

Appendix H
Indicators of Hydrologic Alteration (IHA)

1 INTRODUCTION

Version 7.1 of the Indicators of Hydrologic Alteration (IHA) software (The Nature Conservancy 2009) was used to quantify the degree of alteration from RTF (WY 1933-2015) to MFL flow regimes of the LSFR at the Fort White gage. The software uses daily flow time series data to generate multiple sets of hydrologic statistics.

The five principal attributes of flow data variability (magnitude, duration, amplitude, frequency, and timing) are programmed in IHA because of their influence on aquatic species at various life stages. IHA calculates two types of flow statistics; the first type includes 33 IHA statistics and the second type includes 34 flow statistics calculated for five different environmental flow components (EFCs). EFCs are a more recent suite of hydrologic flow parameters and were developed by the Nature Conservancy in version 7.1 (released in 2009) to identify and compute statistics on hydrological events such as floods and droughts. The 33 IHA statistics and 34 EFCs together describe flow attributes deemed to be ecologically relevant.

1.1 IHA COMPONENTS

The IHA components characterize within-year variation in streamflow based on a series of hydrologic attributes (IHA statistics) organized into five groups (**Table 1**).

Group 1. The IHA Group 1 statistics (mean monthly streamflow) characterize seasonal patterns in the magnitude and timing of streamflow. They describe the normal condition and provide a measure of availability or sustainability of habitat or flows for various river services.

Group 2. The IHA Group 2 statistics focus on the magnitude and duration of annual extreme flow conditions. In addition to maximum and minimum flows over specified periods of time, it includes the base flow index, defined as 7-day minimum flow/mean flow for the year and number of almost zero flow days. Group 2 statistics provide a measure of the amount of environmental stress and disturbance during the year.

Group 3. The IHA Group 3 statistics characterize the timing (dates within a year) of the annual 1-day minimum and 1-day maximum flows. Timing is important to assess the degree of stress or mortality from extreme events during key periods in a species life cycle. It is also important to compare against timeframes needed for recreation or other socioeconomic services.

Group 4. The IHA Group 4 statistics include frequencies of high- and low-flow pulses. A pulse is defined as a daily mean flow above or below selected thresholds. The annual number of daily mean flows greater than the 80th percentile and the annual number less than the 20th percentile over the period of record were selected as thresholds for the LSFR analysis. The duration of time over which a specific water condition exists may determine whether a particular life cycle phase can be completed or the degree to which inundation or desiccation can occur.

Group 5. Group 5 IHA statistics (rise rate, fall rate and number of reversals) characterize the number and mean rate of positive (rise) and negative (fall) flow changes on two consecutive days. The rate of change in water condition affects stranding of certain organisms along the water edge or ability of plant roots to maintain contact with phreatic water supplies.

Table 1. Summary of hydrologic attributes and regime characteristics associated with the IHA component groups
 [Source: (The Nature Conservancy 2009)]

IHA statistics group	Regime characteristics	Hydrologic attributes
Group 1: Magnitude of monthly water conditions	Magnitude, Timing	Mean for each calendar month (median in this application)
Group 2: Magnitude and duration of annual extreme water conditions	Magnitude, Duration	Annual minimums of 1-day means Annual maximums of 1-day means Annual minimums of 3-day means Annual maximums of 3-day means Annual minimums of 7-day means Annual maximums of 7-day means Annual minimums of 30-day means Annual maximums of 30-day means Annual minimums of 90-day means Annual maximums of 90-day means
Group 3: Timing of annual extreme water conditions	Timing	Julian data of each annual 1-day maximum Julian data of each annual 1-day minimum
Group 4: Frequency and duration of high and low flow pulses	Magnitude, Frequency, Duration	Number of high-flow pulses each year Number of low-flow pulses each year Mean duration of high-flow pulses in each year Mean duration of low-flow pulses in each year
Group 5: Rate and frequency of water condition changes	Frequency, Rate of change	Means of all positive differences between consecutive daily means Means of all negative differences between consecutive daily means Number of rises Number of falls

1.2 ENVIRONMENTAL FLOW COMPONENTS

The IHA software calculates 34 EFC parameters grouped into five different types of Environment Flow Components (EFCs): low flows, extreme low flows, high flow pulses, small floods, and large floods. The five EFC types are described in more detail in section 2.3 of the IHA manual (The Nature Conservancy 2009). This categorization of flow into five EFCs is based on the realization by research ecologists that river hydrographs can be divided into a repeating set of ecologically important hydrographic patterns that should be considered to sustain riverine ecological integrity. Not only is it important to maintain adequate flows during low-flow periods, but also higher flows and floods and extreme low-flow conditions that perform important ecological functions.

The IHA software incorporates default parameters for delineating the five EFCs as well as an interface for users to modify the default values (The Nature Conservancy 2009), see **Figure 1**. The thresholds that can be modified include flow exceedances (e.g., 10th percentile), recurrence intervals (e.g., 2-year event), and rate of change (e.g., 25% flow increase from previous day).

In the IHA EFC model, all daily flows fall within one of the five categories, and an algorithm parses the hydrograph accordingly based on the delineation thresholds being employed. The program logic (**Figure 2**) separates flow into base flows and flow pulse periods using a base-flow separation method. Pulses are subsequently classified by flow rate-of-change (i.e., percent difference from previous day), and base flows classified by magnitude (expressed as recurrence interval).

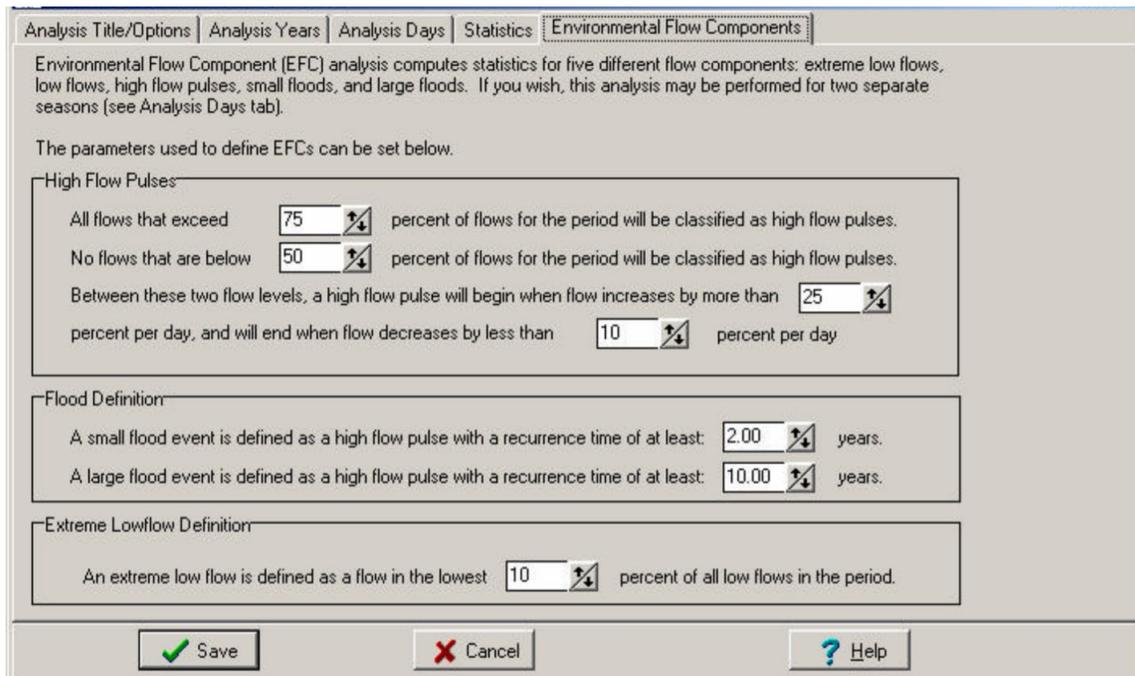


Figure 1. IHA EFC definitions interface screen, displaying default thresholds

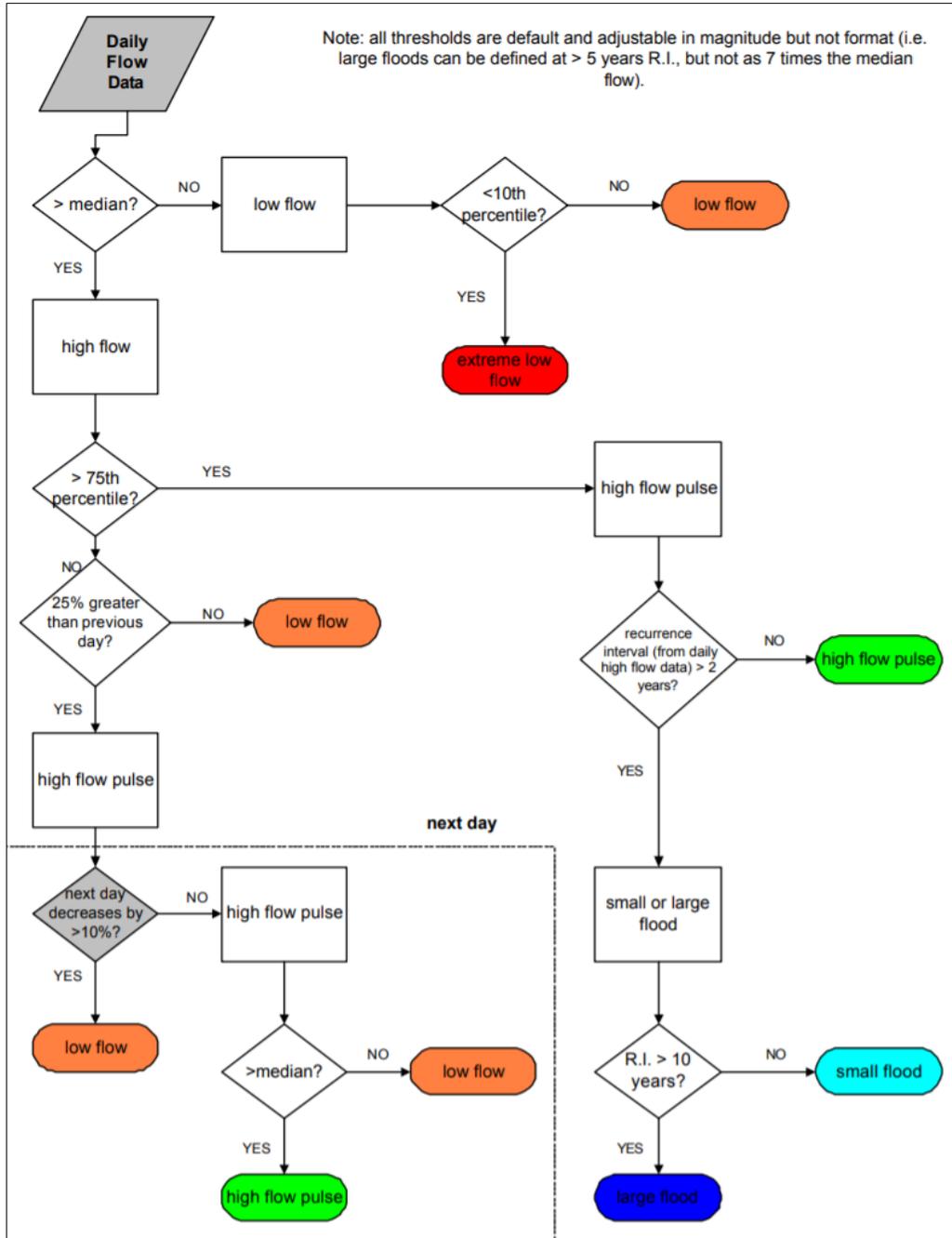


Figure 2. IHA environmental flow component algorithm flow chart
 [Source: (Hersh and Maidment 2006)]

2 IHA RESULTS FOR LSRF AT FORT WHITE

IHA was used to compare the hydrologic characteristics of two time series of flow at the Fort White gage: Reference Timeframe Flow (RTF) for WYs 1933-2015 and MFL flow for WYs 1933-2015. The program calculated deviation factors and corresponding significance counts for the 33 IHA and 34 EFC parameter medians and coefficients of dispersion ((75th percentile-25th percentile)/50th percentile, in **Table 2**). The coefficient of dispersion (C.D. in **Table 2**) is a nonparametric interquartile spread normalized to the median. Deviation factors are calculated by comparing MFL values with RTF values for each parameter, as shown in the equation below, which is interpreted as the proportional change in the median (or coefficient of dispersion) relative to the RTF value.

$$\text{Deviation factor} = \frac{\text{RTF value} - \text{MFL value}}{\text{RTF value}}$$

For example, the median 1-day minimum flow values (highlighted in **Table 2** Parameter Group #2) for RTF and MFL flows are 941 and 838 cfs, respectively. Using the above equation, the deviation factor is 0.11 ((941-838)/941), i.e., an 11-percent change from the RTF value. Similarly, a deviation factor of 0.12 is calculated for the coefficient of dispersion using the RTF and MFL coefficient of dispersion values of 0.273 and 0.306, respectively.

The significance count for the deviation values can be interpreted similar to a p-value in parametric statistics and indicates whether the difference between RTF and MFL flows (deviation factor) is significant. A low significance count (minimum value is 0) implies that the difference between the two flow regimes is significant. The IHA software calculates the significance count values by randomly shuffling all years of input data and recalculates fictitious RTF and MFL medians and coefficient of dispersions 1,000 times (The Nature Conservancy 2009). The significance count is the fraction of trials for which the deviation values for the medians or coefficient of dispersions were greater than for the real case. So, a high significance count (maximum value of 1) means that there is little difference between the RTF and MFL data. The significance counts may differ slightly each time the IHA analysis is completed, since a new set of randomized cases is generated each time.

The IHA analysis quantifies the extent of possible hydrologic alteration (attributable to withdrawal) between RTF and MFL flows. The proposed MFL is implemented as a constant withdrawal, thus the influence of the MFL would be most apparent in the low- to moderately low flow statistics. Assuming a 5-percent level of significance (i.e., probability of rejecting the null hypothesis when it is true), the Group #2 1-day, 3-day, 7-day, 30-day, and 90-day minimums have statistically significant deviation factors for the medians (10% for 90-day minimum and 11% for others) and associated significance counts (i.e., p-values) ranging between 0.005 and 0.012 (**Table 2**). A higher deviation factor approaching or even exceeding 10% would be an indicator that instream habitat is sensitive to flow reduction and could be exposed to an increasing risk of change (Richter, et al. 2011). The significance counts for all but two coefficients of dispersion exceed 0.05 (**Table 3** and **Table 4**) indicating there is no significant change in the variability of flow. The two exceptions are the significance counts for the Group #4 low pulse count (0.021 in **Table 3**) and extreme low duration (0.008 in **Table 4**). While the median low pulse and high pulse count deviation factors of 1 and 0.5, respectively in **Table 3**, are statistically significant, the flow magnitudes are much higher; and the significance counts (p-values) of all five Group #2 median x-day maximums exceed 0.5, indicating the change in flow magnitude is not significant (**Table 3**).

Table 2. IHA output for LSFR at Fort White pre-impact period (RTF) and post-impact period (MFL) flows

Non-Parametric IHA Scorecard								
FW_RTf_MFL								
IHA Parameters								
Pre-impact (RTF) period: 1933-2015 (83 years)			Post-impact (MFL) period: 1933-2015 (83 years)					
Normalization Factor	1			1				
Mean annual flow	1526			1423				
Non-Normalized Mean Flow	1526			1423				
Annual C. V.	0.59			0.63				
Flow predictability	0.6			0.57				
Constancy/predictability	0.97			0.97				
% of floods in 60d period	0.28			0.28				
Flood-free season	0			0				
	MEDIANS		COEFF. of DISP.		DEVIATION FACTOR		SIGNIFICANCE COUNT	
	Pre	Post	Pre	Post	Medians	C.D.	Medians	C.D.
Parameter Group #1								
October	1351	1248	0.6155	0.6663	0.076	0.083	0.20	0.76
November	1191	1088	0.4901	0.5365	0.086	0.095	0.18	0.71
December	1141	1038	0.4044	0.4446	0.090	0.099	0.27	0.62
January	1174	1071	0.5288	0.5797	0.088	0.096	0.12	0.79
February	1314	1211	0.5807	0.63	0.078	0.085	0.43	0.58
March	1302	1199	0.8163	0.8864	0.079	0.086	0.31	0.63
April	1312	1209	0.8618	0.9352	0.079	0.085	0.48	0.73
May	1158	1055	0.6291	0.6906	0.089	0.098	0.27	0.70
June	1118	1015	0.5041	0.5553	0.092	0.10	0.072	0.72
July	1266	1163	0.51	0.5551	0.081	0.089	0.25	0.62
August	1541	1438	0.5735	0.6145	0.067	0.072	0.27	0.74
September	1580	1477	0.6525	0.698	0.065	0.070	0.55	0.87

Parameter Group #2								
1-day minimum	941.2	838.2	0.2725	0.3059	0.11	0.12	0.006	0.50
3-day minimum	943.6	840.6	0.2817	0.3162	0.11	0.12	0.005	0.50
7-day minimum	947.2	844.2	0.287	0.322	0.11	0.12	0.008	0.52
30-day minimum	953.1	850.1	0.2987	0.3348	0.11	0.12	0.010	0.54
90-day minimum	1008	904.7	0.3317	0.3694	0.10	0.11	0.012	0.55
1-day maximum	3793	3690	0.8938	0.9188	0.027	0.028	0.91	0.93
3-day maximum	3746	3643	0.9057	0.9313	0.028	0.028	0.91	0.92
7-day maximum	3531	3428	0.8584	0.8842	0.029	0.030	0.87	0.89
30-day maximum	2539	2436	0.7792	0.8121	0.041	0.042	0.68	0.79
90-day maximum	1985	1882	0.5388	0.5683	0.052	0.055	0.50	0.75
Number of zero days	0	0	0	0				
Base flow index	0.6764	0.6518	0.2135	0.2195	0.036	0.028	0.15	0.87
Parameter Group #3								
Date of minimum	183	183	0.3607	0.3607	0	0	0.99	1.00
Date of maximum	236	236	0.4891	0.4891	0	0	1.00	0.98
Parameter Group #4								
Low pulse count	1	2	3	1.5	1	0.5	0.001	0.021
Low pulse duration	46.75	30	1.572	2.75	0.36	0.75	0.60	0.097
High pulse count	2	3	1	1	0.5	0	0.001	0.48
High pulse duration	23.75	19.25	1.679	1.182	0.19	0.30	0.17	0.18
Low Pulse Threshold	999.1							
High Pulse Threshold	1773							
Parameter Group #5								
Rise rate	24	24	1.125	1.125	0	0	1	1.00
Fall rate	-20	-20	-1	-1	0	0	0.70	0.86
Number of reversals	56	56	0.375	0.375	0	0	0.94	1.00
EFC Low flows								
October Low Flow	1317	1243	0.3727	0.3688	0.056	0.010	0.42	0.96
November Low Flow	1180	1130	0.3698	0.374	0.042	0.011	0.45	0.97
December Low Flow	1183	1107	0.3459	0.3502	0.064	0.013	0.35	0.93
January Low Flow	1164	1114	0.3323	0.4084	0.043	0.23	0.42	0.28
February Low Flow	1268	1214	0.3903	0.4107	0.043	0.052	0.50	0.72
March Low Flow	1279	1186	0.3604	0.3963	0.072	0.099	0.21	0.54

April Low Flow	1226	1143	0.3896	0.4163	0.067	0.068	0.33	0.72
May Low Flow	1151	1128	0.4081	0.4281	0.020	0.049	0.60	0.83
June Low Flow	1146	1086	0.3669	0.4326	0.053	0.18	0.32	0.57
July Low Flow	1217	1178	0.3282	0.4475	0.032	0.36	0.49	0.09
August Low Flow	1372	1366	0.3604	0.3857	0.004	0.070	0.92	0.75
September Low Flow	1319	1272	0.3467	0.4021	0.036	0.16	0.50	0.32
EFC Parameters								
Extreme low peak	744.2	728.1	0.188	0.2531	0.022	0.35	0.64	0.35
Extreme low duration	58	27.75	1.345	5.464	0.52	3.1	0.45	0.008
Extreme low timing	71	154.3	0.4221	0.3402	0.45	0.19	0.22	0.46
Extreme low freq.	0	0	0	0				
High flow peak	2211	2188	0.1939	0.2374	0.010	0.22	0.57	0.31
High flow duration	15.25	13	0.8607	0.8173	0.15	0.050	0.36	0.82
High flow timing	149	183.3	0.4372	0.4341	0.19	0.007	0.60	0.96
High flow frequency	1	2	3	1.5	1	0.5	0.00	0.27
High flow rise rate	75.9	87.89	1.089	0.8974	0.16	0.18	0.52	0.43
High flow fall rate	-43.96	-43.51	-0.4375	-0.732	0.010	0.67	0.96	0.052
Small Flood peak	4746	4754	0.4138	0.3819	0.002	0.077	0.92	0.79
Small Flood duration	68	70	1.145	1.257	0.029	0.098	0.89	0.79
Small Flood timing	195.8	176	0.4536	0.4679	0.11	0.032	0.92	0.79
Small Flood freq.	0	0	0	0				
Small Flood rise rate	211.7	185	1.148	1.319	0.13	0.15	0.87	0.74
Small Flood fallrate	-63.57	-71.97	-0.6285	-0.6098	0.13	0.030	0.38	0.95
Large flood peak	11400	11290	0.2876	0.2902	0.009	0.009	0.93	0.99
Large flood duration	94.5	62.5	2.217	1.288	0.34	0.42	0.65	0.59
Large flood timing	271.5	271.5	0.4775	0.4775	0	0	0.98	0.99
Large flood freq.	0	0	0	0				
Large flood rise rate	1234	1311	1.317	1.336	0.063	0.015	0.84	0.98
Large flood fall rate	-126.5	-228.6	-1.314	-0.784	0.81	0.40	0.16	0.39
EFC low flow threshold:								
EFC high flow threshold:		1773						
EFC extreme low flow threshold:		806.3						
EFC small flood minimum peak flow:		3338						
EFC large flood minimum peak flow:		8726						

Table 3. Summary of 33 IHA parameters for LSFR

[**Bold** indicates a statistically significant change at 5 percent level of significance]

	EFC Parameter	Median		Coefficient of dispersion	
		Deviation Factor	Significance Count*	Deviation Factor	Significance Count*
Group#1	January	0.088	0.12	0.096	0.79
	February	0.078	0.43	0.085	0.58
	March	0.079	0.31	0.086	0.63
	April	0.079	0.48	0.085	0.73
	May	0.089	0.27	0.098	0.70
	June	0.092	0.072	0.10	0.72
	July	0.081	0.25	0.089	0.62
	August	0.067	0.27	0.072	0.74
	September	0.065	0.55	0.070	0.87
	October	0.076	0.20	0.083	0.76
	November	0.086	0.18	0.095	0.71
	December	0.090	0.27	0.099	0.62
Group#2	1-day minimum	<u>0.11</u>	<u>0.006</u>	0.12	0.50
	3-day minimum	<u>0.11</u>	<u>0.005</u>	0.12	0.50
	7-day minimum	<u>0.11</u>	<u>0.008</u>	0.12	0.52
	30-day minimum	<u>0.11</u>	<u>0.010</u>	0.12	0.54
	90-day minimum	<u>0.10</u>	<u>0.012</u>	0.11	0.55
	1-day maximum	0.027	0.91	0.028	0.93
	3-day maximum	0.028	0.91	0.028	0.92
	7-day maximum	0.029	0.87	0.030	0.89
	30-day maximum	0.041	0.68	0.042	0.79
	90-day maximum	0.052	0.50	0.055	0.75
	Number of zero days				
	Base flow index	0.036	0.15	0.028	0.87
Group#3	Date of minimum	0	0.99	0	1.00
	Date of maximum	0	1.00	0	0.98
Group#4	Low pulse count	<u>1</u>	<u>0.001</u>	<u>0.5</u>	<u>0.021</u>
	Low pulse duration	0.36	0.60	0.75	0.097
	High pulse count	<u>0.5</u>	<u>0.001</u>	0	0.48
	High pulse duration	0.19	0.17	0.30	0.18
Group#5	Rise rate	0	1	0	1.00
	Fall rate	0	0.70	0	0.86
	Number of reversals	0	0.94	0	1.00
*Deviation factor is significant if significance count<0.05 Bolded values have significance count<0.05					

Table 4. Summary of 34 IHA environmental flow component parameters for LSFR

[**Bold** indicates a statistically significant change at 5 percent level of significance]

	EFC Parameter	Median		Coefficient of dispersion	
		Deviation Factor	Significance Count*	Deviation Factor	Significance Count*
Low flow	January low flow	0.043	0.42	0.23	0.28
	February low flow	0.043	0.50	0.052	0.72
	March low flow	0.072	0.21	0.099	0.54
	April low flow	0.067	0.33	0.068	0.72
	May low flow	0.020	0.60	0.049	0.83
	June low flow	0.053	0.32	0.18	0.57
	July low flow	0.032	0.49	0.36	0.09
	August low flow	0.004	0.92	0.070	0.75
	September low flow	0.036	0.50	0.16	0.32
	October low flow	0.056	0.42	0.010	0.96
	November low flow	0.042	0.45	0.011	0.97
	December low flow	0.064	0.35	0.013	0.93
Extreme low flow	Extreme low peak	0.022	0.64	0.35	0.35
	Extreme low duration	0.52	0.45	3.1	0.008
	Extreme low timing	0.45	0.22	0.19	0.46
	Extreme low frequency				
High flow pulse	High flow peak	0.010	0.57	0.22	0.31
	High flow duration	0.15	0.36	0.050	0.82
	High flow timing	0.19	0.60	0.007	0.96
	High flow frequency	1	0.00	0.5	0.27
	High flow rise rate	0.16	0.48	0.18	0.43
	High flow fall rate	0.010	0.96	0.67	0.052
Small flood	Small flood peak	0.002	0.92	0.077	0.79
	Small flood duration	0.029	0.89	0.098	0.79
	Small flood timing	0.11	0.92	0.032	0.79
	Small flood frequency				
	Small flood rise rate	0.13	0.87	0.15	0.74
	Small flood fall rate	0.13	0.38	0.030	0.95
Large flood	Large flood peak	0.009	0.93	0.009	0.99
	Large flood duration	0.34	0.65	0.42	0.59
	Large flood timing	0	0.98	0	0.99
	Large flood frequency				
	Large flood rise rate	0.063	0.84	0.015	0.98
	Large flood fall rate	0.81	0.16	0.40	0.39
*Deviation factor is significant if significance count<0.05					
Bolded values have significance count<0.05					

References

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