Appendix K. Functional Flows Calculator User's Guide

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The functional flows calculator (FFC) is a computational tool that calculates the functional flow metrics for a given daily time series data. The FFC relates to the CEFF framework in two aspects:

(1) The FFC was used to determine the functional flow metrics for the reference gauges whose values later were used as input data for the statewide functional flow metric prediction models (*Appendix D: Predicting natural functional flow metrics*),

(2) The FFC is used in CEFF Section C Step 9 for assessing flow alteration. The FFC allows the user to estimate the functional flow metrics for uploaded daily streamflow data at their LOIs. Then, this information is used in accordance with the guidance provided in *Appendix J* to determine the hydrologic alteration for each functional flow metric and component.

This appendix describes: (a) the documentation and resources available to support use of the FFC, (b) the FFC website and its graphical visualizations, (c) the data available for download and (d) how to use the website to analyze and visualize user-uploaded data.

Resource Links

Table 1. Links to helpful FFC documentation and tutorials.

Resource	**Link**	**Description**
eFlows website	https://eflows.ucdavis.edu/hydrology	Website with capability to explore California's natural hydrology, geomorphology, and ecology. The hydrology feature includes reference-condition flow data for 223 gage sites across California that can be visualized and downloaded. Users can also upload and analyze their own streamflow data with the eFlows web tool, described below.
eFlows website documentation	eFlows: Introduction	Webpage describing the content of the eFlows website, including the hydrologic classification, hydrograph visualizations, and functional flow metrics.
Functional flow metric documentation	FFC-Readme: eFlows Overview	In-depth description of each functional flow metric, how it is calculated, and steps for calculation including snippets from the Python source code.

Webinar tutorial	FFC Under the Hood Webinar	This webinar tutorial covers how to perform functional flow analysis of user-uploaded streamflow data using either the eFlows website interface, or the source code in the Python programming language.
Code repository	leogoesger/func-flow: Functional Flow Calculator	Code repository including all scripts and data for running the functional flows calculator source code in the Python programming language, including a catalog of all updates made to the code.
FFC API package in R	ceff-tech/ffc_api_client: An R client for the online Functional Flows Calculator API	The FFC API R package extracts functional flow metrics based on the python source code to assess hydrologic alteration.
Peer-reviewed literature, Patterson et al. 2020	(PDF) A hydrologic feature detection algorithm to quantify seasonal components of flow regimes	Peer-reviewed article in the Journal of Hydrology describing the scientific background and methodology of the functional flows calculator for streamflow analysis.

Navigating the web-based Functional Flows Calculator

Website Purpose

The eFlows website hosts a web application version of the Functional Flows Calculator (FFC), a tool that quantifies key hydrologic aspects of the annual flow regime from daily streamflow time series. Users of the eFlows website can both explore FFC outputs for California reference condition flow data and use the FFC to analyze their own flow data. The FFC web tool produces dimensionless reference hydrographs (defined below) and a suite of annual functional flow metrics. Results are presented visually, and data can be downloaded directly from the website. The FFC generates 24 metrics describing key aspects of streamflow timing, magnitude, duration, frequency, and rate of change, organized into five functional flows: 1) fall pulse flows, 2) wet season baseflow, 3) peak flows, 4) spring recession flows, and 5) dry season baseflow (Table 1). These metrics are described in detail in *Appendix A* and in the Functional flow metric documentation linked in Table 1. Detailed methods are available in Patterson et al. (2020).

Table 1. Summary of functional flow metrics.

Flow Component	Flow Characteristic	Flow Metric Name	Unit	Flow Metric Description
Fall pulse flow	Magnitude	Fall pulse magnitude	cfs	Peak magnitude of fall pulse event (maximum daily peak flow during event)
	Timing	Fall pulse timing	water year day (Oct 1=1)	Water year day of fall pulse event peak
	Duration	Fall pulse duration	days	Duration of fall pulse event
Wet-season baseflow	Magnitude	Wet-season low and median baseflow	cfs	Magnitude of wet-season baseflows (10th percentile and median of daily flows within that season, including peak flow events)
	Timing	Wet-season timing	water year day	Start date of wet-season in water year days
	Duration	Wet-season duration	days	Wet-season baseflow duration (# of days from start of wet-season to start of spring season)
Peak flow	Magnitude	2-year, 5-year, and 10-year flood magnitude	cfs	2-year, 5-year, and 10-year recurrence interval peak flow
	Duration	2-year, 5-year, and 10-year flood duration	days	Seasonal duration of 2-year, 5-year, and 10-year recurrence interval peak flow (cumulative number of days in which this peak flow magnitude is exceeded)
	Frequency	2-year, 5-year, and 10-year flood frequency	occurrences	Frequency of 2-year, 5-year, and 10-year recurrence interval peak flow within a season
Spring recession flow	Magnitude	Spring recession magnitude	cfs	Spring recession magnitude (daily flow on start date of spring-flow period, 4 days after last wet-season peak)
	Timing	Spring timing	water year day	Start date of spring in water year days
	Duration	Spring duration	days	Spring flow recession duration (# of days from start of spring to start of dry-

				season baseflow period)
	Rate of change	Spring rate of change	percent	Spring flow recession rate (median daily rate of change over decreasing periods during the recession)
Dry-season baseflow	Magnitude	Dry-season median and high baseflow	cfs	50th and 90th percentile of daily flow within dry season
	Timing	Dry-season timing	water year day	Dry-season baseflow start timing (water year day of dry season)
	Duration	Dry-season duration	days	Dry-season baseflow duration (# of days from start of dry season to start of wet season)

Website Main Page and California hydrologic classification

The web content described below refers to the Hydrology section of the eFlows website. The Hydrology main page shows a map of California streams color-coded by natural hydrologic class (Fig. 1). California's streams were organized into nine natural stream classes with distinct flow regime patterns and dominant watershed controls (Appendix B). These stream classes represent hydrologic conditions prior to major human impacts such as dams, diversions, and land use changes. The natural stream classes consist of: Snowmelt, High-volume Snowmelt and Rain, Low-volume Snowmelt and Rain, Winter Storms, Groundwater, Perennial Groundwater and Rain, Flashy Ephemeral Rain, Rain and Seasonal Groundwater, and High Elevation Low Precipitation. From this main page, helpful links can be accessed including a Resources tab with many of the links referred to in Table 1, and a website navigation tutorial accessed from the question mark icon at the bottom-right of the main page (Fig. 1).

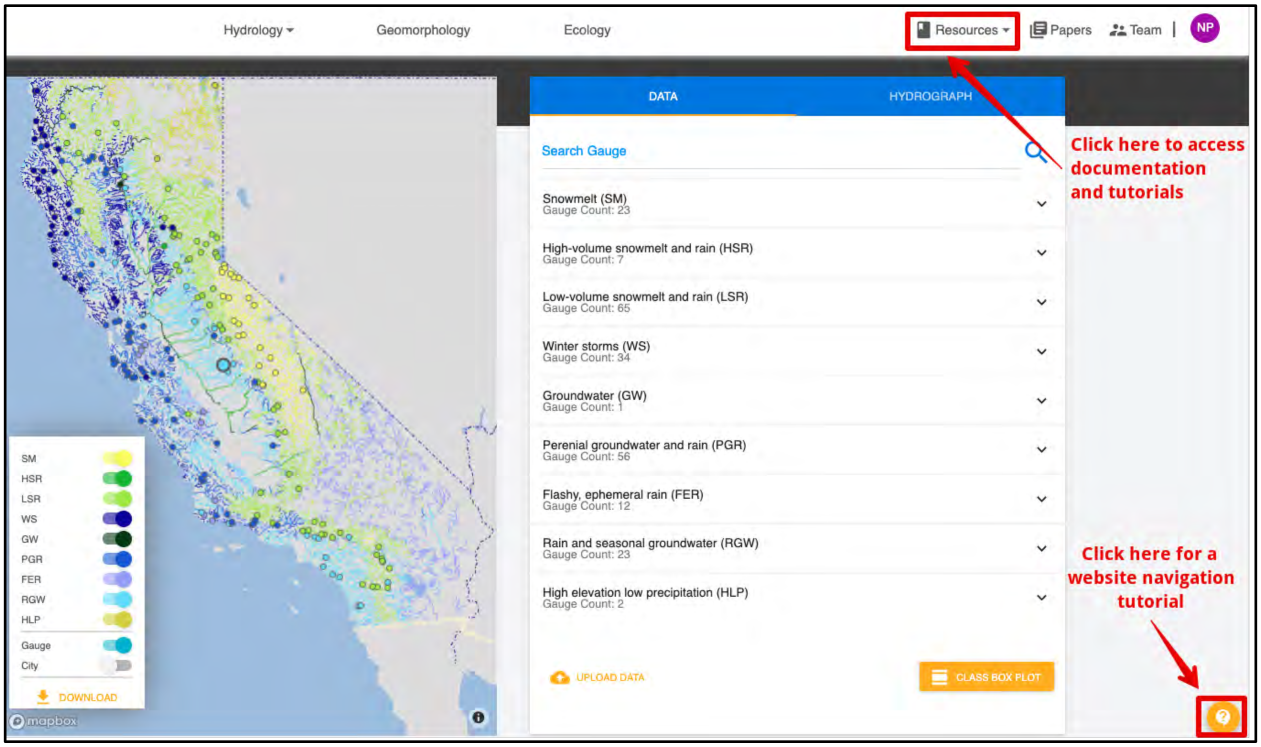

Figure 1. Main page for *Hydrology* section of eFlows website. Access a list of resources from the top of the page, and click the question mark at the bottom of the screen for a website navigation tutorial.

The right side of the Hydrology main page lists all 223 reference streamflow gages for California organized by natural stream class (Fig. 1). Each gage has 6 - 65 years of reference data. Circles on the map of California represent each reference gage, and a list of the 223 gages can be downloaded on this main page from the “All gages” button.

Dimensionless Reference Hydrographs

From the Hydrology main page, individual gages or an entire stream class can be selected to view dimensionless reference hydrographs (DRHs) (Fig. 2). DRHs serve as a descriptive visual depiction of daily and inter-annual streamflow patterns. Every natural stream class and reference gage has an associated DRH.

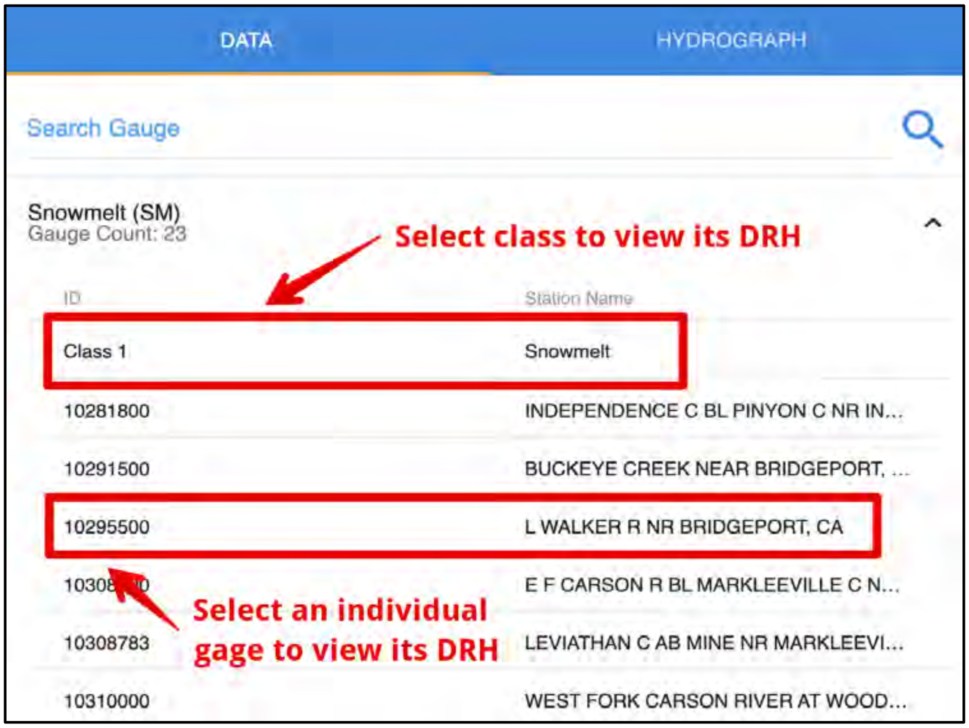

Figure 2. Select gages or natural stream classes to view their dimensionless reference hydrographs (DRH).

DRHs can represent the period of record for one stream gage, or the results can be aggregated across all reference gages in one stream class to summarize the flow patterns of an entire class (hence capturing spatial as well as temporal variability). A DRH is calculated through the following steps: First, daily streamflow data are divided by that water year's average annual flow to produce non-dimensionalized daily flows. This calculation is performed across all water years of flow data, and across all gages if it is a class-wide DRH. Then, the 10th, 25th, 50th, 75th, and 90th percentile non-dimensional flows over the entire reference period of record are determined for each date of the water year. These results are then plotted to visualize the range of non-dimensionalized flow that occurs across the water year at a daily time-step to simultaneously represent daily, seasonal, inter-annual, and spatial hydrologic variability. Figure 3 illustrates an example DRH for the Snowmelt stream class, calculated based on all the reference gages classified as snowmelt over their reference periods of record.

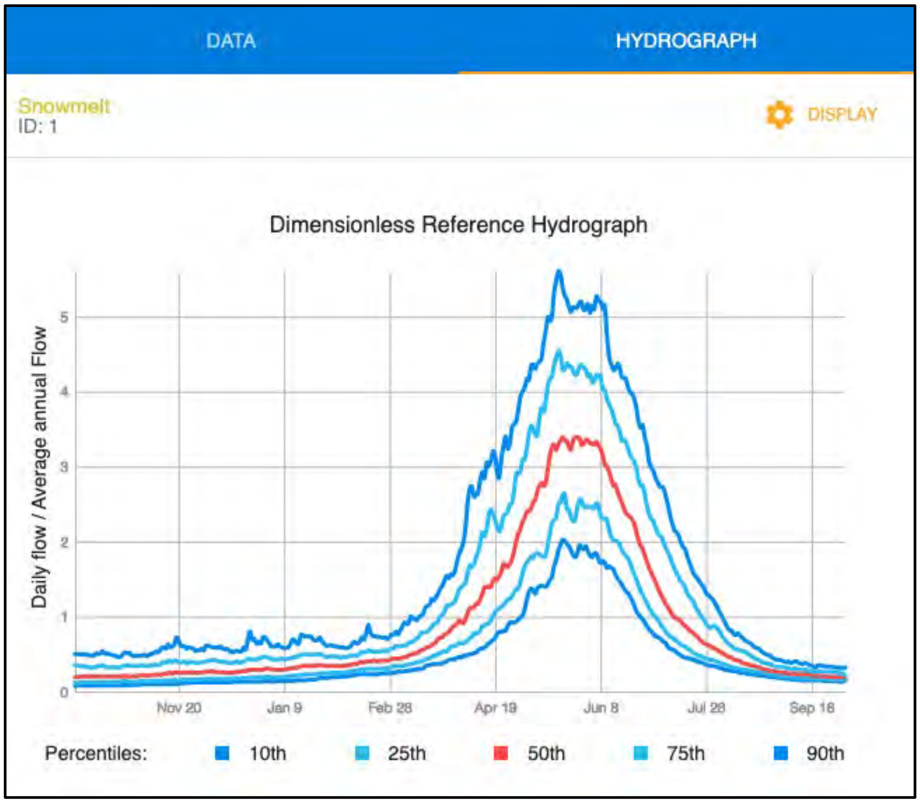

Figure 3. A dimensionless reference hydrograph (DRH) for the Snowmelt hydrologic class, illustrating plots that can be easily generated through the eFlows website.

When a DRH is displayed in the plotting window, functional flow metrics associated with that gage or stream class can be toggled on to visualize flow metric values. When evaluating an entire stream class, the colored bands are used to illustrate the range of metric results (10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles) for each functional flow metric over all the gages in that stream class. For example, Figure 4 illustrates the range of the wet season start timing over all the available water years for all reference gages in the Winter Storms hydrologic class overlaid on the Winter Storms DRH. This indicates that, in these streams, the wet season can start as early as Oct 20 and as late as Jan 5, with a median start date of Nov 20.

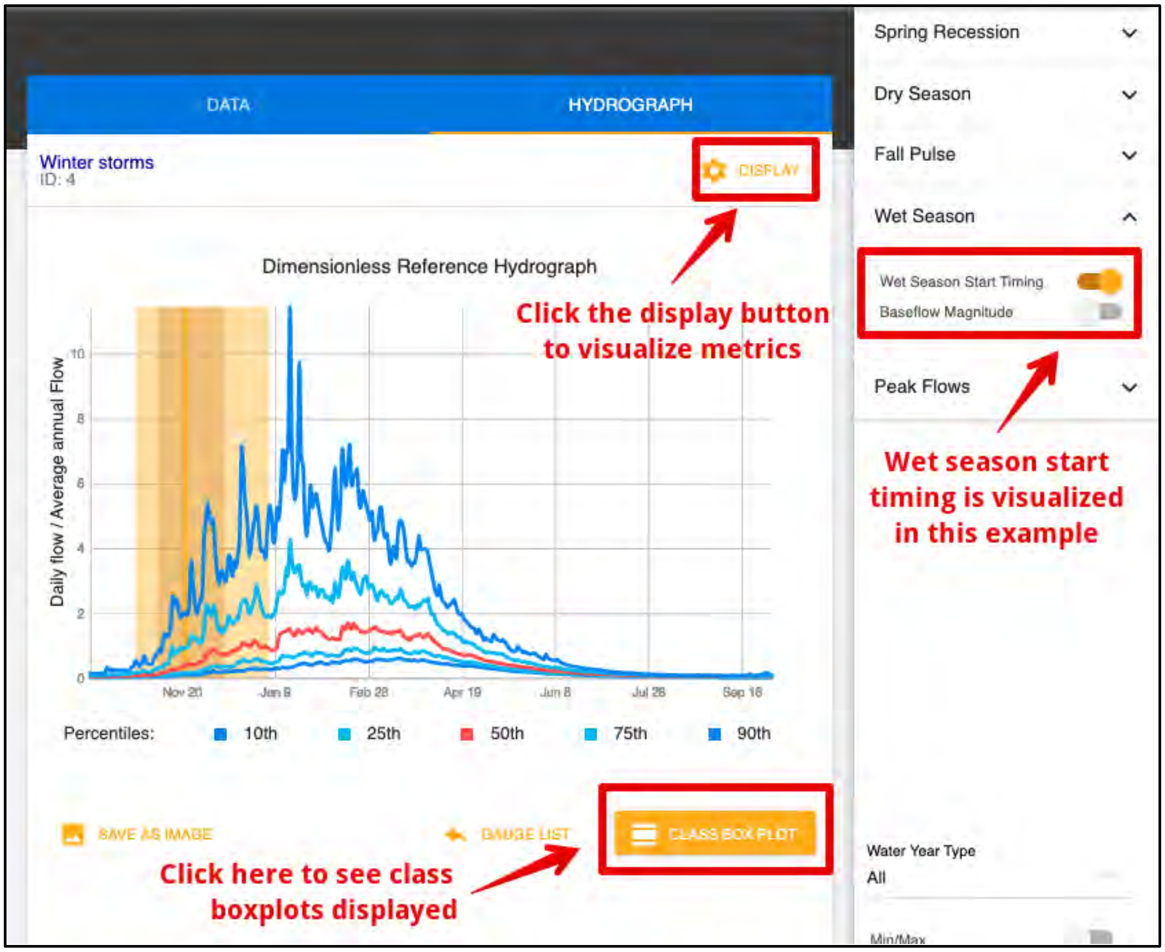

Figure 4. Example of a functional flow metric reference range overlaid on the dimensionless reference hydrograph for Winter Storms hydrologic class, using the *Hydrograph* tab. In this example, the range of values for the wet season start timing is represented by the yellow bands for the 10th-90th percentile of metric values. The *Data* tab provides quantitative information behind this plot.

Functional Flow Metric Boxplots

From the Hydrology main page on the Hydrograph panel (Fig. 6), the Boxplots tab in the lower right hand corner allows users to view boxplot visualizations of flow metric ranges for the California reference dataset. The calculated metric values are aggregated by hydrologic class, and visualized with class-wide boxplots to allow for comparison between classes (Figure 5). For each metric value, boxplots display the median (middle line that divides the box into two parts), interquartile range (75th and 25th percentile values, the top and bottom of the box), and 90th and 10th percentile metric values (the "whiskers" extending above and below the boxes). These boxplots can be visualized for any flow metric of interest and can be stratified by water year type.

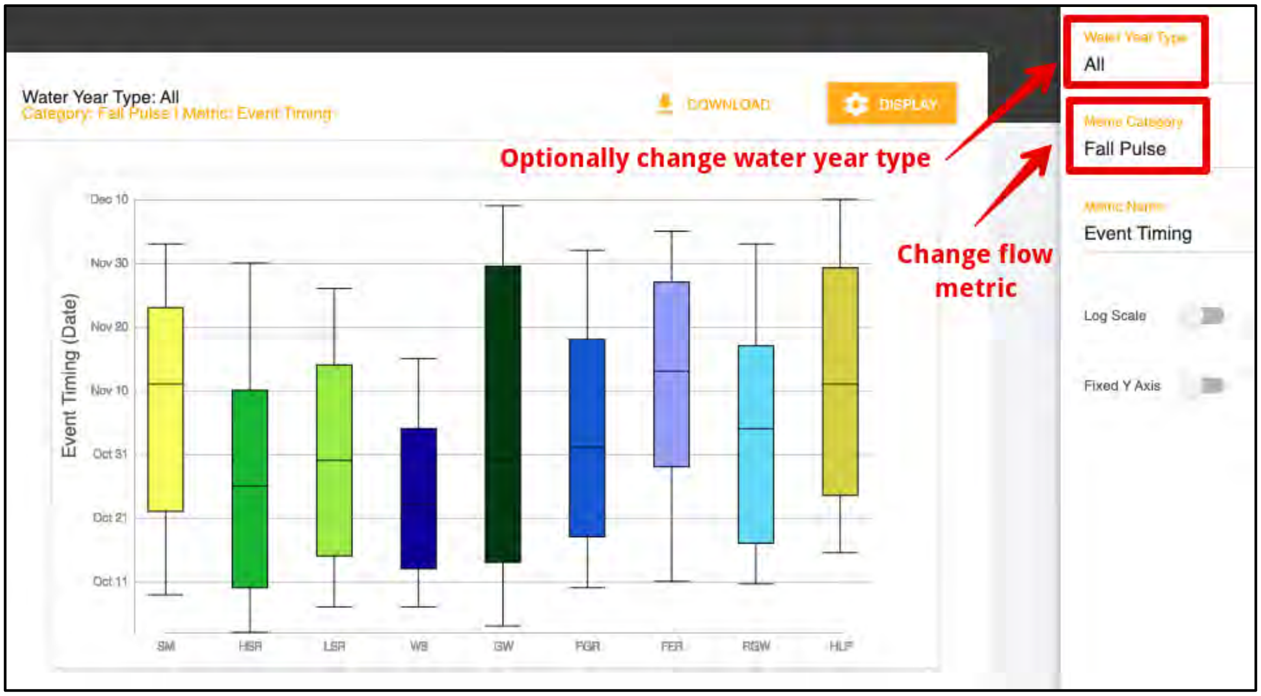

Figure 5. Boxplot visualizations of flow metrics from the California reference gages, categorized by stream class. Boxplots can be viewed for any flow metric, and can be stratified by water year type. Boxplots are accessed from the Hydrograph window of the main page (Fig. 6).

Annual Flow Data and Metric Visualization

In CEFF Section C- Step 9, there are opportunities for users to visualize each year of data from the California reference gages with the flow metrics overlaid for that water year. After selecting a gage from the Hydrology main page, select the “Annual flow plot” button in the bottom right of the hydrograph panel to view annual metric values (Fig. 6).

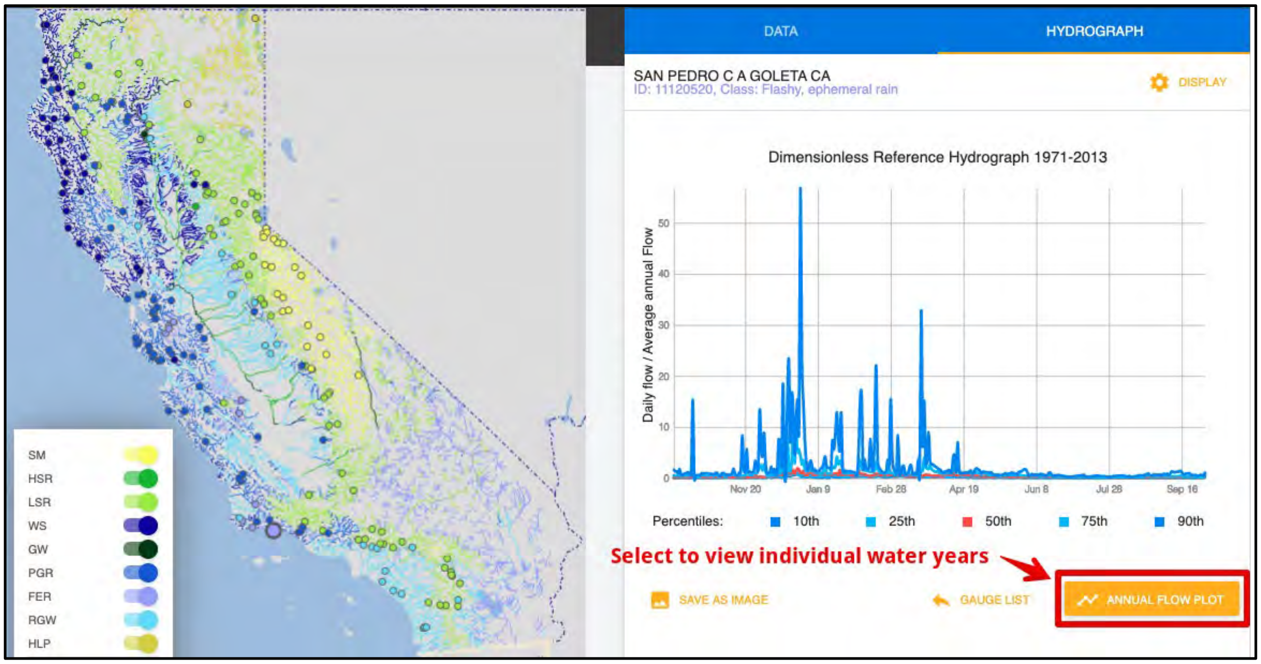

Figure 6. Select the "Annual flow plot" button in the bottom right corner of the hydrograph panel for any selected gage to view annual flow plots with metric values overlaid for each individual year.

Once in the annual flow panel, users can scroll through each available water year, with the option of viewing metric overlays (Fig. 7). It is highly recommended that users view the data for each water year before using data, to ensure that the calculator is appropriately capturing their functional flows of interest. In particular, the timing of each functional flow of interest should be viewed for each water year, because the calculated timing dictates the values of all other metrics (magnitude, duration, frequency, rate of change) for that functional flow. This helps to visualize how the metrics were calculated and ensure that they are indeed capturing the functional flows of interest.

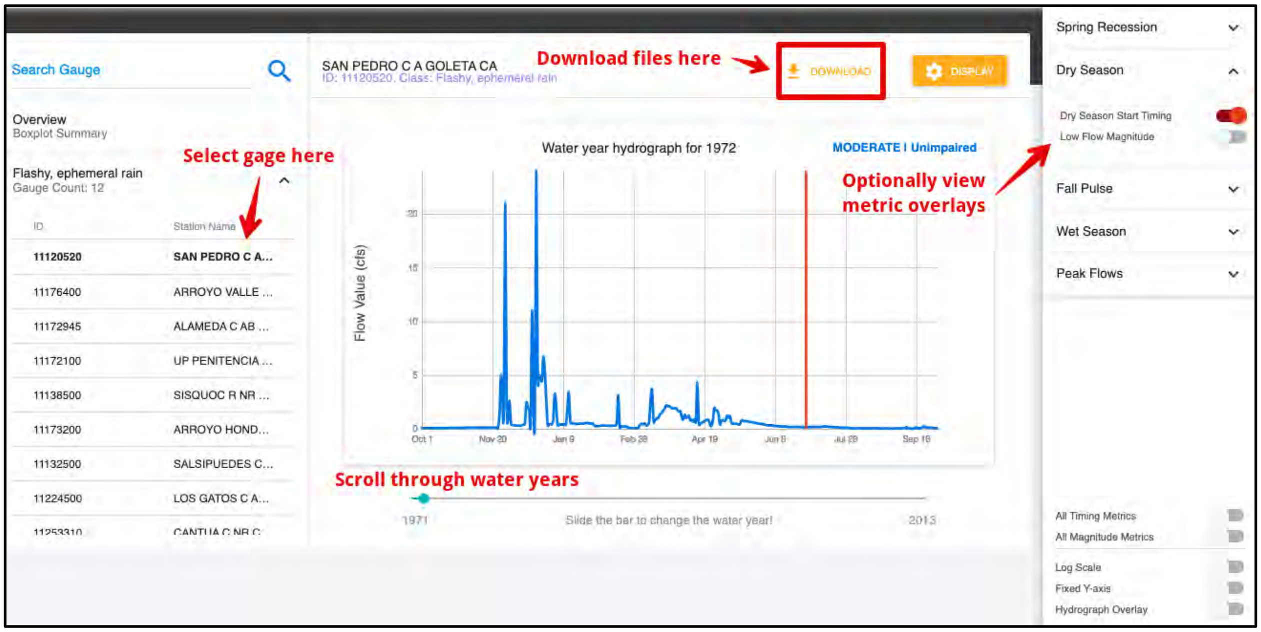

Figure 7. Visualization of individual water years of gage data from the California reference flow dataset, with the option to overlay flow metrics for each water year.

Data Downloads

Users have the ability to download annual functional flow metric values for all California reference gages. Additional files generated by the FFC are available for download in a dropdown menu from the *annual flow* panel page (top-right, Fig. 7).

The files from the drop-down menu (Fig. 8) include:
1) Save As Image, which generates an image file of the hydrograph.
2) Annual Flow Matrix, which arranges daily flow data into columns sorted by water year.
3) Annual Metric Result, the file containing functional flow metric results for each water year of data.
4) Annual Metric Result Supplement, the file containing supplementary metric results such as average annual flow and coefficient of variation.
5) Metrics Read Me, which describes all files and metrics available for download, including metric units, naming codes, and a brief description of each metric.
6) Day of Year Conversions, a file that lists the corresponding Julian date (when January 1 is Day 1 of the year) for each water year date (when October 1 is Day 1 of the year).

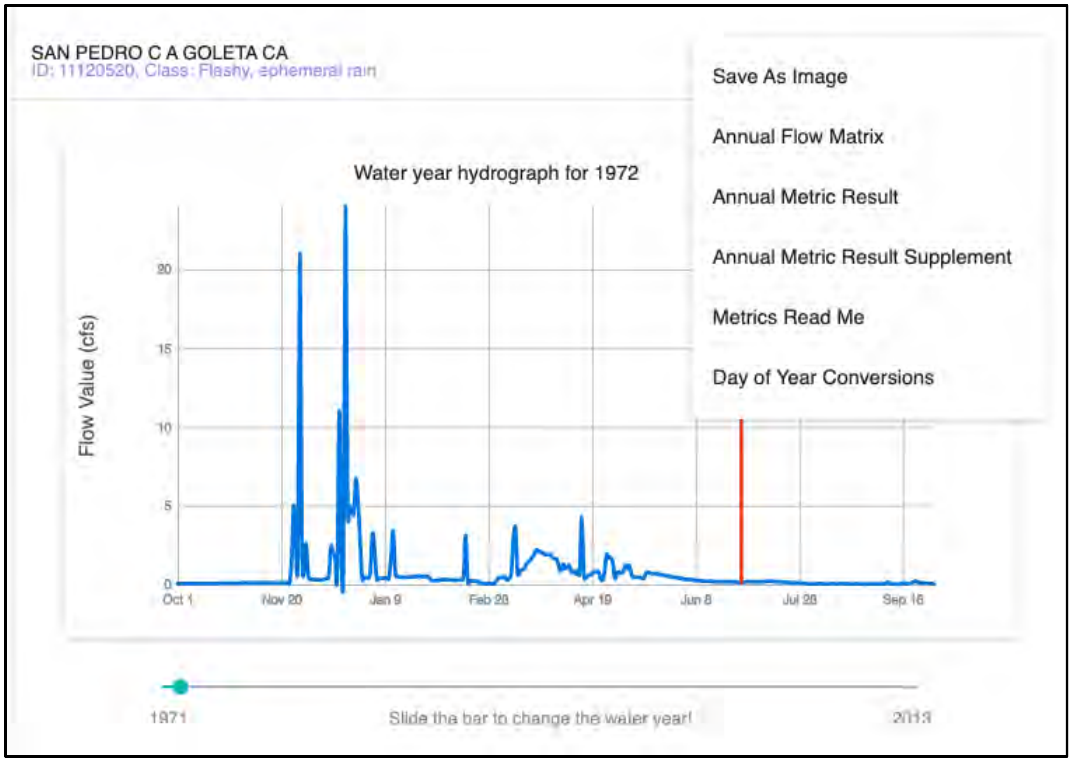

Figure 8. Files available for download for each gage of the California reference dataset.

Using eFlows for data analysis

Users can analyze their own daily modeled or observed streamflow data on the eFlows website, with options to download data and visualizations. Users must first create a profile on the eFlows website, available in the top-right corner of the Hydrology main page (Fig. 9).

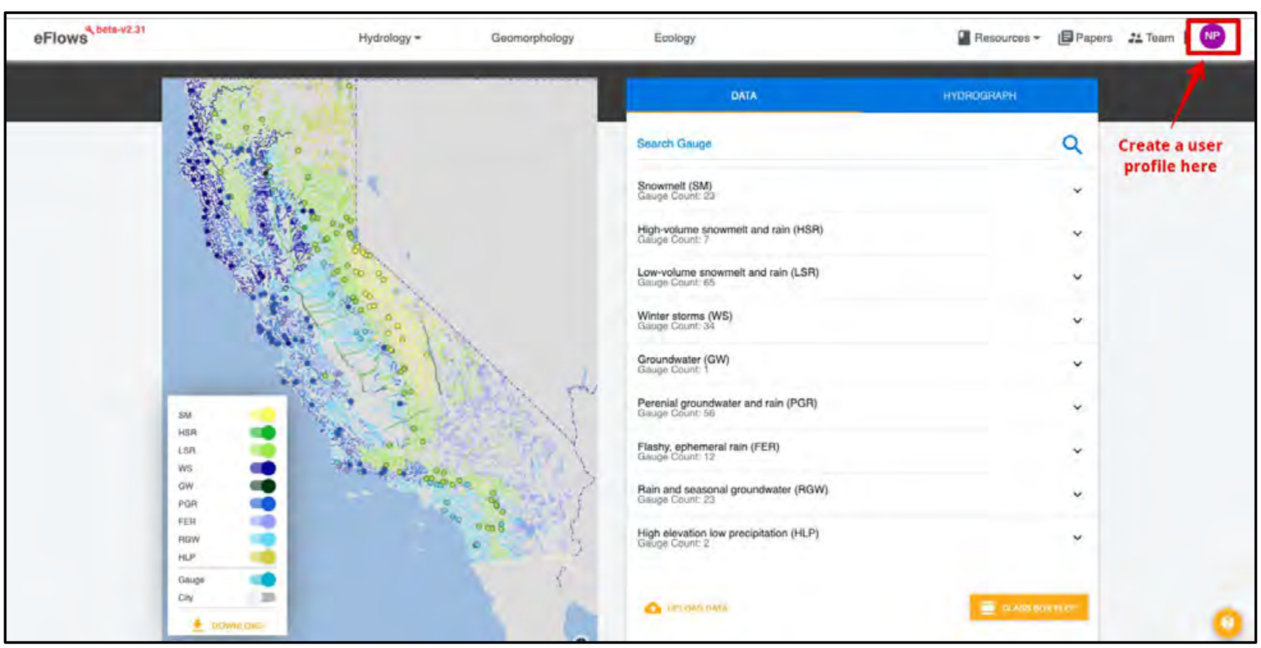

Figure 9. User profile button is highlighted in the top-right corner of the Hydrology main page. Creating a user profile is necessary to upload data to the website.

Data Upload

Once a user profile is created, users can navigate to the profile page, where flow data can be uploaded for analysis with the FFC (Fig. 10). User data must be in comma-separated values (csv) format and files can be selected using the “Pick a File” button on the profile page (Fig. 8). Once selected, names can be defined for the file, the river, and the location, and the water year can be set to any calendar value (default value is October 1st). The start date of the water year affects calculation of functional flow metrics, and October 1st is recommended as the start date for any analyses in California or regions that exhibit a similar Mediterranean climate. Uploaded data must have a specific two-column format with date in mm/dd/yyyy format and flow in cubic feet per second (cfs). Additionally, headers must have the exact names: **date** and **flow**. If these requirements are not met, the data will not upload successfully. Please view the Youtube tutorial in the Resources tab for step-by-step instructions for uploading data (Table 1, *FFC Under the Hood Webinar*).

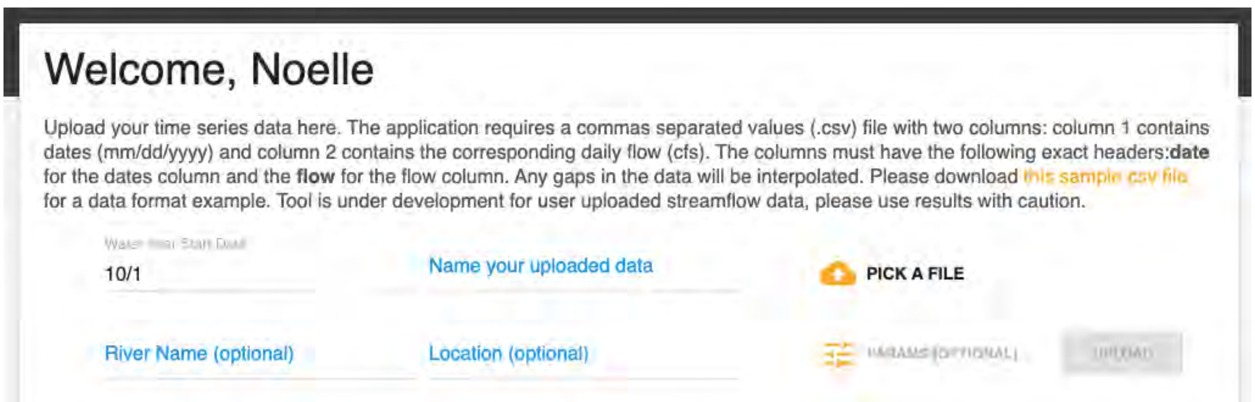

Figure 10. Profile page for user-uploaded streamflow data.

Outputs from FFC Analysis

Files generated by the FFC available to download for user-uploaded streamflow data are the same as those available for reference gages, as described in Data Downloads above.

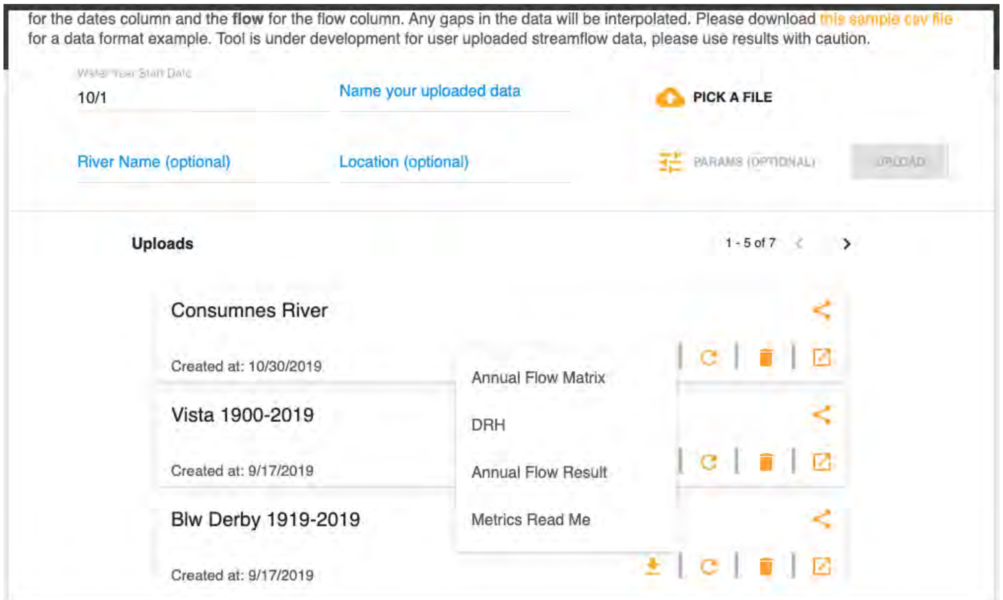

Figure 11. Files available for download from the FFC after processing user-uploaded flow data.

In addition to generating downloadable files, the web tool also allows users to view their uploaded data interactively on the website. By clicking on the name of the uploaded data from the “Uploads” list on the user profile page (Fig. 11), the user is taken to a page showing hydrograph visualizations of the uploaded data. Visualizations include a gage DRH, which can be overlaid with the DRH from a class or gage from the California reference flow dataset (Fig. 12). Visualization options also include *annual flow plot* (top-left, Fig. 12), which can be viewed with flow metrics overlaid (Fig. 13).

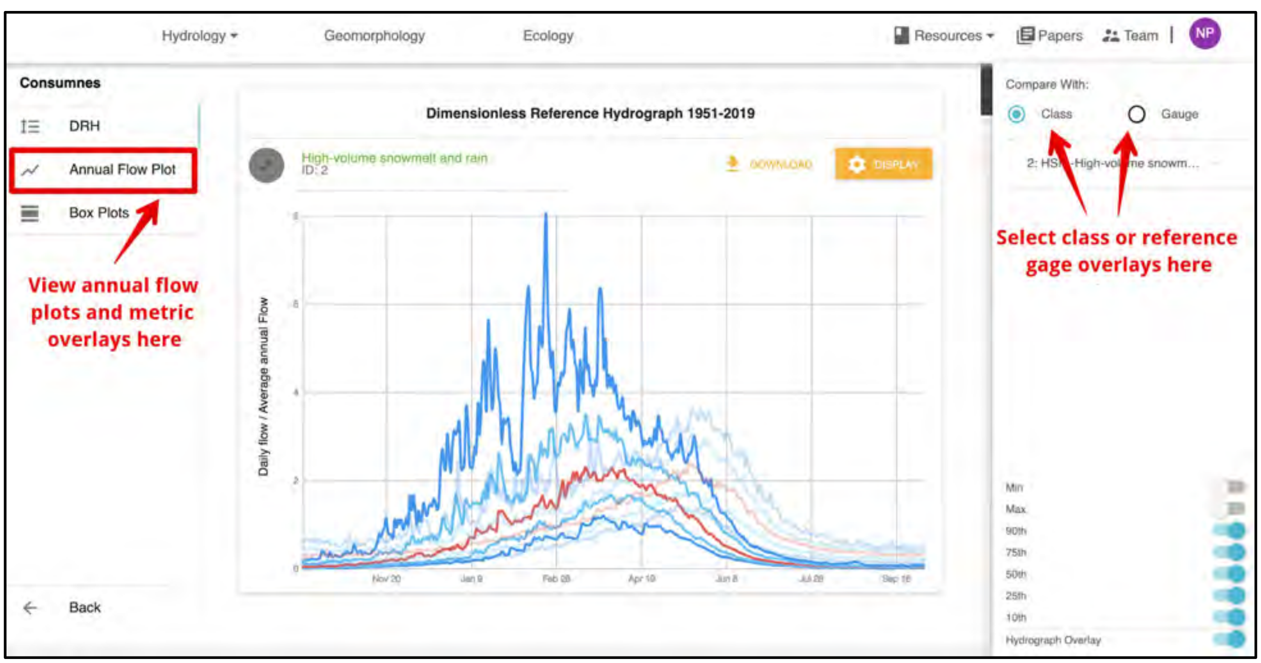

Figure 12. User uploaded data visualized as a DRH, overlaid with a DRH from the California natural stream classes.

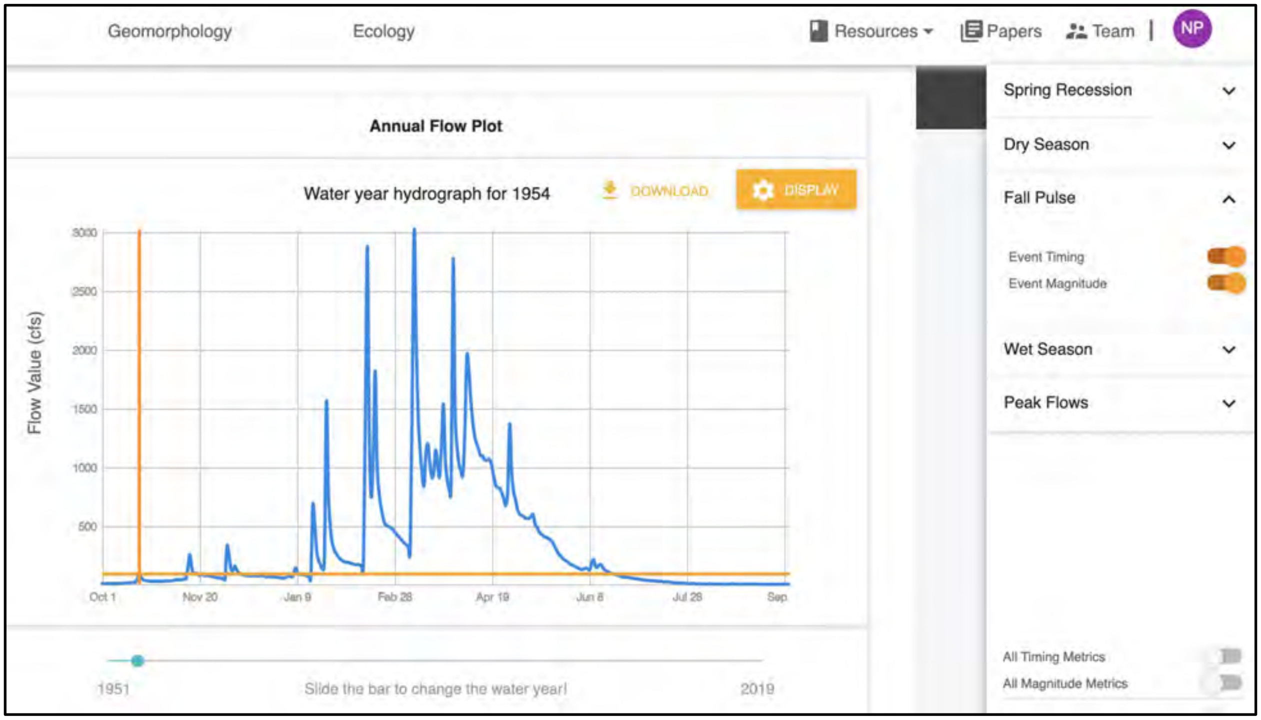

Figure 13. User uploaded data visualized in annual daily hydrographs, with metric values optionally displayed.

FFC Source Code

Advanced users can use the FFC directly from the source code in **both Python and R**. Using the source code is only recommended for users highly proficient in programming or willing to invest time to become familiar with the programming environments.

Guidance for using the python source code is available in a webinar tutorial: https://www.youtube.com/watch?v=iIF3mBGEJag.

An R package is available to extract functional flow metrics based on this python source code to assess hydrologic alteration: https://github.com/ceff-tech/ffc_api_client

Citations

Lane, B.A., Sandoval-Solis, S., Stein, E.D., Yarnell, S.H., Pasternack, G.B. and Dahlke, H.E. (2018). Beyond metrics? The role of hydrologic baseline archetypes in environmental water management. Journal of Environmental Management. DOI: 10.1007/s00267-018-1077-7

Patterson, N.K., Lane, B.A., Sandoval-Solis, S., Pasternack, G.B., Yarnell, S.M., Qiu, Y. (2020). A hydrologic feature detection algorithm to quantify seasonal components of flow regime. J. of Hydrology.