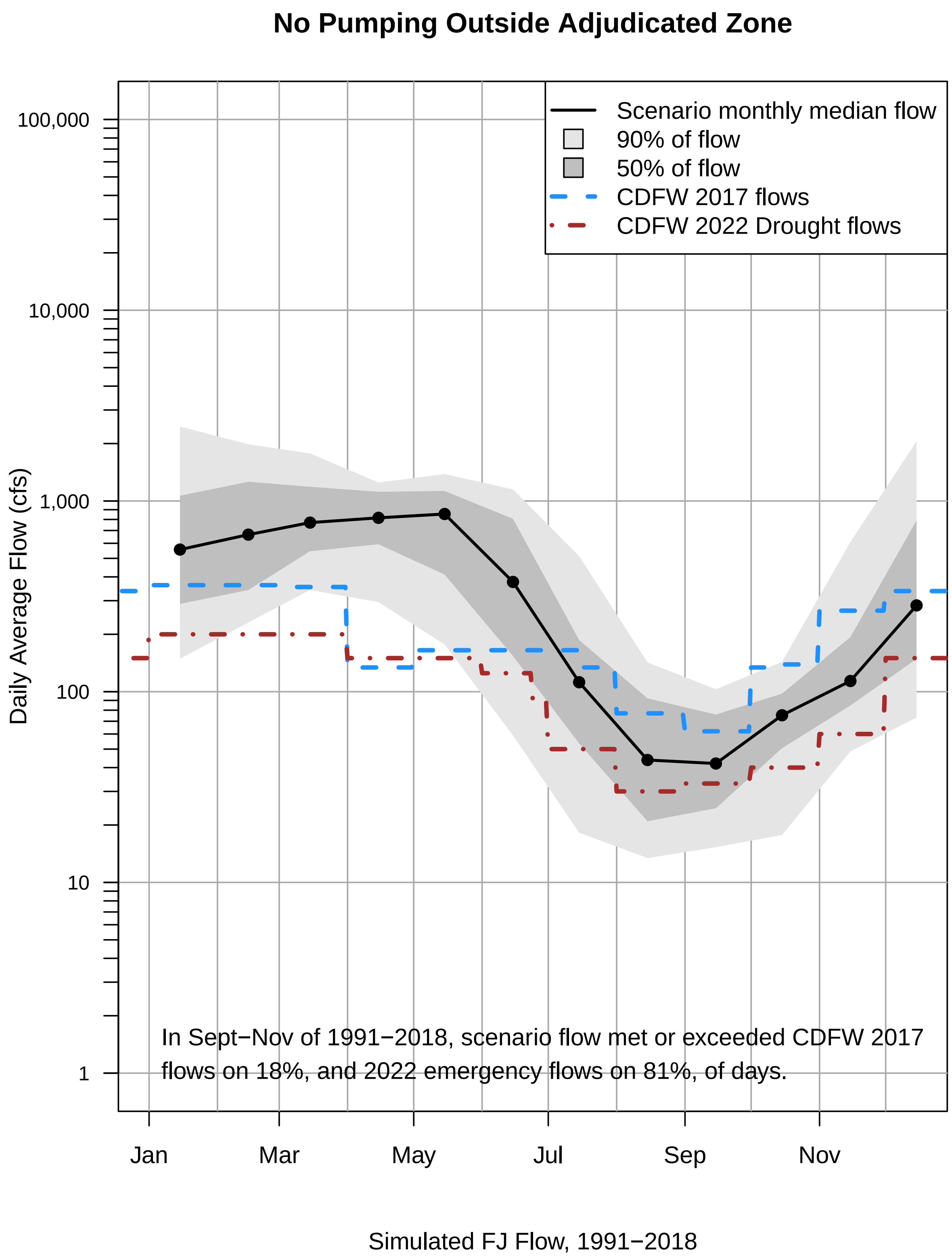

Irrigation Curtailed Starting Aug. 01
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 33%, and 2022 emergency flows on 92%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

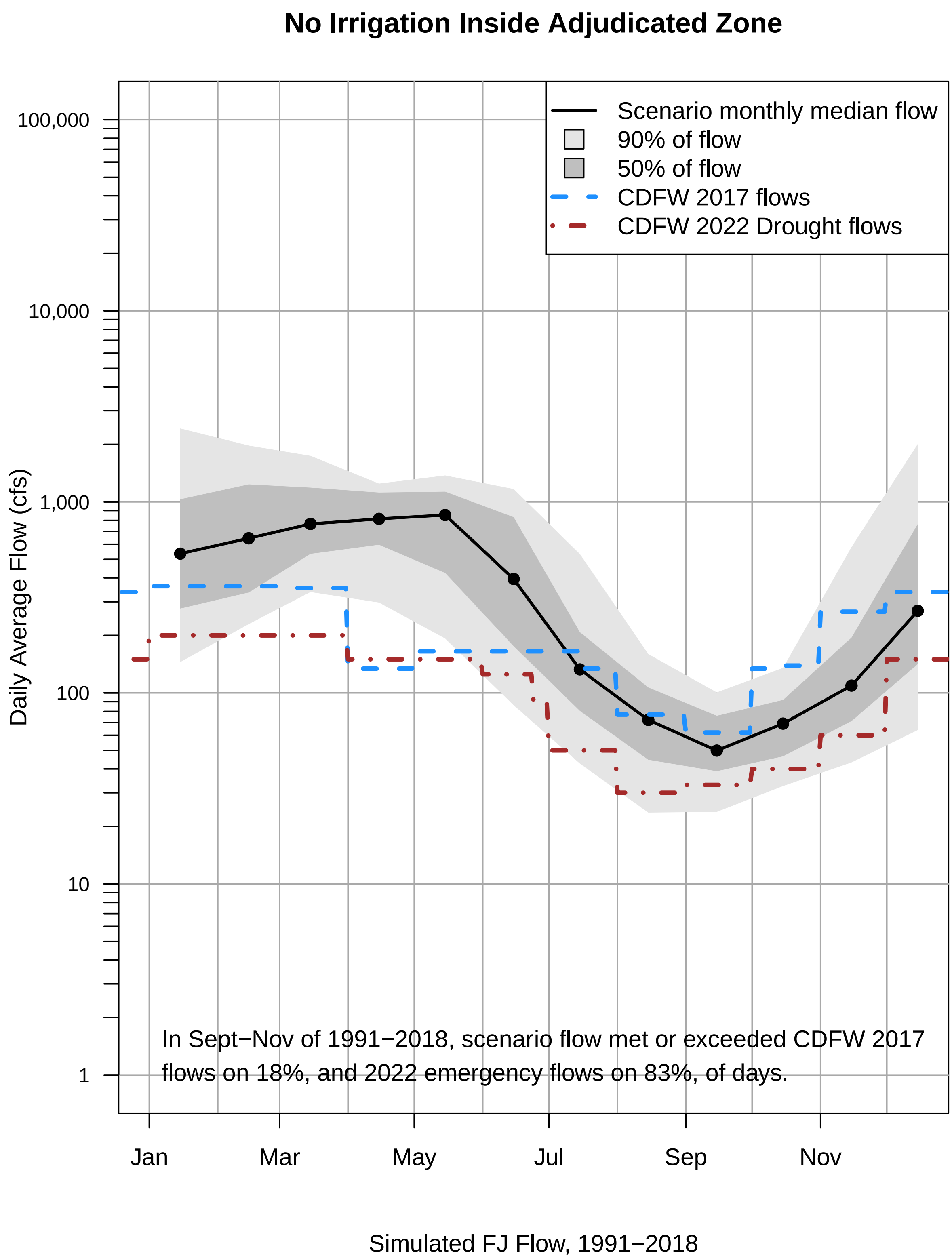

Irrigation Curtailed Starting Aug. 15
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 24%, and 2022 emergency flows on 83%, of days.
Simulated FJ Flow, 1991−2018

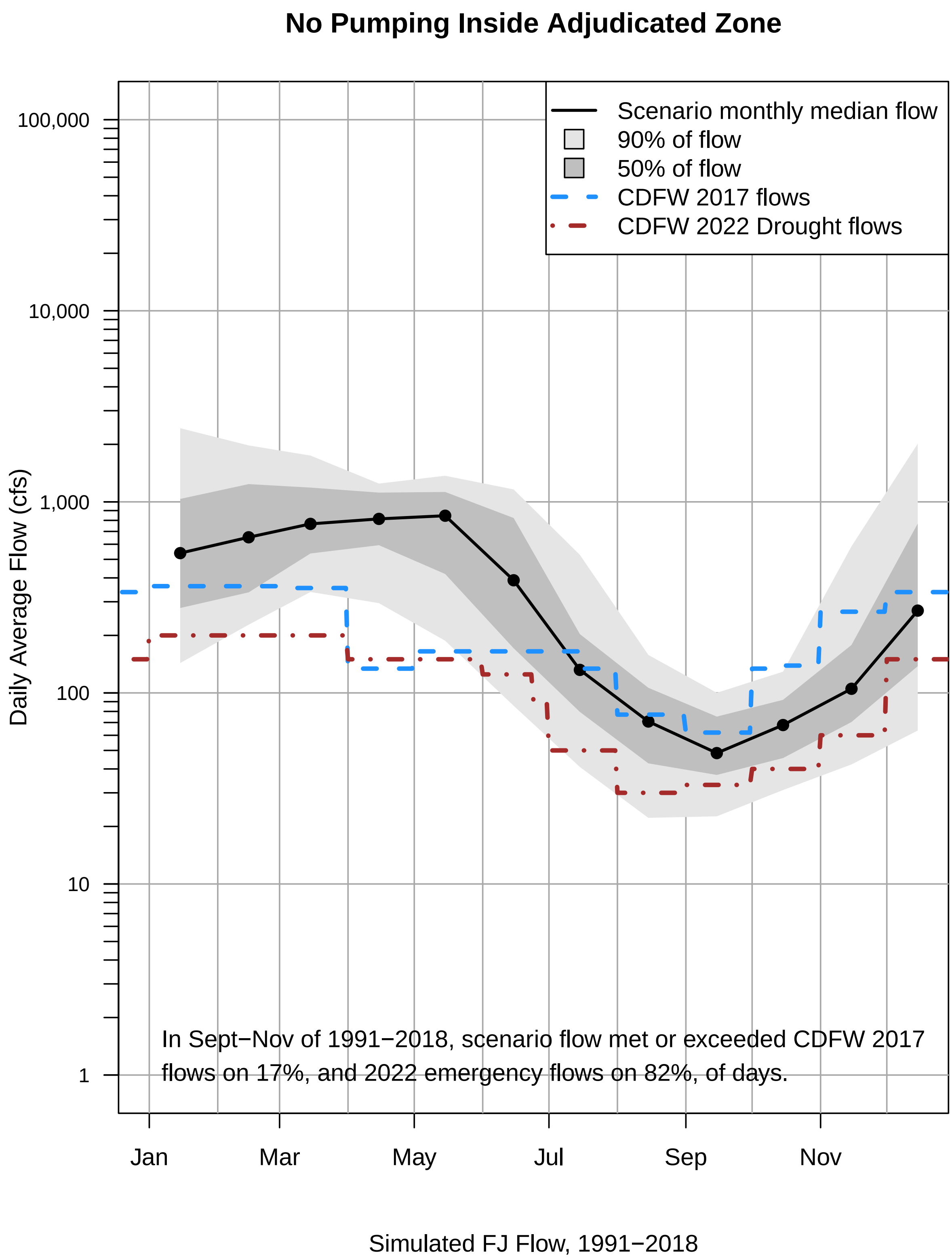

No Irrigation, Both Zones
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 41%, and 2022 emergency flows on 98%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018


No Pumping, Both Zones
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 38%, and 2022 emergency flows on 97%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

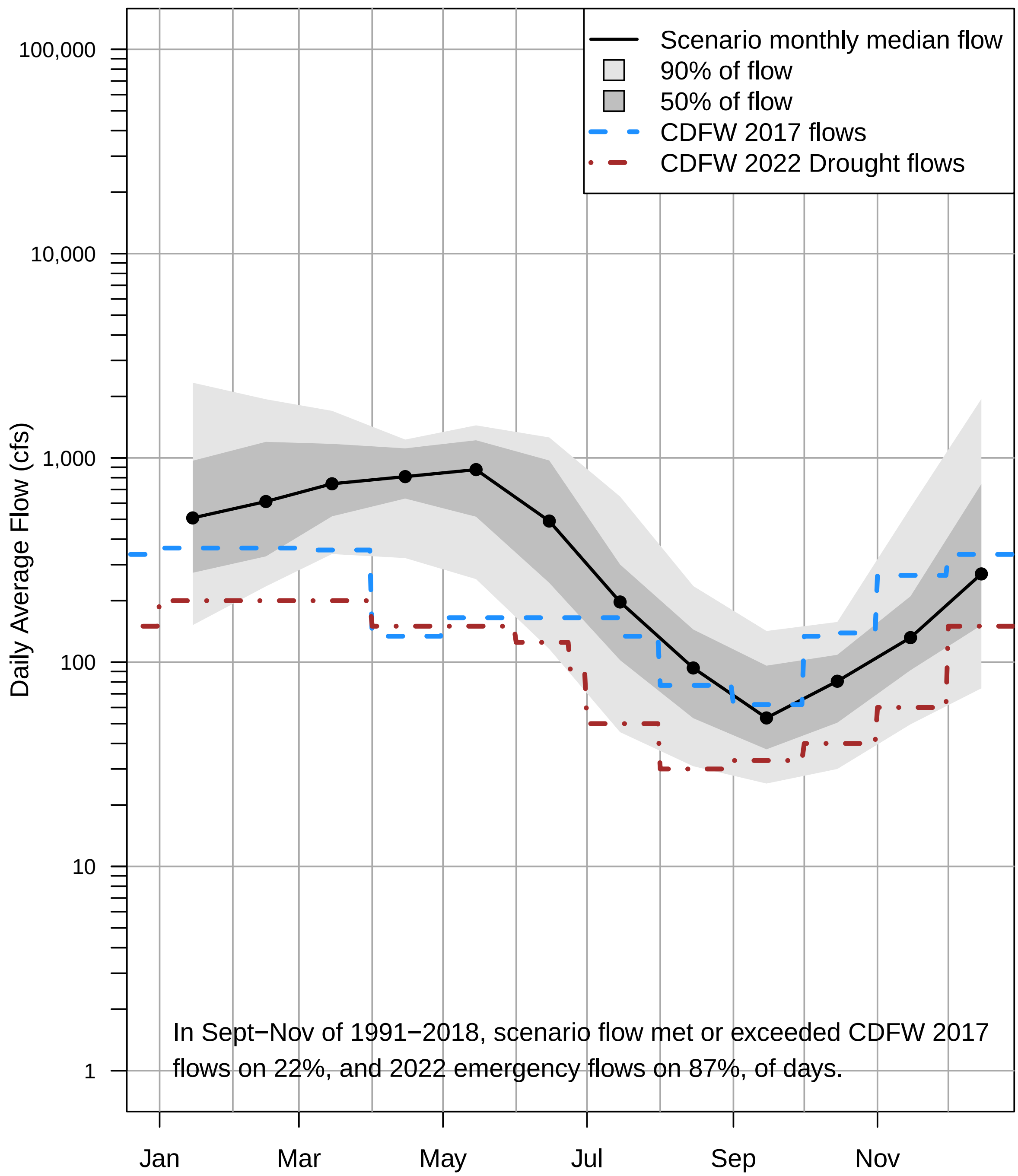

No Irrigation Outside Adjudicated Zone
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 22%, and 2022 emergency flows on 85%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018


No Pumping Outside Adjudicated Zone
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 18%, and 2022 emergency flows on 81%, of days.
Simulated FJ Flow, 1991−2018

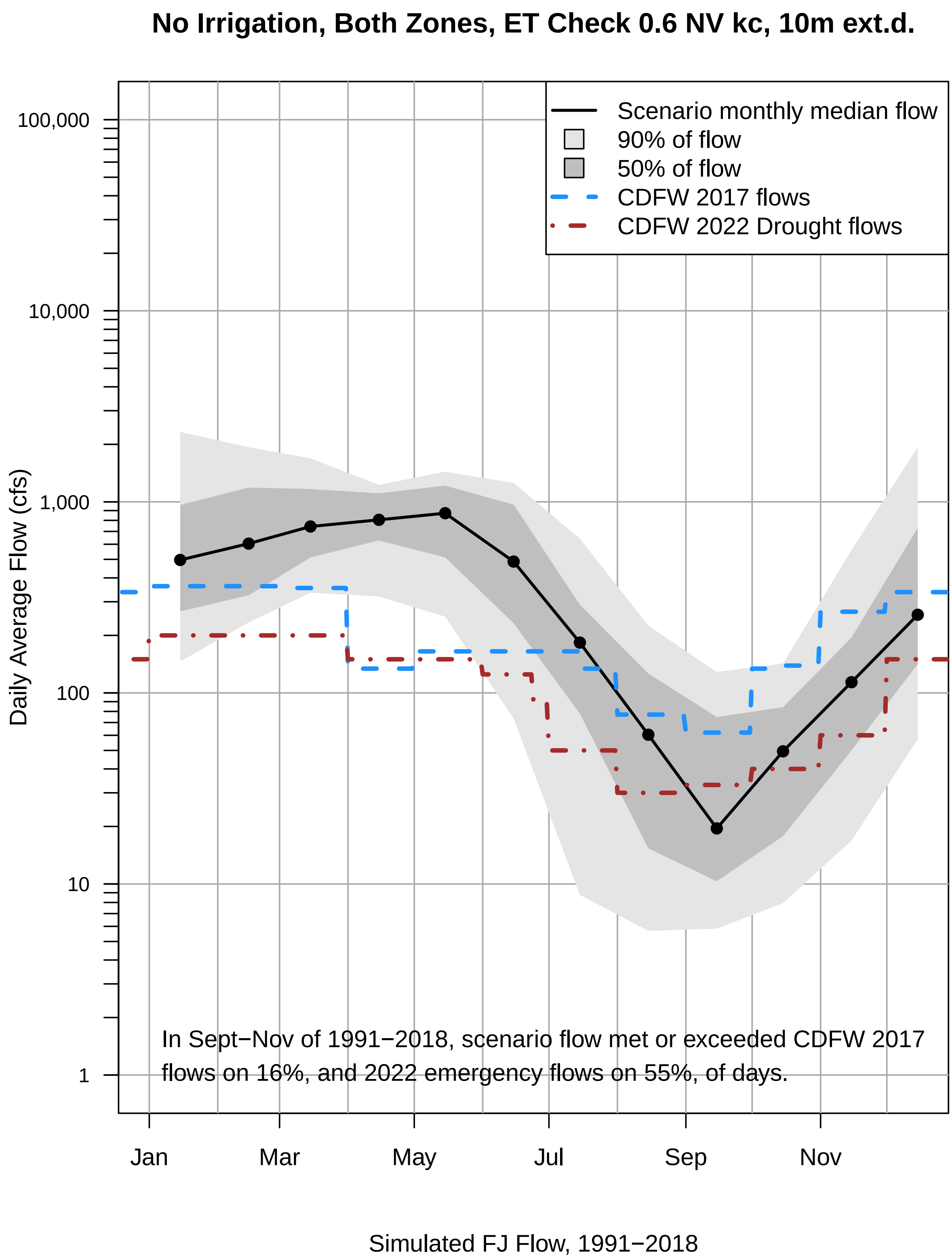

No Irrigation Inside Adjudicated Zone
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 18%, and 2022 emergency flows on 83%, of days.
Simulated FJ Flow, 1991−2018

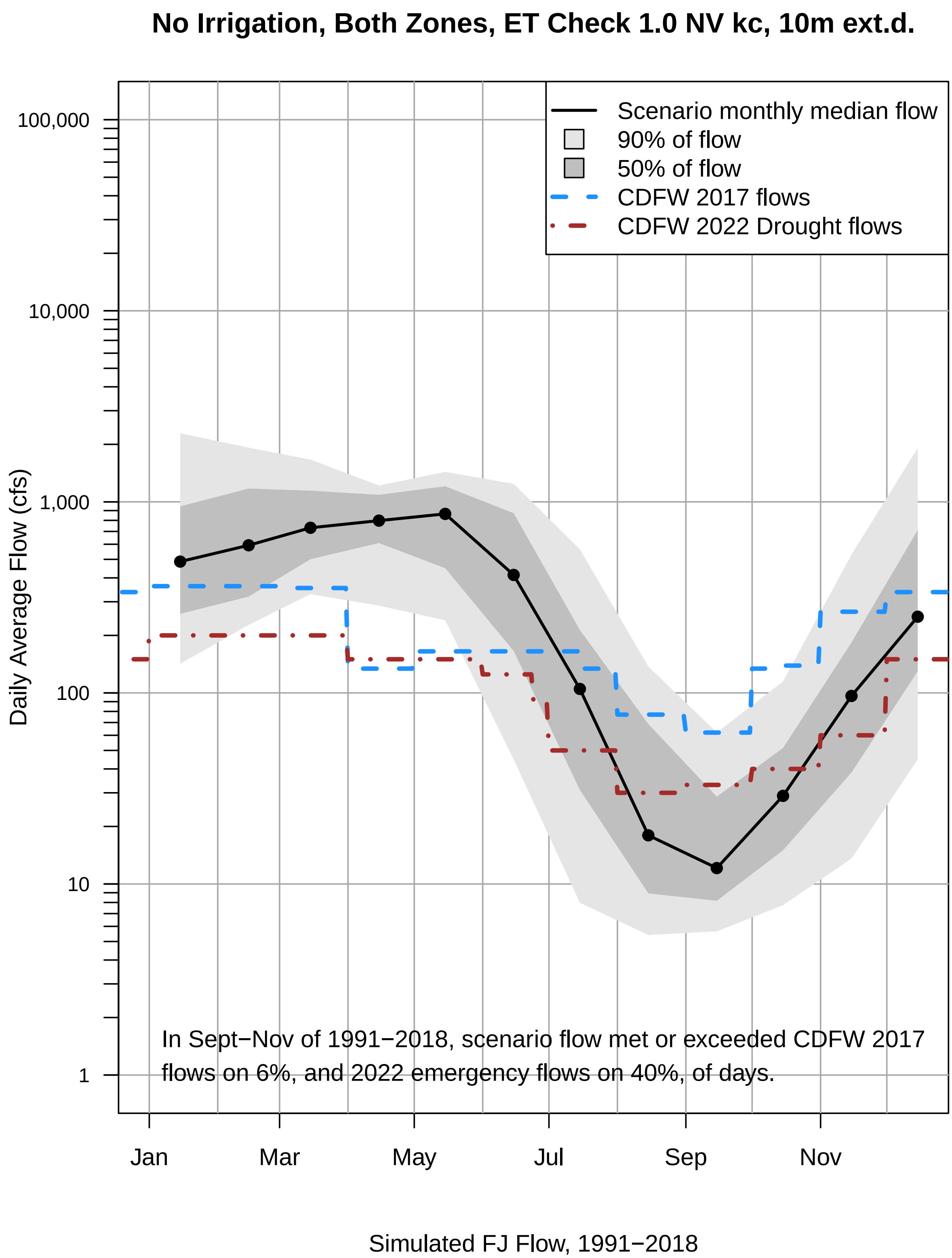

No Pumping Inside Adjudicated Zone
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 17%, and 2022 emergency flows on 82%, of days.
Simulated FJ Flow, 1991−2018

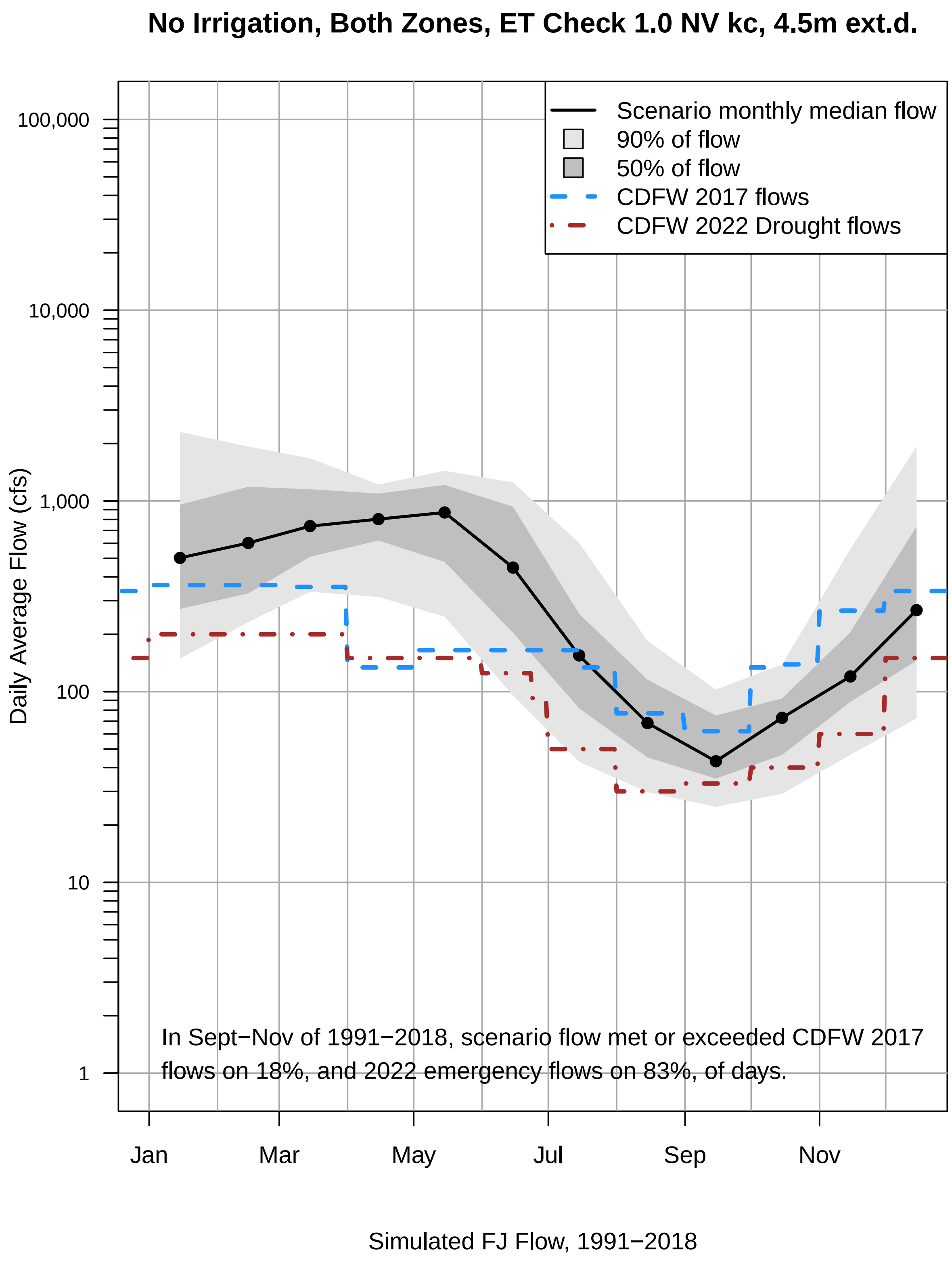
No Irrigation, Both Zones, ET Check 0.6 NV kc, 4.5m ext.d.

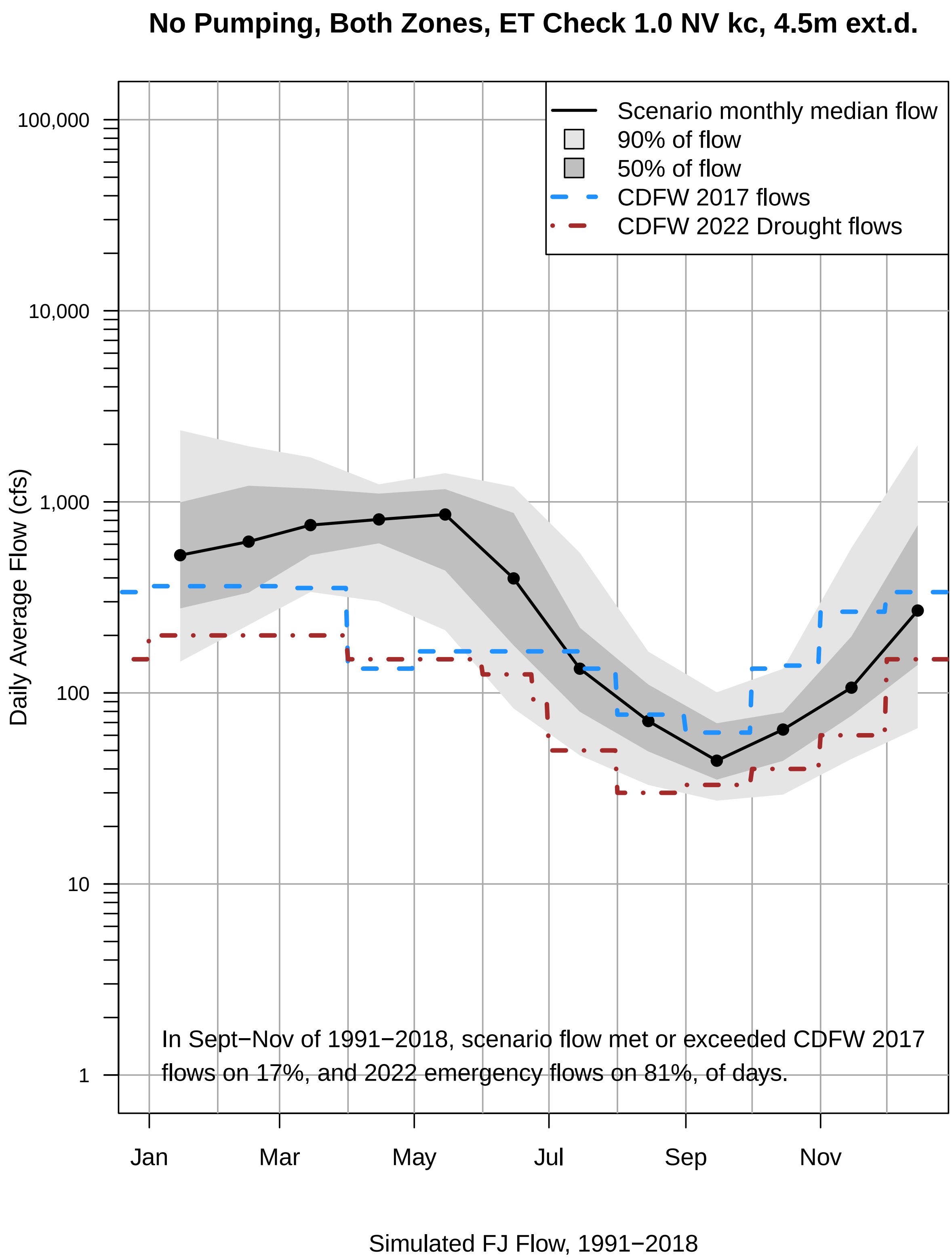


Simulated FJ Flow, 1991−2018

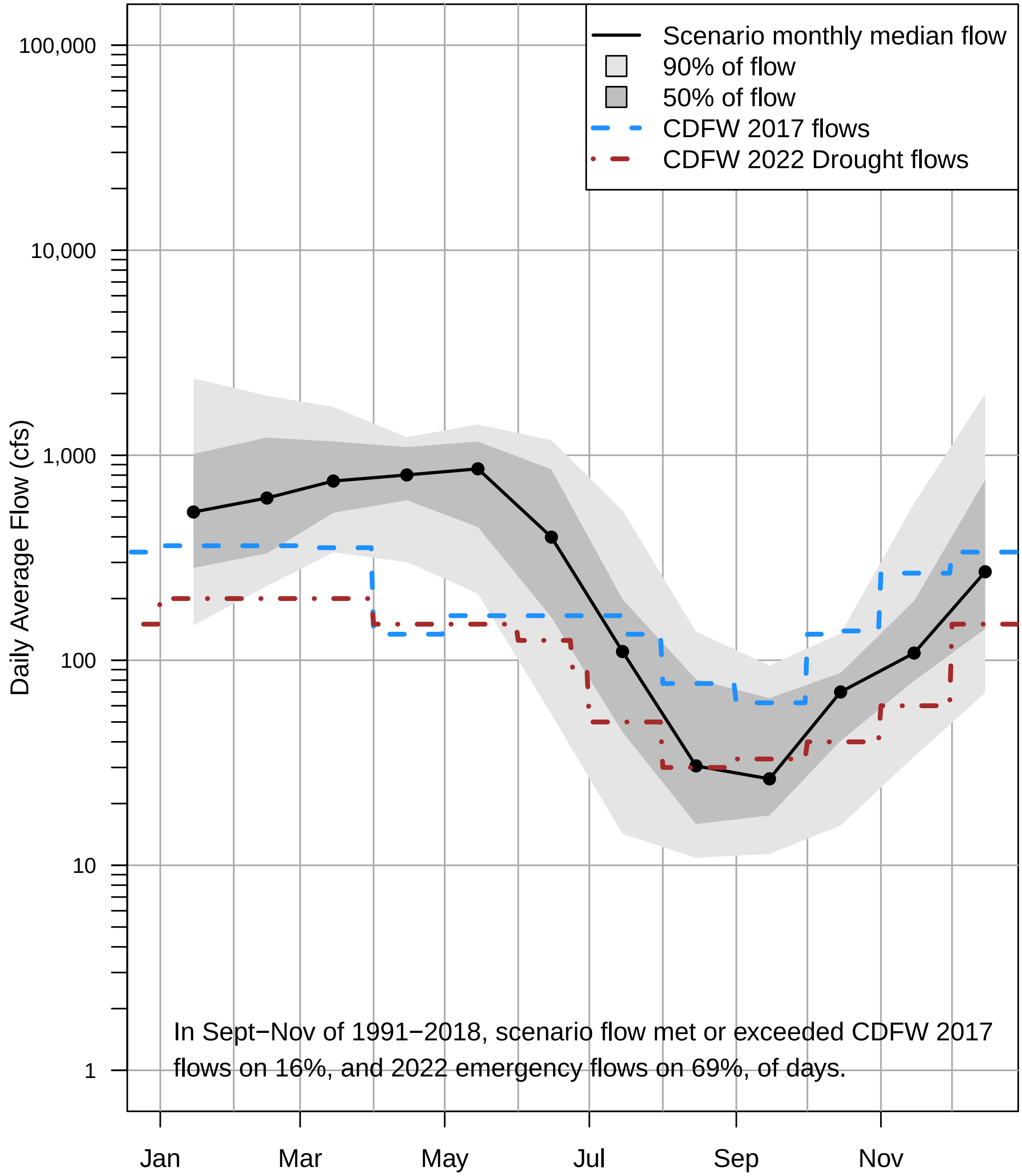

No Irrigation, Both Zones, ET Check 0.6 NV kc, 10m ext.d.
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 16%, and 2022 emergency flows on 55%, of days.
Simulated FJ Flow, 1991−2018


No Irrigation, Both Zones, ET Check 1.0 NV kc, 10m ext.d.
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 6%, and 2022 emergency flows on 40%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018


No Irrigation, Both Zones, ET Check 1.0 NV kc, 4.5m ext.d.
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 18%, and 2022 emergency flows on 83%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

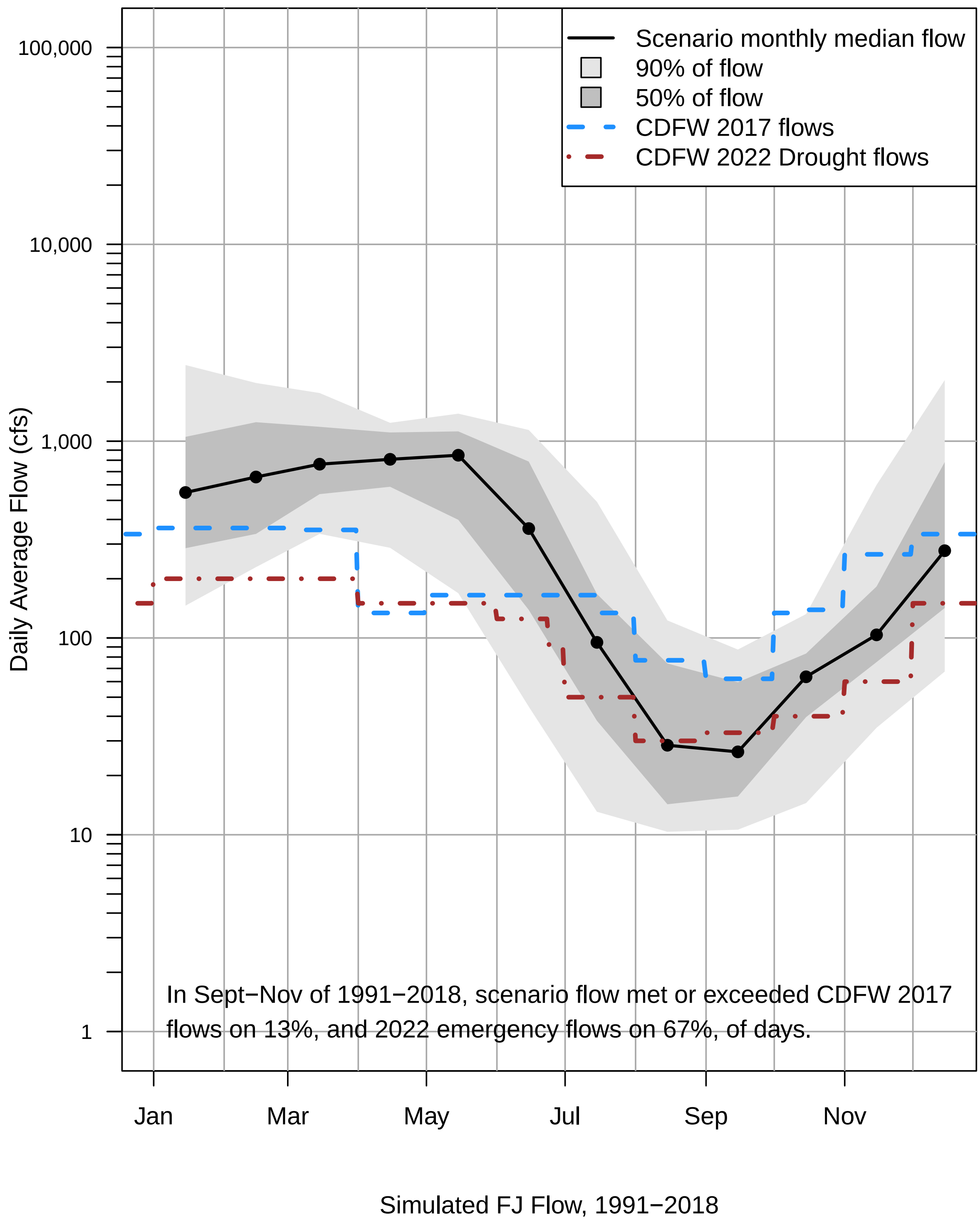

No Pumping, Both Zones, ET Check 1.0 NV kc, 4.5m ext.d.
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 17%, and 2022 emergency flows on 81%, of days.
Simulated FJ Flow, 1991−2018

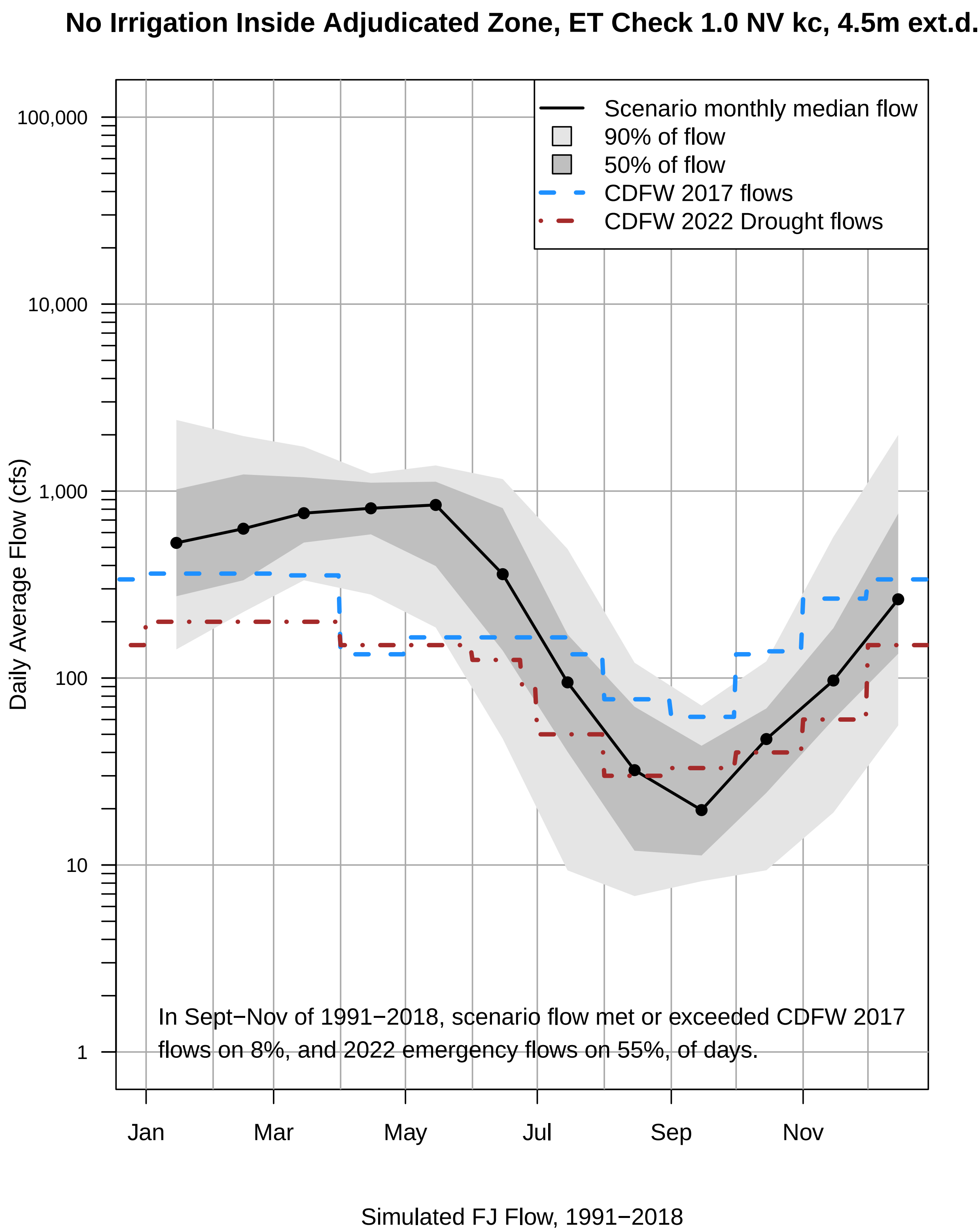
No Irrigation Outside Adjudicated Zone, ET Check 1.0 NV kc, 4.5m ext.d.

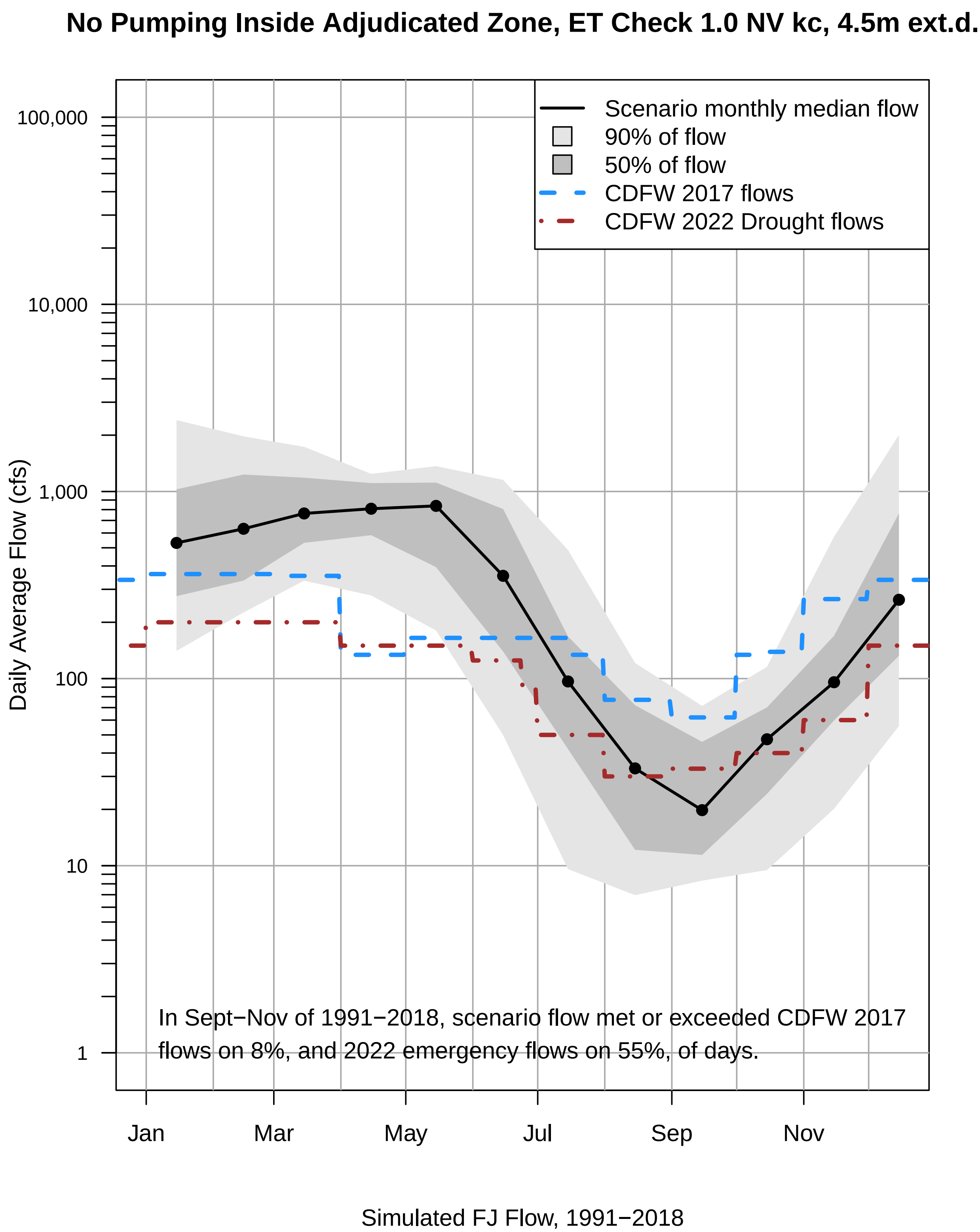


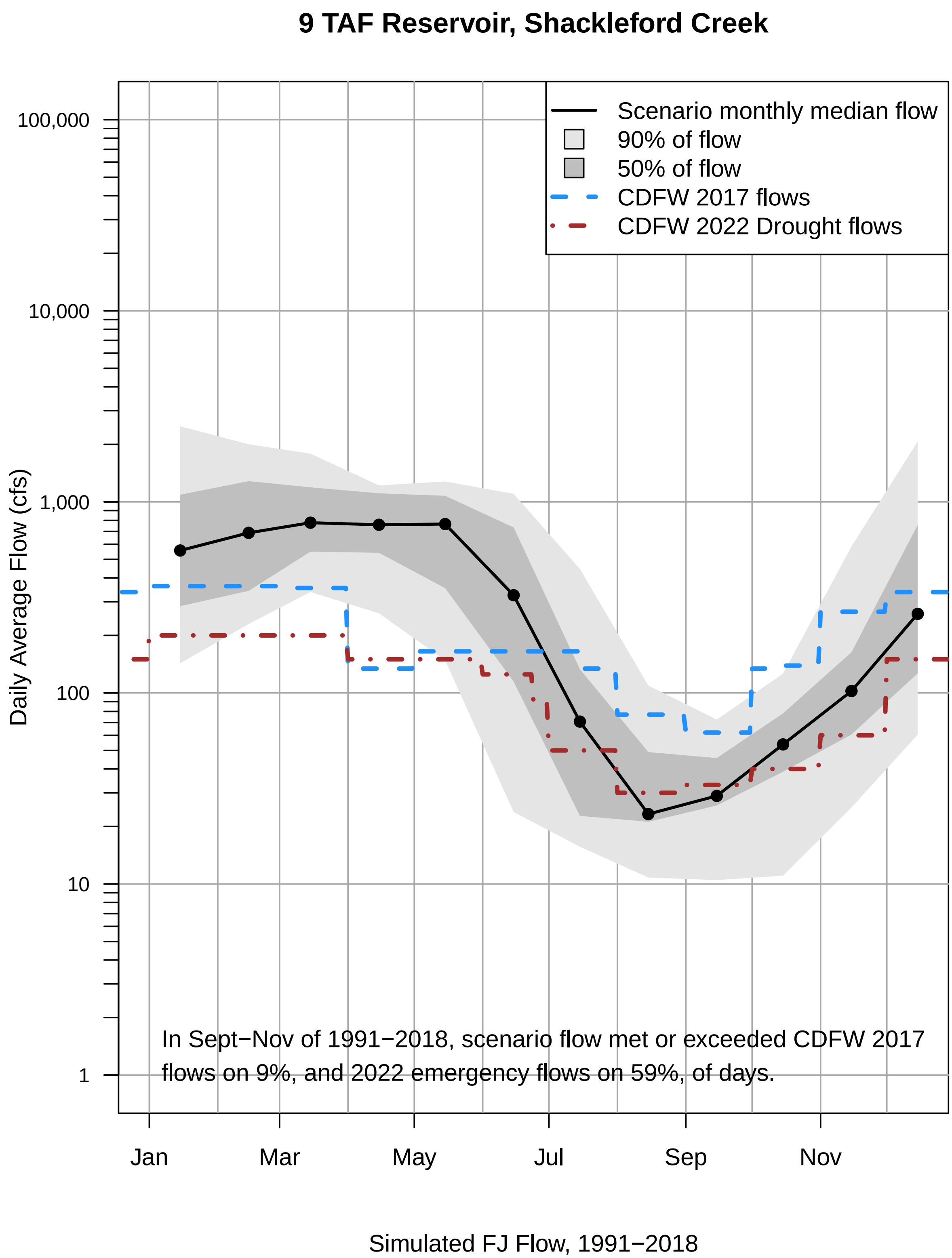
Simulated FJ Flow, 1991−2018

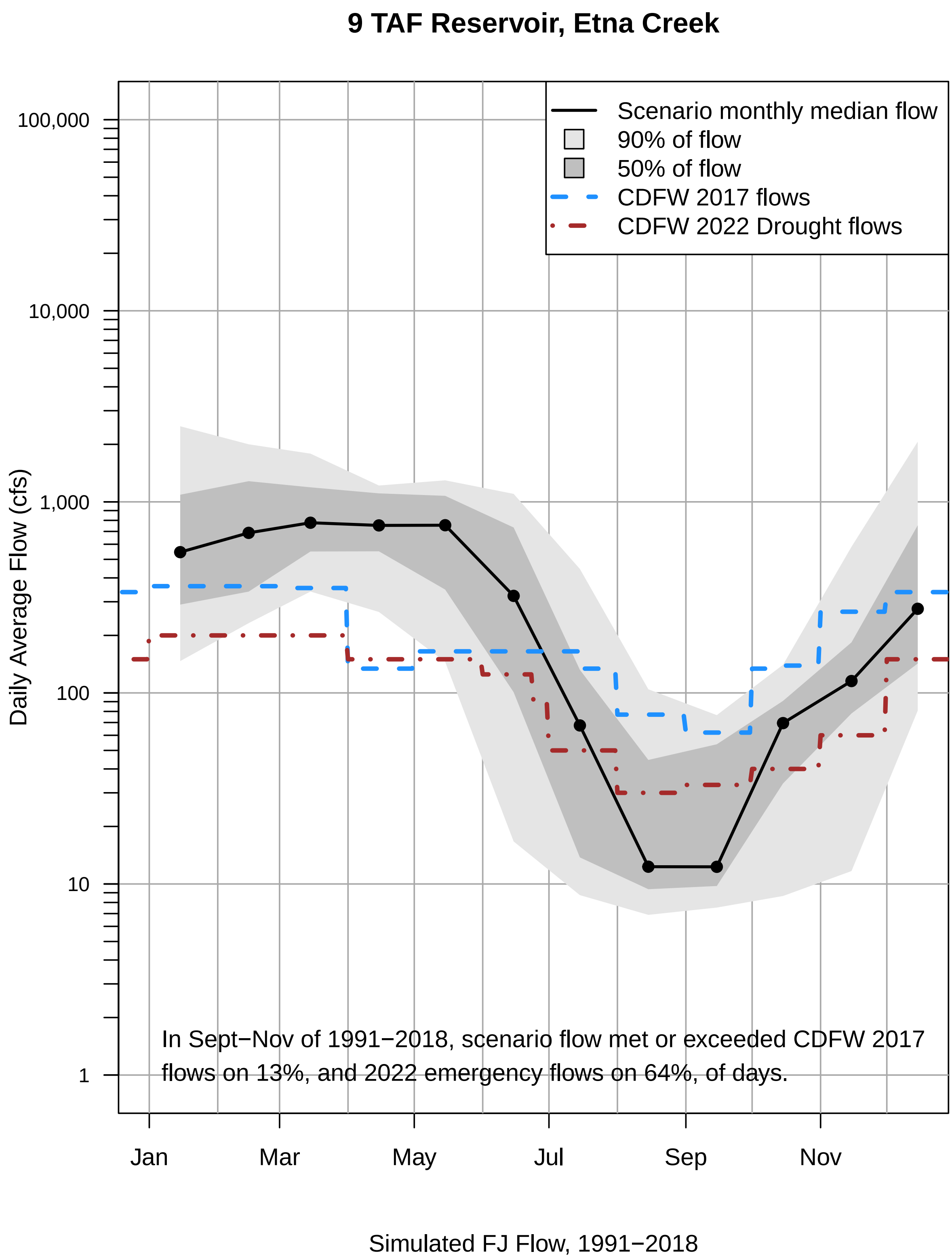
No Pumping Outside Adjudicated Zone, ET Check 1.0 NV kc, 4.5m ext.d.

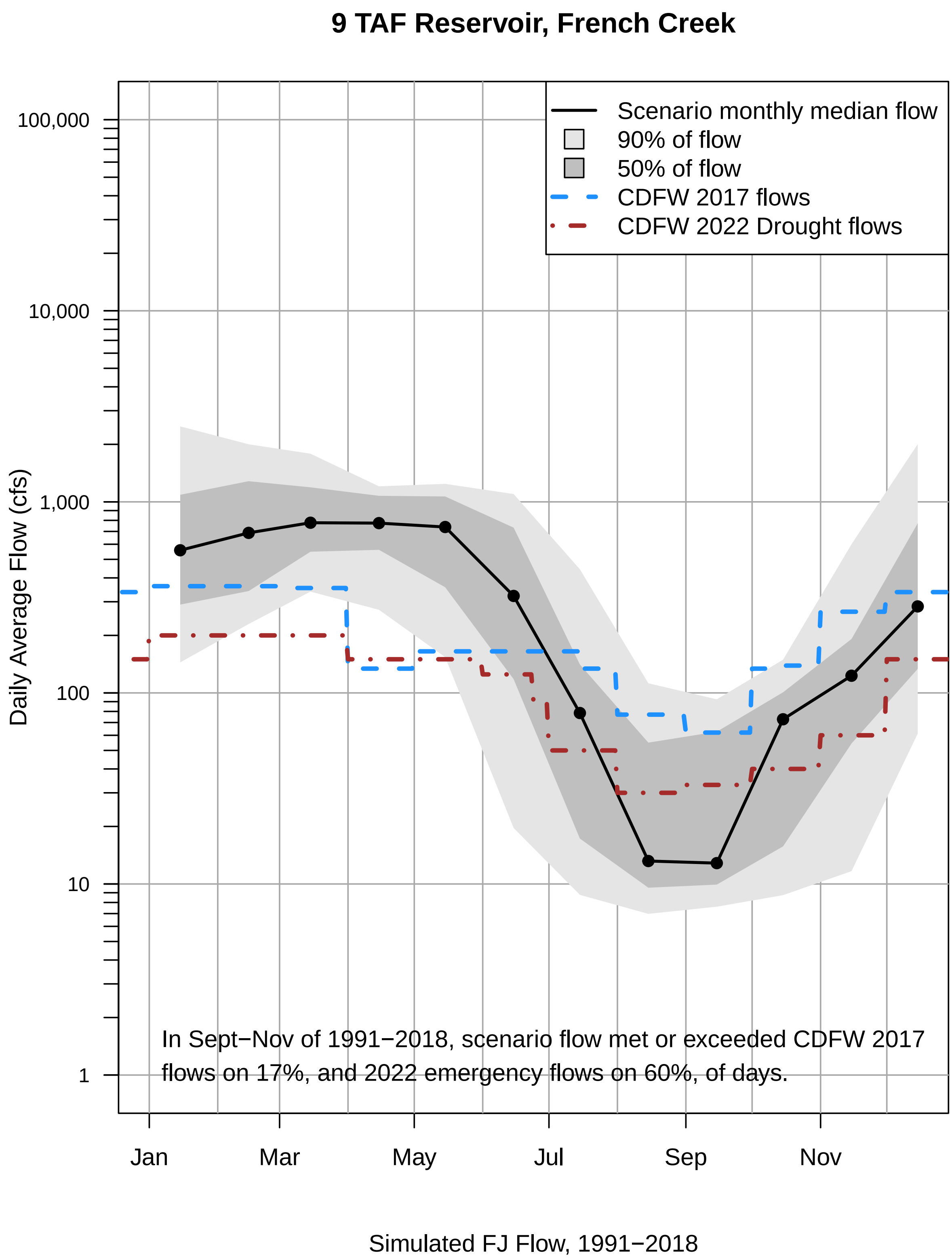


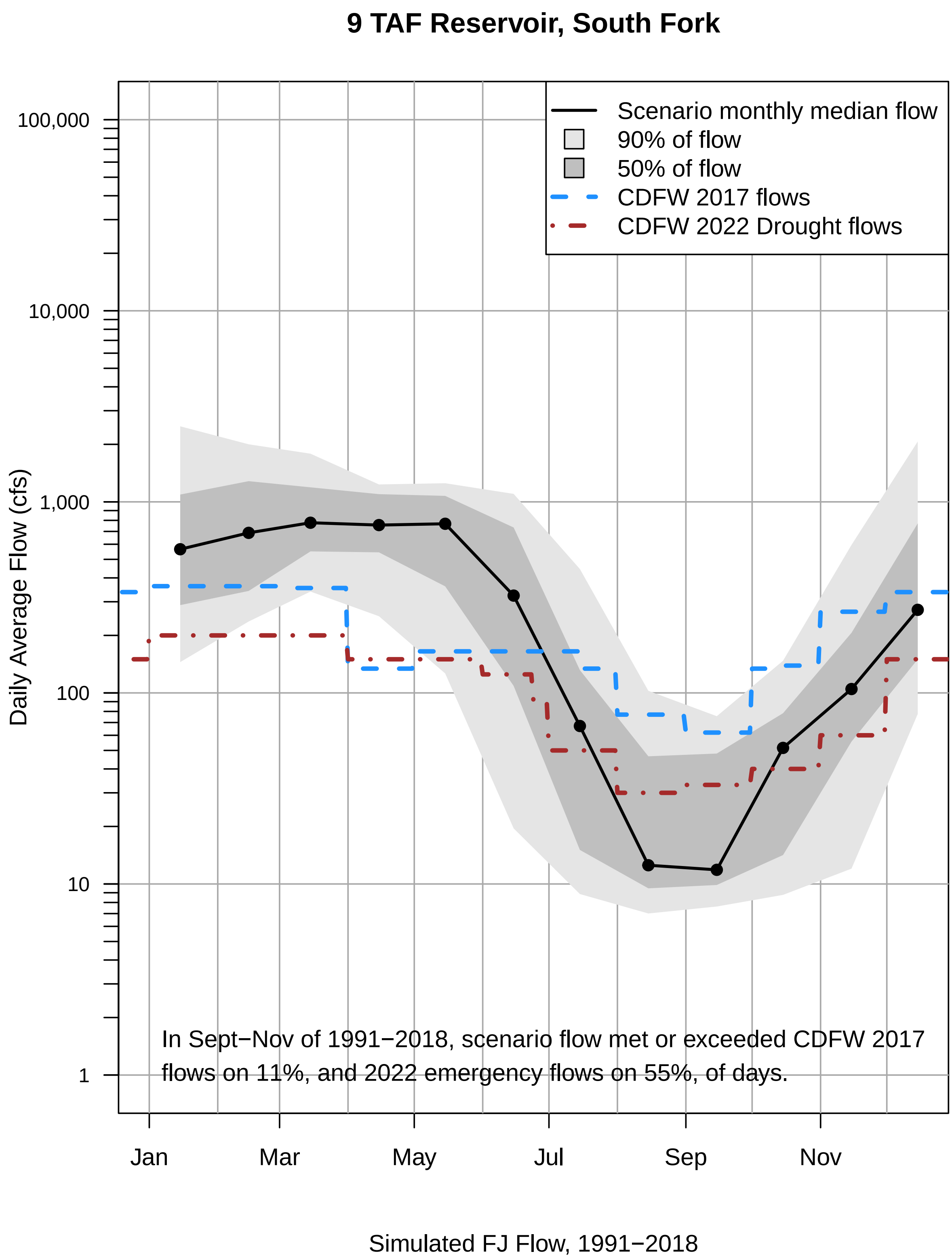

No Irrigation Inside Adjudicated Zone, ET Check 1.0 NV kc, 4.5m ext.d.
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 8%, and 2022 emergency flows on 55%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

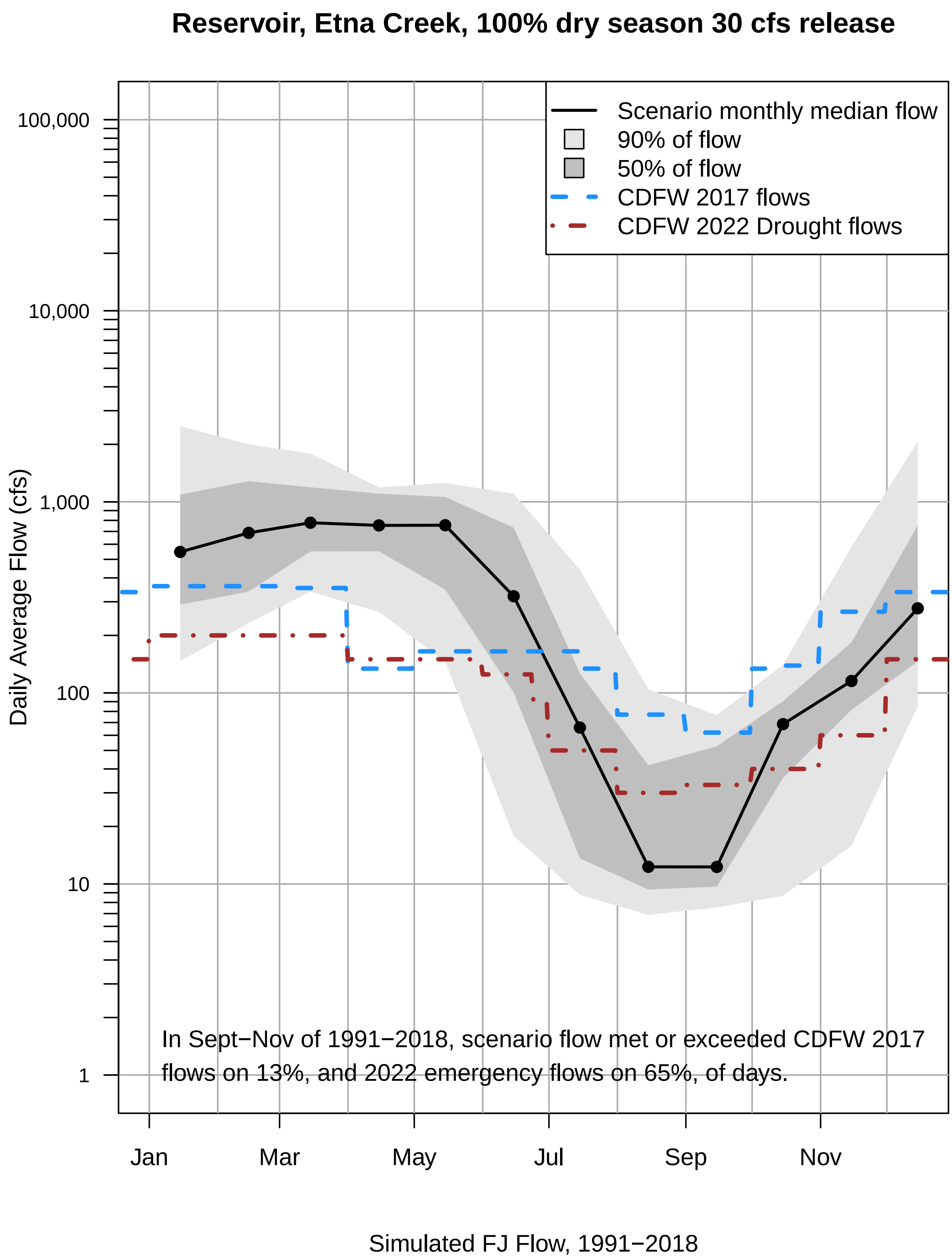

No Pumping Inside Adjudicated Zone, ET Check 1.0 NV kc, 4.5m ext.d.
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 8%, and 2022 emergency flows on 55%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018

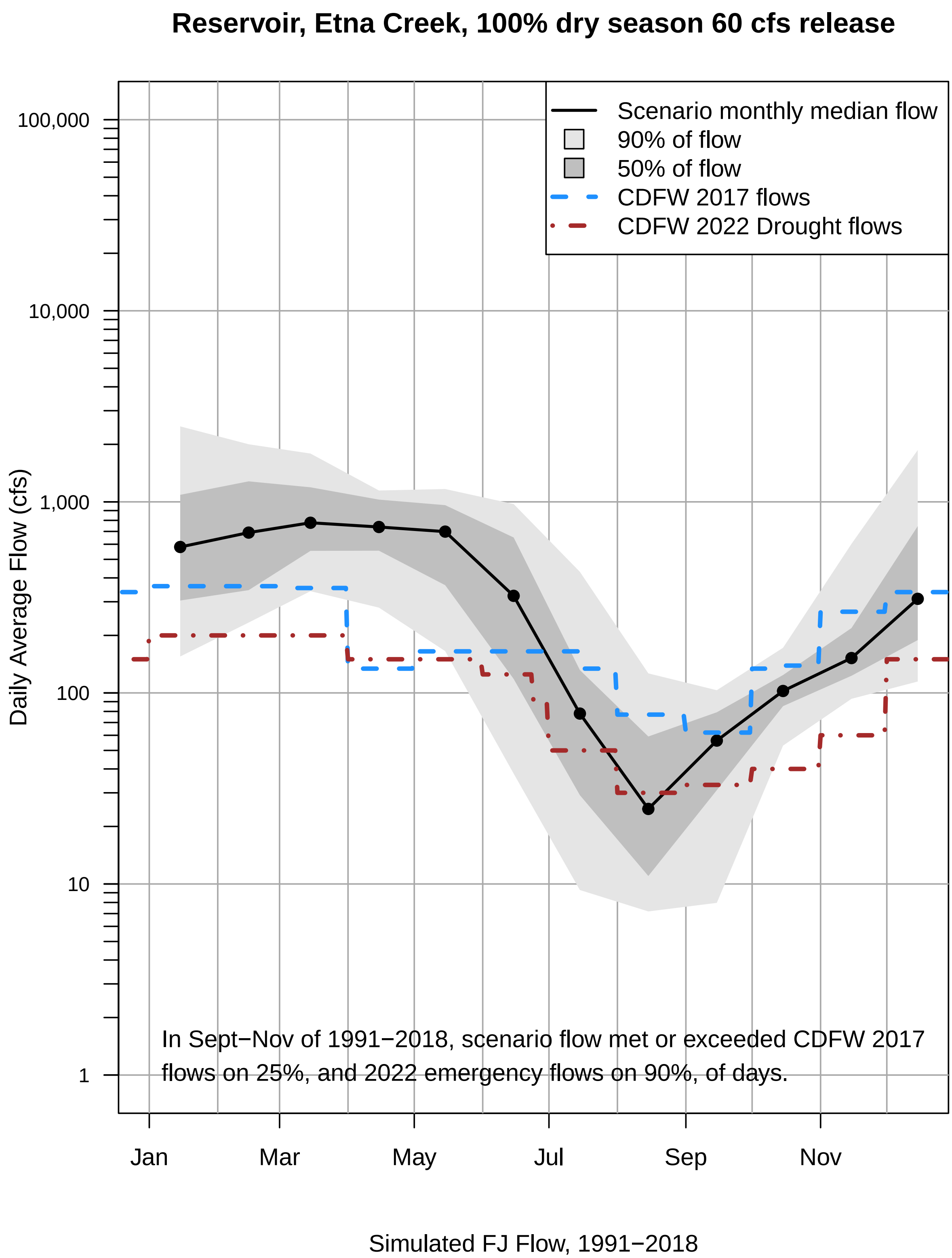

9 TAF Reservoir, Shackleford Creek
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 9%, and 2022 emergency flows on 59%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018


9 TAF Reservoir, Etna Creek
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 13%, and 2022 emergency flows on 64%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018


9 TAF Reservoir, French Creek
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 17%, and 2022 emergency flows on 60%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018


9 TAF Reservoir, South Fork
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 11%, and 2022 emergency flows on 55%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018


Reservoir, Etna Creek, 100% dry season 30 cfs release
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
Daily Average Flow (cfs)
100,000
10,000
1,000
100
10
1
Jan
Mar
May
Jul
Sep
Nov
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 13%, and 2022 emergency flows on 65%, of days.
Simulated FJ Flow, 1991−2018


Reservoir, Etna Creek, 100% dry season 60 cfs release
Scenario monthly median flow
90% of flow
50% of flow
CDFW 2017 flows
CDFW 2022 Drought flows
100,000
10,000
1,000
100
10
1
Daily Average Flow (cfs)
In Sept−Nov of 1991−2018, scenario flow met or exceeded CDFW 2017 flows on 25%, and 2022 emergency flows on 90%, of days.
Jan
Mar
May
Jul
Sep
Nov
Simulated FJ Flow, 1991−2018