International SWAT Conference, 11-13 September, 2024 in Lima, Perú

Using SWAT-modelled discharge to set environmental flow scenarios at sub-basin level in the framework of SDG 6.4.2

M.S.c. Erick García Gonzales
egarciag@ana.gob.pe

September 11,2024

Motivation

- The National Water Authority (ANA) and the NGO WWF-Peru are working since 2022 in a method to determine ecological flows at sub-basin level for water planning purposes with the objective of reserving a volume of water for aquatic ecosystems, which is in agreement with the Sustainable Development Goals (SDG6), Target 6.4.2.

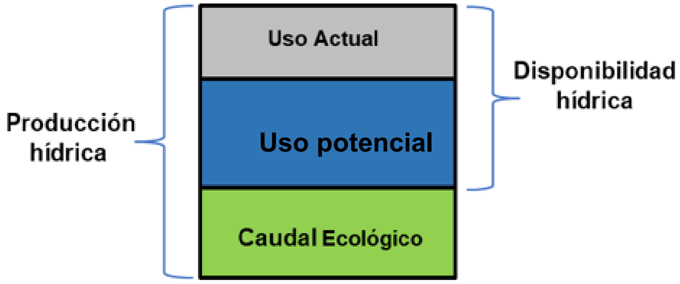
- The methodology was applied in the Pisco river basin and we expected it to gradually move up at national level, so that the volume corresponding to the ecological flow could be reserved from the water availability of each sub-basin.

- One of the key components of the methodology is the information about monthly water discharge in every subbasin outlet of the main basin, so because flow measure is scarce in Peru we choose explore the SWAT model to accomplish that. It was the first application of SWAT in ANA, however some other model are used like WEAP or HydroBID.

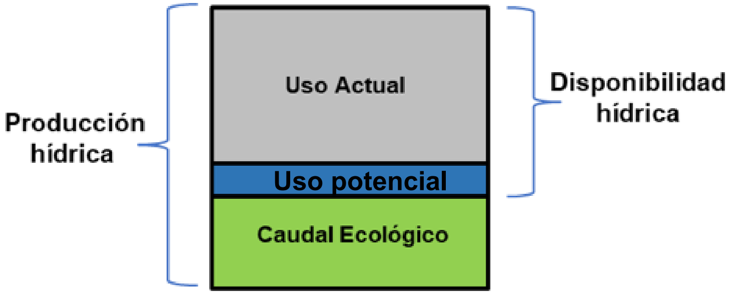
- Priority is given to the use of free data available at national level, like rainfall and temperature daily product called PISCO (an hybrid product derived from remote sensing data), digital elevation model, land cover and land use data and soils information mainly.

Sustainable Development Goal (SDG 6)

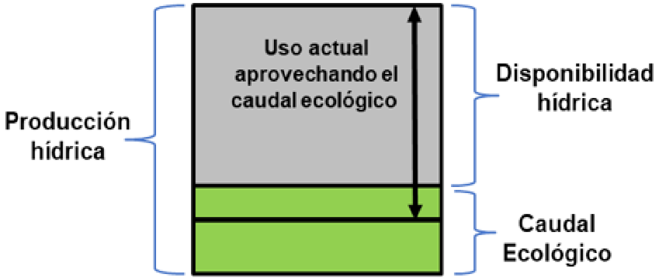
Possible scenarios for the use of water resources



Medio Ambiente seguro



Estrés hídrico



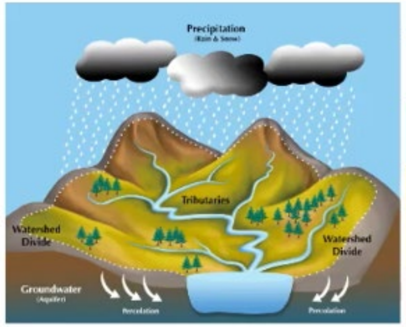
Escases hídrica

$$Water\ Stress\ (\%) = \frac{TFWW}{TRWR - EFR.} * 100$$

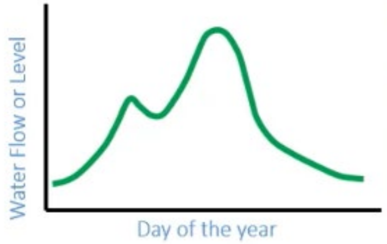
Fuente: Smakthin et al., 2004

Considerations and methods to estimate ecological flow

- Water resources planning at basin or sub-basin scale
- Oriented towards specific objectives
- Based on the natural flow regime
- Ecologically relevant to preserve species and habitats
- Socially and culturally important for the population
- Calculate 04 scenarios, different flows perform different functions, which allows negotiating the condition to be maintained.
- If you want to maintain a river in its most natural or healthy state, you must maintain a greater flow and replicate its annual and interannual variability.



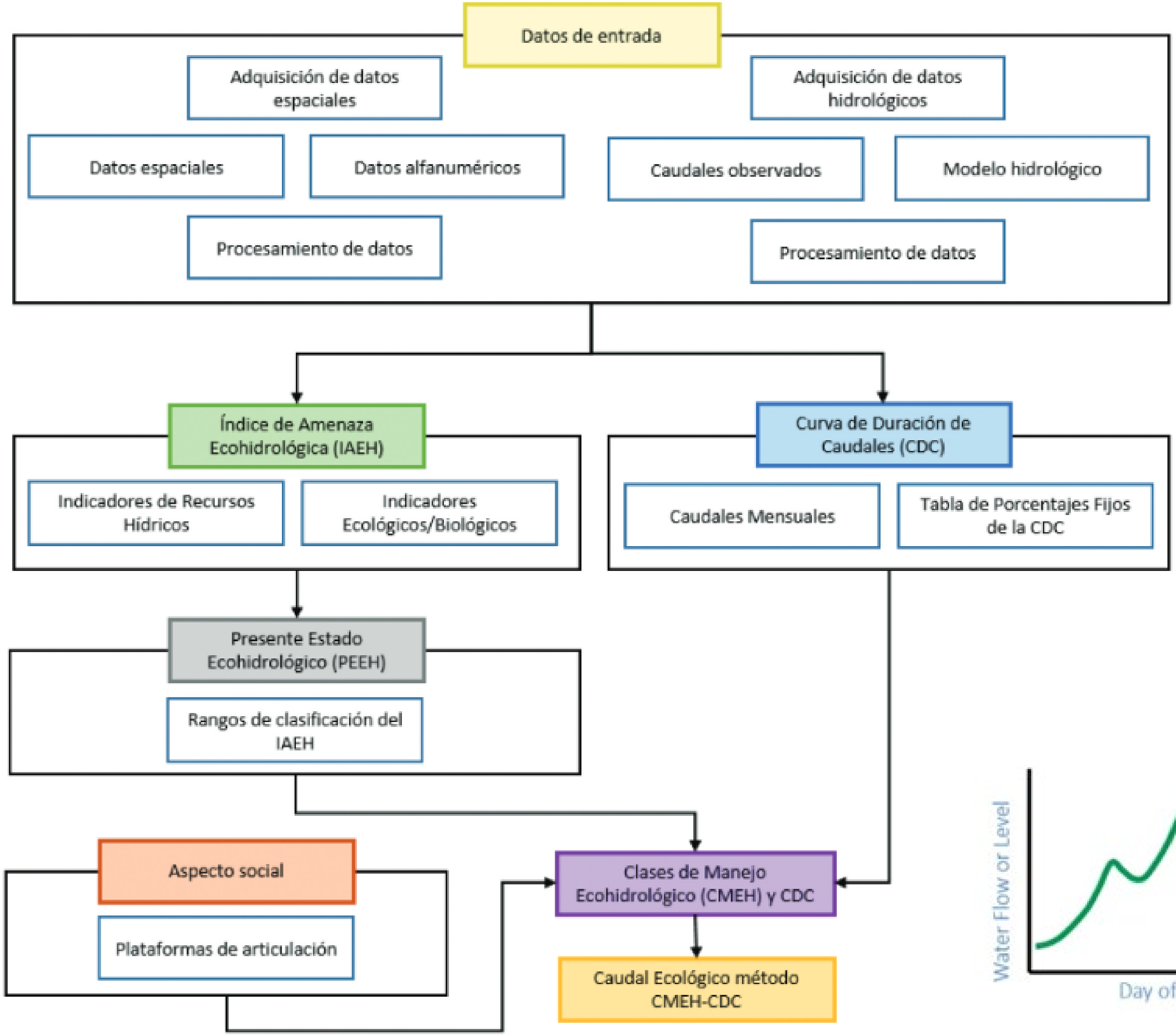
Status	Description
High	Reference conditions
Good	Small deviation from reference conditions
Moderate	Moderate deviation
Poor	Large deviation
Bad	Heavily contaminated



Flowchart of the method

ArcGIS

QGIS



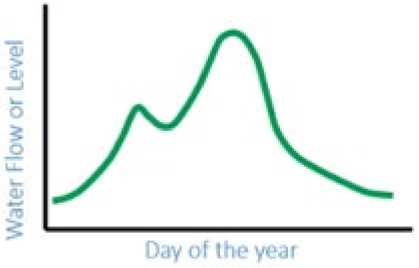
Senamhi

SWAT Soil & Water Assessment Tool

ArcGIS QGIS IBM

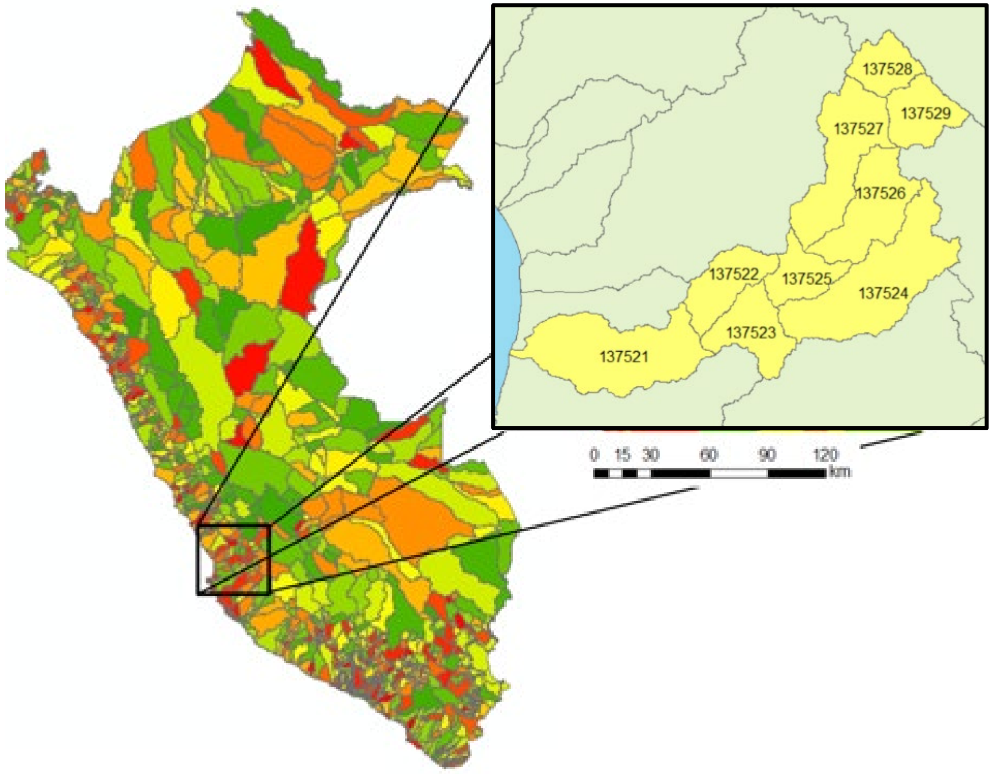
FDCShift

GLOBAL ENVIRONMENTAL FLOW CALCULATOR

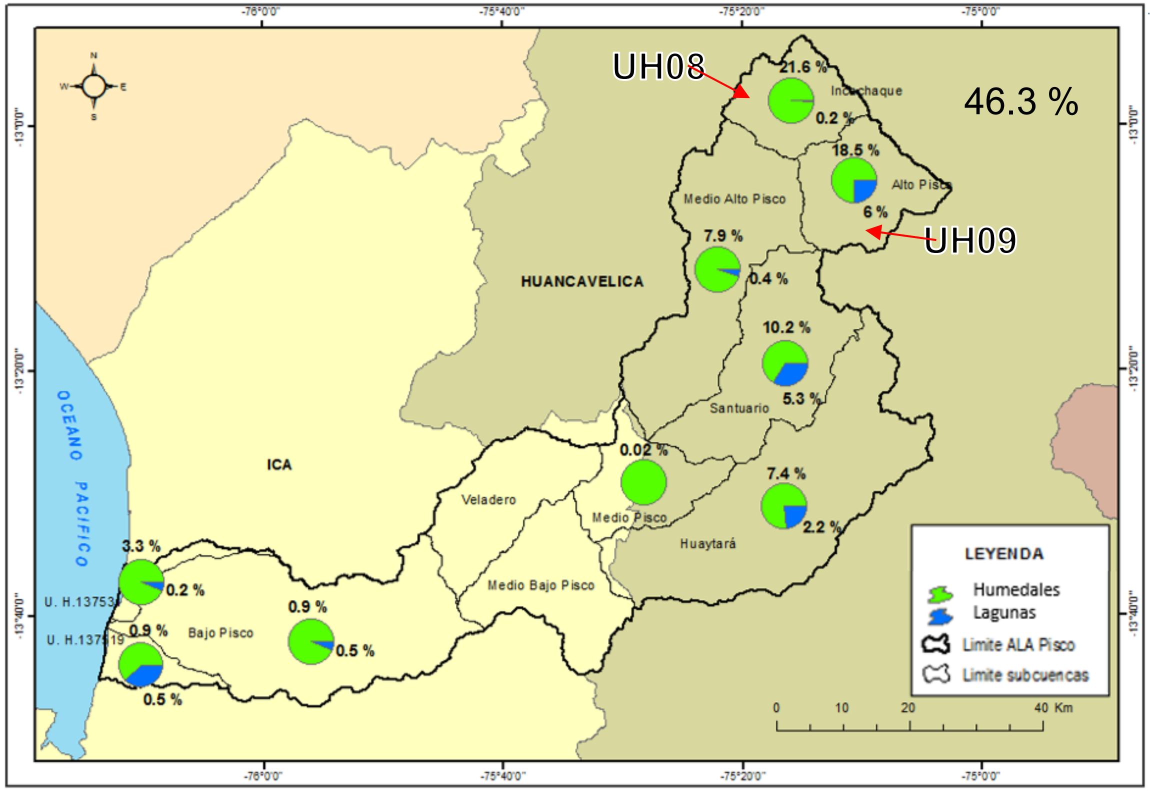


Practical application in the Pisco river basin

2021-2023



Lakes and wetland extension[1]



[1]Autoridad Nacional del Agua. (2018). Estudio piloto: Inventario de Humedales en el ámbito de la ALA Pisco.

Datasets and sources available

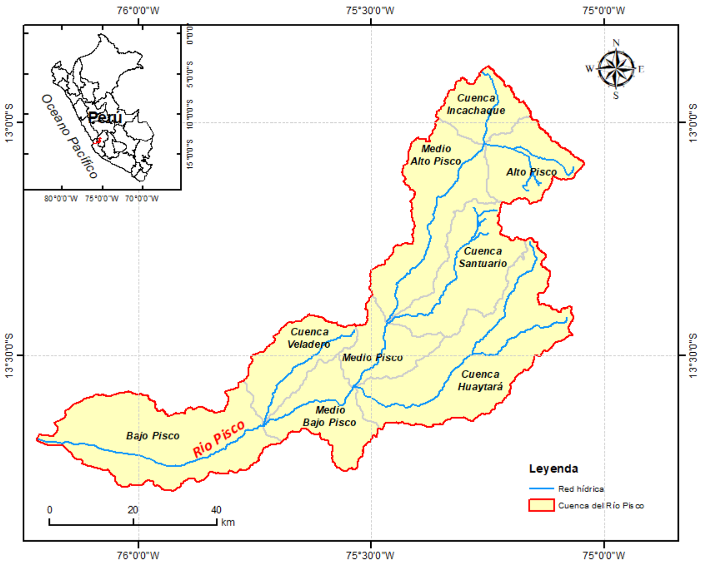
The information used in the construction of the SWAT model came from different national and international organizations and is mostly freely accessible

Input Data for the construction of the SWAT Model

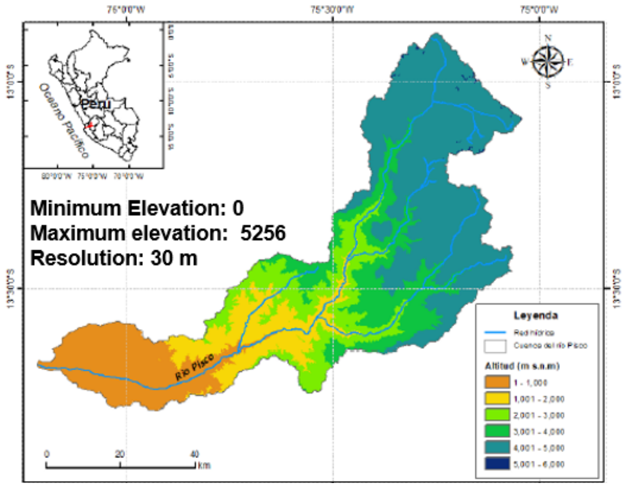
Base maps	River network
	Lakes/ponds
	Wetlands
	Topography
Thematic maps	Boundaries of basin and subbasins
	Soils
	Land cover/Land use
Weather data	Rainfall
	Temperature
	Solar radiation
	Relative humid
	Wind speed
Hydrological data	Observed Flow
	Water demands
	Dam volume and discharge
	Springs
	Wastewater discharge

Main input data to set up the SWAT Model

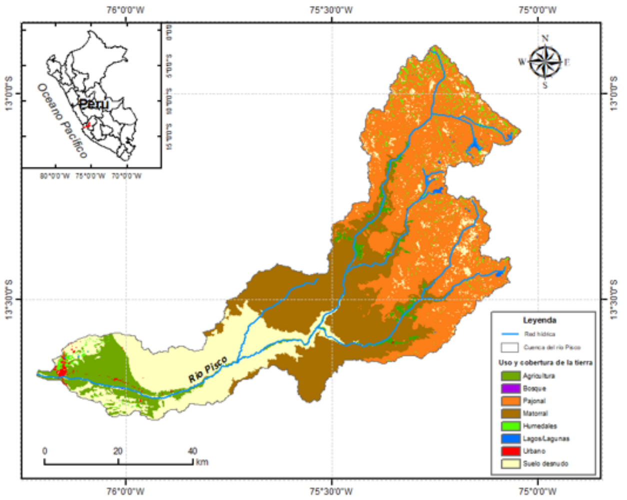
Sub-basin boundaries



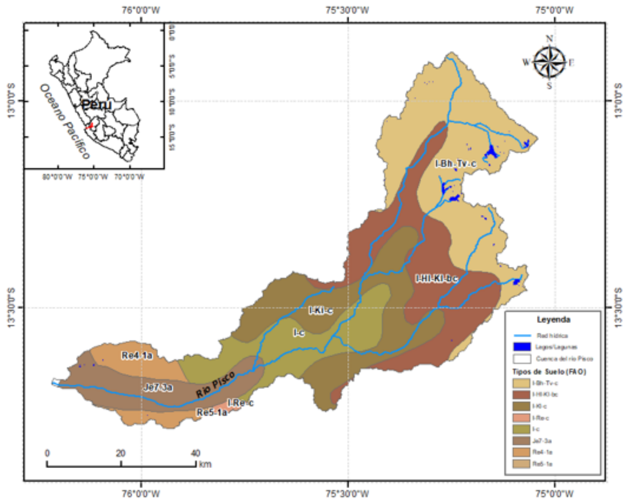
Digital Elevation Model



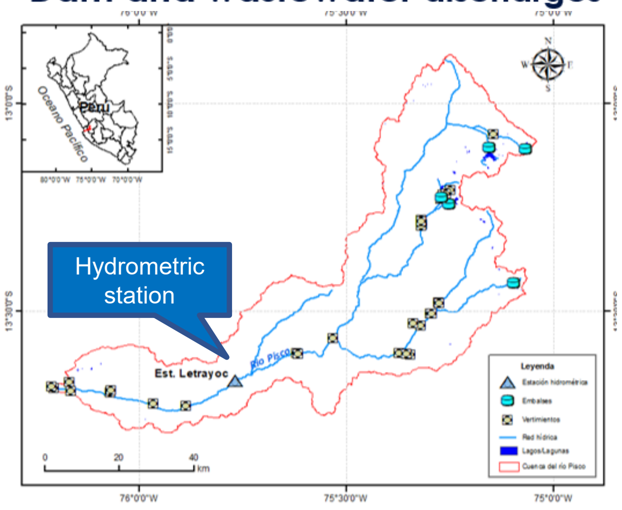
Land Use/Land Cover map



Soil Map



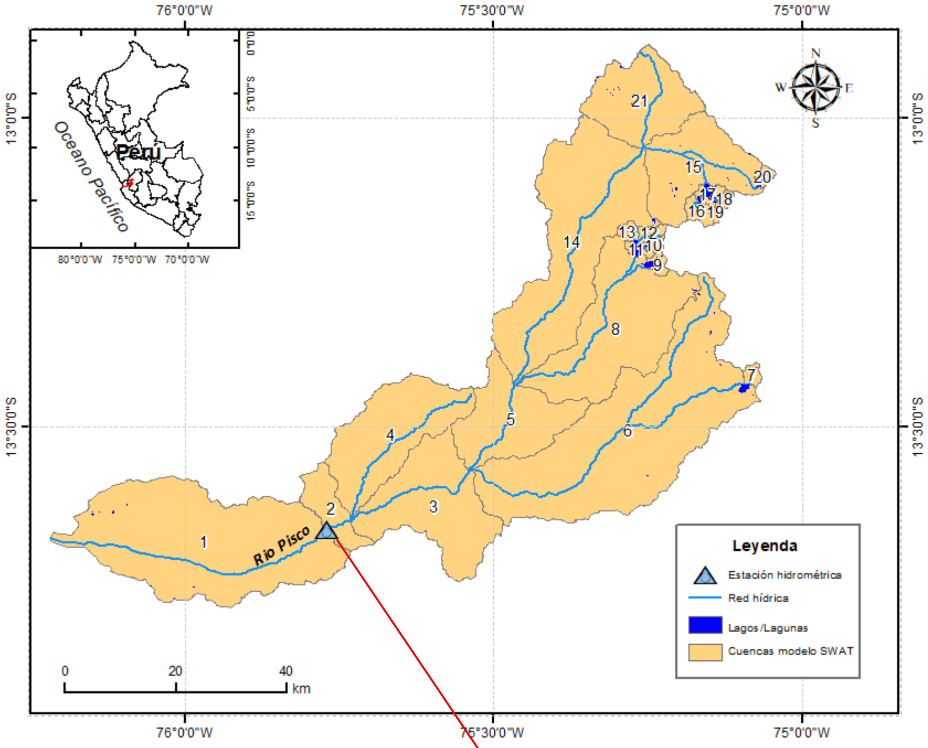
Dam and wastewater discharges



1. Nine Sub-basin were delineated at 1:100 000 with Pfafstetter method which is official in Peru was used.
2. Digital elevation model (DEM) NASADEM was used.
3. The LULC map was taken from the MINAM national map of vegetation cover and from the GlobeLand30, which has a spatial resolution of 30 meters. Both sources were combined and improved.
4. The soil information was taken from the FAO/UNESCO world soil database. Despite its coarse scale 1: 5,000,000, shows a greater number of soil categories (08) than Peruvian soil map.
5. We collect the information of measure stream flow, capacity of dams and discharge and wastewater discharges also. This information is will use in the calibration.

Model Set Up

- We use ArcSWAT version 2012 in ArcGIS 10.7
- We delineated 21 subbasin, initially we had 9 subbasin, but we included the flow gage subbasin and the dam´s subasins.
- 459 HRU by using multiples HRUs LandUse/Soil/Slope option.
- 36 year was used to run the model



Simulation Periods:

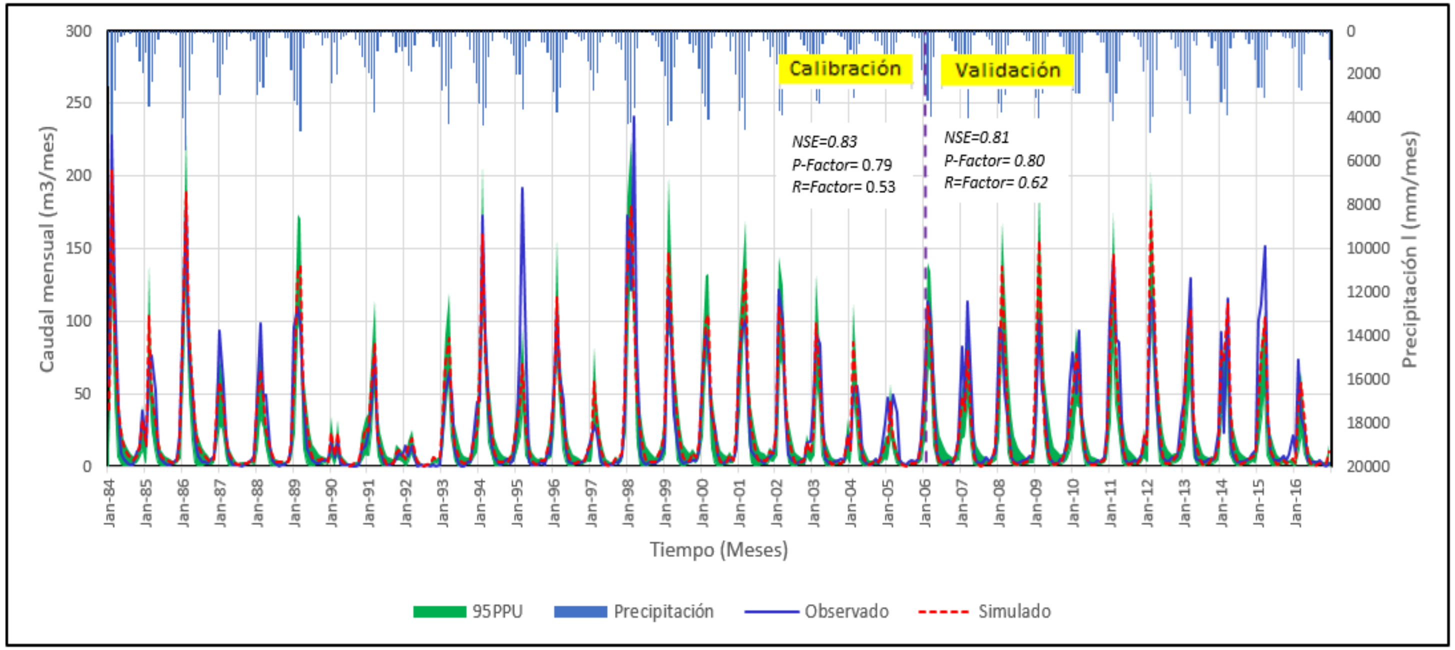
- Warm up period: January 1st, 1981 to December 31st, 1983 (3 years)
- Calibration: January 1st, 1984 to December 31st, 2005 (22 years)
- Validation: January 1st, 2006 to December 31st, 2016 (11 years)

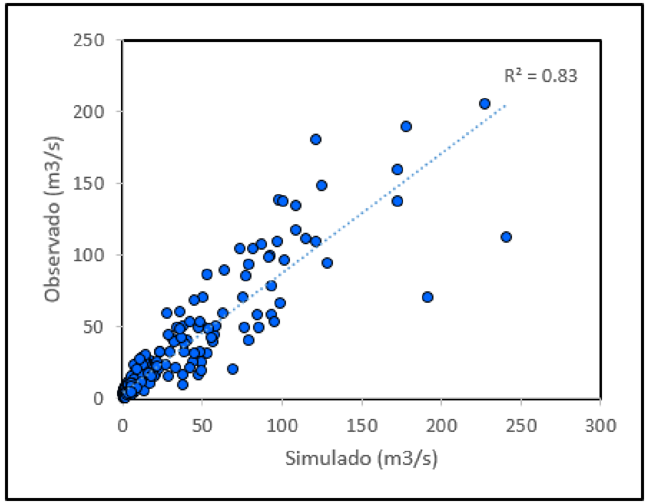
Observed Data:

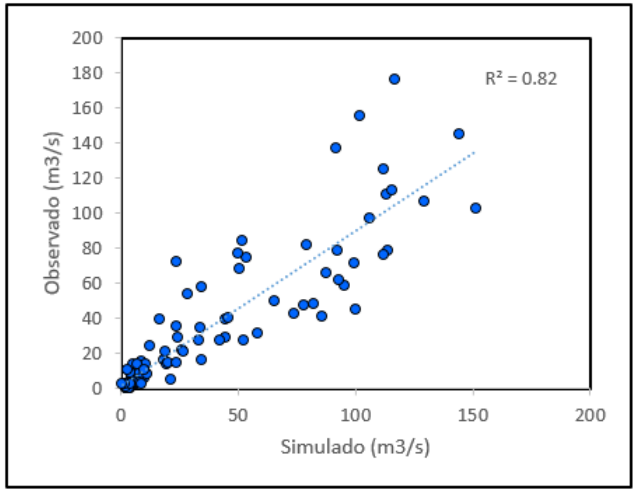
- Stream flow: Daily observed data from January 1st 1981 to December 31st, 2016 at Letrayoc station

Results of Calibration and Validation

- Monthly mean flows observed and simulated with the SWAT model after the calibration and validation at Letrayoc station.



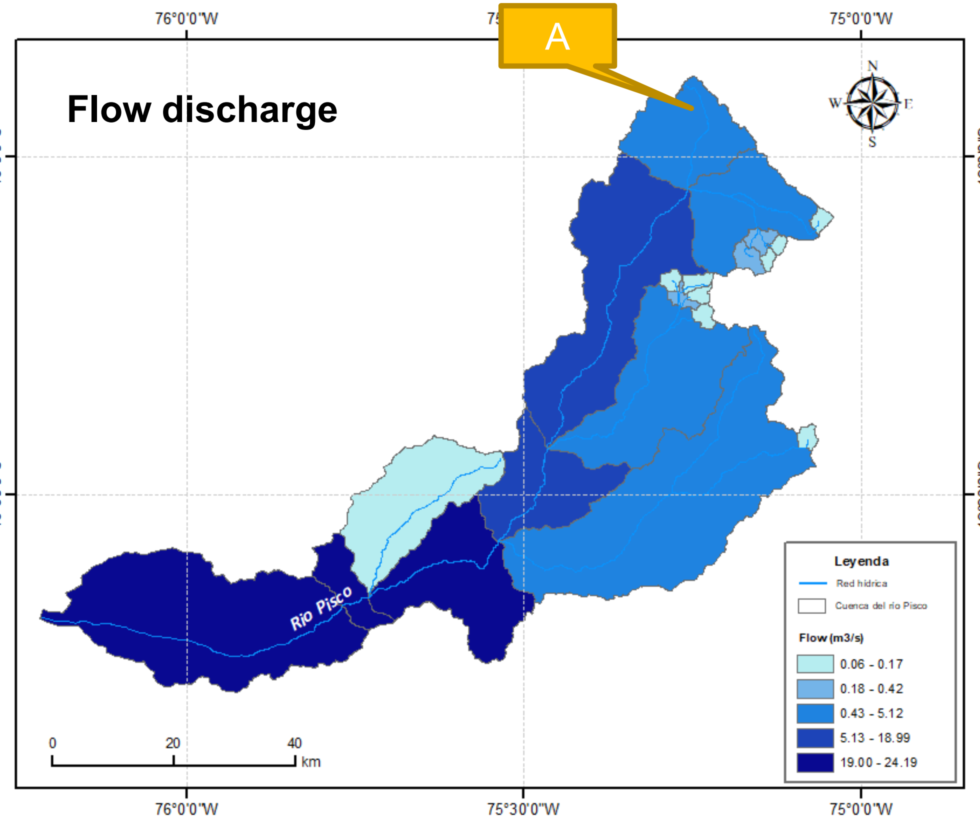




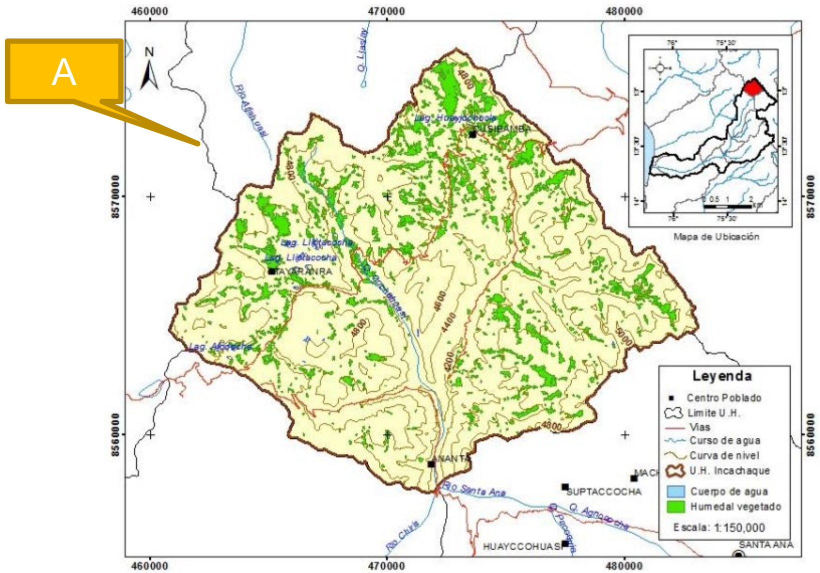
Model stage	Statistical indices			
	NSE	R2	RSR	PBIAS
Calibration (1984-2005)	0.82	0.83	0.41	0.3
Validation (2006-2016)	0.81	0.82	0.44	7.0

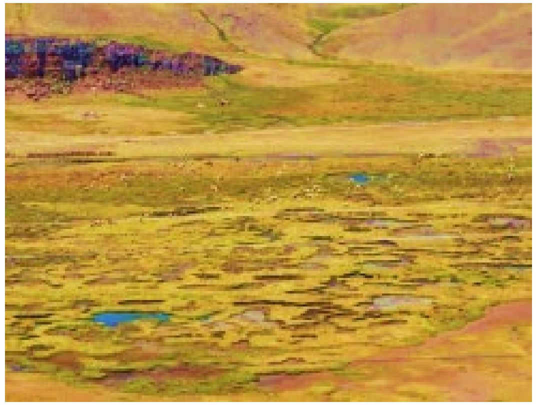
Aplicación en la UH Pisco-Cabecera

From 3.4 m3/s to 24.19 m3/s



Incachaque subbasin



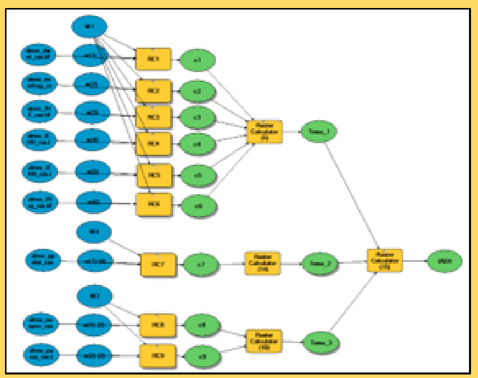


Ecohydrological Threats Index

N° Theme Indicator	Hydrological modelling
I Water resources-Quantity	
1. River fragmentation	
2. Water stress by consumptive use	x
3. Water stress by human use	x
4. Water stress by agricultural areas	x
5. Water detention	x
6. Disconnectivity of river, lakes and wetlands	
II Water resources-Quality	
7. Water pollution	x
III Biotic component	
8. Number of introduced species	
9. Percentage of introduced species	
10. Aquaculture pressure	

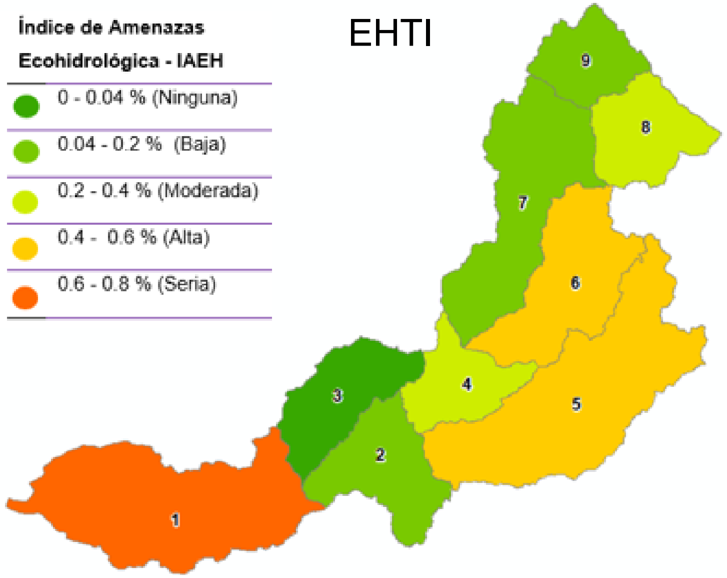
SWAT

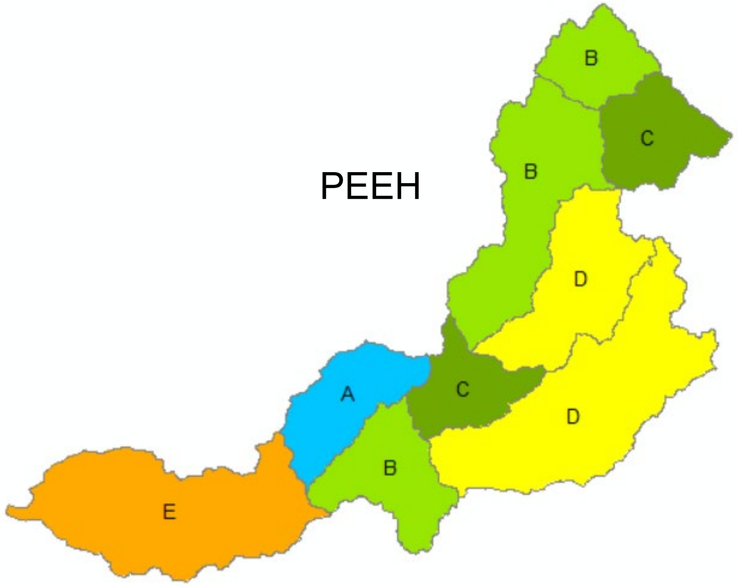
SWAT



$$IAEH_i = \sum_{j=1}^{4}\sum_{k=1}^{d_j} W_j \omega_{k,j} \widehat{D}_{i,j,k}$$

PEEH/CMEH	Descripción
A/A	Natural
B/B	Mayormente natural
C/C	Moderadamente modificado
D/D	Mayormente modificado
E/D	Seriamente modificado
F/D	Extremadamente modificado

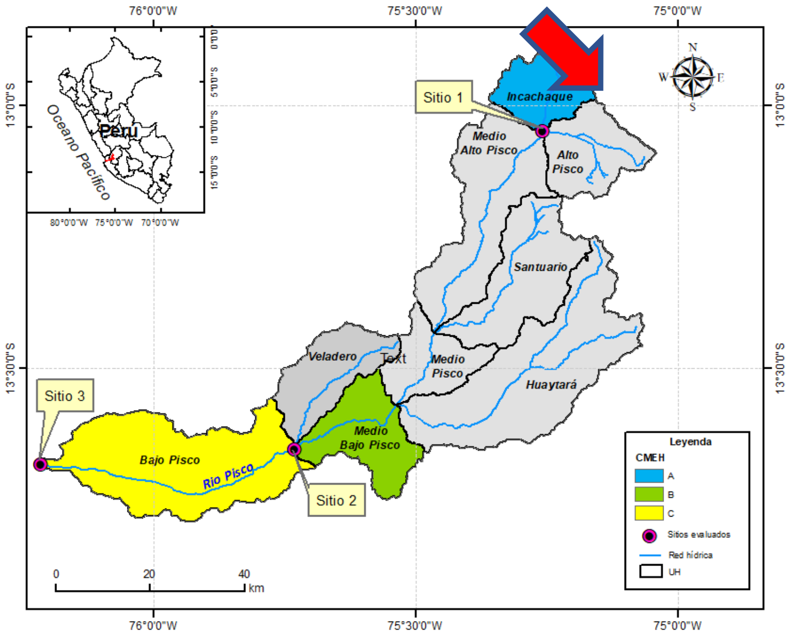




Determination of ecological flow – UH Incachaque

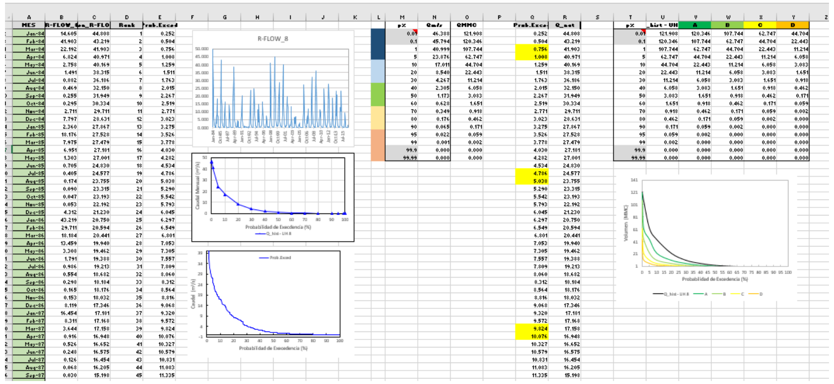
Location of the Incachaque UH and flow duration curve, reference and for each of the four possible ecohydrological management classes (CMEH).

Location of Incachaque subbasin

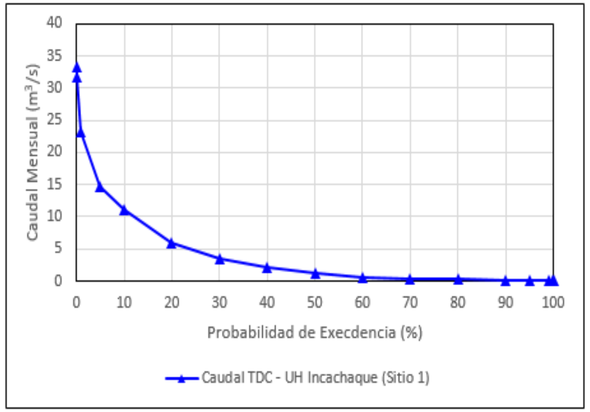


Q_{medio} histórico= 3.46 m3/s

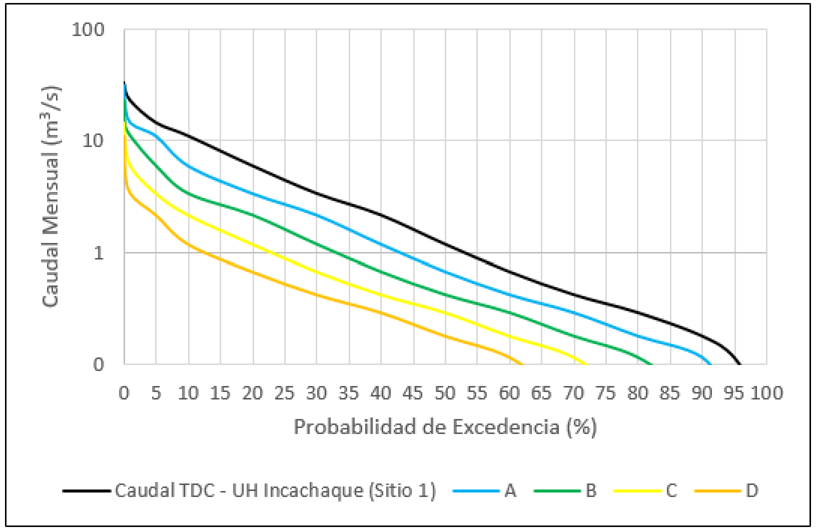
Flow duration curve - Incachaque



Reference flow duration curve - Incachaque



Reference flow duration curve and scenarios- Incachaque



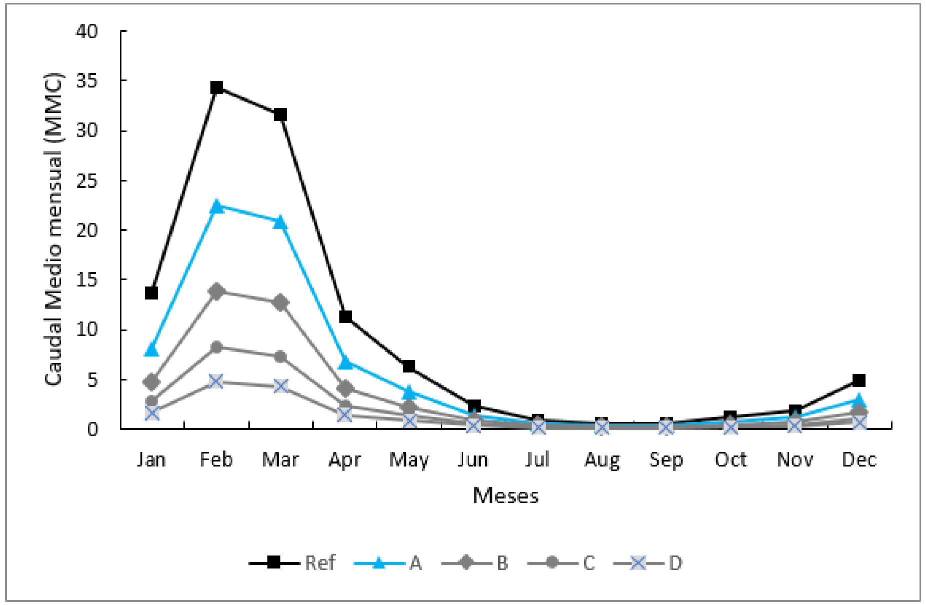
Environmental Flow scenarios in the Incachaque subbasin

Ecological flows determined for the Incachaque subbasin under the four scenarios considered in the method applied. In blue the most appropriate class (Class A)

Values of ecological flow by CMEH

	Caudal Medio		CMEH-A		CMEH-B		CMEH-C		CMEH-D	
Mes	MMC	m^3/s	MMC	m^3/s	MMC	m^3/s	MMC	m^3/s	MMC	m^3/s
Ene.	13.697	5.212	8.026	3.054	4.772	1.816	2.789	1.061	1.615	0.615
Feb.	34.278	13.044	22.433	8.536	13.870	5.278	8.279	3.150	4.769	1.815
Mar.	31.545	12.004	20.921	7.961	12.703	4.834	7.268	2.766	4.287	1.631
Abr.	11.249	4.280	6.857	2.609	4.091	1.557	2.317	0.882	1.375	0.523
May.	6.242	2.375	3.807	1.448	2.147	0.817	1.283	0.488	0.832	0.317
Jun.	2.265	0.862	1.323	0.504	0.848	0.323	0.551	0.210	0.344	0.131
Jul.	0.949	0.361	0.613	0.233	0.389	0.148	0.233	0.089	0.130	0.050
Ago.	0.547	0.208	0.325	0.123	0.187	0.071	0.107	0.041	0.085	0.032
Set.	0.628	0.239	0.395	0.150	0.234	0.089	0.142	0.054	0.095	0.036
Oct.	1.176	0.447	0.736	0.280	0.474	0.180	0.296	0.113	0.179	0.068
Nov.	1.895	0.721	1.157	0.440	0.717	0.273	0.459	0.175	0.280	0.106
Dic.	4.877	1.856	2.894	1.101	1.694	0.645	1.039	0.395	0.669	0.255

Monthly hydrograph of ecological flow by CMEH

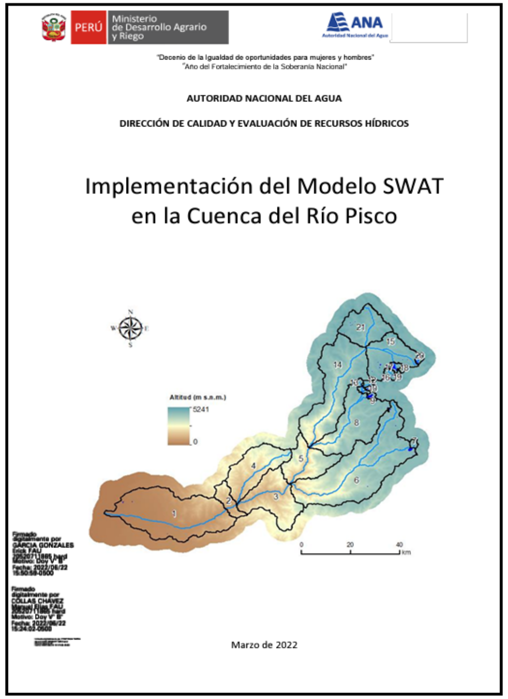


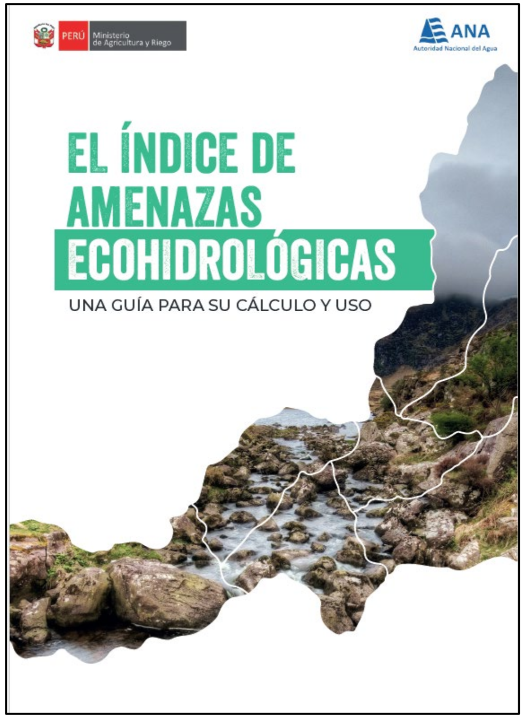
Water avalaibility in the Incachaque subbasin

Balance Hídrico Medio (MMC)-UH Incachaque	Periodo 1984-2016												
	Ago.	Set.	Oct.	Nov	Dic.	Ene.	Feb.	Mar.	Abr.	May.	Jun.	Jul.	Total
PHN.	0.55	0.63	1.18	1.90	4.88	13.70	34.28	31.55	11.25	6.24	2.27	0.95	109.35
CE.-CMEH-CDC “A”	0.32	0.39	0.74	1.16	2.89	8.03	22.43	20.92	6.86	3.81	1.32	0.61	69.49
DHSM	0.22	0.23	0.44	0.74	1.98	5.67	11.85	10.62	4.39	2.44	0.94	0.34	39.86

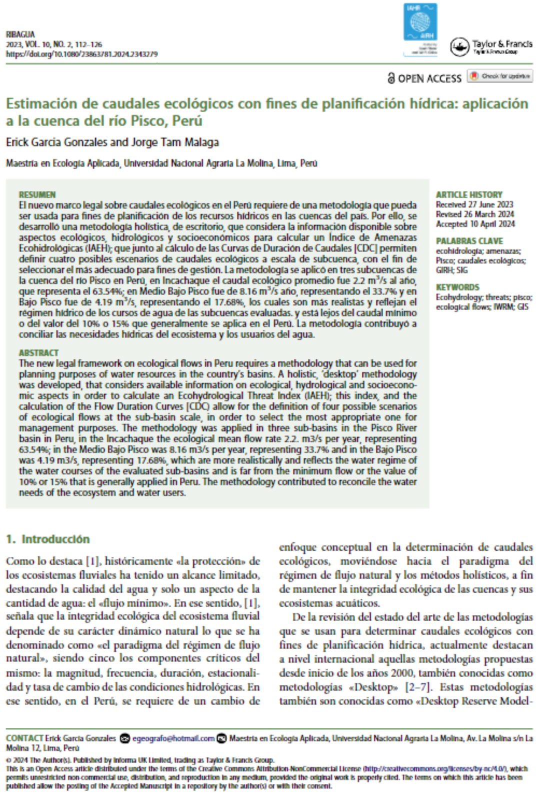
Nota: PHN= Producción hídrica natural, CE= Caudal ecológico; DHSM= Disponibilidad hídrica superficial media.

Reports





Article



RIBAGUA
2023, VOL. 10, NO. 2, 112–126
https://doi.org/10.1080/23863781.2024.2343279

Taylor & Francis

OPEN ACCESS

Estimación de caudales ecológicos con fines de planificación hídrica: aplicación a la cuenca del río Pisco, Perú

Erick Garcia Gonzales and Jorge Tam Malaga

Maestría en Ecología Aplicada, Universidad Nacional Agraria La Molina, Lima, Perú

RESUMEN

El nuevo marco legal sobre caudales ecológicos en el Perú requiere de una metodología que pueda ser usada para fines de planificación de los recursos hídricos en las cuencas del país. Por ello, se desarrolló una metodología holística, de escritorio, que considera la información disponible sobre aspectos ecológicos, hidrológicos y socioeconómicos para calcular un Índice de Amenazas Ecohidrológicas (IAEH); que junto al cálculo de las Curvas de Duración de Caudales [CDC] permiten definir cuatro posibles escenarios de caudales ecológicos a escala de subcuenca, con el fin de seleccionar el más adecuado para fines de gestión. La metodología se aplicó en tres subcuencas de la cuenca del río Pisco en Perú, en Incachaque el caudal ecológico promedio fue 2.2 m^3/s al año, que representa el 63.54%; en Medio Bajo Pisco fue de 8.16 m^3/s año, representando el 33.7% y en Bajo Pisco fue de 4.19 m^3/s, representando el 17.68%, los cuales son más realistas y reflejan el régimen hídrico de los cursos de agua de las subcuencas evaluadas. y está lejos del caudal mínimo o del valor del 10% o 15% que generalmente se aplica en el Perú. La metodología contribuyó a conciliar las necesidades hídricas del ecosistema y los usuarios del agua.

ABSTRACT

The new legal framework on ecological flows in Peru requires a methodology that can be used for planning purposes of water resources in the country's basins. A holistic, 'desktop' methodology was developed, that considers available information on ecological, hydrological and socioeconomic aspects in order to calculate an Ecohydrological Threat Index (IAEH); this index, and the calculation of the Flow Duration Curves [CDC] allow for the definition of four possible scenarios of ecological flows at the sub-basin scale, in order to select the most appropriate one for management purposes. The methodology was applied in three sub-basins in the Pisco River basin in Peru, in the Incachaque the ecological mean flow rate 2.2. m3/s per year, representing 63.54%; in the Medio Bajo Pisco was 8.16 m3/s per year, representing 33.7% and in the Bajo Pisco was 4.19 m3/s, representing 17.68%, which are more realistically and reflects the water regime of the water courses of the evaluated sub-basins and is far from the minimum flow or the value of 10% or 15% that is generally applied in Peru. The methodology contributed to reconcile the water needs of the ecosystem and water users.

ARTICLE HISTORY
Received 27 June 2023
Revised 26 March 2024
Accepted 10 April 2024

PALABRAS CLAVE
ecohidrología; amenazas; Pisco; caudales ecológicos; GIRH; SIG

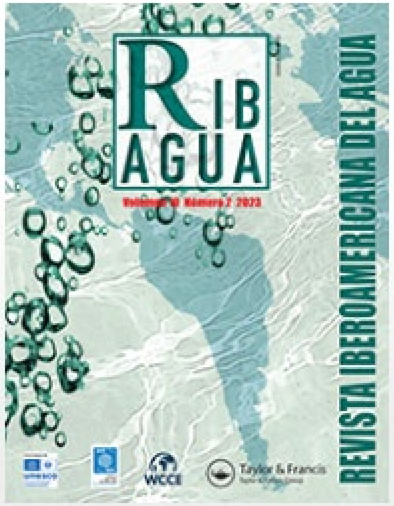
KEYWORDS
Ecohydrology; threats; pisco; ecological flows; IWRM; GIS

1. Introducción

Como lo destaca [1], históricamente «la protección» de los ecosistemas fluviales ha tenido un alcance limitado, destacando la calidad del agua y solo un aspecto de la cantidad de agua: el «flujo mínimo». En ese sentido, [1], señala que la integridad ecológica del ecosistema fluvial depende de su carácter dinámico natural lo que se ha denominado como «el paradigma del régimen de flujo natural», siendo cinco los componentes críticos del mismo: la magnitud, frecuencia, duración, estacionalidad y tasa de cambio de las condiciones hidrológicas. En ese sentido, en el Perú, se requiere de un cambio de enfoque conceptual en la determinación de caudales ecológicos, moviéndose hacia el paradigma del régimen de flujo natural y los métodos holísticos, a fin de mantener la integridad ecológica de las cuencas y sus ecosistemas acuáticos.

De la revisión del estado del arte de las metodologías que se usan para determinar caudales ecológicos con fines de planificación hídrica, actualmente destacan a nivel internacional aquellas metodologías propuestas desde inicio de los años 2000, también conocidas como metodologías «Desktop» [2–7]. Estas metodologías también son conocidas como «Desktop Reserve Model-

CONTACT Erick Garcia Gonzales egeografo@hotmail.com Maestría en Ecología Aplicada, Universidad Nacional Agraria La Molina, Av. La Molina s/n La Molina 12, Lima, Perú



https://repositorio.ana.gob.pe/

https://www.tandfonline.com/doi/epdf/10.1080/23863781.2024.2343279?needAccess=true

Thank you
Gracias

Welcome to Lima and have a nice trip to Macchu Picchu!