# STREAM CLASSIFICATION AND ASSESSMENT OF HYDROLOGIC ALTERATIONS TOWARDS AN ENVIRONMENTAL FLOW APPRAISAL OF THE MAGDALENA-CAUCA RIVER BASIN (COLOMBIA)

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A stream classification was performed in order to propose an environmental flow regionalization for the most stressed hydrologic area in Colombia, the Magdalena-Cauca river basin including its 151 sub-basins. The work was conducted following the Ecological Limits of Hydrologic Alteration (ELOHA) framework with adjustments to the Colombian context. To do so, a stream classification was performed taking into account hydrological variables with ecological relevance, using the Indicators of Hydrologic Alteration trough the IHA software. This work took advantage of experimental design, supported with statistical, computational and expert knowledge tools. On the other hand, identifying when a hydrological alteration has occurred is not an easy task in Colombia, because there are few dams and extractions are relatively small. Besides, hydrologic information is not enough, not only because discharge series are too short, but also because of limited traceability to identify changes in flow regimen due to anthropogenic actions. To sort this situation out, an experimental methodology was developed, trying to identify changes in mean and variance values; trend analysis were also executed. The development of the methodology is accomplished by implementing homogeneity tests using a moving window method. As a result, 174 discharge series were classified into 6 families containing 23 sub-families. Furthermore, it was evidenced that 22% showed trend while 15% and 17% rejected the mean and variance tests respectively. Finally, we recommend the implementation of an eco-hydrological monitoring plan and the improvement in quality of hydrologic data series.

## 1 ENVIRONMENTAL FLOWS AND THE MAGDALENA-CAUCA RIVER BASIN IN COLOMBIA

Most socio-economic activities of a population are supported by water resources, which are altering rivers flow regimes, causing growing deterioration in the health of river ecosystems [1]. This problem has led to the rising of concepts such as minimum flows, ecological flows, and most recently, environmental flow regimes. The environmental flows contribute significantly towards the health of rivers, economic development, and alleviating poverty. In terms of the way to solve this problem, there are many methodologies that have been developed; were 207 have been identified by Tharme, R [2].

Most of the alterations of the water regime are related to the construction and operation of large dams. Although variables such as temperature, water quality, basins coverage, among others, can have a significant influence in any aquatic ecosystem health, the alterations of the hydrological regime seem to constitute, if not the most important variable, one of the most decisive for determining the state of the lotic ecosystems [3].

The Magdalena-Cauca river basin (Colombia) is no stranger to the problem of the determination of environmental flows. Herein, the large amount of geographical, geological, hydrological, biological and climatic conditions, endow it with a unique complexity which is reflected in a great diversity of ecosystems and organisms. In addition, the strategic position, convert it into a densely populated area with many conflicts due to the use of resources. The Magdalena-Cauca basin has a total area of 273459 km$^2$, equivalent to 24% of the Colombian territory, which corresponds to 77% of the country's population (32.5 million inhabitants). In its mouth, the Magdalena River pours into the Caribbean Sea an average of 7100 m$^3$/s. In 2010, the then-named *Ministerio de Ambiente, Vivienda y Desarrollo Territorial*, in order to move forward with this topic, and with the support of The Nature Conservancy Colombia (TNC), initiated the process of implementing the methodology ELOHA in the basin. To achieve this TNC was supported by the consulting firm Ingfocol Ltda.

## 2 THE ELOHA METHODOLOGY, A FRAME OF REFERENCE. A FIRST APPROXIMATION TO THE DETERMINATION OF ENVIRONMENTAL FLOWS IN THE MAGDALENA–CAUCA RIVER BASIN

Ecological Limits of Hydrologic Alteration (ELOHA) is a methodology that arose conceptually in 2006 specifically in order to cover large territories in the regional environmental flows [4]. This is an adaptive methodology divided into three fundamental processes: scientific, social, and monitoring data. In the scientific process both the inputs and the information necessary to negotiate between the different players of the environmental flow regime which is agreed at the social process are obtained. The monitoring process is the one that makes this methodology an adaptive methodology, because it is possible to assess, adapt and improve models, hypothesis and information used in the scientific and social processes.

The flexibility and adaptability of ELOHA, especially in terms of quantity and quality of information, makes this methodology as one of the most appropriate to be applied in the Magdalena-Cauca river basin. Within the scientific process, two of the key components correspond to the classification of river flows and the determination of hydrological alterations in the rivers. These are part of the inputs towards the construction of curves that relate the ecological response to hydrological alteration for different types of flows, which in turn represent perhaps the most important element of the methodology ELOHA.

## 3 FLOW REGIMES CLASSIFICATION

The objective of the river classification of the ELOHA methodology is to identify the different hydrologic regimes that govern certain ecological processes. As a result, eco-hydrological processes are regionalized facilitating the study and evaluation of impacts generated by the hydrological alterations in the health of aquatic and terrestrial ecosystem. In the case of the Magdalena–Cauca river basin, this task was carried out in four sub-processes: building a hydrological information system, selection of variables to classify flows, construction of clusters and validation of the results.

**Hydrologic information system**: the main input for the classification process corresponded to daily discharge series. Initially it was counted with 197 discharge series, which were provided by the *Instituto de Hidrología, Meteorología y Estudios Ambientales* (IDEAM). Average length of the full data set was close to 32 years and series vary from 15 to 39 years long. **Variable Selection**: given the objective of river classification, hydrological variables must have ecological significance. The software IHA (Indicators of Hydrologic Alteration) [5] calculates 67 parameters from a discharge series. However, in order to use the simplest model that better represent river classification we reduce the number of variables, it was performed using principal component, linear and non-linear correlation analysis. **Clusters construction**: It was done in different ways, using the 25 variables with and without standardizations. The cluster method used corresponded to the Expectation Maximization (EM) [6], implemented in the software Waikato Environment for Knowledge

Analysis (WEKA) [7]. **Results validation**: it was supported on the comparison of the results against the maps of other variables like the geomorphology, the biomes, the ecosystems and the drainage network; the comparison of the hydrographs of the gage stations in a same group, and the expert knowledge of the team.

For the final result of the classification, six big groups were obtained, which were designated as families that were subdivided into 23 subfamilies based on more specific hydrological characteristics.

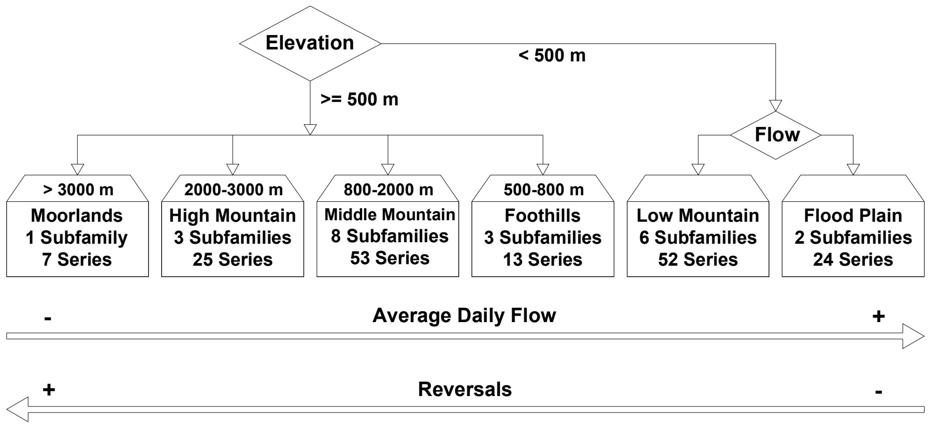


Figure 1. Summary of streams classification.

Every subfamily has a set of features useful for an institution in order to classify a new river or stream. Also those characteristics have ecological importance so that correlations or hypothesis with ecological factors can be made. A catalog of stream types was elaborated including important hydrological and descriptive information.

## 4 HYDROLOGICAL ALTERATIONS IN THE MAGDALENA–CAUCA RIVER BASIN

In order to understand the way how hydrological alteration affects ecosystems associated to rivers, a fundamental step is to identify where and when hydrological alterations have occurred. There are many metrics to evaluate hydrological alterations that have a relation with the ecosystems health. IHA calculates the Analysis by Ranks of Variability (RVA). To be able to determine a hydrological alteration, a comparison must be carried out between parameters obtained from discharges series when the stream was in its pristine state and parameters from discharges series after it was affected in its flow regime. In Colombia this is not an easy task and some of the main are: The fuzzy way in which hydrological alteration has occurred, particularly, on medium and small streams, which are very important in a regionalization of environmental flows. Lack of data and traceability. Little evidence can be obtained in a visual way when a series of discharges is been reviewed.

It was established that 28% of the analyzed series displayed a trend with statistical significance level ($\alpha < 0.1$). In similar ways, the results of the Mann-Kendall test indicated that near 22% of those series displayed a trend. The 40% of the series present a positive trend, whereas the other 60%, present a negative trend. A comparison was performed, allowing us to identify the zones in which variations corresponded to regional processes due to changes in precipitations. Likewise in some cases in which this relation was not evident, attained to identify that the changes in the river flows corresponded to an increase in water resource withdrawals, or, in other cases, to the quality of the river flow data. However, big efforts were not centered in finding alteration causes, but in identifying its existence and characteristics.

Regarding homogeneity in mean values, we used t-test and Mann-Whitney test, results were quite consistent between them and also compared with trend analysis. With respect to homogeneity in variances, we used F-test. In this case, 149 series could be analyzed, 26 (or 17%), with a rejected variance homogeneity test ($\alpha = 0.05$).

The correlations between the values of the IHA and the average discharge of the series that rejected mean homogeneity test, showed that the average daily flow of the rainy season (April, May, September, October and November) are more susceptible to the changes of the average daily flow. The most affected parameters from those gage station's time-series that showed an affectation in the variance were the high and low pulses. Regarding the hydrological series that show a media trend, the maximum and average values by month were the most affected. Finally, the index of alteration of the basic flow, showed a decrease in the cases in which it determined a negative trend.

## 5 CONCLUSIONS

ELOHA framework provide a guide toward the establishment of ecological hydrological relations for every type of regime, and confronting those relations against the alterations encountered in the studied region. The first step is river or regimes classification, which as discussed above the result is 6 types or families and a total of 23 subfamilies of hydrological regimes that were determined. As it can be seen from the results, more types were detected through the ELOHA methodology in different countries as is the case in Australia where 11 types were established.

The 23 resultant subfamilies of the classification can seem as a high number to treat of regionalize the determination of environmental flow regimes; however, the high complexity of the basin, its high altitudinal gradients, the consistent diversity of climates, biomes and landscapes, seem to explain the emergency of flow regimes so different from one another. The geomorphologic and geographical conditions create a diversity of hydrologic regimes which are big and complex. However the classification exercise got a good acceptance among experts as far as it describes in general the main features of the drainages. The robustness of the classification will be tested as more information will be collected. It is expected that the proposed classification scheme will be able to assimilate the information of new streams.

Comparison of found alterations against the ecological relationships for the type of corresponding stream was not performed. Although at this early stage of ELOHA framework, there was not enough ecological information it is also important to mention that hydrological alterations found were diffuse and complex and its merely existence was a debate material before this study. Modifications of mean, variance, trends in some series, depict a picture of the hydrological alterations found, which were not those kind of "book examples" where the flow change after a dam building is evident. This first alterations analysis exercise aimed to encompass all the possibilities, including some apparently desirable as a flow increment. In that sense, this paper presents some useful results for understanding and describing hydrological alterations in the watershed, how they are and what features they have is a result that helps to understand the dynamics of the basin and the interactions between society and water resources.

The relations between IHA parameters and some statistics obtained from series identified with trend or those which rejected the homogeneity test in mean and variance, showed than this sort of analysis constitutes a useful tool in the identification of altered regimes influencing over the ecosystems health.

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