

Holistic Management of Temporary Watersheds in Central Mexico: An Improved Easy Mathematical Model for Decision-Makers

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ABSTRACT

The center of Mexico is dominated by seasonal rivers, with an erratic hydrodynamics due to natural seasonality of the system, and human actions on flows. To date there are no studies on environmental flows in rivers with high seasonality (Natural + Anthropogenic), especially in areas where water demand is extremely high. About 50 million people are living in the region. In addition, this region is considered as one of the most eco-diverse regions in the world. Many mathematical models for estimating environmental flows have been developed, yet no model is truly holistic, by not taking into account a variable of extreme importance to the ecological functioning of the watershed, its marked seasonal nature (temporality). Due to this lack of information on how to manage temporary rivers, most managers use conventional indices to estimate environmental flows or at best, use the standard Integrated River Basin Management. The holism of the third culture is taken as the paradigm framework to build the improved model I present in this paper. It should be noted that an important aspect of the model is its simplicity, since it is to be used by people with little knowledge in mathematics and thus easy to take, and common to all the rivers of the region data. All approaches for estimating environmental flows may have strengths and weaknesses, but the truth is that for management to resolve the conflict between conserving a natural resource and develop a village should be viewed in a holistic perspective. The main objective of this paper is to present an improved mathematical model for the decision makers to better manage a scarce, conflicting and indispensable for life and ecological functioning resource.

Key Words: Running Waters, Intermittently Flowing, Seasonality, Holism, Conservation of Landscape Heritage.

HIGHLIGHTS

- This is an improved model of the socio-ecosystem holistic management for seasonal basins.
- River basins are dynamic over space and time.
- Seasonality of watersheds is an important factor as a source of biodiversity.
- Regulated rivers can be modeled as seasonal rivers.
- The proposed model presents diagnostic and control indicators easy to measure.

INTRODUCTION

To provide drinking water to the population is a human right of great importance. Under this international and national mandate, to ensure that low income population have potable water is a priority in developing countries. By this way, public and private investment in infrastructure to extract, purify and distribute water is the majors of the world. But, because the river basins are

dynamic over space and time, any single management intervention has implications for the system as a whole altering one way or another the landscape ecological balance. Therefore, hydrological basin management is decisive for ensuring the continued provision of ecosystem services and, for limiting potential hazards particularly in densely populated landscapes, surrounded by large mountain chains, deep canyons, erratic weather, environmental seasonality and by far, temporary rivers

and streams (Trabucchi et al. 2012, Ortega-Marín and Gutiérrez-Yurrita 2014). The basin management becomes more problematic when facing three major challenges: overcome the poverty; preserve the great biodiversity; and by far, demands on the region's freshwater is growing as the regional population increases (Gutiérrez-Yurrita 2011, Muñoz et al. 2013). If the population continues to grow, neither does the rate of water demand, which also is much larger than the population augment.

An important factor in the huge regional biodiversity is the extremely diversity of types of watersheds in Central México (CONABIO 2008). There are endorheic basins ending in big shallow wetlands or in deep lakes with a lot of endemic biological species (San Román et al. 2013); but there are also open basins ending in broad estuaries and mangroves that flow into the sea. Waterways across large semi-desert, woodlands, tropical jungle and tropical forest regions, from more than 5000 m high, ending at sea level. Many of these rivers have a strong seasonality and, this gives them greater biological richness than of permanent rivers (Gutiérrez-Yurrita et al. 2013). Further, streams of central Mexico serve to irrigate grassland of cereals, legumes and corn, mainly; so many people depend on this resource for their productive activities. In addition, if we consider that the population of Central México exceeds 30 million inhabitants and the water for human consumption is a clear priority, so that the dams and channels of rivers are essential to maintaining active life in this region (INEGI 2011). However, there is a lack of information on how to manage temporary rivers. Most managers use conventional indices of environmental flow management or at best, estimate of integrated management of watersheds with permanent rivers by the use of standard methodologies overlooking that general methodologies have an effect on the results acquired (Filella 2014).

All the rivers in central Mexico are regulated to a greater or lesser degree (Gutiérrez-Yurrita 2012). However, not only the river suffers from human control, the entire hydrological basin is altered in its ecological structure (some biological and geological elements were –and are currently- transformed, degraded or eliminated), and thus, their overall environmental performance. Resulting in humanized landscapes left out of their management programs to conserve seasonal rivers (Gutiérrez-Yurrita 2011). It is worthy to notice that another important problem is that local human populations composed in many cases by ethnic communities are the owners of the land and by law, of the natural resources of the land; however, they are

living below the poverty threshold (INEGI 2011). So they are using their resources as much as they can. But also, the rivers in better condition of conservation, including their hydrological basin, are located in places with many social problems, and where ethnic people and other communities are in extreme poverty conditions with no options to increase their welfare (Gutiérrez-Yurrita 2011). So, the way in which they use their natural resources is closer to the philosophy “bread for today, hunger for tomorrow” than that of the sustainability (Gutiérrez-Yurrita 2004). At present, the efforts for preserving the ecological processes of these important ecosystems, connected in network with other watersheds are under the paradigm of the “Integrated River Basin Management (IRBM)” developed by Global Water Partnership (2000). One of the most important results of this work was the initiative of the seven key elements to a successful IRBM, developed by World Wildlife Foundation since then (WWF web page 2013). However, no reliable and satisfactory results were obtained by this method due to social and ecological causes, Social causes because the real and formerly roots that generate poverty never were considered into the model at the same time. And ecological causes because at any time is considered the temporary nature of the streams in the watershed management. Nowadays, the holistic approach may give us some clues and suggestions in how to get benefits from a complex situation, in both, social and natural systems (Oshri 2008).

Consequently, to achieve the famous sustainable development should address the management of biotic resources and water from the threefold perspective of ensuring the one hand, to fulfill the social and economic goals for which it was designed water control in a given basin; including, of course, urban water management (Deng et al. 2013). Secondly, to ensure the protection and conservation of ecosystems under such pressure that involves extractive or transformative activities (Auyang 1999). And thirdly, holistic management assessment has become more inclusive over time, linking future ecological and social changes with current environmental risks and other policy concerns (Füssel 2007). This three-way consideration is shown in trying to properly manage water resources, as has been the belief that to provide a steady output of water throughout the year, meets the requirement of preserving aquatic environments downstream. This way, an environmental flow to the amount of water that must drain the dams to minimize their impact on streams located downstream (Arthington et al. 2004). However, most of the time these volumes of water

are assigned a uniform value, which is calculated as a percentage of the annual average contribution. From this perspective, environmental flows could be defined as those flows needed to ensure an ecosystem similar to that existing before the construction of dams, even before that human activities were made apparent in the basin towards regional sustainability (Arthington et al. 2006). From this perspective, studies of environmental flow (minimum flow regimes in channels) should be considered with an academic and practical approach. Thus, management of natural resources (biotic and abiotic) is a reflection of social goals and the scientific understanding of the environment in question, giving us a historical record of both, social and scientific changes (Cubillo et al. 1990). From this perspective, it can be seen that the holistic management of our natural resources has been improved over the trial and error, but to date, has only rarely been possible to anticipate the new challenges posed by society and/or disasters or natural disturbances (Gutiérrez-Yurrita 2014). The aim of this paper is to present a reflection on the management of temporary flows, presenting an improved mathematical model to help decision makers in conducting action plans.

AREA OF STUDY

The general physiography of central Mexico is a large plateau that continues north into the territory of the United States of North America and is bordered to the south by the neo-volcanic axis, to the east by the Sierra Madre Oriental and west by the Sierra Madre Western. The Central Mexico region covers an area close to 150,000km² with an estimated population about of 49,123,993 people; almost all people are living in a very big cities with more than 1,000,000 people each, but the other people are dispersed in thousands of small ethnic communities scattered across the sierras, especially in natural protected areas, like Biosphere Reserve of Sierra Gorda (INEGI 2011). In the agricultural fields as well as in the Sierras there are high rates of migration recorded for the reason that the field is considered an increasingly less profitable. Agricultural fields and deciduous forest in middle and lowlands dominate landscapes of the area. Oak and pine forests are confined at the top of the Sierra, covering part of the Trans Mexican volcanic belt and part of the Eastern and Western Sierra Madre (García-Trejo et al. 2013). General statistical data of watersheds of central Mexico considered in this regional study are shown in Table 1.

The central Mexico is composed essentially of three great watersheds: 1) Lerma river basin, 2) Pánuco river Basin and, 3) the Valley of Mexico Basin also known as basin of Anahuac (Figure 1).

1. The Lerma River is a 708 km-long river in central Mexico that begins in the Trans-Mexican volcanic Belt at an altitude over 3,000 m above mean sea level (MSL), and ends where it empties into Lake Chapala (1500 m above MSL), Mexico's largest shallow water lake of freshwater (INEGI, 2004). The river has a flow towards the western México. The basin is endorheic allochthonous. At least three climates are distinguished in the region, however, the rainfall is similar between them: from June to September. Dry periods are intensified in the spring (CSMN 2012). Lerma-Chapala basin is notorious for its pollution, but the water quality has demonstrated considerable improvement in recent years due mostly through massive upgrading projects of sanitation works.

2. The Pánuco River is a 510 km-long river in central Mexico that begins in Moctezuma river system close to the Anahuac Basin at an altitude over 2000 m above MSL, and ends where it empties into Gulf of México (0 m above MSL), but only the last 15 km is navigable for larger ships (INEGI 2004). The river has a flow towards the northeastern Mexico. The basin is exoreic allochthonous. The greatest rainfall is from June to September. Dry periods are intensified in the spring (CSMN 2012). This basin is probably the most polluted basin in Mexico.

3. The Anahuac basin is a closed basin which geologically divides into three hydrologic zones, the low plain, which is essentially the bed of now practically extinct five former lakes; the piedmont area and the surrounding mountains (San Román et al. 2013). The old lakebeds correspond to the lowest elevations of the valley in the south are mostly clay with a high water content and are almost entirely covered by urban development. In the piedmont area, these clays become mixed with silts and sands, and in some areas close to the mountains, the piedmont is largely composed of basalts from old lava flows. The valley is enclosed completely by mountain ranges, from which flow rain and melting snow into the valley's hydraulic system. This groundwater flow produces a number of springs in the foothills and upwelling's in the valley floor.

Table 1. General statistical of watersheds of central Mexico considered in this regional study.

Hydrological Basin	Administrative Region ¹	Mainland Surface Area (km ²) ²	Renewable Water Resources (km ³) ²	Population in December 2008 ³	Annual Rain-fall (mm) ⁴	Basin type
Anáhuac*	XIII	18,110	3,515	21,815,315	606	Endorheic autochthonous
Lerma-Chapala	VIII	47,116	4,742	22,326,511	816	Endorheic allochthonous
Moctezuma-Pánuco System	IX	84,956	20,330	4,982,167	914	Exorheic allochthonous

* Anáhuac Basin is considered by National Water Commission like Waters of the Valley of Mexicooa.

¹ CONAGUA (2011); ² CONAGUA (2012); ³ INEGI (2011); ⁴ CSMN (2000).

^a In this work I prefer to call the basin by its original name for two reasons, the first is obvious, its original name is Anahuac and has a prehispanic meaning that marked the ideology of a people. And second, call Valley of Mexico has brought confusion on how to manage their water resources. And this confusion has made the basin to be managed as a valley, or at most, as a exorheic basin, regardless of whether it really is a geologically young volcanic closed basin, home to a large lake divided into different sections by salinity. For more information see Gutiérrez-Yurrita and López (2009).



Figure 1. Area of study. Principal basins of the Central Mexico. Black lines mark the boundaries among watersheds, while the gray lines represent the major rivers in each basin. The circles represent sites where the largest cities in the region are located: 1) México City; 2) Querétaro; 3) Tampico.

It is important to mention that every year, two estimations are carried out of droughts in North America, as part of the “North American Drought Monitor” (NADM) project. For the first estimation, corresponding to the end of the dry season, in May 2008 the drought

conditions in the Central Mexico prevailed abnormally dry conditions (D0) to drought extreme (D3). But more importantly it is to say that in the second measurement, taken at the end of the rain season (October) extreme drought increased considerable in the entire region.

This region is in the junction of the Nearctic and Neotropical Biogeographical regions, including four physiographical provinces: Neovolcanic axis, the Central Plateau (Bajío), Sierra Madre Oriental and Sierra Madre Occidental. Because of the high variation in altitude (0 to +5000masl) and the three climates identified (warm, dry, temperate), the following types of vegetation are found in this area: desert scrub, thorn woodlands, pine forest, oak forest, temperate hardwood forest, low tropical deciduous forest and agricultural lands. Many aquatic fauna and macrophytes naturally inhabit shallow, clear, running waters, riffles areas of the streams with no pollution, or not greatly altered by man. Riparian vegetation, rocks, pebbles and cobbles are of considerable importance for invertebrate survival, because during the night, they rest and look for food within macrophyte mass and roots, and inside the great amount of debris deposited in river or stream pools. During the day, aquatic insects hide under the rocks (Gutiérrez-Yurrita et al. 2002, Hurtado et al. 2005, Zambrano et al. 2013, Alcocer-Durand and Bernal 2010, Gutiérrez-Yurrita et al. 2013).

Middle sized rivers and small springs are the most exploited resources for touristic and productive activities, however, there are relative few works concerning their ecological functioning (Gutiérrez-Yurrita et al. 2012). Practically all-aquatic systems are subject to wide variations in flow, due to seasonal weather in the region. Physicochemical of many water bodies ranged from 20 to 28°C; 8 to 12 mg L⁻¹ of oxygen; pH from 7 to 8, total hardness ranges from 90-350 mg CaCO₃ L⁻¹ (Gutiérrez-Yurrita et al. 2002). The ecological importance of this region can be seen in the large number of new species discovered to science of aquatic macroinvertebrates in recent years. Terrestrial habitats, mammals and birds are better studied and a very good synthesis can be found in Gutiérrez-Yurrita and Padilla (2004). Major animal community is comprised by benthonic macroinvertebrates (*Macrobrachium carcinus*, *Macrobrachium olfersi*, *Laccophilus* sp., *Tropisternus* sp., Tricoptera, Heteroptera, Notonecta, Diptera – Culicidae and Chironomidae- (Hurtado et al. 2005), and larvae of Odonata (species of *Hetaerina*, *Anax*, *Aeshna*, and *Libellula*) (Alonso et al. 2002); the zooplankton community is assembled by *Daphnia*, Copepoda and Amphipoda; the most representative fish species are *Poecilia mexicana*, *Heterandria bimaculata*, *Goodea atripinis* and *Astyanax mexicanus* (Gutiérrez-Yurrita et al. 2013). Vegetation that surrounds the rivers are mainly gallery woods (*Taxodium mucronatum*), pines and oaks in the springs, and banana, mango and peach trees in

plantations (canyon's low lands); though hydrophytes are scarce in several places, *Aster subulatus*, *Cyperus flavescens*, *Cyperus niger*, *Typha latifolia* are the most representatives of the highland streams. The exotic macrophytes such *Eichhornia crassipes*, *Egeria densa* and *Lemna gibba* are the most abundant in slow-flowing rivers; *Lemna aequinoctialis*, *Polygonum lapathifolium*, *Bacopa procumbens*, *Bacopa monnieri*, *Hydrocotyle verticulata*, *Eleocharis macrostachya*, *Najas guadalupensis* and *Potamogeton diversifolius* are other macrophytes present in many aquatic systems of the SGBR (García-Trejo et al. 2013, Gutiérrez-Yurrita et al. 2013).

CONCEPTUAL FRAMEWORK

Estimation of environmental flows - a hot topic being discussed by hydraulic engineers, ecologists, planners and politicians, but far from being resolved, is practically in its beginnings of development. The lack of good predictive models is because they are constantly modifying management paradigms of nature, the way in which policy is made and how the ecosystem functioning is conceived. And now the human rights component, specifically speaking of the right to an environment adequate for its development, access to information, the right to take part in decision-making and access to justice is integrated. Thus, the paradigm of integrated watershed management, widely used in the early 1990's, is now almost obsolete to make way for holistic paradigm. This study is not intended as an exhaustive list of all the methods used to calculate environmental flows or minimum flows that would be the subject of a review article. I will only mention the most used models currently worldwide. However, it is important to note that many models, old or new ones, are taking into account seasonality, hydroperiod and water regime of rivers (Gore and Pettts 1989, Stalnaker et al. 1995, Tennant 1976, Poff et al. 1997, Richter et al. 1997, Bovee et al. 1998, García et al. 1999, King et al. 2000, Arthington et al. 2006, Tharme 2003, García de Jalón and González del Tánago 2004, González del Tánago and García de Jalón 2006, Arthington et al. 2006, NMX-AA-159-SCFI-2012). And that some newest approaches are considering of great importance the economic factors to make any political decision, so those models contemplate the Discounted Cash Flow analysis to value a management Project when urban and/or agriculture water systems are involved (Deng et al. 2013) Therefore, the model I propose in this work is entirely new.

The Official Mexican Standard (NOM-011-CNA-2000) published in 2002 deals with Conservation of Water Resources but only states that there are some specifications to determine the ecological flows of national rivers. Unfortunately, because no methods were established, its second transitory article states that the minimum flows are known by an unofficial standard or by studies done by individuals. Thus, it is unclear which method should be used or what variables to take into account when setting minimum flows in a given river. Thus the Mexican standard that establishes the methodology for calculating the minimum river flow is elaborated (this rule is not official) in 2012, called Mexican Standard NMX-AA-159-SCFI-2012. This rule proposes three ways of measuring environmental flows, one called hydrobiological which is what counts in a way aquatic wildlife in hydraulic systems to manage (Bovee et al. 1998). A second way is the conventional method to set the minimum and maximum flows, emerge from the methodology of Tennant (1976). And while the third form contemplates that there may be a holistic method draws on the work of King et al. (2000), which is good, but complex to follow and therefore impractical for quick decision-making with a degree of precision.

HOLISTIC PERSPECTIVE

Holistic perspective to the study of natural systems is the modern way of addressing environmental problems in the management of natural resources in a specific landscape. This approach integrates all relevant information on the socio-economic users of the resources of a watershed, with information gathered from the ecological processes of the ecosystems involved in the operation of the landscape (Savory 2005). It is worth noting two things respect to this approach that make it different from other similar approaches (consilience, integrative basin management or ecosystemic planning): (a) to take special attention on the phenology of rainfall and the monthly mean humidity of the area, and (b) to use the knowledge of all the sciences that relate to nature and man, including politics and economics specific to the study area, but does not a synthesis of this knowledge (Smuts 1966, Wilson 1999, Savory 2005, Gutiérrez-Yurrita 2009). In other words, integrates without scientific reductionism knowledge of different sciences. This paradigm of gathering knowledge is able to analyze complex systems, such as planning in landscapes networking, under different perspectives in a systematic way simultaneously (Margules and Sarkar 2009). It is

understood, then, that a hydrological basin is a complex system considered like the basic unit of operation, where the interactions between water, earth, air and human activities –technology included- are very tight and dependent on each other (Gutiérrez-Yurrita 2009).

THE MATHEMATICAL MODEL

The mathematical model generated meets five conditions simultaneously:

1. Must have high degree of accuracy;
2. Variables must be easily measured;
3. Efficiency indicators must be measurable along the time;
4. Indicators have to be cost effectively; and
5. Indicators have to be socio-economical relevant.

High degree of accuracy means that the variables taken into account serve as indicators of system diagnosis, effectiveness of control measures and management and, to predict future scenarios following the same trend of uses and intensity of uses.

For holistic studies provide a basis for decision-making, it is necessary to overcome three major challenges in the same political decision: State development policy, social and environmental issues.

1. *State development policy*: Public administration has a direct interference in development by its territorial planning strategies. And the concept of environmental justice, which is different from social justice, although they are closely related. Eco-justice is distributive in character and that should not bear the entire burden of environmental conservation the inhabitant of the areas preserved or peasants with limited resources (Martínez 2004).
2. *Social issues*: Large bodies of epicontinental water built in Mexico (big dams) and the regulation of riverbeds of Central Mexico, are used for various purposes, the most important are: drinking water supply; irrigation; industrial; power generation; public services; and finally, preservation of environmental flows (Article 41 of the National Water Act, amended on 29/04/2004).
3. *Environmental issues*: Conservation of the ecological processes of ecosystems from the hydrological basins under the pressure that involve the extractive or transformative activities. Both issues overlapping like complex systems. They are not aggregated into a system unit (integration) but rather which are systems with

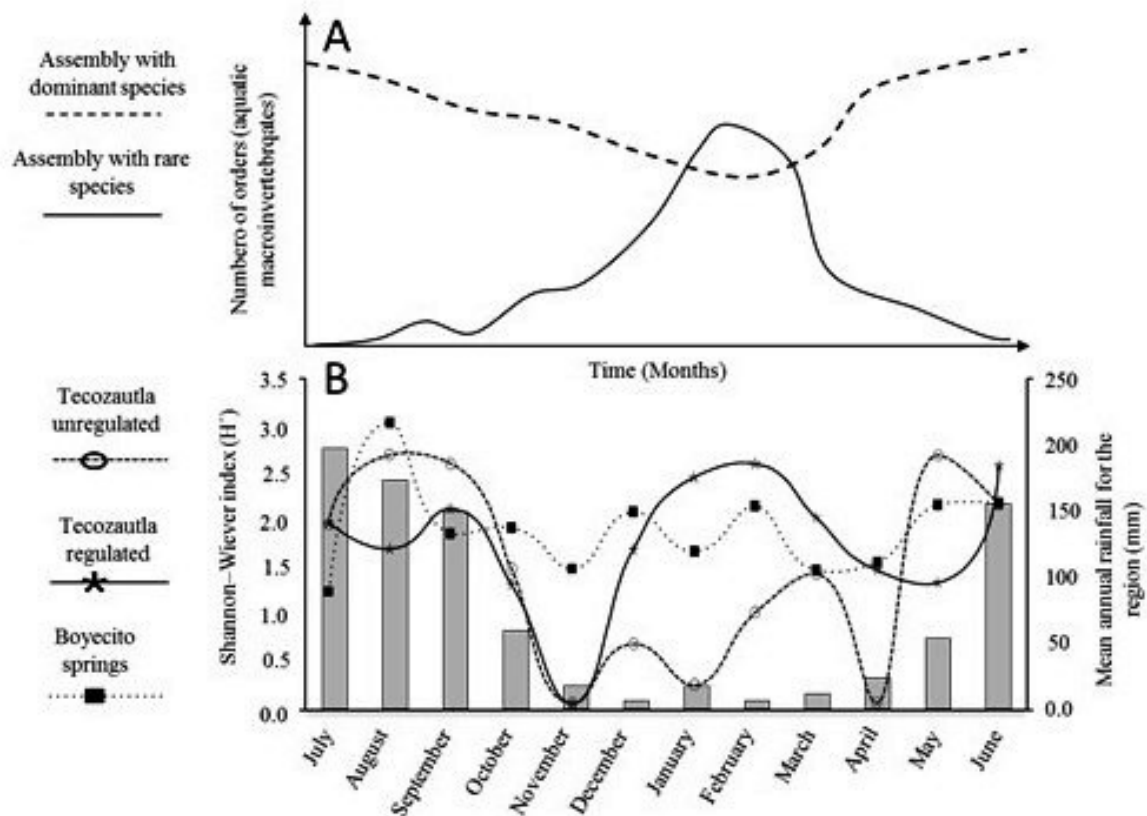


Figure 2. Taxonomic seasonal distribution of aquatic animals respect to the hydrological regime in regulated and unregulated aquatic systems. Boyecito is permanent water systems while Tecozautla is a highly seasonal aquatic system. Data were taken from the work of Hurtado et al. (2005). Hypothetical general curves show how both the dominant and rare species are two fundamental components of a system. The interpretation is based on a collection of 18,809 individuals belonging to 22 orders of macroinvertebrates in aquatic systems of Reserva Biosfera Sierra Gorda. The dominant orders were only 4: Diptera (25.9%), Hemiptera (18.9%); Ephemeroptera (16.3%) and Odonata (10%). Data were taken from Hurtado et al. (2005).

emergent properties at each hierarchical level of organization (Gutiérrez-Yurrita et al. 2014).

Under the holistic paradigm, the study of watersheds is built from two perspectives and two subjects. Perspectives because we have in essence two ways to see the world, the ecocentric and the anthropocentric: Ecocentric perspective is an idealized perspective of the nature functioning, because it must be analyzed in detail the structure and functioning of all ecosystems involved, particularly the seasonal river (analyze each section of the river by separately and together, and reservoirs), with all the existing anthropogenic modifications (natural and anthropogenic phenology). From this information, calculate the ecological flow that would ensure the integrity of ecological processes in the watershed. Anthropocentric perspective is the realistic one, because in no case should be questioned the priority uses of water resources, while respecting the principle of environmental services to be

implemented to manage aquatic environments and overall basin. Analyses should be made monthly because many aquatic systems show a marked seasonality in water regimes.

Under the Ecocentric perspective must be taken into consideration, at least the following factors (E):

1. Morphology and topography of the basin in general and the particular channel;
2. Monthly and daily weather (temperature and rainfall), taking into consideration relative humidity and sun hours every season.
3. Physicochemical characteristics of water and geology of the basin;
4. Average monthly flow rates or contributions of each river basin as well as the hydroperiods and water regime of each type of riverbed habitats (places with or without vegetation, vegetation types and substrates, rocks, pools, etc.);

5. Ecological characteristics of networked ecosystems: biological diversity, density, distribution, dispersal patterns, and organization among biological populations (ecosystem complexity).

By way of example, Figure 2B shows how there is a progression in the ecological assemblages of the present biological communities (Alonso et al. 2002). The seasonality of the system is a determining factor for a biological association becomes dominant in a given period (Gutiérrez-Yurrita et al. 2013). If this fluctuation is broken, changing the water flow of the river, the assembly can be lost at that time when it contained few individuals. And if that association had rare (less than 1% of all species in terms of relative abundance of individuals of the population), this species may become extinct or at least be endangered such as endemic and narrowly distributed crayfish, *Procambarus yagoii* (Gutiérrez-Yurrita et al. 2002). Figure 2B also shows how there is a considerable change in the Shannon-Wiener index (H') of aquatic macroinvertebrates in the river stretches impacted and non-impacted by man with seasonality, but only slight variations can observe in a permanent water body (Boyecito). In addition, a seasonal river varies greatly in abundance of aquatic macroinvertebrate orders before its regulation by building a dam, and how this abundance remains constant in section regulated as the river acts as a permanent one, losing seasonality and the natural flow (Hurtado et al. 2005).

Under the Anthropocentric perspective, we take into account factual indicators of socioeconomic status of users of the networked basins (A):

1. Benefits that would have for the management of water in the short, medium and long term;
2. Present and potential welfares to keep the water system and the natural or historical flow;
3. Consider a time series analysis of the uses of basin water resources, in intensity and weekly amount;
4. Estimate the efficiency and effectiveness in the present form of using water resources of the region;
5. The invasion of introduced species in rivers is facilitated by the alteration of flow regimes, so we need to estimate ecological impact of exotics in the basin in order to stop or to reduce inter-watershed transfers.

The issue of invasive species is of particular importance in the anthropocentric perspective. Man has always loved to travel with their pets, favorite foods and recollections of their origin. Human migrations have been responsible for expanding the distribution of many species of plants and animals outside their normal distribution range. Currently the most successful introductions are being made deliberately, preparing

natural systems so they can welcome the invaders. Clearly, the species to be introduced must have certain characteristics to adapt quickly to their new habitat. If not met these two conditions is failed introduction. One of the most representative examples of environmental damage that can produce an introduced species, is the crayfish *Procambarus clarkii*, shipped with aquaculture purposes from Louisiana to southern Spain in 1972 (Gutiérrez-Yurrita et al. 1998). Figure 3 shows how *P. clarkii* is a key species in the functioning of the freshwater marsh in DNP because this species controls the major routes of energy flow. *P. clarkii* has also been demonstrated that it is an engineer species of the ecosystem, physically transforming its environment and altering the availability of resources for other species. These changes have been achieved principally by structural modification of the freshwater systems (Correia et al. 2005). The crayfish bring this about by reducing or totally eliminating the aquatic macrophyte beds (Ilhéu et al. 2007). The most important ecological consequence of the reduced aquatic vegetation cover is the enriching of the water column with nutrients, which favor the development of phytoplankton communities, changing the ecological balance from fresh to turbid water (Gutiérrez-Yurrita et al. 1999).

Hydrological Subject (H):

1. *Water regime*: the way in which the system filled with water up to the maximum annual average;
2. *Hydro period*: the rate at which water fills the system, the retention time and the time of loss of water until the system returns to the minimum flow;
3. *Extreme water flows* (both minimum and maximum): Extreme minimum water flow can occur in drought. Extreme maximum water can occur during periods of extreme rainfall. These extreme events include catastrophic rains (storms, flooding's) or severe drought;
4. *Estimating temporal pulse of total water recharge system*: Estimating temporal pulse total water recharge system. The duration of the events (rain or drought) are determining factors in understanding ecological processes of seasonal rivers, their watersheds cross (influence of the riverbanks) and longitudinal (along the riverbed). These events in the seasonal rivers are responsible for the biological richness of the system.
5. *Influence of artificial water bodies*: dams, reservoirs, ponds, water retention and channeling of rivers, ostensibly alter the natural hydrology of the rivers, especially

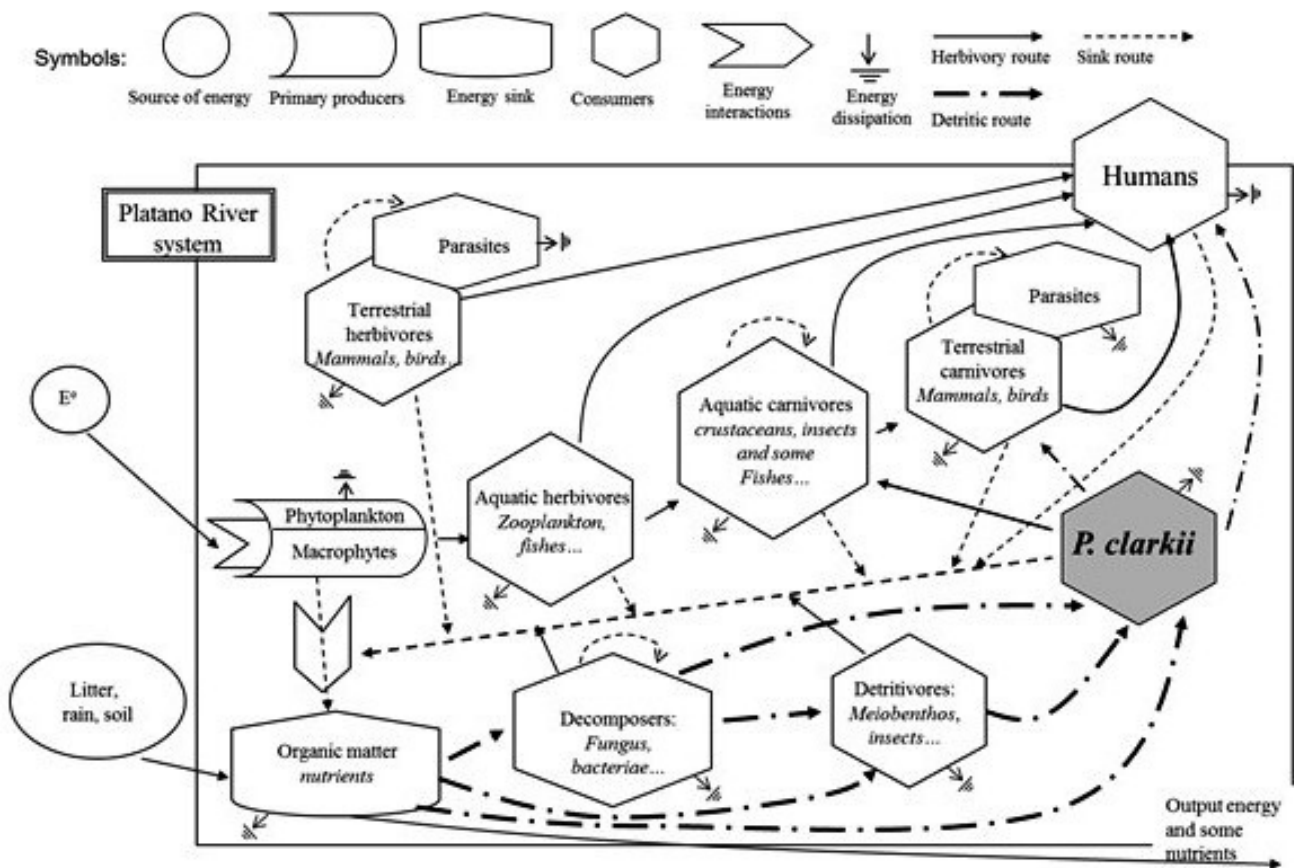


Figure 3. Overall functioning of a shallow water system, when it is invaded by a key and engineer species controlling the ecological functioning. Before the invasion of crayfish, the ecological balance of the system was clear water. Crayfish affected the biomass of aquatic macrophytes allowing greater light penetration and wind action, suspending nutrients in the water and favoring the growth of phytoplankton and algae. The result is a balance of turbid water.

the hydroperiods of seasonal rivers, because most of the time the human management of these water bodies is propitious than ever to dry out the system.

Managing a system that is repeatedly affected by extreme events is not easy, but not impossible. Figure 4 shows how change species richness of a keystone groups in the functioning of the ecosystem along time but they do keep an ecological pattern. These guilds could be used to predict how extreme variations in river flow affect the ecological processes that maintain its functioning.

Integrative Subject to Develop a Simple Mathematical Model (Is):

Because the model for decision-making should be operated by technicians or users with little or no schooling, this should be as simple as possible to deliver

them in a excel sheet, where users just have to input data (data must also be fast tracking from themselves) and get results via computer or calculator. It will have a holistic flow each month. The methodology is divided into five steps:

- 1) We have to divide the river into reaches. A reach of the river is the area of the river that has different characteristics clearly marked with the adjacent top and bottom. The river is considered as a continuum gradient of ecological conditions (physical, biochemical, biological and entropy gain, for instance), where the water goes down is a consequence of what has occurred upstream, thus the biological organization in the rivers conforms structurally and functionally to kinetic energy dissipation patterns of the entire system (Vannote et al. 1980). Rivers could be divided into three reaches:

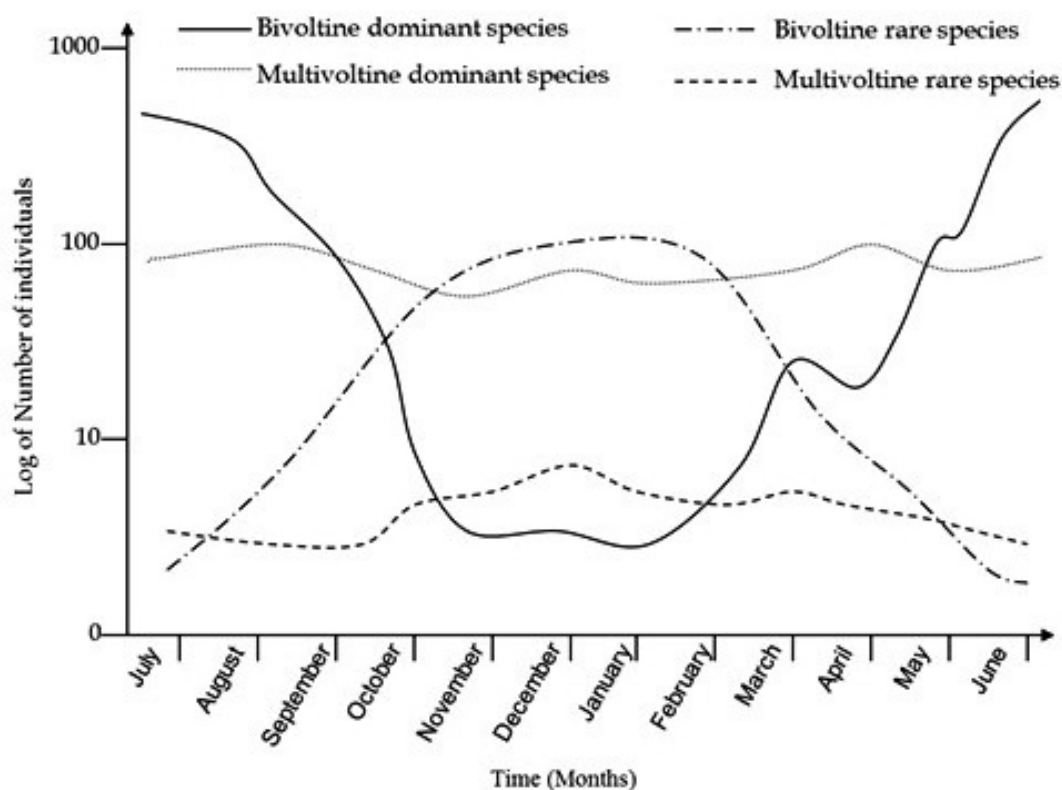


Figure 4. General model of the main factors that influence Odonata diversity in Moctezuma River System. The model considers the synergistic effects of the integration of human impacts with recurrent natural phenomenon. Data were taken from the work of Alonso et al. (2002).

i. Headwater: Production system is less than ecosystemic metabolic processes ($P < R$)

ii. Medium-sized-stream: Production and ecosystemic metabolic processes of the system are equal ($P = R$)

iii. Large-rivers: Production is greater than the ecosystemic metabolic processes ($P > R$)

where P is the total production of the reach and R is the total ecosystemic metabolic processes of the reach. The head is dominated by autogenic biomass while mouth is dominated by allochthonous biomass.

2) We must consider that the river may have regulated sections and unregulated sections. But, stability of the river ecosystem may be viewed as a tendency for reduced fluctuations in energy flow, while community structure and function are maintained in the face of environmental variations including small or huge human impacts, such as big dam. The unregulated sections should be used as units of measurement of mean monthly flows estimated contributions from natural runoff, with a value of probability of occurrence of a given event. In the sections regulated is taken into account the amount of water used for each of anthropocentric activities that

poured through the gates of the reservoirs. These flows should be estimated in each part of the river located between two controlled reservoirs.

3) The third step is an ecological and socioeconomic assessment of the basin under management. The ecological assessment emerges from the scientific characterization of the ecological structure and functioning (natural resources and environmental services). Among all the factors are especially important to consider the hydroperiod and biological communities (macro-invertebrates, fishes and macrophytes). The first is because it will indicate the amount of water and the speed of the current should carry the channel at each weather season. The second is since the community structure and composition of these populations remain more stable over time, especially with constant flow seasonally.

4) Within the economic and social assessment must take into account the current and potential uses of all resources of the basin, and the services to be offered in case the system is keeping unchanged its natural

(unregulated). By establishing a natural resources asset class, is in a position to be accounted for as assets inexpensive produced products, for which, it must be assigned monetary values (prices, production costs, costs of depletion and degradation, etc.), in order to integrate the other cash flows of the economy and to calculate the domestic raw product.

The following equation represents a simple linear model (do not take into account the weighting factors because it is a model to help people not expert in mathematics, to make social and environmental decisions; complicate the model) only makes it more understandable to the non-expert people who must to apply it:

$$IS_{t+1} = IS_t + (1_t \Delta_{IS_{peat}}) - (D_{ISn-peat} + D_{ISn-penvat} + G_{ISaenvn-pt}) + (\Delta I_{ISn-peat} + \Delta I_{ISn-penvat}) + (R_{IS_{eat}} + R_{ISn-peat} + R_{ISenvan-pt}) \quad (eq. 1)$$

where:

IS_{t+1} = total assets at the end of the period;

t = time;

I_t = total non-produced environmental assets;

IS_t = total assets at the beginning of the period;

$\Delta_{IS_{peat}}$ = change in produced economic assets;

$D_{ISn-peat}$ = depletion of non-produced economic assets;

$D_{ISn-penvat}$ = depletion of non-produced environmental assets;

$G_{ISaenvn-pt}$ = degradation of assets environmental non-produced;

$\Delta I_{ISn-peat}$ = change in non-produced economic assets;

$\Delta I_{ISn-penvat}$ = change in non-produced environmental assets;

$R_{IS_{eat}}$ = re-valuation of economic assets;

$R_{ISn-peat}$ = re-valuation of non-produced economic assets;

$R_{ISenvan-pt}$ = re-valuation of environmental assets not produced.

D is depletion;

G is degradation;

R is Re-valuation.

5) What is needed at this moment is to assign monetary value (price) to each non-produced assets (natural resources) involved in the above equation, for which there are basically three methods: the Net Income Method (NIM), the User Cost Method (UCM) and the Discounted Cash Flow Analysis (DCFA) (Prado 1997, Deng et al. 2013). The NIM value units are based on the difference between income, with the current market value of the estimated inflation rate by the Bank of México (or any central bank that could be used as a national or international reference), and total costs of

resource use. The UCM assesses the application based on the cost of exhaustion, which is estimated as a part of the present value of expected net income over the lifetime of the resource. The DCFA is a method of valuing any asset using the concepts of the time value of money in order to get the net present value of the asset, which is taken as the value or price of the cash flows in question.

The analysis of the perspectives (ecocentric and anthropocentric) and the subject of hydrological, results in a value on a scale from zero to ten in each. All of the five features that are assessed in each perspective and subject have three options of values: 0, 1 and 2. Zero indicates that the system or variable is totally damaged, misused or abused to the maximum, while the value of two indicates exactly the opposite, the variable is in good condition, preserved and in their natural state. The sum of each value is the final value of the perspective or subject analyzed. These final values are summed to give a Global Environmental Value (GEV) that represents the ecological status of ecosystems under exploitation:

$$GEV_{t+1} = (E_1 + E_2 + E_3 + E_4 + E_5) + (A_1 + A_2 + A_3 + A_4 + A_5) + (H_1 + H_2 + H_3 + H_4 + H_5) \quad (eq. 2)$$

Finally, the two subsystems are integrated to have the bottom line of the monthly management. The decision must come from comparing bottom lines of at least three integrations. The first taking into account that in managing a flow with minimum monthly flows, other ecological and economic elements are modified, usually decreases or eliminating altogether, as the final production of natural resources and produced changes. Estimating the maximum flow rates achieved for that month, which would bring the economic system to have the same or more products obtain another balance, i.e. more water use does not necessarily lead to more production in a given season. The third balance is obtained by considering environmental conditions closer to the natural average month. Monthly Final Balance (MFB):

$$\begin{aligned} MFB_1 &= IS_1 + GEV_1; \\ MFB_2 &= IS_2 + GEV_2; \\ MFB_3 &= IS_3 + GEV_3 \end{aligned} \quad (eq. 3)$$

An illustrative example of how it can be used in holistic management to discern what may be the best choice to manage natural resources in a way that is most appropriate for regional development and conservation of the

ecological functioning of seasonal rivers, is shown in Figure 5. This figure shows the production of benefits to both consumptive use (i.e.: water for irrigation) and non-consumptive use (i.e.: contemplation) and quasi-option values (bequest value, existence value, support and value option value) that ultimately are willing to pay. Finally, in response to all types of benefits and costs of the option is not taken as a result of a decision, one should make an assessment of recovery of the affected ecosystems, whether real or potential. Figure 5 shows a proposal of major events that may occur to determine the size classes' structure of *P. clarkii* populations in Doñana National Park freshwater marsh (Gutiérrez-Yurrita in prep.). This crayfish was introduced deliberately into freshwater marsh ecosystems in southern Spain almost 40 years ago. And has totally changed the shallow water balance of many aquatic systems in the Park (Gutiérrez-Yurrita et al. 2009) as was shown in Figure 3. This fishing device would reduce some pressure factors dependent of the density of the population for growing populations, and hence, homogenize population growth by promoting the growth of individuals of slower rates (adults), reaching larger sizes at the reproductive period. By this way, the Holistic perception to manage Doñana National Park must include, in an integrated policy, the emergent characteristics of this complex systems, not only the three great themes (economic, social and environmental), but perspectives of how to get benefits from an undesirable situation. Only in this approach we

can assure conservation policies in an area very crowded by tourists, fishermen, peasants and pilgrims to the biggest religious fest in Spain, the Rocío.

The two basic subjects for estimating environmental flows are more technical than theoretical, as were the perspectives presented: Hydrological and integrative. We have chosen these issues to combine different aspects of the physiography, ecology and natural resources of the watershed and man's relationship with it.

DISCUSSION

To resolve the conflict between conserving a natural resource and develop a community (rural or urban) should be viewed in a holistic perspective. Holistic approach to manage any natural or man-managed landscape is a new way to understanding that watershed is a multifunctional territory where the binomial forces "man-nature" do have to interact at different temporal-space scales, that means, we do have basins networked (Gutiérrez-Yurrita 2009, San Roman et al. 2013). The holistic paradigm often includes the view that systems somehow work as a whole and that their functioning cannot be fully understood solely in terms of their constituent parts (Ayuang 1999, Oshri 2008;). Territorial planning strategies allow us to determine other policies in order to get a holistic management of the central Mexican basins. Policies generated by this paradigm

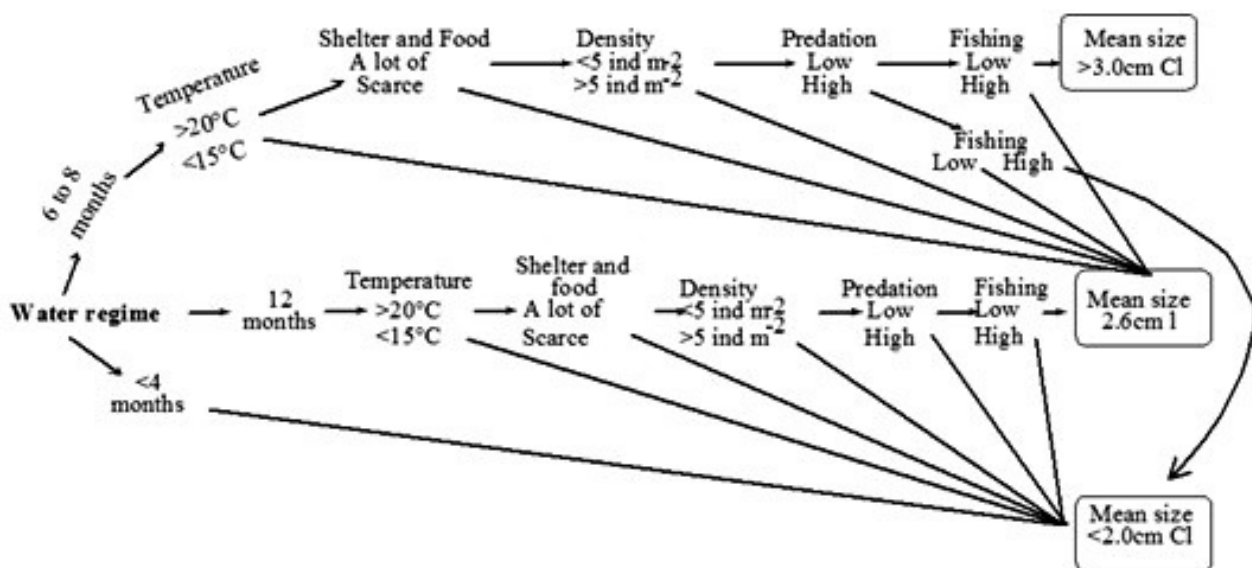


Figure 5. Proposal of major events that may occur to determine the size classes structure of *P. clarkii* populations in Doñana National Park freshwater marsh. (Data from Gutiérrez-Yurrita et al., 2014a).

concerning social aspects (farmers who traditionally use the water to irrigate fields with crops unsuitable for the region, fishermen and other locals that use to poach to survive or to improve their profits, peasants who "steal their own water" and used without current technological advances and unprofitable crops, but with high cultural level, for instance); environmental services (conservation of natural areas can help us improve the already degraded environmental services and stop the deterioration of the ecosystem functions of landscape); and economic and technological issues (an integrative watershed program may enable us to diversify production options in the context of conservation biology) could be the reflection of a well-planned management strategy to the park (Gutiérrez-Yurrita et al. 2014).

All kinds of watershed management models, developed previously to the one I propose in this paper, are based, to a greater or lesser degree, on anthropocentric, utilitarian and immediateness criteria. In some programs the holistic planning is confused with the conciliant and the integrated river basin management, but really do not handle this perspective. The long-term studies and those contemplating seasonality, water regime, relative humidity and hydroperiod are absent. If humans have regulated all rivers, such as in the Central Mexico, it is impossible to have an environmental flow management without considering these factors, as well as the changing needs of the population (Gutiérrez-Yurrita 2011). Management must therefore be dynamic (Muñoz et al. 2013).

Mexican standard setting the minimum flows in Mexico is unique (NMX-AA-159-SCFI-2012), no international counterpart does exist. However, the holistic aspect that handles the model is very complicated to be used as a mathematical model on a daily basis. It has no way to quickly assess the efficacy of management, and the effectiveness of the measures taken. It is also very difficult to measure. The model I have developed presents diagnostic and control indicators easy to measures, which immediately tell us how the system behaves. And the mathematical procedure used, a linear regression by separate and specific steps, makes it easily applicable.

In Mexico, the regulation states that private persons may build their own studies to establish environmental flows; however, so far, studies have been ending to establish the country's watersheds very generally, have not yet been able to establish ecological flows anywhere. Possibly, as explained before, due to the complicated methodology proposed in the Mexican Standard NMX-AA-159-SCFI-2012 and, maybe because of the lack of

data to feed the model. In short, what we have in Mexico is not a model of environmental flows, but a functional characterization, eco-geographic basins of the country. From this point of view and following the functional criteria basins of central Mexico are classified into high and media altitude basin (Garrido et al. 2010). And from the eco-geographic classification, the vast majority of the basins of central Mexico belong to exoreic allochthonous distant type; only the Anáhuac basin is endorheic autochthonous by its height and high slope degree (Ortiz-Pérez 2010). The first classification although can be used for its simplicity, is so simple that it does not really give accurate information for making decisions about the distribution of water for various human activities and the amount of water that must be maintained to ensure the capacity of resilience of the affected ecosystems and its landscape ecological functionality. Meanwhile, the eco-geographical classification is useful since helps to understand that the management of the rivers of central Mexico should be done in a hierarchical manner, following spatial and temporal scales, as outlined in the ecosystemic management paradigm (Gutiérrez-Yurrita 2004). The eco-geographical approach and the bi-hydrological method recognize the heterogeneity of allochthonous landscapes in the watershed, especially in very large basins. Nevertheless as González del Tángano and García de Jalón (2006) pointed out these attributes define the morphology of basin, reflecting solely a static view of the watershed. River ecosystems are highly dynamic; differences in flow depend among other factors on weather spirals and human uses must be accounted for in the model, for its part, also recognized the importance of an endorheic basin in terms of homogeneity of the landscape and scale of action on it, in the sense that the work on a smaller scale, cartographically speaking, it is more sensitive and therefore vulnerable to human activities and environmental impacts. However, for the model to be functional in central Mexico must have a simple way of viewing extreme weather events such as drought in the region, especially at the end of the rainy season, repeatedly. A drought is becoming more pronounced by the possible climate change experienced to region (Gutiérrez-Yurrita et al. 2014).

The classifications of the basins of central Mexico, according to their level of priority for the conservation of biodiversity are classified utmost priority and high priority (Aguilar et al. 2010). These same categories are presented in terms of a classification by human impacts, being extreme in the Anáhuac and Lerma basins and high in Pánuco Basin (CONABIO 2009).

To sum up, the study of the ecology of keystone and invasive species is of great importance in understanding future events in the population dynamics of all ecological association in every ecosystem. These studies are also of the greatest importance in determining the final structure of the landscape and global ecological functioning of the networked basins that necessary must include migratory and reproductive behavior of species, etc., which to a certain extent determine the management strategy to be implemented. When there is an excessive increase in the density of certain species in a community and conditions are stressful, the growth of some species will be deficient; they will develop less and reach maturity without having attained the energy reserves and necessary size to leave offspring in optimal conditions. Something similar occurs when a resource is over-exploited. The strategy of survival of the affected species is reproduced to a size smaller than normal, which leads to more intensively use their habitat. The synergistic result is a disturbance of the ecological structure and a shift in the functioning of the system to be more intense some ecological processes. In all these changes the importance of doing studies at different scales of time and space, as noted previously is appreciated.

CONCLUSIONS

- A new and improved version of the socio-ecosystem holistic management of seasonal aquatic systems model has been presented.
- Social welfare is the main aspect to consider in the management of rivers, which must go hand in hand with the issue of economic development, and of course, overcoming poverty.
- The seasonality of rivers of central Mexico promote high biodiversity of the region, but also is the factor that makes it more vulnerable to its demise.
- Lack of holistic rural development plans, especially when they are the most affected ethnic communities, foster the exploitation of water resources.
- The model I have developed presents diagnostic and control indicators easy to measure, which immediately tell us how the system behaves as. And the mathematical procedure used, a linear regression by separate and specific steps, which makes it easily application.
- A holistic approach to the management of watersheds would be favorable since it allows the evaluation of a comprehensive policy management, which would include a more ample focus considering the social, economic and administrative sectors of complete landscape.

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REFERENCES

- Aguilar, V., Kolb, M., Koleff, P. and Urquiza, T. 2010. Las cuencas de México y su biodiversidad: Una visión integral de sus prioridades de conservación. In: Instituto de Ecología (Eds): Las cuencas hidrográficas de México: diagnóstico y priorización. Instituto de Ecología de México Press. México 142-153 pages.
- Alonso, P., González, E. and Gutiérrez-Yurrita, P. J. 2002. Listado y distribución de los odonatos de la Cuenca del Río Moctezuma, Centro-Occidente de México (Insecta: Odonata). *Folia Entomologica Mexicana* 41 (3): 347-357.
- Alcocer-Durand, J. and Bernal, F. 2010. Limnology in Mexico. *Hydrobiologia* 644: 15–68.
- Arthington, A.H., Tharme, R.E., Brizga, S.O., Pusey, B.J. and Kennard, M. J. 2004. Environmental Flow Assessment with Emphasis on Holistic Methodologies. In: Welcomme, R., Pret, T. (Eds): Sustaining Livelihoods and Biodiversity in the New Millennium. FAO, Bangkok, Thailand: , 37-65.
- Arthington, A.H., Bunn, S.E., Poff, N.L. and Naiman, R.J. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications* 16: 1311-1318.
- Auyang, S. 1999. Foundations of Complex-system Theories: in Economics, Evolutionary Biology, and Statistical Physics. Cambridge University Press. UK, 408 pages.
- Bovee, K.D., Lamb, B.L., Bartholow, J.M., Stalnaker, C.B., Taylor, J. and Henriksen, J. 1998. Stream Habitat Analysis Using the Instream Flow Incremental Methodology. Fort Collins, CO: U.S. Geological Survey-BRD. Information and Technology Report USGS/BRD/ITR-1998-0004. 245 pages.
- CONABIO -Comisión Nacional para el Conocimiento y Uso de la Biodiversidad- 2008. Capital natural de México, Vol. I: Conocimiento actual de la biodiversidad. CONABIO Press, México 158 pages.
- CONABIO -Comisión Nacional para el Conocimiento y Uso de la Biodiversidad- 2009. Capital natural de México, vol. II: Estado de conservación y tendencias de cambio. CONABIO Press, México 100 pages.
- CONAGUA –Comisión Nacional del Agua- 2011. Estadísticas Nacionales. Subdirección General de Programación, México. Available from: doi: <http://www.conagua.gob.mx>.
- CONAGUA –Comisión Nacional del Agua- 2012. Atlas digital del agua en México. CONAGUA, México. Available from: doi: <http://www.conagua.gob.mx/atlas/contexto07.html>.
- CSMN –Coordinación del Servicio Meteorológico Nacional- 2012.

- Estadísticas meteorológicas. México. Available from: doi: <http://www.conagua.gob.mx>.
- Correia, A.M.; Bandera, N. and Anastácio, P. 2005. Predator-prey interactions of , *Procambarus clarkii* , with aquatic macroinvertebrates in single and multiple prey systems. *Acta Oecologica* 28: 337-343.
- Cubillo, F.; Casado, C. and Castillo, V. 1990. Caudales ecológicos. Agencia de Medio Ambiente de Madrid, Madrid, España 220 pages.
- Deng, Y.; Cardin, M.A.; Babovic, V.; Santhanakrishnan, D.; Schmitterm P. and Meshgi, A. 2013. Valuing flexibilities in the design of urban water management systems. *Water Research* 47 (29): 7162-7174.
- Filella, M. 2014. Understanding what we are measuring: Standards and quantification of natural organic matter. *Water Research* 50 (March): 287-293.
- Füssel, H.H. 2007. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustainable Sciences* 2: 265-275.
- García de Jalón, D. and González del Tánago, M. 2004. El concepto de caudal ecológico y criterios para su aplicación en los ríos españoles. Departamento de Ingeniería Forestal, Escuela de Ingenieros de Montes, Universidad Politécnica de Madrid. Madrid, España s/n pages.
- García, E.; González, R.; Martínez, P.; Athala, J. and Paz, G. 1999. Guía de Aplicación de los Métodos de Cálculo de Caudales de Reserva Ecológicos en México. Comisión Nacional del Agua, Instituto Mexicano de Tecnología del Agua. México s/n pages.
- García-Trejo, F.; Hurtado-González, S.; Soto-Zarazúa, G.; Alatorre-Jácome, O. and Gutiérrez-Yurrita, P. J. 2013. Ecophysiological responses to the effect of annual management on an endemic viviparous fish in central plateau of México. *Neotropical Ichthyology* 11 (1): 117-123.
- Garrido, A.; Pérez, J. and Enríquez, C. 2010. Delimitación de las zonas funcionales de las cuencas hidrográficas de México. Pages 14-17, In: Instituto de Ecología (Editor), *Las cuencas hidrográficas de México: diagnóstico y priorización*. Instituto de Ecología de México Press, México.
- González del Tángano, M. and García de Jalón, D. 2006. Attributes for assessing the environmental quality of riparian zones. *Limnetica* 25 (1-2): 389-402.
- Gore, J.A. and Petts, G.E. 1989. Alternatives in regulated river management. CRC Press, Boca Raton, FL, USA. 130 pages.
- Gutiérrez-Yurrita, P.J. 2004. The use of the crayfish fauna in México: Past, Present...and future? *Freshwater Crayfish* 14: 45-51.
- Gutiérrez-Yurrita, P.J. 2009. ¡A diseñar el futuro! El Holismo de la Tercera Cultura: hacia la integración científica y cultura. Instituto Politécnico Nacional-Centro de Estudios Jurídico Ambientales Press, México. 250 pages.
- Gutiérrez-Yurrita, P.J. 2011. How to restore riverbanks in natural ecosystems with many people using ecological services at the same time? *Chemical and Engineering Applications* 23: 15-20.
- Gutiérrez-Yurrita, P.J. 2012. A reflection on the importance of estimating environmental flows in seasonal rivers. The case of rivers in Central Mexico. *Environmental, Energy and Biotechnology* 33: 55-59.
- Gutiérrez-Yurrita, P.J. 2014. A socio-economical perspective for a holistic management of temporary watersheds in Central Mexico based on a simple mathematical model for decision-makers. *International Journal of Natural Sciences and Research* 2(10): 206-226.
- Gutiérrez-Yurrita, P.J. and Padilla, U. 2004. Análisis sintético de la fauna queretana y estrategias para su gestión y preservación. Secretaría de Desarrollo Sustentable del Estado de Querétaro Press. México 180 pages.
- Gutiérrez-Yurrita, P.J. and López, M.A. 2011. Reflexiones iusambientalistas sobre los criterios para proponer espacios naturales protegidos: hacia una nueva categoría de conservación, el Paisaje metafísico (o espiritual). *Revista Aranzadi de Derecho Ambiental* 20 (2): 19-42.
- Gutiérrez-Yurrita, P.J.; Gorka, S.; Bravo, M.A.; Baltanás, A. and Montes, C. 1998. Natural diet of the red swamp crayfish , *Procambarus clarkii* , in the Doñana National Park freshwater marsh (SW-Spain). *Journal of Crustacean Biology* 8 (1): 120-127.
- Gutiérrez-Yurrita, P.J.; Martínez, J.M.; Ilhéu, M.; Bravo, M.A.; Bernardo, J. and Montes, C. 1999. The status of crayfish populations in Spain and Portugal. Pages 161-192, In: Gherardi, F. and Holdich, D.M. (Editors) *Crayfish in Europe as Alien Species: How to Make the Best of a Bad Situation?* Crustacean Issues. Balkema, Rotterdam/Brookfield. UK.
- Gutiérrez-Yurrita, P.J.; Morales-Ortiz, J.A.; Oviedo, A. and Ramírez-Pérez, C. 2002. Distribution, spread, habitat characterization and conservation of the crayfish species (Cambaridae) in Querétaro (Central México). *Freshwater Crayfish* 13: 288-297.
- Gutiérrez-Yurrita, P.J.; García-Serrano, L. and Rebollar-Plata, M. 2012. Is ecotourism a viable option to generate wealth in brittle environments? A reflection on the case of the Sierra Gorda Biosphere Reserve, México. *Transactions on Ecology and the Environment* 161(V): 141-151.
- Gutiérrez-Yurrita, P.J.; Morales-Ortiz, J.A. and Marín-García, L. 2013. Diversidad, distribución y estrategias de conservación de la ictiofauna de la Cuenca del Río Moctezuma, Centro de México. *Limnetica* 32 (2): 215-228.
- Gutiérrez-Yurrita, P.J.; Ortega, A.; Álvarez, A.; García, L. and Rebollar, M. 2014. The holistic management of the landscape of ethnic communities will reduce climate change and promote its sustainability. *International Journal of Environmental Sciences and Development* 5(3):317-323.
- Hurtado, S.; García-Trejo, F. and Gutiérrez-Yurrita, P. J. 2005. Importancia Ecológica De Los Macroinvertebrados Bentónicos de la Subcuenca del Río San Juan, Querétaro, México. *Folia Entomologica Mexicana* 44 (3): 271-286.
- Ilhéu, M.; Bernardo, J.M. and Fernandes, S. 2007. Predation of invasive crayfish on aquatic vertebrates: the effect of *Procambarus clarkii* on fish assemblages in Mediterranean temporary streams. Pages 543-558, In: Gherardi, F. (Editor) *Biological Invaders in Inland Waters: Profiles, Distributions and Threats*. Springer Series in Invasion Ecology 29. Springer, Dordrecht.
- INEGI –Instituto Nacional de Estadística, Geografía e Informática- 2011. Marco Geoestadístico, Versión 5.0. 2011. Available from: doi: <http://www.inegi.org.mx/est/contenidos>.

- INEGI –Instituto Nacional de Estadística, Geografía e Informática- 2004. Sistema nacional de Información Estadística y Geográfica. «Vertiente y principales ríos - longitud - periodo de observación - 2004 - nacional». Available from: doi: <http://www.inegi.org.mx/est/contenidos/espanol/rutinas/ept.a.sp?t=mamb95&s=est&c=8486>.
- King, J.M.; Tharme, R.E. and de Villeers, M.S. 2000. Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Water Research Commission Report No.: TT 131/00. Freshwater Research Unit, University of Cape Town, South Africa. s/n pages.
- Margules, Ch. and Sarkar, S. 2009. Planeación Sistemática de la Conservación. Cambridge University Press-CONABIO. México. 350 pages.
- Martínez, J. 2004. Los conflictos ecológico-distributivos y los indicadores de sustentabilidad. Revista Iberoamericana de Economía y Ecología 1: 21-30.
- National Water Act (Ley de Aguas Nacionales). Published in 1992; amended in 29/04/2004. s/n pages.
- Muñoz, E.; Arumí, J.L. and Rivera, D. 2013. Watersheds are not static: Implications of climate variability and hydrologic dynamics in modeling. Bosque 34 (1): 7-11.
- NMX-AA-159-SCFI-2012 Mexican standard that establishes the procedure for determining the ecological flow in watersheds. Official Journal of the Federation, August 2012. s/n pages.
- Norma Oficial Mexicana NOM-011-CNA-2000, published in 2002 s/n pages.
- Ortiz-Pérez, M. 2010. Clasificación ecogeográfica de las cuencas hidrográficas: el caso de México. Pages 22-25, In: Instituto de Ecología (Editor), Las cuencas hidrográficas de México: diagnóstico y priorización. Instituto de Ecología de México Press, México.
- Oshry, B. 2008. Seeing Systems: Unlocking the Mysteries of Organizational Life. Berrett-Koehler Pub. UK. 469 pages.
- Poff, N.L.; Allan, J.D.; Bain, M.B.; Karr, J.R.; Prestegard, K.L.; Richter, B.; Sparks, R. and Stromberg, J. , 1997. The natural flow regime: a new paradigm for riverine conservation and restoration. BioScience 47: 769-784.
- Prado, J.A. 1997. Economía ambiental y su aplicación en la gestión de cuencas hidrográficas. ICONAF, ERM, DFID. Chile s/n pages.
- Richter, B.D.; Baumgartner, J.V.; Wigington, R. and Braun, D.P. 1997. How much water does a river need? Freshwater Biology 37: 231-249.
- San Román, J.; Marín-García, L.; Muñoz, P.; López, M.A. and Gutiérrez-Yurrita, P. J. 2013. Ecological considerations for the management of a protected area with a strong urban pressure: the case of Lake Texcoco, México. International Journal of Ecology and Environmental Sciences 39 (1): 26-37.
- Savory, A. 2005. Manejo holístico. Un nuevo marco metodológico para la toma de decisiones. SEMARNAT. México 540 pages.
- Smuts, J.C. 1966. Holism and evolution. The Gestalt Journal Press, USA. 358 pages.
- Stalnaker, C.; Lamb, B.; Henriksen, J.; Bovee, K. and Bartlow, J. 1995. The Instream Flow Incremental Methodology. A Primer for IFIM. US Department of Interior National Biological Service, Washington D.C. n/n pages.
- Tennant, D.L. 1976. Instream flow regimens for fish, wildlife, recreation and related environmental resources. Proceedings on Stream Flow Needs Symposium. Billings, USA: 359-373.
- Tharme, R.E. 2003. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19: 397-441.
- Trabucchi, M.; Ntshotsho, P.; O'Farrell, P. and Comín, F.A. 2012. Ecosystem service trends in basin-scale restoration initiatives: A review. Journal of Environmental Management 111: 18-23.
- Vannote, R.L.; Minshall, G.W. and Cummins, K.W. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.
- Wilson, E.O. 1999. Conciliencia. La unificación del conocimiento. Círculo de Lectores, España. 560 pages.
- WWF –World Wildlife Foundation- 2013. Available from: doi: http://wwf.panda.org/about_our_earth/about_freshwater/river_s/irbm/.
- Zambrano, L.; Contreras, V.; Mazari-Hiriart, M. and Zarco-Arista, A. 2009. Spatial heterogeneity of water quality in a highly degraded tropical freshwater ecosystem. Environmental Management 43: 249-263.

Acronyms used

- Integrated River Basin Management (IRBM)
 World Wildlife Foundation (WWF)
 North American Drought Monitor (NADM)
 Official Mexican Standard (NOM in Spanish)
 Mexican Standard (NMX in Spanish)
 Ecocentric (E)
 Anthropocentric (A)
 Hydrological (H)
 Integrative Subject (IS)
 Depletion (D)
 Degradation (G)
 Re-valuation (R)
 Natural Production (P)
 Ecosystem Metabolism (M)
 Net Income Method (NIM)
 User Cost Method (UCM)
 Discounted Cash Flow Analysis (DCFA)
 Global Environmental Value (GEV)
 Monthly Final Balance (MFB)

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