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Physical Habitat Simulation and Comparison within a Lerma River Reach, with Respect to the Same but Modified Reach, to Create a Linear Park

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***Abstract*—**In this work, the *Ictalurus punctatu*s species estimated available physical habitat is compared with the estimated physical habitat for the same but modified river reach, with the aim of creating a linear park, along a length of 5 500 m.

To determine the effect of ecological park construction, on physical habitat of the Lerma river stretch of study, first, the available habitat for the *Ictalurus punctatus* species was estimated through the simulation of the physical habitat, by using surveying, hydraulics, and habitat information gotten at the river reach in its actual situation. Second, it was estimated the available habitat for the above species, upon the simulation of the physical habitat through the proposed modification for the ecological park creation. Third, it is presented a comparison between both scenarios in terms of available habitat estimated for *Ictalurus punctatus* species, concluding that in cases of adult and spawning life stages, changes in the channel to create an ecological park would produce a considerable loss of potentially usable habitat (PUH), while in the case of the juvenile life stage PUH remains virtually unchanged, and in the case of life stage fry the PUH would increase due to the presence of velocities and depths of lesser magnitude, due to the presence of minor flow rates and lower volume of the wet channel.

It is expected that habitat modification for linear park construction may produce the lack of *Ictalurus punktatus* species conservation at the river reach of the study.

***Keywords*—**Habitat modification, *Ictalurus punctatus*, Lerma, river, linear park.

I. Introduction

THE Lerma River Basin is located in the Central West zone of Mexico (Fig. 1). It encompasses near to three percent of the national territory (53 591 km^2) [20]. This River is originated in the Almoloya Lagoon (Westward of Mexico City) and discharges into the Chapala Lake, after having flown through five Mexican states, along 708 km [20].

The Lerma-Chapala Basin is located by parallels 21º 32' y 19º 15' North latitude and by meridians 103º 31' and 99º 22' West longitudes.

This zone of the Country is inhabited by nearly 15% of the whole national population. It is also one of the most industrialized zones, with urban residual water discharges, as well as with water returning from extensive irrigation fields.

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In its last third section, the Lerma River divides the States of Michoacan and Guanajuato, passing through the towns of La Piedad de Cabadas, Michoacan, and Santa Ana Pacueco, Municipio de Penjamo, Guanajuato. In this zone, the Lerma River has wide meanders and slopes, with relatively low depths as well as large widths. Its volume has been large and – considering nearby urban settlements- there have occurred floods. This problem has been partially solved by the construction of a drain (river bed rectification, see Fig. 2) which brought a modification on the water volume flowing through the river, up to the point of the meander isolation and almost its complete drying along some year periods, where it is added the problem of the untreated residual water discharges from the two towns above mentioned. So, the river became unfit as fluvial habitat for the aquatic fauna and as environmental factor for the nearby population.

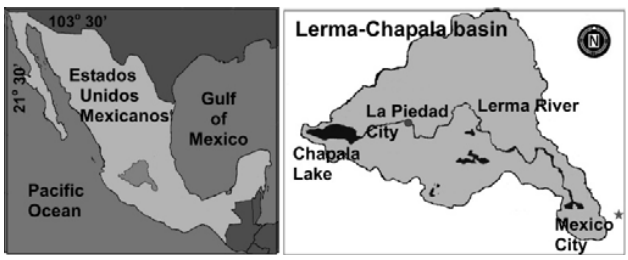

Fig. 1 Location of the Lerma-Chapala basin and the city of La Piedad de Cabadas, Michoacan, Mexico

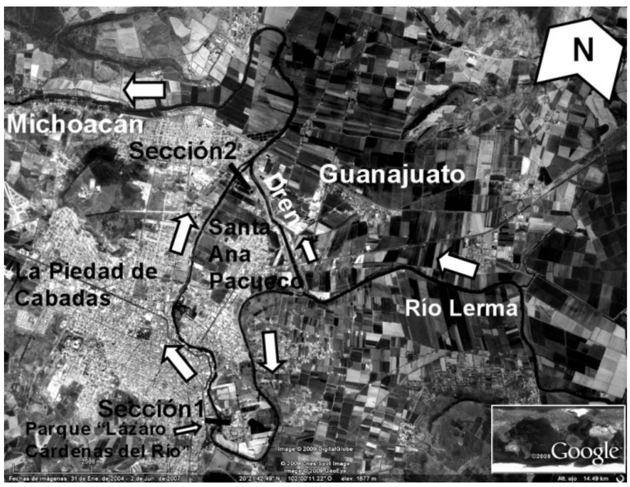

Fig. 2 Lerma River Meander in La Piedad, Michoacan

II. Background

Water usage should be performed within associated ecosystems respectful frame, with the aim of achieving a sustainable regional development. So, for superficial currents it ought to be determined the appropriate flow rates for the ecosystem organisms' healthy development [16], supplying at the same time important information for determining the availability of the hydric resource for other usage (e.g., agricultural, cattle and industrial).

About the flow rates for preserving the fluvial ecosystems, water usage is included in Mexican Legislation to conserve the aquatic ecosystems. So in the National Water Law and its Regulation [5], article 3, Fraction LIV, there is the definition of "Environmental Usage" or "Ecological Conservation Usage," where it is mentioned the rate flow "…that ought to be kept to protect the environmental conditions and the system ecological equilibrium" (author translation).

It is convenient to say that the Lerma River Basin is deficient in hydric resources [4], [9] and that the available surface water in the zone is basically used for agricultural irrigation.

As it has occurred to other Mexican rivers, the Lerma River has suffered a modification in its original flow rates as a result of the usage of the hydric resource for multiple purposes by a number of different hydraulic works, provoking effects of diverse magnitude into the fluvial ecosystem.

The inhabitants of La Piedad de Cabadas and Santa Ana Pacueco Towns behold their Lerma River reach as a health menace because the residual water discharges from their growing population.

III. Justification and Objective

The Lerma River water pollution in La Piedad, Michoacan, as well as water limitation to supply adequate flow rates, have made necessary to analyze possible solutions towards a proper environmental quality and a pleasurable and attractive place for inhabitants and visitors.

Besides the sanitation of water entering the Lerma meander within the towns La Piedad, Michoacan and Santa Ana Pacueco, Guanajuato, it has been proposed the building of a linear park in the meander zone between the dam in Lazaro Cardenas Park and a hydraulic control work 5500 m downstream (Fig. 2). On this regard, it would be important to assess the river's physical habitat in the zone when the linear park is built.

The goal of this article is to define the available physical habitat for the *Ictalurus punctatus* species within a 5500 m reach in the Lerma River, encompassing the riverbed modification for a linear park building, with the aim of finding the amount of the potential usable habitat for the above mentioned species. This would be valuable information for a proper management of the River reach studied.

IV. Methodology

It is applied a methodology based on the fluvial physical habitat simulation to determine the potentially usable habitat by the *Ictalurus punctatus* species, along the reach of the modified river to build a linear park.

The methodology based in the fluvial physical simulation integers two main components from the fluvial ecosystems that determine the aquatic fauna productivity: flow regime and habitat physical structure (channel shape, substrate distribution and vegetal coverage) [11]. To integer such components, habitat, and fluvial hydrodynamics simulation models are used. These models are fed with hydrometric, biological, and geomorphological data, in such a way that for each caudal it is determined the target aquatic species usage habitat availability. In the biological scope, it is assumed that the habitat will be used by the aquatic species suiting its development. Once got the habitat requirements, models for the referenced organisms as well as the hydraulics parameters and the River physiographical characteristics, it will be possible to compute the available habitat in accordance with the different volumes that would flow along the River.

In the IFIM methodology, IFIM (Instream Flow Incremental Methodology) [1], [2], [15] it is simulated the physical habitat by the computer system PHABSIM (Physical Habitat Simulation System) [18], [11], [12] which is the one used in this work to value the habitat modification as a result of the linear park building.

The habitat simulation aims to integer two of the main fluvial ecosystem components which determine the aquatic fauna productivity: flow regime and habitat's physical structure [11]. In order to integrate such components, models are used for simulating the fluvial and habitat hydrodynamics, which are fed with hydrometrical, biological and geomorphological data, coming directly from the studied River, in such a way that for each volume, it is determined the availability of potentially usable habitat (PUH) by the target aquatic organisms.

Habitat simulation systems are basically constituted by two parts: 1) one or various models for simulating the fluvial hydrodynamics, and 2) one or various models for simulating the habitat.

A. Information Achievement

1. Study Zone Description

The City of La Piedad is located at the North-West of the State of Michoacan, and this State is in the Central-West of Mexico (Fig. 3), along the Pacific Ocean Southern coast, between parallels 17°54'34" and 20°23'37'' North Latitude and 100°03'23" and 103°44'09'' West Longitude. Michoacan location, from a physiographic stand-point, corresponds to the Lerma River Depression, as well as to the central part of the Transverse Volcanic System, the Balsas River Depression and the South Sierra Madre.

Since Michoacan is located in the Southwest zone of the Tropic of Cancer, it is in the tropical zone, but the height differences along its territory are the most influencing factors in its weather conditions, in such a way that these conditions are equivalent to those from the temperate zone [6].

2. Climatology

In accordance with the Köpen climate classification, modified by Garcia [10], there are eight climate types within the same Basin, which vary from the cold clime (mountain type) up to the dry and arid one with Summer rain, passing through the temperate one. Rainfall varies from 1600 and 500 mm annually. The highest zone is in the Nevado de Toluca volcano, at 4690 m above sea level (MASL). The lowest zone is in the Chapala Lake, at 1600 MASL.

3. Lerma River Historic Caudal in La Piedad, Michoacan

Lerma River mean caudal, near to la Piedad, Michoacan, vary from 8 to 15 m^3/s in the drought season, reaching 168 m^3/s in the rainy season. These volumes were obtained from the daily mean caudal measured in the hydrometrical station Corrales (*i.e*., the closest to the studied site), along the 1930-2009 period, published in the Surface Water Data Bank (BANDAS) by the Water National Commission [3].

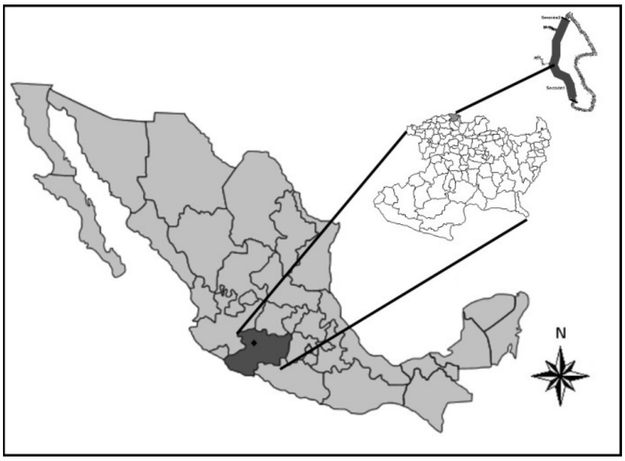

Fig. 3 Location of the area and the Lerma River reach under study

The studied reach, located in one meander of the Lerma River (Fig. 2), has an approximate length of 5500 m [20]. Its upper part is marked by a structure that was part of a small hydroelectric dam, located in the "Lazaro Cardenas del Rio" Park. Its lowest part is in a hydraulical structure with a control gate.

The reach average width is 50 m and its average slope, at thalweg level, is 0.0002 [20].

About the habitat, there are deep poles along the studied reach that can be used by the ichthyofauna as a refuge for catching preys, for nesting and for resting. This habitat has slow water zones (deep poles) with clay substratum, as well as with detritus. Along the study reach there are submerged branches and roots, cornices, logs and rocks that may become a refuge. The predominant substratum is made by clay soil, detritus (with and without trees and bushes), as well as by sand and stone-like material of different sizes, packed into the clay substratum.

4. Fluvial Hydrodynamical Simulation

To perform the hydrodynamical and habitat simulation, it was used a bidimensional model, averaged along the depth, which forecast supercritical flow zones and their associate transitions. It also provides with an underground flow model used as a convenient way to solve the flooded/dried process of the water surface borders. The model uses the finite element method to discretize the problem and find its solution, through an irregular triangle elements mesh. The equations describing the model bidimensional flow are got by the principles of the mass and momentum conservation applied to a water prismatic vertical column, with the low limit of the riverbed and the upper limit of the free surface of water [17].

The computation procedure established in the physical habitat simulation system PHABSIM (Physical Habitat Simulation System) [18] was used to perform the physical habitat simulation, which is part of the IFIM methodology, with adaptations to the computing process, by using a finite element mesh instead of defined cells (quoins in cross sections) along the vertical.

B. Field Information Acquisition

1. Information for the Fluvial Hydrodynamical Simulation

The required data for beginning the project were as follows: (1) river bed topography, the most important and lengthy step; (2) rugosity, as the rugosity height in the Chezy formula; (3) boundary conditions, input cross-sectional caudal (*i.e*., upstream end) and the water surface height at the studied reach outlet and, (4) discretization net, which aims to represent the riverbed topographical characteristics as a series of elements in which the flow field characteristics are determined.

To calibrate the hydrodynamical model there were used the water surface levels (WSL's), got for two caudals (Table I) in two cross sections, one located at the studied reach (5500 meters length) start, and the other one, located at its end.

The hydrometrical data achievement campaign was performed in a three days period, with the support of the water authority and the city hall of La Piedad, Michoacán, obtaining data for two different caudals. Topographical surveys were performed in about 15 days using a total station.

The volume gauging in the two above mentioned cross sections was done using an acoustic profiling machine with a Doppler effect (Fig. 4). At the same time, the water surface level (WSL) was obtained for each gauged caudal and for the two cross sections taken as a reference. To obtain the WSL, topographical equipment consisting in a total station and its correspondent prism was used (Fig. 4).

Hydrometric results appear at Table I and its graphic is in Fig. 8.

2. Topography

175 riverbed cross sections were obtained for representing the river bed morphology in accordance with the discretization method used in the model for the hydrodynamic simulation and data generation. X, Y, Z coordinates for each important point were computed using a topographical equipment with a total station and its prism (Fig. 4).

3. Rugosity

The employed hydrodynamic model uses the rugosity magnitude parameter k_s (Chezy coefficient) to represent this kind of flow resistance. In this work, k_s values were assigned in accordance with riverbed substratum type.

Fig. 4 Getting hydrometrical and topographical information by a Doppler effect acoustic profiler (shown at the top) and a total station

TABLE I
SAMPLING FLOW RATES AND CORRESPONDING WATER SURFACE LEVELS (WSL'S) IN METERS ABOVE SEA LEVEL

Caudal m^3/s	WSL Section 1 m	WSL Section 2 m
13.44	1669.510	1669.030
23.18	1670.075	1669.706

WSL: Water Surface Level

4. Substratum

Substratum information, as a habitat element, was obtained altogether with the bathymetry point coordinates, shown in Fig. 5. The system used for the substratum classification and the corresponding numerical codes introduced in the habitat simulation process, were based in the classification used by Platts, W. S., W. F. Megahan, & G. W. Minshall [13], who accepts as reference the terminology and the size classes accepted by the American Geophysical Union (AGU). The corresponding preference curves used in this work are in Fig. 6 (c).

C. Fluvial Physical Habitat Simulation

1. Target Species Habitat Preference Curves

Habitat preference curves of ichthyofauna species integer the attributes of the computation cell for estimating the habitat quality and quantity. The measurement unit used is the Potentially Usable Habitat (PUH), in square meters for each 1000 meters of the river length, or in square meters along the studied reach, which is computed multiplying the cell area times a composed preference factor, dividing by the studied reach river length. The composed preference factor method (CPF) for a cell or element, used in this work, is that of the multiplicative integration of the associated conveniences to velocity, depth and riverbed index (substratum) of each cell. The PUH computation is done for each finite element or cell in which the velocity and depth of water were simulated.

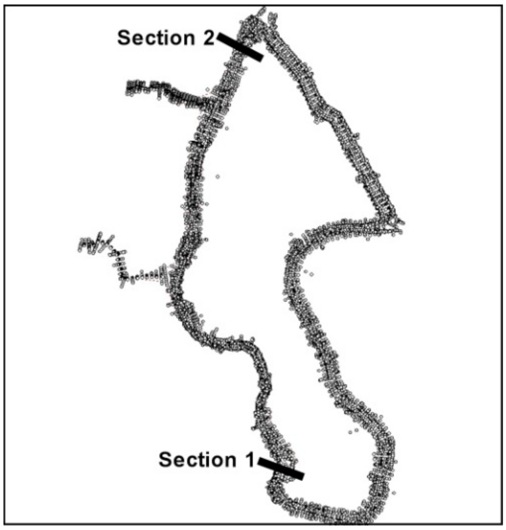

Fig. 5 Lerma River Meander topographical points at La Piedad, Michoacán

To select the target species in order to simulate the fluvial physical habitat, it is common to prefer those species demanding most habitat, with low resilience, as well as the "umbrella" species, whose protection benefits many other species sharing the same habitat, as well as the indigenous species in the studied zone.

Two ichthyofauna species samples were performed [14] in the meander nearby zone, one of them in May (drought season) and another in September (rain season). Both samples were done in the same spots. Fish captured around the Lerma River meander, in La Piedad, Michoacan, correspond to nine species from which five of them were introduced (with ample tolerance intervals for water pollution and used in aquariums). The other four native species are similarly tolerant.

Using ichthyofauna species databases from Mexico and the USA about the studied zone, it was conducted a review with the aim to choose the target species. It was found that the species *Ictalurus dugesii* has lived in the zone, fulfilling the umbrella characteristic above mentioned. So, it could be the target species along the Lerma River reach in La Piedad, Michoacan. However, at present there is not information about habitat preferences of this species. Such information would be used for integrating the corresponding habitat preferences, thus it was decided to use a similar size and habitat preference species [7] like *Ictalurus punctatus* (Fig. 6). There are preference curves developed by Herricks, E. E. *et al.* [8] (Fig. 6) for the physical habitat simulation.

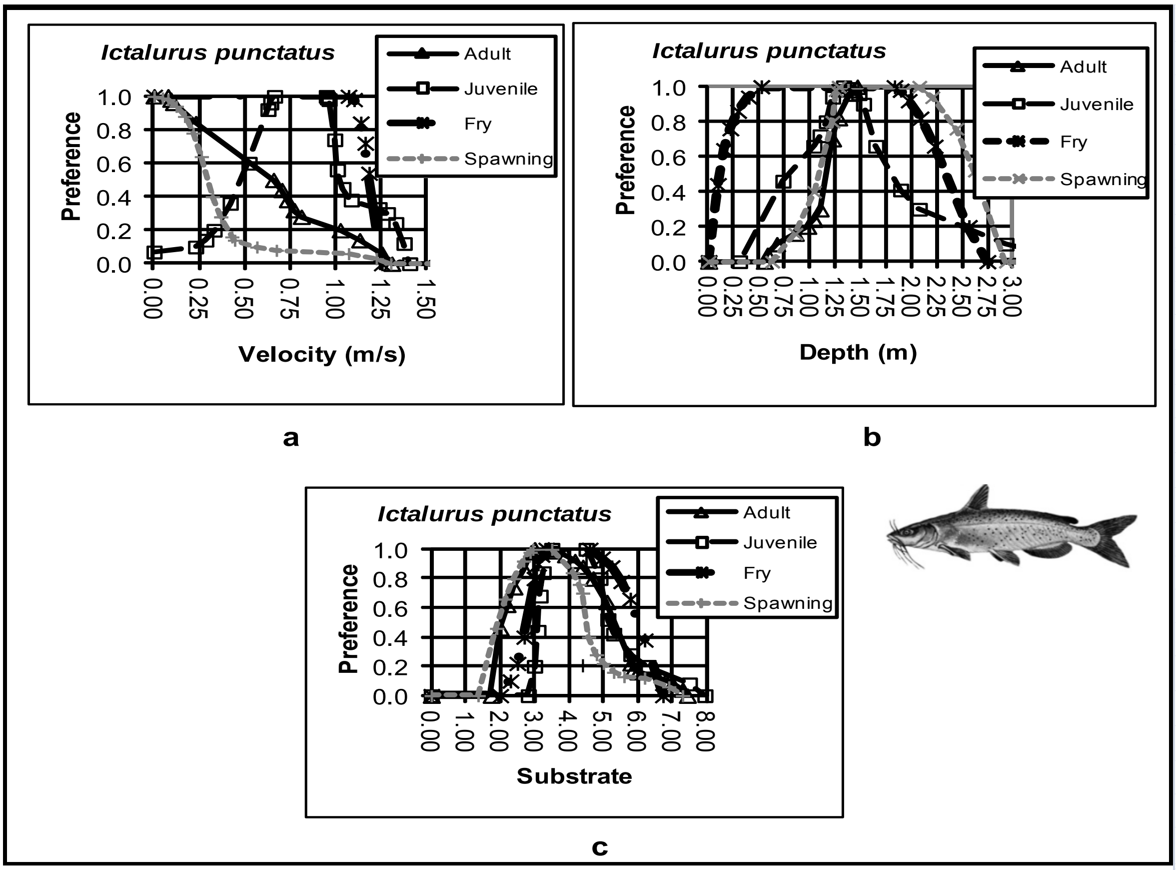

Fig. 6 Habitat preference curves for velocity (a) depth (b) and substrate type (c) for *Ictalurus punctatus* species [8]

2. Potentially Usable Habitat (PUH) Computation

Once the fluvial hydrodynamical simulation was performed, the *Ictalurus punctatus* species PUH was begun

Considering the target Lerma River zone complex scenario, various options were proposed towards the meander sanitation and urban integration. Out of these options, the consensual one by users and institutions in the project, was that about the linear park creation. This option implies some modification to the geomorphology of the Lerma River channel along the La Piedad meander, Michoacan. This modification is planned to begin at the Lazaro Cardenas Park ("La Placa") and then downstream, through the projected building of a riverbed or drought channel, which aim is to conduct water at that season, allowing the usage of the rest of the channel for putting minimum volume elements that favor the zone inhabitants and visitors amusement (*i.e*., benches, lampposts, ramps, etc).

The Lerma River fluvial physical habitat simulation along the studied reach (including the linear park) was performed by modifying the file of the original topography of the riverbed, introducing the drought season riverbed (Fig. 7), and considering the project changes into the substratum and vegetation for the linear park. It is pertinent to mention that complementary files for simulating the hydrodynamics and habitat, were also modified, which basically consisted in the modification of the rugosity coefficient and the type of substratum.

V. Analysis and Results

A. Hydrodynamical Modelling

1. Field Topographical Data File and Finite Element Meshes for Discretization

From the original topographical data files, which were modified for the linear park, there were generated computational meshes based on finite elements, which were fed to the fluvial hydrodynamical simulation model.

Fig. 7 shows the computational mesh used in this work for simulating the seabed hydrodynamics and habitat including the linear park, as well as some details for a better visualization. The finite element mesh in Fig. 7 is composed by 14 957 nodes (29 889 elements, 1409 border segments and 5209 main lines segments or characteristics).

2. Model Calibration in Regard to Water Surface Levels (WSL's) for Caudals Measured on Site (Q = 23.18 m^3/s and Q = 13.44m^3/s)

The WSL's absolute error mean, measured in the four calibration sections with respect to the simulated WSL's, was 1.9 and 1.8 cm, for the 13.44 m^3/s y 23.18 m^3/s caudals, respectively; with maximum errors of 5.3 cm and 5.4 cm for each case. Differences among measured WSL's with simulated ones are ok, since it is feasible to consider that in habitat simulation studies, water depth differences about 5 cm or smaller (WSL's simulation error by-product), will not cause a meaningful variation in the habitat estimated quantity (*i.e.* PUH) [19]. At the end of the day it should be considered that the required precision in the WSL's simulation, will depend on the project goals [19].

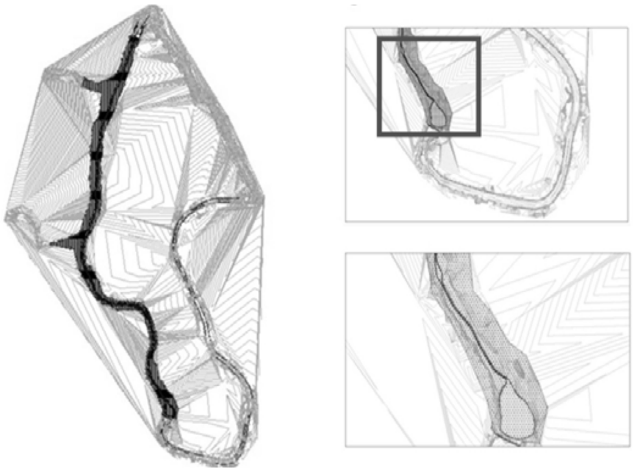

Fig. 7 Finite elements mesh for the Lerma river reach under study, with linear park

Fig. 8 shows measured and simulated WSL's for calibration caudals.

Once the fluvial hydrodynamical simulation model for water level was calibrated, it was determined the water velocities distribution along the studied reach for 23.18 m^3/s y l3.44 m^3/s caudals. Then, it was simulated the water level and the water velocities distribution for other six caudals.

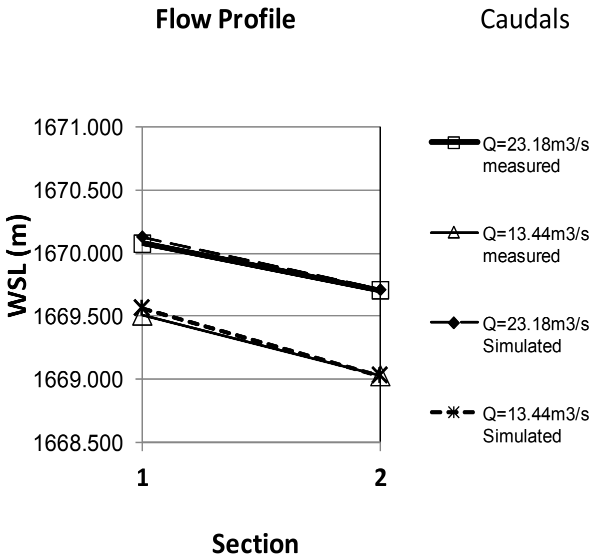

Fig. 8 Water surface levels (WSL's) for sampling flow rates (for calibration), and for simulated WSL's

3. Ichthyologic Habitat Modelling. Potentially Usable Habitat Computation (PUH) Studying Reach with Linear Park

Twenty Potentially Usable Habitat (PUH) maps about the four development stages of the target species, were obtained for the studied breach considering the linear park and five caudals. Fig. 9 shows the habitat quantity with the respect to the caudal, as a result of the habitat simulation for the *Ictalurus punctatus* species and its development stages.

4. Analysis of Riverbed Modified for a Linear Park Design

Fig. 9 shows the caudal-PUH curves obtained by the physical habitat simulation along the studied reach riverbed in the Lerma River at La Piedad, Michoacan, including the linear park and regarding the *Ictalurus punctatus* as the target species. It can be seen in the same Fig. 9 that the caudal that maximizes the PUH for the four developmental stages is 3.2 m^3/s. It is pertinent to say that not larger caudals were considered in the habitat simulation since it is intended to prevent the flow of larger caudals than those that the riverbed can support in the drought season. Fig. 9 also shows that the modification of the riverbed for building a linear park results in a small quantity of potentially usable habitat (PUH) for the adult, juvenile and spawning life stages, while for the fry stage, the PUH is considerably larger, because of low magnitude velocities and depths, due to the diminishing caudal and wet volume from the linear park. Along the modified riverbed the caudal reaches 3.2 m^3/s, since this is its design level, considering the proper quality water availability expected in the project.

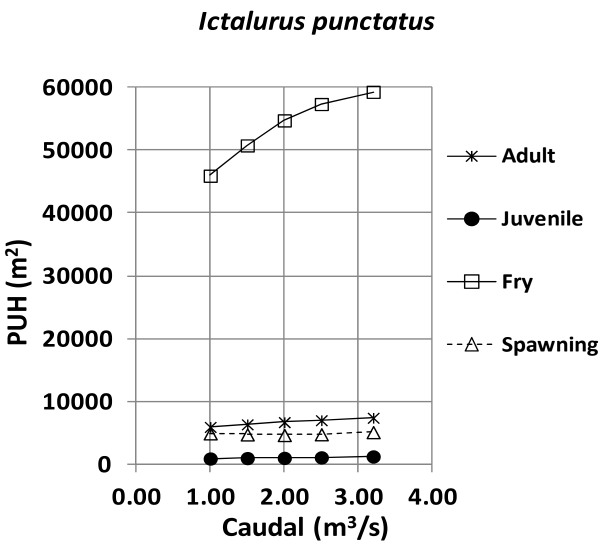

Fig. 9 *Ictalurus punctatus* species habitat-flow curves (Q - *PUH*) for its life stages, obtained by the physical habitat simulation of the Lerma River reach of study, including the linear park project

VI. Conclusion

The modification of the riverbed for building a linear park results in a small quantity of potentially usable habitat (PUH) for the adult, juvenile and spawning life stages of the *Ictalurus punctatus* species, while for the fry stage, the PUH is considerably larger, because of the low magnitude of water velocity and depth due to the diminishing caudal and wet volume.

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