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Environmental flows and water reserves: Principles, strategies, and contributions to water and conservation policies in Mexico

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Abstract

Since the Brisbane Declaration in 2007, implementation of environmental flows in public policies has witnessed a steady increase around the globe. Environmental water reserves are an annual volume that is designated to remain in the ecosystem for the sustainable management of river basins. In Mexico, these reserves are determined on the basis of the Mexican Environmental Flows Norm and must be established at a river basin scale through a presidential decree for 50 years. In this manuscript, we present and discuss the implementation strategy of the norm developed for the National Water Reserves for the Environment Program, and its results in 25 reference sites based on environmental flow assessments conducted from 2012 to 2015 using hydrological and holistic methodologies. An analytical evaluation revealed an overall consistency between the Norm's environmental objectives (baseline) and the current ecological conditions on-site for the 80% of the cases (96% over high confidence rating). Furthermore, in 72% of the reference sites, the coefficient of variation among the reserve's was below the fourth quartile (<11%), whereas those remaining above that limit can be attributed to a difference in the methods' hydrologic scope. The recommended volumes for environmental allocation are feasible under the current water availability conditions in the 94% of the river basins. Although challenges have appeared in the process, to date, one reserve has been decreed on the basis of the strategic approach of setting sustainable limits of water allocation and being built an enriched flow-ecology relationships' understanding system, urgently needed to prevent ecosystems degradation and secure ecological processes.

KEYWORDS

environmental flows, environmental objectives, environmental water reserve, hydrological and holistic methodologies, Mexican norm, river basin

1 | INTRODUCTION

The natural flow regime in aquatic ecosystems plays a critical role in sustaining ecological functions, processes, and services, and the ecological consequences of its alteration are well recognized (Acreman et al., 2014a; Bunn & Arthington, 2002; Davies & Jackson, 2006; Poff et al., 1997; Poff, Tharme, & Arthington, 2017; Poff & Zimmerman, 2010; Richter, Baumgartner, Wigington, & Braun, 1997). The quantity, quality, and timing of water required to preserve ecological functions and environmental services are generally identified as environmental flows (or "e-flows"). Their implementation in public policies such as *environmental water reserves* (EWR)—a volume based on the environmental water science—is an allocation mechanism to manage rivers in a more ecologically and socially sustainable way under current and future water usage, and freshwater biodiversity degradation rates (Acreman et al., 2014a; Horne, O'Donnell, & Tharme, 2017; Poff et al., 2017).

In Mexico, an EWR is an annual volume of water that is allocated, by presidential decree, to benefit the environment and ecological protection of a river basin. It is established for a duration of up to 50 years and defines the usage of remaining water available in its geographical territory. The Mexican Environmental Flows Norm (NMX-AA-159-SCFI-2012) officially establishes the procedure and technical standards (referred as eFlowsNMx in this manuscript) to determine this volume of water.

In 2012, the national water agency launched a National Water Reserves for the Environment Program (NWRP) focusing on 189 river basins—based on their water availability, low demand from current water users, and high biological richness and conservation values (CONAGUA, 2011)—as a strategy to implement EWR. Unlike other national-scale approaches around the globe, the Mexican NWRP aims to establish EWRs in targeted basins to capitalize their favourable conditions of conservation potential while building a network and strengthening capacities in the e-flows standard implementation. These are fundamental aspects for a second phase of the programme, which will focus on basins already facing intense pressure on their water resources (Barrios, 2014; Horne et al., 2017).

In this paper, we present and discuss the implementation strategy of the eFlowsNMx developed in this programme and its results in pilot projects from 2012 to 2015 (Phase I). An analytical assessment of consistency between environmental objectives (national baseline vs. field evaluation) and EWRs determined using hydrological and holistic methodologies was conducted in 25 reference sites across 54 river basins throughout the country. The performance of the NWRP was examined in terms of progress towards the enactment of EWR decrees.

2 | MEXICAN CONTEXT ON WATER RESOURCES, CONSERVATION, AND EARLY ENVIRONMENTAL FLOW ASSESSMENTS

The Mexican National Water Commission (CONAGUA) is the federal agency in charge of managing water resources in 757 river basins and 653 aquifers, located in 13 hydrological regions throughout the country. For each basin, there is an official water availability study published in the Official Journal of the Federation. According to recent publications, Mexico's total renewable water is 446.7 km^3/year, of which 85.6 km^3/year have been allocated to be used (CONAGUA, 2016a). Although these numbers indicate low water stress (19%) at the national level, at the scale of hydrological regions, there are parts of the country that experience severe water stress (>40%). Large natural differences in climate and its variability exist between the arid north and centre of the country, and the humid, tropical South, with water stress and over-allocation of water resources concentrated in the first.

In terms of conservation, the country has a system of 182 federal protected areas with a combined surface area of approximately 908,395 km^2 (10.8% and 22.1% of Mexico's terrestrial and marine territory, respectively). Seventy-nine protected areas are completely or partially designated as wetlands of international importance (CONANP, 2017). However, recent official reports indicated strong negative trends associated to pollution of water bodies, levels of depletion, invasion by exotic species, changes in natural land cover, and development of dams and other water management infrastructure (Baena, Halffter, Lira-Noriega, & Soberón, 2008; Contreras-Balderas, Almada-Villela, Lozano-Vilano, & García-Ramírez, 2003; Valderrama-Landeros et al., 2017).

The first e-flow assessments in Mexico appeared in the early 1990s. Applications of hydrological, hydraulic, habitat simulation, and holistic methodologies raised awareness of ecosystem water requirements and paved the way towards the development of a national standard for integrated water and conservation planning and management (Alonso-Eguía Lis, Gómez-Balandra, & Saldaña-Fabela, 2007). Among the first e-flow assessments at basin level that demonstrated the ecological significance of water and its social recognition for the establishment of EWR are the studies of the Conchos, Copalita-Zimatán-Huatulco, and San Pedro Mezquital rivers developed by the alliance between the World Wildlife Fund (WWF) and the Gonzalo Río Arronte I.A.P. Foundation (FGRA) from 2004 to 2010 (Barrios, 2014). Additionally, key institutions such the Mexican National Commission for the Knowledge and Use of Biodiversity and the National Institute of Ecology and Climate Change (former National Institute of Ecology) developed official national scale assessments such as the Conservation Priorities and the Eco-hydrological Alteration State in Mexican River Basins (Aguilar, Kolb, Koleff, & Urquina Haas, 2010; Garrido, Cuevas, Cotler, González, & Tharme, 2010).

These earlier experiences contributed to the development of the eFlowsNMx (Secretaría de Economía, 2012). Since its publication, researchers from universities and the Mexican Institute of Water Technology have conducted e-flow assessments to determine the amount of water for the environment and demonstrated the utility of the eFlowsNMx as a regulatory instrument (De la Lanza Espino, Carbajal Pérez, Salinas Rodríguez, & Barrios Ordóñez, 2012; De la Lanza Espino, Salinas Rodríguez, & Carbajal López, 2015; Gómez-Balandra, Saldaña-Fabela, & Martínez-Jiménez, 2014).

3 | MEXICAN ENVIRONMENTAL FLOWS NORM: PRINCIPLES AND IMPLEMENTATION STRATEGY

The eFlowsNMx aims to find a balance between water use and conservation and provides a standardized strategic approach for conducting e-flow assessments, which consists of:

- Setting suitable water and conservation management objectives (onwards referred to as environmental objectives) to deal with current and future water demands, ecological status and risks in water management, avoid conflicts over water availability between the environment and other users, particularly during water scarcity episodes (Bunn & Arthington, 2002; Davies & Jackson, 2006; King, Tharme, & de Villiers, 2000; Poff & Matthews, 2013).

- Assessing the e-flows requirements based on the analysis of the natural and current flow regime components of intra and inter-annual variability, as well as the related ecological functions, processes, and environmental services to achieve a specific ecological status (Mathews & Richter, 2007; Poff et al., 1997; Poff & Zimmerman, 2010; Richter et al., 1997).
- Delivering science-based outcomes to decision makers in order to be able to determine the amount of water to be allocated as an environmental reserve volume, which should be linked to achieving a particular ecological target condition.

In general, this process follows what is considered the common thread in state-of-the-art e-flows science, practice, and policy (Acreman et al., 2014b; Horne et al., 2017; Poff et al., 2017).

3.1 | Methods and implementation strategy for determining e-flow requirements

3.1.1 | Environmental objectives

Environmental objectives or desired ecological status are established based on two factors in a river basin (Figure 1). The first factor is the *ecological importance* of an ecosystem, which is established on the basis of a generic ecological status assessment that combines biotic aspects, ecological integrity condition, and expected state of ecohydrological alteration of the components and attributes of the flow regime. The second factor is the human pressure on water resources, where *water pressure* is defined as the ratio of allocated volume for all uses divided by its availability. This factor is considered an independent variable in environmental water allocation, due to its importance for water management as a proxy of societal objectives in meeting water demand, current, and under projected development conditions.

Environmental objectives are selected on the basis of a matrix with four classes (A, B, C, and D), according to a combination of water pressure and ecological importance levels as a practical implementation of conceptual flow-ecology and flow alteration-ecological response relationships (Acreman, et al., 2014b; Poff & Matthews, 2013; Poff & Zimmerman, 2010). The extremes of these classes range from a very good desired or optimal ecological status ("A") to a deficient ecological status ("D").

3.1.2 | Methodologies for assessing e-flows

The norm allows determination of e-flow requirements based on any of the methodologies commonly grouped according to the type of their approach: *hydrological*, *hydraulic*, *habitat simulation*, or *holistic* (Poff et al., 2017). In the context of the NWRP, e-flows were determined on the basis of the implementation of two different methodologies. One is a desktop hydrological approach originally developed by the WWF-FGRA alliance to determine e-flow requirements in the San Pedro Mezquital river basin (Sánchez Navarro & Barrios Ordóñez, 2011). The second is a holistic approach, adapted from the Building Block Methodology (King et al., 2000) to the Mexican context.

These methodologies were mainly selected due to their suitability for water planning and management. In the implementation of the methodologies, e-flows aim to encompass (a) an ordinary seasonal flow pattern considering intra-annual (seasonality) and inter-annual variability (hydrological conditions); and (b) a flood regime with at least three flow magnitude categories typified according to their recurrence interval (frequency): intra-annual, low and moderate inter-annual with corresponding attributes of duration, timing and rate of change (Table 1). The previous flow components allow guiding the ecohydrological working hypotheses to understand flow-ecology and flow alteration-ecological response relationships, usually based on specialized literature and validated in the context of an expert panel in interdisciplinary workshops for developing e-flow recommendations (Acreman et al., 2014a; Acreman et al., 2014b; Poff & Zimmerman, 2010).

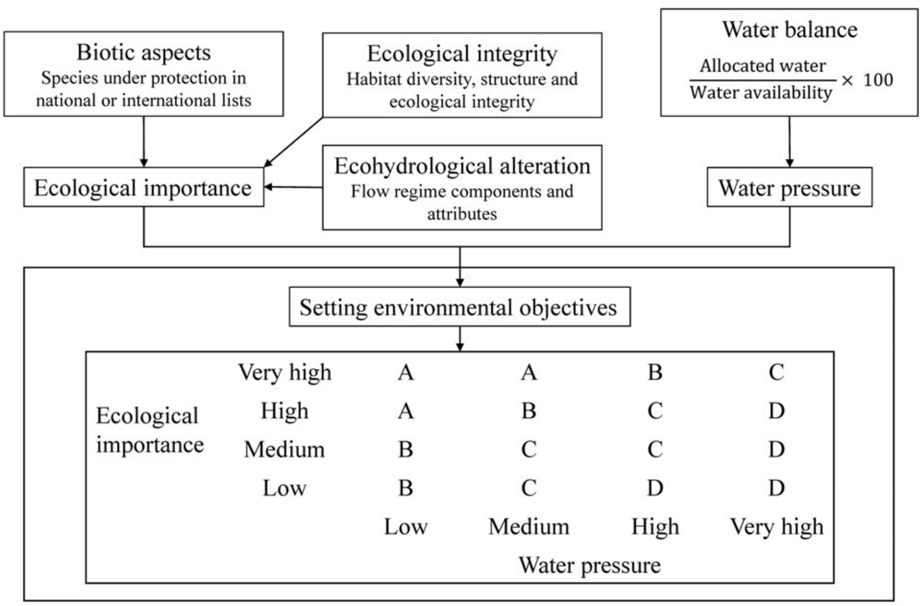

FIGURE 1 Process for setting environmental objectives based on the ecological importance and the water pressure factors

TABLE 1 Flow regime components and metrics according to the hydrological and holistic methods of the Mexican Environmental Flows Norm (NMX-AA-159-SCFI-2012)

Method	Flow regime component	Metrics
Hydrological	Intra-annual and inter-annual variability	Mean monthly flows in cubic metres per second of percentiles 75th, 25th, 10th, and 0th as representative of wet, average, dry, and very dry annual conditions, respectively.
Holistic	Intra-annual and inter-annual variability	Mean seasonal flows in cubic metres per second based on percentiles ranges 50th–25th and 25th–0th as representative of average and dry annual conditions, respectively.
Hydrological and holistic	Flood regime	Category I. Intra-annual flood magnitude in cubic metres per second typified by a frequency of 1-year recurrence interval. Category II. Low inter-annual flood magnitude in cubic metres per second typified by a frequency of 1-year and a half recurrence interval. Category III. Moderate inter-annual flood magnitude in cubic metres per second typified by a frequency of 5-year recurrence interval.

3.1.3 | Implementation strategy

Between 2012 and 2015 eight pilot zones were selected and e-flow assessments conducted with both hydrological and holistic methodologies (Figure 2): The Colorado, Piaxtla, Acaponeta, San Pedro, and Chamela zones located in Western Mexico; Copalita in the South of the country, all discharging into the Pacific Ocean; and the Sierra Gorda and Papaloapan zones in the centre flowing to the Gulf of Mexico. Regional academic groups were formed to cover all the areas of expertise required for the holistic approach. Water managers from CONAGUA and representatives from the Mexican Commission of Natural Protected Areas (CONANP) participated in the assessment workshops.

The workshops for the general approach (Figure 3) were conducted at two different levels:

- National scale, to present the norm, its objectives, technical guidelines, and procedures, in particular within the holistic method to discuss and agree on a work plan and fieldwork protocols for this assessment. Additionally, the hydrological approach was applied as a capacity-building, hands-on workshop directed to hydrologists and water managers.
- Basin-scale, where the holistic method was applied in each pilot zone with two-field surveys (dry and wet season). Hydrological information at a daily scale was taken from the National Data Bank of Surface Water (CONAGUA, 2016b), or rainfall–run-off models were developed.

For the implementation of the hydrological approach, the environmental objectives provided by the eFlowsNMx were adopted as a baseline. In the case of the holistic methodology, 25 reference sites were selected. These sites were defined as river reaches or streams with available hydrological information (daily flow records from gauging stations or rainfall–run-off models) and with homogenous characteristics of ecological importance and water pressure. The ecological

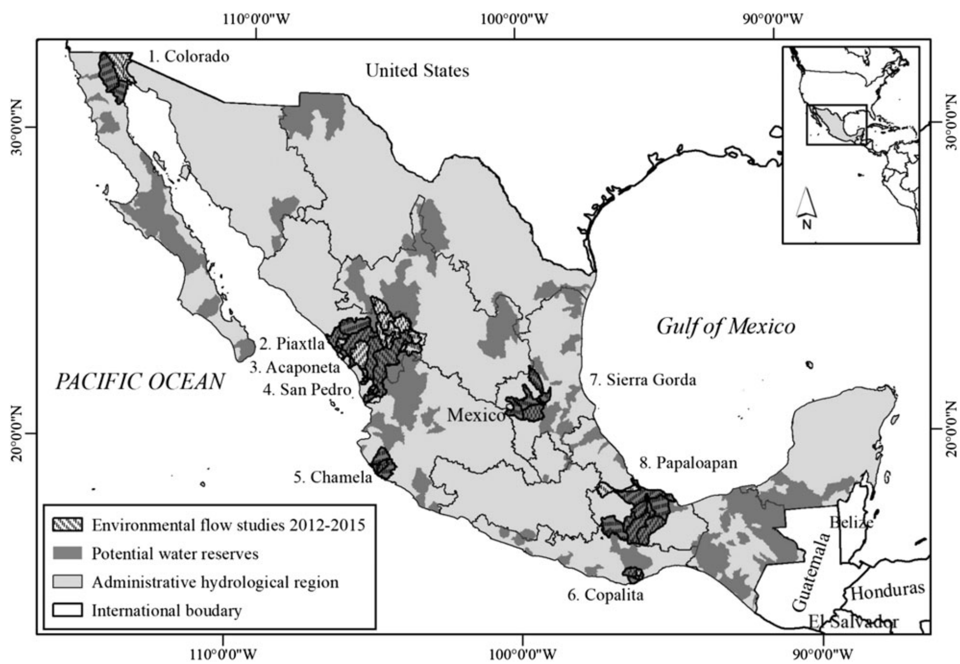

FIGURE 2 Potential water reserves and pilot zones for environmental flow assessments in 2012–2015 of the National Water Reserves for the Environment Program

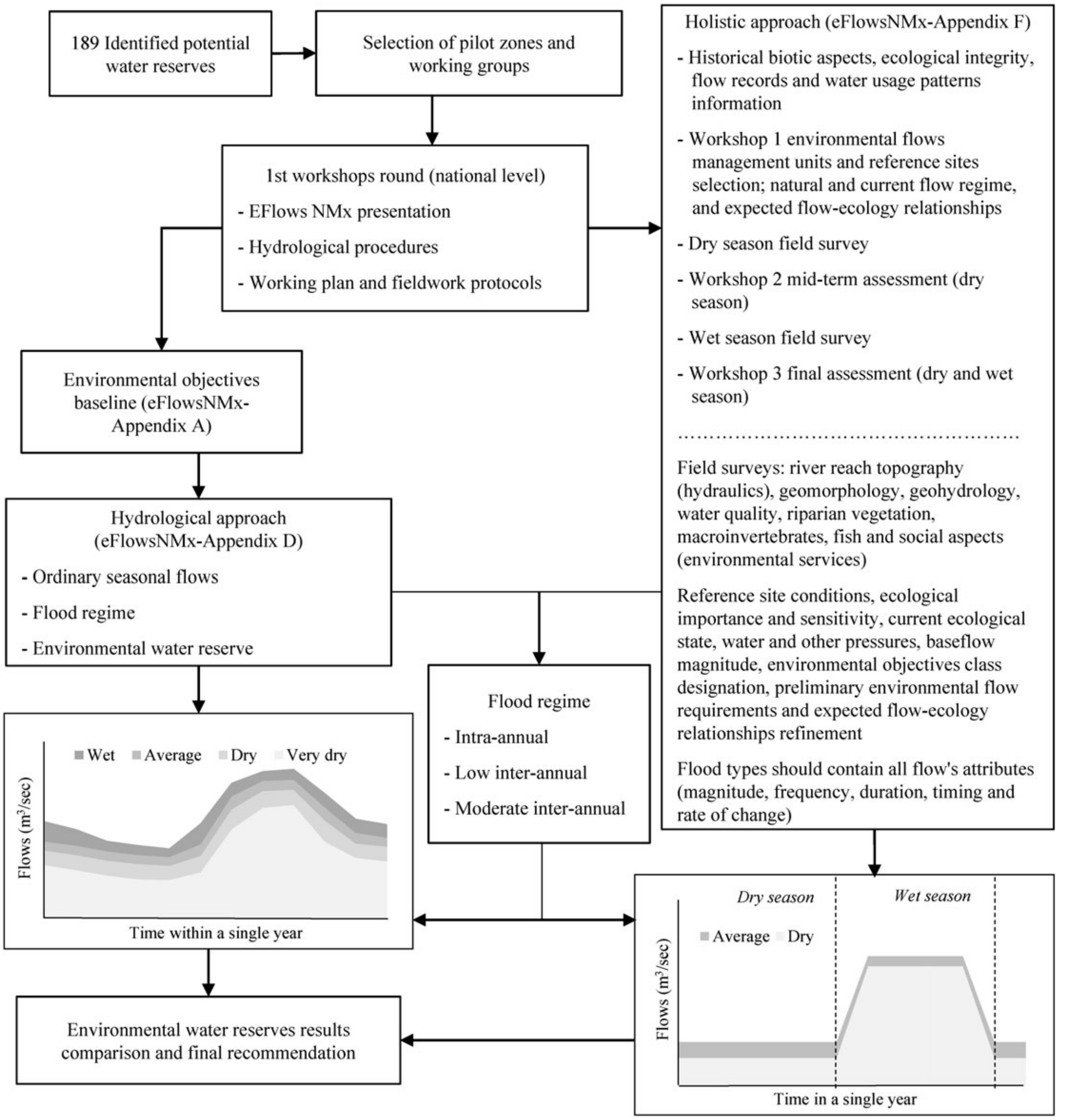

FIGURE 3 General strategy implemented in the environmental flow assessments of the National Water Reserves for the Environment Program. Conceptual hydrograms represent the environmental flow regime at monthly scale in the hydrological approach (bottom left), and seasonal scale in the holistic approach (bottom right). Tones of grey represent the ordinary flow conditions obtained using the hydrological approach (wet, average, dry, and very dry years) and the holistic methodology (average and dry years)

importance of each site was assessed on the basis of the details of each reference site in terms of biotic (*ecological importance and sensitivity*), ecological integrity, and ecohydrological alteration (*habitat integrity*) conditions or subfactors (Appendix A). In addition to the information surveyed on-site, historical species presence, conservation status, and experts or local knowledge were also considered (CONABIO, 2016).

3.2 | E-flow regimes and water reserves volumes

Monthly and seasonal regimes of yearly flow conditions, in addition to the flood regime, were synthesized from both the hydrological and holistic approaches into the annual volumes of EWRs, and their coefficient of variation was calculated to analyse their differences.

In order to understand the scope of these results and their consistency, flow variability indices of the natural regimes were calculated and analysed based on the proposed by Hughes and Hannart (2003), adapted to the norm's outcomes. These include the mean annual run-off (MAR) and mean annual baseflow (MABF). A coefficient of variation index (CV) as an indication of long-term variability of wet and dry seasons. It is calculated, first, based on the coefficient of variation for all monthly flows for each calendar month; and second, by summing the three main months of both seasons from such monthly coefficients averages. A baseflow index (BFI) representative of short-term variability of flows (ratio of the MABF to the MAR), and their logical combination (CV/BFI) for an overall index of variability (CVB).

Finally, the EWR volumes were evaluated to confirm that they do not affect existing water rights. For this purpose, EWR volumes were compared with the current water available for potential environmental allocation (total volume for environmental use, water committed downstream, and water availability), as established by the water balance agreements currently in place (CONAGUA, 2016c).

4 | RESULTS AND DISCUSSION

4.1 | Water and conservation management objectives

Generally, a strong consistency was found between the environmental objectives baseline and the outcomes of the holistic method applied at an individual basin scales (Table 2). The on-site assessment revealed 17 cases with a very high ranking in ecological importance, seven ranked high, and one ranked medium, in comparison with 12, 11, and two from the baseline, respectively. According to the environmental objectives baseline classification, the desired ecological status of 22 out of 25 basins (88%) ranked as very good (class “A”), two ranked as good (“B”), and one as moderate (“C”); whereas based on the holistic approach, 21 basins (84%) were determined to have a very good (“A”), and four showed a good (“B”) ecological status. In 20 basins (80%), the environmental objective baseline was confirmed by the holistic assessment, whereas five revealed a different current ecological condition. The units Verde 3, Papaloapan, and Jamapa-Cotaxtla showed a loss of ecological integrity due to ecohydrological alteration; whereas Trinidad and Blanco presented a very good or good biotic, ecohydrological, and ecological integrity conditions (Table A1).

One last remark from the on-site assessment is that 17 basins were assessed with a very high confidence rating score (3.5–4.0) of ecological importance, seven with high (2.5–3.0), and only one with medium or moderate (2.0). This result, as well as the consistency between the environmental objectives, is due to the strategic selection of pilot basins. From the 25 reference sites, all are potential water reserves with the only exception of Blanco that is under very high pressure over water demand (193%).

4.2 | Water reserves volumes and flow regime characteristics

EWR volumes among basins and pilot zones were predictably diverse. For the hydrological and the holistic method, respectively, they ranged from 6.5 to 7.8 million cubic metres per year (Mm^3/year) in El Borrego (arid basin) to 27,305 or 29,874 Mm^3/year in Llanuras de Papaloapan (humid tropical), mostly due to their geographical location and climatic conditions (Table 3). In terms of EWR volumes coefficient of variation between both methods, we found values ranging 1.6–33.2% across the full range of distribution, with 13 out of 25 basins in the first two quartiles (≤6.4%), five in the third (6.9–10.2), and seven in the last threshold (11.1–33.2%, Jamapa-Cotaxtla, El Borrego, Presidio 2, Trinidad, Cuitzmala, Cerrada Laguna Salada, and Verde 3).

This variation of volumes is explained by two reasons. First, due to a difference in the hydrologic scope or temporary resolution among methods (monthly vs. seasonal, Table A2). Basins in arid or tropical regions from Western Mexico exhibit higher seasonal variability (CV >110%), some with remarkable differences between ordinary high and low flows magnitudes. These streams show the lowest baseflow buffer capacity (BFI ≤ 11%) and the highest overall CVB index from 14.9 to 655.7 (Figure 4). Together, these results indicate that these basins could tend to be affected regularly by droughts (Hughes & Hannart, 2003). In these regions, the hydrological approach encompassed natural dry episodes better, which is consistent with the metrics of flow regime components (percentiles 10th and 0th at monthly scale hydrological vs. 25th–0th holistic at seasonal).

About the second cause, the expert panel evaluated EWR volumes within the on-site assessment for a different class of baseline environmental objectives, in coherence with the current ecological status and following a more accurate desired condition. In this case, Papaloapan and Blanco have the major baseflow contribution (BFI >40%) and the lowest overall variability in its flow regime (CVB <1.3); therefore, these rivers did not present meaningful variability in EWR volumes.

With regard to the feasibility of EWR under the current basins' water allocation, most of the recommended volumes are lower than the currently available water for potential environmental allocation. Exceptions are Copalita 1 unit which has a deficit in EWR (17 Mm^3/year) and San Nicolás A (303–424 Mm^3/year). These deficits are because of significant differences between the calculated MAR from gauging stations used in the e-flow assessments and the amounts officially recognized in the water balance agreements, where the MAR is based on annual-scale rainfall–run-off models for the last 20 years. These differences should be analysed in more detail (e.g., recent flows and rainfall records from gauging stations within these or neighbouring basins).

4.3 | Recommendations for flow-ecology based water reserves, the process for their establishment, and progress achieved

The volumes that were recommended to CONAGUA for environmental allocation which were assessed using the holistic methodology showed that they would provide the most comprehensive flow-ecology relationships and were grounded on on-site knowledge about current ecological conditions. The recommended volumes seem feasible in most cases and received feedback and approval from panels of experts. However, it should be recognized that e-flow assessments are merely a first step towards a much longer and complex administrative and legal process in establishing water reserves (Figure 5).

In addition to each EWR assessment, an economic evaluation (cost–benefit analysis) should be performed to demonstrate that securing a healthy flow regime and the related environmental services outweigh the associated costs; the most relevant of these would be the need for changes in the water tariffs due to the decrease in the relative water availability. According to the present legislation, these costs' increases would be charged to the productive users of water. This implication is a misconception of the social benefit of the water reserves, and its unpopularity has become an important challenge to the process and progress of allocating environmental water. The alignment of the EWR and the water tariff mechanisms are currently under discussion between the Deputy Director General's Office for Technical Affairs and the Coordination of Fiscal Revision and Payments of CONAGUA in order to make the legislation coherent with current environmental water science and to prevent social rejection.

Among the technical studies supporting the EWR that have passed the approval stage are San Pedro (1:16 cost–benefit ratio in

TABLE 2 Environmental objectives baseline (eFlowsNMx Appendix A) and on-site assessments using the holistic method

		National baseline				On-site assessments					
Pilot zone	River basin	Water pressure (percentage)	Water pressure (class)	Ecological importance	Environmental objective	Biotic aspects	Ecological integrity	Ecohydrological alteration	Overall confidence rating score (median)	Ecological importance	Environmental objective
Colorado	Cerrada Laguna Salada	0.1	Low	Very high	A	4.0	4.0	3.5	4.0	Very high	A
	El Borrego	0.0	Low	Very high	A	2.0	4.0	4.0	4.0	Very high	A
Piaxtla	Piaxtla 2	0.6	Low	Very high	A	4.0	3.0	4.0	4.0	Very high	A
	Quelite 2	0.4	Low	High	A	3.5	3.0	4.0	3.5	Very high	A
	Presidio 2	0.2	Low	Medium	B	4.0	3.0	2.5	3.0	High	B
Acaponeta	Acaponeta 1	1.7	Low	High	A	4.0	4.0	4.0	4.0	Very high	A
San Pedro	San Pedro Desembocadura	8.2	Low	Very high	A	4.0	3.0	4.0	4.0	Very high	A
Chamela	San Nicolás A	2.2	Low	Very high	A	4.0	4.0	4.0	4.0	Very high	A
	Purificación	8.1	Low	Very high	A	4.0	3.0	3.0	3.0	High	A
	Cuiztmala	1.7	Low	High	A	4.0	4.0	4.0	4.0	Very high	A
Copalita	Copalita 1	0.3	Low	Very high	A	4.0	2.0	4.0	4.0	Very high	A
Sierra Gorda	Santa María 3	4.2	Low	Very high	A	4.0	4.0	4.0	4.0	Very high	A
	Verde 3	6.1	Low	High	A	4.0	2.0	2.5	2.5	High	B
	El Salto	6.2	Low	High	A	4.0	4.0	4.0	4.0	Very high	A
	Tampaón 1	2.3	Low	High	A	4.0	3.0	4.0	4.0	Very high	A
Papaloapan	Valle Nacional	0.1	Low	High	A	4.0	4.0	4.0	4.0	Very high	A
	Papaloapan	0.3	Low	Very high	A	2.0	2.0	2.5	2.0	Medium	B
	Playa Vicente	0.1	Low	High	A	4.0	3.0	4.0	4.0	Very high	A
	Tesechoacán	0.0	Low	High	A	1.0	3.0	4.0	3.0	High	A
	Trinidad	0.1	Low	Medium	B	4.0	3.0	4.0	4.0	Very high	A
	San Juan	7.2	Low	Very high	A	4.0	2.0	4.0	4.0	Very high	A
	Llanuras de Papaloapan	0.1	Low	Very high	A	4.0	1.0	3.0	3.0	High	A
	Grande	7.3	Low	High	A	1.0	3.0	4.0	3.0	High	A
	Blanco	193.1	Very high	Very high	C	4.0	3.0	4.0	4.0	Very high	A
	Jamapa-Cotaxtla	0.0	Low	High	A	4.0	2.0	3.0	3.0	High	B

Note. Scoring system: 1 = low, 2 = medium, 3 = high, and 4 = very high importance for biotic aspects; and 1 = completely modified, 2 = moderately modified, 3 = few modifications, and 4 = natural or without significant changes for ecological integrity and ecohydrological alteration conditions.

TABLE 3 Hydrological and holistic environmental water reserves volumes, natural flow regime characteristics and volume of water availability for environmental allocation in the reference sites of the pilot river basins

		Environmental water reserve					Flow variability indices					Environmental water availability
Pilot zone	River basin	Hydrological (Mm^3)	Holistic (Mm^3)	*SD*	AVG (Mm^3)	CV (%)	MAR (Mm^3)	MABF (Mm^3)	CV (%)	BFI (%)	CVB	(Mm^3)
Colorado	Cerrada Laguna Salada	21.9	31.3	6.7	26.6	25.1	56.9	3.1	274.2	5.4	50.6	59.6
	El Borrego	6.5	7.8	0.9	7.2	13.1	17.4	0.5	325.1	2.6	123.1	17.5
Piaxtla	Piaxtla 2	889.5	826.8	44.3	858.2	5.2	1,460.1	55.2	138.6	3.8	36.6	1,405.0
	Quelite 2	61.2	63.3	1.5	62.3	2.4	101.6	0.4	272.9	0.4	655.7	153.4
	Presidio 2	327.7	404.0	54.0	365.9	14.7	997.8	30.7	379.7	3.1	123.6	975.1
Acaponeta	Acaponeta 1	829.4	860.0	21.7	844.7	2.6	1,310.8	50.4	250.8	3.8	65.3	1,357.3
San Pedro	San Pedro Desembocadura	1,711.0	1,920.0	147.8	1,815.5	8.1	2,708.3	95.7	195.4	3.5	55.3	2,640.2
Chamela	San Nicolás A	776.0	897.0	85.6	836.5	10.2	1,210.0	26.1	111.6	2.2	51.8	472.6
	Purificación	388.0	428.0	28.3	408.0	6.9	540.5	7.5	110.7	1.4	79.4	458.3
	Cuiztmala	157.0	204.0	33.2	180.5	18.4	296.8	33.9	170.3	11.4	14.9	229.8
Copalita	Copalita 1	584.0	554.0	21.2	569.0	3.7	941.6	208.3	122.2	22.1	5.5	566.6
Sierra Gorda	Santa María 3	584.0	571.0	9.2	577.5	1.6	944.9	319.8	135.9	33.8	4.0	600.8
	Verde 3	192.0	119.0	51.6	155.5	33.2	367.4	72.4	147.5	19.7	7.5	195.8
	El Salto	467.0	499.0	22.6	483.0	4.7	801.4	151.6	108.5	18.9	5.7	815.8
	Tampaón 1	2,997.0	3,225.0	161.2	3,111.0	5.2	5,372.8	1,264.4	117.3	23.5	5.0	4,461.3
Papaloapan	Valle Nacional	2,306.0	2,549.0	171.8	2,427.5	7.1	3,279.5	635.5	87.9	19.4	4.5	3,797.7
	Papaloapan	14,672.0	15,358.0	485.1	15,015.0	3.2	18,434.6	9,064.2	64.2	49.2	1.3	19,597.8
	Playa Vicente	4,413.0	4,878.0	328.8	4,645.5	7.1	6,012.0	1,338.4	65.8	22.3	3.0	6,120.0
	Tesechoacán	4,821.0	4,545.0	195.2	4,683.0	4.2	5,365.4	1,232.8	53.0	23.0	2.3	6,614.3
	Trinidad	4,275.0	5,272.0	705.0	4,773.5	14.8	6,352.0	1,310.5	51.4	20.6	2.5	6,329.0
	San Juan	6,961.0	6,584.0	266.6	6,772.5	3.9	8,088.9	2,169.6	74.0	26.8	2.8	8,510.4
	Llanuras de Papaloapan	27,305.0	29,874.0	1,816.6	28,589.5	6.4	38,767.7	9,385.5	79.5	24.2	3.3	40,518.1
	Grande	765.0	807.0	29.7	786.0	3.8	1,209.9	178.0	100.6	14.7	6.8	819.8
	Blanco	1,489.0	1,602.0	79.9	1,545.5	5.2	1,750.0	752.9	45.0	43.0	1.0	2,081.2
	Jamapa-Cotaxtla	1,341.0	1,146.4	137.6	1,243.7	11.1	1,886.6	437.0	68.3	23.2	2.9	1,849.2

Note. *SD* = standard deviation; AVG = average; CV = coefficient of variation; MAR = mean annual run-off; CV = coefficient of variation index; MABF = mean annual baseflow; BFI = baseflow index; and CVB = overall index (CV/BFI) of flow variability. Volumes are shown in millions of cubic metres per year.

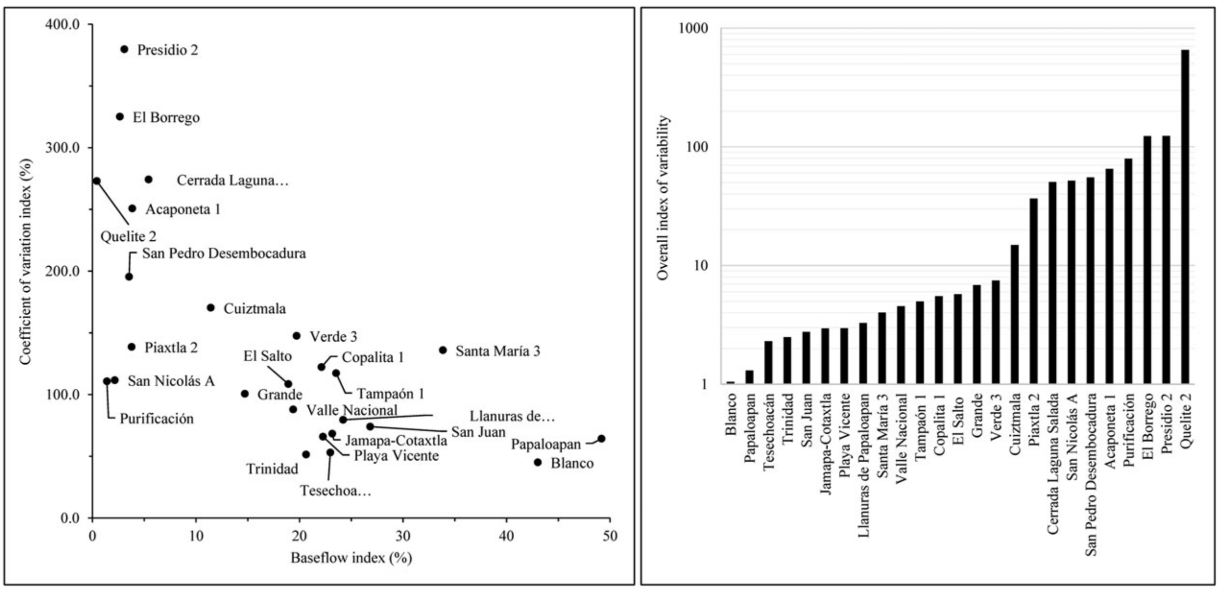

FIGURE 4 Relationship between short and long-term seasonal flows (left) and the overall index of variability (right) in reference sites across pilot river basins

a 20-year horizon at a 12% discount rate), Papaloapan (1:31), and Copalita (benefits only; Agroder, 2014; IMIDA, 2013). Thus far, only EWR for the San Pedro zone has been adopted as a precautionary measure. The process for the corresponding decree has been completed, declaring for this basin an environmental use of 2,297 Mm^3/year for a 50-year term (SEMARNAT, 2014), higher than the volume originally recommended. This EWR is currently being integrated to the Marismas Nacionales management plan, based on flow-ecology relationships for on-site monitoring (Blanco et al., 2011; Téllez Duarte et al., 2014; González-Díaz, Soria-Barreto, Martínez-Cardenas,

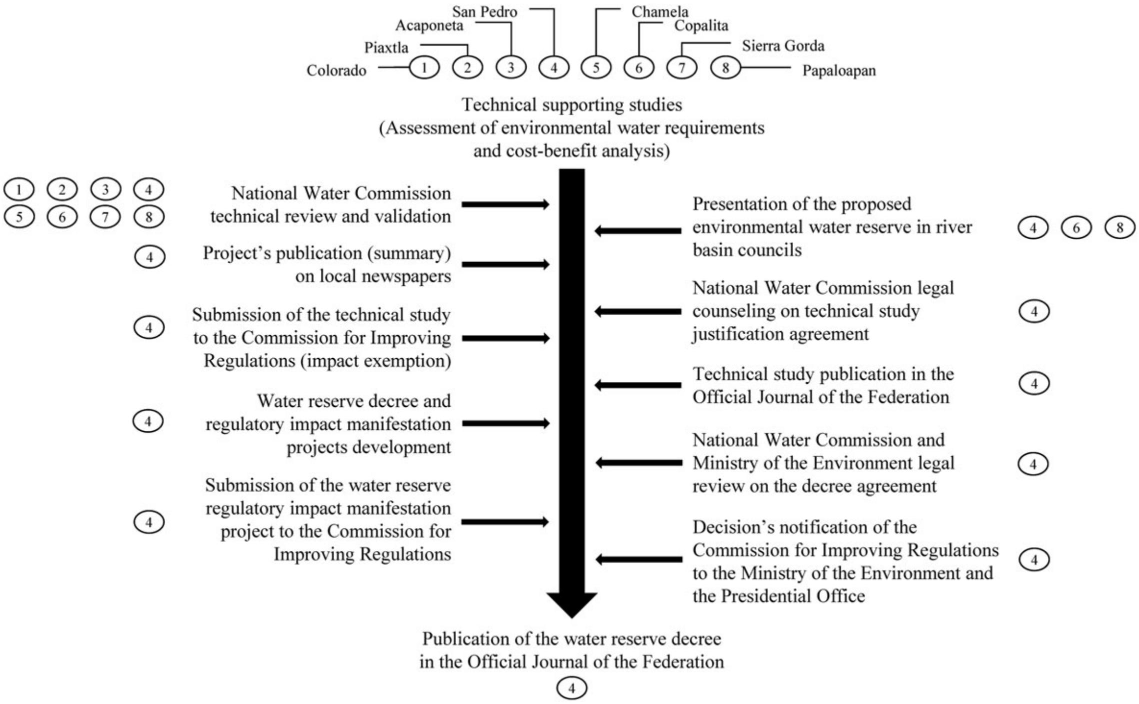

FIGURE 5 General process and progress for establishing environmental water reserves

& Blanco y Correa, 2015; Wickel, Salinas Rodríguez, Martínez Pacheco, Colditz, & Ressl, 2016; Table A3).

5 | LESSONS LEARNED AND RECOMMENDATIONS

5.1 | General strategy in e-flows norm implementation

Despite differences, a general consistency is apparent between the baseline environmental objectives and the outcomes of the on-site comprehensive approach, as well as among the hydrological and holistic methods for assessing e-flows. The increased detail in the assessment of the ecological importance factor, which integrated site-level information and an expert panel evaluation, confirmed or supported a change in the environmental objectives for a more accurate and balanced water use and conservation. Additionally, this factor was assessed largely with high or very high levels of confidence. This result is consistent with the high biological richness and conservation values criteria used for the identification of potential water reserves (CONAGUA, 2011).

The e-flow regimes and reserves were determined, and volume differences occurred due to the aforementioned changes in environmental objectives and because of the metrics of the flow regime components used in each method. The final similarity between volumes and the use of indices of regime variability (CV, BFI, and CVB) to understand the scope of the flow components metrics suggest the potential for developing a desktop reserve model for Mexican streams, along the lines of the South African method developed by Hughes and Hannart (2003). This would require further in-depth analysis in more river basins characteristic of the wider climatic and geographic conditions throughout the country, in order to represent the full range of short and long-term seasonal flows variability, their ecological functioning and the flow-habitat requirements.

For 94% of the sites, EWR annual volumes are within current water availability for potential environmental allocation, although e-flow assessments advise the need for further detailed analysis of the MAR recognized in official agreements. Despite the fact that the hydrological approach has a higher temporary resolution, applying the holistic methodology to assess the volume of an EWR provides a greater understanding of a basin's current conditions, integrates higher levels of ecological knowledge and builds on expert review and validation. It is important to recognize that the methodologies described do not exclude but rather complement each other.

5.2 | NWRP contributions and limitations

The allocation of environmental flows assessed under National Water Reserves Program would pre-emptively secure water, limit the flow alteration, and sustain the ecological integrity of a river basin. Biologically, e-flows in the 25 reference sites presented in this paper were assessed to meet the water needs and habitat requirements of 93 freshwater-dependent species (40 under protection). This information provides a baseline for conducting further in-depth research and an opportunity for inclusion of environmental water requirements in protected area management plans, as is currently piloted in the Marismas Nacionales' management plan. With regard to the social dimension, EWR would secure the provision of water for small rural communities settled along the rivers with low net consumption and high vulnerability in terms of access to water. For instance, in the context of the overall water balance of the considered basins that would mean water provision for 1,833,136 inhabitants (35% of total basins' population) from 21,888 communities below 2,500 inhabitants.

It is very important to recognize that the outcomes of this programme, thus far, are mainly based on systems with low water resource demands and little development of water management infrastructure. E-flow assessments are also required across basins with greater impacts in biotic aspects, ecological integrity, and flow regime components, in order to evaluate the consistency and performance of the outcomes of both methods in terms of wider objectives (e.g., restoration). Furthermore, more research in the systematic analysis of concrete and quantitative flow-ecology and social relationships could enrich the variety of cases and provide feedback for improving the norm and setting strategic monitoring indicators for the implementation of the EWRs. One last limitation of the current methods that should be recognized is that the hydrological analysis is based exclusively on historical flow records and associated flow-ecology relationships, regardless if the methods are applied in basins with or without relative pressure. An important aspect for future research would be to consider climate change impacts on flow variability and adaptive capacities of people and nature to provide climate-smart EWR.

5.3 | Final remarks

Mexico's National Water Reserves for the Environment Program is focused on establishing environmental flow allocations in basins that currently experience low water pressure and that are of high conservation value, through conducting e-flow assessments that are based on and further enrich the Mexican Environmental Flows Norm. As the norm has been applied in eight pilot zones, strategic capacities for its implementation have been built and have provided the opportunity for setting ecologically and socially sustainable limits of current and future water extraction, preventing ecosystems degradation and sustaining ecological processes and services.

Although the process of establishing an EWR may take years, there are significant advantages for the Mexican environmental water science and allocation practice. On one hand, water planning and management are strengthened by enhancing water security through preempting over-allocation and therefore overexploitation risks. On the other hand, natural resources and biological conservation efforts benefit from the more comprehensive implementation of integrated water resources management and the specific definition of environmental water requirements.

The most important contribution of this approach consists in the production of functional proposals for water allocation that are mostly grounded in international state-of-the-art e-flow practices. In the meanwhile, a system of EWR is being built and enriched, on the basis of the standardization and systematization of experiences, creating a growing institutional and expert network and community of practice, which directly inserts flow-ecology knowledge and feedback mechanisms into the integrated management of water resources in Mexico. This strategy provides the foundations for a subsequent stage in the allocation of water for the environment, across basins where higher pressure on water resources exists.

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APPENDIX A

Rating system for the *ecological importance* factor

Ecological importance and sensitivity

The following biotic determinants were considered: rare, endangered, unique or intolerant biota, species or taxon richness, diversity of aquatic habitat types or features, refuge values or habitat types, sensitivity of habitat to flow changes, sensitivity to flow-related water quality changes, migration route or corridor for instream and riparian biota, and protected areas including Ramsar sites. The scoring system used was a four- or five-point rating classes (0–4), depending on each determinant, where zero or one means none or marginal (low), two moderate, three high, and four a very high relative importance or sensitivity.

Habitat integrity

In this work is considered as the current ecological status. It is based on the assessment of two separate groups of modifiers with a specific set of indicators. First, the ecological integrity with signs of modification in the rivers' geomorphology, water quality, vegetation, and fauna (macroinvertebrates and fish); and second, the ecohydrological alteration such as water abstraction or flow components modification (hydrology and geohydrology). The system classification was rated from one to four where one means completely modified, two moderately modified, three with few modifications, and four natural or without significant changes. In this case, no data means not present and therefore not relevant for the assessment (e.g., fish in ephemeral streams).

Overall ecological importance

It was set according to the score (median) of individual subfactors, where one implies low, two medium or moderate, three high, and four very high *ecological importance* and confidence ratings. Environmental objectives were set according to its combination with the water pressure factor.

TABLE A1 Detail assessment in biotic determinants (ecological importance and sensitivity: 0 or 1 = non or marginal, 2 = moderate, 3 = high, and 4 = very high), ecological integrity, and ecohydrological conditions (1 = completely modified, 2 = moderately modified, 3 = few modifications, and 4 = natural or without significant changes) in pilot river basins reference sites using the holistic method

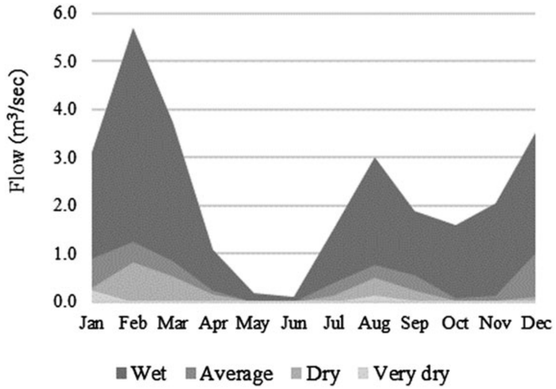
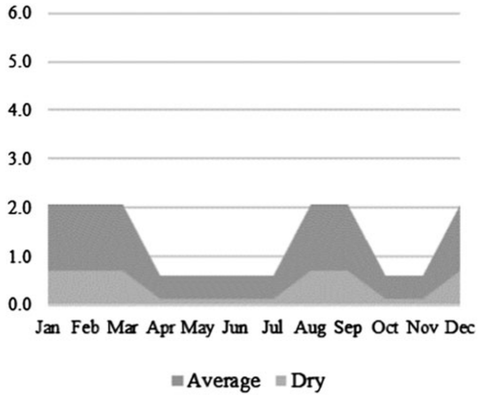
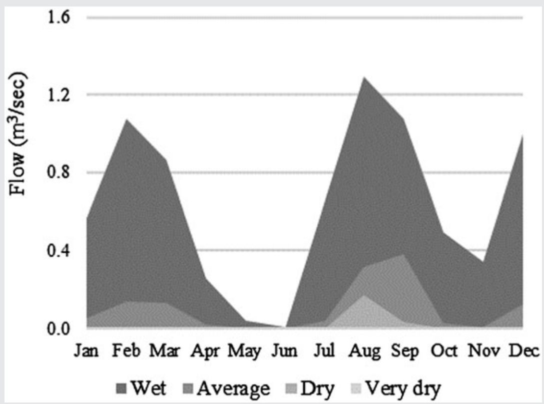
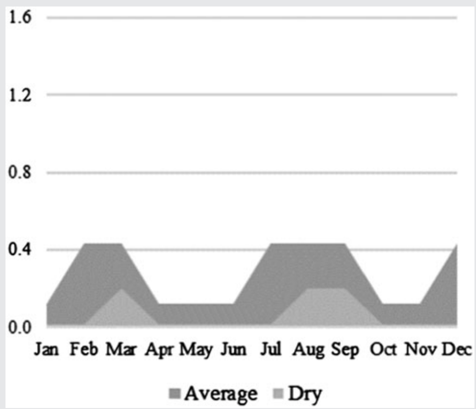
River basin	Ecological importance and sensitivity									
	Rare and endangered biota	Unique biota	Intolerant biota	Species or taxon richness	Diversity of aquatic habitat types or features	Refuge value of habitat types	Sensitivity of habitat to flow changes	Sensitivity to flow-related water quality changes	Migration route or corridor for instream and riparian biota	Natural protected areas or Ramsar sites
Cerrada Laguna Salada	4	4	4	2	4	4	2	4	4	4
El Borrego	4	2	0	2	1	1	2	4	0	4
Piaxtla 2	4	4	4	4	4	4	3	3	3	4
Quelite 2	4	4	4	3	4	3	3	3	3	4
Presidio 2	4	4	4	4	4	4	4	2	2	4
Acaponeta 1	4	4	4	4	4	4	4	3	4	4
San Pedro Desembocadura	4	4	3	4	3	4	4	3	4	4
San Nicolás A	4	3	4	4	4	4	4	4	4	4
Purificación	4	3	4	4	4	4	4	4	4	4
Cuiztmala	4	3	4	4	4	4	4	4	4	4
Copalita 1[†]	4	3	2	3	3	2	2	3	2	4
Santa María 3	4	4	4	2	4	4	4	4	4	4
Verde 3	4	4	3	2	2	4	4	4	4	0
El Salto	4	4	4	4	4	3	4	4	4	3
Tampaón 1	4	4	4	4	3	4	4	4	4	4
Valle Nacional	4	4	4	4	4	4	4	3	4	0
Papaloapan	2	2	2	2	2	2	2	3	1	0
Playa Vicente[†]	4	4	4	2	4	2	2	2	1	0
Tesechoacán	0	1	2	2	1	1	1	1	0	4
Trinidad[‡]	0	4	4	2	3	3	3	2	0	0
San Juan[‡]	1	4	4	2	3	3	3	3	2	0
Llanuras del Papaloapan[†]	4	3	4	2	4	2	2	3	0	4
Grande	0	1	1	1	1	1	1	1	0	4
Blanco	4	4	4	3	4	4	3	3	2	4
Jamapa-Cotaxtla[†]	4	4	4	3	4	4	3	3	3	0

Note. The highest score possible in ecological importance and sensitivity, due to the presence of species under protection at the national level (†) or unique biota (‡).

TABLE A1 (Continued)

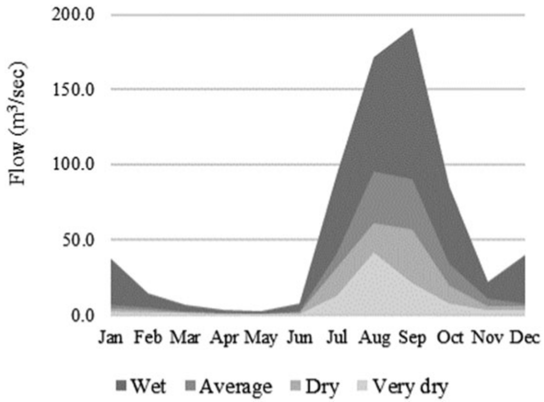
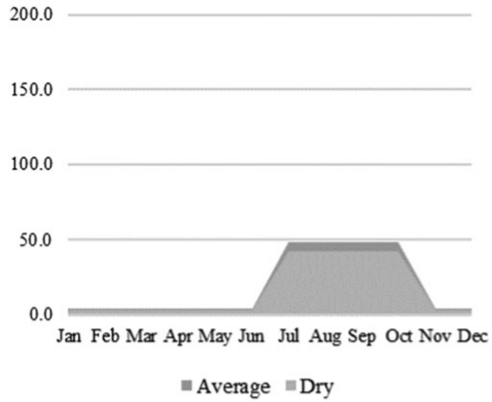
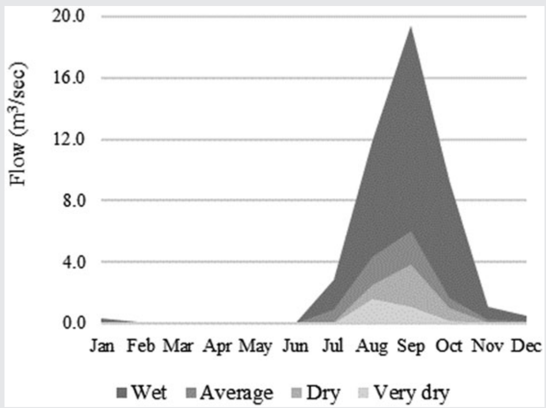
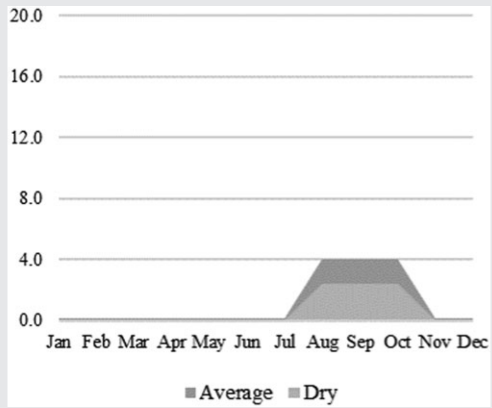
River basin	Ecological importance and sensitivity	Ecological integrity						Ecohydrological alteration		
	Score (median)	Geomorphology	Water quality	Vegetation	Macroinvertebrates	Fish	Score (median)	Hydrology	Geohydrology	Score (median)
Cerrada Laguna Salada	4.0	4	4	4	2		4.0	4	3	3.5
El Borrego	2.0	4	4	4	1		4.0	4	4	4.0
Piaxtla 2	4.0	2	3	3	2	3	3.0	4	4	4.0
Quelite 2	3.5	3	3	2	3	4	3.0	4	4	4.0
Presidio 2	4.0	3	4	3	2	2	3.0	3	2	2.5
Acaponeta 1	4.0	4	4	2	4	3	4.0	4	4	4.0
San Pedro Desembocadura	4.0	2	3	3	3	3	3.0	4	4	4.0
San Nicolás A	4.0	4	4	2	4	4	4.0	4	4	4.0
Purificación	4.0	4	3	3	3	2	3.0	3	3	3.0
Cuiztmala	4.0	4	3	3	4	4	4.0	4	4	4.0
Copalita 1†	4.0	1	3	2	3	1	2.0	4	4	4.0
Santa María 3	4.0	4	4	4	4	3	4.0	4	4	4.0
Verde 3	4.0	3	3	2	2	2	2.0	2	3	2.5
El Salto	4.0	3	4	3	4	4	4.0	4	4	4.0
Tampaón 1	4.0	4	3	3	4	3	3.0	4	4	4.0
Valle Nacional	4.0	4	3	4	4	4	4.0	4	4	4.0
Papaloapan	2.0	2	2	2	2	2	2.0	2	3	2.5
Playa Vicente†	4.0	4	2	3	2	3	3.0	4	4	4.0
Tesechoacán	1.0	4	2	3	2	3	3.0	4	4	4.0
Trinidad‡	4.0	4	3	3	3	3	3.0	4	4	4.0
San Juan‡	4.0	3	2	3	2	2	2.0	4	4	4.0
Llanuras del Papaloapan†	4.0	3	1	3	1	1	1.0	3	3	3.0
Grande	1.0	3	2	3	2	3	3.0	4	4	4.0
Blanco	4.0	4	2	4	3	3	3.0	4	4	4.0
Jamapa-Cotaxtla†	4.0	3	2	2	2	2	2.0	3	3	3.0

TABLE A2 Hydrological and holistic methods environmental flow regimes in pilot river basins reference sites

River basin	Environmental flows regimes (intra and inter-annual variability): Hydrological approach	Holistic method	Flood regime per category (Cat) of flow events: Flow attribute	Cat I	Cat II	Cat III
Cerrada Laguna Salada			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/sec)	23	48	90
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)		1	
			Timing (months)		May–July	
			Rate of change (%)		114.2 −57.7	
El Borrego			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	9	20	46
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	1		
			Timing (months)	May–July		
			Rate of change (%)	221.1 −71.9		

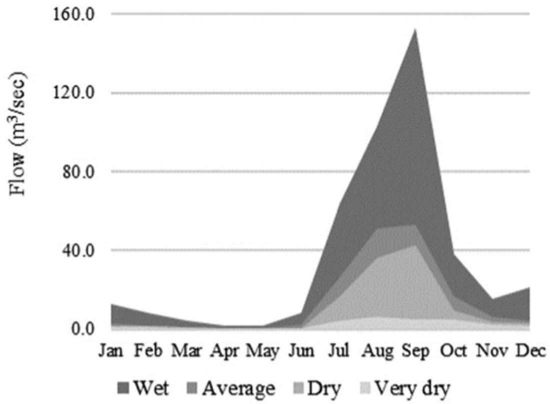
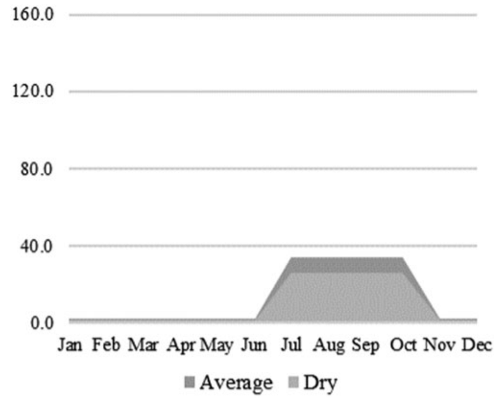
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability)		Flood regime per category (Cat) of flow events			
	Hydrological approach	Holistic method				
Piaxtla 2			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	180	515	1,330
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	7	2	1
			Timing (months)	July–October		
			Rate of change (%)	81.7 −42.6		
Quelite 2			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	20	95	325
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	7	2	1
			Timing (months)	July–October		
			Rate of change (%)	309.7 −67.7		

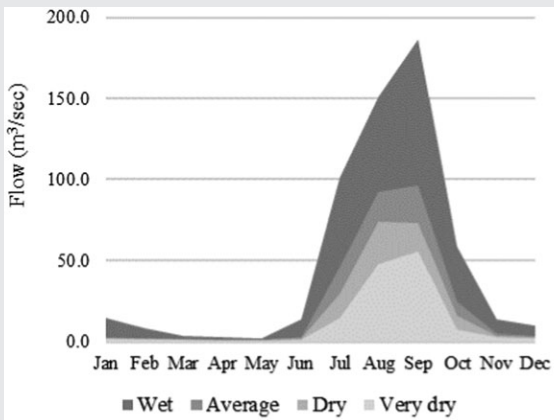
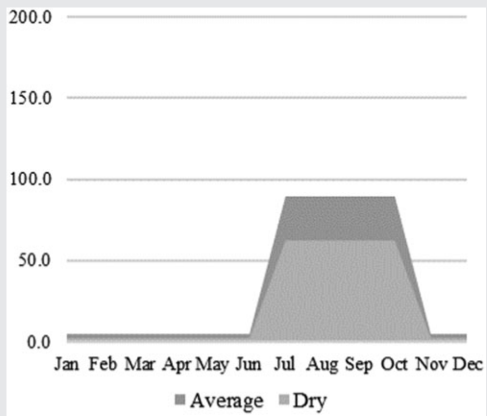
(Continues)

TABLE A2 (Continued)

<table>
<tr><th></th><th colspan="2">Environmental flows regimes (intra and inter-annual variability)</th><th colspan="4"></th></tr>
<tr><th>River basin</th><th>Hydrological approach</th><th>Holistic method</th><th colspan="4">Flood regime per category (Cat) of flow events</th></tr>
<tr><td>Presidio 2</td><td>
</td><td>
</td><td>Flow attribute
Magnitude (m^3/s)
Frequency
Years of recurrence intervals
Events in 10 years
Duration (days)
Timing (months)
Rate of change (%)</td><td>Cat I
105

1.0
5
7
July–October
86.3
−46.3</td><td>Cat II
330

1.5
3
4</td><td>Cat III
1,150

5.0
2
1</td></tr>
<tr><td>Acaponeta 1</td><td>
</td><td>
</td><td>Flow attribute
Magnitude (m^3/s)
Frequency
Years of recurrence intervals
Events in 10 years
Duration (days)
Timing (months)
Rate of change (%)</td><td>Cat I
215

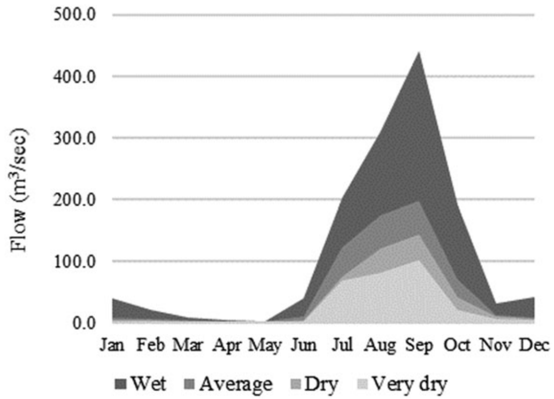
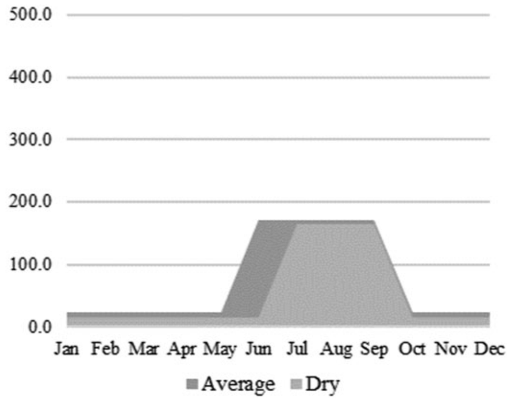
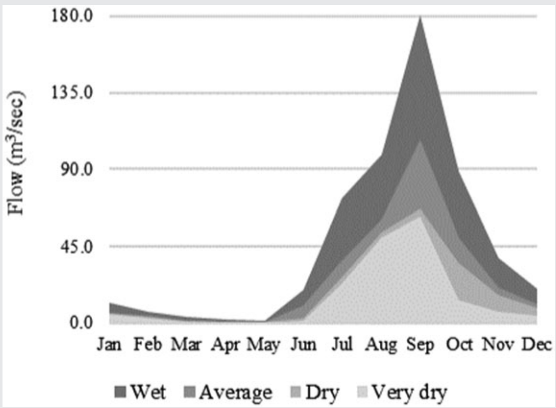
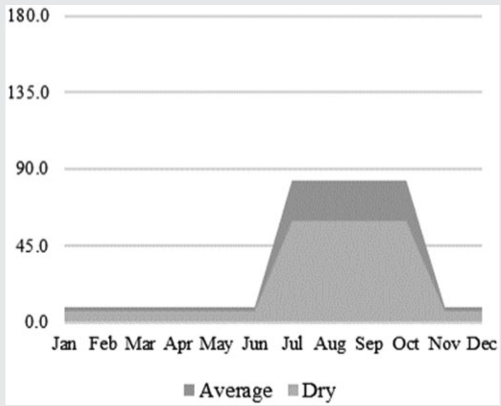
1.0
10
3
June–October
113.7
−57.7</td><td>Cat II
595

1.5
6
2</td><td>Cat III
1,760

5.0
2
2</td></tr>
</table>

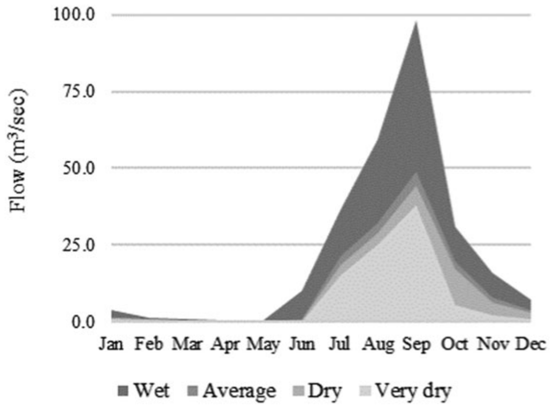
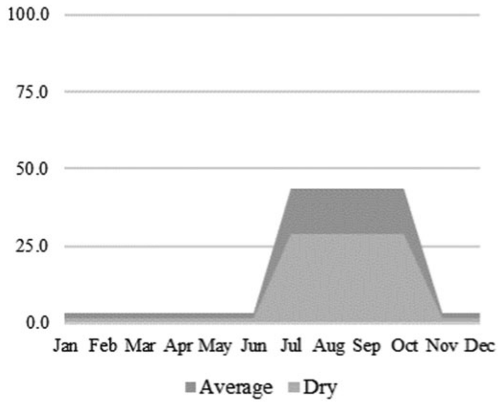
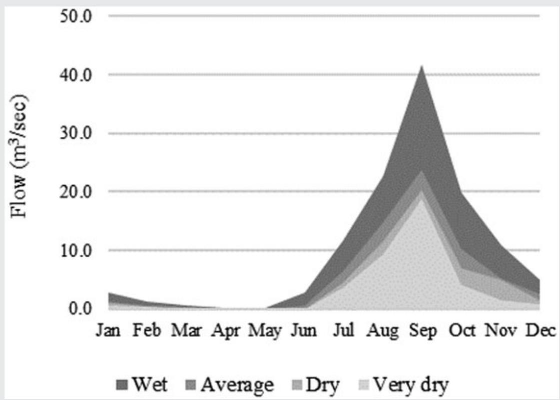
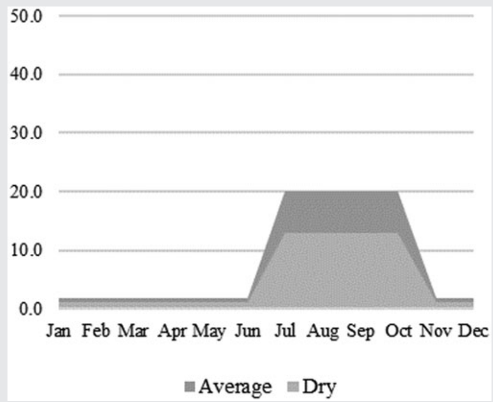
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability): Hydrological approach	Holistic method	Flood regime per category (Cat) of flow events			
San Pedro Desembocadura			Flow attribute Magnitude (m^3/s) Frequency Years of recurrence intervals Events in 10 years Duration (days) Timing (months) Rate of change (%)	Cat I 350 1.0 10 3 July–October 74.5 −39.5	Cat II 800 1.5 6 2	Cat III 1,900 5.0 2 1
San Nicolás A			Flow attribute Magnitude (m^3/s) Frequency Years of recurrence intervals Events in 10 years Duration (days) Timing (months) Rate of change (%)	Cat I 205 1.0 10 2 June–October 61.9 −36.1	Cat II 295 1.5 6 2	Cat III 605 5.0 2 1

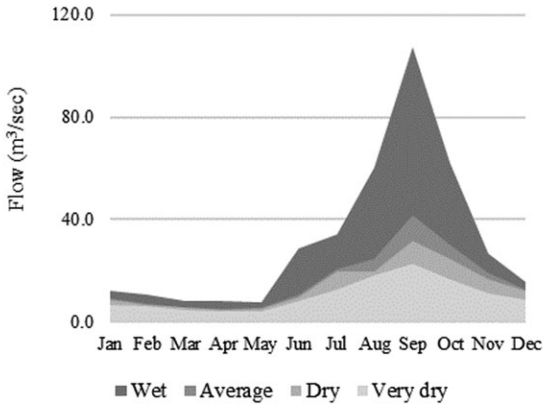
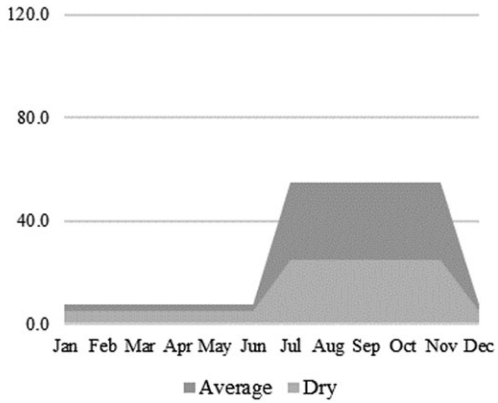
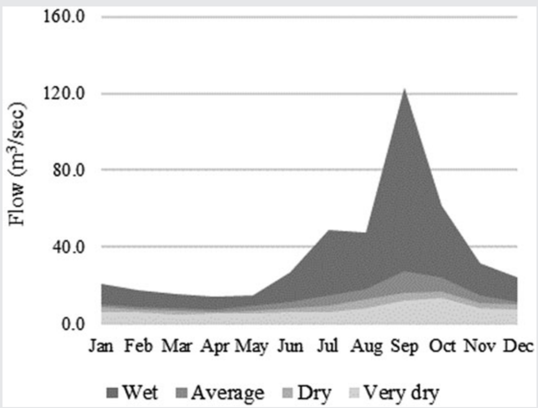
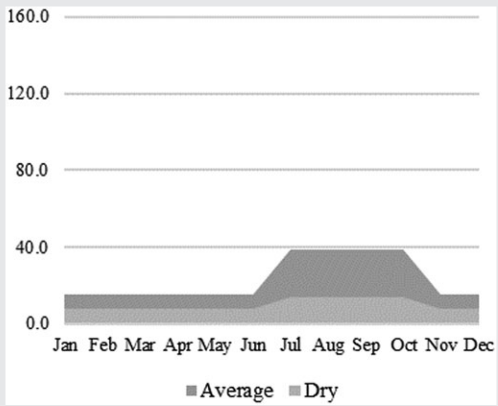
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability)		Flood regime per category (Cat) of flow events			
	Hydrological approach	Holistic method				
Purificación			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	110	200	435
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	2	1	1
			Timing (months)	June–October		
			Rate of change (%)	56.7 −53.4		
Cuitzmala			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	40	85	385
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	2	2	2
			Timing (months)	June–October		
			Rate of change (%)	137.4 −55.9		

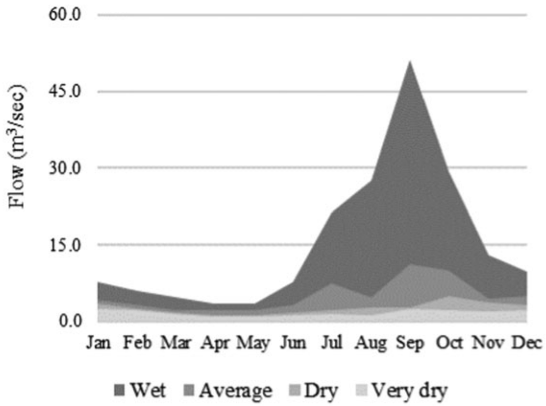
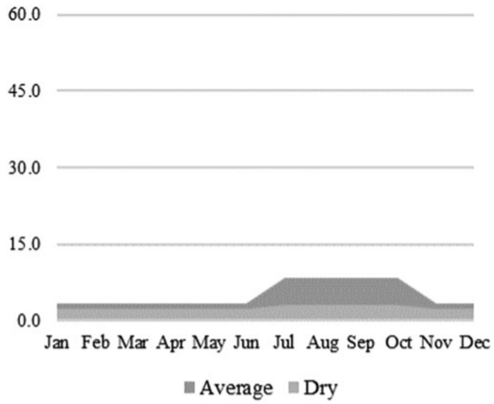
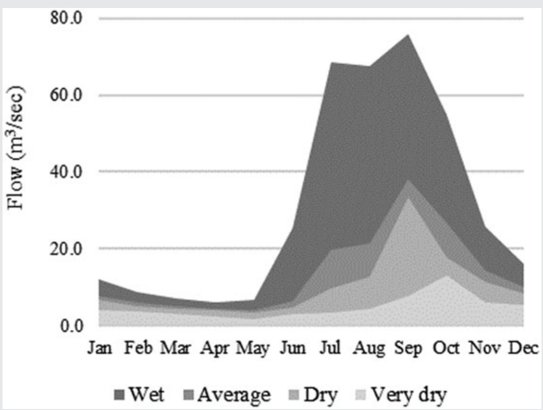
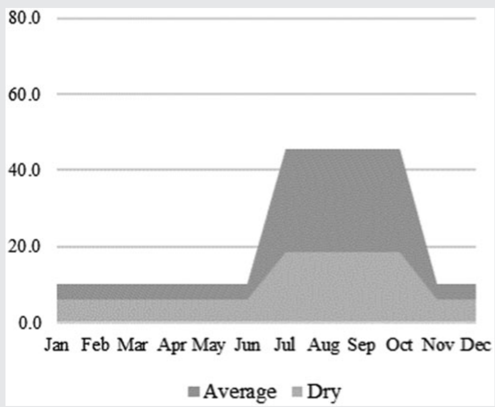
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability)		
	Hydrological approach	Holistic method	Flood regime per category (Cat) of flow events
Copalita 1			Flow attribute: Cat I / Cat II / Cat III Magnitude (m^3/s): 30 / 90 / 560 Frequency Years of recurrence intervals: 1.0 / 1.5 / 5.0 Events in 10 years: 10 / 6 / 2 Duration (days): 4 / 5 / 6 Timing (months): July–October Rate of change (%): 55.1 −21.4
Santa María 3			Flow attribute: Cat I / Cat II / Cat III Magnitude (m^3/s): 95 / 220 / 775 Frequency Years of recurrence intervals: 1.0 / 1.5 / 5.0 Events in 10 years: 10 / 6 / 2 Duration (days): 4 / 2 / 3 Timing (months): June–October Rate of change (%): 128.6 −34.9

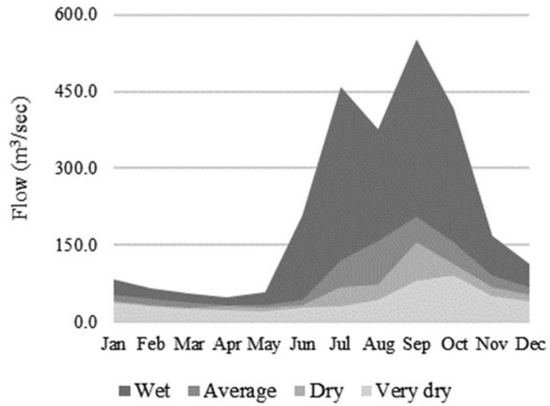
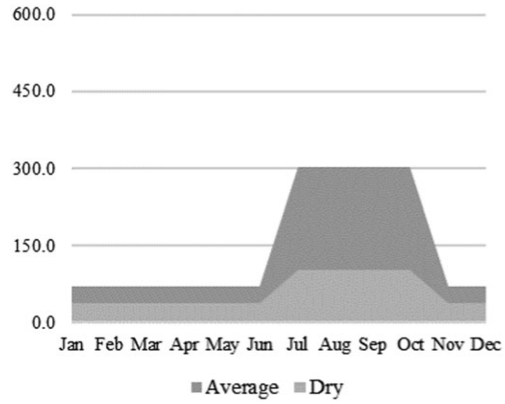
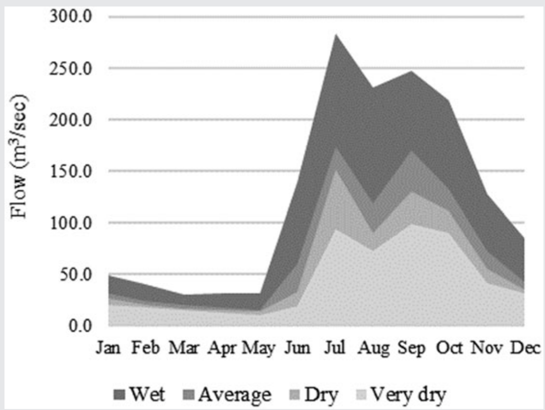
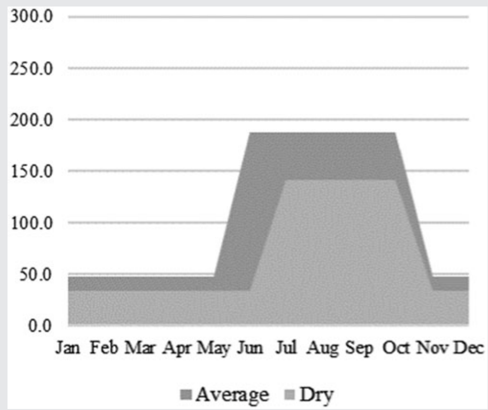
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability)		Flood regime per category (Cat) of flow events			
	Hydrological approach	Holistic method	Flow attribute	Cat I	Cat II	Cat III
Verde 3			Magnitude (m^3/s)	40	95	315
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	5	3	2
			Duration (days)	4	3	3
			Timing (months)	June–October		
			Rate of change (%)	165.1 −34.9		
El Salto			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	75	185	345
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	4	3	3
			Timing (months)	June–October		
			Rate of change (%)	67.5 −26.2		

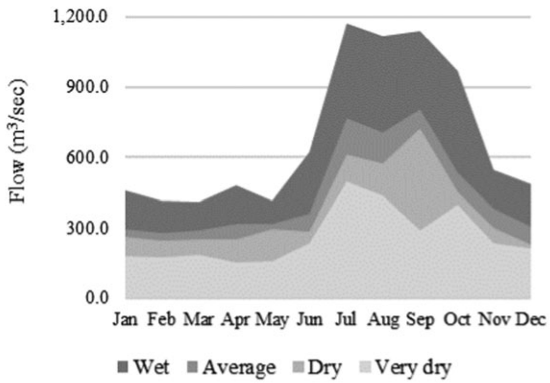
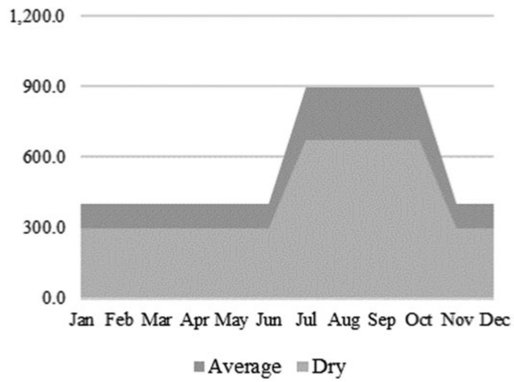
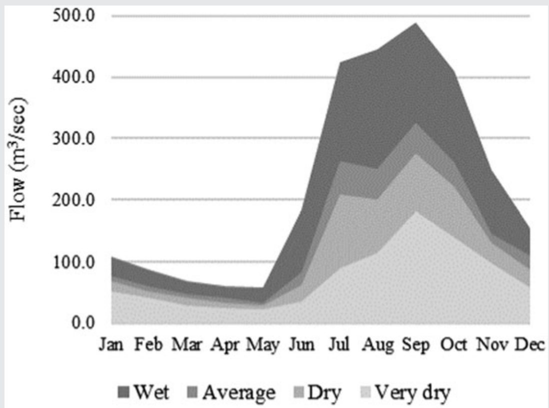
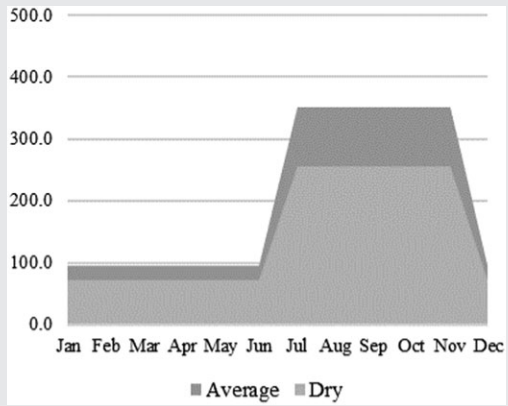
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability): Hydrological approach	Holistic method	Flood regime per category (Cat) of flow events
Tampaón 1			Flow attribute: Cat I / Cat II / Cat III Magnitude (m^3/s): 530 / 1,180 / 2,625 Frequency Years of recurrence intervals: 1.0 / 1.5 / 5.0 Events in 10 years: 10 / 6 / 2 Duration (days): 4 / 3 / 3 Timing (months): June–October Rate of change (%): 75.4 −26.6
Valle Nacional			Flow attribute: Cat I / Cat II / Cat III Magnitude (m^3/s): 525 / 890 / 1,400 Frequency Years of recurrence intervals: 1.0 / 1.5 / 5.0 Events in 10 years: 10 / 6 / 2 Duration (days): 2 / 2 / 1 Timing (months): July–October Rate of change (%): 78.5 −48.5

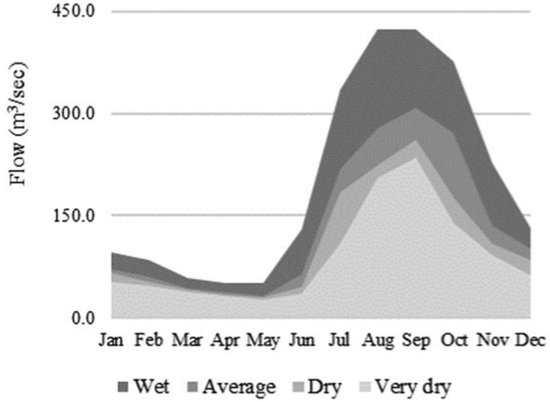
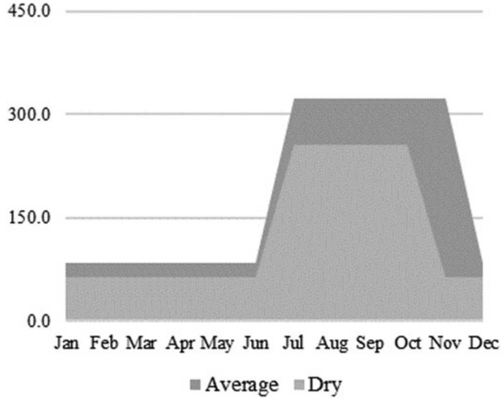
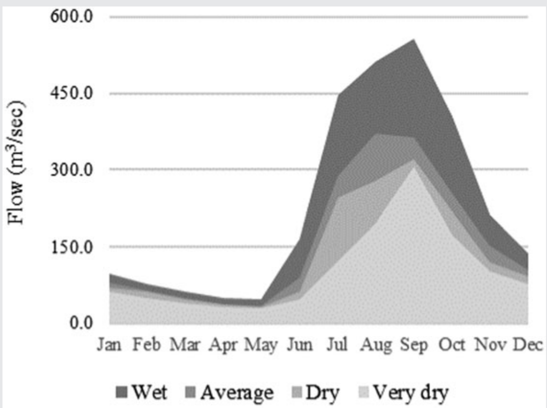
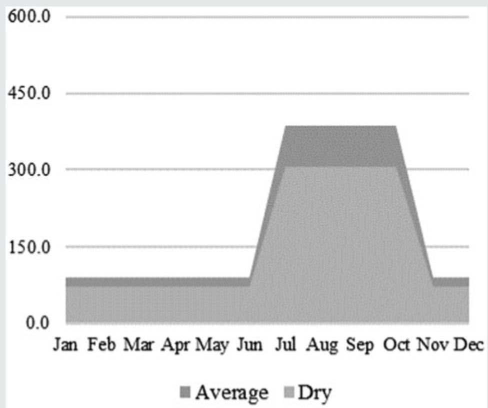
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability): Hydrological approach	Environmental flows regimes (intra and inter-annual variability): Holistic method	Flood regime per category (Cat) of flow events			
Papaloapan			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	1,620	3,250	5,195
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	5	3	2
			Duration (days)	4	3	3
			Timing (months)	June–September		
			Rate of change (%)	36.33 −21.3		
Playa Vicente			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	560	870	1,275
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	3	2	2
			Timing (months)	July–October		
			Rate of change (%)	34.8 −23.9		

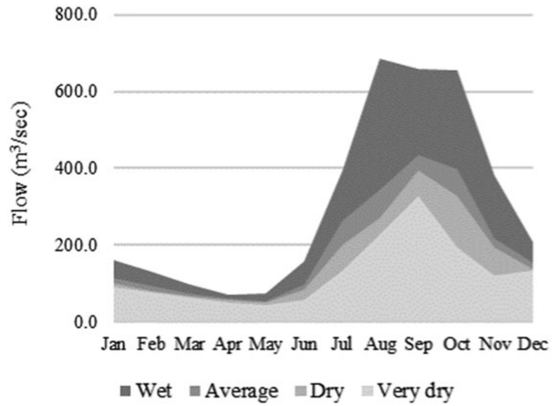
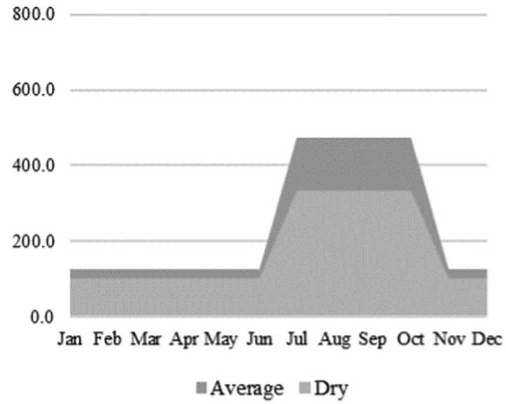
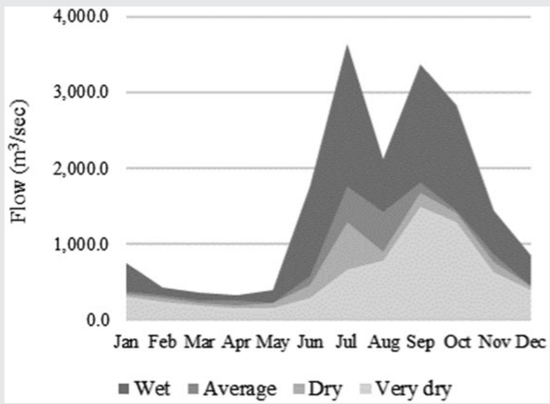
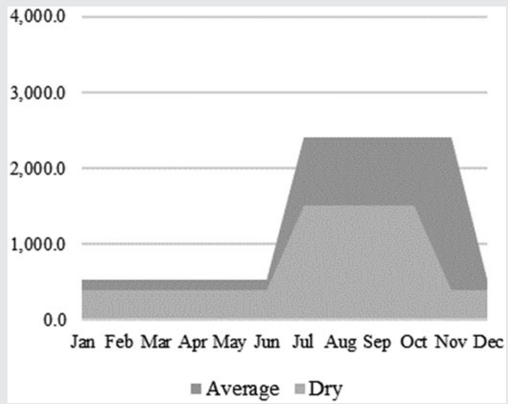
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability): Hydrological approach	Holistic method	Flood regime per category (Cat) of flow events: Flow attribute	Cat I	Cat II	Cat III
Tesechoacán			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	440	585	790
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	12	8	8
			Timing (months)	July–October		
			Rate of change (%)	42.9 −24.2		
Trinidad			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	735	1,065	1,480
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	5	3	3
			Timing (months)	July–October		
			Rate of change (%)	30.5 −20.4		

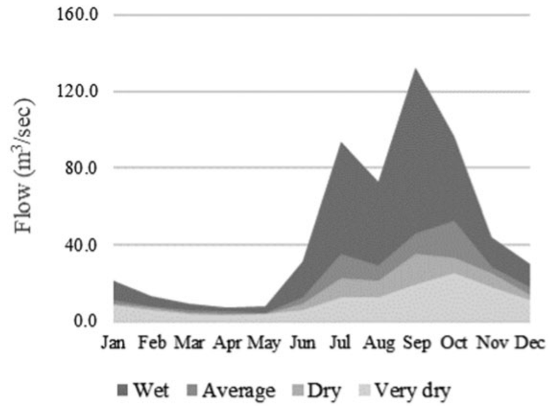
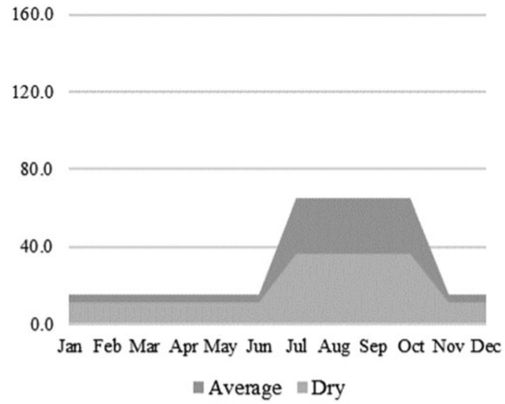
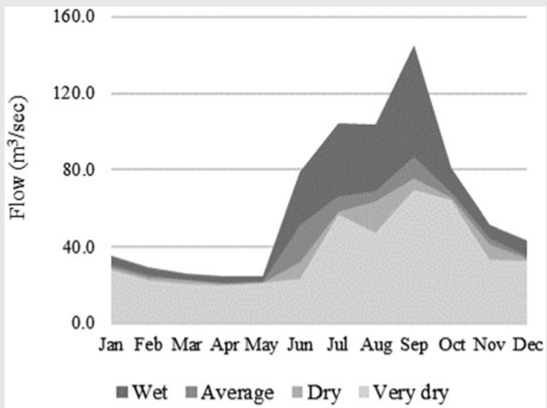
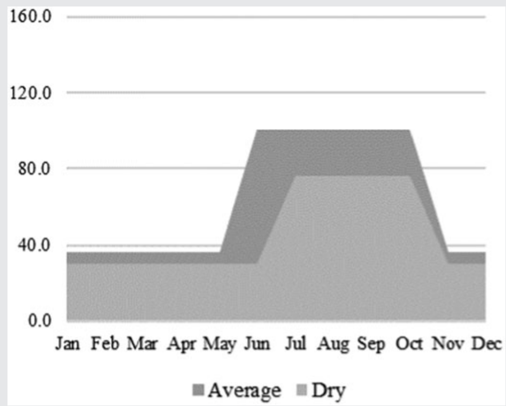
(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability): Hydrological approach	Environmental flows regimes (intra and inter-annual variability): Holistic method	Flood regime per category (Cat) of flow events			
			Flow attribute	Cat I	Cat II	Cat III
San Juan			Magnitude (m^3/s)	585	970	1,520
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	15	9	7
			Timing (months)	August–October		
			Rate of change (%)	18.6 −12.7		
Llanuras de Papaloapan			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	3,295	5,450	7,620
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	10	6	2
			Duration (days)	7	5	3
			Timing (months)	July–October		
			Rate of change (%)	29.7 −17.3		

(Continues)

TABLE A2 (Continued)

River basin	Environmental flows regimes (intra and inter-annual variability) Hydrological approach	Holistic method	Flood regime per category (Cat) of flow events
Grande			Flow attribute: Cat I / Cat II / Cat III Magnitude (m^3/s): 85 / 245 / 590 Frequency Years of recurrence intervals: 1.0 / 1.5 / 5.0 Events in 10 years: 10 / 6 / 2 Duration (days): 8 / 3 / 2 Timing (months): July–October Rate of change (%): 83.6 −26.5
Blanco			Flow attribute: Cat I / Cat II / Cat III Magnitude (m^3/s): 145 / 270 / 475 Frequency Years of recurrence intervals: 1.0 / 1.5 / 5.0 Events in 10 years: 10 / 6 / 2 Duration (days): 2 / 3 / 4 Timing (months): July–September Rate of change (%): 59.4 −36.4

(Continues)

TABLE A2 (Continued)

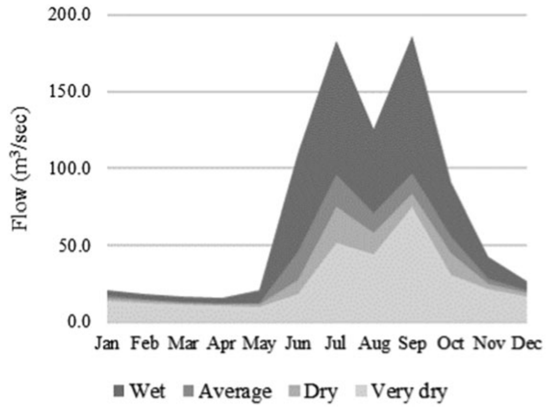
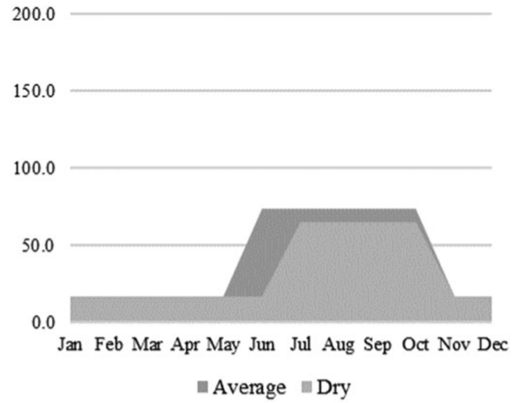
River basin	Environmental flows regimes (intra and inter-annual variability): Hydrological approach	Holistic method	Flood regime per category (Cat) of flow events: Flow attribute	Cat I	Cat II	Cat III
Jamapa-Cotaxtla			Flow attribute	Cat I	Cat II	Cat III
			Magnitude (m^3/s)	175	500	945
			Frequency			
			Years of recurrence intervals	1.0	1.5	5.0
			Events in 10 years	5	3	2
			Duration (days)	4	3	3
			Timing (months)	July–September		
			Rate of change (%)	94.6		
				−39.0		

TABLE A3 San Pedro river's flow-ecology relationships and quantitative indicators of the environmental flow regime in Marismas Nacionales

Conservation objective	Ecological functions	Key environmental flow components	Quantitative indicators	References
Fish biological richness, composition, and relative frequency of freshwater protected species	Ecological connectivity for the community's feeding and reproduction requirements	Extreme low, low, and high pulse flows	Biological diversity: 11 freshwater and 41 marine species (baseline); 30–40% relative frequency of *Atherinella crystallina* and *Poecilia butleri* and 15–25% of *Poeciliopsis prolifica* and *Poeciliopsis latidens*	González-Díaz et al. (2015)
Mangrove forest extension, structure, and vegetal associations	Inland flows and hydroperiod salinity gradient dependency	Seasonal flows full range of variability	63,593 hectares of vegetal associations dominated by mangrove species with 2–8 m height and 8–55 tree's density in tidal systems influenced by the river's discharge	Blanco et al. (2011)
Sediments cumulative rate and textures proportions	Shaping physical habitat in the river's delta	High pulse flow, small, and moderate floods	0.9–3.9 ± 0.1–0.6 cm/year and 64%, 33%, and 3% of sand, silt, and clay, accordingly	Téllez Duarte et al. (2014)
Floodplain inundation	Nutrients and organic matter supply and deposition in flood-related seasonal aquatic habitat	Full range of small-large floods	65–95, 95–140, 140–160, and 160–175 km^2 flooded surface corresponding to 1.0–1.5, 1.5–5.0, 5.0–10.0, and 10.0–20.0 years of flows' recurrence intervals, respectively	Téllez Duarte et al. (2014) and Wickel et al. (2016)