Appendix C. Functional Flows Metrics Calculation

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This appendix describes the functional flow metrics, their significance, and their calculation. Further information describing the functional flow metric calculations, including description of the Python code used in the calculations, is available online at https://eflow.gitbook.io/ffc-readme/functional-flow-calculator/metrics. The peer-reviewed publication Patterson et al. (2020) contains more details on the methodology and is attached at the end of this document.

Citation:
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Functional Flow Metrics overview

The functional flow metrics are organized into five seasonally-based functional flow components, in addition to two annual summary metrics (average annual flow and coefficient of variation) calculated for each water year (Table 1). There are 24 total metrics, nine of which are Peak Flows metrics (magnitude, duration, and frequency calculated for each of the three percentile thresholds). The following sections describe the functional flow metrics, as grouped by functional flow component.

Table 1. Summary of functional flow metrics.

Functional Flow Component	Flow Characteristic	Functional Flow Metric
Fall pulse flow	Magnitude (cfs)	Peak magnitude of fall season pulse event (maximum daily peak flow during event)
	Timing (date)	Start date of fall pulse event
	Duration (days)	Duration of fall pulse event (# of days start-end)
Wet-season baseflow	Magnitude (cfs)	Magnitude of wet season base flow (10th and 50th percentile of daily flows within that season, including peak flow events)
	Timing (date)	Start date of wet season
	Duration (days)	Wet season base flow duration (# of days from start of wet season to start of spring season)
Wet-season Peak flows	Magnitude (cfs)	Peak-flow magnitude (50%, 20%, and 10% exceedance values of annual peak flows over the period of record; these correspond to the 2-, 5-, and 10-year recurrence intervals, respectively)
	Duration (days)	Duration of peak flows over wet season (cumulative number of days in which a given peak-flow recurrence interval is exceeded in a year)
	Frequency	Frequency of peak flow events over wet season (number of times in which a given peak-flow recurrence interval is exceeded in a year)

	Magnitude (cfs)	Spring peak magnitude (daily flow on start date of spring recession-flow period)
	Timing (date)	Start date of spring recession (date)
	Duration (days)	Spring flow recession duration (# of days from start of spring to start of summer base flow period)
Spring recession flow	Rate of change (%)	Spring flow recession rate (Percent decrease per day over spring recession period)
	Magnitude (cfs)	Dry season base flow magnitude (50th and 90th percentile of daily flow within summer season)
	Timing (date)	Dry season start timing (start date of summer)
Dry-season baseflow	Duration (days)	Dry season base flow duration (# of days from start of summer to start of wet season)

Data Smoothing and Splines

Data smoothing is used widely to calculate annual flow metrics, dampening daily to weekly fluctuations in the hydrograph while leaving seasonal patterns intact. The level of smoothing is defined by a smoothing parameter called sigma (⌠). A higher value for sigma (large ⌠) causes more smoothing, and a smaller value of sigma (small ⌠) leads to less smoothing, which leaves the hydrograph closer to its "raw" form (Fig. 1). The ⌠ parameter will be referred to in some metric calculations throughout this document.

Splines are functions constructed from segments of polynomials between each time series observation that are constrained to be smooth at the junctions. The purpose of fitting a spline curve to data is to perform a derivative of the spine function, which results in a highly accurate slope estimate for streamflow data. Splines will be referred to throughout the metric calculations, when needed to find the slope of the hydrograph at a certain point.

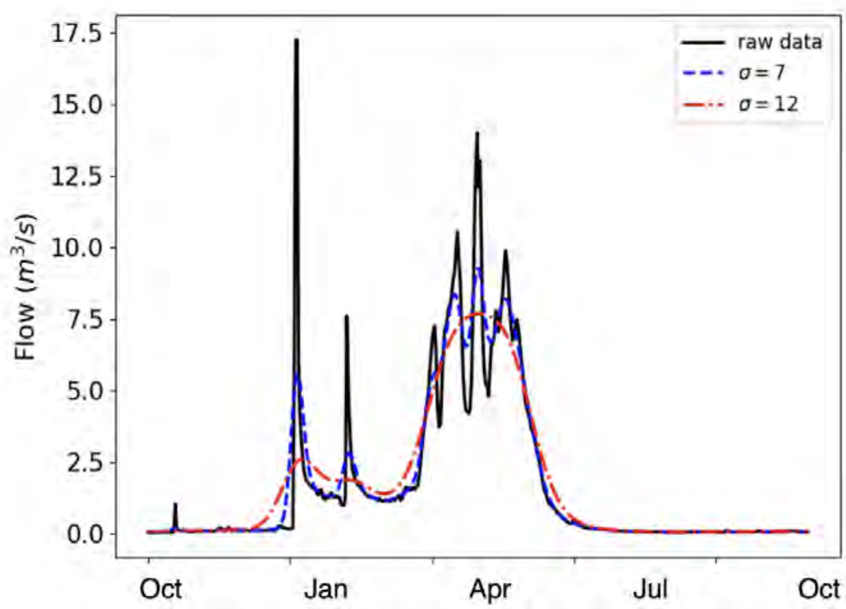

Figure 1. Annual hydrograph raw data, shown with two levels of smoothing (modifications to ⌠ value).

Fall Pulse Flow

The fall pulse flow describes a peak in the annual hydrograph created by the first significant increase in flow following the dry season low flow period. This event often takes the form of a storm event that introduces a pulse of flow into the stream. This flow typically occurs each year but may not occur in some years depending on climate conditions and specific storm events. The metrics calculated for the fall pulse flow include timing, magnitude, and duration.

Timing

The fall pulse flow timing captures the date of the first storm event of the new water year. This is meant to characterize the first significant increase in flows following the dry season. The fall pulse flow is the first date between October 1st to December 15th in which flow exceeds a magnitude threshold defined as twice the magnitude of the previous dry season's base flow or 0.08 cubic meters per second (cms) (equivalent to 1 cubic foot per second (cfs)), whichever is greater. This metric is outputted in both Julian days, where January 1st = 1 and December 31st = 365, and in water year days, where October 1st = 1 and September 30th = 365.

The calculation for fall pulse flow timing is described below. To calculate the timing of the fall pulse flow for each water year, first raw flow data is smoothed with a small smoothing filter (G1, σ=0.2) in the windowed range from the start of the water year to the start of the wet season, which is calculated previously. The derivative of a spline function is used to identify all local peaks in the windowed period based on a sign change in the derivative from positive to negative (triangles, Fig. 2). Searching forward through time from the start of the water year, the first local peak meeting the following requirements is selected as the fall pulse flow: (1) magnitude exceeds 200% of previous dry season median baseflow magnitude; (2) duration of the peak's rising limb is less than 20 days; and (3) maximum peak magnitude is at least 30% higher than the valleys on either side of the peak. This event does not occur in all water years in California, particularly dry water years with limited fall-season rainfall.

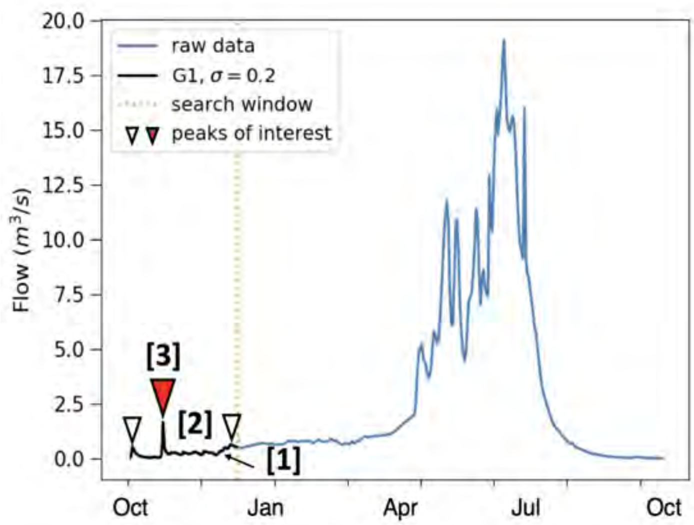

Figure 2. Illustration of steps to calculate the timing of the fall pulse flow.

There are two exceptions to the relative magnitude requirement described above. First, if the previous dry season median magnitude was relatively high (above 0.7 cms/25 cfs), the relative magnitude threshold was set as 150% of the previous dry season baseflow instead of 200%; this prevented the magnitude threshold from being set too high. Second, 0.08 cms (1 cfs) is set as the minimum allowable magnitude threshold based on expert judgment that lower flows would not be ecologically significant across most gaged streams in California.

Magnitude

The fall pulse flow magnitude is set as the peak flow magnitude during the pulse flow event. This metric is in units of cms/cfs.

Duration

The fall pulse flow duration is generally calculated as the number of days from the beginning of the flow event until the event's peak. In cases when the beginning of the flow event cannot be identified, the duration is instead calculated as the number of days between the event peak and the end of the falling limb of the event peak. A signal processing algorithm is used to identify the beginning of the rising limb and end of the falling limb of the fall pulse flow, and is described in more detail at https://eflow.gitbook.io/ffc-readme/. This metric is measured in number of days.

Wet Season Baseflow

The wet season baseflow is the period of the water year in which streams receive the greatest inputs from storm runoff or snowmelt, and flows are elevated above the level of dry season baseflow. Calculate metrics include start timing, magnitude, and duration.

Wet season start timing

The calculation for wet season start timing is described below (Figure 3). This metric is outputted in both Julian days, where January 1st = 1 and December 31st = 365, and in water year days, where October 1st = 1 and September 30th = 365. First, raw flow data is smoothed with a large smoothing filter (G1, σ=10), which is used to detect the water year's global peak (P1) and preceding global valley (V1). A relative magnitude threshold M1 is then set based on the magnitude of P1 and V1 as an upper limit ($M1=\gamma*(P1-V1)$, where $\gamma=0.2$), to ensure that wet season start timing is not set after flows have already increased during the water year. A spline curve is then fit to G1 so that its derivative can be used as a hydrologic requirement in the final feature detection step. Finally, searching backwards in time from P1, the date that discharge first falls below M1 and below a rate of change equaling (δ*P1, where $\delta=0.002$) is selected as the wet season start timing. Similarly, the values for γ and δ were defined based on expert consultation and knowledge of California flow regimes.

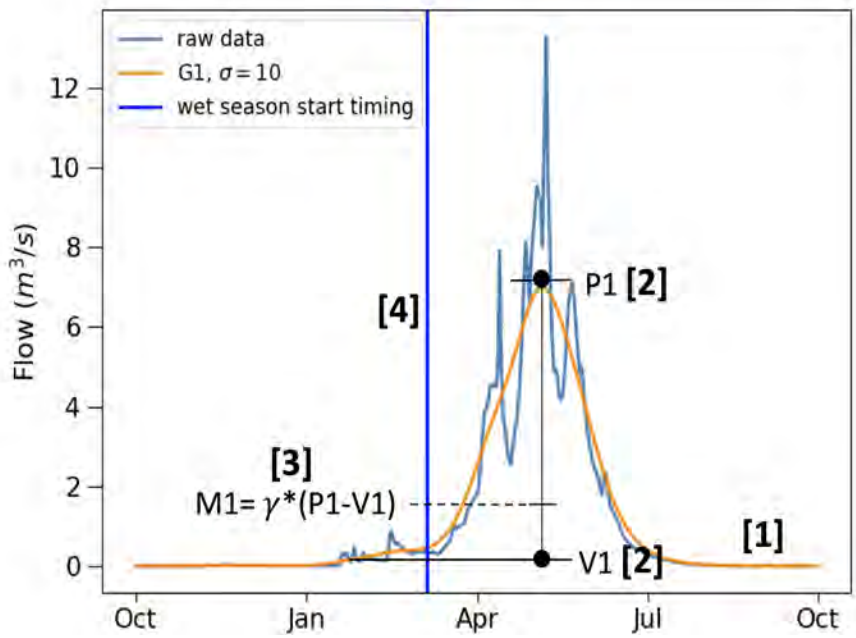

Figure 3. Illustration of steps to calculate the start timing of the wet season baseflow period.

Magnitude (10th and 50th percentile)

The wet season baseflow magnitude is calculated as the 10th and 50th percentile daily flow magnitudes from the start of the wet season to the start of the dry season. This metric is in units of cms/cfs.

Duration

The wet season baseflow duration is defined as the number of days from the start of the wet season until the start of the next spring recession. This metric is in units of days.

Peak Flows

Peak flow metrics describe the long-term peak flow magnitudes and the duration and frequency of events that exceed these magnitude thresholds.

Magnitude

These metrics refer to the long-term exceedance flow associated with 10^{th}, $20^{th,}$ and 50^{th} percentile exceedance flows over the period of record, which correspond to 10-, 5-, and 2-year recurrence intervals. These metrics are in units of cms/cfs.

Duration

Peak flow duration is the median number of days that all exceedance flow events stay over the flow thresholds (10^{th}, $20^{th,}$ and 50^{th}) in that water year. This metric is measured in number of days.

Frequency

Peak flow frequency is the number of times per water year that flow crosses over an exceedance flow threshold (10^{th}, $20^{th,}$ or 50^{th} percentile). This metric is measured in frequency count (number of occurrences).

Spring Recession Flow

The spring recession marks the seasonal shift from high magnitude winter flows to dry season baseflow. This season is often marked by a continuous decline in flows until dry season baseflow is reached. The metrics calculated for the spring recession include timing, magnitude, rate of change, and duration.

Spring recession start timing

The calculation for spring recession start timing is described below and in Figures 4 and 5. This metric is outputted in both Julian days, where January 1st = 1 and December 31st = 365, and in water year days, where October 1^{st} = 1 and September 30^{th} = 365.

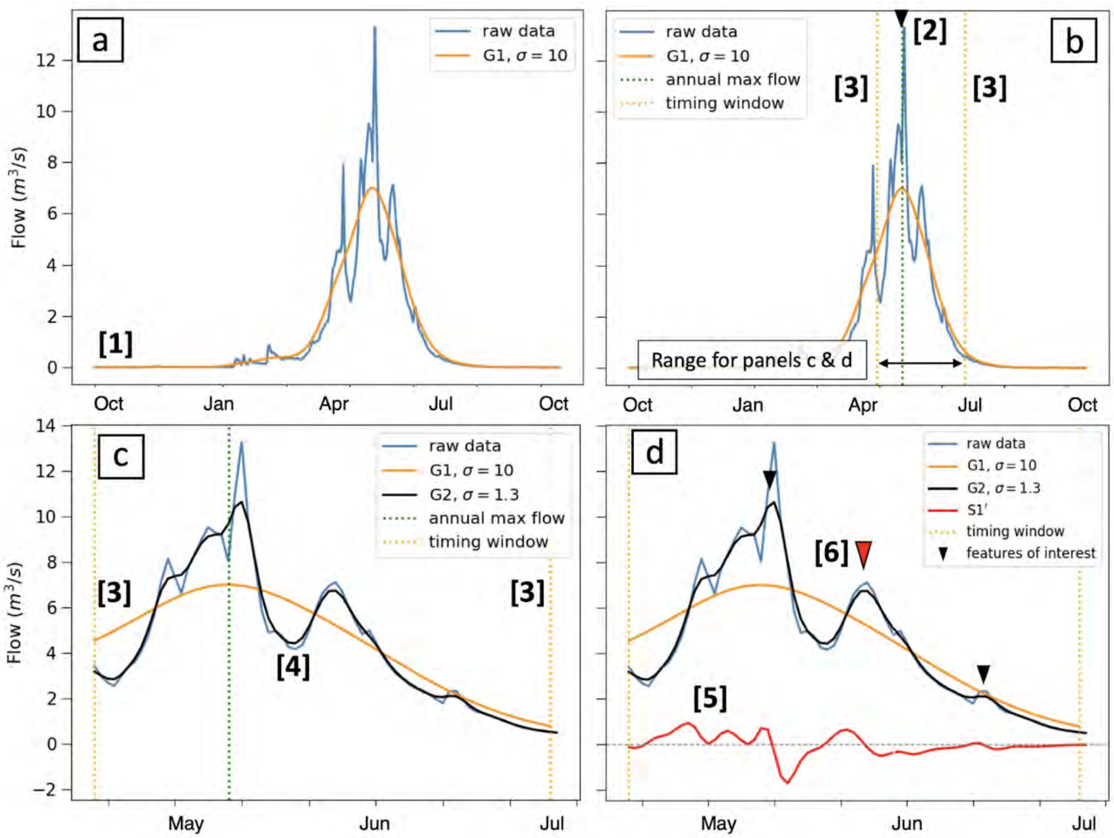

Figure 4. Illustration of primary steps to calculate the start timing of the spring recession.

To calculate the start timing of the spring recession for each water year, first raw flow data is smoothed with a large smoothing filter (G1, σ=10) to detect major wet and dry seasons (Fig. 4a, step 1). The peak flow of the wet season is then identified from G1 to determine the subsequent high to low flow transition (Fig. 4b, step 2). A 70-day search window (20 days before and 50 days after) is applied around the peak flow date to constrain further analysis (Fig. 4b, step 3). Within the search window, a second, smaller smoothing filter (G2, σ=1.3, Fig. 4c, step 4) is applied to the raw time series and the derivative of a spline function (S1') is used to detect individual storm events within the windowed range based on the occurrence of sign reversals in S1' from positive to negative (Fig. 4d, step 5). The algorithm then searches through the identified peaks moving backward in time (arrows, Fig. 4d) until it detects a peak feature exceeding a magnitude threshold of 50% of the smoothed maximum flow, and a rate of change threshold based on a percentage (0.02-0.08%) of the water year's maximum slope. These hydrologic requirements are intended to distinguish the last major storm event of the wet season (red arrow, Fig. 4d), when the hydrograph transitions from wet season flow to a gradual baseflow recession that occurs as the catchment drains.

Once the last storm event feature is identified, a second, partial iteration of the SFDA is applied to a relatively narrow time window to more precisely identify spring recession start timing (Fig. 5). A narrow search window of four days before to seven days after (black dotted lines, step 6,

Fig. 5) is set around the final identified peak from the first iteration of calculation steps (black dashed line, Fig. 5), and the peak flow value within this window is identified from the raw daily streamflow time series (black dashed line, step 7, Fig. 5). Finally, the spring recession start timing is set as four days following this peak flow value (red line, step 8, Fig. 5) to limit the effects of individual storm events on the spring recession timing and subsequent flow metric calculations.

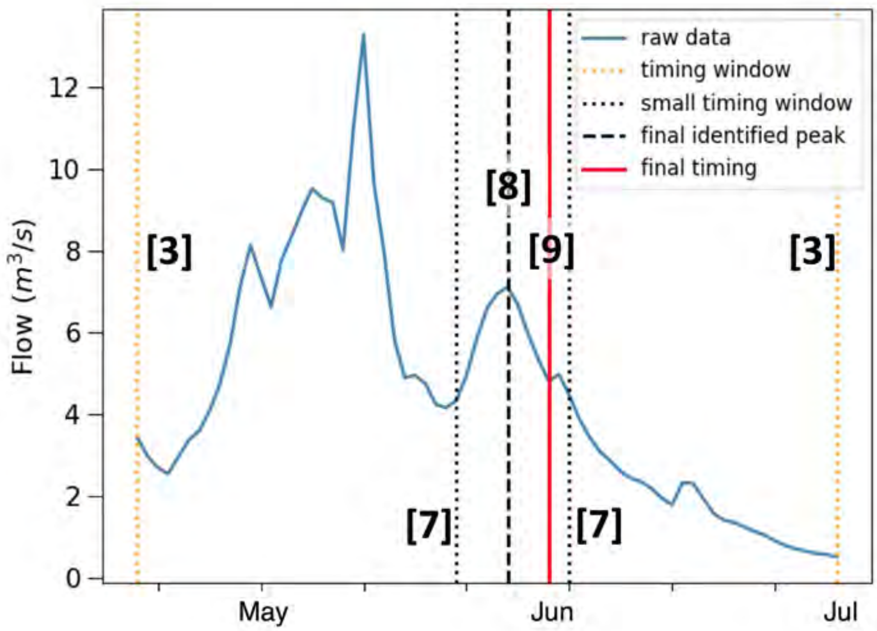

Figure 5. Illustration of secondary steps to calculate the start timing of the spring recession.

Magnitude

The magnitude of the spring recession is the flow magnitude on the start date of the spring recession. This metric is in units of cms/cfs.

Rate of Change

The spring recession rate of change is the median daily rate of change in flow from the start date of the spring recession until the start of dry season baseflow. Only days with negative change (i.e. a decreasing rate) are used in the calculation. This metric is measured as a percentage rate of decrease.

Duration

The duration of the spring recession is the period of elapsed time from the start date of the spring recession until the start date of the following dry season baseflow. This metric is measured in number of days.

Dry Season Baseflow

Dry season baseflow refers to the low magnitude, low variability portion of the water year in California's seasonally dry Mediterranean climate. The metrics calculated for the dry season baseflow include timing, magnitude, and duration.

Dry season start timing

The calculation for dry season baseflow start timing is described below (Figure 6). This metric is outputted in both Julian days, where January 1st = 1 and December 31st = 365, and in water year days, where October 1st = 1 and September 30th = 365. First, raw flow data is smoothed with a large smoothing filter (G1, σ=7) to detect the water year's global peak (P1) and subsequent global valley (V1). A relative magnitude upper threshold M1 is then set based on the magnitude of P1 and V1 (M1=α*(P1-V1), where α=0.125), to ensure that the magnitude at the dry season start is sufficiently below seasonal peak flows. A spline curve is then fit to G1 so that its derivative can be used as a hydrologic requirement in the final feature detection step. Finally, G1 is searched moving forward in time to identify the first date that flow falls below magnitude M1 and below a rate of change threshold equaling (β*P1, where β=0.001). The values for α and β were defined based on expert consultation and knowledge of California flow regimes.

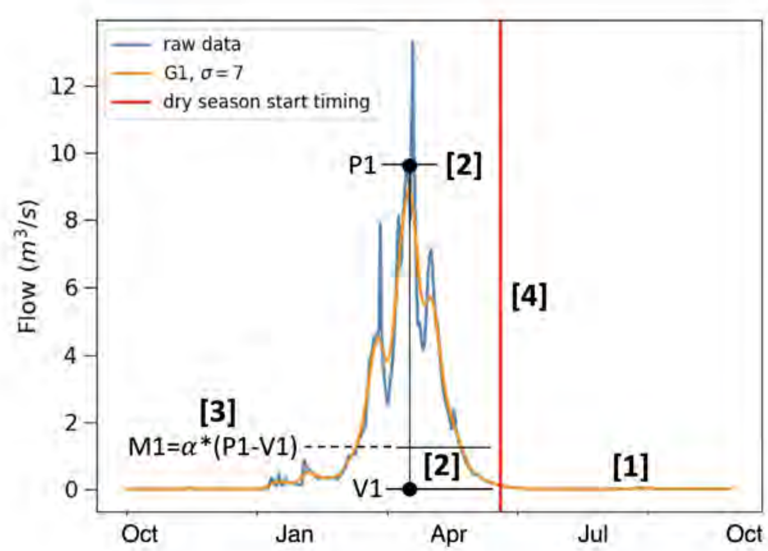

Figure 6. Illustration of steps to calculate the dry season start timing.

Magnitude (10th and 50th percentile)

The magnitude of the dry season is calculated as the 50th and 90th percentile of flows ranging from the start date of the dry season baseflow period until the start date of the following wet season. This metric is measured in units of cms/cfs.

Duration

The dry season baseflow duration is defined as the number of days from the start of the dry season until the start of the next wet season. This metric is measured in number of days.

Annual

Annual flow metrics are summary statistics that broadly represent the entire water year. These annual metrics include the average annual flow and the coefficient of variation.

Average annual flow

The arithmetic mean of daily flow is calculated individually for each water year. This metric is in units of cms/cfs.

Coefficient of Variation

Coefficient of variation is defined as the standard deviation divided by the mean and is calculated for each water year. This metric is a unitless coefficient.