ESM 121

Water Science
and Management

Environmental Water Demand

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Contents

Overview

Imagine the land around you before people started changing it: no houses, no farms, no roads, no cities. Before people starting removing water from rivers (and putting some back afterwards). How did the rivers flow across the land? *Environmental flows* are the amounts of water a river or stream needs to sustain its various ecosystems, including variability needed at different times of the year. Both high and low flows play an important role in the physical development of rivers as well as the plants and animals that live in river biomes.

Before diving into the details of characterizing *Environmental Flows*, first let's take a look at this video that explains the idea of environmental flows (actually *instream flows*, you will learn later). Take note of the terminology introduced.

By the end of this section you should be able to describe environmental water needs--instream flows. You will learn basic concepts related to instream flows (*environmental flows* versus *instream flows*, *river ecosystems*, *components of instream flows*, *natural flow regimes*). With this foundation, we will compare some methods for determining environmental water needs (*A very short story of instream flows*).

Next you will apply the *Functional Flows Approach* to a river system using data (functional flow metrics) from a river data repository called *eflows*. You will explore these data using a spreadsheet interface in Google Sheets (*Functional Flows Interface*). Finally, you will characterize the instream flows for the Pajaro River using all available water year data, as well as for a typical wet, moderate, and dry year.

Don't worry about remembering all of this right now! But do keep in mind this roadmap as you progress through the section.

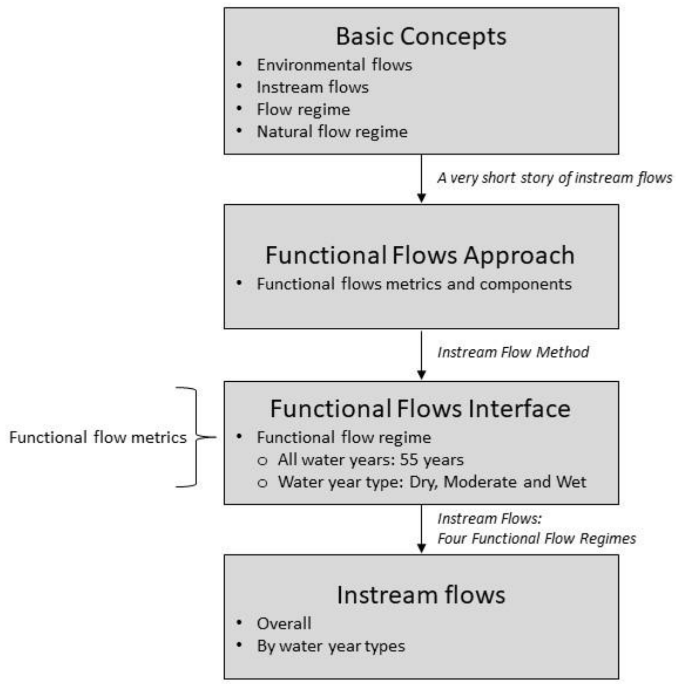
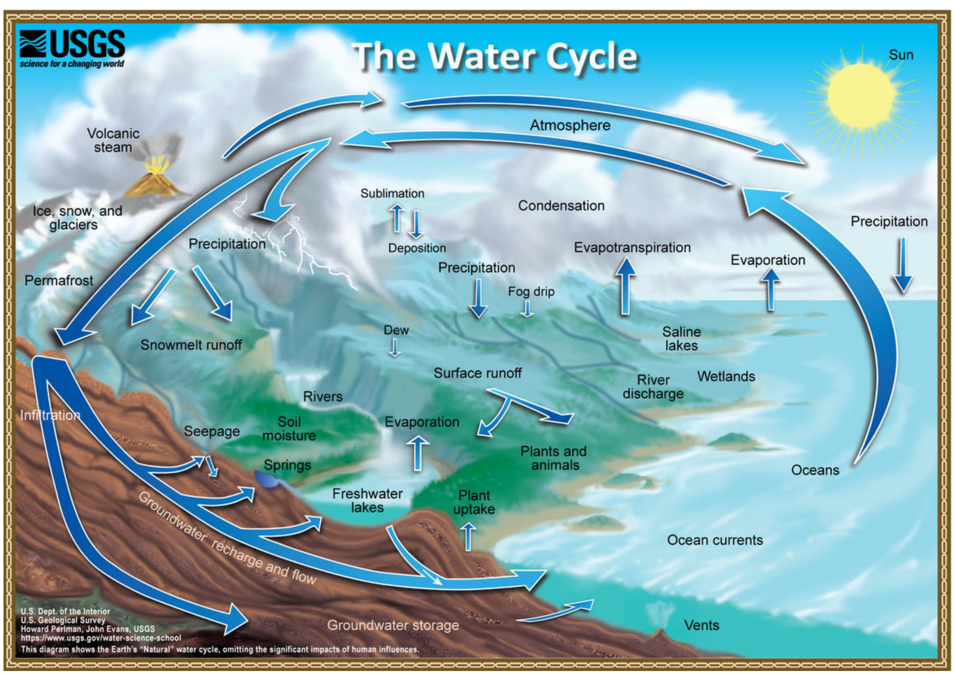


Figure 1 - Overall section to estimate instream flows

Context of Environmental Flows

"**How much water does the environment need?**" Seems like a simple question at first glance. You might imagine the answer is a single number, like 300 cubic feet per second. As you will find in the next few sections, this question gets rather complicated as we identify the ecosystem that we want to protect and all the flow components needed to keep the environment thriving. Often environmental flows are an afterthought when estimating water demands. But not here. In our case study of the Pajaro River Valley we will begin with estimating how much water is needed to sustain the river ecosystems.

There is a misconception that the environment is another user waiting in line for water from the river basin. However, the reality is that **the environment is the water provider for all other water uses**. You name it; **all water on Earth comes from the environment and all users depend on it**. Every drop of water can be traced back to the environment: water in rivers, lakes and reservoirs comes from rain and snow; groundwater stored in aquifers comes from rivers (and rain and snow); recycled city water originally came from the water supply (rivers and aquifers); desalinated water comes from the ocean; fog comes from atmospheric moisture. Think about this: all water comes from the environment. Remember the water cycle you learned when you were young? If you could read the tiny print at the bottom of this figure, it says "this diagram shows the Earth's natural water cycle, omitting the significant impacts of human influence."



The water cycle (USGS)

Unfortunately there are two typical problems in the professional water management practice. First, we do not think of environmental water as another user and if it is considered as another user, the thought is what is the minimum amount of water that should be left over once humans have taken our portion. Traditionally (and legally under the National Environmental Policy Act) Environmental Impact Reports (EIRs) estimate impact or damage to the environment from a given project. EIRs may propose some restoration or mitigation strategies, but the focus is on documenting impact, not providing water to the environment as an equal user. In California, there are five legal instruments to obtain a water right for the environment for protecting or restoring riparian and freshwater ecosystems at risk: (1) the California Wild and Scenic Rivers Act in 1972, (2) the Endangered Species Act (ESA) in 1973, (3) Section 5937 of Fish and Game Code, (4) through a biological opinion under the Federal Energy Regulation Commission (FERC) relicensing process for hydropower dams, and (5) Public Trust Doctrine. Second, planners think about environmental needs at the end of the analysis, after estimating how much water humans need. That means the environmental water analysis becomes an exercise in how to distribute the leftover water rather than determining actual environmental need. As a result of these two common planning mistakes, most rivers throughout the world are currently degraded.

In our analysis, we will avoid these two very common traps by estimating environmental water water needs upfront.

Figure 2. Overlook of Monterey bay from Pajaro Valley

Environmental Flows

In order to determine environmental water needs let's start by defining environmental flows and why these flows are important. When we refer to **environmental flows**, we mean "the amount of water needed to sustain river functions and services while maintaining human water demands" (Pof et al. 1997[1]). While the name may not be intuitive, environmental flows consider both water for the environment and human use.

Why do we need to protect water to the environment? You can answer this question from two different perspectives. First, from an environmental justice perspective, the environment provides

[1] Poff N, LeRoy J, Allan D, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC. 1997. The natural flow regime. BioScience 47(11): 769–784

water to all users, so it is fair to maintain enough water in rivers to sustain all species and organisms that depend on it. It is the right thing to do. The better we take care of mother nature, the better mother nature will take care of us, as she has done for millennia. Second, from an utilitarian point of view, the environment provides many benefits that we value as society, called ecosystem services. Ecosystem services are things rivers naturally do that we value as society. For example, rivers recharge aquifers whose water we can pump out and use. Rivers provide water to irrigate crops for food. Rivers transport nutrients that are important to fertilize valley soils and sustain fisheries at the coast. This video explains further about environmental flows.

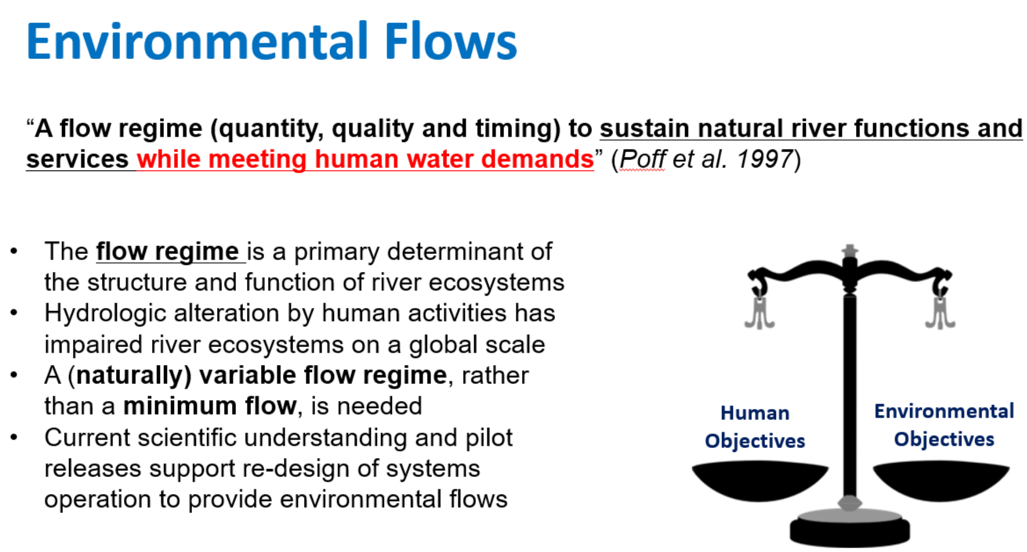


Figure 3 - Definition of environmental flows

Instream Flows

While *environmental flows* consider both human and environmental needs, we are also interested in isolating just those flows that meet environmental needs which are called *instream flows*.

Instream flows are flows in rivers that sustain adequate conditions of the river ecosystem. As ecosystem needs change throughout the year, instream flows are a set of variable flow rates (both within seasons and among years) that maintain adequate water quantity, quality, and timing necessary to support physical habitat and river connectivity. The specific instream flow characteristics for physical habitat and river connectivity:

- Physical habitat: water depth, water velocity, sediment transport and deposition, channel form, and
- River connectivity: longitudinally, from the headwaters to the ocean, horizontally from river bank to river bank, and vertically for surface water and groundwater interactions.

Instream flows are necessary to sustain freshwater and riparian ecosystems. This video explains the key aspects of instream flows.

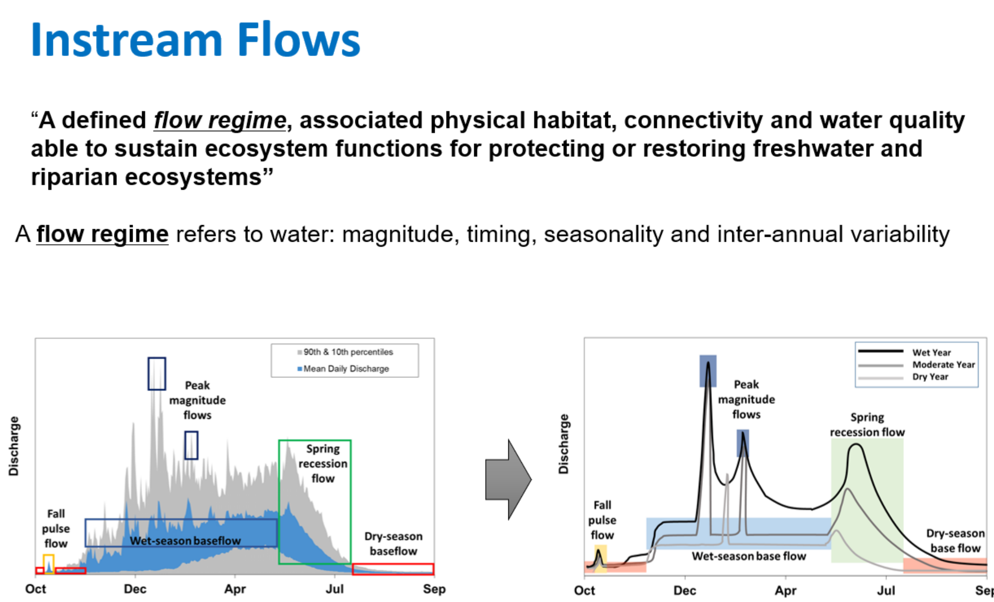


Figure 4 - Definition of instream flows

Check your Understanding

Select the adequate statement. The main difference between environmental flows and instream flows are that:

What is the main difference between the concepts of environmental flows and instream flows?

( ) Instream flows includes human and environmental water needs, and environmental flows only include environmental water needs

( ) Environmental flows includes human and environmental water needs, and instream flow only include environmental water needs

( ) There is no difference, they refer to the same concept

Relevant Ecosystems

While the concept of instream flows is clear ("those flows in rivers dedicated to sustain adequate conditions of the river ecosystem that depend on it"), the questions are: **How can we estimate the amount of water needed to sustain the environment that lives in the river and depend on it?** And, **What are the main components for estimating instream flows?** In order to respond to these questions, first let's start by identifying the ecosystems that depend on rivers, select those ecosystems that are more relevant, and describe the flow characteristics to sustain these ecosystems.

What is an ecosystem? An ecosystem is "*a community of living organisms in conjunction with the nonliving components of their environment, interacting as a system*". **Typically, we also refer to the ecosystem as "*the environment*" (Figure 5).** All ecosystems on Earth depend on water flowing in rivers and groundwater from aquifers. Specifically, we can identify three ecosystems that directly depend on how much water is in a river: freshwater, riparian, and terrestrial ecosystems. This [video](#) describes each of these ecosystems in detail.

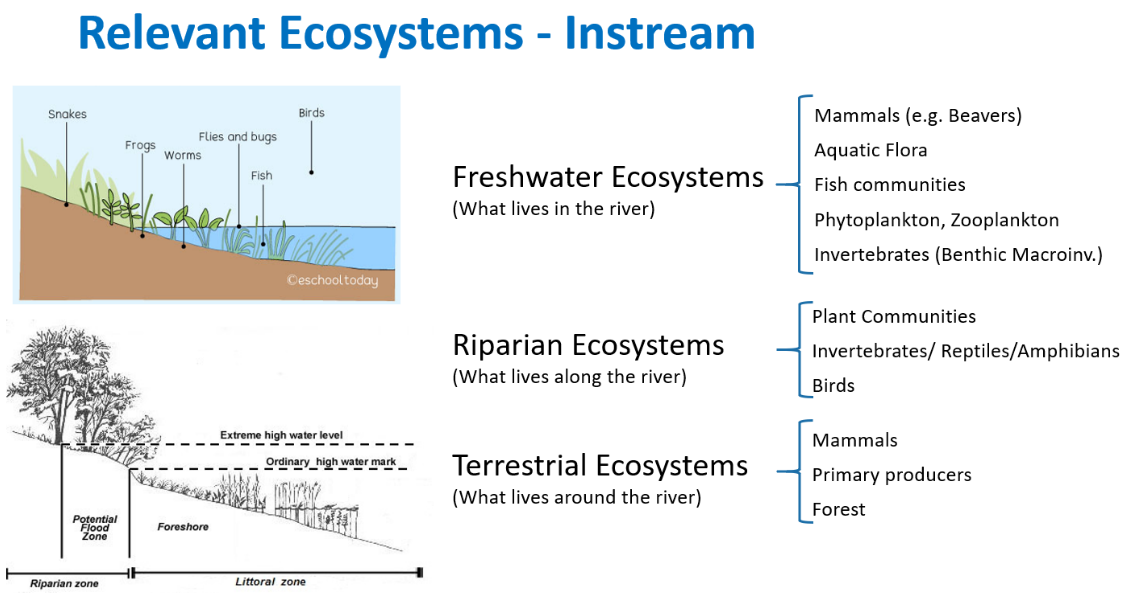


Figure 5. Relevant ecosystem for instream flows

Check your Understanding

Select the relevant ecosystems that directly depend on the amount of water flowing in the river:

( ) freshwater ecosystem

( ) riparian ecosystem

( ) terrestrial ecosystem

Instream Flow Components

Now that we have identified the relevant ecosystems that instream flows support, let's identify the different building blocks of instream flows (Figure 6). Think of these elements as the main ingredients in the recipe:

- **Water quantity**--river ecosystems require some minimum volume of water, but also need seasonal variability and inter-annual variability of flow. In other words, the river ecosystems need different water quantities each season of the year and from year-to-year. Both can be estimated by quantifying the magnitude, timing, frequency, duration, and rate of change of ecologically relevant flow events (also called *functional flow components*)..
- **Water quality**--river ecosystems need good water quality to adequately sustain all the organisms that live within the water column (inside the river) and along the riparian corridor (along the banks). The native species in a given river evolved based on a particular water quality regime. This means the seasonal and inter-annual variations of particular water quality parameters (like temperature or suspended sediment content).
- **Physical habitat**--river ecosystems need certain physical conditions to thrive. Organisms in a particular river system evolved to take advantage of the river channel shape and type (geomorphology). They have adapted to this form to survive. Perhaps a species grows on a point bar in the middle of a braided stream. In some streams there might be pools where certain organisms live during a stage of their lifecycle or backwater channels where they can hide from predators. If a levee is built or the river channel is straightened, then some of this complexity is lost. As a result, the health of the ecosystem is threatened.

- **River connectivity**--every river has different degrees of connectivity, but all of them are connected with other water bodies in one way or another. A perennial river (a river that naturally contains water all year) has three degrees of connectivity: (1) longitudinally, from its headwaters to the ocean, (2) transversely from bank to bank, during high flows both sides of the river are connected, and (3) vertically, the river is connected with the groundwater aquifer beneath. At different times of the year the river may be gaining (baseflow enters river from groundwater) or losing (the river recharges the groundwater). Typically, the mainstem of a river is perennial, however in arid regions especially, you find ephemeral rivers (rivers that naturally contain water only sometimes during the year, generally during the rainy season). Ephemeral rivers exhibit all three degrees of connectivity only during certain times of the year.

The following video provide an explanation of the previous concepts.

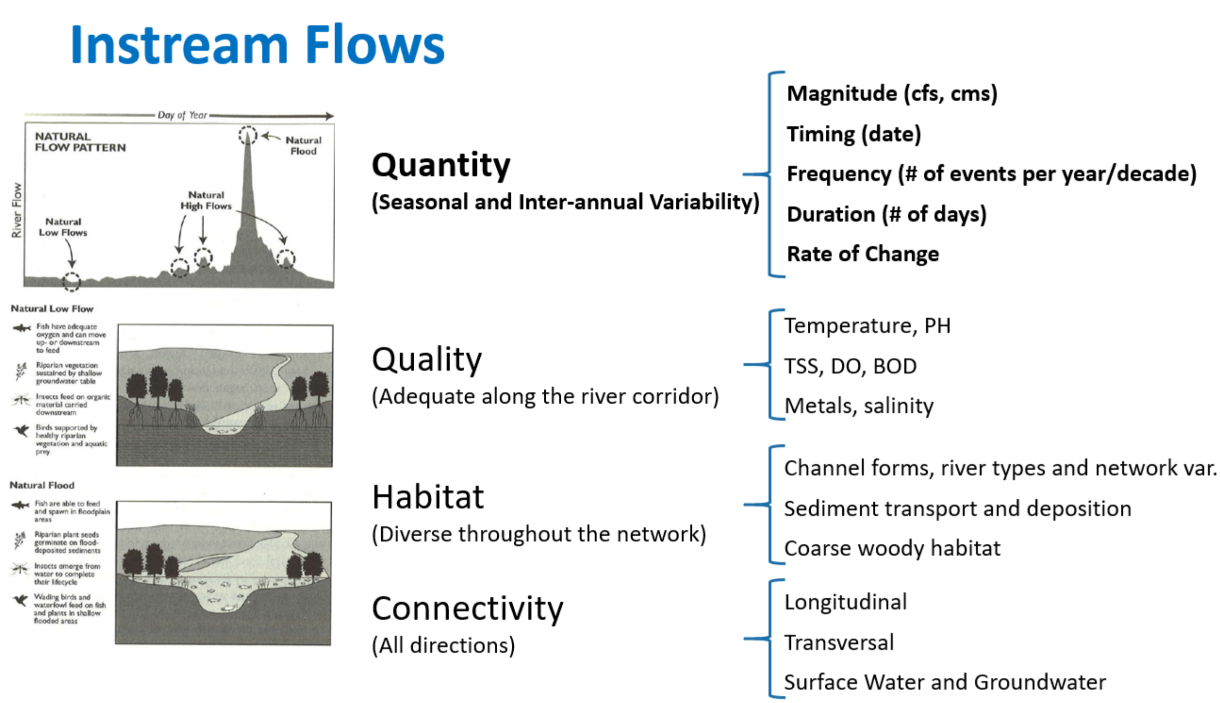


Figure 6. Instream flows components

Check your Understanding

In terms of water quantity, a given river ecosystem needs:

( ) the same amount of water throughout the year all years

( ) a seasonal variation of streamflow, but the same every year

( ) a seasonal and interannual variation of streamflow (yes)

In terms of water quality, a given river ecosystem needs:

( ) no water quality at all, the organisms living in river are not dependent on water quality, only water quality

( ) A variation of water quality constituents according to the natural variation

In terms of physical habitat, a given river ecosystem needs:

( ) a simple physical habitat, like an irrigation canal, with no variation of the form, slope or shape throughout its mainstem

( ) a complex physical habitat like a meandering pool-riffle river, that has a changing slope and channel type throughout the basin

In terms of connectivity, a given river ecosystem needs:

( ) longitudinal connectivity from its headwaters to the river outlet,

( ) vertical connectivity with aquifers that a river passes through

( ) transversal connectivity with its banks, for bringing nutrients into the river, moving sediment and reshaping the channel form

Natural Flow Regime

In the previous sections different concepts have been introduced such as environmental and instream flows. Another key concept is the natural flow regime. **A flow regime is the statistical description of the seasonal and inter-annual (among different years) variation of flow of a river. The natural flow regime is a time tested flow regime that supports the needs of native riparian and freshwater ecosystems.** For more details, read Poff et al. (1997) for a thorough description of the natural flow regime. For example, the figure below is composed of five time series, the 10th, 25th, 50th (median), 75th, and 90th flow percentiles of every day. This is one way that a flow regime can be described. Take a look at the median streamflow (Black line), it changes within a year, meaning there is a seasonal change in climate within a year and the streamflow responds accordingly to those climate variations. The interannual variability can be seen in the difference between the 10th and the 90th percentile time series, there are parts of the year that the flow does not change that much among years (dry season, i.e. August to November), but there are other times that the streamflow changes mode dramatically between year, typically the rainy season (i.e. December to May).

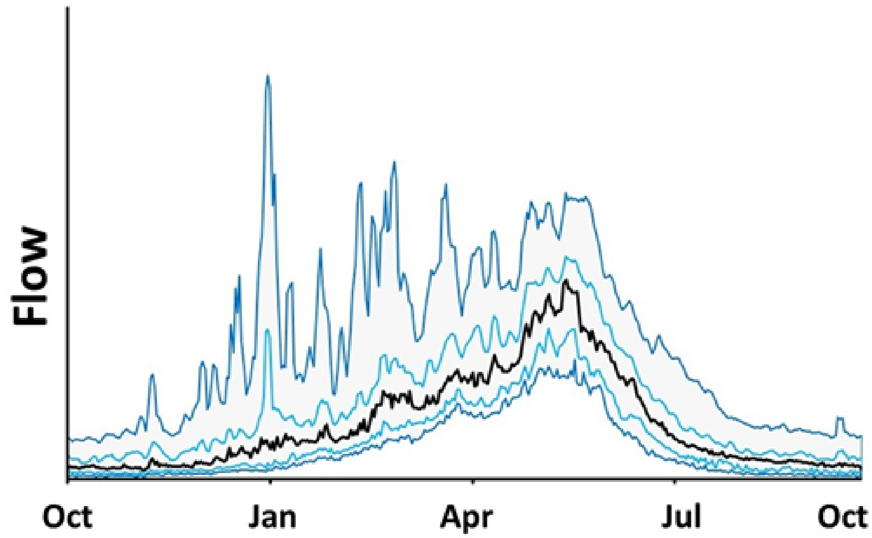


Figure 7. A snowmelt and rainfall natural flow regime of California

The following video describes in more detail the concept of the natural flow regime and its significance.

Natural streamflow classes for California

The natural flow regime can be calculated using streamflow data collected in watersheds with limited or no human disturbance. The two figures below show the location and the flow regime of the nine natural streamflow classes estimated for the state of California (Lane et al. 2017 and 2018). They can be explored at eflows.ucdavis.edu.

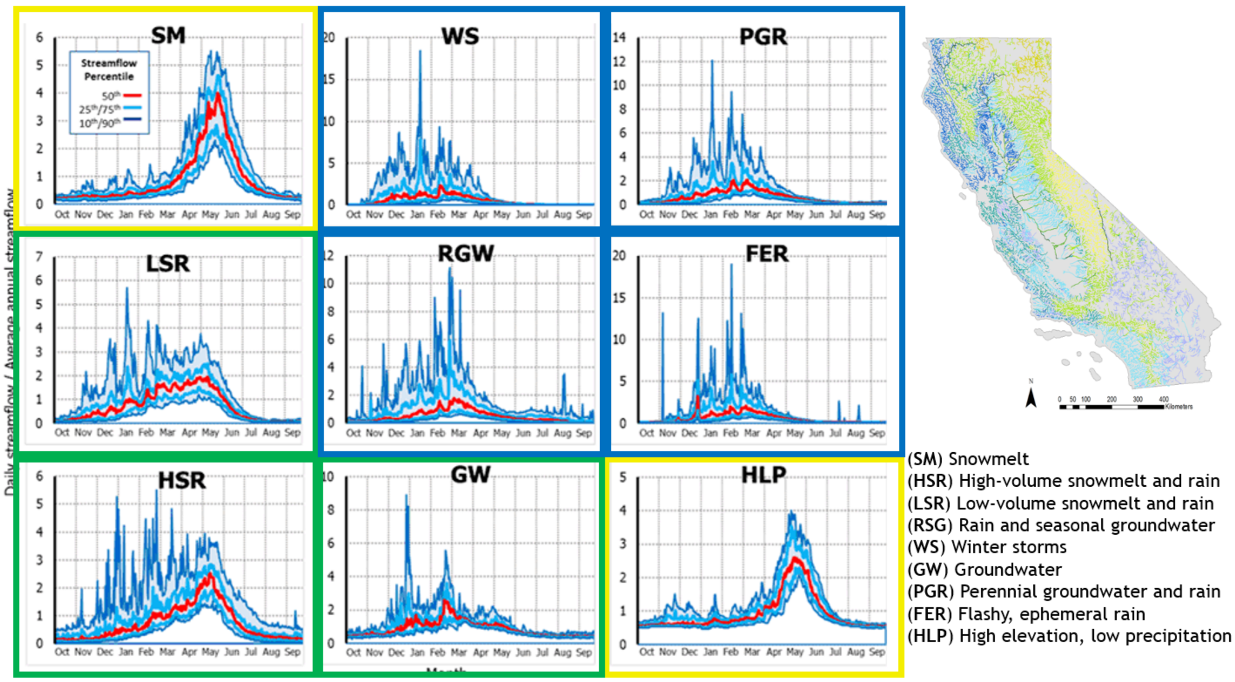


Figure 8. Nine natural streamflow classes of California

Now that you understand the concept of natural flow regime, take a look at the following video where the nine natural streamflow classes of California are explained.

Check your Understanding

Select the assumptions that natural flow regime consider:

( ) Mimicking the natural hydrology to which species are adapted will provide ecological benefit even if the driving mechanisms at work are not explicitly understood

( ) It offers a time-tested recipe for river restoration and protection.

( ) The needs of all river species are met over the course of seasons, years, decades and centuries by the natural variations of the river flow.

Instream Flows: "A very short story"

Now that we have a good understanding of the concepts of environmental flows, instream flows and natural flow regime, the following video provides a very brief description of some of the instream flow methods developed in the last four decades. (Figure 9).

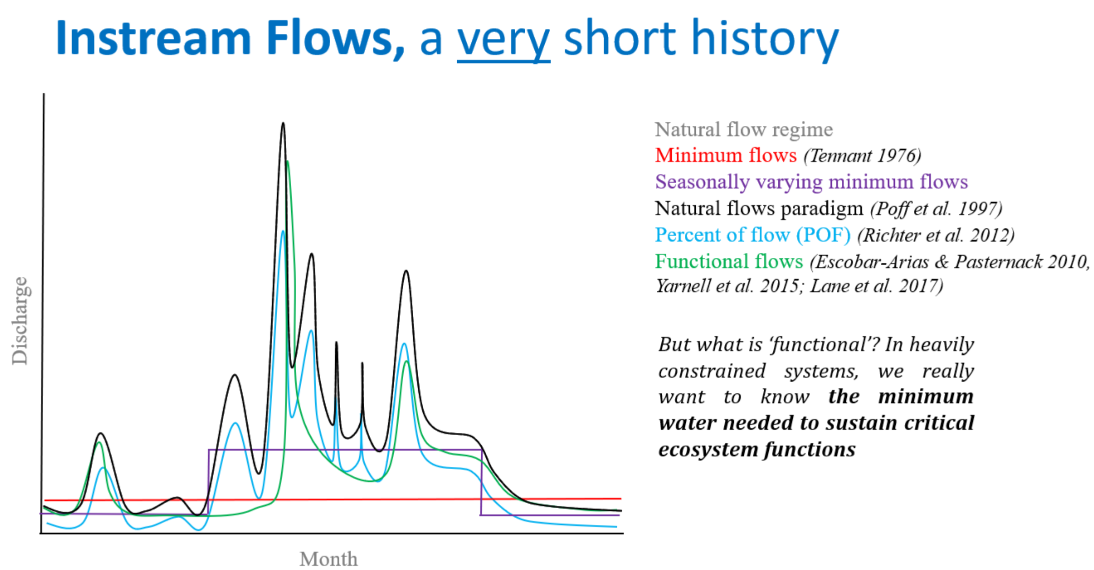
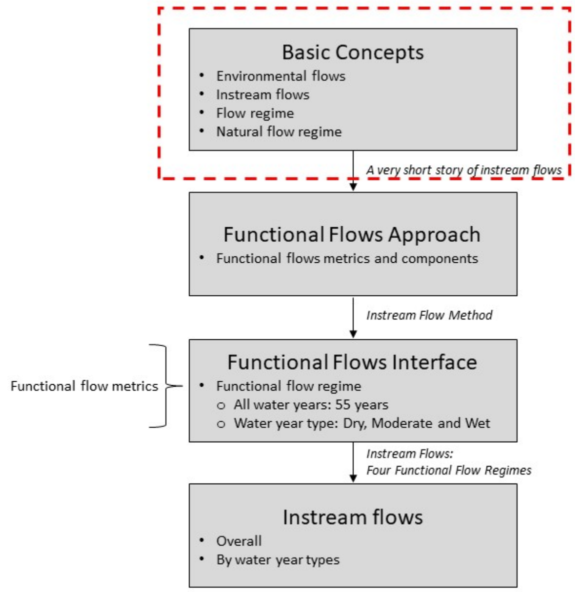


Figure 9. A comparison of different instream flow regime methods

The following figure shows your overall progress with respect to the Environmental water needs section.



Functional Flows Approach

In basins where there is already human alteration, there is a method to determine instream flows called **Functional Flows Approach** that estimates ecological relevant flows to sustain the different types of flows (quantity, quality, physical habitat and connectivity) needed to adequately sustain a healthy river ecosystem (Arias and Pasternack 2010, Yarnell et al. 2015, Yarnell et al. 2020). **Functional flows** are those aspects of the flow regime that directly relate to ecological, geomorphic, or biogeochemical processes in a river (see figure below). In other words, functional flows support foundational processes related with the ecology of the river (freshwater and riparian ecosystems), the physical habitat (geomorphology), water quality, connectivity and in general the well-being of the biological communities.

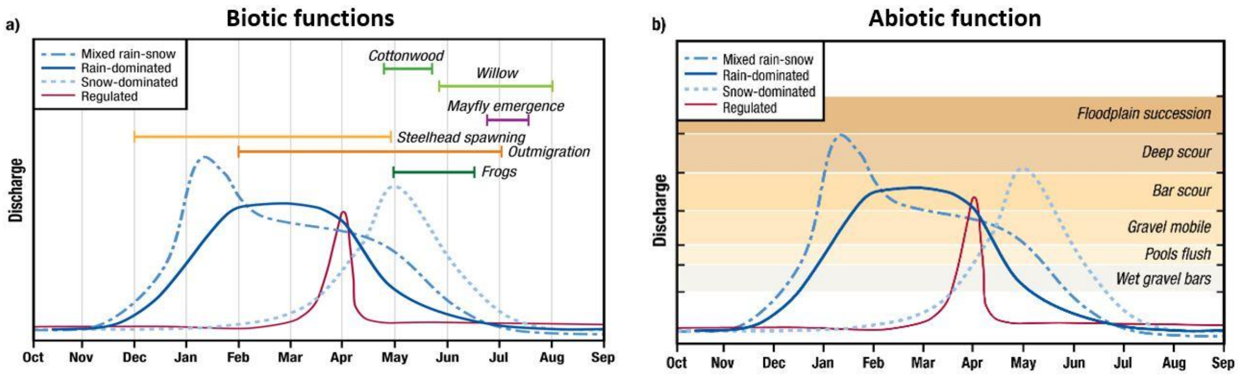


Figure 10. A relationship of flow and the ecosystem functions that flows provide to living organisms (biotic) and non-living organism (abiotic)

The functional flows approach is based on five seasonally varying **flow components** that provide ecological functions that sustain the entire river ecosystem while still leaving room for water diversion for human purposes (Figure 11).

1. *Fall pulse flow*, or the first major storm event following the dry season. These flows represent the transition from dry to wet season and serve important functions, such as moving nutrients downstream, improving streamflow water quality, and signaling species to migrate or spawn.
2. *Wet-season base flow*, which supports native species that migrate through and overwinter in streams.
3. *Peak magnitude flows*, which transport a significant portion of sediment load, inundate floodplains, and maintain and restructure river corridors.

4. *Spring recession flows*, which represent the transition from high to low flows, provide reproductive and migratory cues, and redistribute sediment.
5. *Dry-season low flow*, which support native species during the dry-season period when water quality and quantity limit habitat suitability

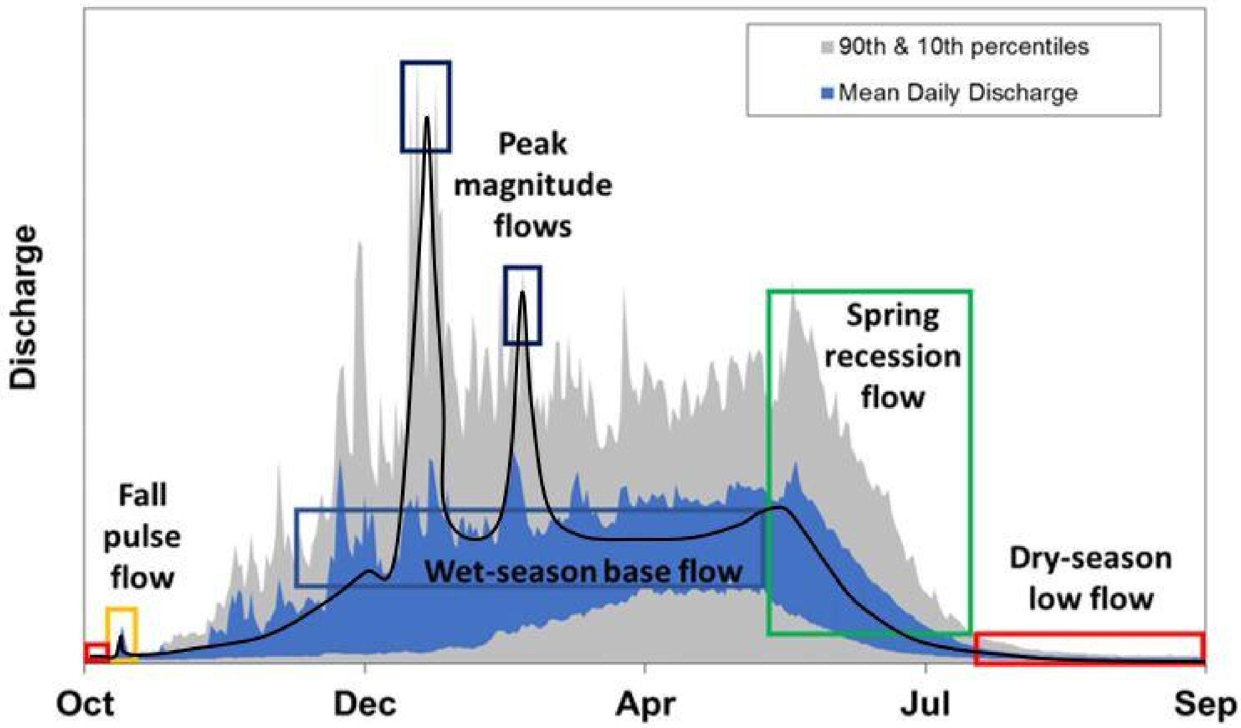


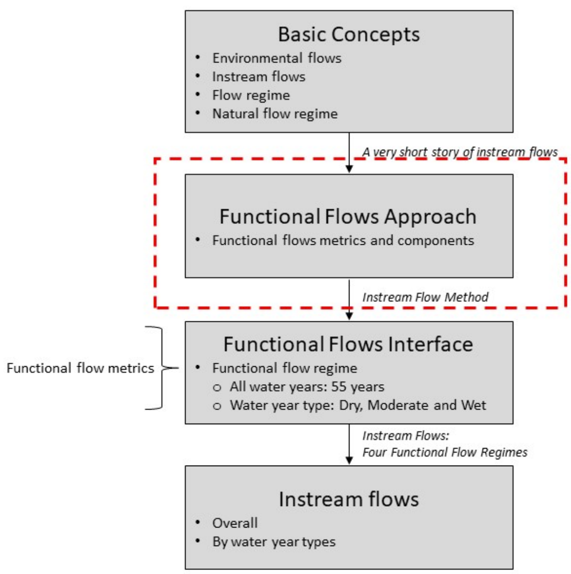
Figure 11. Functional flow components

The following video explains the Functional Flow Approach, each functional flow component and why they are important for sustaining healthy freshwater and riparian ecosystems.

Natural flow regime and functional flows

The following video connects the nine natural streamflow classes for the state of California with the functional flows approach, specifically relating the natural flow regime with the determination of functional flow components and metrics for each of the classes and ultimately each river reach in the State of California. This video shows how the combination of determining the natural flow regime and the functional flows are key milestones for sustaining healthy freshwater and riparian ecosystems.

The following figure shows your overall progress with respect to the Environmental water needs section.

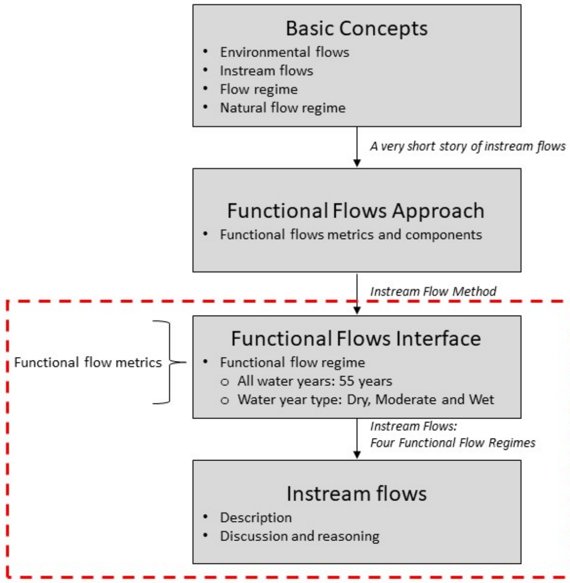


Learning Activity: Calculate instream flows

To complete this activity, students will obtain and examine how much water is needed to sustain aquatic and riparian ecosystem using functional flow metrics readily available for Pajaro River. Students will also compare three functional flow regimes for dry, moderate and wet conditions and discuss their functional flow components. Specifically, students will determine instream flows for the Pajaro River by:

- obtaining functional metrics available for the state of California,
- exploring the different functional flow components
- determining and comparing functional flow regimes for different water year types: all, dry, moderate and wet, and
- integrating these results into a functional flow regime and discussing the environmental and human benefits associated with the recommended flow regimes

The progress on this activity is shown in the figure below.



The results for this activity should include

- Two charts showing the reference hydrograph with units and dimensionless
- A description of the natural flow regime of of Pajaro River including the seasonal and interannual variability
- The *Recommended Instream Flows* table and a brief description of each recommended instream flows
- One chart showing the monthly volumes of the recommended instream flows for: all, dry, moderate and wet water years.
- One chart showing the recommended daily instream flows where the functional flow components are shown conceptual and estimated for: dry, moderate and wet water years.
- Discussion on the reasoning for considering environmental water demands (*instream flows*) and what are the benefits for the river ecosystem and the society. Hint: you can frame your response in terms of ecosystem functions and ecosystem services.

Resources

- Google sheet template Environmental Demand - Functional Flow Interface
- Google document tutorial with detailed instructions (see document below)
- Exercise submission template
- California Natural Flows Database
- California Environmental Flows Framework

- Functional Flows Calculator
- Atmospheric rivers

Instructions

1. Set up the functional flows interface. Follow the instruction from page 26 to 36
2. Analyze reference hydrographs. Follow up the instructions from page 36 to 39
3. Determine instream flow recommendations. Follow the instructions from page 39 to 53

Summary Questions

1. What is the natural flow of Pajaro River and how flashy is its natural flow regime?
2. Estimate the instream flow by using the functional flows approach and how large or small are the recommended instream flows in comparison with the natural flows?

Detailed Instructions

Setting up the Functional Flows Interface

Go the California Natural Flows Database webpage (Figure 11)

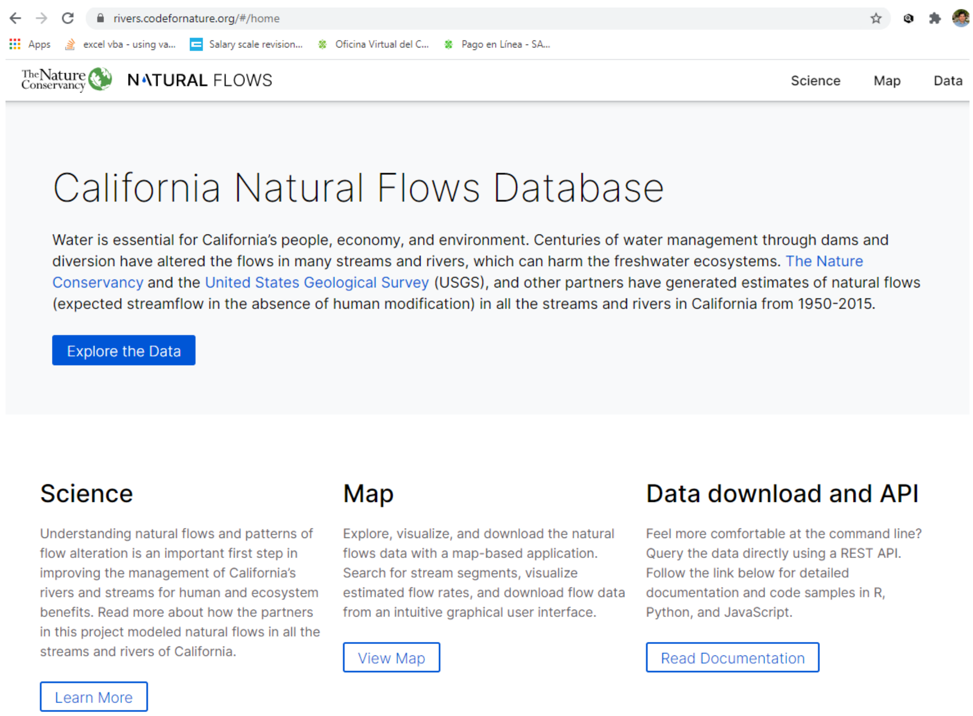


Figure 11

Click on “Explore Data”, a map like figure 12 should appear.

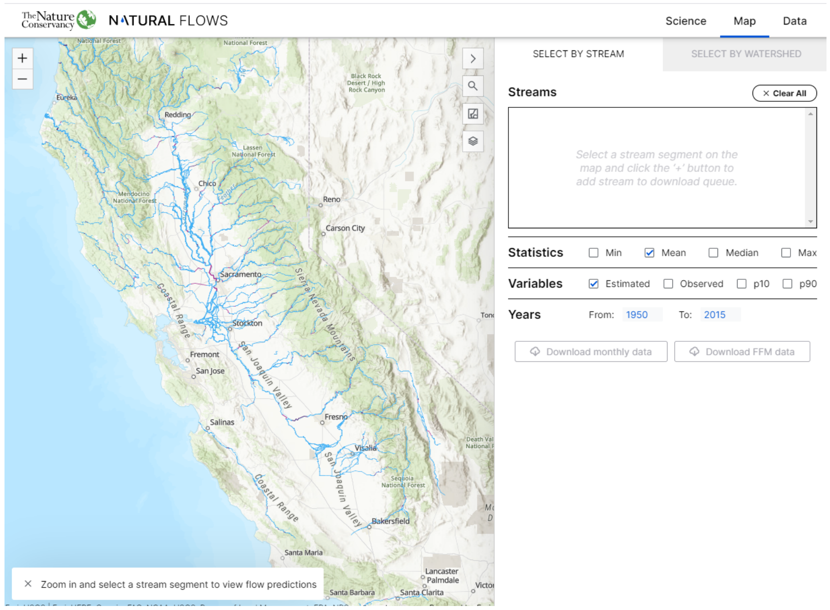


Figure 12

Now, zoom in Monterey Bay by using the scroll wheel (Figure 13).

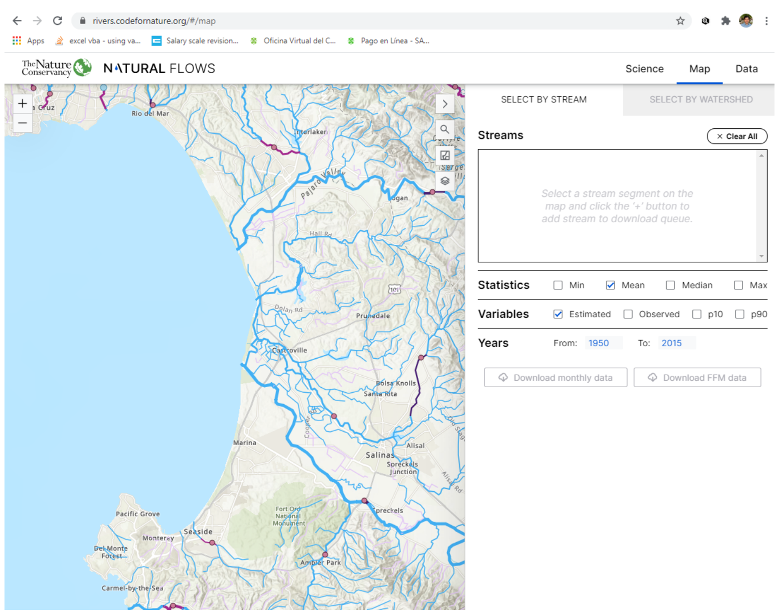


Figure 13

Click on the river outlet of Pajaro Valley as shown in Figure 14, then click on the right arrow below the monthly hydrograph.

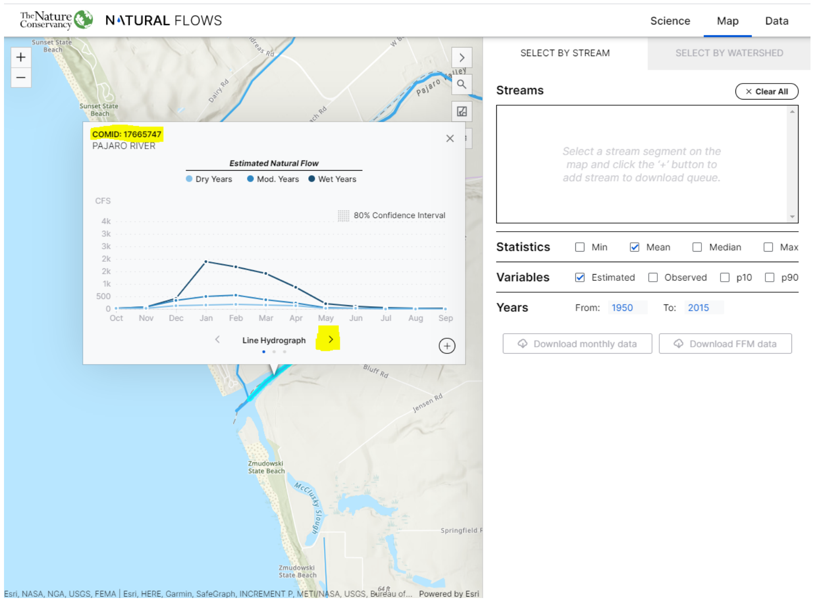


Figure 14

This will bring a screen with the estimated functional flows for the selected reach (Figure 15). Take you time in this window to look at the functional flow metrics for different functional flow components (explore the dropdown menu of *Flow Component*). Also, notice that these metrics have been calculated for all, dry, moderate and wet water year types. Cool! A group of scientists worked very hard in the California Environmental Flows Framework project to have all these estimations available for everyone in California!

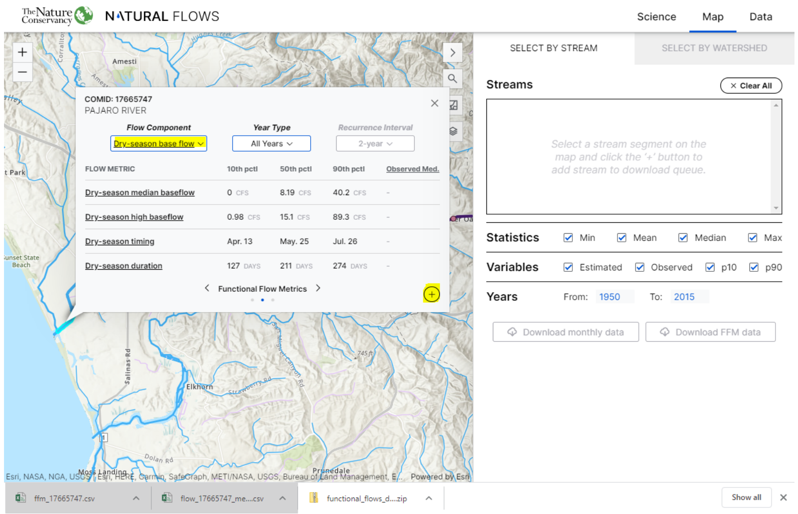


Figure 15

Then, click on the "+" sign in the lower right corner of the results window to add this reach into the queue (Figure 15). Make sure that the stream reach ID that you are selecting is **17665747** (see Figure 16). Click on the "Download FFM data" button in the lower right corner. A dialogue box should come asking you for the folder where you want to save the file. The default name is "ffm_17665747.csv"

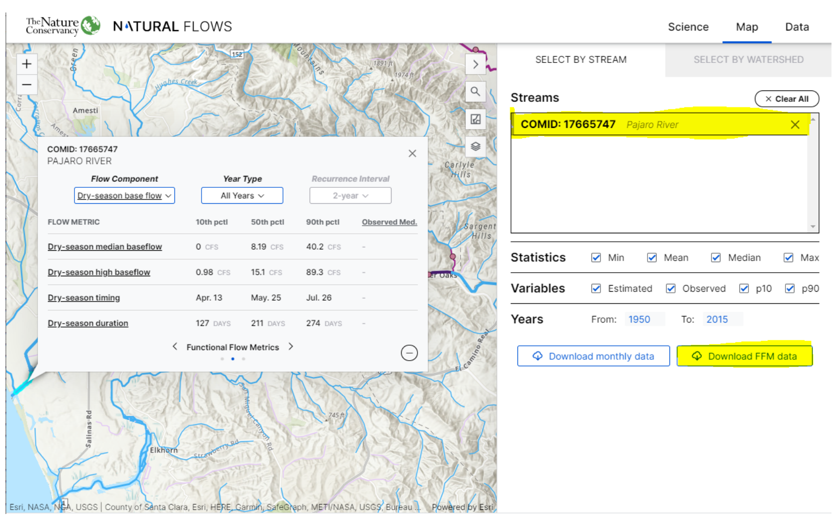
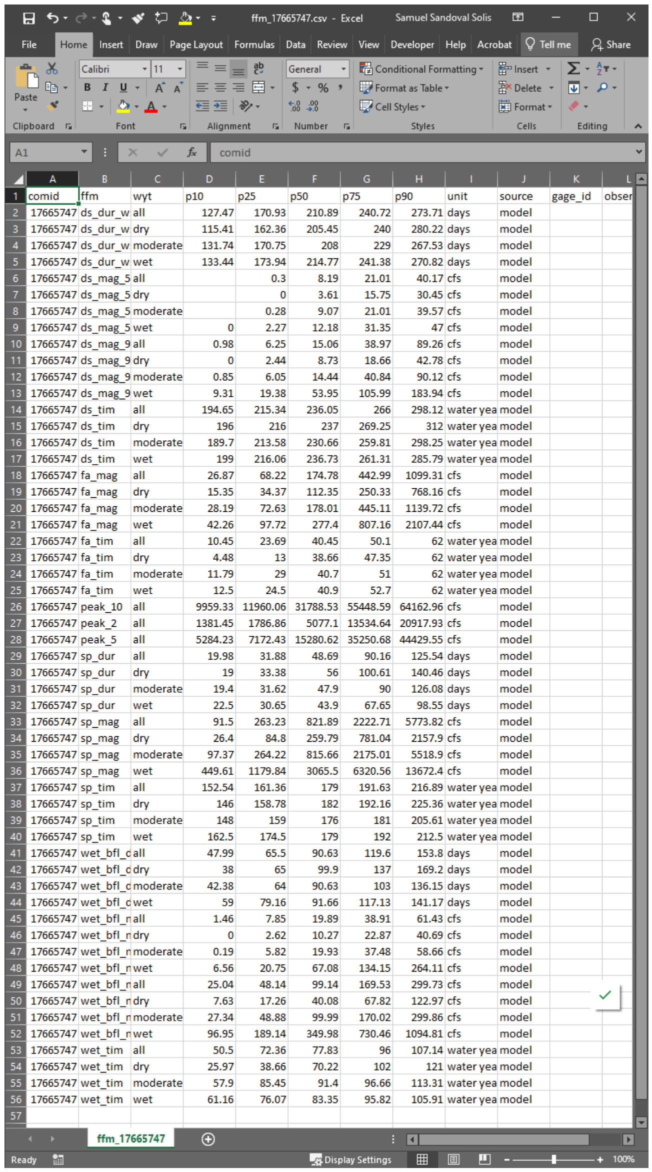


Figure 16

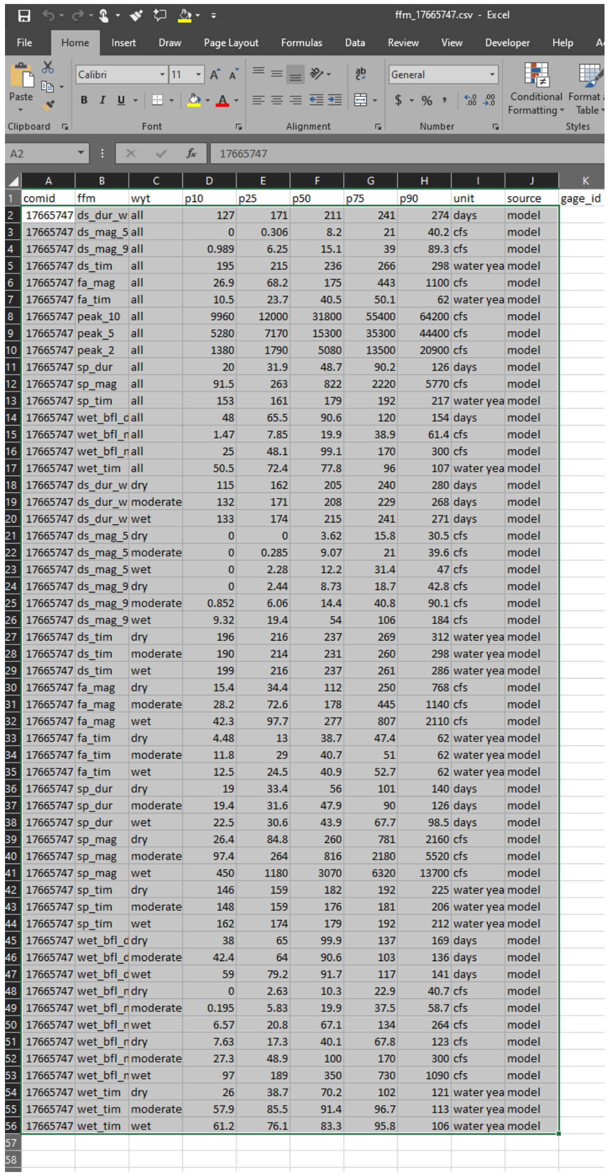
Open the file (see Figure 17). As you can see, the downloaded data has all the functional flow metrics that you have already explored, even filtered by water year type, so you can build an instream flow regime.



	comid	ffm	wyt	p10	p25	p50	p75	p90	unit	source	gage_id	obser
2	17665747	ds_dur_w	all	127.47	170.93	210.89	240.72	273.71	days	model		
3	17665747	ds_dur_w	dry	115.41	162.36	205.45	240	280.22	days	model		
4	17665747	ds_dur_w	moderate	131.74	170.75	208	229	267.53	days	model		
5	17665747	ds_dur_w	wet	133.44	173.94	214.77	241.38	270.82	days	model		
6	17665747	ds_mag_5	all		0.3	8.19	21.01	40.17	cfs	model		
7	17665747	ds_mag_5	dry		0	3.61	15.75	30.45	cfs	model		
8	17665747	ds_mag_5	moderate		0.28	9.07	21.01	39.57	cfs	model		
9	17665747	ds_mag_5	wet	0	2.27	12.18	31.35	47	cfs	model		
10	17665747	ds_mag_9	all	0.98	6.25	15.06	38.97	89.26	cfs	model		
11	17665747	ds_mag_9	dry	0	2.44	8.73	18.66	42.78	cfs	model		
12	17665747	ds_mag_9	moderate	0.85	6.05	14.44	40.84	90.12	cfs	model		
13	17665747	ds_mag_9	wet	9.31	19.38	53.95	105.99	183.94	cfs	model		
14	17665747	ds_tim	all	194.65	215.34	236.05	266	298.12	water yea	model		
15	17665747	ds_tim	dry	196	216	237	269.25	312	water yea	model		
16	17665747	ds_tim	moderate	189.7	213.58	230.66	259.81	298.25	water yea	model		
17	17665747	ds_tim	wet	199	216.06	236.73	261.31	285.79	water yea	model		
18	17665747	fa_mag	all	26.87	68.22	174.78	442.99	1099.31	cfs	model		
19	17665747	fa_mag	dry	15.35	34.37	112.35	250.33	768.16	cfs	model		
20	17665747	fa_mag	moderate	28.19	72.63	178.01	445.11	1139.72	cfs	model		
21	17665747	fa_mag	wet	42.26	97.72	277.4	807.16	2107.44	cfs	model		
22	17665747	fa_tim	all	10.45	23.69	40.45	50.1	62	water yea	model		
23	17665747	fa_tim	dry	4.48	13	38.66	47.35	62	water yea	model		
24	17665747	fa_tim	moderate	11.79	29	40.7	51	62	water yea	model		
25	17665747	fa_tim	wet	12.5	24.5	40.9	52.7	62	water yea	model		
26	17665747	peak_10	all	9959.33	11960.06	31788.53	55448.59	64162.96	cfs	model		
27	17665747	peak_2	all	1381.45	1786.86	5077.1	13534.64	20917.93	cfs	model		
28	17665747	peak_5	all	5284.23	7172.43	15280.62	35250.68	44429.55	cfs	model		
29	17665747	sp_dur	all	19.98	31.88	48.69	90.16	125.54	days	model		
30	17665747	sp_dur	dry	19	33.38	56	100.61	140.46	days	model		
31	17665747	sp_dur	moderate	19.4	31.62	47.9	90	126.08	days	model		
32	17665747	sp_dur	wet	22.5	30.65	43.9	67.65	98.55	days	model		
33	17665747	sp_mag	all	91.5	263.23	821.89	2222.71	5773.82	cfs	model		
34	17665747	sp_mag	dry	26.4	84.8	259.79	781.04	2157.9	cfs	model		
35	17665747	sp_mag	moderate	97.37	264.22	815.66	2175.01	5518.9	cfs	model		
36	17665747	sp_mag	wet	449.61	1179.84	3065.5	6320.56	13672.4	cfs	model		
37	17665747	sp_tim	all	152.54	161.36	179	191.63	216.89	water yea	model		
38	17665747	sp_tim	dry	146	158.78	182	192.16	225.36	water yea	model		
39	17665747	sp_tim	moderate	148	159	176	181	205.61	water yea	model		
40	17665747	sp_tim	wet	162.5	174.5	179	192	212.5	water yea	model		
41	17665747	wet_bfl_d	all	47.99	65.5	90.63	119.6	153.8	days	model		
42	17665747	wet_bfl_d	dry	38	65	99.9	137	169.2	days	model		
43	17665747	wet_bfl_d	moderate	42.38	64	90.63	103	136.15	days	model		
44	17665747	wet_bfl_d	wet	59	79.16	91.66	117.13	141.17	days	model		
45	17665747	wet_bfl_n	all	1.46	7.85	19.89	38.91	61.43	cfs	model		
46	17665747	wet_bfl_n	dry	0	2.62	10.27	22.87	40.69	cfs	model		
47	17665747	wet_bfl_n	moderate	0.19	5.82	19.93	37.48	58.66	cfs	model		
48	17665747	wet_bfl_n	wet	6.56	20.75	67.08	134.15	264.11	cfs	model		
49	17665747	wet_bfl_n	all	25.04	48.14	99.14	169.53	299.73	cfs	model		
50	17665747	wet_bfl_n	dry	7.63	17.26	40.08	67.82	122.97	cfs	model		
51	17665747	wet_bfl_n	moderate	27.34	48.88	99.99	170.02	299.86	cfs	model		
52	17665747	wet_bfl_n	wet	96.95	189.14	349.98	730.46	1094.81	cfs	model		
53	17665747	wet_tim	all	50.5	72.36	77.83	96	107.14	water yea	model		
54	17665747	wet_tim	dry	25.97	38.66	70.22	102	121	water yea	model		
55	17665747	wet_tim	moderate	57.9	85.45	91.4	96.66	113.31	water yea	model		
56	17665747	wet_tim	wet	61.16	76.07	83.35	95.82	105.91	water yea	model		

Figure 17

Open the Google Sheet template Environmental Demand - Functional Flow Interface and make a copy in your google drive (File / Make a copy). Through this means, you will be able to modify it. Make sure you remember where you save it. Select the range of cell A2 to J56 (D2:H56) from the "ffm_17665747.csv" and copy them (Ctrl+C) (Figure 18). Go to the Template Environmental Demand file and paste them in the sheet Functional Flow Metrics cell A2:J56 (yellow cells in Figure 19).



comid	ffm	wyt	p10	p25	p50	p75	p90	unit	source	gage_id
17665747	ds_dur_w	all	127	171	211	241	274	days	model	
17665747	ds_mag_5	all	0	0.306	8.2	21	40.2	cfs	model	
17665747	ds_mag_9	all	0.989	6.25	15.1	39	89.3	cfs	model	
17665747	ds_tim	all	195	215	236	266	298	water yea	model	
17665747	fa_mag	all	26.9	68.2	175	443	1100	cfs	model	
17665747	fa_tim	all	10.5	23.7	40.5	50.1	62	water yea	model	
17665747	peak_10	all	9960	12000	31800	55400	64200	cfs	model	
17665747	peak_5	all	5280	7170	15300	35300	44400	cfs	model	
17665747	peak_2	all	1380	1790	5080	13500	20900	cfs	model	
17665747	sp_dur	all	20	31.9	48.7	90.2	126	days	model	
17665747	sp_mag	all	91.5	263	822	2220	5770	cfs	model	
17665747	sp_tim	all	153	161	179	192	217	water yea	model	
17665747	wet_bfl_d	all	48	65.5	90.6	120	154	days	model	
17665747	wet_bfl_n	all	1.47	7.85	19.9	38.9	61.4	cfs	model	
17665747	wet_bfl_n	all	25	48.1	99.1	170	300	cfs	model	
17665747	wet_tim	all	50.5	72.4	77.8	96	107	water yea	model	
17665747	ds_dur_w	dry	115	162	205	240	280	days	model	
17665747	ds_dur_w	moderate	132	171	208	229	268	days	model	
17665747	ds_dur_w	wet	133	174	215	241	271	days	model	
17665747	ds_mag_5	dry	0	0	3.62	15.8	30.5	cfs	model	
17665747	ds_mag_5	moderate	0	0.285	9.07	21	39.6	cfs	model	
17665747	ds_mag_5	wet	0	2.28	12.2	31.4	47	cfs	model	
17665747	ds_mag_9	dry	0	2.44	8.73	18.7	42.8	cfs	model	
17665747	ds_mag_9	moderate	0.852	6.06	14.4	40.8	90.1	cfs	model	
17665747	ds_mag_9	wet	9.32	19.4	54	106	184	cfs	model	
17665747	ds_tim	dry	196	216	237	269	312	water yea	model	
17665747	ds_tim	moderate	190	214	231	260	298	water yea	model	
17665747	ds_tim	wet	199	216	237	261	286	water yea	model	
17665747	fa_mag	dry	15.4	34.4	112	250	768	cfs	model	
17665747	fa_mag	moderate	28.2	72.6	178	445	1140	cfs	model	
17665747	fa_mag	wet	42.3	97.7	277	807	2110	cfs	model	
17665747	fa_tim	dry	4.48	13	38.7	47.4	62	water yea	model	
17665747	fa_tim	moderate	11.8	29	40.7	51	62	water yea	model	
17665747	fa_tim	wet	12.5	24.5	40.9	52.7	62	water yea	model	
17665747	sp_dur	dry	19	33.4	56	101	140	days	model	
17665747	sp_dur	moderate	19.4	31.6	47.9	90	126	days	model	
17665747	sp_dur	wet	22.5	30.6	43.9	67.7	98.5	days	model	
17665747	sp_mag	dry	26.4	84.8	260	781	2160	cfs	model	
17665747	sp_mag	moderate	97.4	264	816	2180	5520	cfs	model	
17665747	sp_mag	wet	450	1180	3070	6320	13700	cfs	model	
17665747	sp_tim	dry	146	159	182	192	225	water yea	model	
17665747	sp_tim	moderate	148	159	176	181	206	water yea	model	
17665747	sp_tim	wet	162	174	179	192	212	water yea	model	
17665747	wet_bfl_d	dry	38	65	99.9	137	169	days	model	
17665747	wet_bfl_d	moderate	42.4	64	90.6	103	136	days	model	
17665747	wet_bfl_d	wet	59	79.2	91.7	117	141	days	model	
17665747	wet_bfl_n	dry	0	2.63	10.3	22.9	40.7	cfs	model	
17665747	wet_bfl_n	moderate	0.195	5.83	19.9	37.5	58.7	cfs	model	
17665747	wet_bfl_n	wet	6.57	20.8	67.1	134	264	cfs	model	
17665747	wet_bfl_n	dry	7.63	17.3	40.1	67.8	123	cfs	model	
17665747	wet_bfl_n	moderate	27.3	48.9	100	170	300	cfs	model	
17665747	wet_bfl_n	wet	97	189	350	730	1090	cfs	model	
17665747	wet_tim	dry	26	38.7	70.2	102	121	water yea	model	
17665747	wet_tim	moderate	57.9	85.5	91.4	96.7	113	water yea	model	
17665747	wet_tim	wet	61.2	76.1	83.3	95.8	106	water yea	model	

Figure 18

comid	ffm	wyt	p10	p25	p50	p75	p90	unit	source
17665747	ds_dur_ws	all	127	171	211	241	274	days	model
17665747	ds_mag_50	all	0	0.306	8.2	21	40.2	cfs	model
17665747	ds_mag_90	all	0.989	6.25	15.1	39	89.3	cfs	model
17665747	ds_tim	all	195	215	236	266	298	water yea	model
17665747	fa_mag	all	26.9	68.2	175	443	1100	cfs	model
17665747	fa_tim	all	10.5	23.7	40.5	50.1	62	water yea	model
17665747	peak_10	all	9960	12000	31800	55400	64200	cfs	model
17665747	peak_5	all	5280	7170	15300	35300	44400	cfs	model
17665747	peak_2	all	1380	1790	5080	13500	20900	cfs	model
17665747	sp_dur	all	20	31.9	48.7	90.2	126	days	model
17665747	sp_mag	all	91.5	263	822	2220	5770	cfs	model
17665747	sp_tim	all	153	161	179	192	217	water yea	model
17665747	wet_bfl_dur	all	48	65.5	90.6	120	154	days	model
17665747	wet_bfl_mag_10	all	1.47	7.85	19.9	38.9	61.4	cfs	model
17665747	wet_bfl_mag_50	all	25	48.1	99.1	170	300	cfs	model
17665747	wet_tim	all	50.5	72.4	77.8	96	107	water yea	model
17665747	ds_dur_ws	dry	115	162	205	240	280	days	model
17665747	ds_dur_ws	moderate	132	171	208	229	268	days	model
17665747	ds_dur_ws	wet	133	174	215	241	271	days	model
17665747	ds_mag_50	dry	0	0	3.62	15.8	30.5	cfs	model
17665747	ds_mag_50	moderate	0	0.285	9.07	21	39.6	cfs	model
17665747	ds_mag_50	wet	0	2.28	12.2	31.4	47	cfs	model
17665747	ds_mag_90	dry	0	2.44	8.73	18.7	42.8	cfs	model
17665747	ds_mag_90	moderate	0.852	6.06	14.4	40.8	90.1	cfs	model
17665747	ds_mag_90	wet	9.32	19.4	54	106	184	cfs	model
17665747	ds_tim	dry	196	216	237	269	312	water yea	model
17665747	ds_tim	moderate	190	214	231	260	298	water yea	model
17665747	ds_tim	wet	199	216	237	261	286	water yea	model
17665747	fa_mag	dry	15.4	34.4	112	250	768	cfs	model
17665747	fa_mag	moderate	28.2	72.6	178	445	1140	cfs	model
17665747	fa_mag	wet	42.3	97.7	277	807	2110	cfs	model
17665747	fa_tim	dry	4.48	13	38.7	47.4	62	water yea	model
17665747	fa_tim	moderate	11.8	29	40.7	51	62	water yea	model
17665747	fa_tim	wet	12.5	24.5	40.9	52.7	62	water yea	model
17665747	sp_dur	dry	19	33.4	56	101	140	days	model
17665747	sp_dur	moderate	19.4	31.6	47.9	90	126	days	model
17665747	sp_dur	wet	22.5	30.6	43.9	67.7	98.5	days	model
17665747	sp_mag	dry	26.4	84.8	260	781	2160	cfs	model
17665747	sp_mag	moderate	97.4	264	816	2180	5520	cfs	model
17665747	sp_mag	wet	450	1180	3070	6320	13700	cfs	model
17665747	sp_tim	dry	146	159	182	192	225	water yea	model
17665747	sp_tim	moderate	148	159	176	181	206	water yea	model
17665747	sp_tim	wet	162	174	179	192	212	water yea	model
17665747	wet_bfl_dur	dry	38	65	99.9	137	169	days	model
17665747	wet_bfl_dur	moderate	42.4	64	90.6	103	136	days	model
17665747	wet_bfl_dur	wet	59	79.2	91.7	117	141	days	model
17665747	wet_bfl_mag_10	dry	0	2.63	10.3	22.9	40.7	cfs	model
17665747	wet_bfl_mag_10	moderate	0.195	5.83	19.9	37.5	58.7	cfs	model
17665747	wet_bfl_mag_10	wet	6.57	20.8	67.1	134	264	cfs	model
17665747	wet_bfl_mag_50	dry	7.63	17.3	40.1	67.8	123	cfs	model
17665747	wet_bfl_mag_50	moderate	27.3	48.9	100	170	300	cfs	model
17665747	wet_bfl_mag_50	wet	97	189	350	730	1090	cfs	model
17665747	wet_tim	dry	26	38.7	70.2	102	121	water yea	model
17665747	wet_tim	moderate	57.9	85.5	91.4	96.7	113	water yea	model
17665747	wet_tim	wet	61.2	76.1	83.3	95.8	106	water yea	model

Figure 19

Click on the sheet "Functional Flow Regime", this sheet is the interface between the functional flow for the reach that you selected and their graphical display (Figure 20). The sheet contains:

- *Summary of functional flow results*, in these cells you can explore the five functional flow components timing (start and ending water year days), magnitude, duration, rate of change and frequency.
- *Main controls* to change the results: (a) Dimensionless (scaled by the average daily average flow) or with units (in cfs) and (b) for displaying the different water year types: all, dry, moderate and wet.
- *Graphical interface* which provides a visual representation of the functional flow regime according to the selected water year type. This interface will be used for submitting your graphs.
- Monthly instream flows. results from these cell will be used to build your summary table

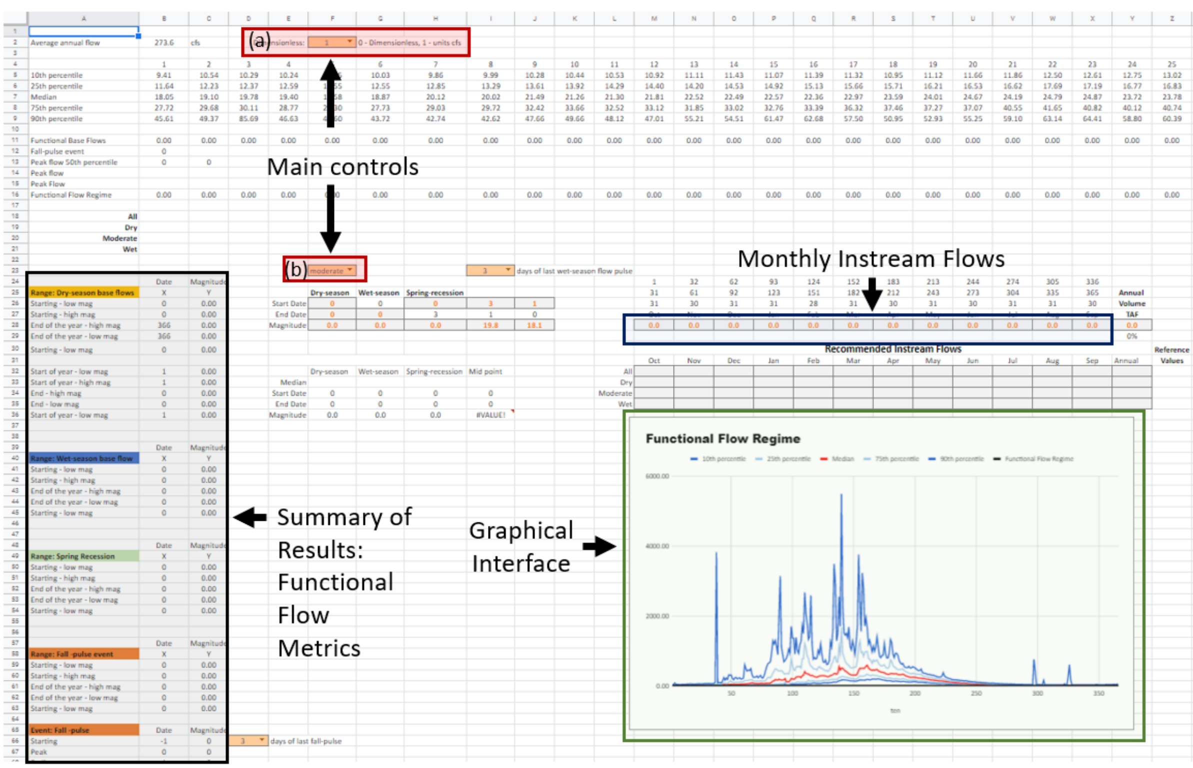


Figure 20

The graphical interface (Figure 21) shows the reference hydrograph (in blue lines and red line) for the river reach that was selected and the functional flow regime (black line). The reference hydrograph depicts the seasonal and interannual variation of flow of a Rain and Seasonal Groundwater river. The red line represents the median flow in a given date, the flow with the fiftieth probability. The outer dark blue lines represent the 10th percentile flow (low flows) and 90th percentile flow (high flow), in fact 80 percent of the natural Pajaro River flow occurred between these bounds. The inner light blue lines represent the 25th and 75th percentile flow, half of the time the natural pajaro river flow occurred between these bounds. Super cool!

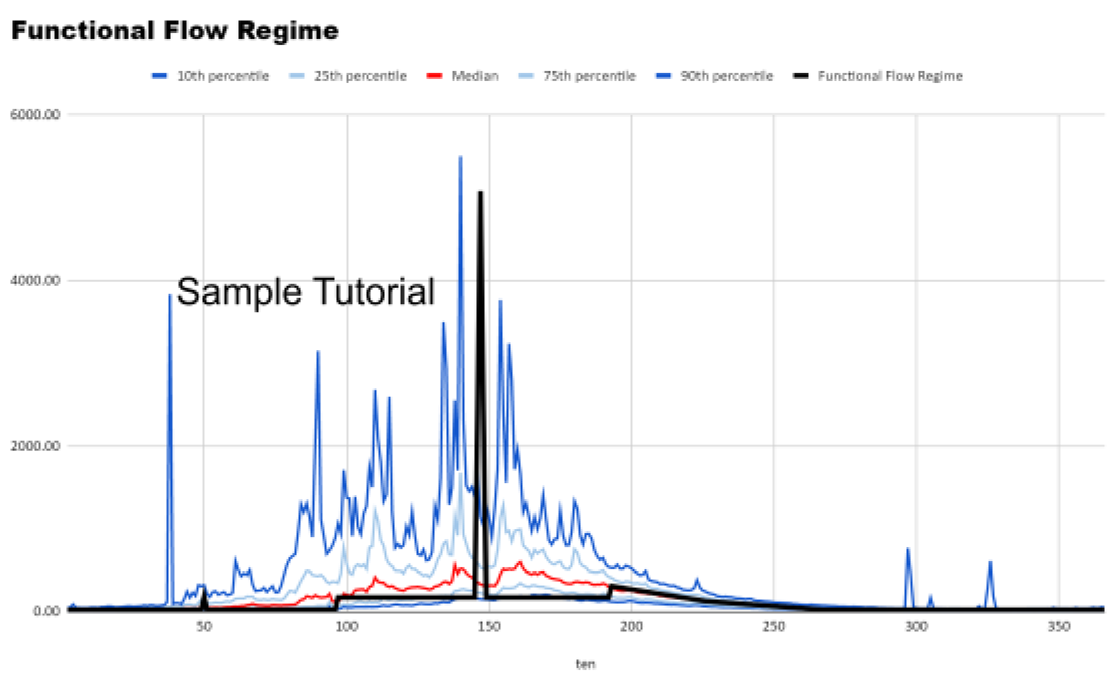


Figure 21

The black line depicts the function flow regime. Notice that the x-axis is in days, and that it starts in October first, the first day of the water year. As you can see, the flow regime has a dry period season called *Dry-season baseflows* (approximately from day 250 all the way to day 100), a wet season called *Wet-season baseflows* (approximately from day 100 to day 190) and a transicion season called *Spring recession baseflows* (approximately from day 190 to 250). Also, it has two flow events, one in fall called *Fall pulse flow* (located in day 50 in Figure 21), and another in winter called *Peak Magnitude Flows* (located in day 150 in Figure 21).

Analyzing reference hydrographs

Let's start playing with the graphical interface. Go to cell F2 and select "1" (Figure 22) and go to cell F23 and select "moderate". As you can see in the graphical interface the y-axis has units which are cfs (cubic feet per second). Think of cubic feet per second as basketballs per second passing through the river. As you can see, the flow changes quite a lot, from almost 0 cfs (no basketballs passing through) to 5,000 cfs (5,000 basketballs per second passing through the river!). You can distinguish the season and have an idea of the natural flow regime. Also, you can notice that the system is driven by climate, mostly rain. From day 50 to day 175 you can see the spikes in the flow regime (look at the 90th percentile dark blue line), those streamflows are rain events that the river responds to by a sudden increase and decrease in the streamflow. Also, you can see that there is almost no rain from day 200, all the way to the next water year in day 30.

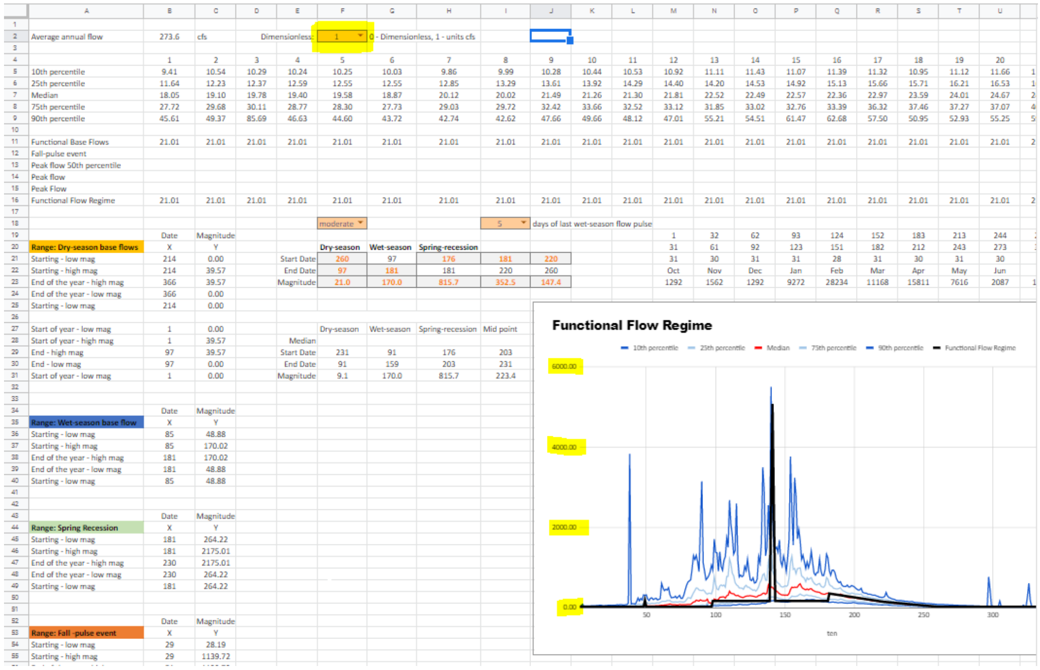


Figure 22

The next question will be: How flashy is the natural flow regime of Pajaro River? And by flashy, I mean how much the streamflow in the river changes when it rains (most likely when an [atmospheric river](#) occurs) in comparison to normal conditions? Go to cell F2 and select "0" (Figure 23). As you can see now the y-axis has values from 0 to 25. In this case, the streamflow values have been scaled (divided) by the average annual daily flow, which is 273.6 cfs (see cell B2). So, 1 unit in the y-axis means 273.6 cfs, 10 units means 2,736 cfs and so on. Dimensionless reference hydrograph gives you a good sense of how much the river changes from average conditions (1 unit) to high flow conditions, which in some days it can go 20 times larger! Cool! To have a sense if this variation is large or small, some snowmelt driven flow regimes in the high Sierra Nevada have a streamflow variation up to 6 times the annual daily average flow (see Figure 24.a), and some rain and snowmelt rivers in the foothills of the Sierra Nevada have a streamflow variation up to 9 times the annual daily average flow (see Figure 24.b). Take a look at the Functional Flow Calculator (Figure 25) which is a graphical interface that shows the nine natural flow regime classes (that you saw on the videos) as well as the reference gauges that were deemed as unimpaired. Data from these 223 gages was used in statistical models (using machine learning algorithms) to predict the functional flow metrics that can be downloaded from the California Natural Flows Database website. Everything is coming together!

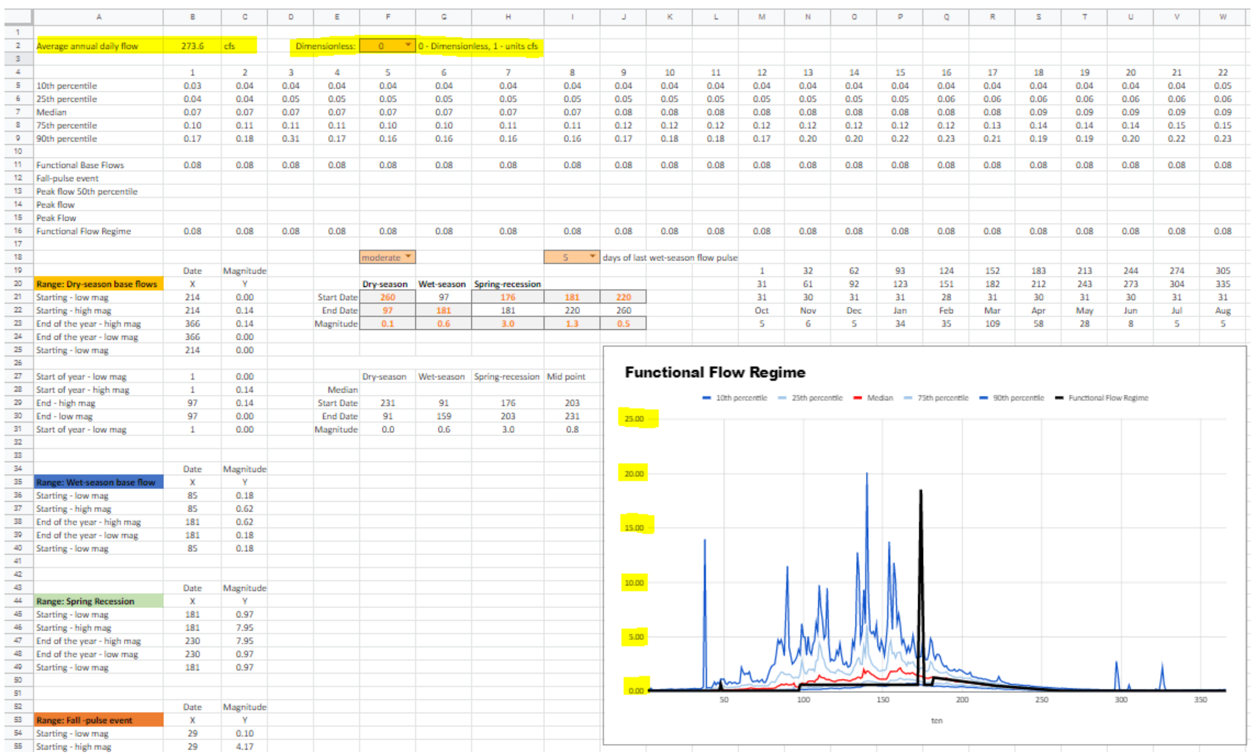


Figure 23

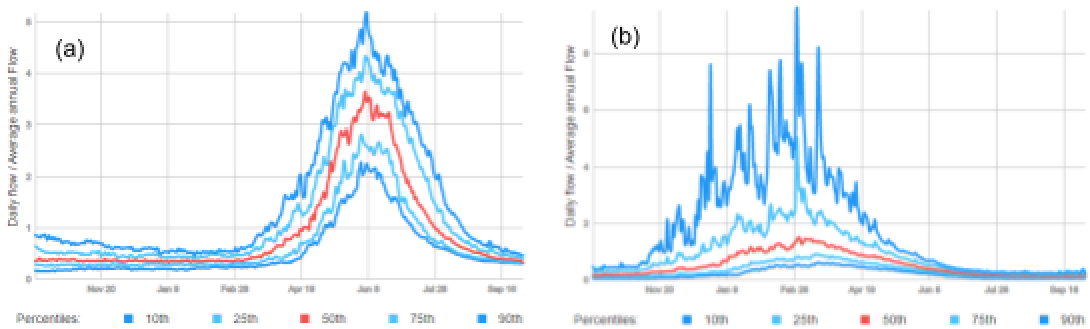


Figure 24. Snowmelt (a) and snow and rain (b) flow regimes

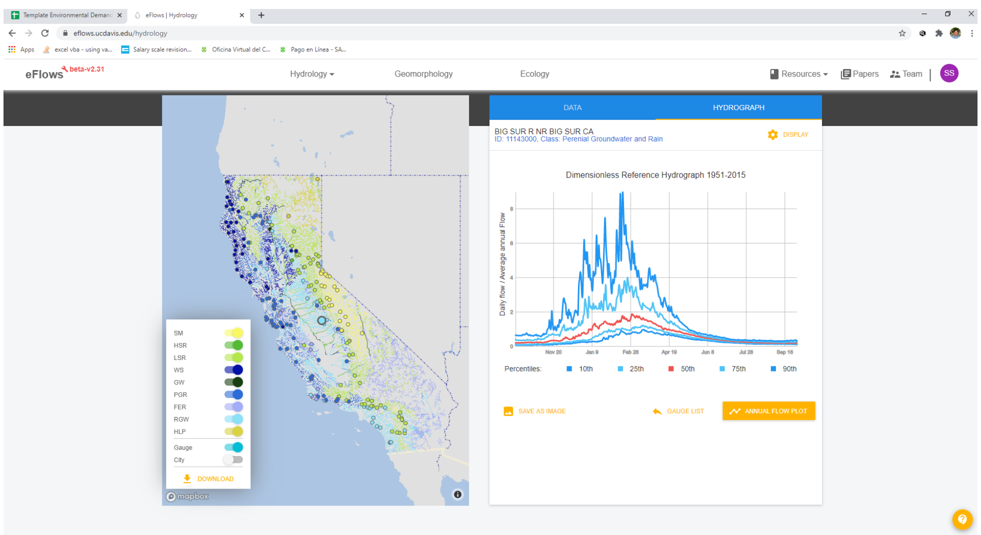


Figure 25. Functional Flows Calculator

To be turned in:

- Two charts showing the reference hydrograph with units and dimensionless (similar to Figure 21),
- A description of the seasonal and interannual variability of Pajaro River.

Determining instream flow recommendations

In the previous section, we explored and analyzed the natural flow regime. In this section we will focus our attention in the functional flow components from which a functional flow regime can be built. The functional flow regime (black line) can be used for recommending instream flows considering that it provides ecosystem functions (biotic and abiotic) that are beneficial for the river ecosystems living in it. Go to cell F2 and select “1”, then go to cell F23 and select “all”. The functional flow should look something like Figure 26. Notice that the interface randomly assigns the *fall-pulse flow* and *peak magnitude flow* component in late fall and the wet-season, respectively, so don’t worry if these components are not located on the same date as in Figure 26.

	A	B	C	D	E	F	G	H	I	J	K
2	Average annual flow	273.6	cfs		Dimensionless:	1	0 - Dimensionless, 1 - units cfs				
3											
4		1	2	3	4	5	6	7	8	9	10
5	10th percentile	9.41	10.54	10.29	10.24	10.25	10.03	9.86	9.99	10.28	10.44
6	25th percentile	11.64	12.23	12.37	12.59	12.55	12.55	12.85	13.29	13.61	13.92
7	Median	18.05	19.10	19.78	19.40	19.58	18.87	20.12	20.02	21.49	21.26
8	75th percentile	27.72	29.68	30.11	28.77	28.30	27.73	29.03	29.72	32.42	33.66
9	90th percentile	45.61	49.37	85.69	46.63	44.60	43.72	42.74	42.62	47.66	49.66
10											
11	Functional Base Flows	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01
12	Fall-pulse event										
13	Peak flow 50th percentile										
14	Peak flow										
15	Peak Flow										
16	Functional Flow Regime	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01
17											
18	All										
19	Dry										
20	Normal										
21	Wet										
22											
23						all			3	days of last wet-season flow pulse	
24		Date	Magnitude								
25	Range: Dry-season base flows	X	Y			Dry-season	Wet-season	Spring-recession			
26	Starting - low mag	215	0.00		Start Date	266	96	179	182	224	
27	Starting - high mag	215	40.17		End Date	96	192	182	224	266	
28	End of the year - high mag	366	40.17		Magnitude	21.0	169.5	821.9	346.2	131.0	
29	End of the year - low mag	366	0.00								
30	Starting - low mag	215	0.00								
31											
32	Start of year - low mag	1	0.00			Dry-season	Wet-season	Spring-recession	Mid point		
33	Start of year - high mag	1	40.17		Median						
34	End - high mag	96	40.17		Start Date	236	78	179	207		
35	End - low mag	96	0.00		End Date	78	161	207	236		

	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
2														
3														
4	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5	10.53	10.92	11.11	11.43	11.07	11.39	11.32	10.95	11.12	11.66	11.86	12.50	12.61	12.75
6	14.29	14.40	14.20	14.53	14.92	15.13	15.66	15.71	16.21	16.53	16.62	17.69	17.19	16.77
7	21.30	21.81	22.52	22.49	22.57	22.36	22.97	23.59	24.01	24.67	24.19	24.79	24.87	23.72
8	32.52	33.12	31.85	33.02	32.76	33.39	36.32	37.46	37.27	37.07	40.55	41.65	40.82	40.12
9	48.12	47.01	55.21	54.51	61.47	62.68	57.50	50.95	52.93	55.25	59.10	63.14	64.41	58.80
10														
11	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01
12														
13														
14														
15														
16	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01	21.01
17														
18														
19														
20														
21														
22														
23														
24		1	32	62	93	124	152	183	213	244	274	305	336	
25		31	61	92	123	151	182	212	243	273	304	335	365	Annual
26		31	30	31	31	28	31	30	31	30	31	31	30	Volume
27		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TAF
28		1.3	1.6	1.3	9.5	28.2	10.4	13.2	7.7	2.6	1.3	1.3	1.3	79.6
29														40%
30														
31		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
32	All													
33	Dry													
34	Normal													
35	Wet													

Figure 26

As we learned in the section *Functional Flows Approach*, the functional flow regime is composed of 5 functional flow components (Figure 27): (1) dry-season low flow, (2) wet season base flow, (3) spring recession flow, (4) fall pulse flow, and (5) peak magnitude flows.

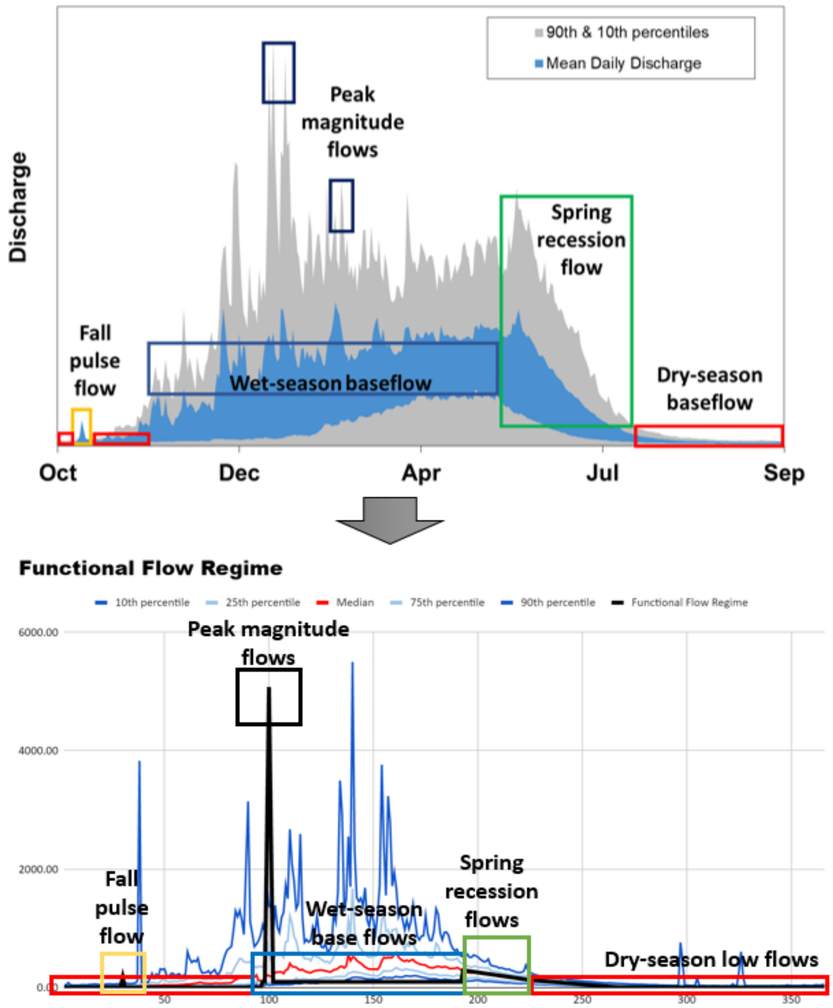


Figure 27. Identifying functional flow components in Pajaro River

Taking a closer look at the functional flow components, there are three functional flow components (1 to 3) associated with the adequate baseflow required to sustain the river ecosystem all year around. These *baseflows* provide the right amount of water quantity and quality all year around for any aquatic and riparian organism to live in <u>adequate conditions.</u> Adequate conditions are different from *minimum conditions*, because the ecosystem requires conditions to live adequately and not minimum conditions to barely survive. In this document we have moved away from the concept of minimum conditions because it implies that we should leave in the river the minimum amount of water for the ecosystem to barely survive and not necessarily to thrive. Coming back to the description of *baseflows*, they provide longitudinal connectivity with the ocean and vertical connectivity with the aquifer underneath. In addition, there are two flow components (4 and 5) associated with rain events that provide ecosystem function to sustain water quality, physical habitat (movement of sediment, access to floodplains, sediment transport and deposition, bring wood material into the river channel and move it, etc.). The interaction of all the functional flow components provide suitable conditions for the river ecosystem within a year and among years.

For the rest of the exercise, we will focus on obtaining instream flows considering: all available years, and considering water type years (dry, moderate and wet). For doing these, we will fill the table in cell M32:Y35 (Figure 28) with the monthly values. Also, we will estimate the daily flow regime, similar to Figure 4, so we can graphically show the instream flows for three water year types.

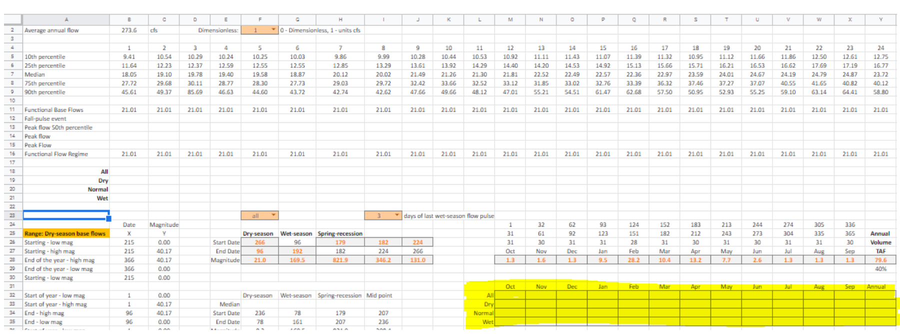


Figure 28

Go to cell F23 and select “all”. Then select, cells M28 to Y28 (M28:Y28), copy them (Ctrl+C) and paste them special in cell M32 (right click, Paste Special, Paste Values Only, or

Ctrl+Shift+V) in "Recommended Instream Flows" table for the row "all" (Figure 29 and 30). Also, copy all the row 16 from B16 to NC16 (B16:NC16) and paste it special as values (Ctrl+Shift+V) in row 18 (Figure 31). Repeat this procedure 3 more times, by selecting in cell F23 dry, moderate and wet. As you are changing the water year type, notice how the functional flow regime changes, the baseflows (wet-season base flow, spring recession flows, and dry-season low flows), false pulse flow and peak magnitude flows. Copy and pasting special (only values) in table Recommended Instream Flows and in rows 19 to 21. The Recommended Instream Flows table and rows 18 to 21 should look like Figure 32.

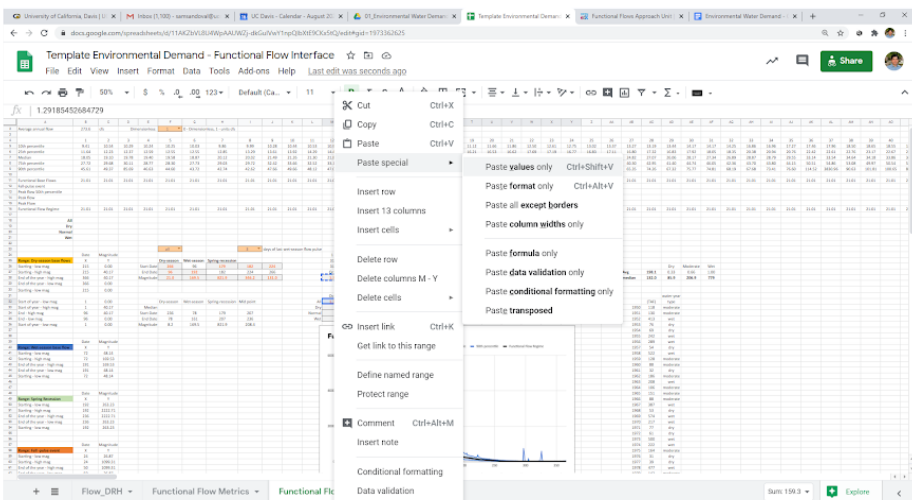


Figure 29

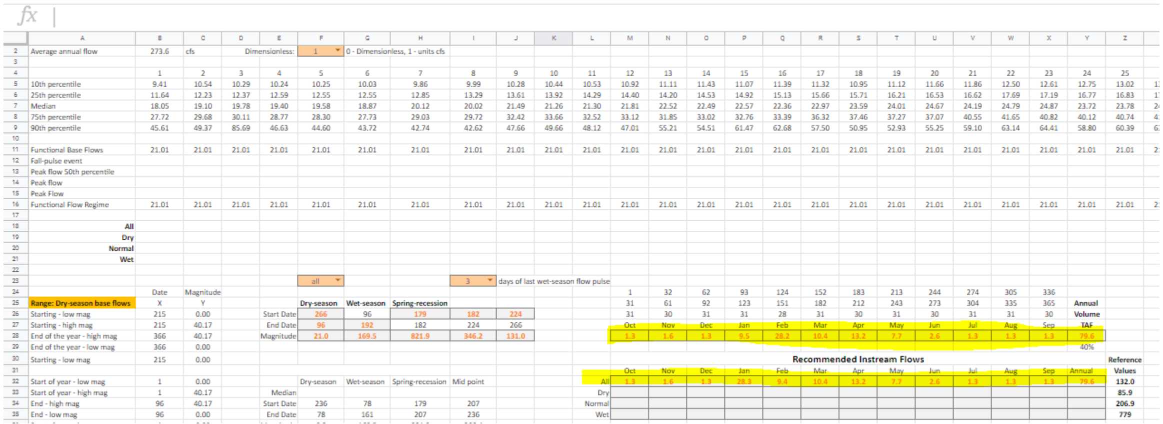


Figure 30

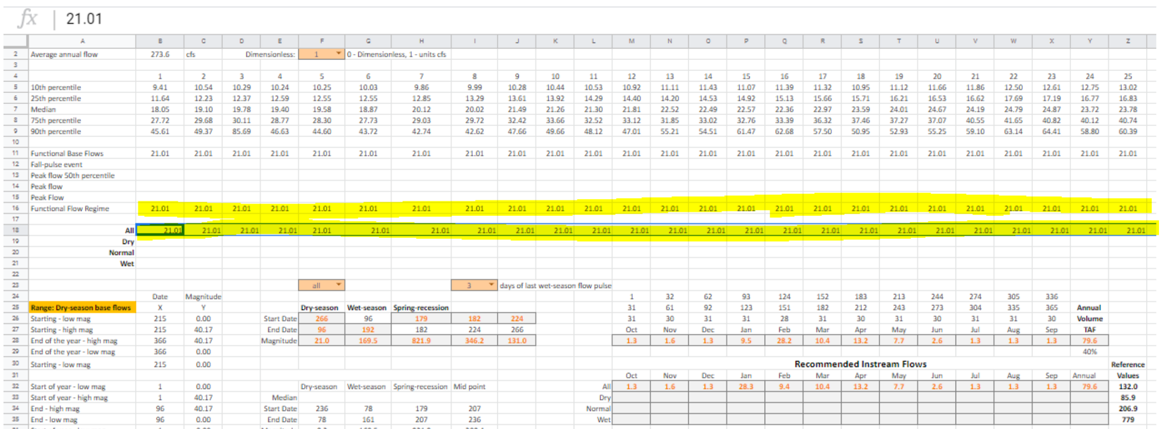


Figure 31

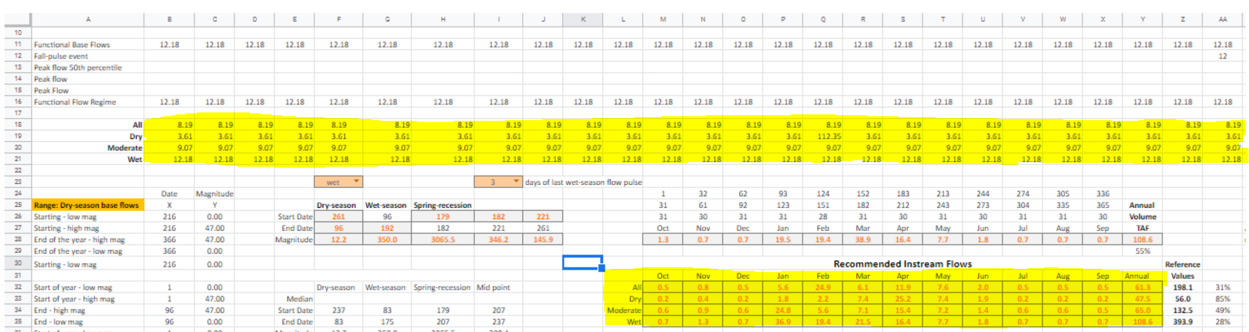
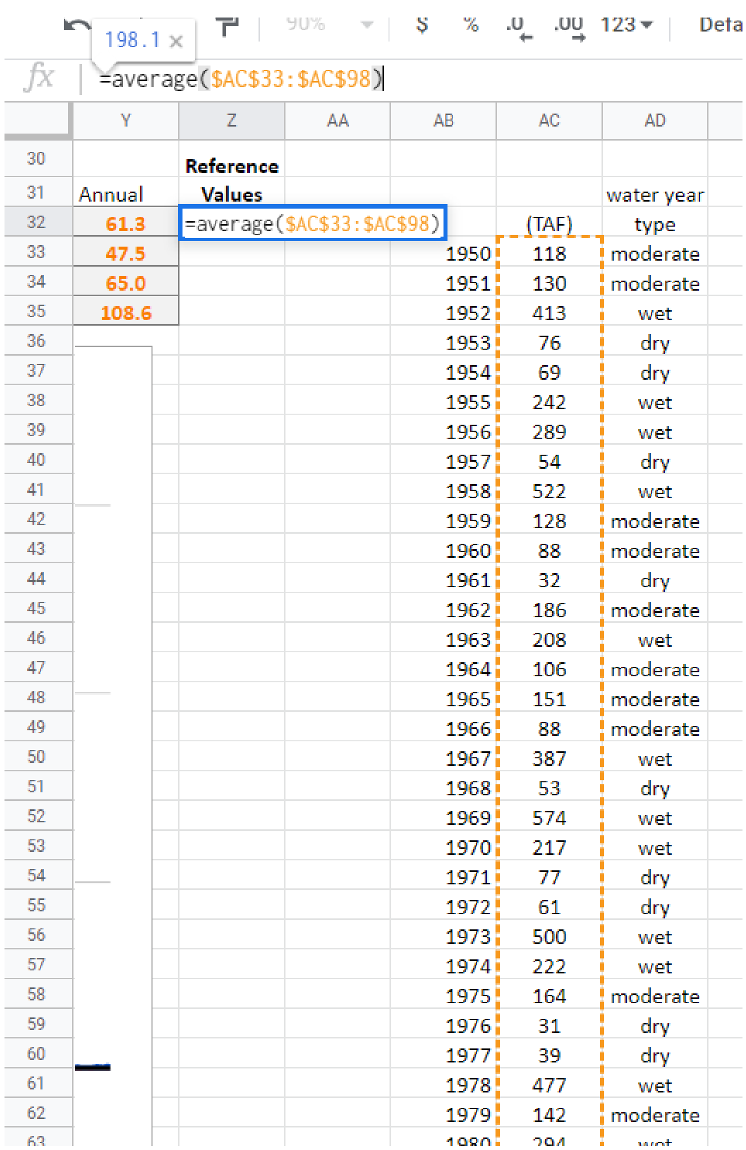


Figure 32

Take a closer look at the Recommended Instream Flows table (Figure 33). How large or small are the recommended instream flows in comparison with the natural flows? We can estimate this easily. Go to cell Z32 and estimate the overall annual average flow for the time series data of annual natural flows in column AC (AC33:AC98) using the following formula: "`=average($AC$33:$AC$98)`" (See figure 34).

	Recommended Instream Flows													Reference	
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Values	
All	0.5	0.8	0.5	5.6	24.9	6.1	11.9	7.6	2.0	0.5	0.5	0.5	61.3	198.1	31%
Dry	0.2	0.4	0.2	1.8	2.2	7.4	25.2	7.4	1.9	0.2	0.2	0.2	47.5	56.0	85%
Moderate	0.6	0.9	0.6	24.8	5.6	7.1	15.4	7.2	1.4	0.6	0.6	0.5	65.0	132.5	49%
Wet	0.7	1.3	0.7	36.9	19.4	21.5	16.4	7.7	1.8	0.7	0.7	0.7	108.6	393.9	28%

Figure 33



	Y	Z	AA	AB	AC	AD
30		Reference				
31	Annual	Values				water year
32	61.3	=average($AC$33:$AC$98)			(TAF)	type
33	47.5			1950	118	moderate
34	65.0			1951	130	moderate
35	108.6			1952	413	wet
36				1953	76	dry
37				1954	69	dry
38				1955	242	wet
39				1956	289	wet
40				1957	54	dry
41				1958	522	wet
42				1959	128	moderate
43				1960	88	moderate
44				1961	32	dry
45				1962	186	moderate
46				1963	208	wet
47				1964	106	moderate
48				1965	151	moderate
49				1966	88	moderate
50				1967	387	wet
51				1968	53	dry
52				1969	574	wet
53				1970	217	wet
54				1971	77	dry
55				1972	61	dry
56				1973	500	wet
57				1974	222	wet
58				1975	164	moderate
59				1976	31	dry
60				1977	39	dry
61				1978	477	wet
62				1979	142	moderate

Figure 34

You can also estimate the average of dry, moderate and wet conditions using the "Average if …" function. Go to cell Z33 and estimate the annual average flow for dry conditions in column AC (AC33:AC98) using the following formula (See figure 35):

"`=averageifs($AC$33:$AC$98,$AD$33:$AD$98,L33)`". Notice that the first range of cells that are declared in this function ("`$AC$33:$AC$98`") are the cells that the average will be calculated. The cells that will filter the average calculation are the one in the following column (`$AD$33:$AD$98`), and the discriminator is in cell `L33`, which is the text "Dry". Also, notice that the dollar sign is written before declaring the columns and rows, this is to fix the range, so when you copy and paste this formula, they refer always to the same range. You can easily fix the rows and cell by typing the cell "F4" (in the upper left corner of your keyboard) to fix the cells. Notice that this is how you can estimate very quickly an average estimation considering filtering for certain characteristics. Do the same procedure for estimating the average annual flow for moderate and wet conditions. Copy cell Z33 (Ctrl+C) and paste it on cells Z34 and Z35 (Ctrl+V). Results should look like figure 36.

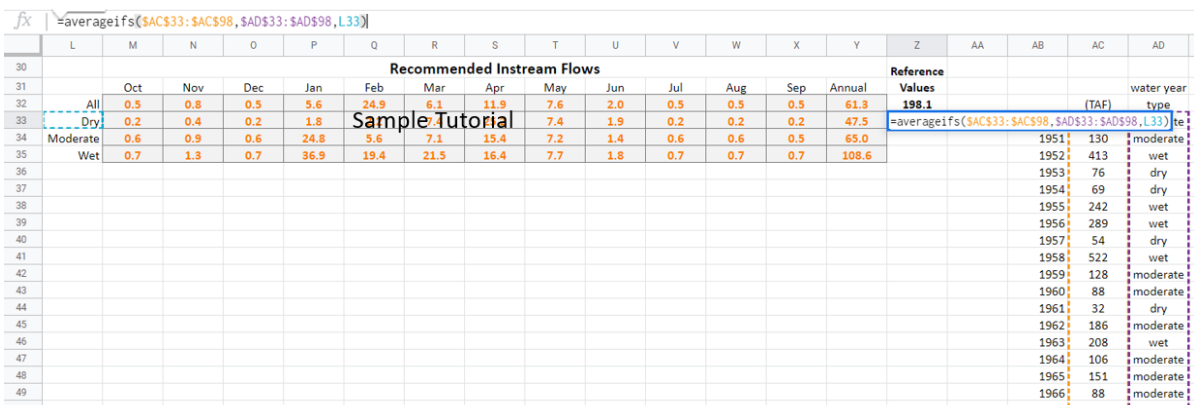


Figure 35

	Recommended Instream Flows													Reference
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Values
All	0.5	0.8	0.5	5.6	24.9	6.1	11.9	7.6	2.0	0.5	0.5	0.5	61.3	198.1
Dry	0.2	0.4	0.2	1.8	2.2	7.4	25.2	7.4	1.9	0.2	0.2	0.2	47.5	56.0
Moderate	0.6	0.9	0.6	24.8	5.6	7.1	15.4	7.2	1.4	0.6	0.6	0.5	65.0	132.5
Wet	0.7	1.3	0.7	36.9	19.4	21.5	16.4	7.7	1.8	0.7	0.7	0.7	108.6	393.9

Figure 36

In order to respond to the question "How large or small are the recommended instream flows in comparison with the natural flows?" you have to compare the results of the recommended instream flows (Y32:Y35) with the annual average streamflow that you just calculated (Z32:Z35). Let's start with all years, by dividing the recommended instream flow (cell Y32) over the all year annual streamflow (cell Z32) using the following equation in cell AA32 (see figure 37): "=Y32/Z32". Copy (Ctrl+C) and paste (Crtl+V) this formula in cells AA33, AA34 and AA35. Results should look like Figure 38.

31% × | 90% | $ | %

fx =Y32/Z32

	X	Y	Z	AA
30			Reference	
31	Sep	Annual	Values	
32	0.5	61.3	198.1	=Y32/Z32
33	0.2	47.5	56.0	
34	0.5	65.0	132.5	
35	0.7	108.6	393.9	

Figure 37

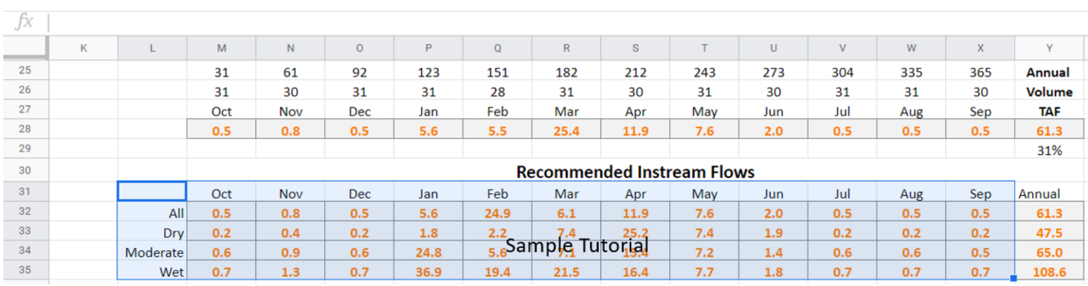
	Recommended Instream Flows													Reference	
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual	Values	
All	0.5	0.8	0.5	5.6	24.9	6.1	11.9	7.6	2.0	0.5	0.5	0.5	61.3	198.1	31%
Dry	0.2	0.4	0.2	1.8	2.2	7.4	25.2	7.4	1.9	0.2	0.2	0.2	47.5	56.0	85%
Moderate	0.6	0.9	0.6	24.8	5.6	7.1	15.4	7.2	1.4	0.6	0.6	0.5	65.0	132.5	49%
Wet	0.7	1.3	0.7	36.9	19.4	21.5	16.4	7.7	1.8	0.7	0.7	0.7	108.6	393.9	28%

Figure 38

Now, we can respond to the question: "How large or small are the recommended instream flows in comparison with the natural flows?" 31% if you consider all years, 85% during dry years, 49% during moderate years, and 28% during wet years. Cool!

The last part of this exercise is to display these results graphically, at the monthly and daily time-scale. Let's start by creating a display at the monthly scale. Select cells L31 to X35 from the

Recommended Instream Flows table (Figure 39). Go to the menu Insert / Chart. Change on the Chart Editor (shown in the left side of the screen) in chart type "Line Chart" (Figure 40), and all the way down to the bottom in the Chart Editor check the box "Switch rows / columns" (Figure 41). Modify the colors of the chart as a gradient to identify all (black) wet, moderate and dry years (a gradient of green). <u>Give this chart a personal touch, use a different color other than green</u>. Add the units of the y-axis by selecting in the Chart Editor "Chart & axis titles / Vertical axis title " and typing "Volume (thousand acre-foot)" (Figure 42). **IMPORTANT: Notice that the Functional Flows Interface automatically assigns a random date (within the timing range) for the Fall Pulse Flow and Peak Flow components. What this means is that your <u>Functional Flow regime in these components should look different than ours shown in Figure 52, they should look different but the overall annual volumes should be similar</u>.**



	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
25			31	61	92	123	151	182	212	243	273	304	335	365	**Annual**
26			31	30	31	31	28	31	30	31	30	31	31	30	**Volume**
27			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**TAF**
28			0.5	0.8	0.5	5.6	5.5	25.4	11.9	7.6	2.0	0.5	0.5	0.5	61.3
29															31%
30								**Recommended Instream Flows**							
31			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
32		All	0.5	0.8	0.5	5.6	24.9	6.1	11.9	7.6	2.0	0.5	0.5	0.5	61.3
33		Dry	0.2	0.4	0.2	1.8	2.2	7.4	25.2	7.4	1.9	0.2	0.2	0.2	47.5
34		Moderate	0.6	0.9	0.6	24.8	5.6	7.1	13.4	7.2	1.4	0.6	0.6	0.5	65.0
35		Wet	0.7	1.3	0.7	36.9	19.4	21.5	16.4	7.7	1.8	0.7	0.7	0.7	108.6

Sample Tutorial

Figure 39

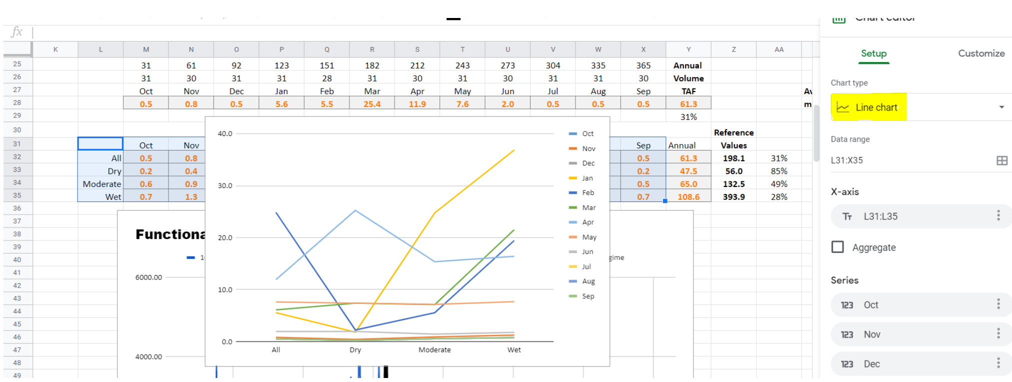


Figure 40

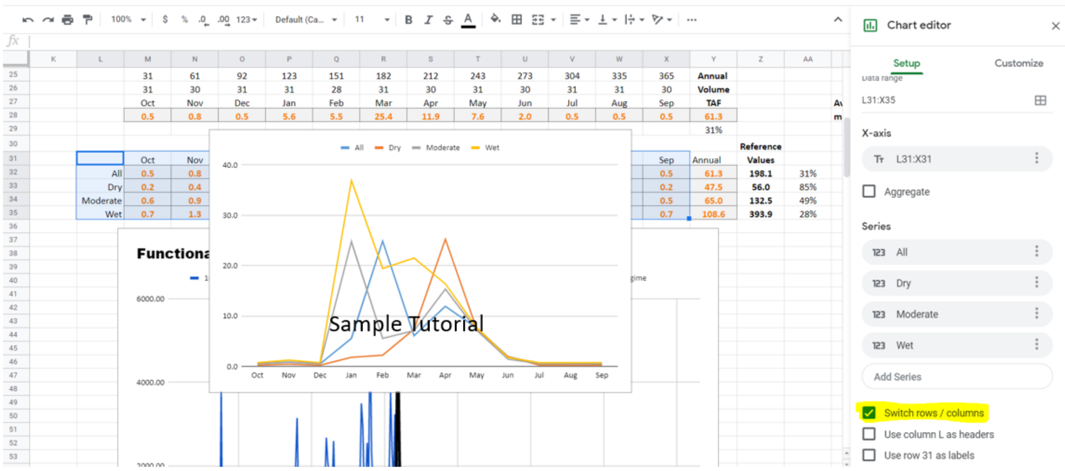


Figure 41

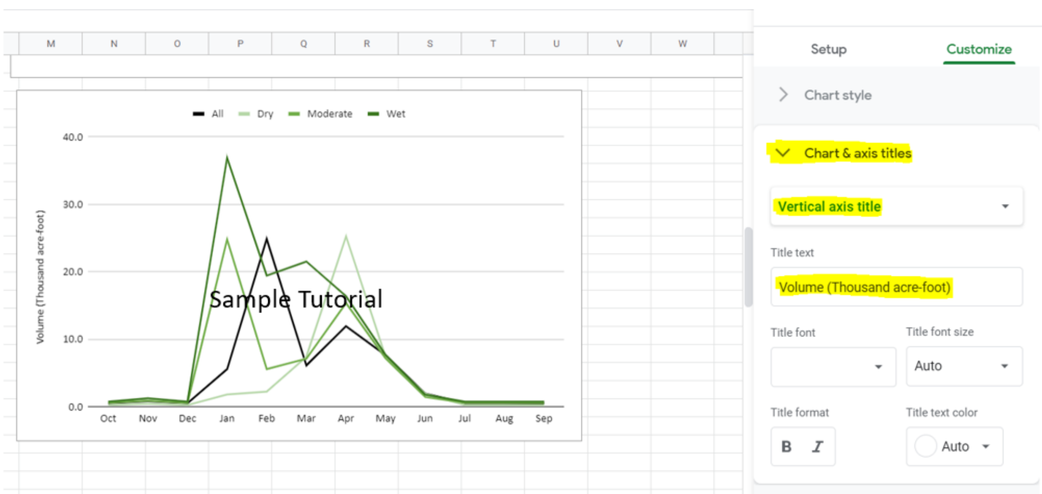


Figure 42

Now, go to cell F23 and select "all". Then select the daily Functional Flow Regime chart, click on the three dots in the upper right corner of the chart and select Edit Chart (Figure 43). In the window if "Setup" go all the way to the bottom and select "Add Series" and Select "Add data range" in the upper portion of the window. In select data range, use the mouse to select cells of the dry daily flow regime: A19:NC19 (Figure 44). Repeat the same procedure for the moderate and wet flow regimes.

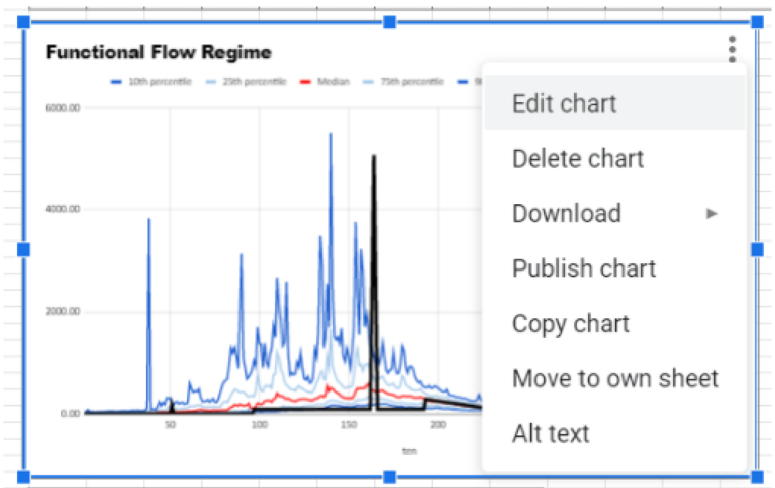


Figure 43

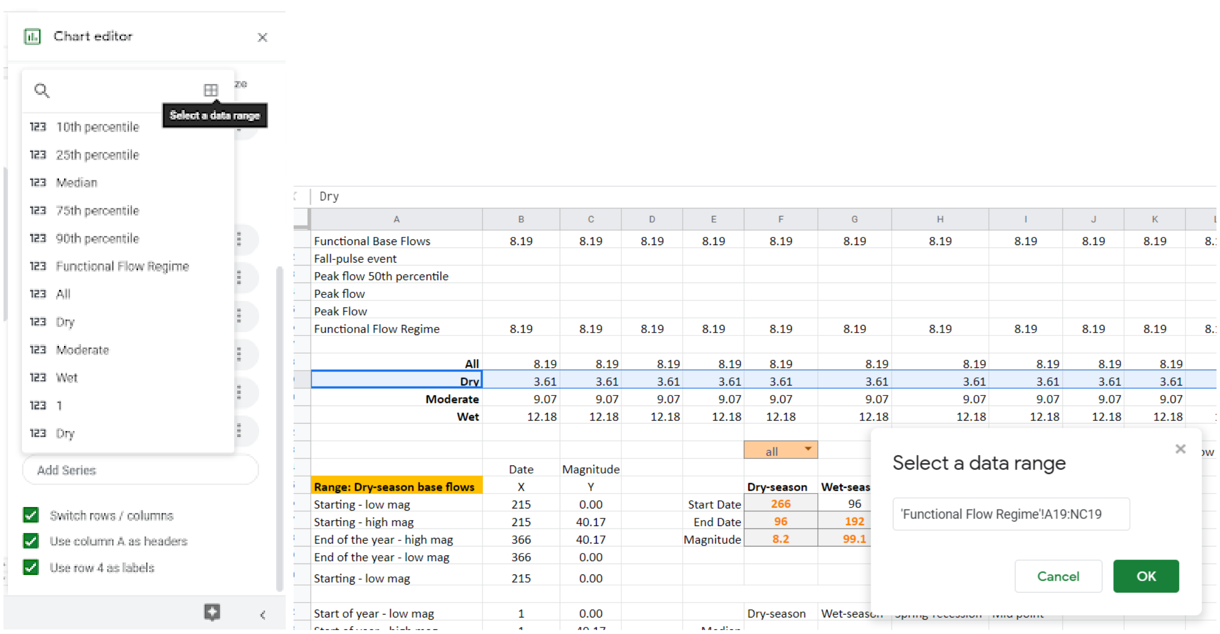
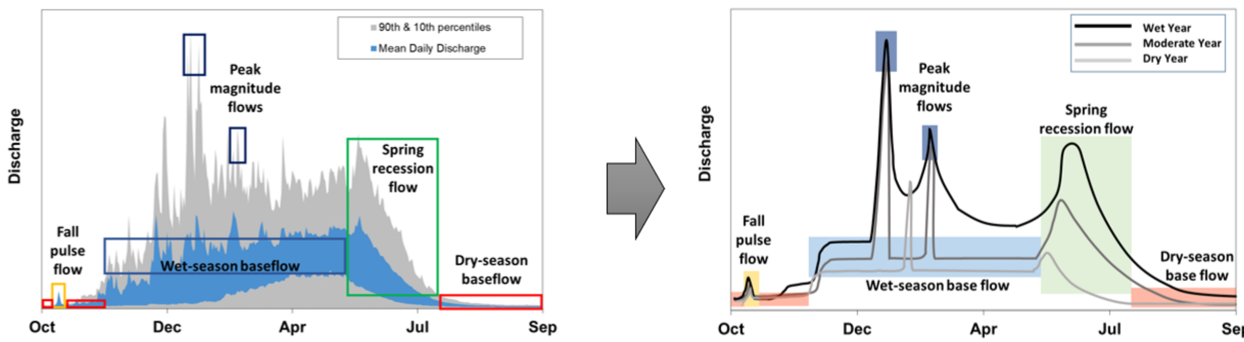
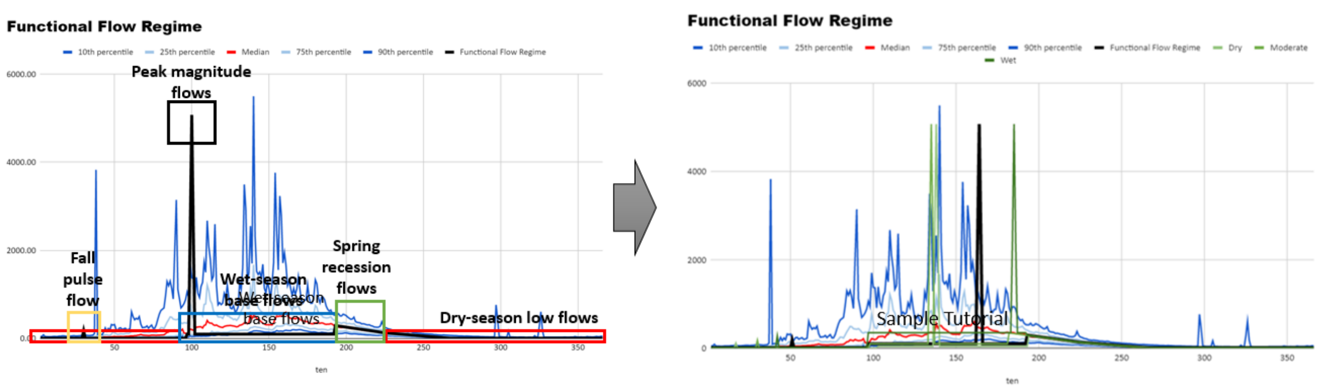


Figure 44



(a) Conceptual instream flows obtained from the functional flows approach



(b) Recommended instream flows for Pajaro River for dry, moderate and wet years

Figure 45. Recommended instream flows

To be turned in:

- The Recommended Instream Flows Table (similar to Figure 38), a brief description of each recommended instream flows
- One chart showing the monthly volumes of the recommended instream flows (similar to Figure 42) for: all, dry, moderate and wet water years.

- One chart showing the recommended daily instream flows (similar to Figure 45.b) where the functional flow components are shown conceptual and estimated for: dry, moderate and wet water years.
- Discussion on the reasoning for considering environmental water demands and what are the benefits for the river ecosystem and the society. Hint: you can frame your response in terms of ecosystem functions and ecosystem services.
- Extra points: Make a table relating each functional flow component for an ecosystem function and how these functions will help to sustain the river ecosystem that depends on the instream flows)

Functional Flow Component	Ecosystem Function (Biotic or abiotic function)	Benefit to the relevant ecosystem
Fall pulse flow	e.g. flush of water that eliminates poor water quality along the river	resets water quality after a long period of low flows
Peak magnitude flows		
Wet-season base flow		
Spring recession flows		
Dry-season low flow		