Inter-annual and seasonal variability: A Mexican rivers classification towards climate-smart environmental flows

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1. INTRODUCTION

The study of flow-ecology relationships is key in environmental flow assessments (EFA; Poff et al., 2017). Nowadays, the more advanced hydrologic-based methods in EFA focus on building those relationships for the inter-annual and seasonal flow regime variability components (e.g. Richter et al., 1997; Hughes & Hannart, 2003; Matthews & Richter, 2007).

In Mexico, the most detailed hydrological method is set by the norm NMX-AA-SCFI-159-2012 for EFA (Secretaría de Economía, 2012), applicable nation-wide, in which the natural frequency of occurrence integrates these variability components (Figure 1).

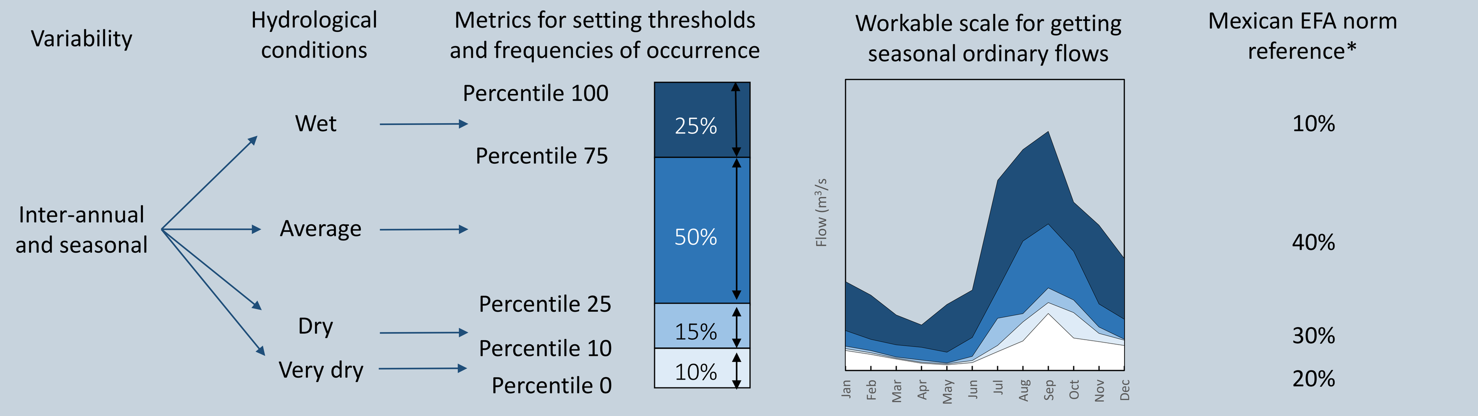


Figure 1. Procedure for setting the inter-annual and seasonal variability of the hydrological conditions of ordinary flows based on frequencies of occurrence.

However, to date it hasn't been investigated the magnitude of the hydrological contributions from the flow variability components, and if is it differentiated on rivers and streams by climatic-influence or their geographic location. The primary goal of this work is to fill this gap.

2. MOTIVATION

Recommend a science-based adjustment to the criteria of frequency of occurrence for Mexican rivers according to (1) a typology sensitive to the flow variability components, and based on (2) the runoff historical tendency on flows variability shifts to manage preventively the impacts of climate change. The goal of the present study is to evaluate the inter-annual and seasonal flow variability contributions of Mexican rivers types.

3. METHODOLOGY

- Information requirements.
  - Daily flow regimes with periods of records for at least 20 consecutive years.
  - Periods of flow records with less than 10% of gaps in the series.
- Nation-wide hydrological and geographical variability representation of rivers (Figure 2).
  - Type of current (perennial [17], intermittent [12] or ephemeral [11] streams).
  - With regard to the Tropic of Cancer (Northern [13] or Southern [27]).
  - Drainage zone (exorreic [Atlantic |13| or Pacific |21|] and endorreic [6]).

3.1 Study sites

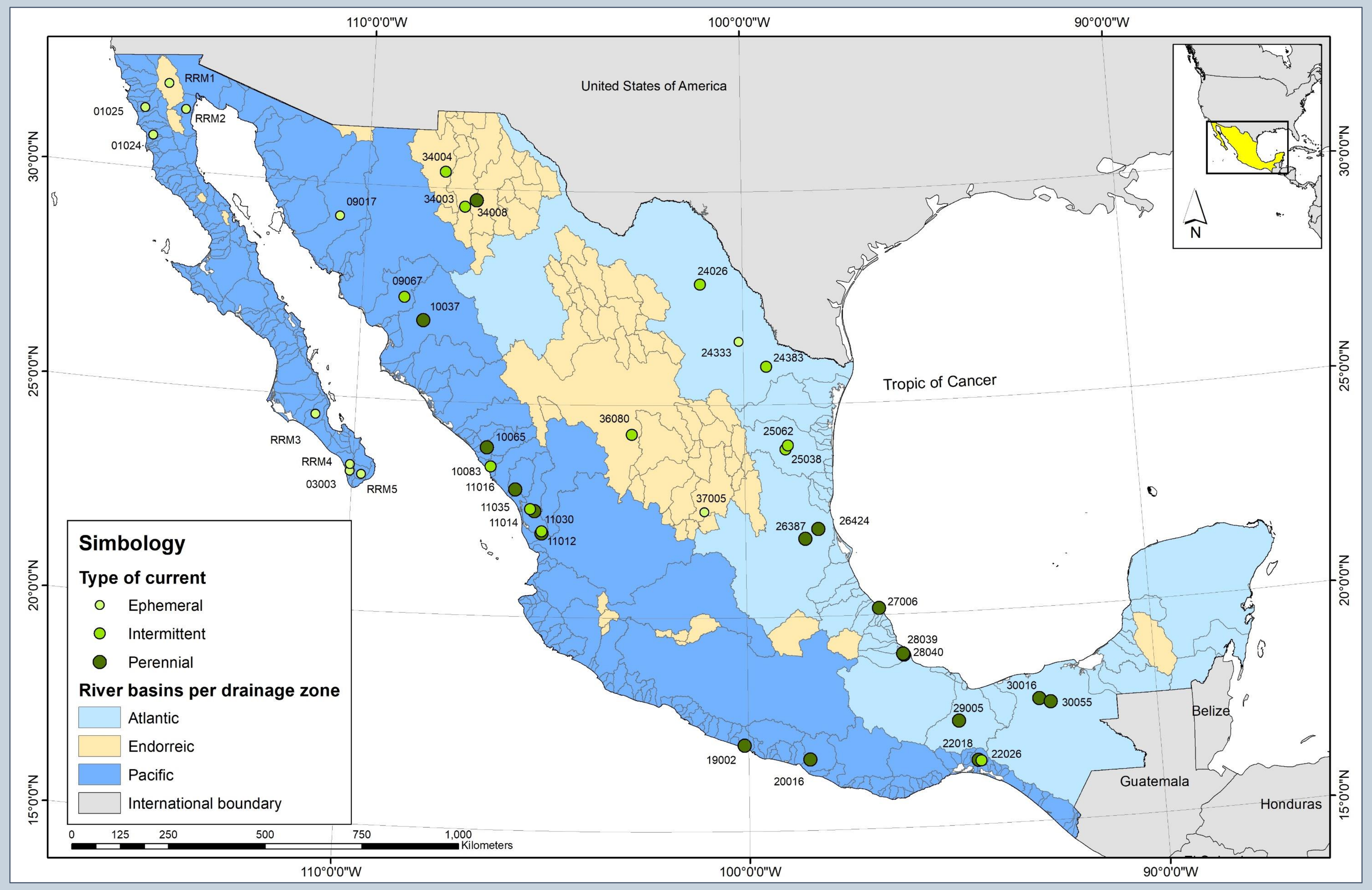


Figure 2. Selection of 40 rivers for conducting the analysis. The type of current was set based on a flow duration curve criteria (ephemeral if Q >1 m³/s ≤ 30% of exceedance time; intermittent = Q > 1 between 30-90%; perennial = Q > 1 ≥ 90%).

3.2 Indices of hydrological conditions contribution and statistical tests

Inter-annual variability

Condition	Percentile	Dry season						Wet season			Dry season			Inter-annual contribution	Dry season contribution	Wet season contribution
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Very dry	0th	0.8	0.6	0.3	0.1	0.0	0.0	16.0	23.7	10.2	2.0	1.0	0.9	55.4	5.5	49.9
Dry	10th	1.5	1.3	0.6	0.3	0.1	0.2	25.8	51.5	20.2	4.0	1.7	1.3	108.4	10.9	97.5
Average	25th	2.8	2.4	1.2	0.6	0.2	0.5	32.7	69.7	35.1	6.0	2.1	2.4	155.8	18.2	137.6
Wet	75th	21.0	27.6	8.0	2.1	1.5	3.2	78.3	126.0	88.7	26.6	10.1	22.1	415.2	122.2	293.0
Max. historical	100th	150.5	155.4	156.9	37.5	5.2	15.2	134.4	249.7	207.2	179.5	57.6	256.0	1605.1	1013.8	591.3

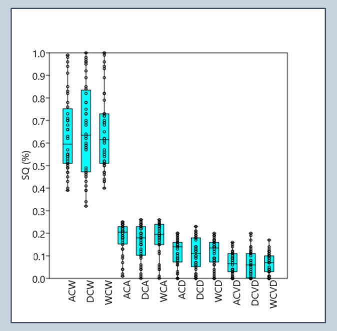
$$RQ_j = 100 \times \frac{\sum_{i=1}^{n} Q_i}{Q_{max}} \qquad SQ_j = 100 \times \frac{RQ_i}{\sum_{i=1}^{n} RQ_i}$$

- RQ_j is the relative discharge volume contribution of the variability *j* (inter-annual, dry or wet season); Q is the discharge volume of condition *i* (wet, average, dry or very dry) of the variability *j*; *n* is the total discharge volume from the months representative of condition *i* of the variability *j*; Q_{max} is the maximum historical discharge volume (percentile 100th) of the variability *j*.
- SQ_j is the standardized discharge volume contribution of the variability *j* (inter-annual, dry season or wet season); RQ is the relative discharge volume contribution for the condition *i* (wet, average, dry or very dry) of the variability *j*; *n* is the total relative discharge volume contribution of all conditions *i*.
- Multivariate analysis: (1) Principal components (PC) analysis for ordination of river classifications; and (2) One-way PERMANOVA for the differences on response variables (SQ) between the groups of the better river classification according to the PC analysis outcome.

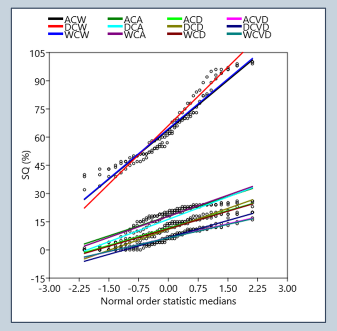
4. RESULTS

4.1 Exploratory graphs and Principal Components Analysis

Box plot



Normality plot



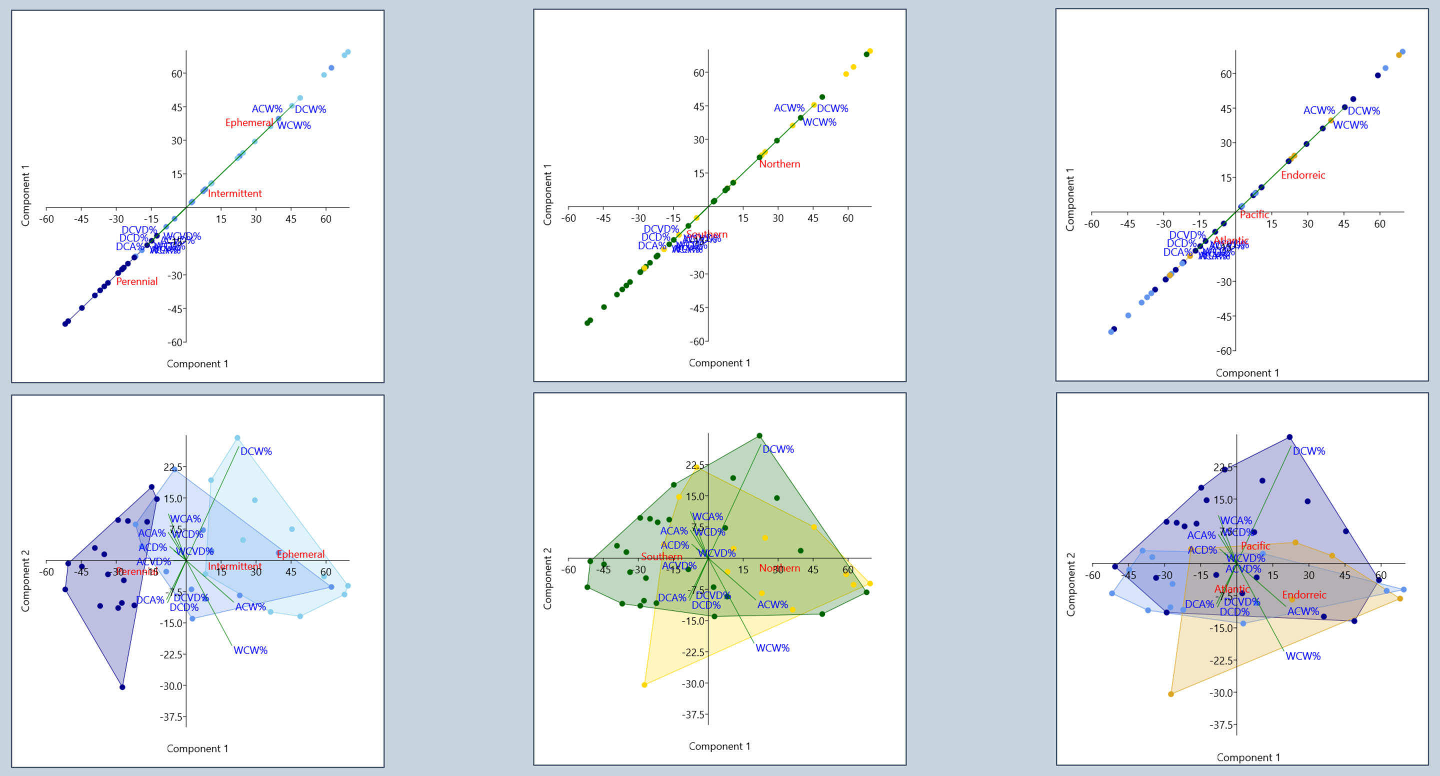
Eigenanalysis

PC	Eigenvalue	% Variance	% Cum. Var.
1	1,185.43	88.10	88.10
2	137.32	10.21	98.30
3	14.55	1.08	99.38
4	4.02	0.30	99.68
5	1.81	0.13	99.81
6	1.42	0.11	99.92
7	0.62	0.05	99.97
8	0.16	0.01	99.98
9	0.12	0.01	99.99
10	0.08	0.01	99.99
11	0.05	0.00	100.00
12	0.04	0.00	100.00

Matrix of correlations

Variability	Condition	Code	PC1	PC2
Inter-annual	Wet	ACW	0.98	-0.16
	Average	ACA	-0.93	0.28
	Dry	ACD	-0.98	0.16
	Very Dry	ACVD	-0.94	0.00
Dry season	Wet	DCW	0.92	0.38
	Average	DCA	-0.90	-0.34
	Dry	DCD	-0.91	-0.39
	Very Dry	DCVD	-0.88	-0.37
Wet season	Wet	WCW	0.94	-0.33
	Average	WCA	-0.87	0.43
	Dry	WCD	-0.93	0.34
	Very Dry	WCVD	-0.92	0.14

Type of current — Tropic of Cancer — Drainage zone



4.2 ONE-WAY PERMANOVA

Source (Condition)	Sum sqrs	Within-group Sum sqrs	F	P-value
Wet	38,460	13,520	34.12	0.0001
Average	6,151	2,870	21.15	0.0001
Dry	4,815	1,760	32.12	0.0001
Very dry	3,051	846	48.19	0.0001

Notes: Euclidean similarity index; Permutation (N) 9999.

Pairwise	Wet condition			Average condition			Dry condition			Very dry condition		
Type of current	Eph	Int	Per	Eph	Int	Per	Eph	Int	Per	Eph	Int	Per
Ephemeral		0.0177	0.0003		0.0141	0.0003		0.0354	0.0003		0.0336	0.0003
Intermittent	0.0177		0.0003	0.0141		0.0003	0.0354		0.0003	0.0336		0.0003
Perennial	0.0003	0.0003		0.0003	0.0003		0.0003	0.0003		0.0003	0.0003	

Note: Bonferroni corrected p-values; significance differences for the three types of variability (inter-annual and seasonal) in wet, average, dry and very dry conditions.

5. CONCLUSIONS

- PC1 and PC2 encompass 98% of the cumulative variance. They separate the groups better by types of current and explain the variables effects.
- Ephemeral and intermittent streams in Northern Mexico within an endorreic system are highly dependent of wet condition contributions.
- There are significant differences in the SQ of all the conditions (wet, average, dry and very dry) of the hydrological variability considered (inter-annual and seasonal). These differences are reflected in the full spectrum of types of current (perennial, intermittent and ephemeral).

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