Environmental Flow Analysis on the NF KERN

A Case Study: 1997-2020 Data Set

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Summary

Contemporary science has advanced the understanding of flow management for environmental integrity in hydropower operations. In this document, we will review and apply current analysis methods to the North Fork of the Kern (NF Kern) drainage. Flows have been diverted for hydropower on the NF Kern since 1921 when the Kern River No. 3 ("KR3") project first went online, and diversion has continued in similar manner for the subsequent 100 years. In 1987, the NF Kern was designated as Wild and Scenic because of its outstanding array of scenic, recreational, fish, wildlife, geological, cultural/historical, and ecological assets. In support of those assets, this analysis examines fundamental environmental flow protections and the natural flow paradigm which is supported by the scientific and ecological community, recommended by standards and regulatory boards worldwide, and adhered to by the state of California. Note that 30 of 33 (91%) of the papers and guidance documents reviewed and cited in this analysis have been published since the last relicensing of KR3 in 1996, indicating that the science in this field has been evolving rapidly since the environmental conditions included in that license were made. Simply maintaining the status quo in terms of environmental impact is not an environmentally sound option.

Background

The Kern River traverses nearly 165 miles from its headwaters at over 13,000' down to Bakersfield, California. The NF Kern is the main branch of the Kern, running from snow fields near Mount Whitney down to Lake Isabella and its junction with the South Fork. The NF Kern has a mean annual flow of 763 cfs. The climate is Mediterranean, with little precipitation in summer; water is provided primarily by snowmelt.

The Kern River No. 3 Hydroelectric Project (KR3) is categorized as a high-head run of river (RoR) scheme (Anderson, 2015). The project diverts up to 605 cfs of water from the river at Fairview Dam, and pipes it 16 miles downstream to the KR3 powerplant, where it is returned to the river. Fairview Dam itself is small with no storage pool behind it; it simply enables the diversion. KR3 was constructed between 1910 and 1921, and generators began operations on April 1, 1921 (NPS, 2012).

The diversion of river water to the KR3 conveyance means that the stretch of river from Fairview Dam to the KR3 powerplant is always depleted of water when the project is operating. This alteration of the natural setting disrupts flow, sediment, and thermal regimes downstream, which in turn impacts ecological functions and river characteristics (Thieme, 2020). These changes include alterations to physical habitat (including availability, complexity, connectivity, and chemistry) with consequences for all organisms therein (Anderson, 2015; Poff 1997; Biggs 2005; Ward 1989; Tockner et al. 2000). Organisms affected range from the riparian vegetation and invertebrates that are the basis of the ecosystem, all the way up to the fish (Bilotta, 2016), reptiles, amphibians, birds, and mammals that contribute to the biodiversity of the freshwater ecosystem.

Because of the potential severity of their environmental impacts, dams within protected areas (such as those designated within the Wild and Scenic River System) should all implement environmental flow regimes (Thieme, 2020). Among the ecological science community, the consensus view is that a natural flow regime sustains the ecological integrity of river systems (McManamay, 2013). A large body of scientific literature supports the "natural flow paradigm" as an important ecological objective to guide river management (Richter, 1997; Poff, 1997; Bunn, 2002; Postel, 2003; Arthington, 2006). Stated simply, the key premises of the natural flow paradigm are that "maintaining some semblance of natural flow regimes is essential to sustaining the health of river ecosystems and that health is placed at increasing risk with increasing alteration of natural flows" (Richter, 2011). Determining the requisite flow regime and analyzing the impacts can be daunting due to the numbers of metrics and variables surrounding such complex systems. The Instream Flow Council recognizes over 30 different documented methods for flow analysis (McManamay, 2013), all of which attempt the quantify and mitigate against the impacts of flow depletion caused by RoR hydropower schemes. Analyses generally fall into one of three main categories:

1) Hydrological methods;
2) Hydraulic rating; and
3) Habitat rating.

Hydrological methods

Hydrological methods are often considered to be the "rule of thumb", "threshold" or "standard setting" methodologies (Arthington, 1998). Hydrological methods require a fairly robust record of historic flows upon which to perform data analysis for flow characterization. USGS records for the NF Kern, used in this analysis, are publicly available. Gauge 11186000 measures flows in the riverbed below Fairview Dam; Gauge 11185500 measures flows diverted into the KR3 conveyance.

Hydrological methods rest on the observation that there is a close relationship between natural flows and the existing ecology in the river stretch (Jowell, 1997), and that the quantity, complexity, and quality of riverine habitat available for aquatic species depend to a large extent on the timing, frequency, duration, rate of change, and magnitude of instream flows. (Whittaker, 2006). So, by characterizing the natural changes in flow on an hourly, daily, monthly, and annual basis (Richter, 1996), and the range in variability of those flows (Richter, 1997; 1998), guidelines can be determined to define the instream flows. Metrics used include:

- Percent Mean Annual Discharge (%MAD): Defining a threshold flow based upon the mean annual discharge (MAD, or Qmean) for the reach.
- Mean minimum and maximal flows (by day, week, season, or year): Further refinement to compare to time- or condition-matched average flows.
- Exceedance probability (Q-value): Defining a threshold flow based upon the percent of time at which that flow value exceeded.
- Flow duration analysis (including by water year type, month, or season): Generating a table and graph from the range of exceedance probabilities for analysis, for all data or selected data.
- Percent of flow (POF): Evaluating amount of water diverted in terms of current incoming flows in the reach.

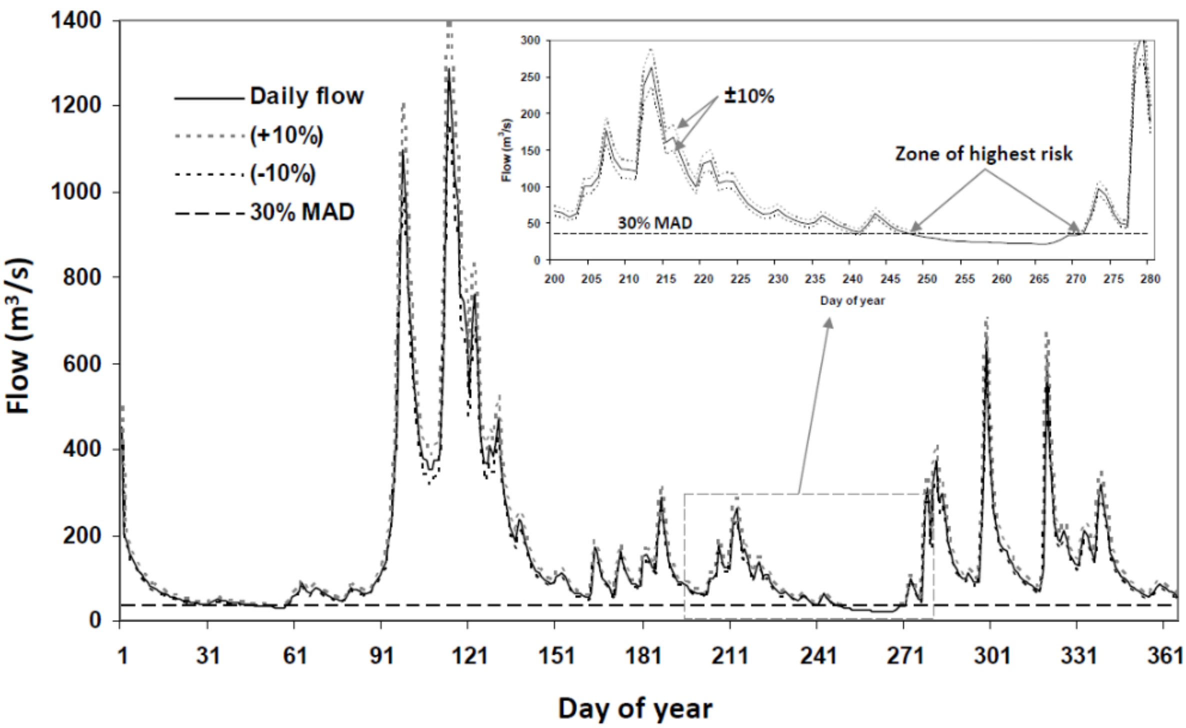


Figure 1: Image of Sustainability boundary method illustrating %MAD low flow threshold plus POF boundaries from DFO, 2013.

These metrics are combined to define a number of prominent methods:

- Tennant method: A very commonly used baseline setting method, developed in 1976, and used widely (Tennant, 1976). The method calls for maintaining flows of 30% MAD in season, 10% off season, with no flow variability protection.
- Aquatic base flow (ABF): Use a measured minimum flow (often from August when flows are low) and use to set year-round thresholds. "The fundamental assumption of the ABF method is that fish are adapted to survive the lowest flow month, so the median flow of the low-flow month can serve as the year-round base flow." (Railsback, 2000). A variant of this will calculate the lowest flows per month, and prescribe these as low flow thresholds. The assumption that fish are adapted to not

just survive but thrive at these lowest measured flows has been questioned, as has the lack of natural flow variability (Richter, 2011; Railsback, 2000).

- Natural Flow Paradigm: an evolution from a simple baseline setting method like Tennant or the ABF. These methods recognize the importance of mimicking and maintaining natural flow alterations for the health of the ecosystem. As such, these methods recommend defining “boundaries” around the natural flow to define environmental flow needs:

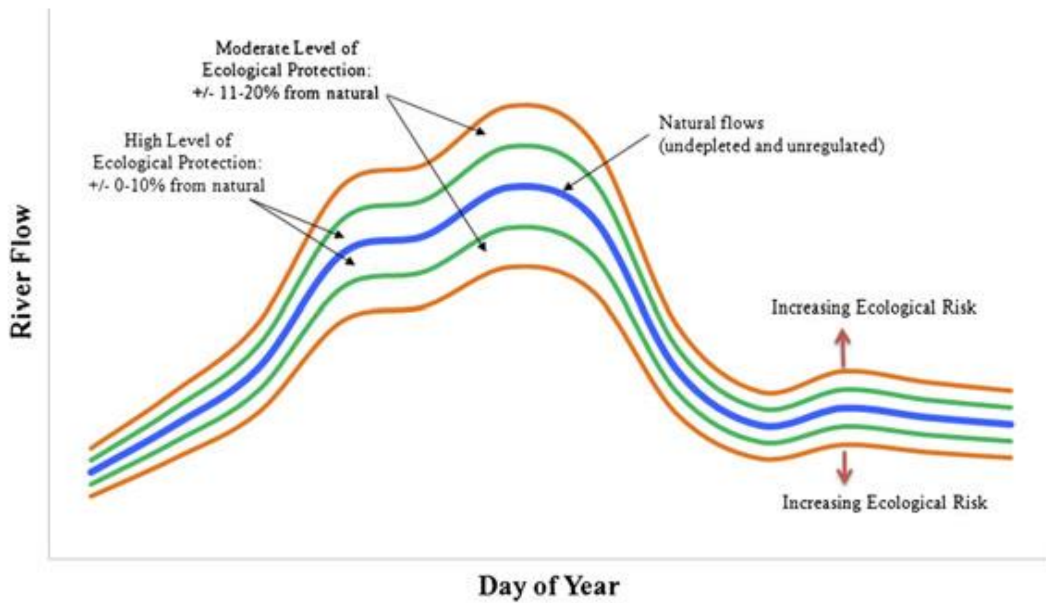


Figure 2: Image of Sustainability Boundary from Richter, 2011

These boundary approaches use a combination of a low flow threshold as before but add in a flow variability control component to ensure the ecological risk is reduced as much as feasible.

- Statistical methods: These methods, such as Range of Variability (Richter, 1997) or Functional Flow Analysis (CEFWG, 2021), attempt to characterize the instream flows comprehensively with 30 or more parameters based upon mean, minimum, maximum, and percentile flows by day, week, month, season, and year. They are then able to prescribe a rigorous schedule of flow features to maintain that characterization. These methods can be significantly more complex and subject to statistical anomalies, and are often difficult to implement, especially in a RoR scenario such as the NF Kern. Because these methods also do not specify any maximum diversion or minimum instream flow values, they will not be included explicitly for further analysis here. However, the variability concepts (Fig. 3) will be referenced in the Flow Variability Comparison, and a functional flow analysis for the NF Kern is provided and discussed briefly in Appendix A.

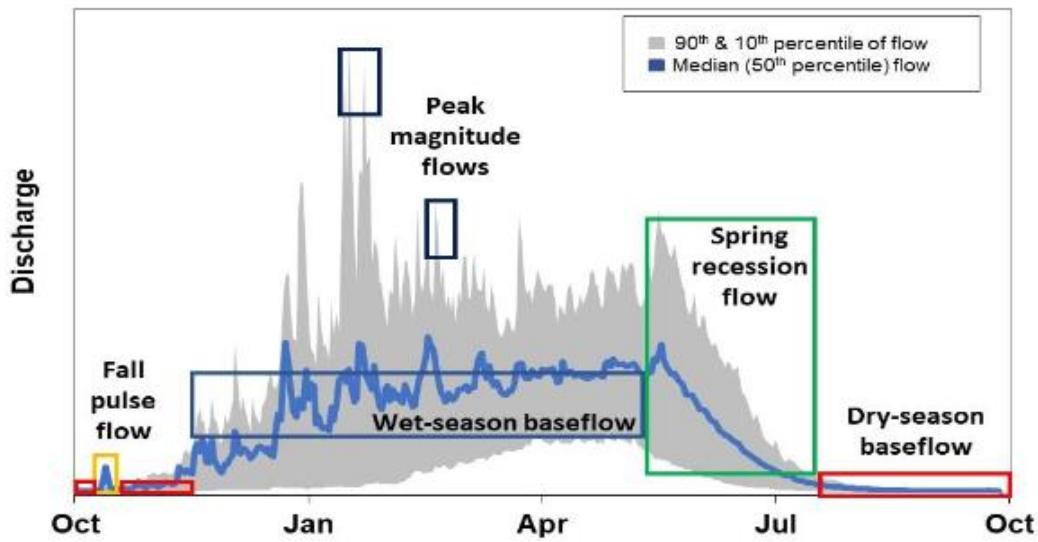


Figure 3: Image of functional flow components for a representative California hydrograph from CEFWG, 2021.

Hydrological methods are used across the country and across the world to establish environmental baselines, from which to finetune the flow management regime. Some examples:

- **California**: The California Department of Fish and Wildlife (CDFW) has a well-developed Instream Flow program and supports the use of a variety of methods to quantify flow regimes for fish, wildlife and their habitats (CDFW, 2017). Used in conjunction with habitat and hydraulic modeling, flow duration analysis and exceedance probabilities are used as standard operating procedures by the state (CDFW, 2013). They acknowledge that "There is a consensus among experts that cumulative flow alterations resulting in instantaneous flows that are ≤30% of the MAD have a heightened risk of impacts to ecosystems that support fisheries" (CDFW, 2017).
- **Florida, Michigan, and Maine** all implement Percent of Flow (POF) schemes, which recognize the importance of natural flow variability and avoid flow flat-lining (Richter, 2011).
- **Canada** defines a framework for ecological flow requirements that include a 30% mean annual discharge (MAD) low flow limit, and cumulative flow alterations less than 10% of actual flows for low impact management. (DFO, 2013).
- **Environment Agency (UK):** UK policy requires a sustainability boundary approach defined with a maintenance of a "hands off" flow in depleted stretches. The diversion may only operate when flows exceed a particular threshold, typically between Q85 and Q95 (Anderson, 2015). Above the HOF, a percent of flow (POF) is implemented to define maximum water take (EA, 2017).
- **Australia**: Recommends a first approximation of minimum flows based on percentage exceedance (flow duration boundaries) or percent of mean, with additional hydraulic and habitat rating methods to complement and monitor

(Arthington, 1998). Note that the Q80 (identical to 20th percentile) lower boundary is firm and flows that are "less than or equal to the 20th percentile flow should be released downstream in very dry years" (Arthington, 1998).

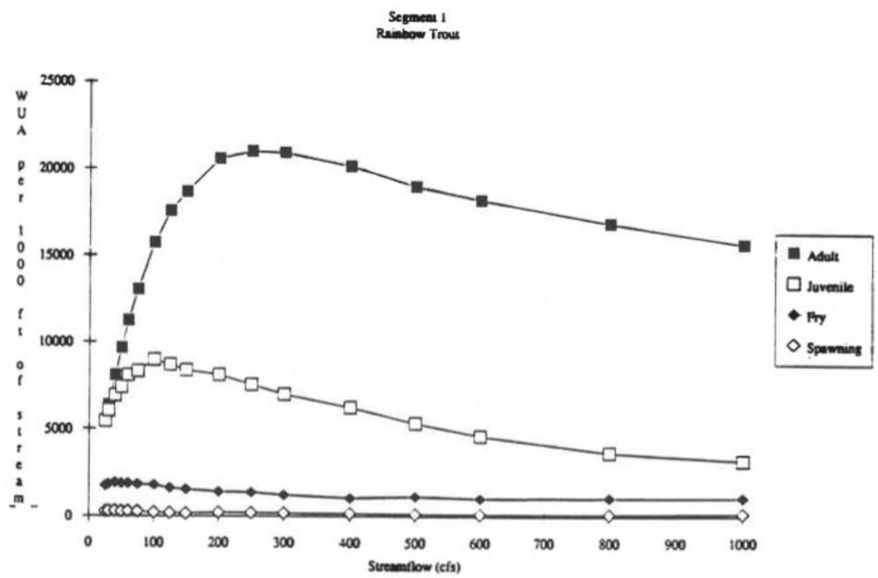
Hydraulic- and habitat-rating methods

More complicated are the hydraulic rating and habitat rating methods of instream flow analysis. These categories include a variety of methods, most of which require often extensive field research efforts to complete. Common methods include wetted perimeter analysis, critical riffle analysis, or 2D hydraulic habitat models. However even with the increased cost and effort, these methods are not without their own challenges. In fact, "highly accurate hydraulic modeling seems infeasible for streams with complex channel geometry, and in any event practical hydraulic modeling cannot resolve flow patterns at the short length scales at which fish often respond to the hydraulic environment" (Kondolf, 2000).

One method (and one which has been conducted as a part of the previous KR3 relicensing process) is PHABSIM (for Physical Habitat Simulation system). This popular method attempts to measure and model the habitat area available for a fish species as the flow varies. It can be expensive to conduct and difficult to establish appropriate spatial resolution of results (Railsback, 2000).

The results of a previous PHABSIM on the dewatered reach of the NF Kern are seen in the image below (Fig. 4), which plots habitat area availability (weighted usable area, WUA) vs streamflow for specifically rainbow trout, measured across various segments of the NF Kern. In the conclusions of that study, it was noted that "WUA values indicate that these [boulder pocket water and boulder run] habitat types provide maximum habitat for [rainbow trout] fry and juvenile rearing at flows of 75 to 200 cfs. For adult rainbow trout, maximum habitat values were reached in these habitats at flows of 200 cfs." (SCE, 1991). The report also notes that issues of water temperature and angling pressure are critical factors affecting the rainbow trout, in addition to habitat suitability analysis (SCE, 1991).

Figure 3-23. Habitat Response Curves for Rainbow Trout in Segment 1 and Segment 2 for All Habitat Types Combined.



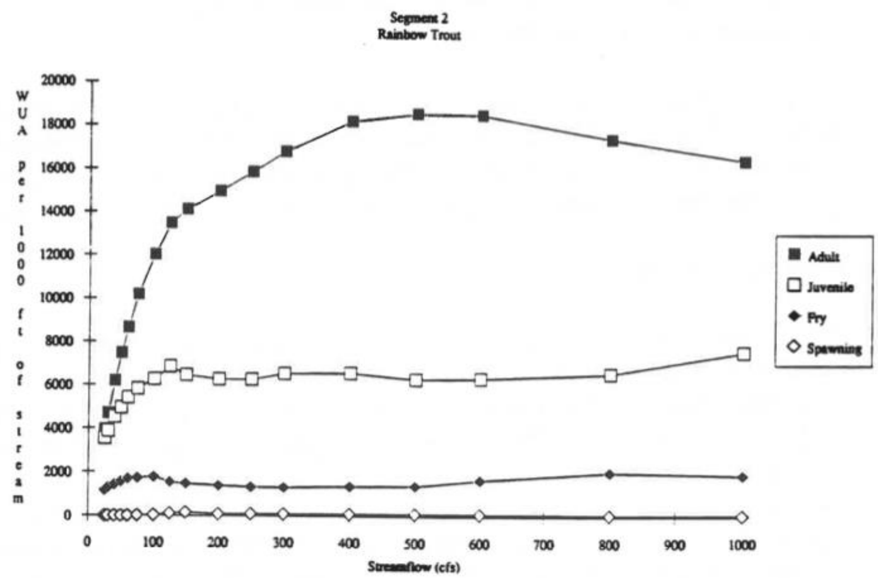


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Figure 4: Image from SCE, 1991.

Methods

For this analysis, we compare the current minimum instream flow (MIF) regime and resulting flow hydrograph to 6 methods that have been used to determine ecological and environmental limits for instream flow alteration. The methods included are:

1) Current MIF regime: monthly lookup table low flow threshold, ranging from 40 cfs in winter to 130 cfs in summer, with no other flow variability protection, and 100% POF take above threshold.
2) Tennant method: the original 1976 method as defined with 30% MAD flow threshold in season (April – September), and 10% MAD in offseason (October – March). The Tennant method is somewhat outdated and frequently criticized for lack of flow variability and ecosystem impact, but nonetheless is still a useful initial baseline comparison.
3) EA Standard: the standard starting point for hydropower regimes in the UK under the Environment Agency hydropower guidance document (EA, 2017).
4) EA Low Limit: the most aggressive diversion allowable according to the EA guidance document, suitable only for "steep, upland tributaries of low ecological sensitivity with no migratory fish" (EA, 2017). Note that the Threshold Requirement remains the same; only the POF take varies (see table).
5) SB High: A sustainability boundary scheme recommended for high ecological protection. This is a regime recommended by both California (CDFW, 2017) and Canada (DFO, 2013) which recommends 30% MAD always, with 10% POF taken above the threshold. This is an evolution of the Tennant method which adds a high level of flow variability protection for the sustainability of the ecosystem.
6) SB Moderate: A sustainability boundary scheme with moderate ecological protection, which allows for 20% POF above threshold.
7) Flow duration boundaries: an initial threshold setting process is recommended in Australia to address flow requirements for fish. The method uses flow durations values of Q80, Q50, and Q20 percentile flows for drought, median and flood flows, along with statistical recommendations of variability within monthly flows (Arthington, 1998).

Methods	Threshold Requirement	Flow Variability Requirement
Current	130 cfs (summer) down to 40 cfs (winter)	None
Tennant	30% MAD in season; 10% MAD off season	None
EA Standard	Q95 HOF	Max 35% POF
EA Low Limit	Q95 HOF	Max 75% POF
SB High	30% MAD always	Max 10% POF
SB Moderate	30% MAD always	Max 20% POF
Flow duration boundaries	Q80	Q50 and Q20 events, plus prescribed variability

The goal of this analysis is to answer the question: What is an ecologically sound minimum instream flow regime and particularly low flow threshold for the NF Kern watershed, according to widely accepted standards?

Analysis

Data Set and Incoming Flow Duration Curve

For the Flow Duration Curve, data was compiled from USGS gauges 11186000 (KERN R NR KERNVILLE (RIVER ONLY) CA) ("flows in diverted reach") and USGS 11185500 (KERN R NO 3 CN NR KERNVILLE CA) ("flows diverted"). Period of data included is 10/01/1996 - 09/30/2020, for a total of 8,766 days. Data was available as a single daily average from each gauge.

By adding the flows in diverted reach and flows diverted as recorded by the two included gauges, total incoming flows above the diversion in cfs were calculated. During the study period, the minimum, maximum, and mean values for the incoming flow can be seen in the following table:

Measure	Value
Minimum incoming flow	67 cfs
Maximum incoming flow	25,219 cfs
Mean incoming flow	763 cfs

A Flow Duration Curve (FDC) was generated by calculating the number of days on which the incoming flows exceeded a flow threshold.

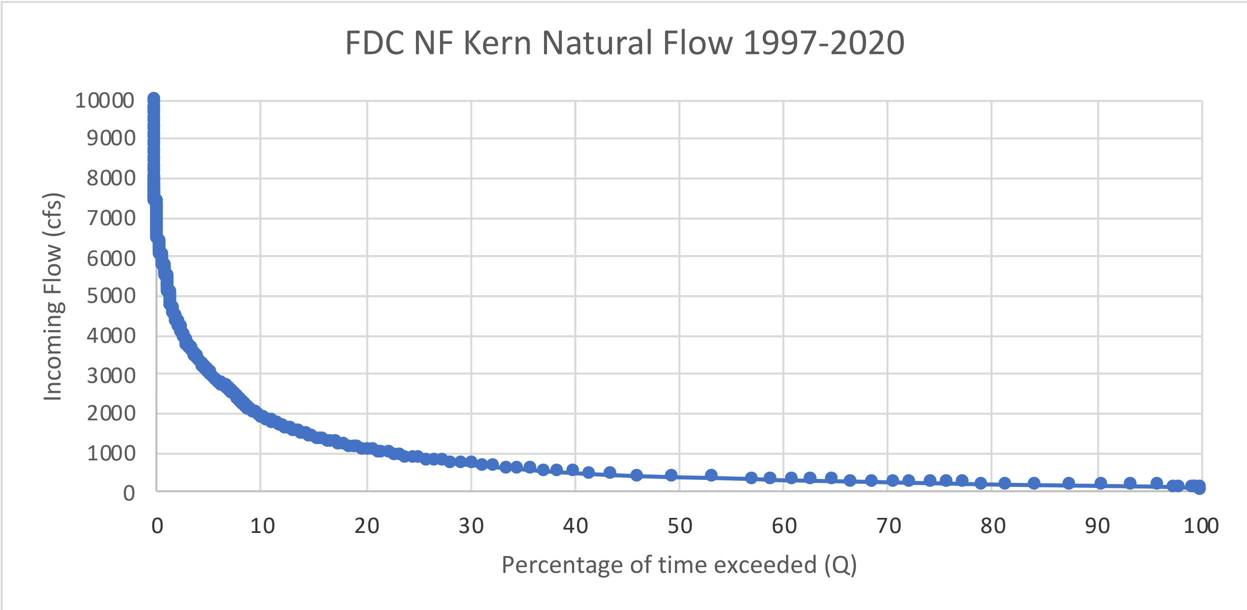

Figure 5: NF Kern flow duration curve

Zooming in on the y-axis to better see the high percentage tail of the plot:

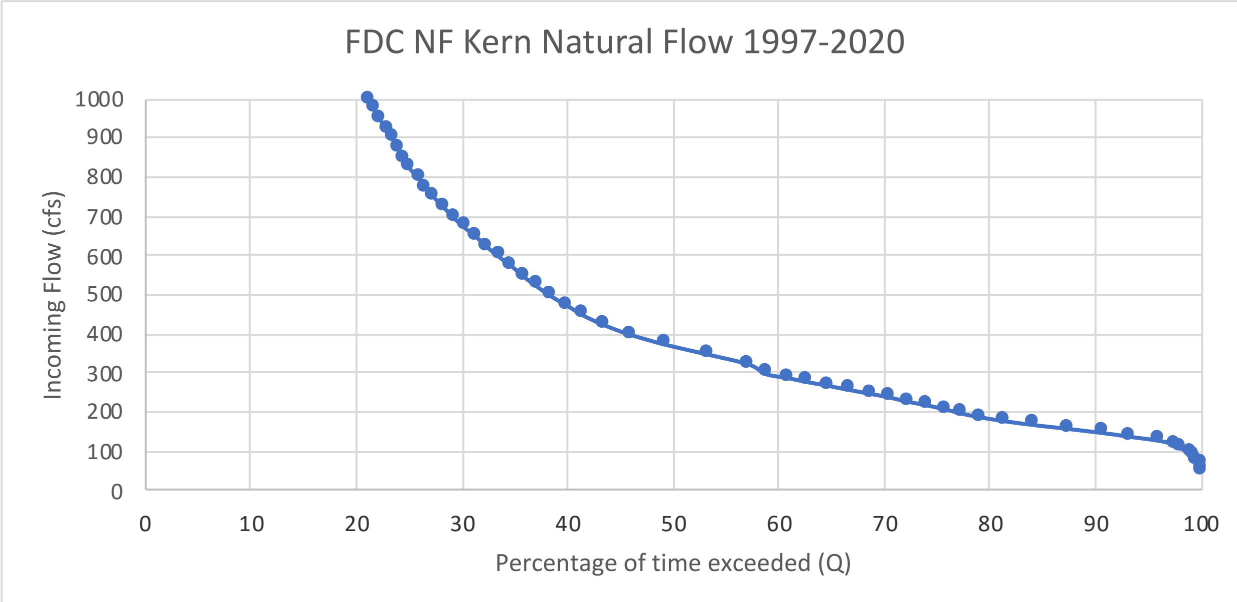

Figure 6: NF Kern flow duration curve, zoomed in to inspect low flows

Percentage of time exceeded (Q)	Value (cfs)
Qmean	763
Q99	100
Q95	135
Q90	150
Q85	170
Q80	190
Q50	375
Q40	475
Q30	675
Q20	1050
Q10	1900

Although made with a more modern data set, this flow duration curve closely resembles the one generated as a part of the 1996 relicensing (SCE, 1991). Among the current data set, 99 percent of the days recorded an incoming flow above 100 cfs (the Q99 value). 50 percent of the days recorded an incoming flow of 375 cfs or above, and 30 percent of the days recorded flows of 675 cfs or above.

Exemplary Water Year Curves
For the Exemplary Water Year Curves, data was compiled from the same pair of USGS gauges (11186000 and 11185500) for same period of data (10/01/1996 - 09/30/2020). Data was available as a single daily reading from each gauge.

Among each of 24 water years of data present, the years were broken into thirds and categorized as a Low, Medium, or High according to the average annual incoming flow at Fairview Dam. Within each third, one of the central years (not on the category boundary) was chosen as a representative case. The resulting final years selected are seen highlighted in the table below, with the average flow shown and ordered for all years:

	Average Annual Incoming Flow (cfs)	Water Year Category, by Thirds
2015	166	L
2014	239	L
2013	287	L
2007	**334**	**L**
2020	416	L
2002	434	L
2001	438	L
2012	451	L
2016	456	M
2018	485	M
1999	502	M
2004	**510**	**M**
2000	546	M
2009	571	M
2008	613	M
2003	646	M
2010	967	H
2005	1204	H
2006	1222	H
2019	**1381**	**H**

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1997	1387	H
2011	1506	H
1998	1570	H
2017	1986	H

Plotting the incoming flow at Fairview for each of the High, Medium, and Low years is seen in Fig. 7, below.

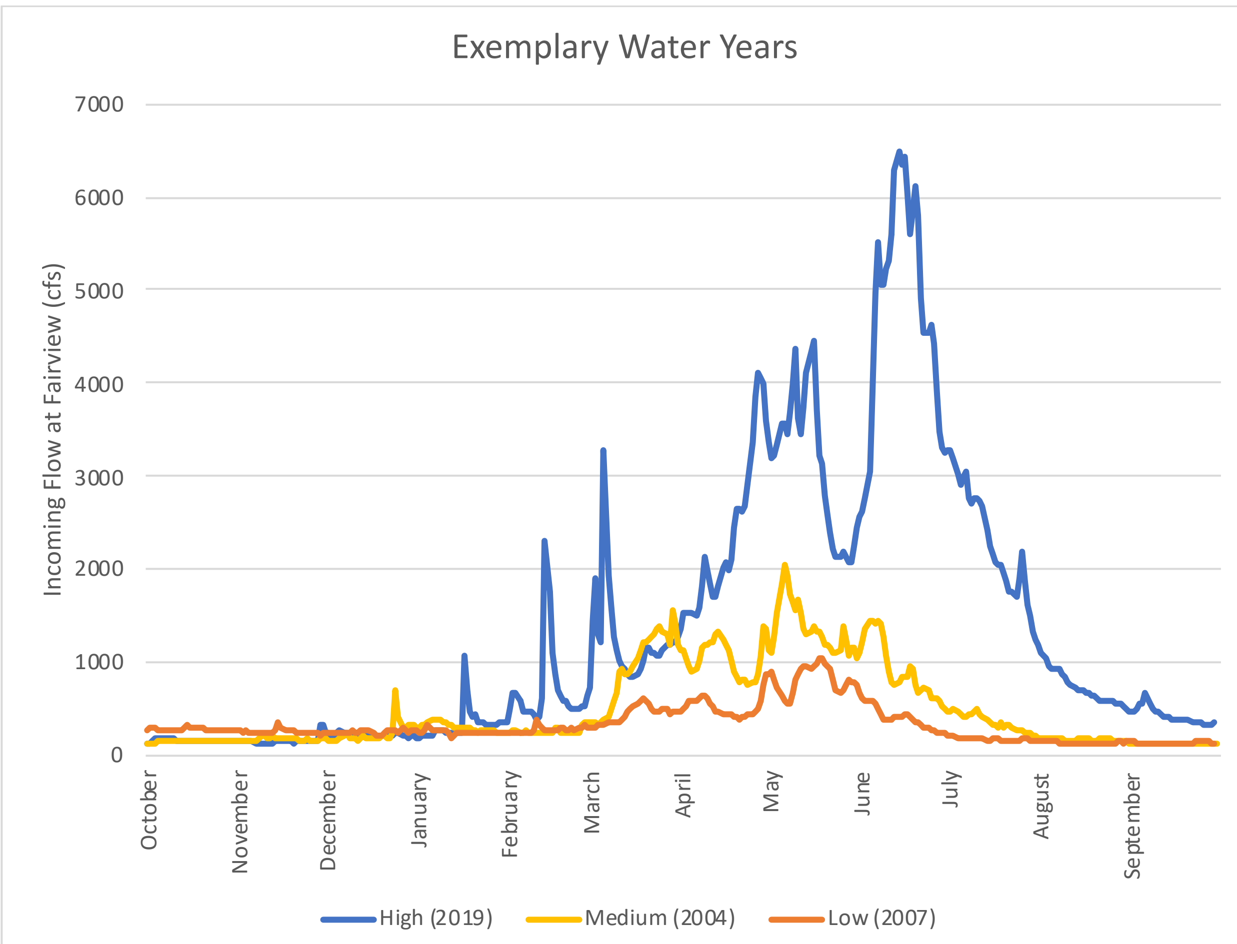


Figure 7: Incoming flow hydrographs for exemplary flow years

Current Low Flow Table

Under the current minimum instream flow regime for KR3, the water released into the bypassed reach of the NF Kern must adhere to this table, defined monthly:

Month	Flow in cfs
January	40
February	40
March	70
April	100
May	100
June	100
July	130
August	130
September	100
October	80
November	40
December	40

The mean annual discharge (MAD) and flow duration curves can be converted to the equivalent percentage of MAD and percentage exceedance (the percentage of time in which the total incoming flows would exceed that value). These values are seen in the table below:

Low Flow Threshold in Diverted Reach (cfs)	%MAD	Percent Exceedance
40	5.2	100.0
50	6.6	100.0
60	7.9	100.0
70	9.2	100.0
80	10.5	99.7
90	11.8	99.5
100	13.1	99.2
110	14.4	98.2
120	15.7	97.5
130	17.0	96.1
140	18.3	93.4

Recall that as the Q99 value is 100 cfs, much of this table is at or lower than that Q99 value; that is, ten out of twelve months of the year (83% of the year), the minimum instream flow is set at or below a value that the natural incoming flow of the river only ever drops to 1 percent of the time.

The winter low flow threshold of 40 cfs corresponds to 5.2% of the MAD (and is naturally exceeded 100 percent of the time), while the summer low flow threshold of 130 cfs corresponds to 17% MAD (and is naturally exceeded 96.1 percent of the time).

According to estimates provided by the California DFW (Fig. 8), this winter flow is below the lowest 10% flow characterization and falls into the "Severe degradation" category. The summer flow at 17.0% is categorized as "Poor or minimum habitat":

Department of Fish and Wildlife Water Branch Instream Flow Program

Narrative Description of Flow	April to September	October to March
Flushing or maximum flow	200% from 48 to 72 hours	
Optimum range of flow	60-100%	60-100%
Outstanding habitat	60%	40%
Excellent habitat	50%	30%
Good habitat	40%	20%
Fair or degrading habitat	30%	10%
Poor or minimum habitat	10%	10%
Severe degradation	<10%	<10%

Figure 8: Image from CDFW, 2017.

Mapping each of the monthly flow thresholds of the current MIF regime to the corresponding %MAD and CDFW categorization is seen in the table below. No monthly flow threshold exceeds the "Poor or minimum habitat" characterization.

Month	Flow in cfs	%MAD	Percent Exceedance	CDFW Narrative Description of Flow
January	40	5.2	100.0	Severe degradation
February	40	5.2	100.0	Severe degradation
March	70	9.2	100.0	Severe degradation
April	100	13.1	99.2	Poor or minimum habitat
May	100	13.1	99.2	Poor or minimum habitat
June	100	13.1	99.2	Poor or minimum habitat
July	130	17.0	96.1	Poor or minimum habitat
August	130	17.0	96.1	Poor or minimum habitat
September	100	13.1	99.2	Poor or minimum habitat
October	80	10.5	99.7	Poor or minimum habitat
November	40	5.2	100.0	Severe degradation
December	40	5.2	100.0	Severe degradation

Finally, there is no flow variability component to the current MIF regime. See the Flow Variability discussion, below.

Low Flow Threshold Comparison

The first component of this environmental flow analysis compares the low flow thresholds between the current MIF regime and the comparison methods. The results of calculating out the low flow thresholds based upon either the %MAD or percent exceedance Q-values are displayed in the following table:

Methods	Threshold Definition	Threshold Value (cfs)
Current	130 cfs (summer) down to 40 cfs (winter)	130; 40
Tennant	30% MAD in season; 10% MAD off season	229; 76
EA Standard	Q95 HOF	135
EA Low Limit	Q95 HOF	135
SB High	30% MAD always	229
SB Moderate	30% MAD always	229
Flow duration boundaries	Q80 always	190

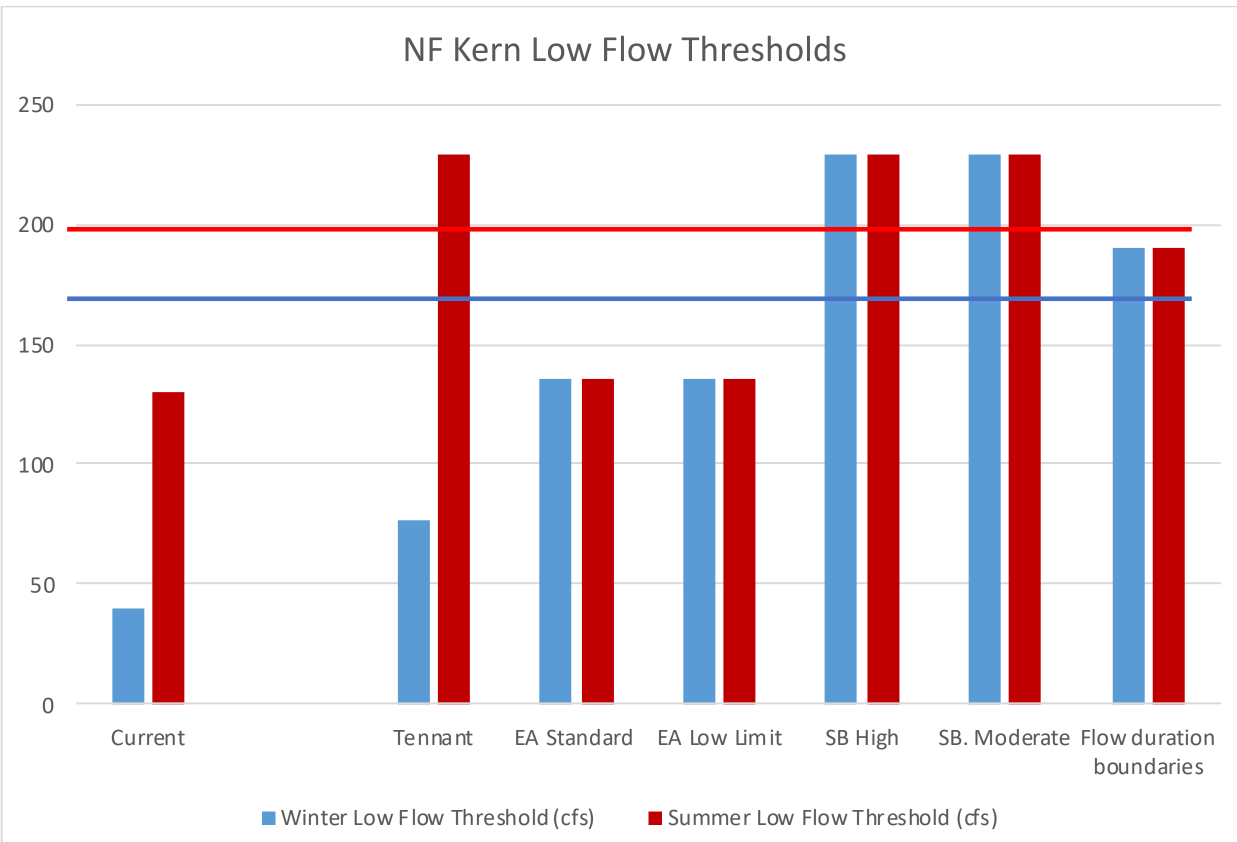


Figure 9: Bars show recommended winter and summer low flow thresholds compared to current minimum instream flow regime. The horizontal lines indicate averages of recommended methods.

The low flow thresholds of the current MIF regime are lower than every one of the comparison methods tested:

	Winter Low Flow Threshold (cfs)	Summer Low Flow Threshold (cfs)
Current	40	130
Averaged Comparison Methods	166	191
Difference (Averaged – Current)	126	61
Current as percent of recommended	24.1%	68.0%

The current summer low flow threshold is only 68% of the averaged recommended summer low flow threshold of 191 cfs. The current winter low flow threshold is even further from the averaged recommendations, at only 24.1% of the recommended winter low flow threshold of 166 cfs. The low flow thresholds would need to be increased by 126 cfs in winter, and 61 cfs in summer to meet the averaged recommendations. While not seemingly a large amount of water, recall from the habitat suitability curves for rainbow trout on the NF Kern that as the flow decreases from 150 cfs to 100 cfs to 50 cfs, there is a steep drop-off on those habitat suitability curves; this is the zone that these threshold changes are moving through.

Even the Tennant method, the oldest of those methods included and one which existed at the time of the previous licensing, recommends increases to the low flow thresholds of an additional 99 cfs in summer and 36 cfs in winter, values in line with the "Narrative Description of Flow" table provided by CDFW (Fig. 8).

Flow Variability Comparison

The second component of this environmental flow analysis is to compare the flow variability between the current MIF regime and the comparison methods. Methods such as Range of Variability, Functional Flows Analysis and Sustainability Boundaries all attempt to quantify and prescribe what this natural variability should look like, and this can be performed in future analyses. For the flow variability comparison performed here, the variability differences will be plotted and visualized on hydrograph curves.

Plots of the three exemplary years are seen in Fig. 10. Each hydrograph shows the incoming flow curve along with the calculated minimum instream flow required by the current MIF regime. Note that these calculated flows are used instead of the flows recorded in the diverted stretch for the corresponding year because in various instances throughout the dataset, the KR3 project was not taking the full volume of water that is allocated to them (due to project outages, maintenance, lags in responding to changes in incoming flows, or recreational releases). In other instances, minimum power generation or hatchery flows were allowed to supersede the MIF, forcing instream flows even lower. A future comparison could evaluate the impact of outages and other disruptions to actual flows in the diverted stretch of river.

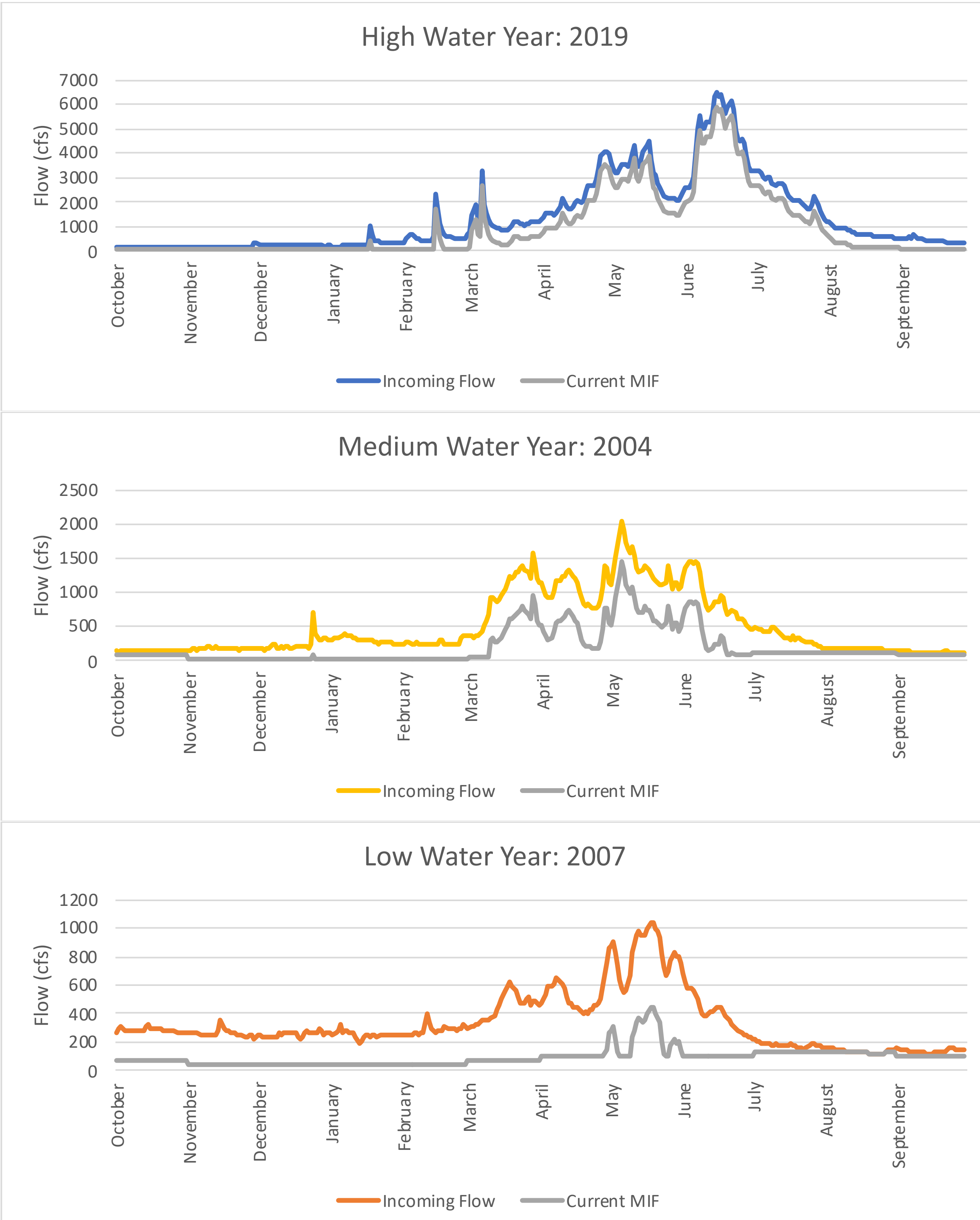


Figure 10: Hydrograph of flows for exemplary years (a) High water, (b) Medium water, and (c) Low water

In a medium- or high-water year, some natural variability of the incoming flows is propagated through to the bypassed stretch because the incoming flows will surpass the maximum possible diversion for parts of the year; but as flows drop, or during the entirety of a dry water year, the lack of a flow variability requirement means that the flows in the depleted reach will frequently flatline because the diversion is allowed to take 100% of flows over the minimum instream flow requirement.

Note in the medium year hydrograph (Fig. 10b) the extended periods of absolutely flat and unwavering flows from October until early April. Only a small one day fall pulse flow (storm bump) in December and the change of flow threshold value break the monotony. Then note again starting in July that the end of the spring recession flow (snowmelt runoff) is entirely flattened all the way through the end of September and the end of the water year.

The situation is exacerbated in a low water year (Fig. 10c) in which except for three small flow bumps spread through a 33 day period from the end of April through the entire month of May, the flows in the diverted stretch were held unvarying at the low flow threshold, showing flat lines on the hydrograph. The peack magnitude flows and spring recession flows are almost unrecognizable. This regime has removed nearly all of the incoming flow variability, which even in this low water year shows significant seasonal-, monthly- and weekly- changes.

Recall that 99 percent of the time the natural, incoming flows on the NF Kern are equal to or in excess of 100 cfs (the 1-percentile flow value). However, under the current MIF regime, flows are held at or below 100 cfs on 76% of the days in this representative water year, even though not one single day (0%) of the year had incoming flows below this 1-percentile value.

Next, each of the comparison methods are applied to the exemplary years' hydrographs. Calculated flows in the diverted stretch are determined based upon the low flow thresholds and variability requirements of the scheme. Max possible diversion is capped at 600cfs for the calculations. Note that for this analysis, the "Flow duration boundaries" will be omitted because of the vagaries of statistical definition and difficulty of implementation.

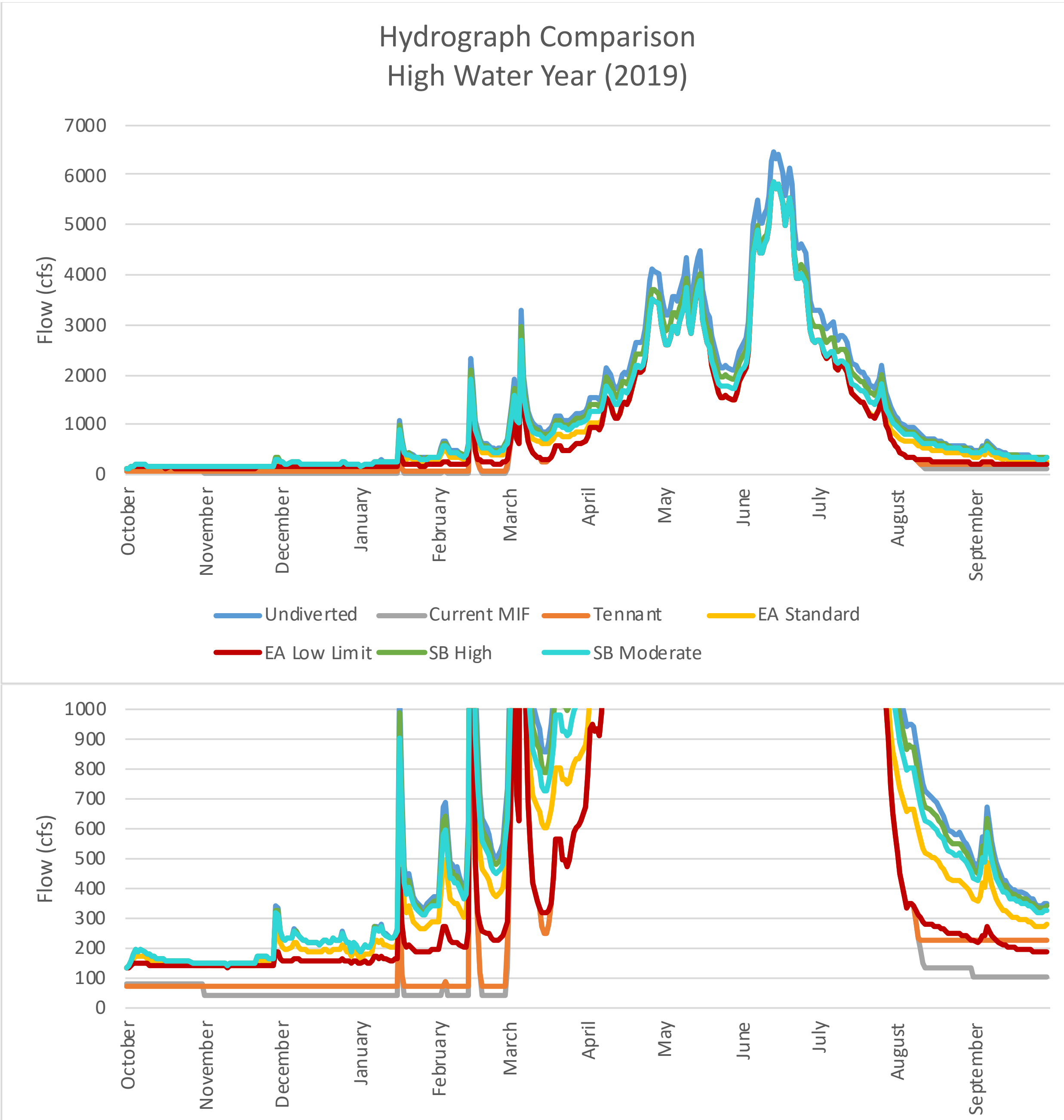


Figure 11: Hydrograph of flow comparison for example High water year (a) full plot, and (b) zoomed in to low flow zone

In the high-water year (Fig. 11), each of the comparison methods perform similarly over the full range of flow values. All exhibit significant variability correlated to incoming flows during the runoff, since based on the project capacity limits, much of the incoming flows are passed through to the diverted stretch. However, examining the low flow periods in Fig. 11b (October – March and August – September) there are still notable differences between the schemes. The low flow thresholds are obviously different, as discussed in the previous section. But the variability of the flows is also affected. Under the Current or Tennant methods, even in this high-water year there are still significant, multi-month-long periods of flow flatlines, despite the presence of existing and fluctuating inflows. Note also that any of the methods which use a percentage take approach (EA and SB methods) preserve flow variability.

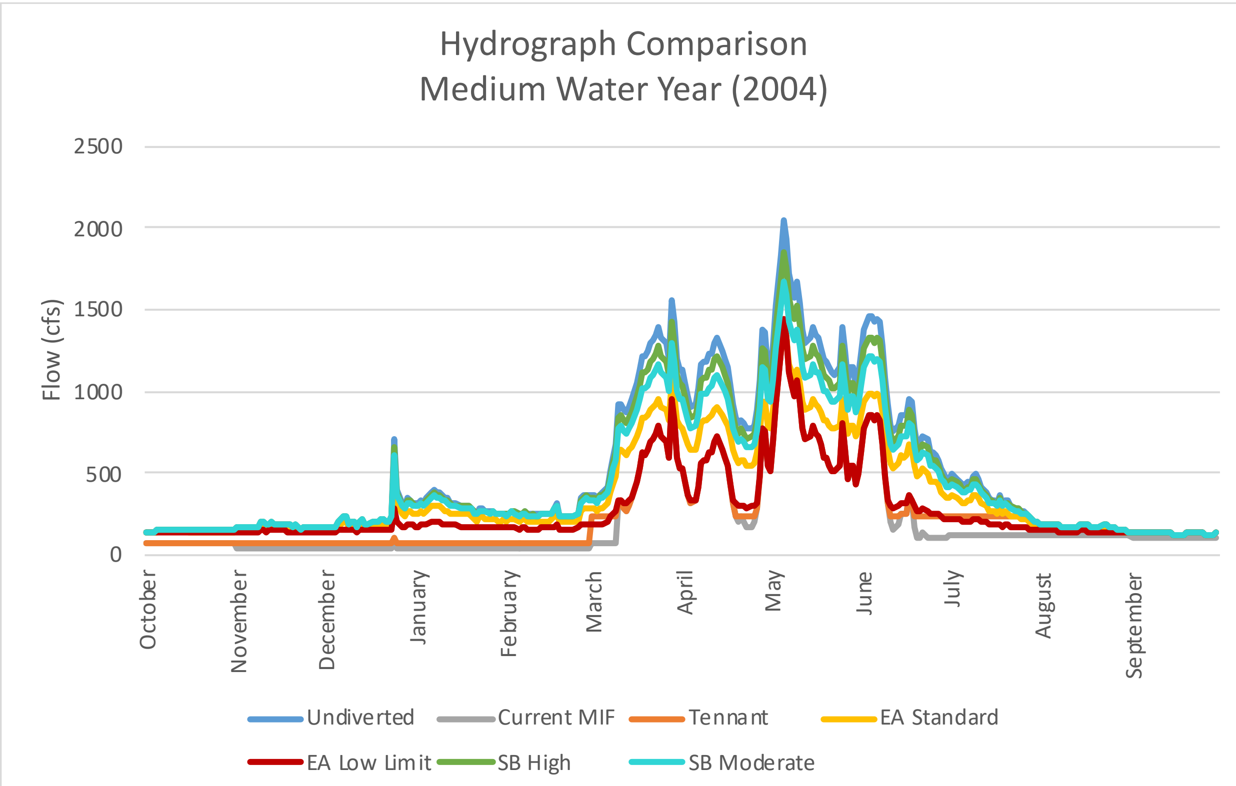


Figure 12: Hydrograph of flow comparison for example Medium water year

The same trends are observed in the medium-water year hydrograph comparison (Fig. 12). Again, during the peak runoff (mid-March through mid-June) the methods perform similarly. However, during the flow ramping period the differences become more obvious, particularly the first 5 months of the water year and again from late June through the end of September. In each of the percentage take methods (EA and SB), the calculated flows show both an increased low flow threshold value as previously discussed, but significantly also preserve flow changes and oscillations which match the variability of the incoming flow on the weekly, monthly, and seasonal windows of comparison. Under the Current or Tennant methods, the unnatural flatlined nature of the hydrograph during these periods are pronounced.

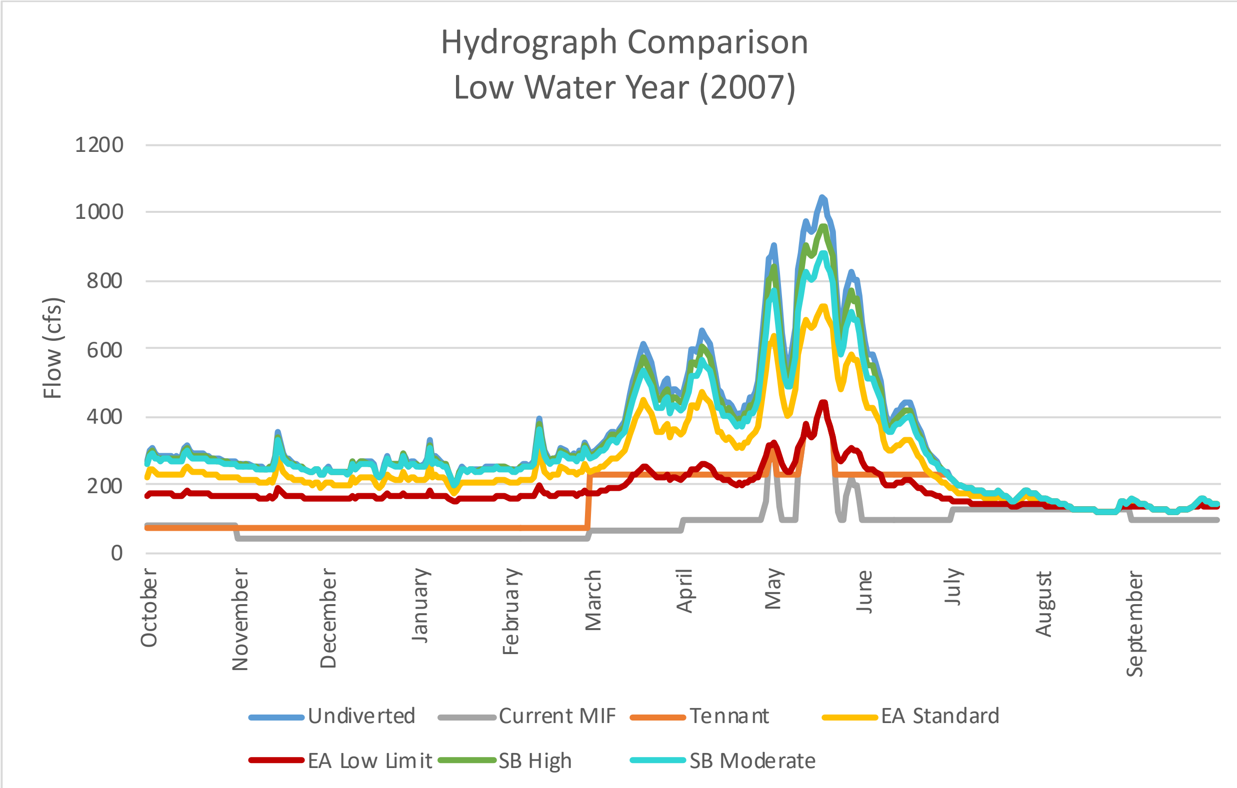
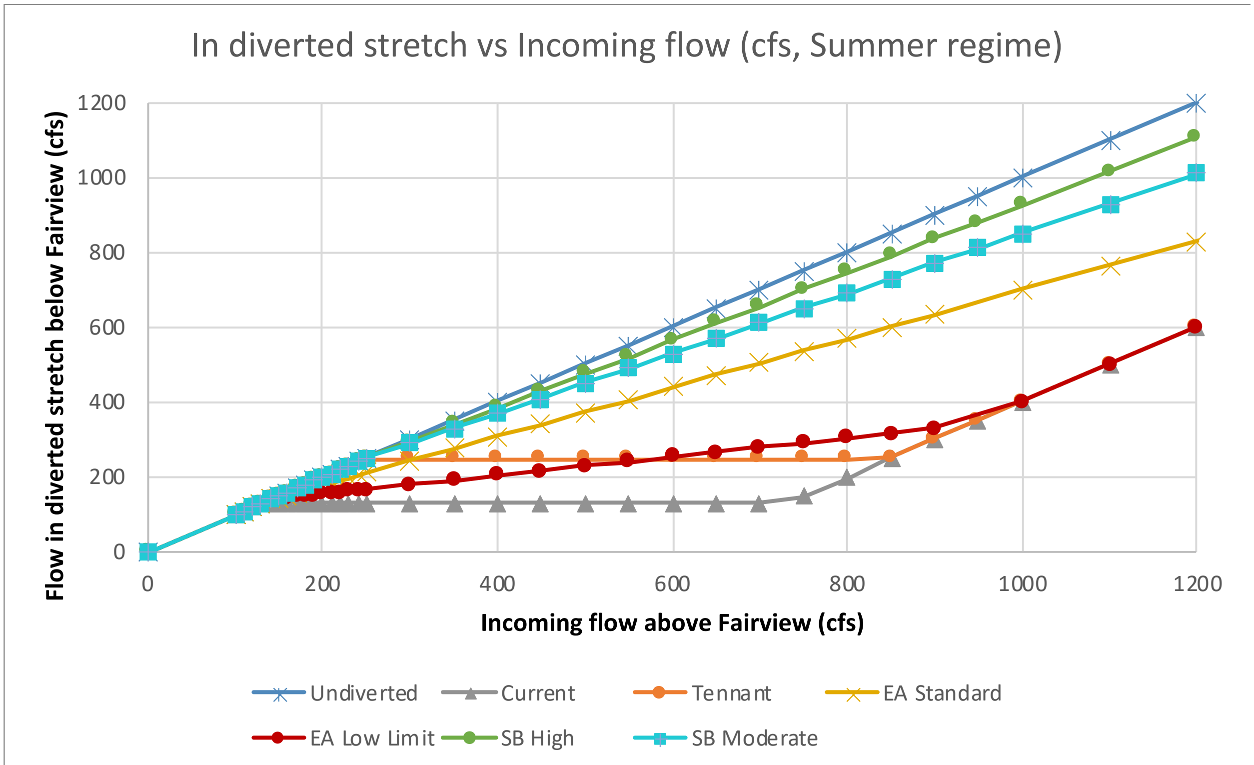


Figure 13: Hydrograph of flow comparison for example low-water year

Each of these trends are even more apparent in the Low water year hydrograph. The EA and SB methods preserve the variability of incoming flows over the entire course of the year. Even the most severe "EA Low Limit" (intended only for areas of low ecological importance) flow method preserves significant variability in the hydrograph compared to the current MIF regime. The somewhat outdated Tennant method agrees with the "EA Low Limit" in terms of flow magnitudes, but like the current MIF regime, Tennant preserves no flow variability apart from the biannual threshold change, and the forced variability when the incoming flows drop below the required threshold (most of August and September in this example).

An alternate way to visualize flow variability is by plotting the flows that remain in the diverted stretch compared to the incoming flows above Fairview Dam, and comparing the resulting curve from the Current compared to the same 5 comparison methods. This can be seen in Fig. 14. Viewed in this fashion, it can be seen that under the current MIF regime, when the incoming flows are less 600 or 700 cfs (in winter or summer respectively) all variability in the incoming flows is lost and flows in the diverted stretch are always set at the minimum instream flow regime's flatline. The Tennant method shows an identical pattern, but with a higher threshold value. All of the other methods (both EA methods and both SB methods) show higher values in the diverted stretch at all times, as well as flow variability at all times as the incoming flows move through this currently flat lined area.



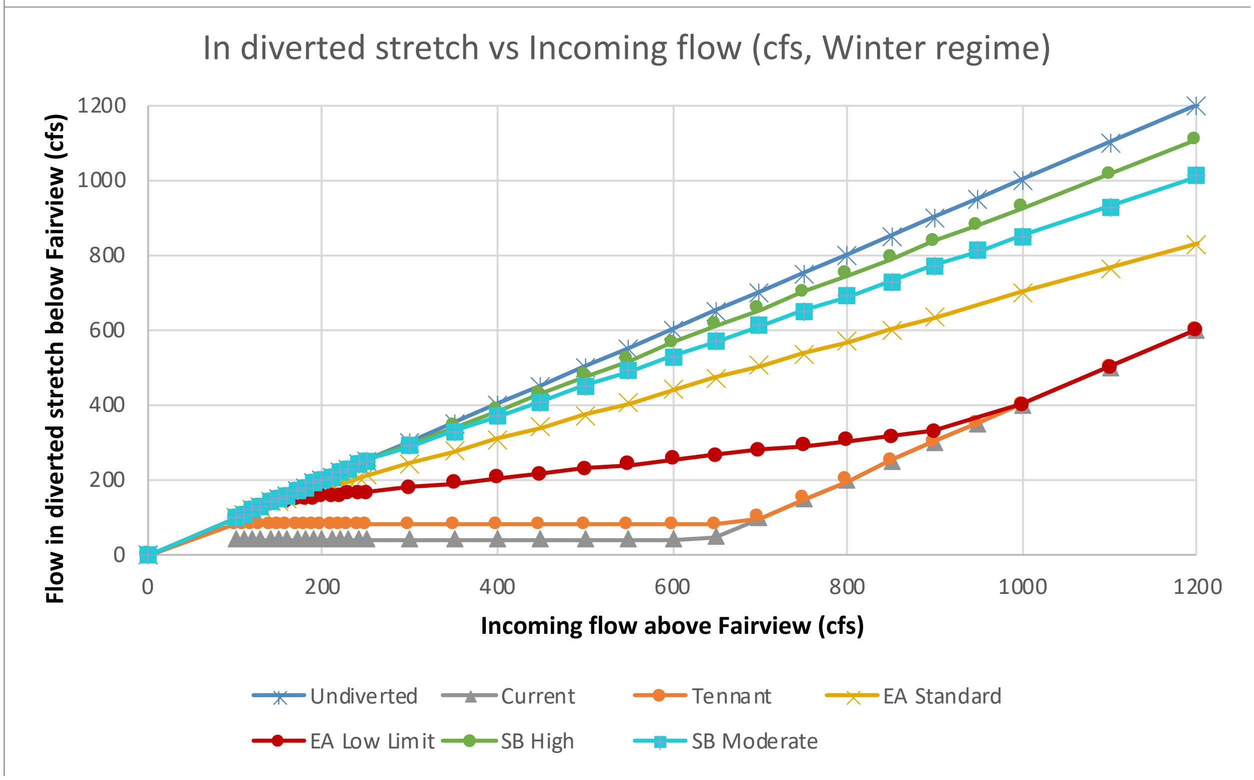


Figure 14: Incoming flows in the diverted stretch of river for (a) Summer and (b) Winter. Note only Current and Tennant methods vary by season.

Note that these incoming flows in diverted stretch plots do not consider or include the minimum power generation flow, which is permitted to take priority over the minimum instream flow and can drive the actual flow in the diverted stretch up to 45 cfs lower than the current minimum instream flow regime would otherwise allow.

Discussion

In an analysis of six hydrological methods representing the collective consensus on ecological responsibility for hydropower regimes as recommended by the California DFW, Canada Department of Fisheries, Environment Agency of UK, and Environment Australia, as well as broad unanimity across the ecological research community, there is agreement amongst all methods that the NF Kern is currently underwatered as a result of KR3 hydropower operations, and lacks the requisite features of an environmental flow regime. The methods analyzed recommend:

- Maintain 166 – 191 cfs hands-off flow in the diverted stretch at all times as permitted by incoming flows;
- Use a percentage take above the hands-off flow in order to better mimic the natural hydrograph

The health and maintenance of the Wild & Scenic NF Kern ecosystem depends upon a restoration of flows to better align with these flow requirements. The leadership of the state of California (via the California Water Resilience Portfolio initiative) understands and emphasizes the importance of prioritizing the protection and enhancement of natural ecosystems (CNRA, 2019). The California Department of Fish and Wildlife have developed a thorough suite of guidance documents (the Instream Flow Program) which provide the guidance to implement these protections (CDFW, 2017) and to specifically consider the specific needs of the trout fishery within the Kern (CDFW, 2021).

For a more local and specific example of why this is important, consider the yellow-legged frog. The yellow-legged frog was once abundantly present in the Sierra Nevadas (CBD, 2021; Hayes, 2016). Currently, the yellow-legged frog has experienced significant population decline in most known historical locations and is nearing extinction in parts of its range. “Water development and diversions are likely to be the primary cause of population declines and are currently a prominent risk factor because they result in hydrological changes that chronically affect several aspects of the species’ life history” (Hayes, 2016). Over the last 100 years of water diversion within the Kern drainage, the number of yellow-legged frogs present has plummeted in the affected project environment. They do still exist nearby and just a few miles upriver (SCE, 2021), but the current minimum instream flow regime and other project impacts have removed them from their historic habitat. Notably, one of the requirements of the yellow-legged frog is a flow regime that can “Mimic natural hydrograph to degree possible [and] restore some components of spring snow-melt hydrograph” (Hayes, 2016).

Other topics for future exploration include the impacts of the flows in the diverted stretch on health (temperature, contaminants, and bacterial load), aesthetic, and recreational value of the project reach. Additionally, at times there can be significant diurnal swing in the flows of the NF Kern that cannot be captured or analyzed in a dataset that is an average of one day's flows. If hourly flow data were available, more analysis could be conducted.

Finally, since only desktop methods are included here, none of these methods can portray a full picture of the complex riverine habitat, and it must be acknowledged that all included methods are recommended as a starting point for river integrity.

Further data can and should be acquired through additional field data collections or analyses including hydraulic, habitat, and population monitoring. Note that when this has been done historically, the physical habitat analysis for trout and rainbow trout specifically agreed with the present survey of international consensus in recommending flows around 200 cfs for the native and stocked trout of interest to survive and thrive at all stages of life (SCE, 1991, 2021). And when population surveys have been carried out, it was found that "the estimated density and biomass of both naturally produced and hatchery-raised rainbow trout declined abruptly at all monitoring sites in 2016" due to drought, as had happened before "during the 1987 to 1992 drought". (SCE 2017, 2021). The estimates of rainbow trout abundance at five sites above and below Fairview Dam showed that while 51% of the rainbow trout survived from 2011 to 2016 samples at site above the dam, only 5% of the rainbow trout remained over the same period from sites below the dam in the dewtered reach (SCE, 2021). So there is a large space above the current regime for ecological improvement.

Further analysis with the statistical and functional flows methods could also be applied to identify and balance the most critical functional flow elements with the biological and ecological functions and requirements on the NF Kern, and thereby inform an ideal functional flow regime for this riverscape.

Overall, the disparate methods analyzed in this report do have significant application globally, and all agree in their portrayal of a significantly underwatered Wild and Scenic North Fork Kern below Fairview Dam, for which more modern and environmentally aware hydropower mitigation is strongly recommended.

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Appendix A

Using the methodology presented in CEFWG (2021) and the data provided via the CEFWG Database (2021) and Zimmerman (2021), a functional flow metrics table was generated for the NF Kern River. An additional column was added to map the current MIF regime values to the flow components for comparison.

Location of Interest (LOI) = Kern River COMID: 14972877 NF Kern River between Camp Owens and Kernville			
Flow Component	**Flow Metric**	**Predicted Range at LOI** **median (10th - 90th percentile)**	**Current MIF regime in NF Kern in diverted stretch**
Fall pulse flow	magnitude	510 (213 - 1250) cfs	40 (40 - 650) cfs
	timing	Nov 14 (Oct 5 - Dec 2)	only present if incoming pulse > 600cfs
	duration	3 (2-7) days	reduced
Wet-season baseflow	magnitude	464 (198 - 605) cfs	100-130 cfs
	timing	Feb 7 (Jan 18 - Mar 26)	April - September
	duration	124 (60-146) days	182
Wet-season peak flows (2 yr flood)	magnitude	2930 (1880 - 10000) cfs	2330 (1280-9400) cfs
	duration	63 (1-47) days	reduced
	frequency	6 (1-5) occur	reduced
Spring recession flow	magnitude	2440 (1400 - 5250) cfs	1850 (800 - 4650) cfs
	timing	June 11 (May 21 - June 25)	earlier
	duration	78.5 (49-104) days	reduced
	rate of change	4.12 (4.27 - 8.94) %	~
Dry-season baseflow	baseflow	228 (67 - 382) cfs	40-80 cfs
	timing	Aug 25 (Jun 23 - Sept 14)	October - March
	duration	168 (149 - 236) days	182

Box plots can be generated for each of the functional flow components as described in the CEFF (CEFWG, 2021). When doing so, box plots were generated which show whiskers from 10^{th} - 90^{th} percentile as well as median values. 25^{th} and 75^{th} percentile box lines were interpolated from the available data.

The median values for three of the measures (fall pulse magnitude, wet season base flow, and dry season base flow) falls outside of the 10^{th} to 90^{th} percentile range, suggesting that the current regime is likely altered in the negative direction (Fig. A1).

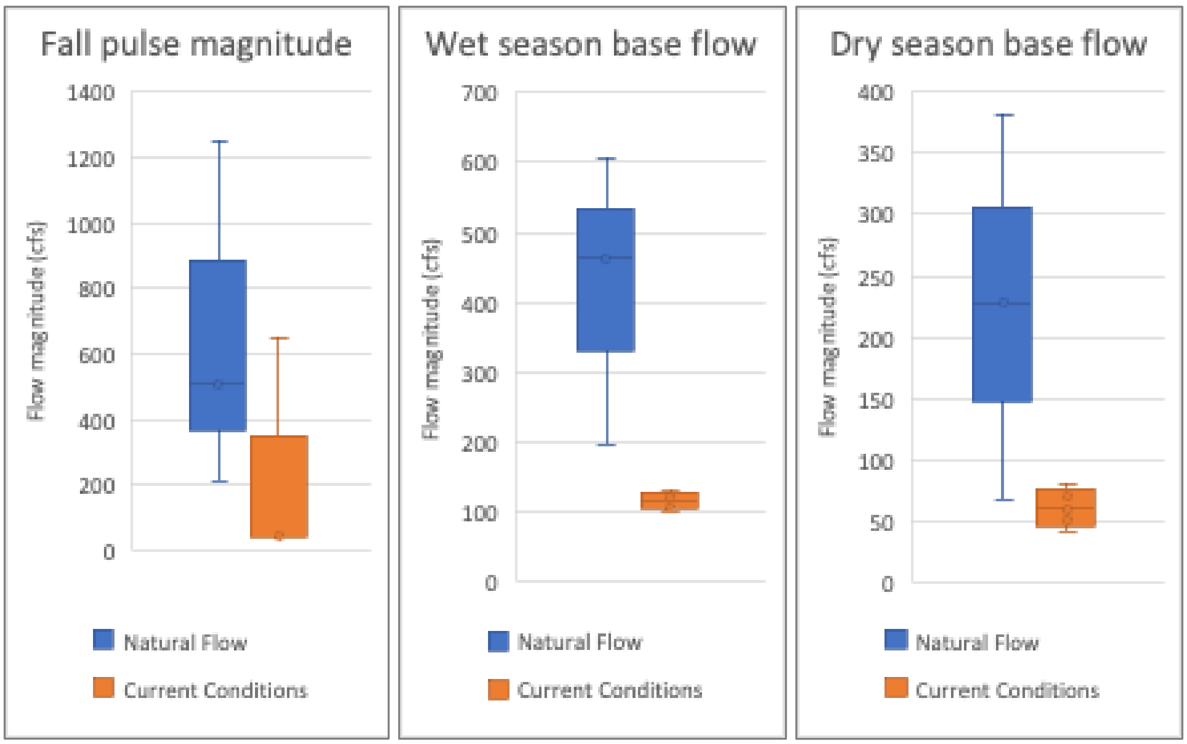


Figure A1: Comparing the "Likely Altered" Natural Flow and Current Conditions of NF Kern.

The median values for the remaining two measures (wet season peak flow (2yr flood) and spring recession flow) are not significantly altered (Fig. A2). This matches with the nature of the diversion scheme, as these measures are both capturing high water characterizations, and due to the 600cfs limitation on what the diversion can remove these are not impacted in the same way as the low water characterizations are.

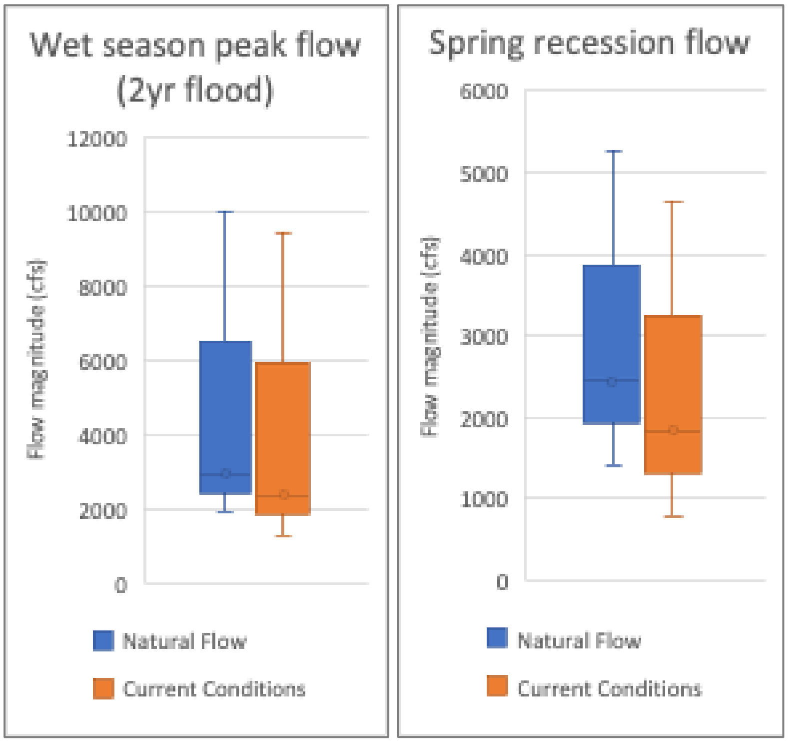
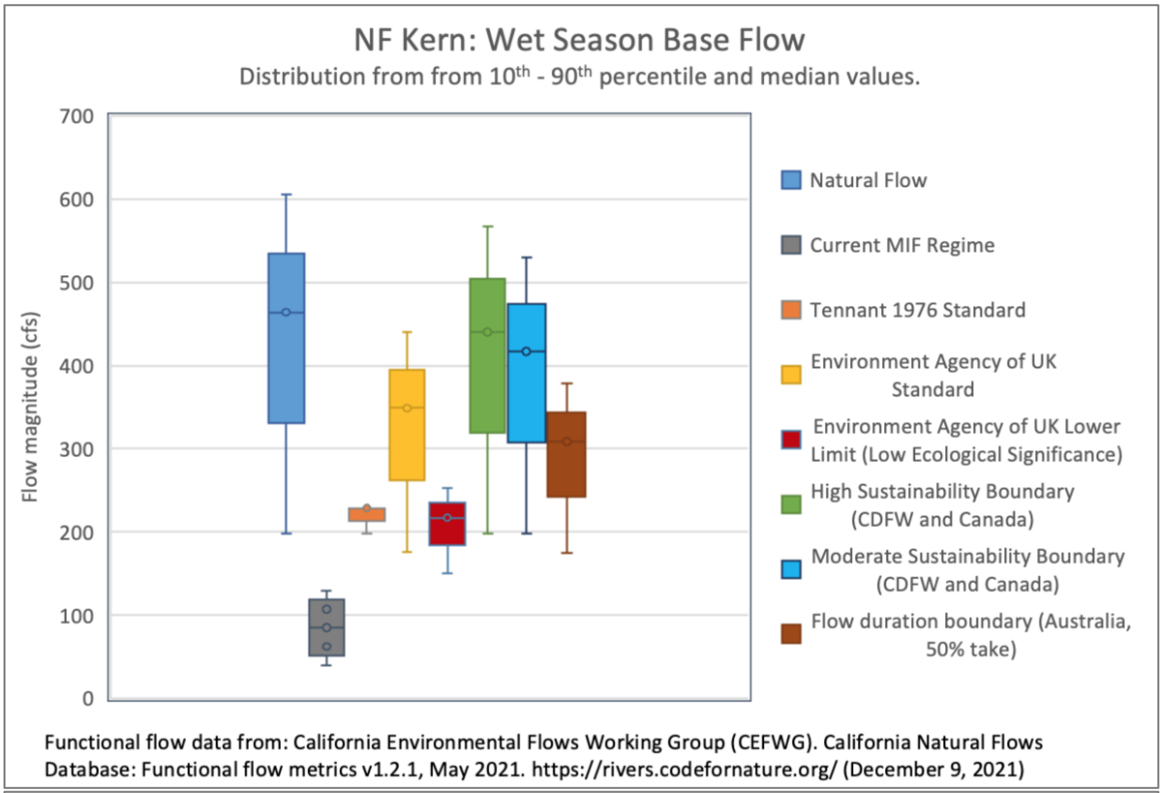


Figure A2: Comparing the "Likely Unaltered" Natural Flow and Current Conditions of NF Kern.

Finally, these functional flow "base flow" metrics for both dry- and wet- season can be compared to the international standard methods analyzed in body of this document which provide low flow threshold and flow variability recommendations (see Methods Table, above in text). For this comparison, a 50% POF take above threshold was assigned to capture the flow variability protection for the "Flow duration boundary" method. Note that this 50% POF take also matches the current guidance (not followed by current license) from the USFS SQF Federal Land Resource Management Plan (1988) for the NF Kern River. For each of the included methods, the incoming Natural Flow distribution values were subjected to the terms of each of the environmental flow protection methods, and the resulting recommended flow ranges in the diverted stretch for each method are also plotted. Results can be seen in Fig. A3.

The Current MIF Regime is significantly out of line not only with the Natural Functional Flow characterization, but also with every one of the recommendation sets, for both the wet season base flow and dry season base flow. For the wet season base flow, no part of the Current distribution even reaches the lowest recommended base flow range. The distribution of dry season base flow in the Current MIF Regime at least shares some overlap in distribution, but the median value is still significantly different and below the entirety of each recommendation's range.

Plotting in this way concisely captures not only the low flow limit but also the distribution of instream flow magnitudes, and further supports the conclusion that the Current MIF Regime for the NF Kern is significantly underwatering the river and lacks the features required for environmental and ecological protection.



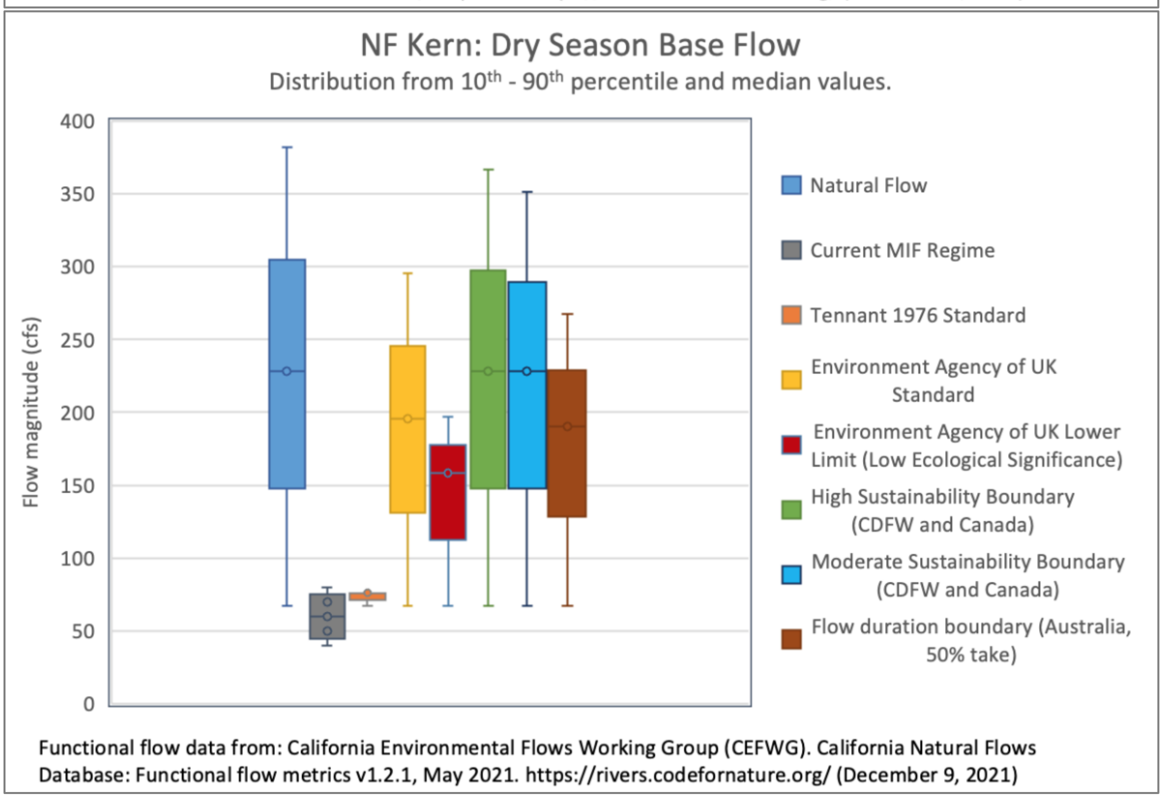


Figure A3: Comparison of environmental flow recommendations for (a) Wet season base flow and (b) Dry Season base flow functional flow components.