Hydrological approaches for Environmental Flow Guidelines in Prince Edward Island

Olivier Chimi-Chiadjeu[1]
André St-Hilaire[1]
Michael R van den Heuvel[2]

1. Canadian Rivers Institute, INRS-ETE, University of Québec, Québec City
2. Canadian Rivers Institute, UPEI, 550 University Ave, Charlottetown, PE C1A 4P3

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1. Context

Global warming and water demand increases will likely lead to more challenging decisions for water resources management. Human activities such as agriculture, and other ecosystem services related to aquatic wildlife need to be accounted for in the regulatory framework related to environmental flows. That is why scientists developed over 200 ecological flow approaches to address this question (Tharme 2003). Given the current and future levels of potential water needs, environmental flow (E-flow) guidelines need to be reevaluated or refined. The main objective of this study is to update the knowledge on hydrological methods that can be used in the definition of E-flows in Prince Edward Island (PEI). A first study, covering the Maritime Provinces and consequently PEI, was completed by Caissie et al., (2014). In their study, some common methods such as duration and statistical low-flow frequency analysis are used to define E-flows. Of the 52 hydrometric stations used in the study in the Maritimes provinces, only five stations were located in PEI.

In the present study, we are revisiting the methods of Caissie et al. (2014) (comparison of duration methods and statistical low frequency approaches) on more complete discharge time series from the hydrological stations in PEI which are still in operation. In addition, the Sustainable Boundary /Presumptive Standard and the Range of Variability approaches were also applied. The main advantage of the latter two methods is the definition of E-flows month by month or even daily. Our main objective is to compare these approaches for several rivers for which discharge data are still available in Prince Edward Island.

In this document, we start with the brief presentation of our methodology. Some common metrics, which were already described by Caissie et al. (2014), were calculated, such as: Median (Q50, or a percentage thereof), the 95th percentile (Q95), low flows with a return period of 2 and 10 years and duration of 7-days (7Q2, 7Q10). Range of Variability, Sustainable Boundary and Presumptive Standard approaches, which are also applied, are presented. The hydrological stations selected for the study and results are presented in the following section. In the subsequent sections, the results from one station are presented as an illustration. Results for the other stations are presented in an appendix. The last part of this document is a section with conclusions and recommendations.

2. Methodology

Approaches used here are well described in the review of methods to assess environmental flow across Canada and internationally of Linnansaari et al. (2012). All the proposed methods have shown their ability to define the ecological criteria in several regions in the world (Belzile , et al., 1997; Armanini, et al., 2015; Caissie & El-Jabi, 1995a). The Mean Annual Flow (MAF, or percentage thereof) is the oldest metric used to define ecosystem protection (Tennant, 1976; Park, 1977; Caissie & El-Jabi, 2003).

The low-flow quantiles obtained by frequency analysis, as well as many other descriptive statistics are yearly metrics. The duration method can be applied annually and monthly. Sustainable Boundary Approaches (SBA) give a daily value of E-flow: this means that an ecological criterion is defined for each day of the year. Range of Variability approaches metrics can be calculated monthly and yearly. The annual metrics have been compared to MAF. The ratio between the various statistical metrics and drainage area is also used to compare these metrics between stations. In PEI, the inter-annual mean monthly 70%Q50 is presently used to determine minimum E-flows. The inter-annual monthly 70%Q50 is the monthly 70%Q50 of observed flows on all available data. Evaluated at each station, this metric has also been used to compare with other monthly and daily flow metrics.

2.1. Q50, 70%Q50 and Q95 metrics

Low flow metrics are descriptive statistics calculated from time series of observed flow. We propose to compare common metrics such as: Median (Q50), 70 percent of median (70% Q50) and the 95th percentile (Q95: flow equaled or exceeded 95% of the time). The low flow metrics will be evaluated on whole series of data and for each month.

The Q50 method or Median Monthly Flow (MMF) has been used by the New England U.S. fish and Wildlife Service (USFWS, 1981). Defined for each month, this metric has been used for the protection of fish population. For relatively large drainage areas (>130 km^2), the environmental flow is defined on median monthly flows but for small watersheds (drainage area smaller than 130 km^2), it is recommended to use the Q50 of the lowest flow month (Caissie, et al., 2014; USFWS, 1981). This metric is often compared from station to station by calculating this value as a percentage of MAF (Caissie & El-Jabi, 1995a; Cassie & El-Jabi, 1995b). Q50 metric has been applied in the Maritime Provinces and compared with MAF (Caissie, et al., 2014).

As indicated by its name, 70%Q50 method is calculated as 70 percent of median flow. Several stations in this study were used by Caissie et al. (2014) to calculate 70%Q50. In the present report, the comparison is repeated with longer time series.

Similar to the Q50 metric, the Q95 metric is calculated and compared with other metrics and methods. Developed by the North Great Plains Resource Program (MGPRP, 1974), the Q95 method has been mainly implemented for the Prairie region. It was subsequently applied in the Maritime Provinces (Caissie & El-Jabi, 1995a; Cassie et al 2015).

2.2. Statistical low flow frequency analysis.

Frequency analysis is a statistical approach that relates the magnitude of events, e.g. minimum annual discharge, to a probability of exceedance for a given duration. A return period is calculated based on the probability that the event will be equalled or exceeded in any given year. The return period is defined in equation (1):

$$T(x) = \frac{1}{1-p} \quad (1)$$

where $T(x_t)$ is the return period associated with a given event x_t, $p = 1 - F(x,\theta)$ is the exceedance probability associated with probability distribution $F(x,\theta)$ of x with n observation ($x = \{x_1, \ldots, x_n\}$) and θ represents the vector of the parameters of the probability distribution F. Hence, a statistical distribution is fitted to annual or seasonal extremes and this model is used to calculate probabilities of exceedance for different return periods. The complete theory and detailed description of frequency analyses are described in many books such as Hamed & Rao (1999).

The 7-day, 2-year (7Q2) and 10-year (7Q10) low flow quantiles are based on an annual series of the smallest values of mean discharge computed over any 7-consecutive days during the annual period. The probability distribution is fitted on annual minimum values of a 7-day moving average. The 7Q2 and 7Q10 statistics are respectively the annual 7-day minimum flow with a return period of 2 and 10-years. This means that this extreme event is expected to occur on average once every 2 (10) years. Low flow statistical frequency analysis has been applied in several regions to define the appropriate level of ecological protection (Mohamed, et al., 2002; Belzile , et al., 1997; Snelder , et al., 2011).

In this study, we have tested several probabilistic distributions, such as Weibull, Weillbull3 (Weibull with 3 parameters), Gamma, Gamma3 (Gamma with 3 parameters), Generalized Extreme Value (GEV) and Gumbel. Unlike the normal distribution, they are not symmetric and are deemed better suited than the normal distribution for extreme value analysis. Parameters of the fitted distribution are estimated using the maximum likelihood method. The distribution which has the best fit is selected. This means the distribution which minimizes the Akaike information criterion, corrected Akaike information criterion (Burnham & Anderson, 2004) and Anderson Darling (Stephens, 1974) statistic is selected. These goodness of fit criteria will have the lowest value for the best fitted distribution, while also accounting for the number of parameters (i.e. if two distributions have the same performance, the one with fewer parameters will be selected).

2.3. Sustainable Boundary and Presumptive Standard approaches

The Presumptive standards (PS) approach is an upgraded version of the Sustainable Boundary (SB) approach. The latter approach consists of determining the range of so-called “normal” or “low” flows. What is considered “normal flow” can be defined by experts using different criteria. As an initial step, the mean or median daily flow can be used to define “normal flow”. Similarly, “low flow” can be initially defined as the minimum or Q95 values from the observation period. Using these thresholds, the managers can determine the percentage of allowable depletion. Richter, et al., (2011) Suggest using three conditions to determine upper and lower boundaries:

(i) the desired consumption (or dam regulation) of water upstream, which might deplete or unnaturally increase river flows;

(ii) the use of water downstream; and,

(iii) the desired ecological condition and ecosystem services to be maintained.

Expert derived advice and scientific peer review of site-specific studies are used to provide percentage values (Richter, et al., 2011). Figure 1 represents the example of sustainable boundary approach. Here, the percentage of allowable flow depletion and augmentation are constant during a year. To define several levels of ecological risks, the Presumptive Standard (PS) approach is used. The main difference between PS and Sustainable Boundary is the definition of the ecological protection level. The PS defined it using three levels of assessment:

(i) A high level of ecological protection: Daily flow alterations are not greater than 10% of natural flow;
(ii) A moderate level of protection: Daily flow alterations are altered by 10-20% of the natural flow; and
(iii) Moderate to major *changes* in natural structure and ecosystem: Daily flow alterations are > 20% of the natural flow.

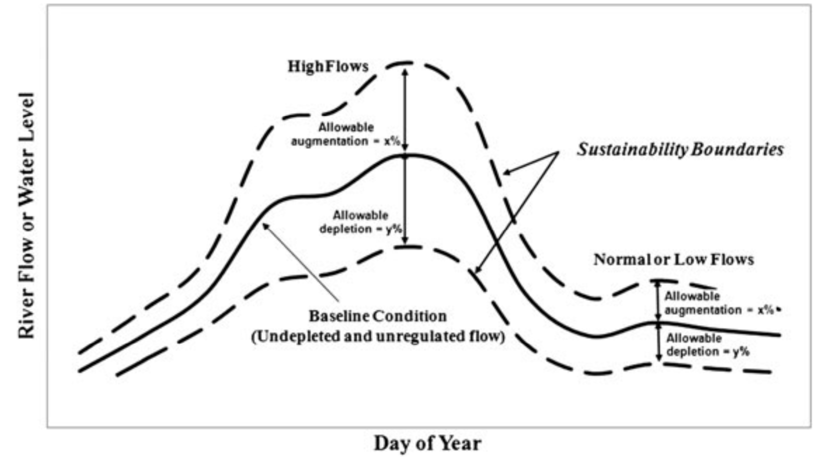


Figure 1: Illustration of the sustainability boundary approach from Richter et al. (2011). The sustainability boundaries set limits on the degree to which natural flows can be altered, expressed as a percentage of natural flows.

Figure 2 presents an example of the presumptive standards with several ecological levels (Richter, 2010).

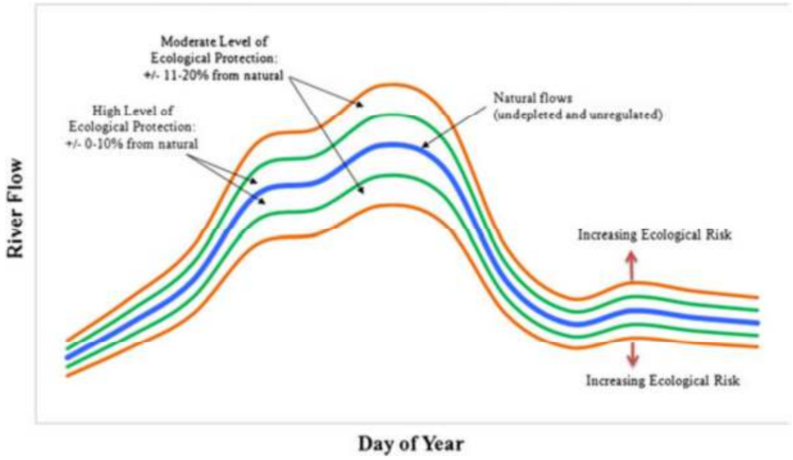


Figure 2: Presumptive standards suggested for providing moderate to high levels of ecological protection (Richter, 2010).

The depletion allowed while minimizing ecological risk depends on location and period of the year, e.g.: 8-19% of daily flow in Florida, 6-15% of August median flow in Michigan, 10% of daily flow in Maine and 7.5-20% of daily flow on lower flow period and 20-50% of daily flow on higher flow period in European Union countries (Richter, et al., 2011). For the rigorous estimation of alterations, it is important to take into account the seasonality and the year's variability of alterations on the presumptive standards approach.

The main advantage of this approach is the definition of E-Flows for every day of a year. This approach can help water resources managers to adjust the protection level depending on the period of the year. For example: On salmon rivers, the ecological protection could be more restrictive during the spawning period.

2.4. Range of Variability

The range of variability consists of examining a number of descriptive statistics known as Indicators of Hydrologic Alteration (IHA) (Richter, et al., 1997; Richter, et al., 1998). Table 1 presents 32 IHA that describe various characteristics of the natural hydrograph: Amplitude, timing, duration and frequency of specific hydrologic events, as well as variability. The aim is to identify the range of each IHA. The proposed algorithm uses these 32 IHA in 2 steps to estimate the range variability:

- Calculate 32 IHA values on (>20 years) of observed daily stream flows. Estimate the central tendency (mean, median) and dispersion (range, standard deviation, coefficient of variation) of each IHA.

- Define the range of natural variation of each 32 IHA. The range can be defined by ±1 or 2 standard deviation(s) from the mean, taking 20th percentile and 80th percentile etc. With the absence of ecological information use ± 1 standard deviation (Richter, et al., 1997).

Table 1: Summary of Indicators of Hydrologic Alteration (IHA) variables and ecological influences (Armanini, et al., 2015).

IHA Parameter Group	Hydrologic Parameters	Number of parameters	Ecosystem influences
Group 1: Magnitude of monthly water conditions	Mean or median value for each calendar month	12	Habitat availability for aquatic organisms Soil moisture availability for plants Availability of water for terrestrial animals Availability of food/cover for fur-bearing mammals Reliability of water supplies for terrestrial animals Access by predators to nesting sites Influences water temperature, oxygen levels, photosynthesis in water column
Group 2: Magnitude and duration of annual extreme water conditions	1-day, 3-day, 7-day, 30-day, 90-day annual minimum 1-day, 3-day, 7-day, 30-day, 90-day annual maximum Number of zero-flow days Base flow index: 7-day minimum flow/mean flow for year	12	Balance of competitive, ruderal, and stress-tolerant organisms Creation of sites for plant colonization Structuring of aquatic ecosystems by abiotic vs. biotic factors Structuring of river channel morphology and physical habitat conditions Soil moisture stress in plants Volume of nutrient exchanges between rivers and floodplains Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatics environments Distribution of plant communities in lakes, ponds, floodplains Duration of high flows for waste disposal, aeration of spawning beds channel sediments
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1-day minimum and 1-day maximum	2	Compatibility with life cycles of organisms Predictability/avoidability of stress for organisms Access to special habitats during reproduction or to avoid predation Spawning cues for migratory fish Evolution of life history strategies, behavioral mechanisms
Group 4: Frequency and duration of high and low pulses	Number of low pulses within each water year Mean or median duration of low pulses (days) Number of high pulses within each water (year) Mean median duration of high pulses (days)	4	Frequency and magnitude of soil moisture stress for plants frequency and duration of anaerobic stress for plants Availability of floodplain habitats for aquatic organisms Nutrient and organic matter exchanges between river and floodplain Soil mineral availability Access for water birds to feeding, resting, reproduction sites Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
Group 5: Rate and frequency of water condition changes	Fall rates: Mean or median of all positive differences between consecutive daily values Rise rates: Mean or median of all positive differences between consecutive daily values Number of hydrologic reversals	3	Drought stress on plants (falling levels) Entrapment of organisms on islands, floodplains (rising levels) Desiccation stress on law-mobility stream edge (varial zone) organisms

This method was used to compare the ecological protection for pre-dam and post-dam hydrological conditions on the Tang river Basin in Beijing (Pan, et al., 2014). Recently, IHA was used to define environmental flow assessment based on the maximization of the possible utilization of water while complying with the alteration target according to global alteration metrics (David & Antonino, 2016).

The first and second group of Range Variability metrics can be compared to SBA because values are defined month by month. However, it is difficult to interpret and compare all Range of Variability parameters with other approaches (low flow metrics, statistics of low flow). In addition, there is some redundancy in the pre-selected metrics. To select a subset of IHA, a correlation analysis is performed. Selected IHAs are those that are not correlated with other parameters, while ensuring that at least one parameter per category of IHA is selected. Here, we assume that two IHA are highly correlated if their correlation coefficient is higher than 0.8 or lower than -0.8.

2.5. Metrics analysis

All methods described above have several metrics. Multivariate statistical analysis was used here to reduce the number of hydrological indices. This was done by using correlation analysis and principal component analysis. The correlation analysis is used as a first step to pre-select a reduced number of parameters for principal component analysis (PCA). The main criterion during the reduction of parameter is to keep one parameter for each metrics group and methods.

PCA is a data reduction technique that is used to construct linear combinations of the original variables (called Principal Components) that are not correlated with each other (Geladi, et al., 1987). The components are designed to maximize explained variance, which is usually called inertia, by each component. Thus, the first component is the one with the greatest inertia, i.e. the direction that explains the largest percentage of variance. The second component is the one with the second largest inertia and so on. We usually select the component for which the sum of inertia is higher than 80% of total variance.

We also used a hierarchical clustering method on the principal components (PC) to group hydrological stations. Hierarchical clustering (HC) groups stations by calculating a statistical distance between them. It can be done in ascending (i.e. starting with all stations in separate groups and coalescing them) or descending order, i.e. starting with one group including all stations and separating them (Johnson, 1967). In this study, we will focus our attention on the ascending approach. The choice of the number of classes is generally made visually from the dendrogram or using statistical criteria.

3. Study area and data

Of the 41 hydrological stations installed since 1850 in PEI, we used data from the 7 stations still in operation in 2016. Extracted by Water Survey of Canada, data are available from the HYDAT database, which is managed by the Environment and Climate Change Canada.

Table 2 presents the hydrological stations used in this study with their geographic position, drainage area, period of available data and MAF. The drainage area varied between 14.8 km^2 and 114 km^2, the number of years of available data between 56 years and 22 years and the Mean Annual Flow (MAF) between 0.24 m^3/s and 2.57 m^3/s. The highest MAF value is observed Station 01CB002, while the lowest observed is at Station 01CC010.

On the last column of Table 2 we present the ratio between MAF and drainage area (MAF/A) for each station.

Table 2: Hydrological stations

Stations	Station names	latitude	longitude	A (km2)	Period of record	MAF (m^3/s)	MAF/A (% $m^3.s^{-1}/Km^2$)
01CA003	CARRUTHERS BROOK NEAR ST. ANTHONY	46.74411	-64.187	46.8	1961-2016	0.98	2.09
01CB002	DUNK RIVER AT WALL ROAD	46.34586	-63.63333	114	1961-2016	2.57	2.26
01CB004	WILMOT RIVER NEAR WILMOT VALLEY	46.39331	-63.65939	45.4	1972-2016	0.95	2.08
01CC002	WINTER RIVER NEAR SUFFOLK	46.33206	-63.06547	37.5	1967-2016	0.67	1.80
01CC005	WEST RIVER AT RIVERDALE	46.23139	-63.35108	70.1	1986-2016	1.84	2.62
01CC010	WINTER RIVER AT UNION	46.31481	-63.12336	16.8	1992-2016	0.24	1.44
01CD005	BEAR RIVER AT ST. MARGARETS	46.45314	-62.38233	14.8	1995-2016	0.39	2.65

Given that stations 01CC010 and 01CC002 are highly impacted, they were not considered in the characterization of metrics for natural systems.

4. Results

4.1. Q50, 70%Q50 and Q95 and low-flow statistical metrics

Table 3 presents flow metrics for each station. The table also presents the best distribution used for the estimation of quantiles from statistical low-flow frequency analysis (7Q2 and 7Q10). The two metrics calculated using frequency analysis, 7Q10 and 7Q2, should theoretically be estimated using the statistical distribution that best fitted the data at each station. This would mean that the underlying statistical model changes from station to station. To alleviate this problem, a common distribution that could be adjusted to all stations was selected. It is acknowledged that the Generalized Extreme Value distribution (GEV) is often best suited for this. The Kolmogorov-Smirnov goodness of fit test showed that the minimum of 7-days average can be thought of as being distributed according to the GEV. Table 3 and Figure 3 compare the metrics with the 7Q2 and 7Q10 fitted with the GEV distribution.

Table 3: Metrics calculated using Flow duration method and low-flow frequency analysis method.

Station	**MAF (m^3/s)**	**Q50 (m^3/s)**	**70%Q50 (m^3/s)**	**Q95 (m^3/s)**	**Distribution**	**7Q2 (m^3/s)**	**7Q10 (m^3/s)**
01CA003	**0.98**	**0.50**	**0.32**	**0.14**	**GEV**	0.15	0.10
01CB002	**2.57**	**1.70**	**1.15**	**0.62**	**Gamma**	0.88	0.62
01CB004	**0.95**	**0.63**	**0.44**	**0.32**	**Gamma**	0.32	0.23
01CC005	**1.84**	**1.25**	**0.87**	**0.60**	**Gumbel**	0.58	0.46
01CD005	**0.39**	**0.23**	**0.16**	**0.07**	**GEV**	0.06	0.04

For all stations, sorting from the most to less restrictive criterion, yields the following order: MAF, Q50, 70%Q50, 7Q2, Q95 and 7Q10. Because maximum difference between Q95 and 7Q2 is 0.02 $m^3.s^{-1}$, we can say that both metrics give very similar values and it should be noted that Q95 is easier to calculate than 7Q2. Stations 01CA003 and 01CB004 have similar drainage areas (46.8 km^2 and 45.4 km^2 respectively) and hence, similar metrics. The number of years of available data at station 01CA003 is 56 years and 45 years at station 01CB004. Figure 3 provides a more visual comparison of metrics. Again, with the possible exception of station 01CB002, the similarity between Q95 and 7Q2 can be noted.

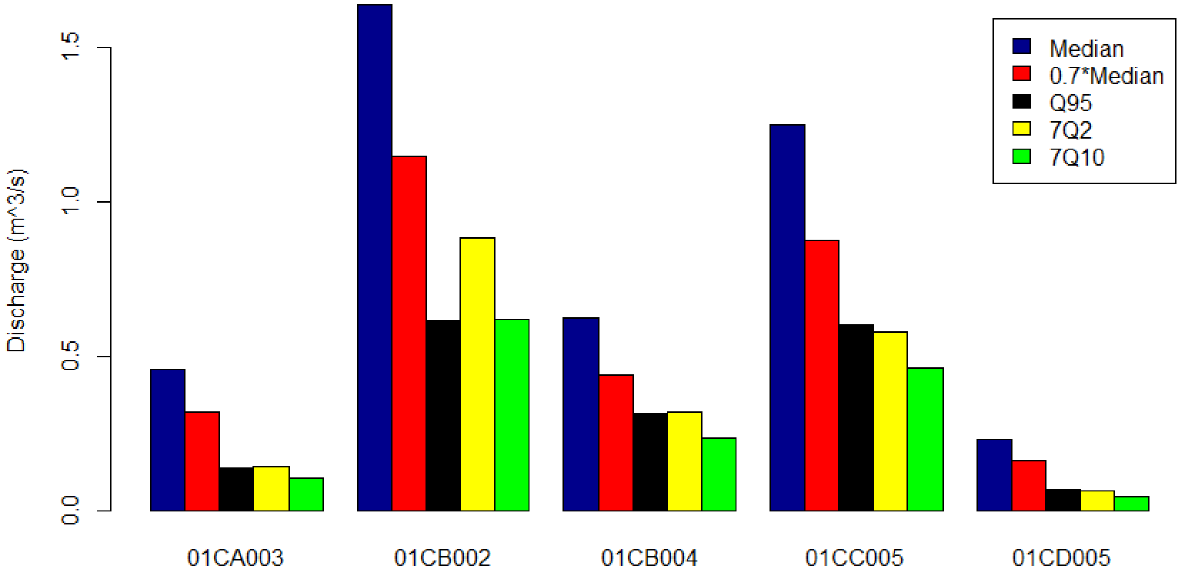


Figure 3: Comparison between statistical low flows indices when the GEV is used to estimate 7Q2 and 7Q10.

Table 4 shows the values of the same indices, in specific discharge. This means that each flow value was divided by the drainage area at the gauging station. Table 4 also shows that specific low flow indices Q95 and 7Q2 are very similar.

Table 4: Interannual Metrics calculated using Flow duration method and low-flow frequency analysis divided by drainage area

Station	**Drainage area**	**MAF**	**Q50**	**70%Q50**	**Q95**	**7Q2**	**7Q10**
	(km2)	**(m^3/s/km2)**	**(m^3/s/km2)**	**(m^3/s/km2)**	**(m^3/s/km2)**	**(m^3/s/km2)**	**(m^3/s/km2)**
01CA003	**46.800**	**0.021**	**0.009**	**0.007**	**0.003**	**0.003**	**0.002**
01CB002	**114.000**	**0.023**	**0.015**	**0.010**	**0.006**	**0.008**	**0.005**
01CB004	**45.400**	**0.021**	**0.014**	**0.010**	**0.007**	**0.007**	**0.005**
01CC005	**70.100**	**0.026**	**0.018**	**0.012**	**0.009**	**0.008**	**0.007**
01CD005	**14.800**	**0.026**	**0.016**	**0.011**	**0.005**	**0.004**	**0.003**

- Q50 ranges between 42-70% MAF,
- 70%Q50 ranges between 33-48% MAF,
- Q95 ranges between 14-35% MAF,
- 7Q2 ranges between 14–36% MAF,
- 7Q10 ranges between 10-27% MAF.

Figure presents boxplots of the percentage of MAF for monthly values of Q50, 70%Q50, and Q95 flow at station 01CA003. The same figures were produced for the other stations in Appendix A. All metrics have the same pattern of inter-monthly variation. The highest values are observed in April and the lowest values in September, except for a few stations for which the lowest values can be found in August.

Monthly statistics were calculated as means for a particular month through the years of the record. As expected, the inter-annual monthly values of 70%Q50 are close to the median of the monthly 70%Q50. At station 01CA003 in April, the median of monthly Q50 is 261% MAF, the median of monthly 70%Q50 is 183% MAF, the median of monthly Q95 is 107%MAF and the inter-annual monthly mean of 70%Q50 is 170% MAF. At the same station, during the lowest flow month (September), the median of monthly Q50 is 18% MAF, the median of monthly 70%Q50 is 13% MAF, the median of monthly Q95 is 15%MAF and the inter-annual mean monthly of 70%Q50 14% MAF.

For all stations, in the highest flow month of April the median of:

- Q50 ranges between 39-500 % MAF,
- 70%Q50 ranges between 12-355 % MAF,
- Q95 ranges between 22-289% MAF,
- inter-annual monthly mean of 70%Q50 ranges between 140-228% MAF

For lower flow months (August),

- Q50 ranges between 12-90% MAF,
- 70%Q50 ranges between 8-63% MAF,
- Q95 ranges between 2-37% MAF,
- inter-annual monthly mean of 70%Q50 ranges between 9-40% MAF

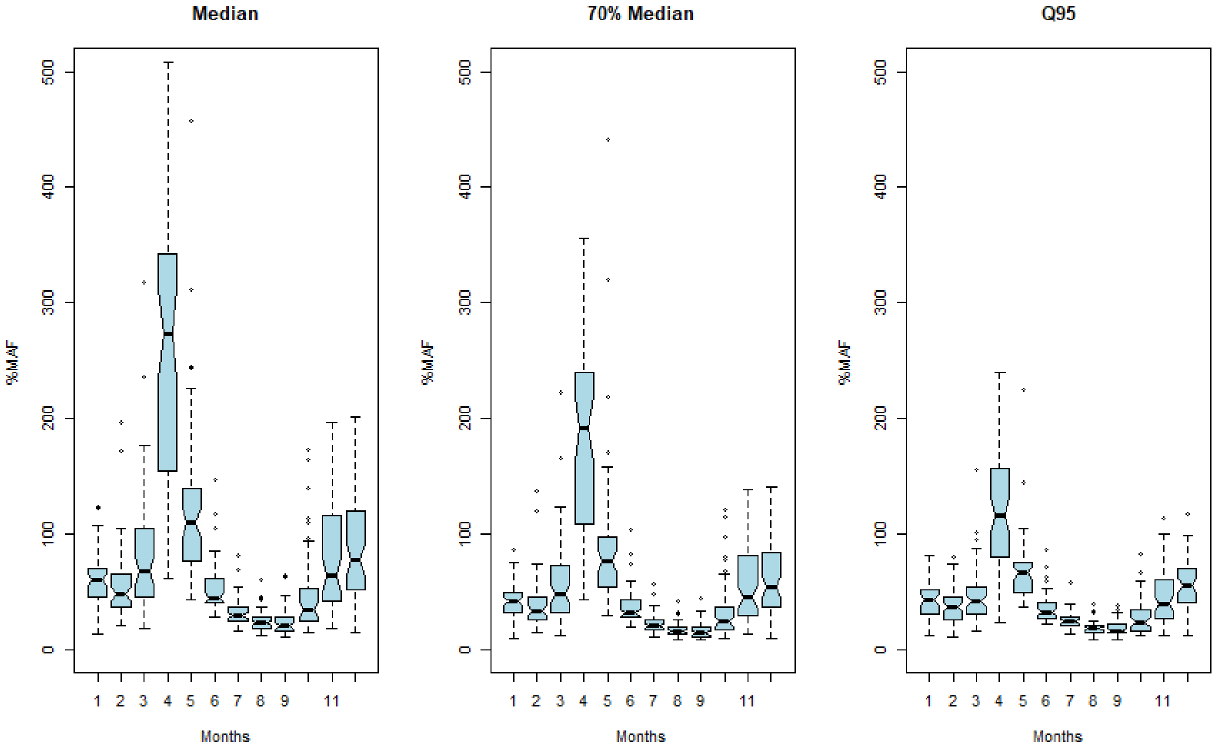


Figure 4: Station 01CA003: Boxplots of percentage of MAF for month duration metrics.

Duration metrics have also been converted to specific discharge values by dividing them by drainage area. Figure presents these ratios for annual metrics as well as for the monthly values for the months with the lowest discharge. The figure shows that during the month with the lowest discharge values, 70%Q50 is between 4 to 7 L/s/km^2 of drainage area, except for stations 01CA003 (2L/s/km^2) and 01CC010 (0.5 L/s/km^2). The latter is impacted by withdrawals.

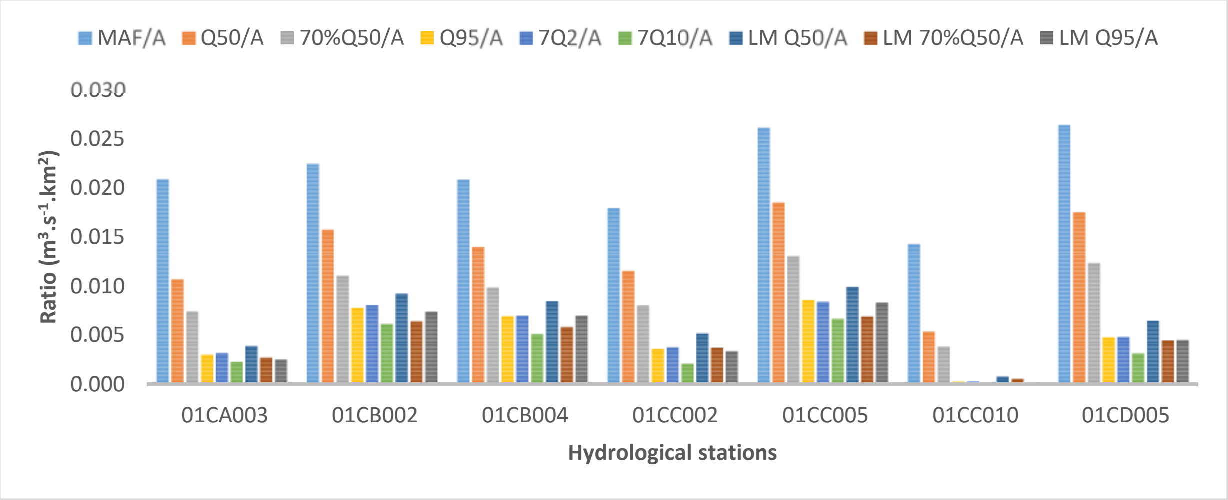


Figure 5: Ratio between metrics and drainage area $m^3.s\text{-}^1.km^{-2}$. LM means that values are evaluated on the month with the lowest discharge.

4.2. Sustainable Boundary and presumptive Standard approaches

Figure 6 presents the results of PS and SB approaches at station 01CA003 with the two levels of protection suggested by (Richter, et al., 2011). The red curve represents the inter-annual monthly means of 70%Q50.

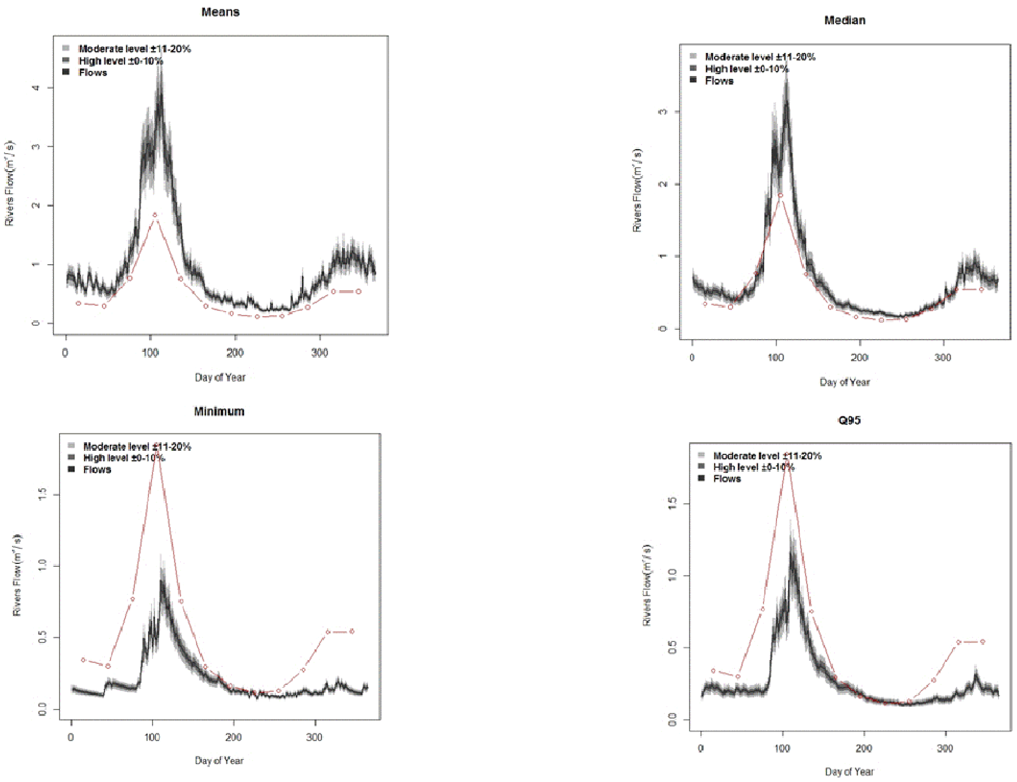


Figure 6: Station 01CA003: Sustainable Boundary and Presumptive Standard approaches with different flow statistics (mean, median, minimum, Q95) used as the guideline. The red curve represents the inter-annual monthly stream flow preserved in the stream after depletion allowed in PEI (Q70 - 70%Q50). .

In Figure 6, it is assumed that "normal flow" can be quantified using daily mean and daily median flow. Similarly, "low flows" are characterized using inter-annual daily Q95 and daily minimum values. These guidelines can be reviewed subsequently by local expertise. The first (dark) interval of values around the black line is used to provide a range of values that would maintain a high level of ecological protection with ±0-10% of allowable augmentation and depletion. The second (grey) interval shows a range of values providing a so-called moderate level of protection with ±11-20% of allowable augmentation and depletion. Figure 7 is an example for one station and similar results were found for the other stations

After the evaluation of PS/SB approaches, we have evaluated the minimum values for a moderate level ecological protection. This has been done with "normal flows" (daily mean and median) and "low flows" (daily minimum and Q95). Using historical data, for each year and each level of protection, the number of days when the ecological protection was not respected were counted. Figure 747 presents for each year, for "normal" and "low" flows, the number of days for which the moderate level is not met. This is compared with the number of days that inter-annual monthly 70%Q50 is larger than the observed flow. For other stations, similar figures are presented in appendix B.

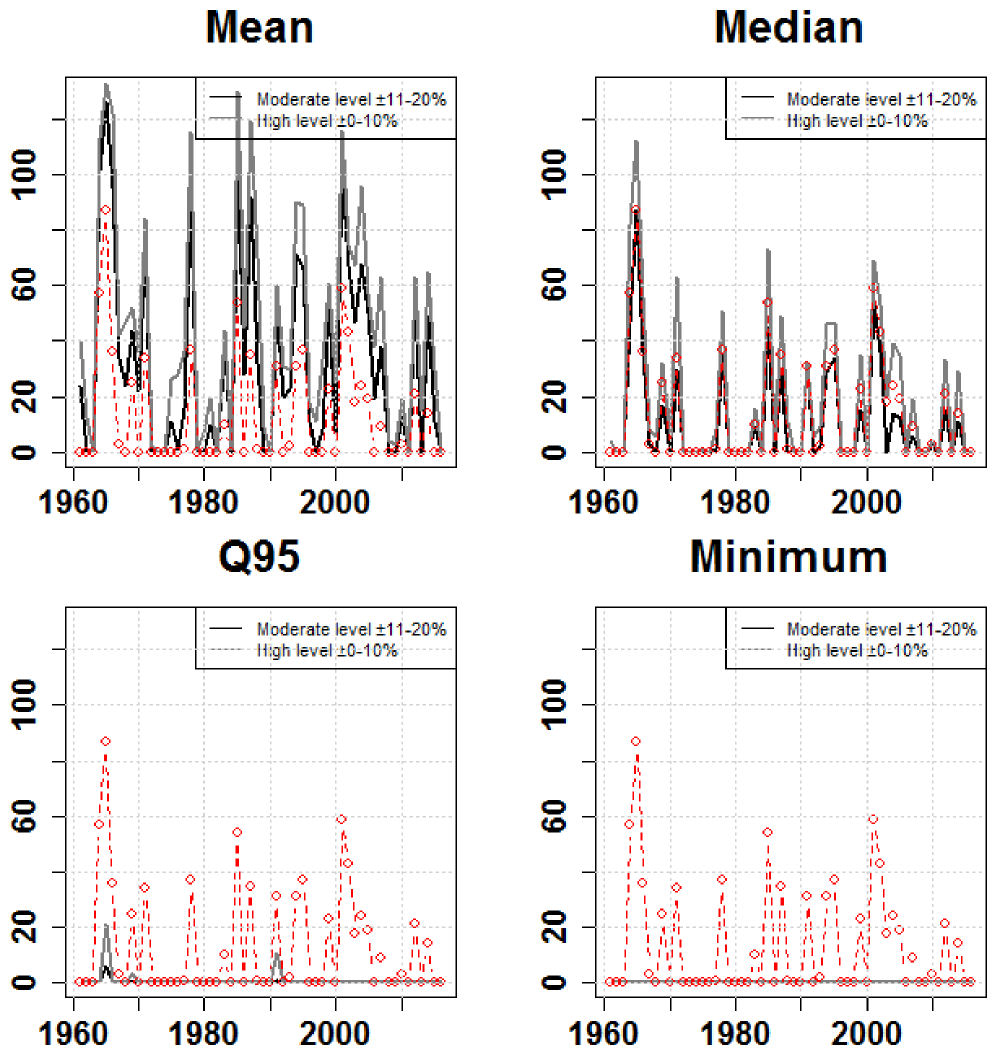


Figure 74: Number of days when the lower threshold of moderate level of protection is not respected. The red curve represents the number of days when the minimum inter-annual mean monthly of 70%Q50 is not respected: Station 01CA003

Obviously, if the low flow considered as a threshold is the minimum flow, the observed flows always exceed this value. If we suppose that the ecological protection criterion is defined by the mean, the number of days where the criterion is not respected is large. That is less the case for the median and Q95. Ordering by the most to less restrictive ecological protection we have: mean, Q50, Q95. The results obtained at stations other than 01CA003 have resulted in the same conclusion (see figures in Appendix B). It is difficult to clearly decide that one metric is better than the other without biological/ecological validation. The comparison with the number of days that the smaller inter-annual monthly 70%Q50 is smaller than the observed flow show that, on each year and all stations, the number of days of threshold exceedance obtained using inter-annual mean monthly 70%Q50 are smaller than those obtained with mean (High and moderate level protect) and median (high level protection). However, they are close to the number of days obtained with median (moderate level protection) and higher than the number of day obtained with Q95 and minimum (high and lower level protection).

In order to compare with the flow duration method, the minimum values for “moderate” and “high” levels of ecological protection defined using the SB approach are divided by the MAF of each station. To obtain Figure , we evaluated the minimum of the moderate level on “low flow” and “normal flow” then divided the result by MAF for each station. Except for 01CB002, where the mean moderate level is more restrictive than the median high level, the most to least restrictive ecological protection for all other stations are ordered as follows: minimum moderate (MiM), minimum high (MiH), Q95 moderate (Q95M), Q95 high (Q95H), median moderate (Q50M), median high (Q50H), mean moderate (MM) and mean high (MH).

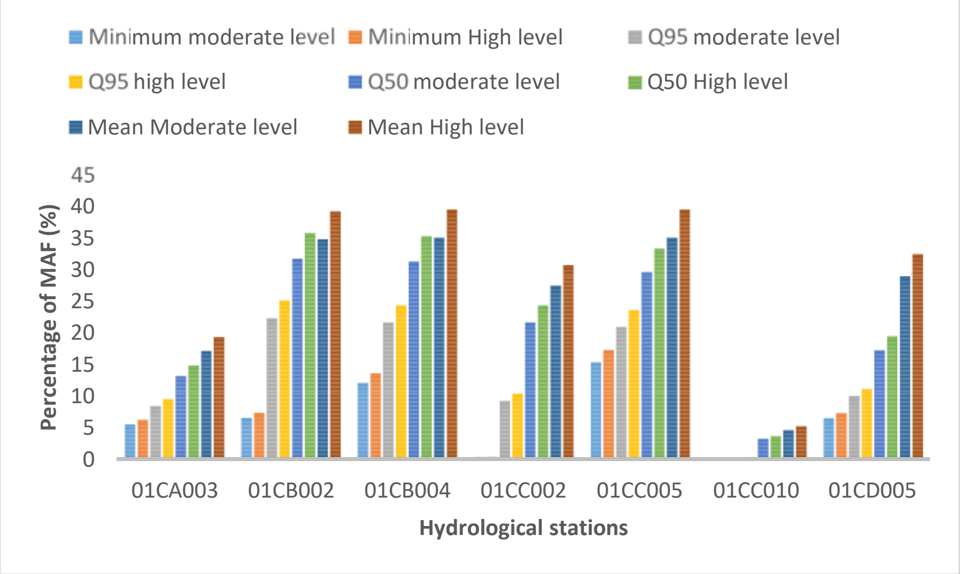


Figure 8: Ratio between moderate and high level of protection evaluated on SB approaches and MAF.

For all other stations 5 stations (excluding 01CC002 and 01CC010), the ranges are:

- MiM ranges between 0.3 - 12% MAF.
- MiH ranged between 0.4 - 12% MAF.
- Q95M ranged between 9 – 24 % MAF
- Q95H ranged between 10 - 29% MAF
- Q50M ranged between 13 - 32% MAF
- Q50H ranged between 19 – 36 % MAF

- MM ranged between 17 - 35% MAF
- MH ranged between 19 -40 % MAF

4.3. Range of Variability approaches

The RVA approach uses a number of Indices of Hydrological Alteration (IHA: descriptive statistics derived from flow time series) to investigate the variability in amplitude, timing, duration and frequency of hydrological events. Table 5 presents the range of variability metrics (the mean, standard deviation, minimum and maximum of each 32 IHA variables for Station 01CA003). For all other stations, similar tables are presented in Appendix C.

Table 5: Indicators of Hydrologic Alteration (IHA) variables of the 01CA003 station.

		Short Name	Average	SD	Low	High
Group 1: Magnitude of monthly water conditions (m^3/s)	January	G1JA	0.77	0.82	0.10	10.70
	February	G1FE	0.66	0.73	0.10	9.50
	March	G1MA	1.27	1.66	0.14	18.40
	April	G1AP	3.20	2.87	0.38	35.00
	May	G1MY	1.59	2.02	0.30	24.80
	June	G1JN	0.61	0.57	0.19	7.10
	July	G1JL	0.36	0.33	0.11	4.20
	August	G1AU	0.29	0.44	0.07	7.60
	September	G1SE	0.28	0.41	0.08	11.00
	October	G1OC	0.59	0.99	0.09	20.20
	November	G1NO	1.00	1.19	0.11	14.60
	December	G1DE	1.15	1.59	0.11	39.70
Group 2: Magnitude and duration of annual extreme water conditions (m^3/s)	1-day means maxima	G21MI	11.72	6.40	4.40	39.70
	1-day means minima	G21MA	0.14	0.04	0.07	0.26
	3-day means maxima	G23MI	9.15	4.64	3.32	25.67
	3-day means minima	G23MA	0.15	0.04	0.08	0.27
	7-day means maxima	G27MI	6.85	3.22	2.24	18.67
	7-day means minima	G27MA	0.15	0.04	0.09	0.28
	30-day means maxima	G230MI	3.95	1.51	1.43	8.17
	30-day means minima	G230MA	0.18	0.06	0.10	0.36
	90-day means maxima	G290MI	2.12	0.54	1.01	3.28
	90-day means minima	G290MA	0.25	0.09	0.11	0.54
Group 3: Timing of annual extreme water conditions (Days)	Julian date of each annual 1 day maximum	G3MA	102.52	33.63	15.00	248.00
	Julian date of each annual 1 day minimum	G3MI	255.07	25.99	202.00	357.00
Group 4: Frequency and duration of high and low pulses (Days)	Low pulse count	G4LPC	1.45	1.14	1.00	7.00
	High pulse count	G4HPC	1.00	0.00	1.00	1.00
	Low pulse duration	G4LPD	1.30	0.87	1.00	6.00
	High pulse duration	G4HPD	1.00	0.00	1.00	1.00
Group 5: Rate and frequency of water condition changes	Fall rate (m^3/s)	G5FR	0.48	0.20	0.14	1.18
	Rise rate (m^3/s)	G5RR	-0.20	0.09	-0.59	-0.07
	Number of reversal	G5NR	110.96	15.49	46.00	141.00

Figure presents the monthly mean flows divided by drainage area for all hydrological stations in Group 1 of IHA (metrics related to amplitude). For all stations, the monthly maximum is in April. The minimum is in September for stations 01CA003, 01CB004, 01CC002 and August for stations 01CC005, 01CC010, 01CD005. For every month, Station 01CB002 has the highest specific monthly discharge. Station 01CC010, which is highly impacted, has the smallest one. Those values range between 1.22 – 5.61 ($m^3.s^{-1}/km^2$) for 01CB002 and 0.03 – 0.74 ($m^3.s^{-1}/km^2$) for 01CC010.

Figure 5 and Figure 6 present respectively the mean of minima and maxima of magnitude and duration of extreme water conditions divided by drainage area (Group 2).

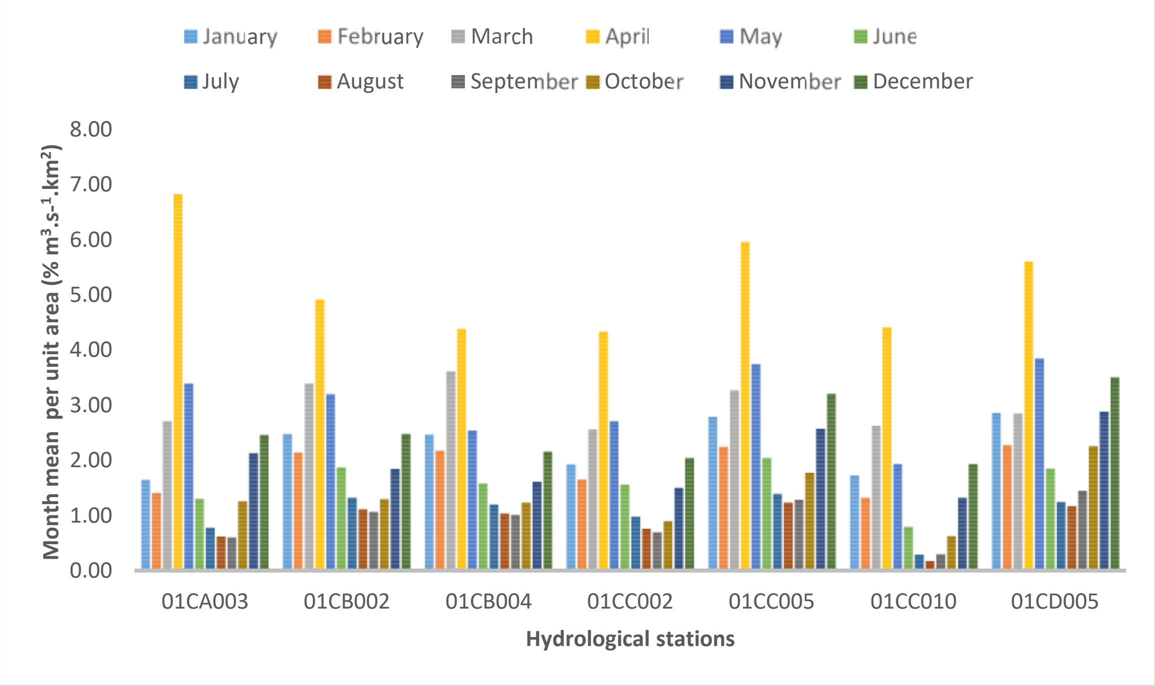


Figure 9: Mean of first group of IHA parameter for all stations.

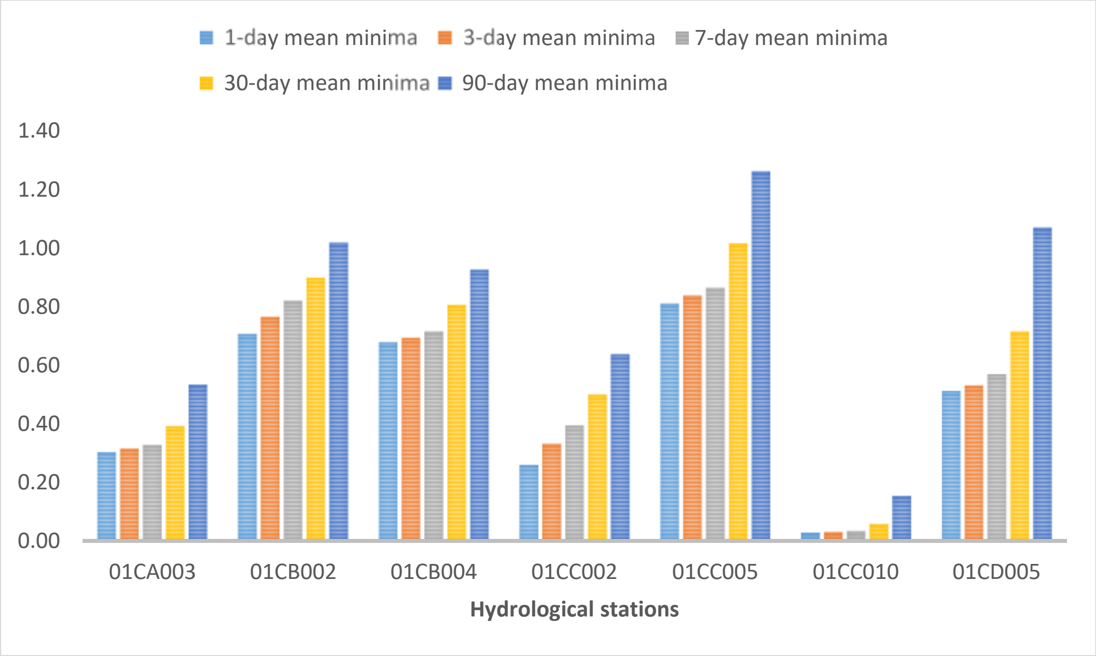


Figure 5: Interannual mean of minima for different durations at all stations (Group 2)

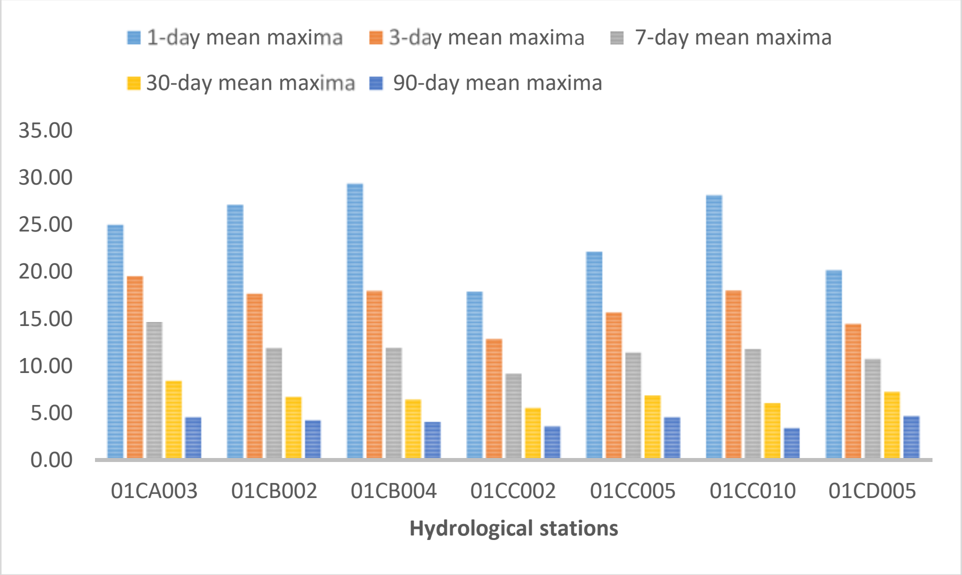


Figure 6: Interannual mean of maxima for different durations at all stations (Group 2)

Error! Reference source not found. Figure presents the durations of high and low pulse averages (Group 4). The high pulse count and duration averages are equal to 1 at all stations (1 event of duration 1 day). Except at station 01CC0010 where the low pulse count and low pulse duration averages are respectively equal to 8.48 days and 4.28 days, the averages range between

1 - 1.45 days. As can be seen on Figure , low flow periods can be relatively long at station 01CC010, with several consecutive days having very similar flow values. This explains the higher values of low pulse count and duration at station 01CC0010. Given that this station is highly impacted by groundwater extraction, it should not be included in future analyses.

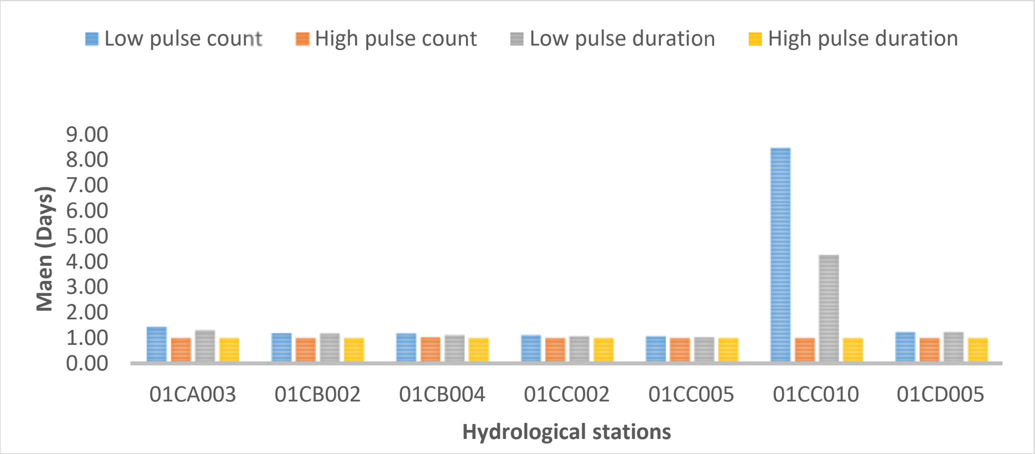


Figure 7: Mean total annual number of days and mean duration of low and high flow pulses for all stations (Group 4)

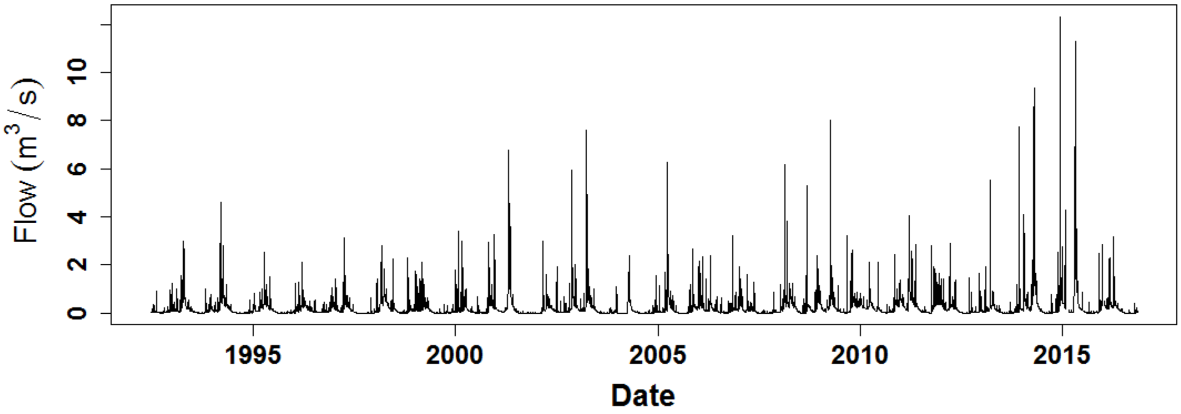


Figure 8: Observed discharge at station 01CC010

Figure and 15 present the average rate of discharge fall and rise and the number of reversals (change between fall and rise of hydrogram). The fall changes are positive and smaller than 1 (m^3/s) and the rises are negative and larger than -1 (m^3/s). The number of reversal range between 108-152 days.

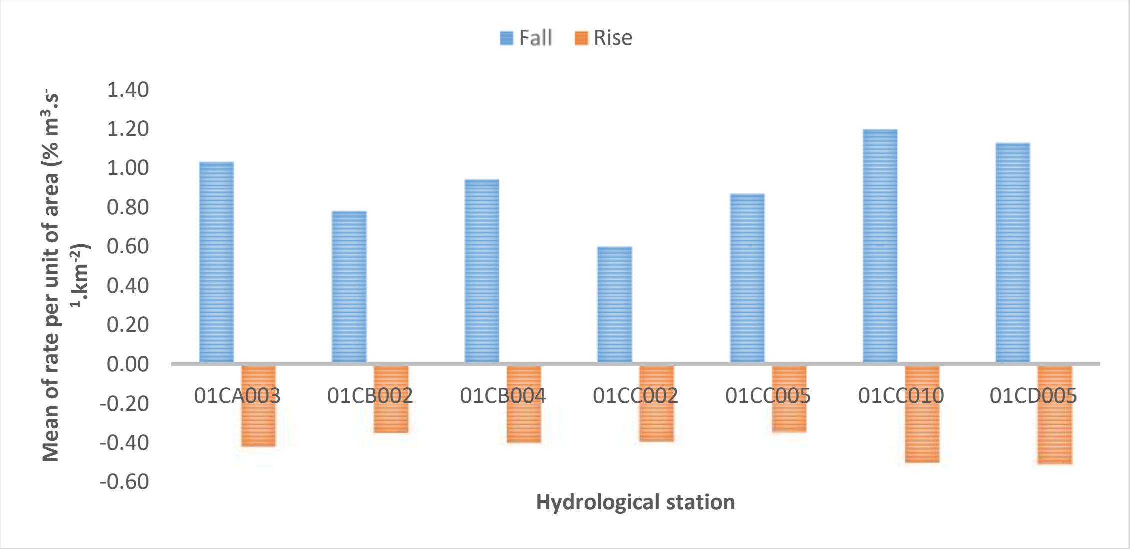


Figure 9: Mean of rate of water condition changes on all stations (Group 5)

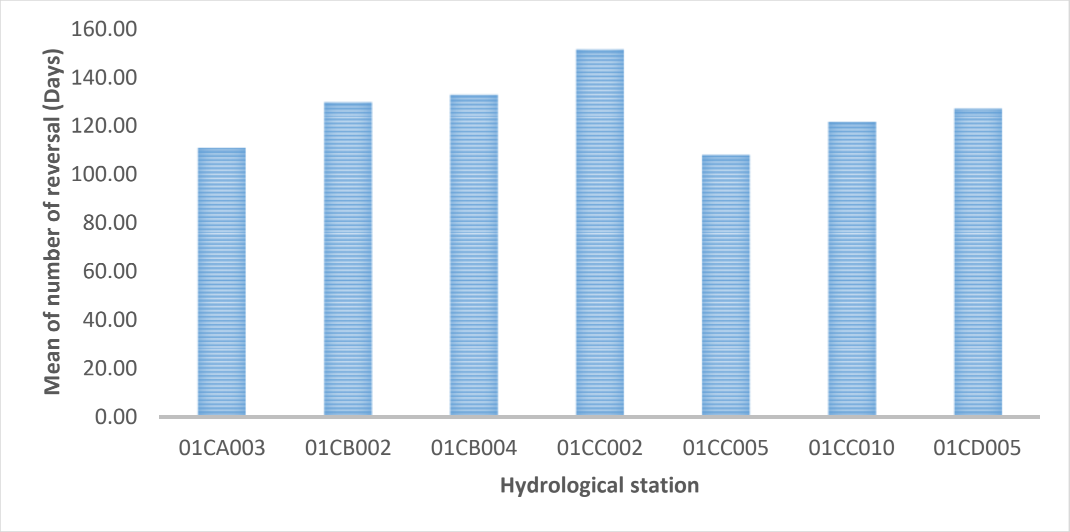


Figure 10: Mean number of reversals for all stations (Group 5)

4.4. Result of metrics analysis

4.4.1. Q50, 70%Q50, Q95 and statistical low-flow metrics

A Principal Component Analysis (PCA) performed on all metrics is presented in Figure . The first Principal Component (PC) explains 92% of the variance of original metrics and the two first components explain more than 97% of variation. All metrics are well represented by two component. Two groups of metrics can be identified on the PCA graph: The first one includes MAF, Q50 and 70%Q50, which can characterize the central values of the distribution of discharge, or “normal flows”, while the second group of metrics is more associated with “low flow”.

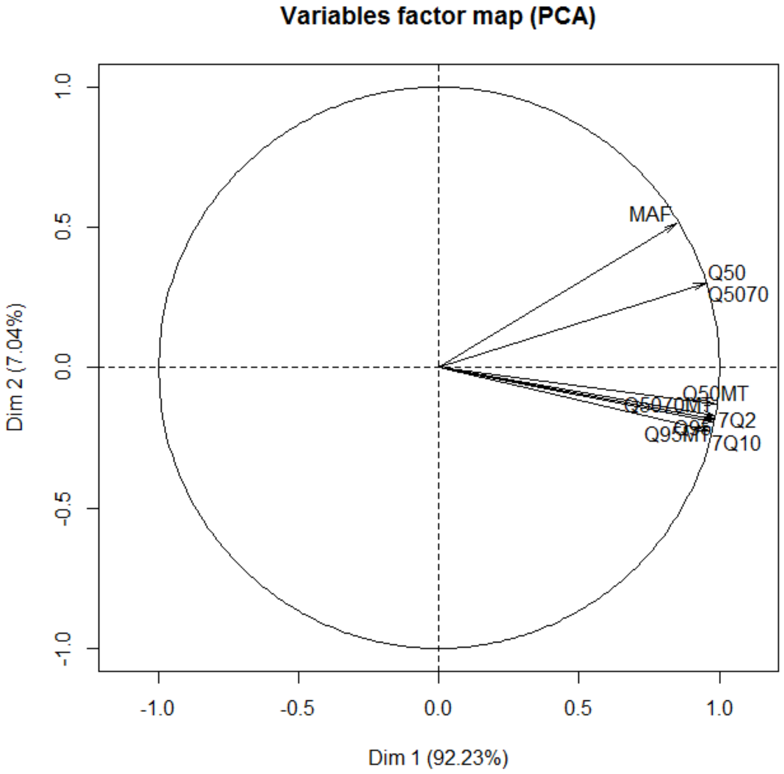


Figure 16: Principal Component Analysis on metrics.

The hierarchical clustering was completed using first two principal components in order to group stations according to their hydrological behavior. Figure 17 presents the dendrogram and the cluster project on first two component of PCA. This allowed us to cluster our station in 5 groups. The first group (blue) contain stations 01CB002 and 01CB004. The second group (red) contain stations 01CA003 and 01CC002. Other group have only one station.

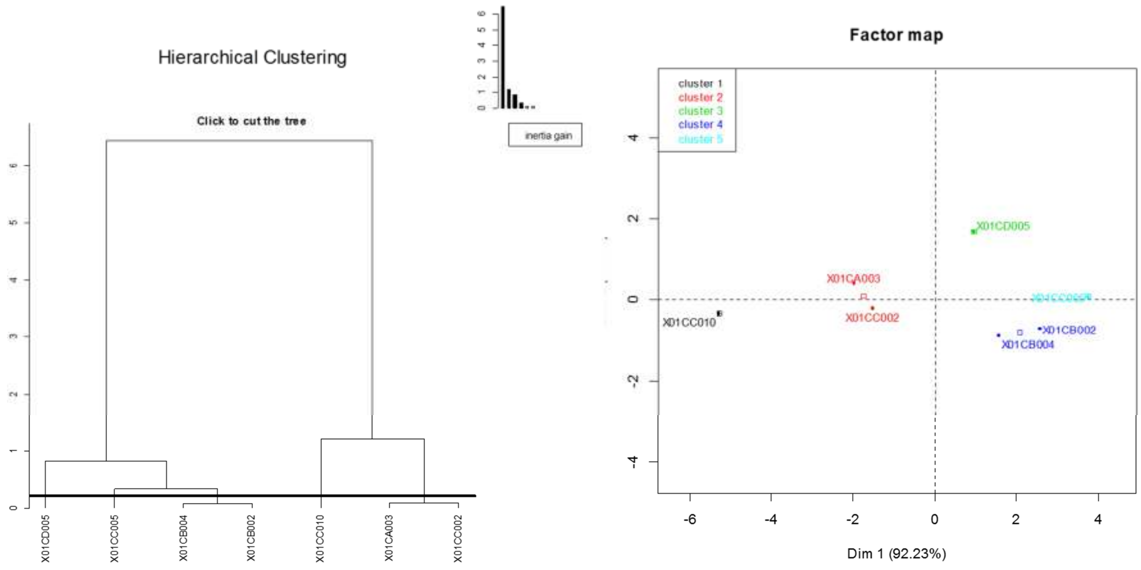
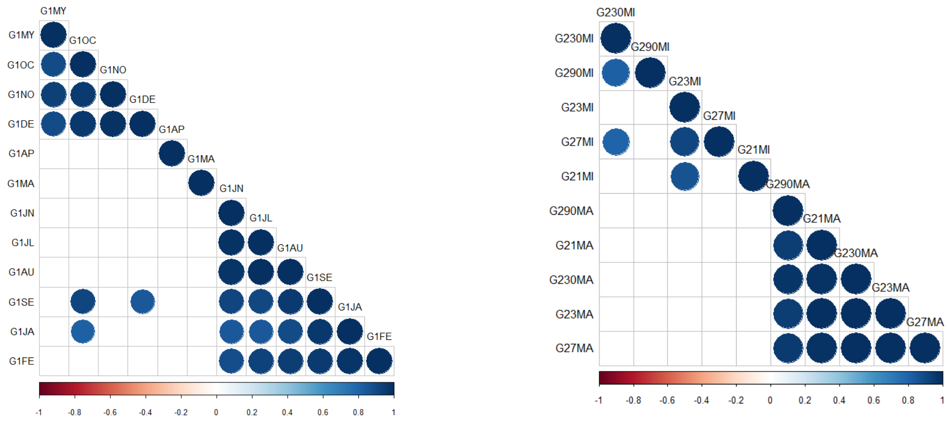


Figure 17: Hierarchical clustering of stations based on PCA

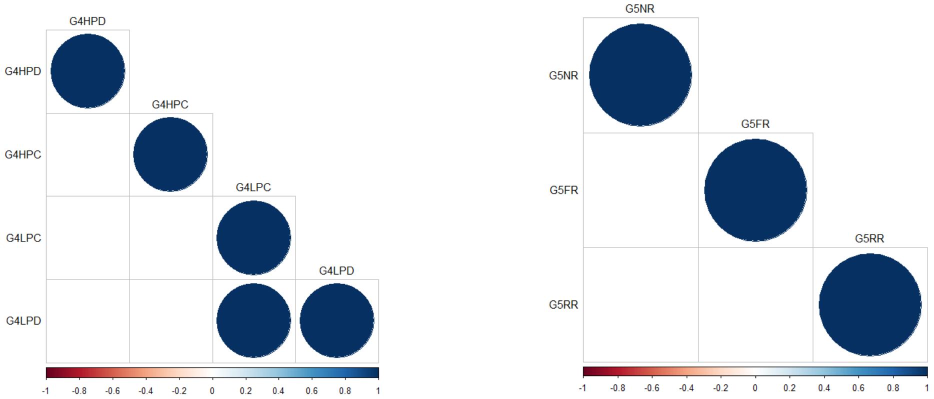
4.4.2. Indicators of Hydrologic Alteration

Because the number of IHA variables is greater than the number of station, we start this analysis by eliminating some redundant IHAs using correlation analysis.

The correlation coefficients are evaluated on the mean of IHA for each station. For instance: For the first group we have the correlation coefficient matrix evaluated on the 12X7 matrix (12 selected IHA x 7 hydrometric stations). The aim here is to select the non-correlated IHA or one parameter on the group of correlated IHA. In Table 16 we present the IHA and their short name. Figure 118 presents the correlations coefficients higher than 0.8 or lower than -0.8 of each group of IHA. On the first group of IHA, we have a correlation between G1MY, G1OC, G1ON and G1DE. We also have a correlation between G1JN, G1JL, G1AU, G1JA and G1FE. G1AP and G1MA are not-correlated. By the end, four IHA can be used for Group 1: G1MY, G1AP, G1MA and G1FE. Because we have a correlation between G1OC and G1JA, Group 1 can be represented by G1OC, G1AP and G1MA. Using the same reasoning, Group 2 can be represented by G230MI, G290MA and G23MA. Group 3 can be represented by G4HPD, G4HPC, and G4LPC. Group 5 and 3 can be represent by all their IHA.



Group 1 Group 2



Group 4 Group 5

Figure 11 : Correlation coefficient on each group of IHA. Correlations coefficients presented here are those who higher than 0.8 or lower than -0.8.

Using the selected IHA presented in Table 6, PCA was performed to further reduce the number of relevant indices, followed by hierarchical clustering to classify the stations. Figure 19 presents the results of PCA on selected IHA. The first tree component explain more than 80% of variance. Our aim is to select uncorrelated metrics in each group of IHA and keep at least one metric per group. Using these criteria, G230MI or G1AP and G5RR or G290MA can be selected.

Table 6: Selected IHA

		Short Name
Group 1: Magnitude of monthly water conditions: (m3/s/km2)	March	G1MA
	April	G1AP
	October	G1OC
Group 2: Magnitude and duration of annual extreme water conditions: (m3/s/km2)	3-day means maxima	G23MA
	30-day means minima	G230MI
	90-day means maxima	G290MA
Group 3: Timing of annual extreme water conditions (Days)	Julian date of each annual 1 day maximum	G3MA
	Julian date of each annual 1 day minimum	G3MI
Group 4: Frequency and duration of high and low pulses (Days)	Low pulse count	G4LPC
	High pulse count	G4HPC
	High pulse duration	G4HPD
Group 5: Rate and frequency of water condition changes	Fall rate (m3/s/km^2)	G5FR
	Rise rate (m3/s/km^2)	G5RR
	Number of reversal (Days)	G5NR

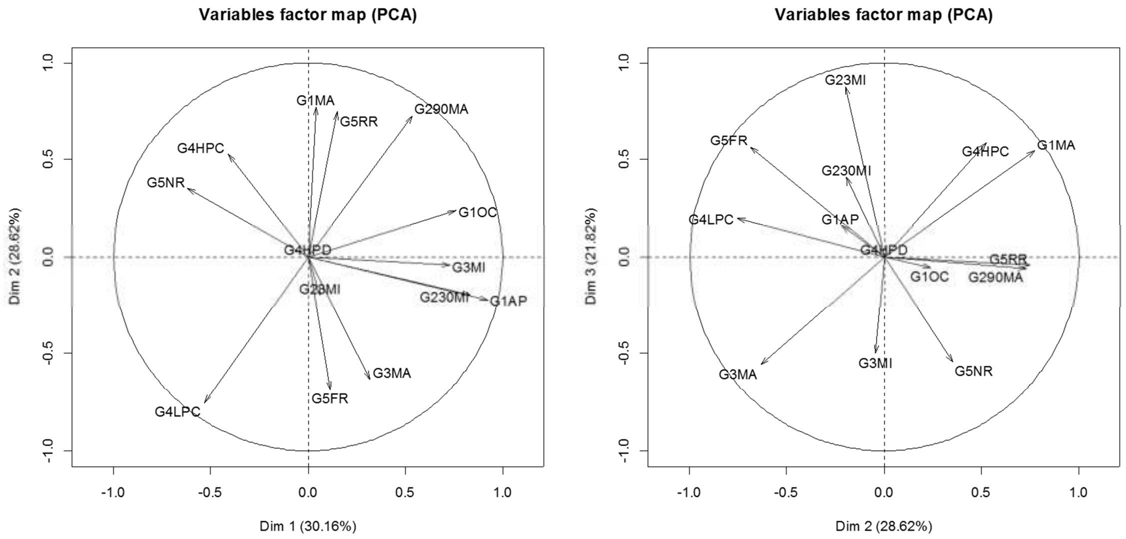


Figure 1912: Principal component analysis on selected IHA.

A second hierarchical clustering was constructed using the first tree principal components. Figure presents the result of HC on selected IHA. Here, there is only one group with two stations (01CB002 and 01CC005). Other groups contain only one station. When compared with Figure 17, it can be seen that the two stations grouped together by HC were also identified as being similar in the previous analysis.

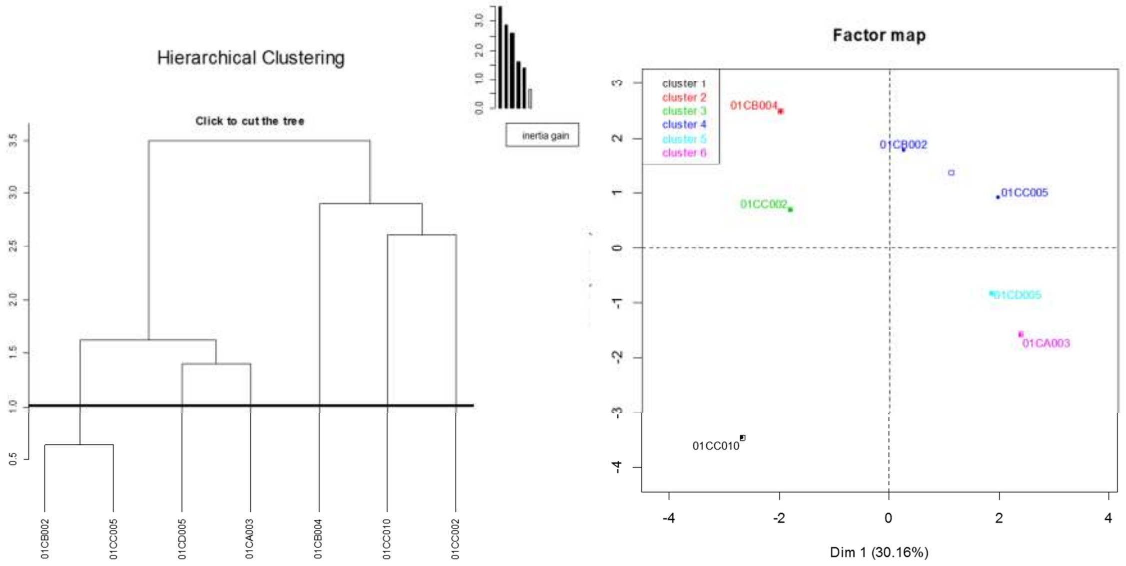


Figure 20: Hierarchical clustering on selected IHA

To compare the results of stations classification made with Flow duration methods and statistical low-flow metrics and those obtained with IHA metrics, we assume that we want only tree groups of hydrological stations. For each group of metrics we have tree groups at stations: One group with one station, one with two stations and the last group with four stations. When the metrics used change, the stations groups change too. Only group 3 has common hydrological stations with the two classification approaches.

Table 7: Hydrological station group.

	Goup1	Goup2	Group3
Classification with Flow duration methods and statistical low-flow metrics	01CC010	01CA003, 01CC002	01CC005,01CD005, 01CB004,01CB002
Classification with IHA metrics	01CB004	01CC010, 01CC002	01CB002, 01CC005, 01CD005, 01CA003

5. Conclusion

The following methods: duration (Q50, 70%Q50, Q95), low-flow frequency analysis (7Q10, 7Q2), Range of Variability, Sustainable Boundary and Presumptive Standard approaches were used to compare potential E-flow criteria at 7 hydrological stations in PEI. The metrics were compared to the MAF and the monthly 70%Q50. Those metrics can be used to define a level of ecological protection for several rivers in PEI.

These approaches have allowed us to compare daily, monthly and yearly metrics to MAF and monthly 70%Q50, the latter being the metric currently used to manage E-flows in PEI rivers. For yearly metrics, the order of metrics from most to least restrictive are: MAF, Q50, 70%Q50, 7Q2, Q95 and 7Q10. The duration metrics have also been evaluated month by month at all stations and compared to the inter-annual monthly 70%Q50. The peak is always in April and the minimum value in August or September, depending on stations. Compared to the median of each metrics, the annual monthly 70%Q50 is always more restrictive than Q95 in April and less restrictive than Q95during the summer. Compare to the median, the inter-annual monthly 70%Q50 are in general most restrictive than Q50 and less restrictive than Q95.

According to Caissie et al. (2014), when the drainage area is smaller than 130 km^2, low flow metrics should be evaluated on the month with lowest discharge. Because all of the drainage areas of our basins area are smaller than 130 km^2, we have compared metrics evaluated on available data to metrics evaluated on data available for the month with the lowest flow. Obviously, the metrics evaluated on against that period of the year are more restrictive than those calculated on annual flow statistics or other months.

Using a PCA, low-flow and duration metrics evaluated on all available data and on low-flow month, we defined three groups of stations. The grouping associated with Q50, 70%Q50 and Q95 and low-flow quantiles is not the same as the grouping obtained using IHA metrics. Further analysis will be required to select the best approach to define groups of hydrological stations.

The SBA is defined for "normal" (daily Mean and Median) and "low" flow (daily Q95 and minimum) with two levels of alteration (high: ±1-10%, moderate: ±11-20%). We show that, the 70%Q50 values are less restrictive than "normal" flow SBA for each month. 70%Q50 is more restrictive than "low"-flow SBA for each month for several stations, but not all. In order to compare the SBA to duration metrics, we evaluated the lower values on each alteration level and compared it to MAF. We showed that the SBA values are more restrictive than the duration method.

For the range of variability approaches, 32 hydrological alteration variables were calculated at each station. Those variables are separated in four groups: in the first group, the variables define the magnitude of monthly water conditions. Group 5 of RVA shows that mean of number of high pulse count is equal to one (i.e. only the spring flood is considered). Except for one station (01CC0010) where the low pulse duration is on average equal to 4.28 days and the low pulse count is on average equal to 8.48 days, all other stations have values around 1 day for both metrics. The inter-annual monthly 70%Q50 is used in PEI to define the environmental flows.

The correlation analysis allowed us to reduce the number of IHA from 32 to 14. The 14 selected IHA are those for which the intra-Group correlation coefficients are between 0.8 and -0.8. Using PCA we can reduce from 14 to 12 IHAs (G1MA, G1AP, G1OC, G23MA, G290MA, G3MA, G3MI, G4LPC, G4HPC, G4HPD, G5FR, G5NR). The next step in implementing RVA would be to investigate flow requirements to maintain the properties of the hydrograph represented by the values of the selected IHAs.

Although all of previously defined metrics are easy to estimate, the difficulty resides in the interpretation of obtained results. To have the best interpretation of results, it is important to acquire more physiographic and hydraulic data on the investigated rivers. This will help us to define different level of ecological protection or acceptable level of water in the rivers and consequently the best metrics.

As with the study of Richter et al. (1997), which compared IHA for pre-dam and post-dam conditions, the IHA could be used for the evaluation of the ecological alteration as a function of climate change. To achieve this, synthetic flow time series associated with future climate scenarios will have to be generated using a calibrated hydrological model that uses climate model outputs (e.g. precipitation and air temperature scenarios for the 2050 or 2100 horizons). It is also the case of SBA, which can be used to compare the median alteration of two periods (Golladay & Hicks, 2015).

Appendix A: Result of duration method

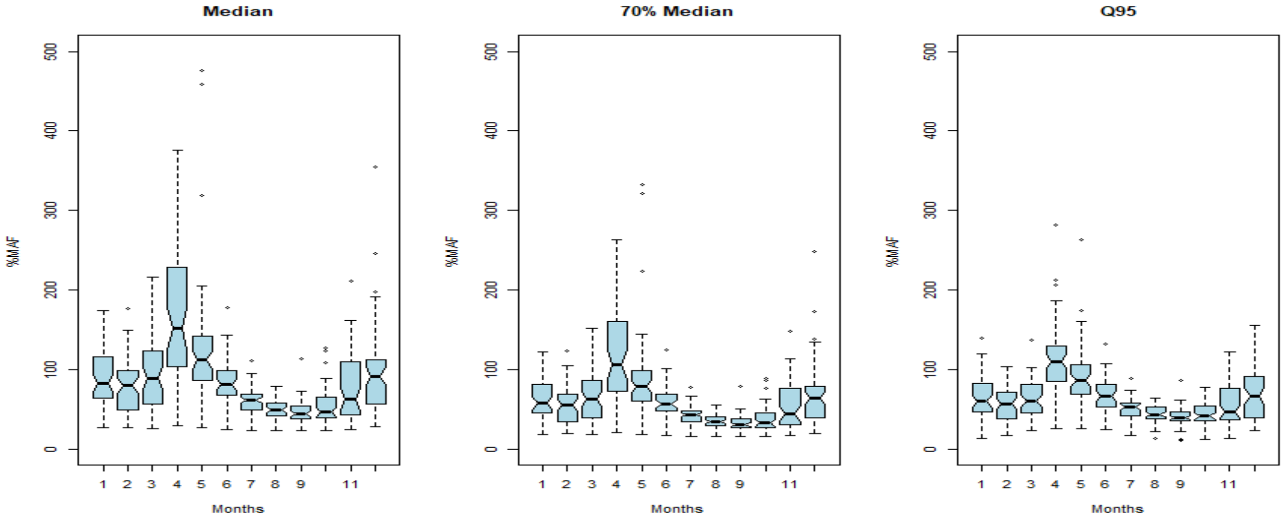


Figure 2113: Percentage of mean for month duration metrics at station 01CB002.

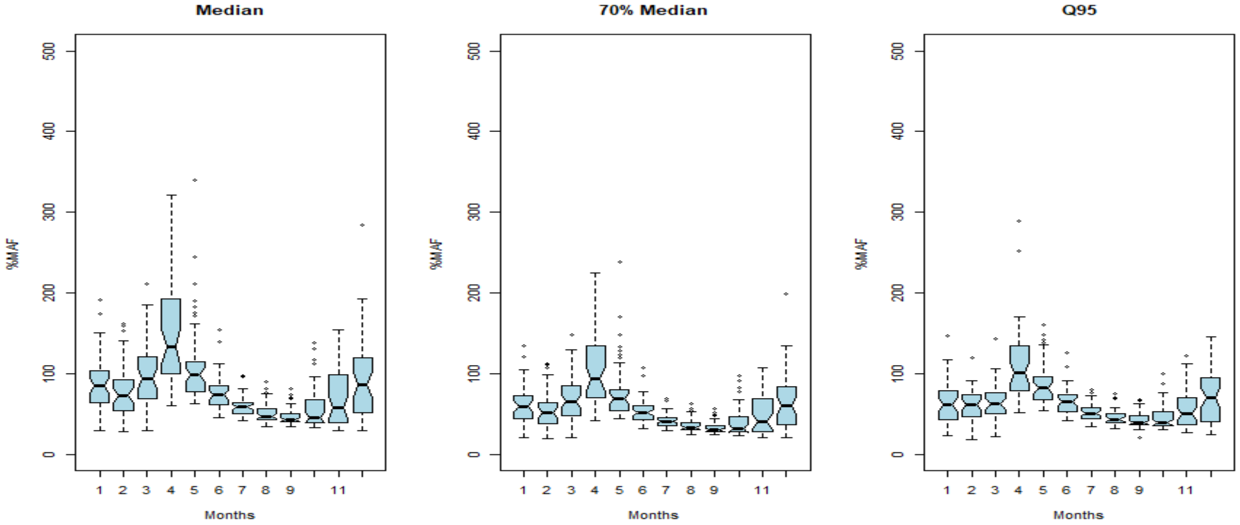


Figure 2214: Percentage of mean for month duration metrics at station 01CB004.

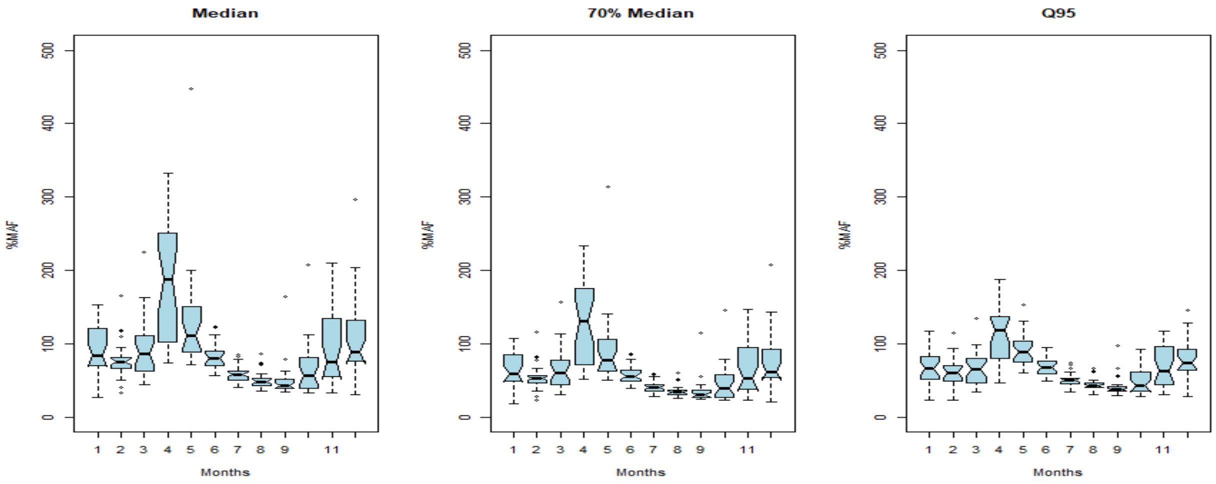


Figure 15: Percentage of mean for month duration metrics at station 01CC005.

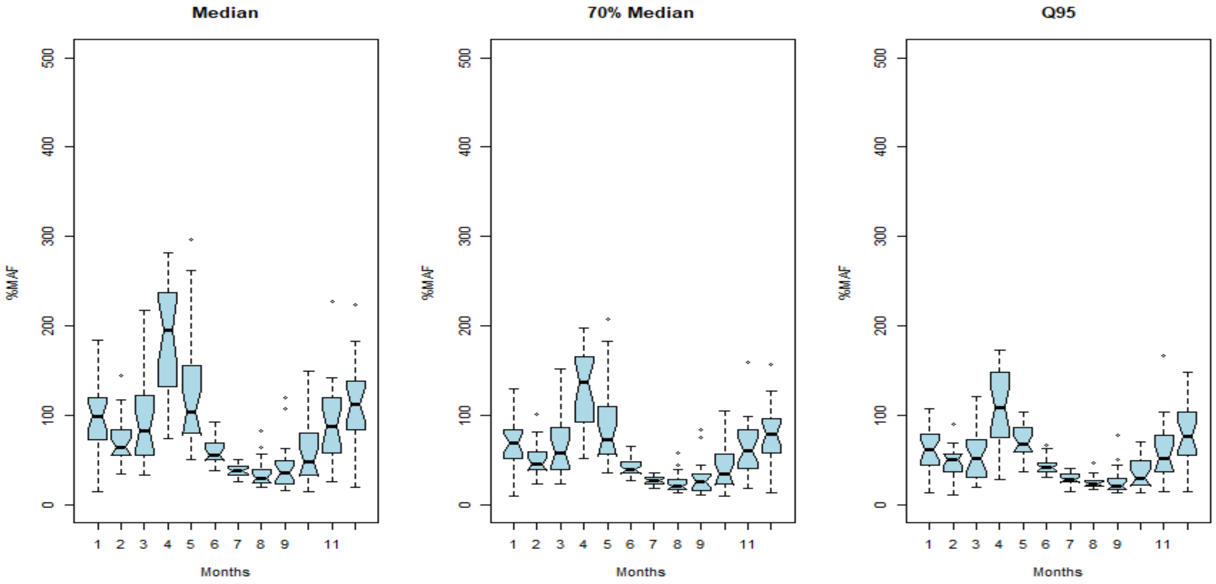


Figure 24: Percentage of mean for month duration metrics at station 01CD005.

Appendix B: Sustainable Boundary and presumptive Standard approaches

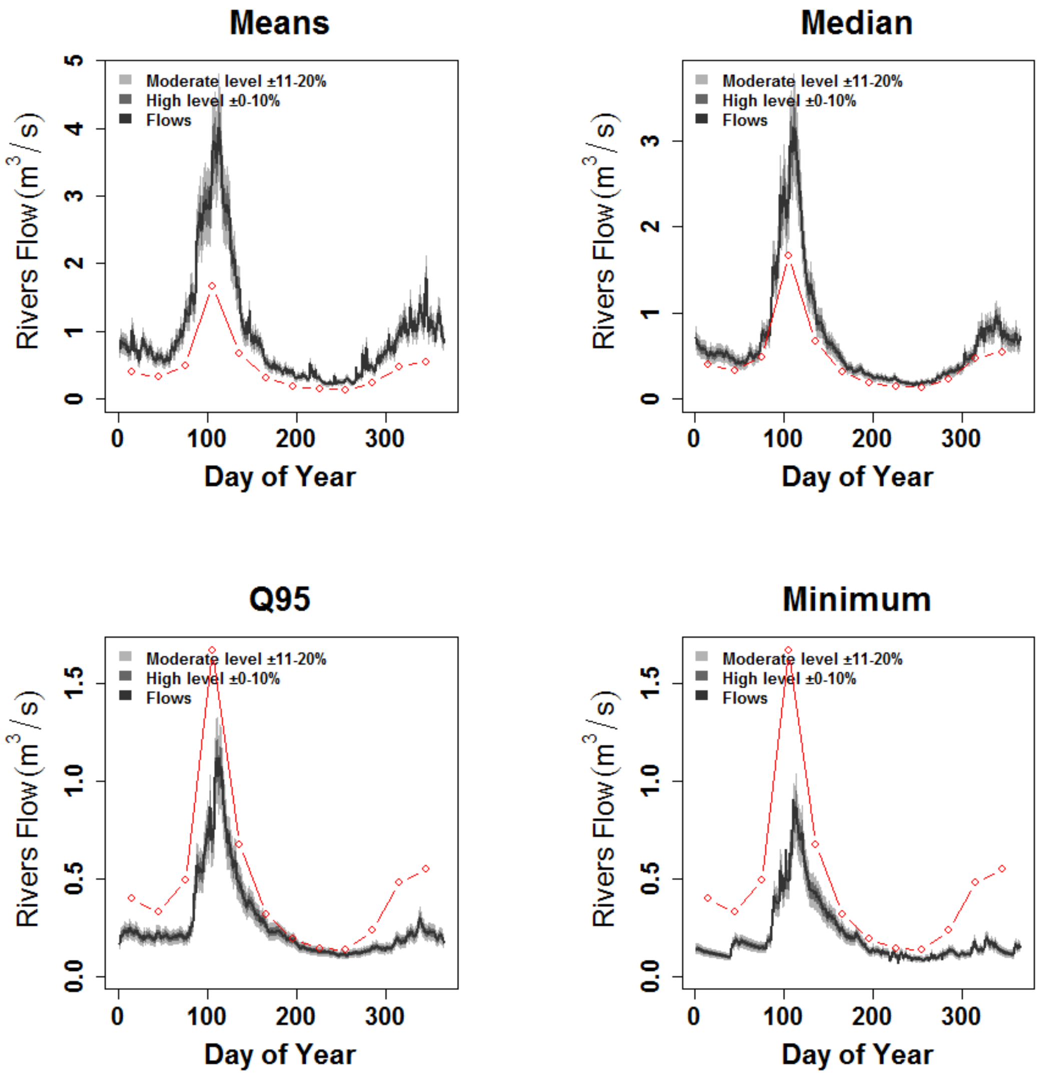


Figure 25: Sustainable Boundary and Presumptive Standard approaches with Normal flow (daily mean and median flow), low flow (daily Q95 and minima flow): Station 01CA003. The red curve represents the inter-annual mean monthly values of 70%Q50.

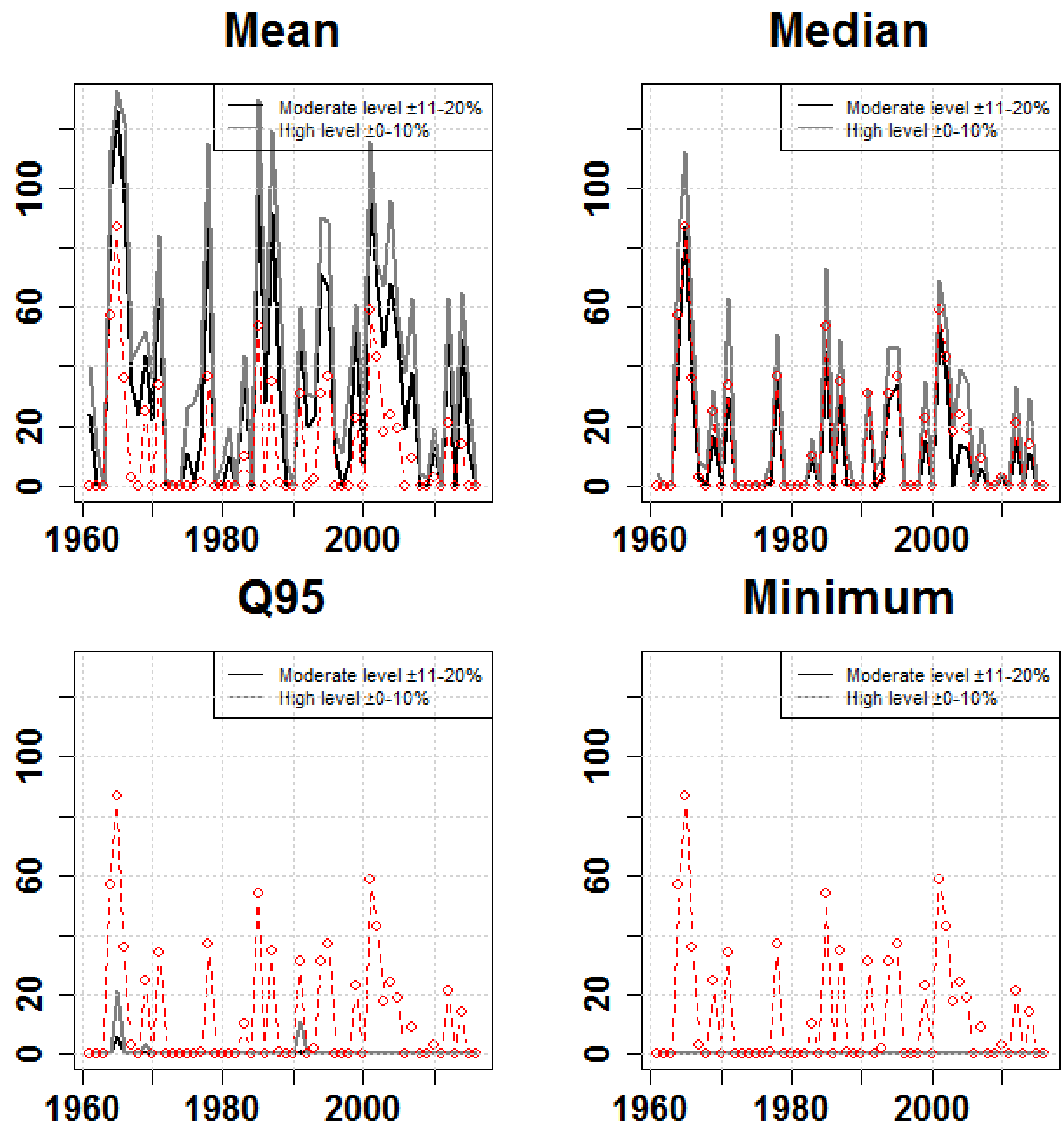


Figure 26: Number of day when the minimum of moderated level protection is not respected. The red curve represents the number of days when the minimum inter-annual mean monthly of 70%Q50 is not respected: Station 01CA003.

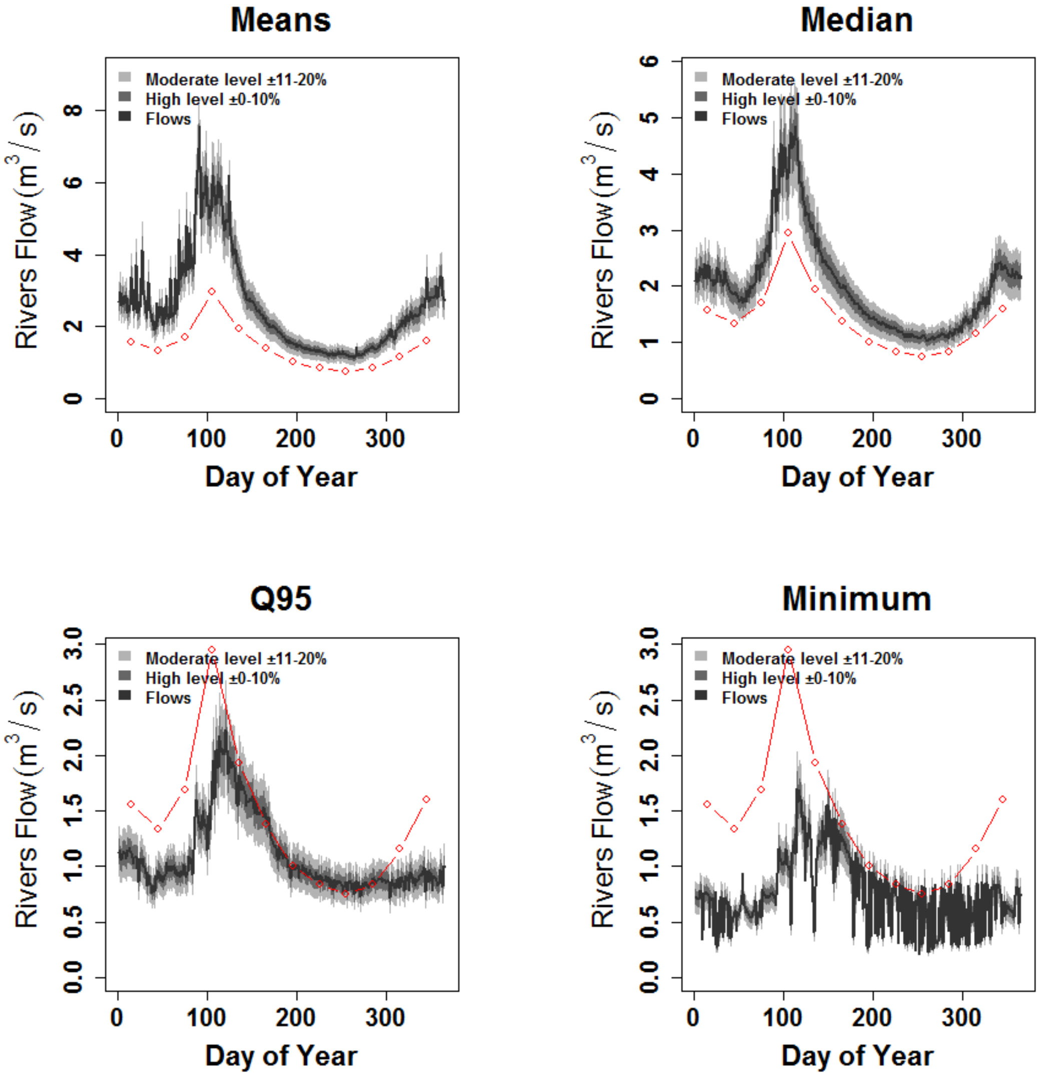


Figure 2716: Sustainable Boundary and Presumptive Standard approaches with Normal flow (daily mean and median flow), low flow (daily Q95 and minima flow): Station 01CB002. The red curve represents the inter-annual mean monthly values of 70%Q50.

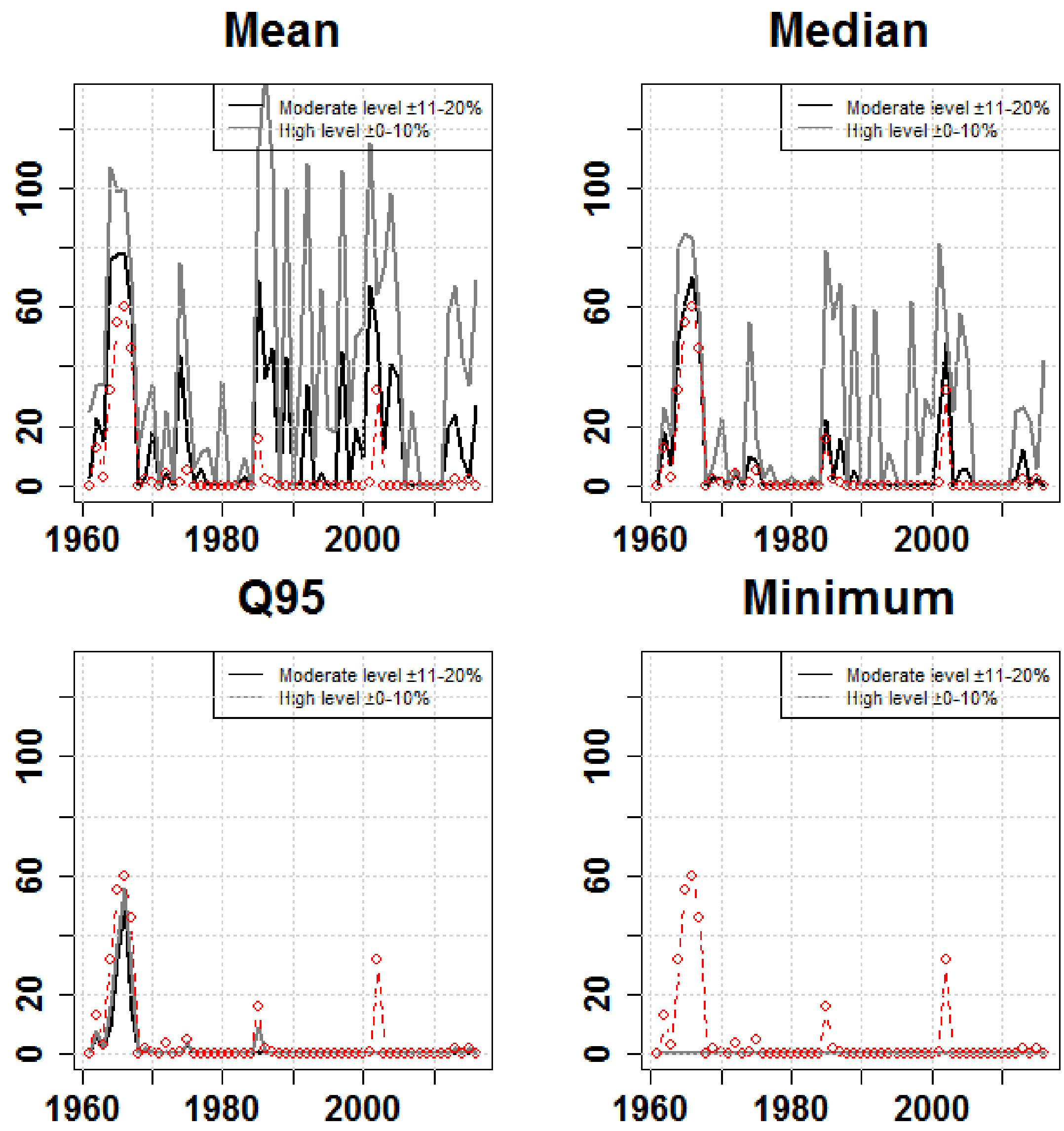


Figure 2817: Number of day when the minimum of moderated level protection is not respected. The red curve represents the number of days when the minimum inter-annual mean monthly of 70%Q50 is not respected: Station 01CB002.

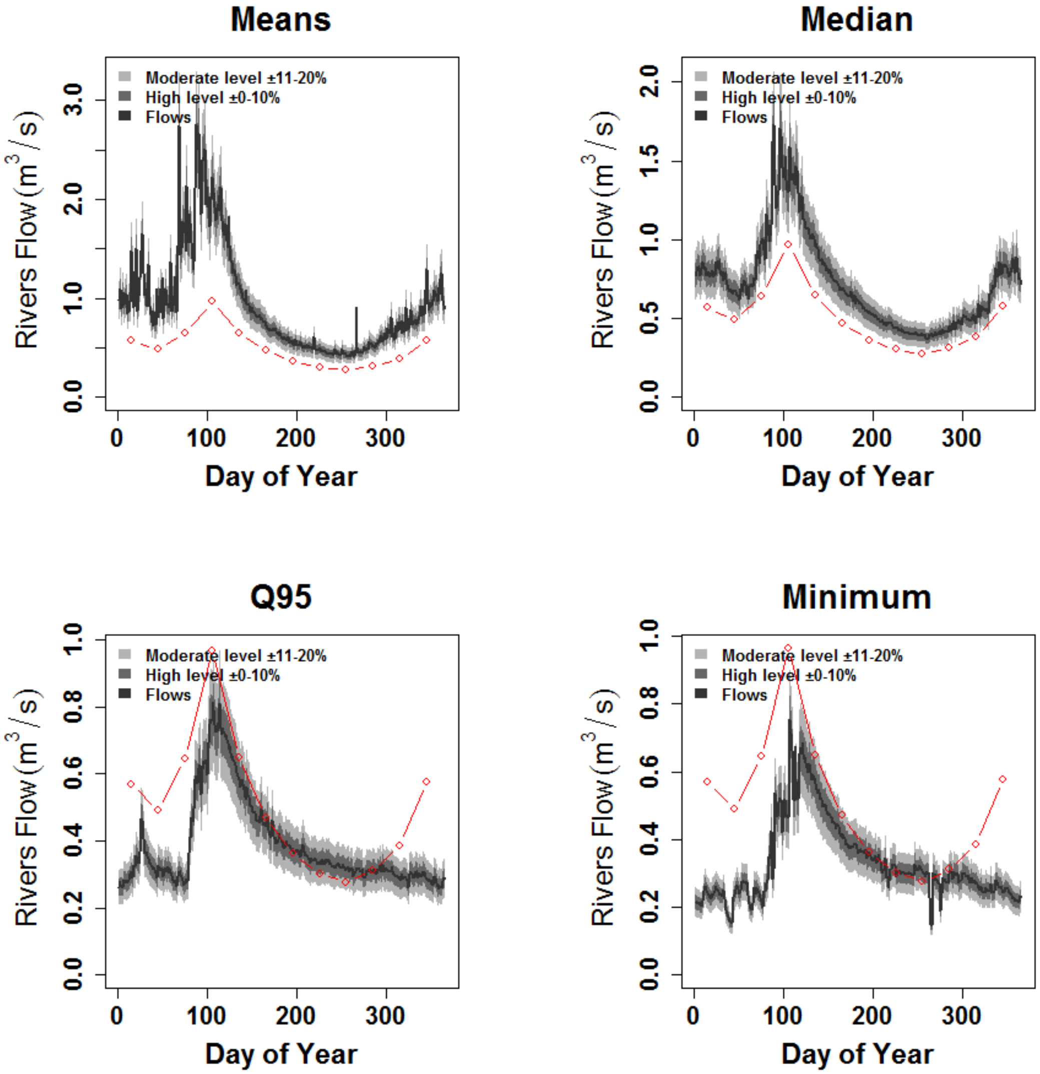


Figure 2918: Sustainable Boundary and Presumptive Standard approaches with Normal flow (daily mean and median flow), low flow (daily Q95 and minima flow): Station 01CB004. The red curve represents the inter-annual mean monthly values of 70%Q50.

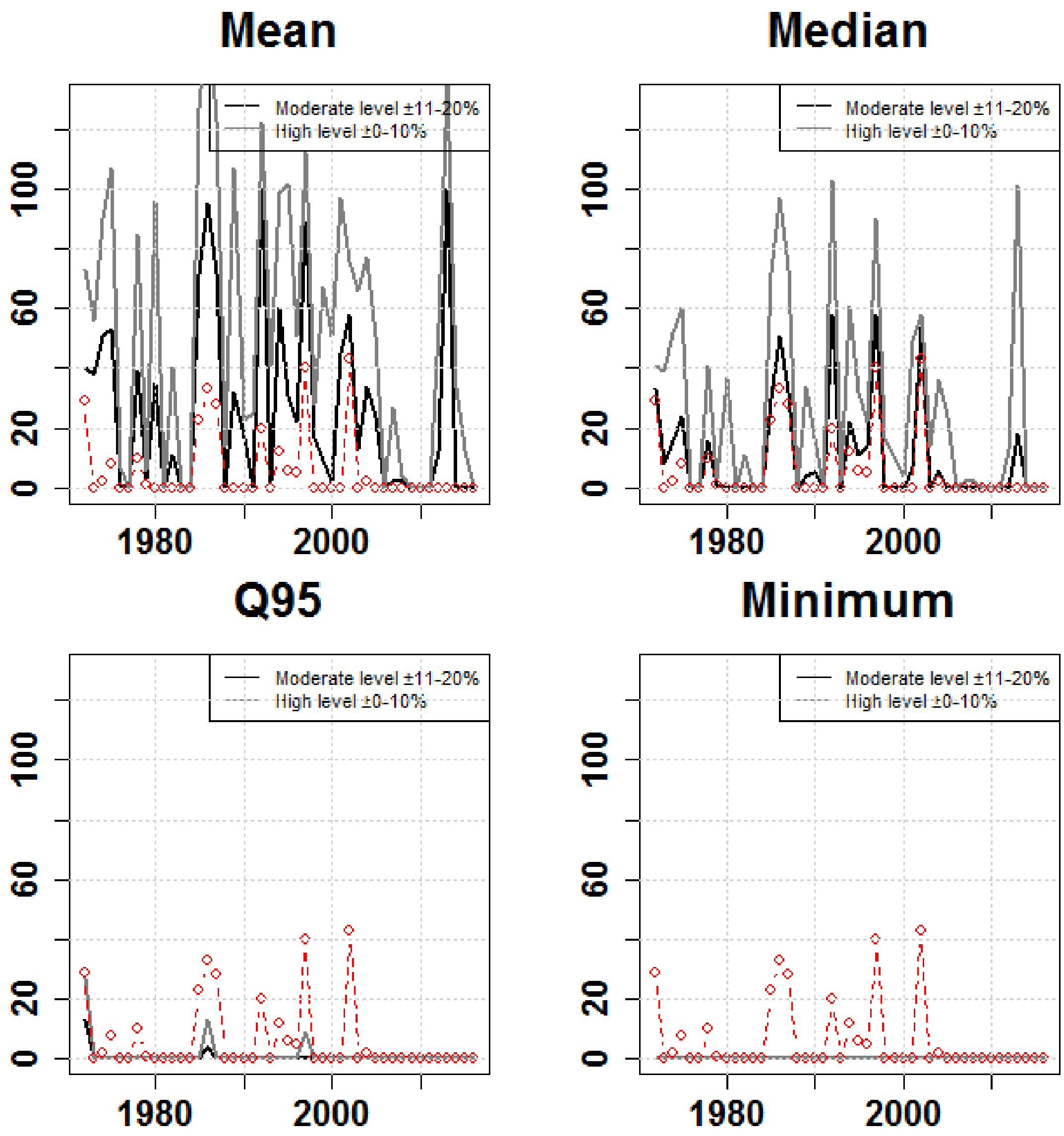


Figure 3019: Number of day when the minimum of moderated level protection is not respected. The red curve represents the number of days when the minimum inter-annual mean monthly of 70%Q50 is not respected: Station 01CB004.

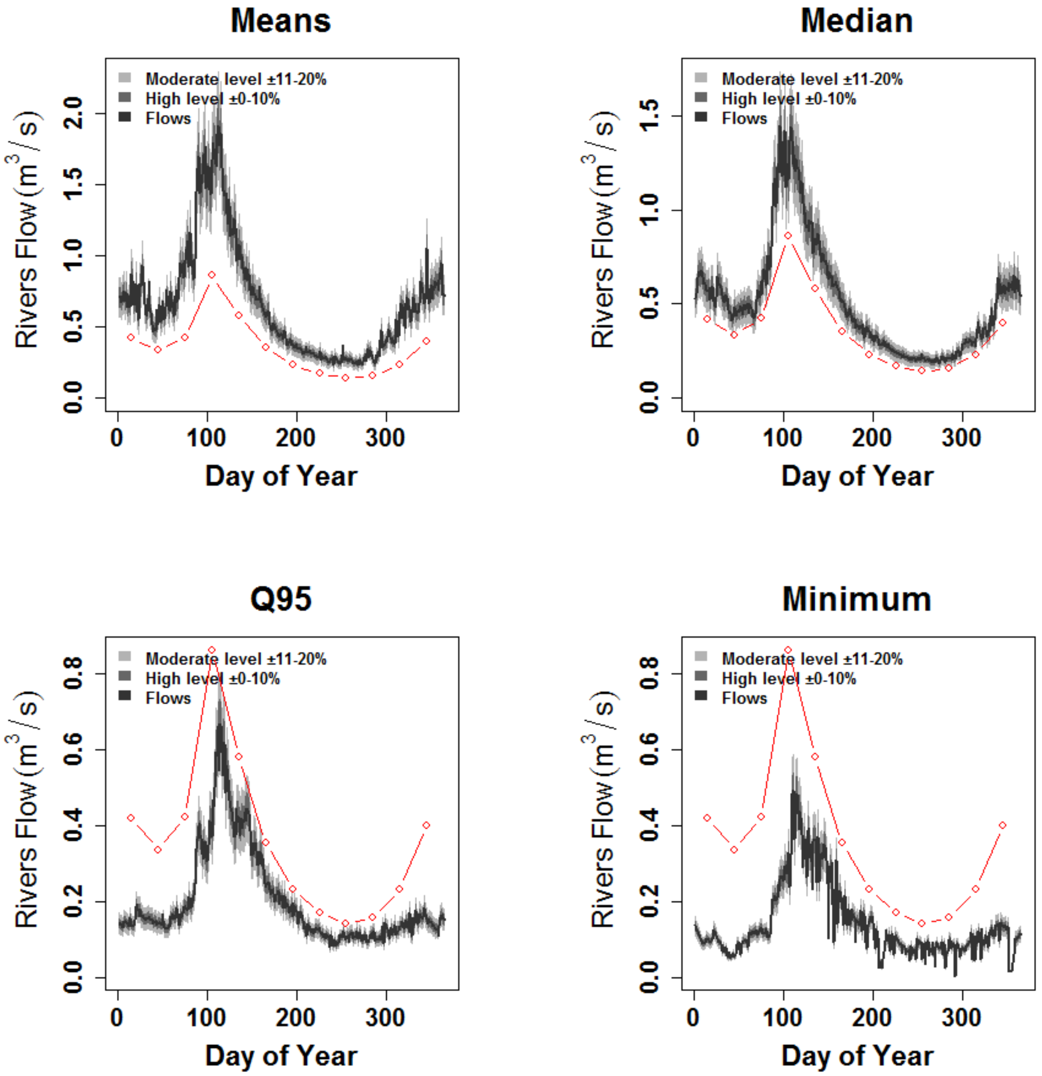


Figure 3120: Sustainable Boundary and Presumptive Standard approaches with Normal flow (daily mean and median flow), low flow (daily Q95 and minima flow): Station 01CC002. The red curve represents the inter-annual mean monthly values of 70%Q50.

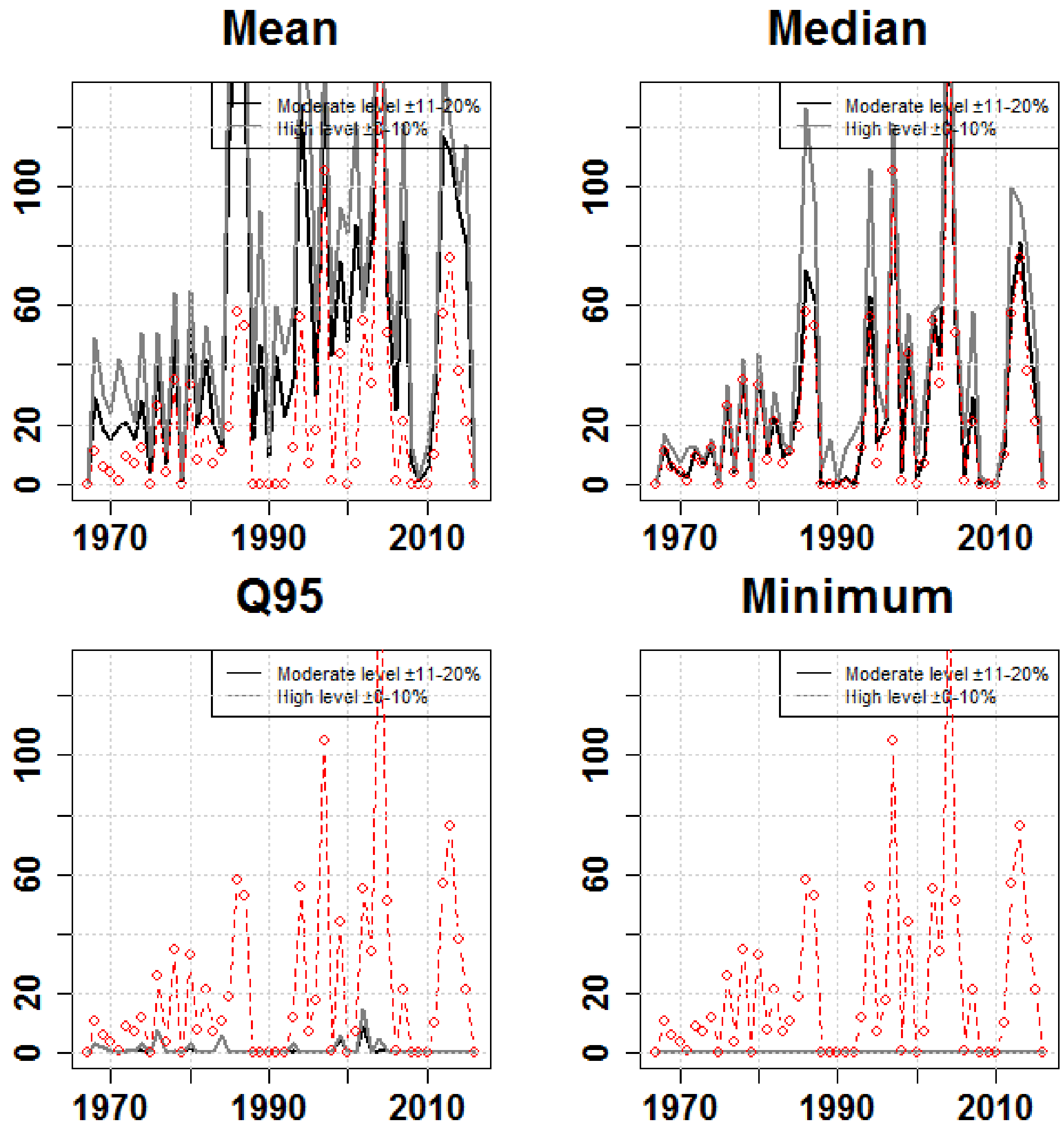


Figure 3221: Number of day when the minimum of moderated level protection is not respected. The red curve represents the number of days when the minimum inter-annual mean monthly of 70%Q50 is not respected: Station 01CC002

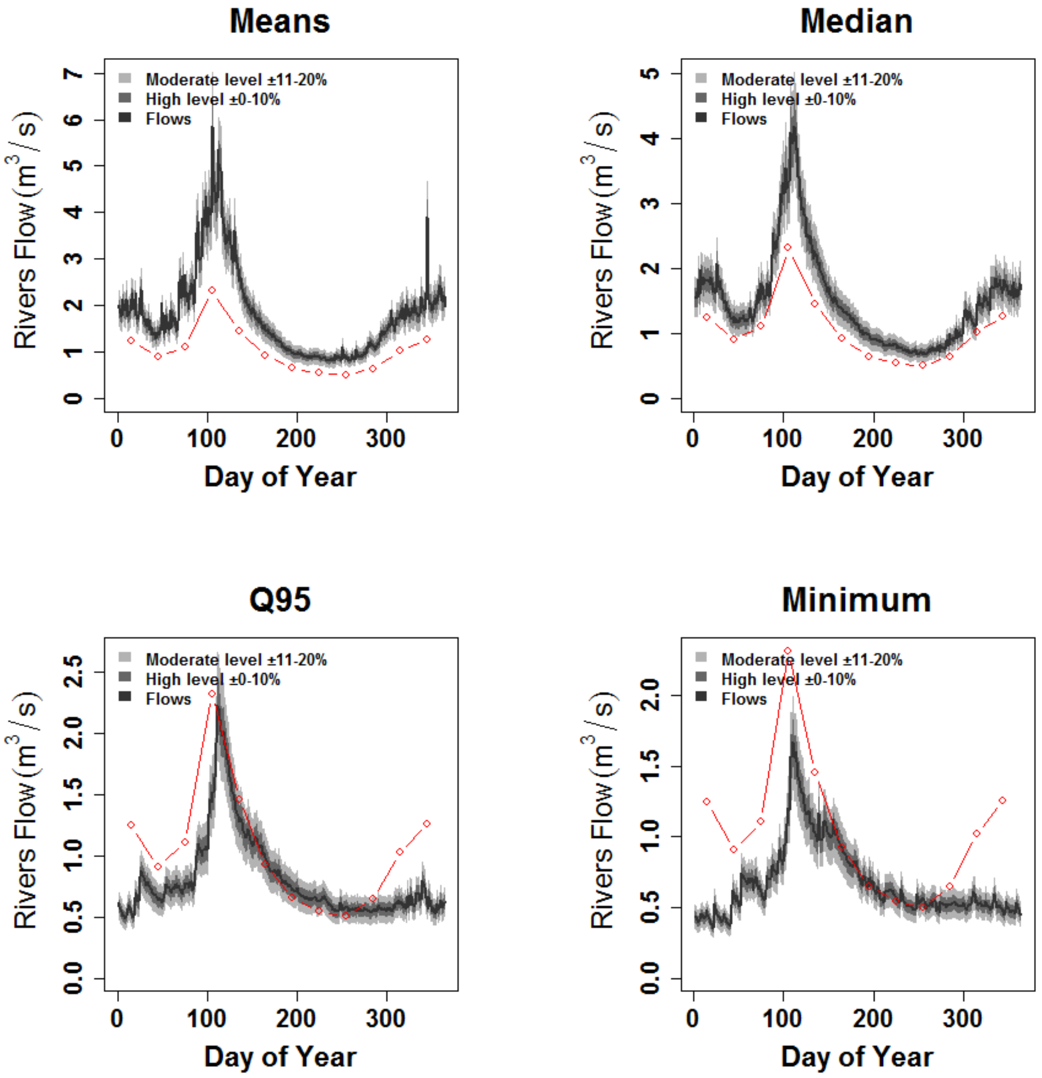


Figure 3322: Sustainable Boundary and Presumptive Standard approaches with Normal flow (daily mean and median flow), low flow (daily Q95 and minima flow): Station 01CC005. The red curve represents the inter-annual mean monthly values of 70%Q50.

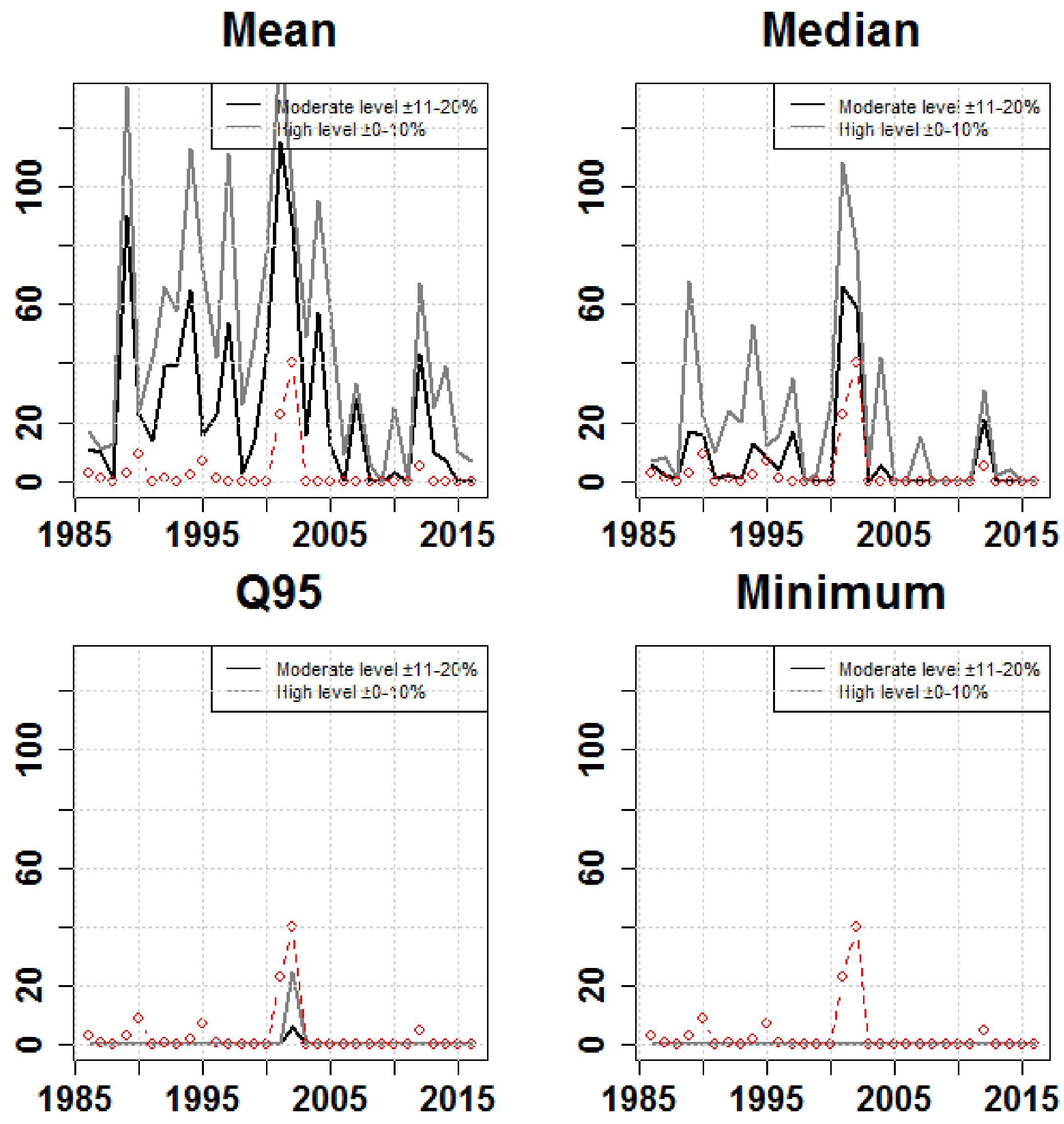


Figure 3423: Number of day when the minimum of moderated level protection is not respected. The red curve represents the number of days when the minimum inter-annual mean monthly of 70%Q50 is not respected: Station 01CC005.

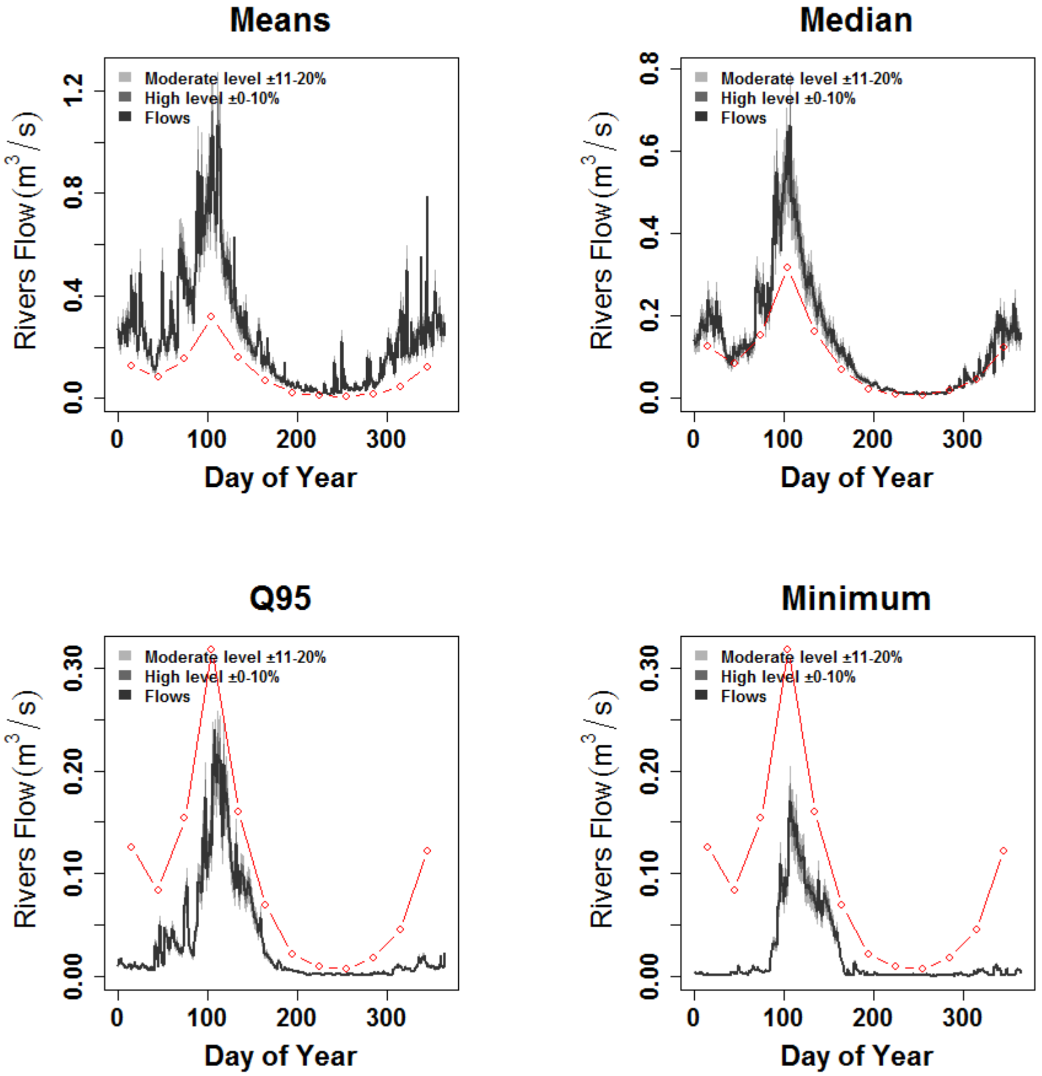


Figure 35: Sustainable Boundary and Presumptive Standard approaches with Normal flow (daily mean and median flow), low flow (daily Q95 and minima flow): Station 01CC010. The red curve represents the inter-annual mean monthly values of 70%Q50.

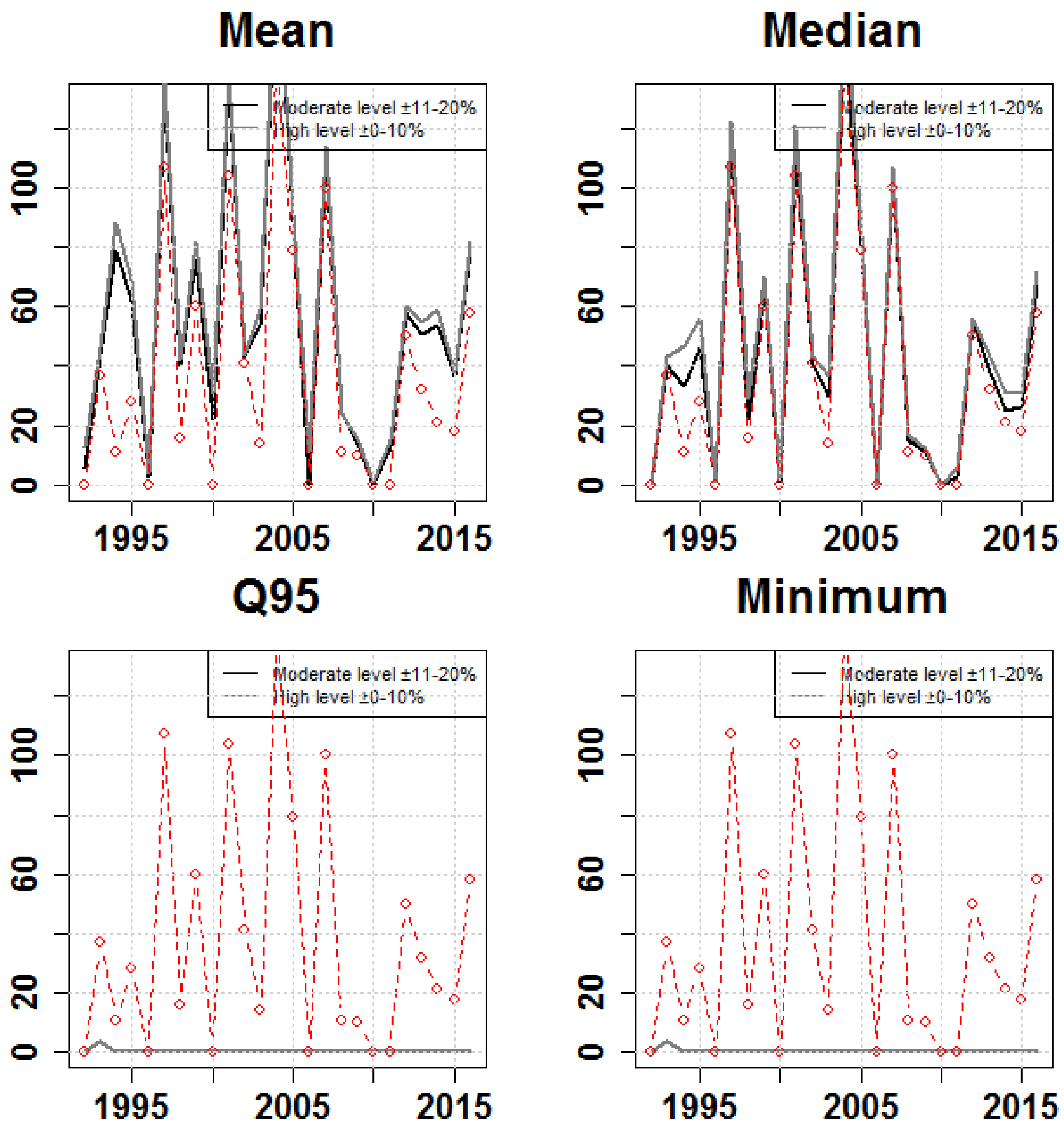


Figure 3624: Number of day when the minimum of moderated level protection is not respected. The red curve represents the number of days when the minimum inter-annual mean monthly of 70%Q50 is not respected: Station 01CC010.

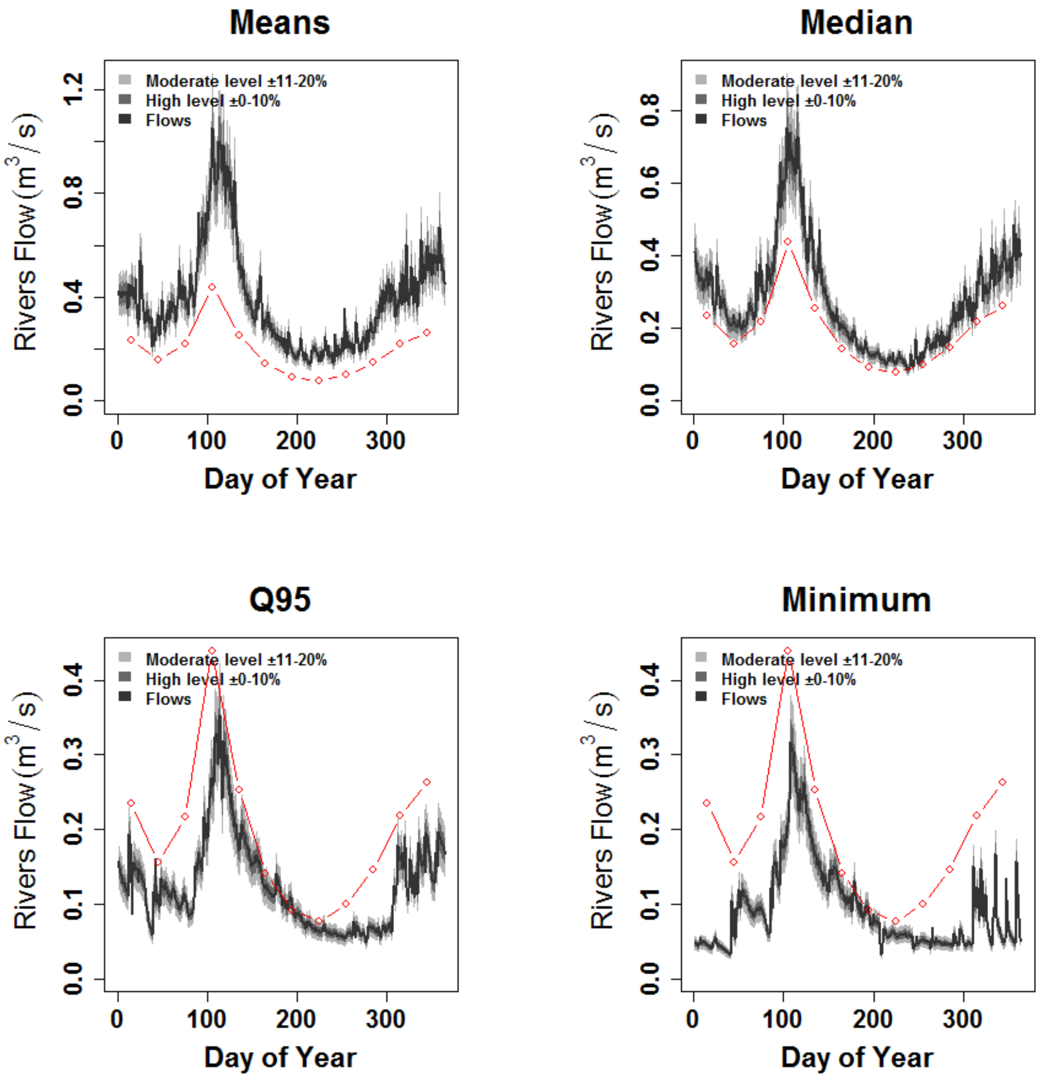


Figure 3725: Sustainable Boundary and Presumptive Standard approaches with Normal flow (daily mean and median flow), low flow (daily Q95 and minima flow): Station 01CD005. The red curve represents the inter-annual mean monthly values of 70%Q50.

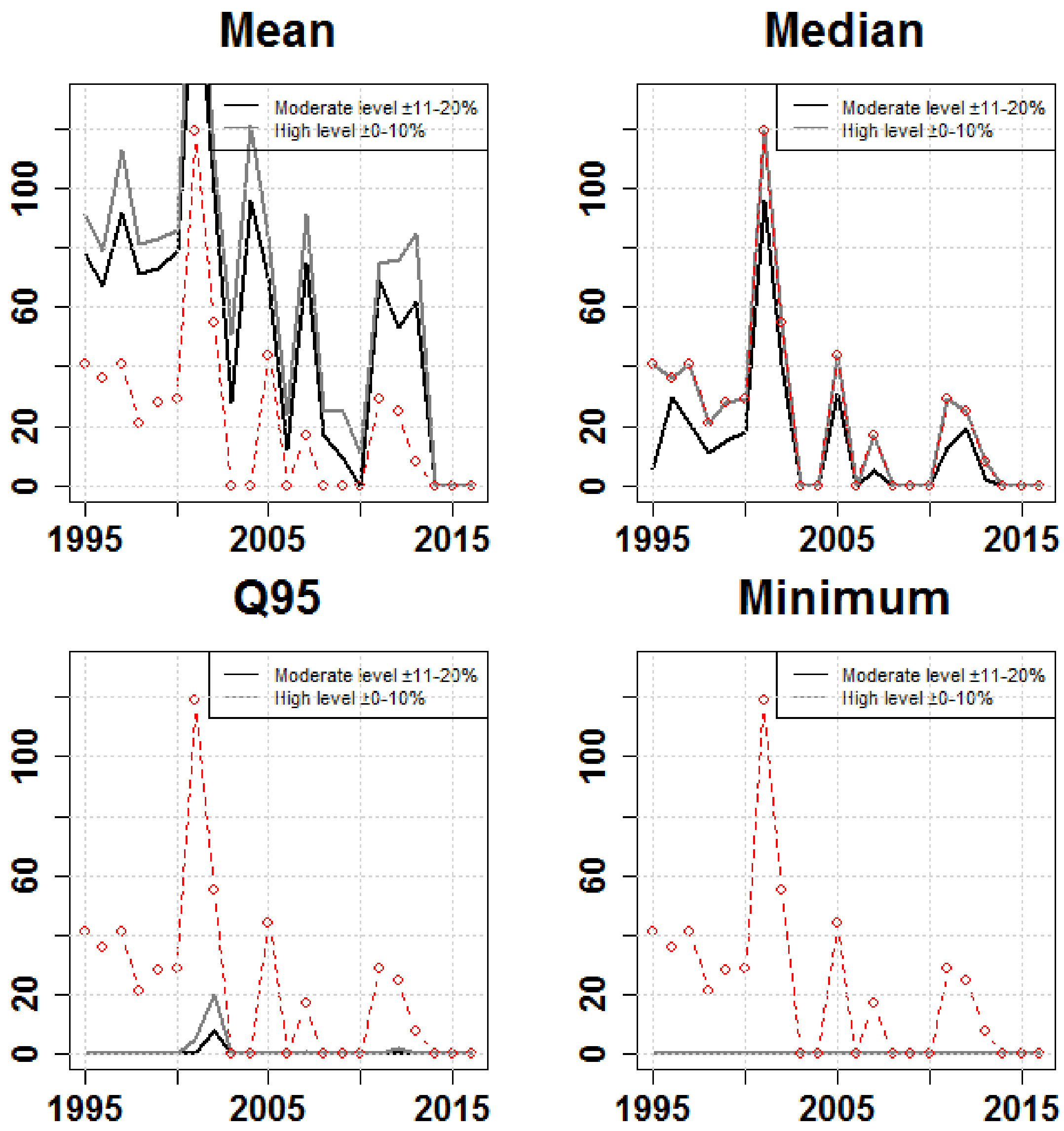


Figure 3826: Number of day when the minimum of moderated level protection is not respected. The red curve represents the number of days when the minimum inter-annual mean monthly of 70%Q50 is not respected: Station 01CD005.

Appendix C: Range variability

Table 8: Hydrological Alteration (IHA) variables of the 01CB002 station

		Average	SD	Low	High
Group 1: Magnitude of monthly water conditions	January	2.83	2.82	0.27	53.20
	February	2.44	2.73	0.35	45.30
	March	3.87	5.20	0.47	54.40
	April	5.61	5.67	0.47	84.70
	May	3.65	3.36	0.40	60.90
	June	2.13	0.79	0.36	8.77
	July	1.51	0.44	0.26	4.86
	August	1.27	0.39	0.29	5.38
	September	1.22	0.61	0.21	11.50
	October	1.48	0.86	0.27	10.30
	November	2.10	1.41	0.28	16.70
	December	2.82	2.40	0.48	49.50
Group 2: Magnitude and duration of annual extreme water conditions	1-day means minima	30.93	16.81	3.91	84.70
	1-day means maxima	0.81	0.27	0.21	1.37
	3-day means minima	20.17	10.80	3.00	70.80
	3-day means maxima	0.87	0.23	0.36	1.38
	7-day means minima	13.57	6.40	2.55	37.48
	7-day means maxima	0.94	0.19	0.55	1.40
	30-day means minima	7.69	2.97	2.37	15.42
	30-day means maxima	1.03	0.20	0.61	1.48
	90-day means minima	4.79	1.13	1.90	7.28
	90-day means maxima	1.16	0.23	0.77	1.69
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1 day maximum	80,09	22,46	16,00	124,00
	Julian date of each annual 1 day minimum	284,42	49,06	198,00	365,00
Group 4: Frequency and duration of high and low pulses	Low pulse count	1.20	0.59	1.00	4.00
	High pulse count	1.00	0.00	1.00	1.00
	Low pulse duration	1.18	0.58	1.00	4.00
	High pulse duration	1.00	0.00	1.00	1.00
Group 5: Rate and frequency of water condition changes	Fall rate	0.89	0.40	0.24	2.00
	Rise rate	-0.40	0.21	-1.13	-0.15
	Number of reversal	130.11	30.15	72.00	236.00

Table 9: Hydrologic Alteration (IHA) variables of the 01CB004 station

		Average	SD	Low	High
Group 1: Magnitude of monthly water conditions	January	1.12	1.28	0.20	14.80
	February	0.99	1.31	0.15	19.10
	March	1.64	2.58	0.19	35.50
	April	1.99	2.05	0.42	23.29
	May	1.15	0.89	0.47	17.10
	June	0.72	0.26	0.38	2.73
	July	0.55	0.18	0.30	2.96
	August	0.47	0.22	0.26	6.23
	September	0.46	0.45	0.15	13.80
	October	0.56	0.38	0.19	5.67
	November	0.73	0.64	0.24	10.30
	December	0.98	1.01	0.22	18.57
Group 2: Magnitude and duration of annual extreme water conditions	1-day means minima	13.33	6.72	5.43	35.50
	1-day means maxima	0.31	0.07	0.15	0.46
	3-day means minima	8.17	3.47	2.97	17.93
	3-day means maxima	0.31	0.07	0.16	0.46
	7-day means minima	5.42	2.20	2.01	10.95
	7-day means maxima	0.32	0.07	0.17	0.47
	30-day means minima	2.93	0.99	1.45	5.86
	30-day means maxima	0.37	0.08	0.24	0.57
	90-day means minima	1.83	0.35	1.17	2.58
	90-day means maxima	0.42	0.10	0.28	0.76
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1 day maximum	80,09	22,46	16,00	124,00
	Julian date of each annual 1 day minimum	284,42	49,06	198,00	365,00
Group 4: Frequency and duration of high and low pulses	Low pulse count	1.18	0.44	1.00	3.00
	High pulse count	1.02	0.15	1.00	2.00
	Low pulse duration	1.11	0.32	1.00	2.00
	High pulse duration	1.00	0.00	1.00	1.00
Group 5: Rate and frequency of water condition changes	Fall rate	0.43	0.20	0.14	0.87
	Rise rate	-0.18	0.08	-0.37	-0.06
	Number of reversal	133.18	18.10	95.00	177.00

Table 10: Hydrologic Alteration (IHA) variables of the 01CC002 station

		Average	SD	Low	High
Group 1: Magnitude of monthly water conditions	January	0.72	0.66	0.07	8.67
	February	0.62	0.65	0.05	8.00
	March	0.96	1.09	0.08	11.70
	April	1.63	1.39	0.20	16.30
	May	1.02	0.78	0.10	10.80
	June	0.58	0.34	0.09	4.75
	July	0.37	0.20	0.02	3.35
	August	0.28	0.20	0.05	3.39
	September	0.26	0.27	0.03	7.27
	October	0.34	0.36	0.00	3.85
	November	0.56	0.65	0.05	7.48
	December	0.76	0.86	0.02	17.00
Group 2: Magnitude and duration of annual extreme water conditions	1-day means minima	6.72	2.78	2.77	17.00
	1-day means maxima	0.10	0.05	0.00	0.26
	3-day means minima	4.81	2.04	1.93	11.27
	3-day means maxima	0.12	0.06	0.02	0.31
	7-day means minima	3.44	1.46	1.34	7.69
	7-day means maxima	0.15	0.07	0.04	0.38
	30-day means minima	2.10	0.76	0.82	4.38
	30-day means maxima	0.19	0.08	0.07	0.47
	90-day means minima	1.34	0.31	0.82	2.06
	90-day means maxima	0.24	0.11	0.10	0.66
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1 day maximum	85,81	31,70	9,00	186,00
	Julian date of each annual 1 day minimum	270,52	41,67	185,00	359,00
Group 4: Frequency and duration of high and low pulses	Low pulse count	1.12	0.39	1.00	3.00
	High pulse count	1.00	0.00	1.00	1.00
	Low pulse duration	1.06	0.24	1.00	2.00
	High pulse duration	1.00	0.00	1.00	1.00
Group 5: Rate and frequency of water condition changes	Fall rate	0.23	0.08	0.10	0.54
	Rise rate	-0.15	0.06	-0.32	-0.06
	Number of reversal	151.66	30.08	42.00	202.00

Table 11: Hydrologic Alteration (IHA) variables of the 01CC005 station

		Average	SD	Low	High
Group 1: Magnitude of monthly water conditions	January	1.96	1.27	0.36	12.50
	February	1.57	1.22	0.37	17.60
	March	2.29	2.36	0.54	29.50
	April	4.17	3.57	0.73	57.70
	May	2.62	1.97	0.97	23.00
	June	1.43	0.52	0.70	6.33
	July	0.98	0.23	0.45	2.32
	August	0.87	0.30	0.50	5.38
	September	0.90	0.70	0.47	11.00
	October	1.24	0.93	0.47	8.84
	November	1.80	1.31	0.48	13.80
	December	2.25	2.61	0.45	62.20
Group 2: Magnitude and duration of annual extreme water conditions	1-day means minima	15.50	11.19	4.49	62.20
	1-day means maxima	0.57	0.13	0.36	1.03
	3-day means minima	11.02	6.41	3.96	36.57
	3-day means maxima	0.59	0.13	0.37	1.04
	7-day means minima	8.01	3.80	3.53	21.48
	7-day means maxima	0.61	0.13	0.39	1.07
	30-day means minima	4.85	2.28	2.08	11.27
	30-day means maxima	0.71	0.17	0.43	1.23
	90-day means minima	3.17	0.83	1.84	5.21
	90-day means maxima	0.89	0.27	0.47	1.45
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1 day maximum	91,44	39,24	9,00	250,00
	Julian date of each annual 1 day minimum	268,70	35,11	208,00	366,00
Group 4: Frequency and duration of high and low pulses	Low pulse count	1.06	0.25	1.00	2.00
	High pulse count	1.00	0.00	1.00	1.00
	Low pulse duration	1.03	0.18	1.00	2.00
	High pulse duration	1.00	0.00	1.00	1.00
Group 5: Rate and frequency of water condition changes	Fall rate	0.61	0.29	0.27	1.64
	Rise rate	-0.24	0.15	-0.80	-0.10
	Number of reversal	108.00	31.55	13.00	144.00

Table 12: Hydrologic Alteration (IHA) variables of the 01CC010 station

		Average	SD	Low	High
Group 1: Magnitude of monthly water conditions	January	0.29	0.41	0.00	4.29
	February	0.22	0.40	0.00	6.15
	March	0.44	0.70	0.00	7.59
	April	0.74	1.00	0.03	11.30
	May	0.32	0.38	0.06	4.58
	June	0.13	0.18	0.00	2.24
	July	0.05	0.09	0.00	1.93
	August	0.03	0.13	0.00	3.20
	September	0.05	0.24	0.00	5.28
	October	0.10	0.28	0.00	2.94
	November	0.22	0.46	0.00	5.92
	December	0.32	0.67	0.00	12.30
Group 2: Magnitude and duration of annual extreme water conditions	1-day means minima	4.73	3.00	0.96	12.30
	1-day means maxima	0.00	0.00	0.00	0.01
	3-day means minima	3.03	1.85	0.79	8.45
	3-day means maxima	0.01	0.00	0.00	0.01
	7-day means minima	1.98	1.19	0.52	5.18
	7-day means maxima	0.01	0.00	0.00	0.01
	30-day means minima	1.02	0.55	0.32	2.55
	30-day means maxima	0.01	0.01	0.00	0.03
	90-day means minima	0.57	0.20	0.24	1.04
	90-day means maxima	0.03	0.02	0.00	0.08
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1 day maximum	81,26	27,12	9,00	115,00
	Julian date of each annual 1 day minimum	232,61	26,49	171,00	268,00
Group 4: Frequency and duration of high and low pulses	Low pulse count	8.48	11.40	1.00	57.00
	High pulse count	1.00	0.00	1.00	1.00
	Low pulse duration	4.28	3.02	1.00	11.00
	High pulse duration	1.00	0.00	1.00	1.00
Group 5: Rate and frequency of water condition changes	Fall rate	0.20	0.09	0.08	0.46
	Rise rate	-0.08	0.04	-0.20	-0.03
	Number of reversal	121.56	12.54	72.00	141.00

Table 13: Hydrologic Alteration (IHA) variables of the 01CD005 station

		Average	SD	Low	High
Group 1: Magnitude of monthly water conditions	January	0.42	0.32	0.04	3.20
	February	0.34	0.32	0.03	2.72
	March	0.42	0.39	0.06	5.31
	April	0.83	0.72	0.12	6.30
	May	0.57	0.64	0.12	5.37
	June	0.27	0.21	0.09	2.10
	July	0.18	0.14	0.03	1.12
	August	0.17	0.19	0.06	2.61
	September	0.21	0.28	0.04	4.25
	October	0.33	0.40	0.04	3.52
	November	0.43	0.41	0.05	4.40
	December	0.52	0.43	0.05	2.84
Group 2: Magnitude and duration of annual extreme water conditions	1-day means minima	2.98	1.47	1.51	6.30
	1-day means maxima	0.08	0.05	0.03	0.23
	3-day means minima	2.14	1.10	1.16	5.18
	3-day means maxima	0.08	0.05	0.03	0.23
	7-day means minima	1.59	0.89	0.86	4.51
	7-day means maxima	0.08	0.05	0.04	0.24
	30-day means minima	1.08	0.68	0.56	3.56
	30-day means maxima	0.11	0.06	0.04	0.27
	90-day means minima	0.69	0.34	0.46	1.82
	90-day means maxima	0.16	0.09	0.06	0.46
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1 day maximum	89,81	36,22	1,00	158,00
	Julian date of each annual 1 day minimum	246,14	31,35	165,00	295,00
Group 4: Frequency and duration of high and low pulses	Low pulse count	1.23	0.43	1.00	2.00
	High pulse count	1.00	0.00	1.00	1.00
	Low pulse duration	1.23	0.43	1.00	2.00
	High pulse duration	1.00	0.00	1.00	1.00
Group 5: Rate and frequency of water condition changes	Fall rate	0.17	0.04	0.09	0.27
	Rise rate	-0.08	0.03	-0.16	-0.04
	Number of reversal	127.41	13.19	105.00	152.00

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