Design of a Biological Corridor for Migration of Freshwater Prawn over a Dam in the Southwestern Slopes of Los Andes, Peru

Aníbal S. Verástegui[*1], Jesús A. Mejía[2], Andrés Goyburo[3]

[1]Departamento de Acuicultura e Industrias Pesqueras, Programa de Doctorado en Recursos Hídricos, Universidad Nacional Agraria La Molina, Lima, Perú

[2,3]Departamento de Recursos Hídricos, Universidad Nacional Agraria La Molina, Lima, Perú

[1]avm@lamolina.edu.pe; [2]jabel@lamolina.edu.pe; [3]anesgoyburo@gmail.com

Abstract*-Faced with the effects of climate change, forms of environmentally friendly energy production, such as hydroelectric plants, are promoted. However, the building of these structures in a riverbed represents an obstacle to the movement of migratory aquatic species. A new case involves rivers of southwestern slopes of Los Andes, inhabited by crustaceans with economic and environmental importance. Considering the proposed construction of a diversion dam for a hydroelectric plant on the Ocoña River, 120 km upstream from its mouth, from 8 sampling points, the freshwater prawn (*Cryphiops caementarius*) population and its corresponding intensity of migration were estimated. The results were used to make hydraulic calculations, the sizing of passage for migrating species and for hydraulic modeling using HEC-RAS software. From the collection and analysis of the samples, it was found that the population is distributed depending on altitude. The intensity of migration was found between 0.88-23.67 and 4.02-34.92 prawns.min^{-1} for wet and dry season respectively. The average migration intensity was 10.08 prawns. min^{-1}. It was calculated the ratio of required space/total length specie in 0.83, equivalent to a surface density of 1.35 migrating prawns per square meters. Considering an area of 4.80 m^2 and the referred migration density, it was determined for each square meter a migration rate of 6.48 prawns. min^{-1}. The biological corridor width results in 1.56 m, and an operating water flow of 0.33 m^3. s^{-1}. The population composition and the ability of this specie to climb over surfaces, out of the water, indicated that the most suitable step is the type pool - weir. In conclusion, the work allowed defining the architecture and dimensioning of the migration passage, according to specific requirements of the specie.

Keywords- Cryphiops Caementarius; Freshwater Prawn; Migration; Fish Passage; Ecohydraulics; Hec-Ras

I. INTRODUCTION

Facing with the risks of global climate change, the Clean Development Mechanism component of Kyoto Protocol, promotes business investment in projects that use clean technologies such as construction of hydroelectric plants. The purpose is to reduce the emission of greenhouse gases (GHG) in developing countries, according to the Millennium Development Goals for sustainable development and improving the quality of human life [1]. However, these forms of industrial use of inland water sources have ignored their value in sustaining ecosystems [2].

For centuries, there has been awareness and concern about diversion dams and reservoirs, which affect the free migration of fish [3]. In many cases, as [4] points out, the lack of design criteria in the development of projects of these hydraulic structures have resulted in no satisfactory solutions. Environmental mitigation measures are increasingly considered as an integral part of the design process of a hydraulic project [5].

The methodology for design calculations of migration structures, consider the swimming ability and behavior of the species as a key factor in the hydraulic design of fishways. Other major factors to consider in the design of these buildings, is the displacement capacity of the species [6-7], comprising swimming speed. It is also important to know the maximum distance that they can travel at a given water speed. So, references [8] and [9], they developed curves relating water velocity with maximum distance traveled by species of freshwater shrimp. To complement this knowledge, new hydraulic tools, such as simulation models, can configure the operation of hydraulic systems before they are built, ensuring river connectivity and creating a biological corridor that meets environmental objectives. This developed knowledge, mainly for rivers in the northern hemisphere inhabited by salmonid species, is required to apply in other realities. One of them is the system of rivers of the western slope of Los Andes highlands, where there is a need to build hydroelectric plants, but at the same time to preserve the populations of migratory aquatic species.

Caring species becomes more important when these have economic and environmental importance and social roots for families who inhabit the riverside towns; it is the case of river prawn *Cryphiops caementarius* which presents migratory movements. For purposes of this work, given the lack of information on systems for migration of crustaceans, it has been taken as models reference fish ladder, widely studied and presented by [10] and [11] among others.

This study aimed (1) to estimate the population of freshwater prawn that live upstream of Ocoña river above 880 m.o.s.l. (2) at estimating of migration intensity at the point of location of the diversion dam and (3) to define the geometry of passage for

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prawn and make the hydraulic modeling. This is a contribution to the design of biological corridors or migration steps for river prawns.

II. MATERIALS AND METHODS

A. Study Area

The study was conducted at 120 km upstream from the mouth of Ocoña river, in an area between the point where the diversion dam is located (73°05'06.15 " O and 15°35'48.27 " S, 880 m.o.s.l.), and another point located in Cotahuasi river, a tributary of Ocoña river (73° 18' 08" O, 15° 35' 27 " S, 979 m.o.s.l.) (Fig. 1). The area has rugged geography, with average temperatures 15.8 to 18.2 °C, absolute maximum of 24.5 °C and absolute minimum 8.4 °C, relative humidity between 64 and 81 per cent and precipitation from 0 to 22.3 mm [12].

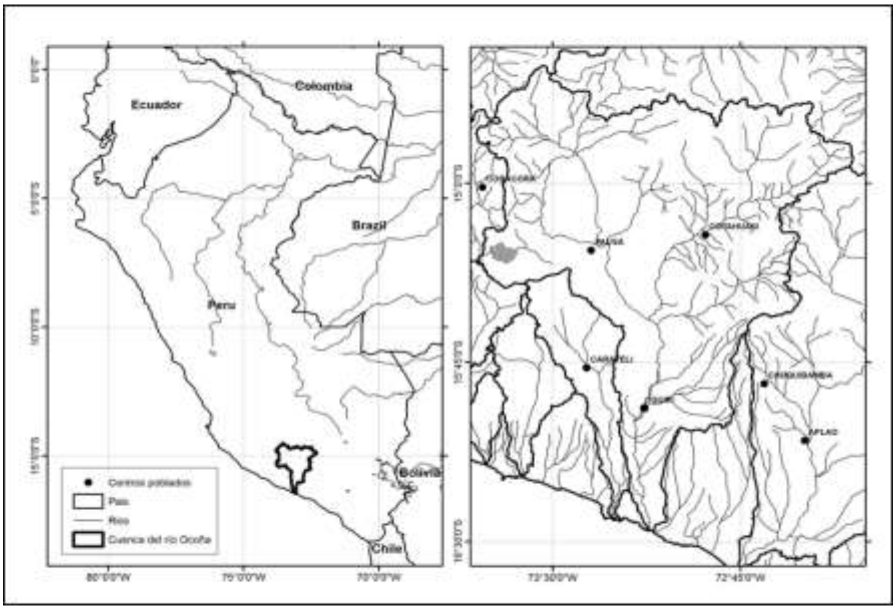

Fig. 1 Location of hydroelectric diversion dam

B. Prawn Population Estimate

The collection of prawn was made in representative stations altitudinal strata of 200 m, at least three stations per stratum, upstream from the point where the dam, two in the same river Ocoña and four in the tributaries (two points in Cotahuasi river and two on the Maran river) [13]. The prawns were caught by local fishermen, following the method of free diving, obtaining adults and sub-adults specimens. Each sampling was performed on a stretch of 40 m length of the river, to standardize the method used by [14] and [15].

C. Dimensioning Step for Shrimp and Hydraulic Modelling

With sampling prawn, abundance indices expressed in prawns.m^{-2} and g.m^{-2} were calculated. Considering the river area upper to the location of the dam strata, the amount of prawn that inhabits the river upstream of this point was estimated. The estimated population is considered to have passed through the section where the dam is located. The estimated population is considered to have passed through the section where the dam is located. With this value, width needed to meet the intensity of migration 10.08 prawns.min-1 was calculated by the following formula:

$$Ar = \frac{Cm}{\rho m.Vd} \quad (1)$$

Where, *Ar* is the amplitude of passage for migration (m^2), *Cm* the intensity of migration (prawns.min^{-1}); *ρm* the density of migration (prawns.m^{-2}), *Vd* the travel speed (m.min^{-1}).

After determining section proceeded with hydraulic calculations stair prawns, using the equation for landfills, modified for application in this case:

$$Q = 1.84(b - 0.2\,\Delta h)\,\Delta h^{1.5} \quad (2)$$

Where, Q is water flow rate (m^3.s^{-1}); *b* is the width of weir (m); Δh is the water head on the weir (m).

To define the hydraulic characteristics (section, slope and speed) of the passage of migration and to model its operation, HEC- RAS program (Version 4.1, U.S. Army Corps of Engineers, California) was used. The application of this model,

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results of hydraulic profiles, speeds and water depths in sections of interest.

As result of modeling the cross sections containing hydraulic and speed profiles are obtained along the entire stretch of migration step. Hydraulic parameters were used to make the necessary adjustments design elements.

For the analysis of the hydraulic simulation by the model, were assumed steady flow conditions, i.e. in the energy equation were not included terms that depend on the time. Furthermore calculations were performed from considerations of normal flow (S = 0.0001), because it wants to resemble as much as possible to a horizontal surface. The HEC-RAS software also allowed to define the hydraulic characteristics in each one of the sections, for different proposed flows.

Geometry design prawn step, on the diversion dam in the Ocoña River, was drawn to scale using the Auto CAD (version 2010, Autodesk Inc. California United States) program.

III. RESULTS

A. Prawn Population and Migration Estimation in the Study Area

The population is distributed depending on the altitude, according to the equation $y = 1.5587e^{-0.002x}$ and, $y = 0.9297e^{-0.002x}$, for dry and wet season respectively (Fig. 2).

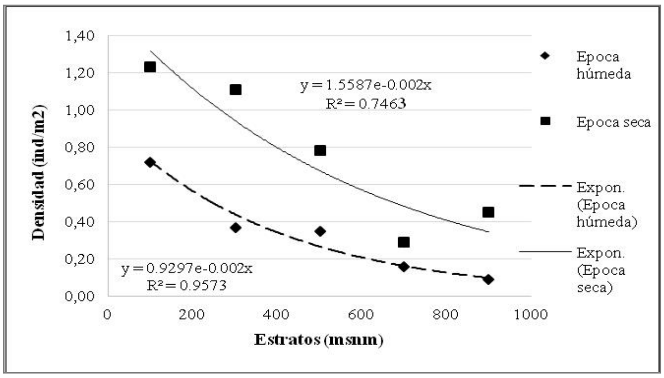

Fig. 2 Relationship of the density of river prawn by altitudinal strata in the Basin of Ocoña River, according to seasons (*x*: meters above sea level, *y*: individuals per square meter)

The average densities were 10.33 ± 1.816 and 2.83± 0.694 $g.m^{-2}$ for dry and wet season respectively (Table 1).

TABLE 1 CONCENTRATION INDICES OF PRAWN, ACCORDING ALTITUDINAL STRATA IN OCOÑA RIVER, 2011 [13]

Stratums (m.o.s.l.)	Average biomass density ($g.m^{-2}$)		Density ($prawns.m^{-2}$)		Population (Nº of prawns)	
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
1000 - 800	0.99	9.88	0.09	0.45	63,016	725,831
800 - 600	1.09	7.13	0.16	0.29	184,400	289,619
600 - 400	2.61	11.91	0.35	0.78	508,670	1,476,103
400 - 200	2.20	12.01	0.37	1.11	640,541	2,054,216
200 - 0	4.82	9.25	0.72	1.23	1,703,923	2,514,227
AVERAGE	2.83	10.33	0.42	0.84		
TOTAL					**3,100,551**	**7,059,996**

The least populated stratum was between 800 and 1000 m.o.s.l., with an average of 65.885 and 722,471 prawns in the wet and dry season respectively, while the maximum populations was located in the stratum 200–000 m.o.s.l. 1,703,923 and 000 – 200 m.o.s.l. 2’514,227 for the above periods (Table 1). The range of the intensity of migration was 0.88-23.67 and 4.02-34.92 $prawns.min^{-1}$, corresponding to the wet season and dry season, respectively (Table 2). For the altitude where the projected dam (880 m.o.s.l.) is located, the intensity of migration was 0.88 and 10.08 $praws.min^{-1}$ for wet and dry seasons, respectively.

TABLE 2 ESTIMATED MIGRATION RATE FOR ALTITUDINAL STRATA IN OCOÑA RIVER IN THE WET AND DRY SEASONS, 2011 [13]

Stratums (m.o.s.l)	Area (m^2)	Density ($praws.m^{-2}$)	Prawns travelers per minute
Wet season			
1000 - 801	700,178.6	0.09	0.88
800 - 601	1,152,500.8	0.16	2.56
600 - 401	1,453,344.4	0.35	7.06
400 - 201	1,731,192.8	0.37	8.90

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Stratums (m.o.s.l)	Area (m^2)	Density ($praws.m^{-2}$)	Prawns travelers per minute
200 - 0	2,366,560.2	0.72	23.67
AVERAGE		0.42	8.61
TOTAL	7,403,776.8		43.06
Dry season			
1000 - 801	1,612,957.5	0.45	10.08
800 - 601	998,686.8	0.29	4.02
600 - 401	1,892,440.0	0.78	20.50
400 - 201	1,850,644.7	1.11	28.53
200 - 0	2,044,086.7	1.23	34.92
AVERAGE		0.84	19.61
TOTAL	8,398,815.70		98.06

B. Prawn Population and Migration Estimation in the Study Area

At the location area of the projected dam, it was found adult prawns (Fig. 3a). With the observed body proportions, the ratio occupied area / prawn body length has resulted in 0.83, equivalent to a density of migration 1.35 prawns. m^{-2}.

(a)

(b)

Fig. 3 (a) Prawn male adult, in the dam location; (b) *C. caementarius* juvenile prawn, climbing on the tank walls, out of water

Considering an area of 4.80 m^2 and the density of migration, it results that for each square meters corresponds 6.48 prawns min^{-1}. With this value the amplitude of migration step, corresponding to a displacement rate of 10.08 $prawns.min^{-1}$, using Equation (1), resulting a width 1.56 m.

Laboratory evidences show the ability of the species to scale vertical surfaces out of the water (Fig. 3b), which serves as a basis for designing structures of migration, and in this specific case for migration step design for river prawn, has been selected pool–weir type, conditioned with rough surfaces so that the prawn can overcome climbing the slopes between pools (Fig. 4).

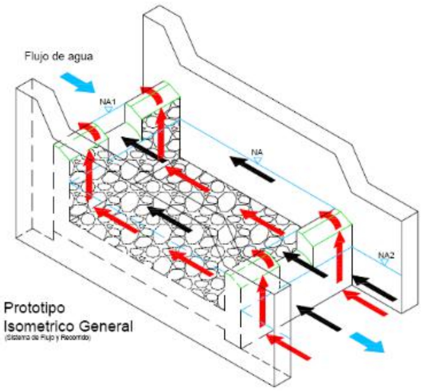

Fig. 4 Isometric view of a segment of the passage of prawns ‘pool – weir’ type, with surfaces that enhance its scaling (red arrows - travel prawn, black arrows – swimming fish and light blue – water flow)

Then, the water flow rate for the migration stairs operation was calculated Q = 0.33 $m^3.s^{-1}$, with Equation (2), considering b = 0.6 m, Δh = 0.45 m and water depth in pools h = 0.30 m. With these parameters, the flow velocity in the central weir resulted in 1.86 $m.s^{-1}$. It was determined, the dissipated energy equal to P = 433.56 $w.m^{-3}$ with a pool volume V = 3.36 m^3.

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C. Hydraulic Modeling of Prawn Step

The hydraulic characteristics were found (Table 3) for the basic operation water flow of 0.3 $m^3.s^{-1}$. The model was run by Hec- Ras with other flows (0.5; 0.8; 1; 1.2; 1.5 $m^3.s^{-1}$).

TABLE 3 RESULTS OF THE SIMULATION MODEL FOR A WATER FLOW OF 0.33 $M^3.S^{-1}$

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Caidas	60	0.33 m3/s	0.33	13.00	14.09	13.14	14.10	0.000022	0.15	2.19	2.00	0.05
Caidas	59	0.33 m3/s	0.33	13.00	14.09	13.14	14.10	0.000022	0.15	2.19	2.00	0.05
Caidas	58.5		Inl Struct									
Caidas	58	0.33 m3/s	0.33	12.95	13.64		13.65	0.000075	0.24	1.39	2.00	0.09
Caidas	57	0.33 m3/s	0.33	12.95	13.64	13.09	13.65	0.000075	0.24	1.38	2.00	0.09
Caidas	56.5		Inl Struct									
Caidas	56	0.33 m3/s	0.33	12.50	13.19		13.20	0.000075	0.24	1.39	2.00	0.09
Caidas	55	0.33 m3/s	0.33	12.50	13.19	12.64	13.20	0.000075	0.24	1.39	2.00	0.09
Caidas	54.5		Inl Struct									
Caidas	54	0.33 m3/s	0.33	12.05	12.74		12.75	0.000075	0.24	1.39	2.00	0.09
Caidas	53	0.33 m3/s	0.33	12.05	12.74	12.19	12.75	0.000075	0.24	1.38	2.00	0.09
Caidas	52.5		Inl Struct									
Caidas	52	0.33 m3/s	0.33	11.60	12.29		12.30	0.000075	0.24	1.39	2.00	0.09
Caidas	51	0.33 m3/s	0.33	11.60	12.29	11.74	12.30	0.000075	0.24	1.38	2.00	0.09
Caidas	50.5		Inl Struct									
Caidas	50	0.33 m3/s	0.33	11.15	11.84		11.85	0.000075	0.24	1.39	2.00	0.09
Caidas	49	0.33 m3/s	0.33	11.15	11.84	11.29	11.85	0.000075	0.24	1.39	2.00	0.09
Caidas	48.5		Inl Struct									
Caidas	48	0.33 m3/s	0.33	10.70	11.39		11.40	0.000075	0.24	1.39	2.00	0.09
Caidas	47	0.33 m3/s	0.33	10.70	11.39	10.84	11.40	0.000075	0.24	1.38	2.00	0.09
Caidas	46.5		Inl Struct									
Caidas	46	0.33 m3/s	0.33	10.25	10.94		10.95	0.000075	0.24	1.39	2.00	0.09
Caidas	45	0.33 m3/s	0.33	10.25	10.94	10.39	10.95	0.000075	0.24	1.38	2.00	0.09
Caidas	44.5		Inl Struct									
Caidas	44	0.33 m3/s	0.33	9.80	10.49		10.50	0.000075	0.24	1.39	2.00	0.09
Caidas	43	0.33 m3/s	0.33	9.80	10.49	9.94	10.50	0.000075	0.24	1.38	2.00	0.09
Caidas	42.5		Inl Struct									
Caidas	42	0.33 m3/s	0.33	9.35	10.04		10.05	0.000075	0.24	1.39	2.00	0.09
Caidas	41	0.33 m3/s	0.33	9.35	10.04	9.49	10.05	0.000075	0.24	1.38	2.00	0.09
Caidas	40.5		Inl Struct									
Caidas	40	0.33 m3/s	0.33	8.90	9.59		9.60	0.000075	0.24	1.39	2.00	0.09
Caidas	39	0.33 m3/s	0.33	8.90	9.59	9.04	9.60	0.000075	0.24	1.39	2.00	0.09
Caidas	38.5		Inl Struct									
Caidas	38	0.33 m3/s	0.33	8.45	9.14		9.15	0.000075	0.24	1.39	2.00	0.09
Caidas	37	0.33 m3/s	0.33	8.45	9.14	8.59	9.15	0.000075	0.24	1.38	2.00	0.09
Caidas	36.5		Inl Struct									
Caidas	36	0.33 m3/s	0.33	8.00	8.69		8.70	0.000075	0.24	1.39	2.00	0.09
Caidas	35	0.33 m3/s	0.33	8.00	8.69	8.14	8.70	0.000075	0.24	1.38	2.00	0.09
Caidas	34.5		Inl Struct									
Caidas	34	0.33 m3/s	0.33	7.55	8.24		8.25	0.000075	0.24	1.39	2.00	0.09
Caidas	33	0.33 m3/s	0.33	7.55	8.24	7.69	8.25	0.000075	0.24	1.39	2.00	0.09
Caidas	32.5		Inl Struct									
Caidas	32	0.33 m3/s	0.33	7.10	7.79		7.80	0.000075	0.24	1.39	2.00	0.09
Caidas	31	0.33 m3/s	0.33	7.10	7.79	7.24	7.80	0.000075	0.24	1.38	2.00	0.09
Caidas	30.5		Inl Struct									

With modelling profiles and hydraulic parameters, adjustments to the design elements were made. According to the model, V_{max}=0.24 $m.s^{-1}$, it was significantly less than that required for swimming prawn, of V= 0.4 $m.s^{-1}$.

Section No. 60 (Fig. 5a), was obtained from the simulation with Hec – Ras, corresponded to the beginning of the staircase, which connects to a horizontal surface; at this section V_{max}= 0.15 $m.s^{-1}$. Section No. 1 (Fig. 5b) corresponds to the end of the staircase that connects to the river; at this section V_{max}= 0.26 $m.s^{-1}$.

Resulting in the migration step comprises an inclined section of 80 m and another in seashell shape with a height equivalent to the column variation of water level in the reservoir (7.50 m) which can be adapted to the architecture of the dam and establish connectivity between the upstream and downstream from the diversion dam.

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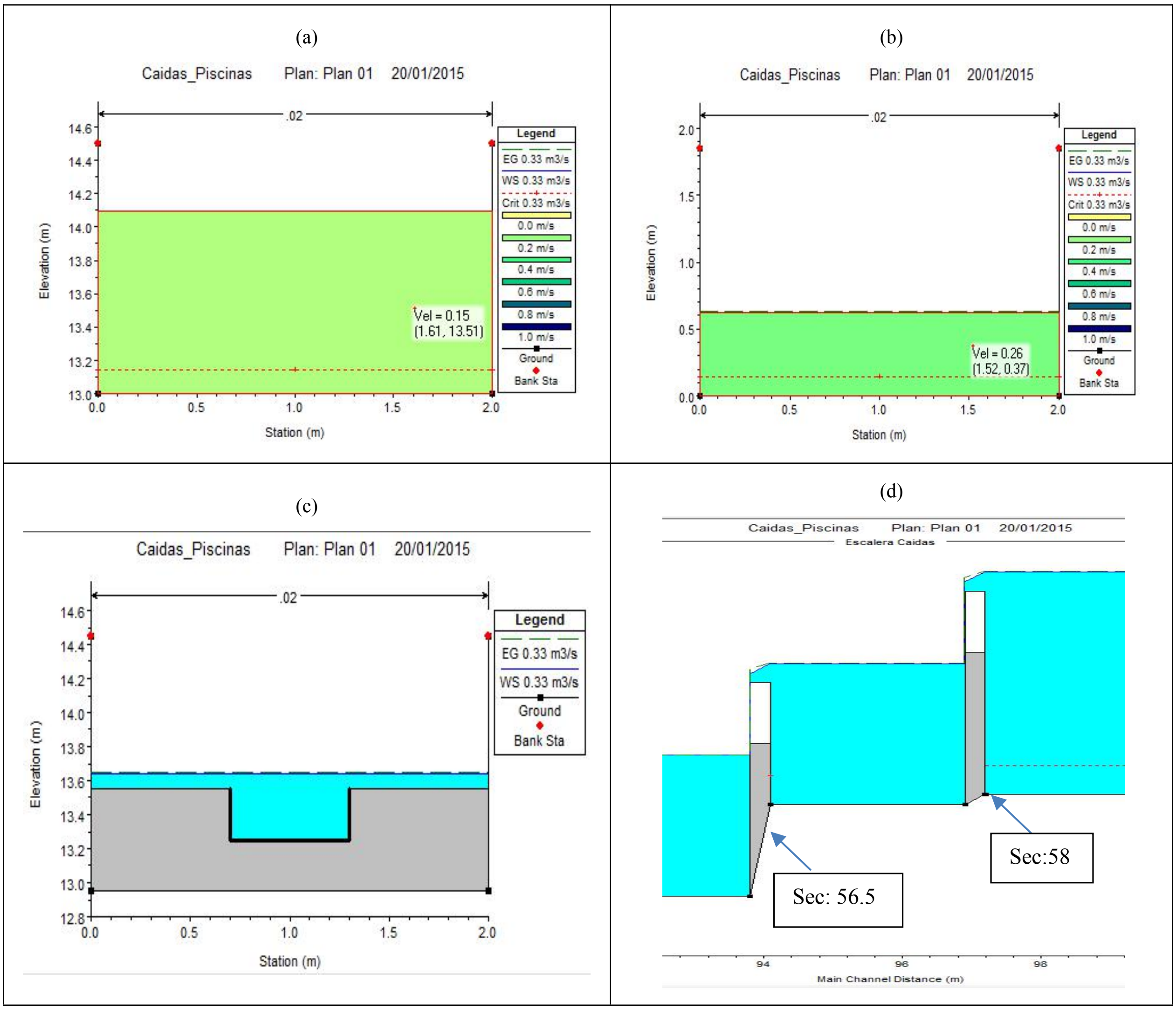

Fig. 5 (a) Section No. 60, average flow rate at the start of the stairs (upper section), (b) Section No. 1 considered the end of the ladder for prawns (lower section), (c) Section 56.5, the tie that will occur in the pools (Y = 0.7 m), is observed and on the walls of landfill, with a head h = 0.1 m. (d) Longitudinal segment of the hydraulic profile of the ladder to prawns

IV. DISCUSSION

A. Dimensioning of the Ladder as Function of the Migrant Population

It has been observed an inverse relationship between altitude and population density for both dry season ($y = 1.5587e^{-0.002x}$, $R^2 = 0.746$) and wet season ($y = 0.9297e^{-0.002x}$, $R^2 = 0.957$). This result was similar to those reported [16], in Ocoña rivers ($y = 3192.1e^{-1.532x}$, $R^2 = 0.779$) and Cañete ($y = 1267.8e^{-5.493x}$, $R^2 = 0.586$). Under the consideration that the density altitudinal strata has a gradient inverse relationship with altitude in the rivers of Arequipa [17], and this being as a result of migration, the most critical situation was adopted in the calculations (maximum intensity of migration) 10.08 camarones.min^{-1}. This estimate was based on the assumption that the existing population on the benchmark (880 m.o.s.l.) had migrated the previous year and the migration period (at the end of the wet season). This assumption is considering that each year a replacement of 100 per cent of the population, an aspect that merits study for further analysis.

Considering the distribution of the population was estimated that 2.1 per cent and 10.3 per cent of the population of prawn Ocoña River, in wet and dry, respectively, when waters were above the diversion of water to the projected hydroelectric plant, which would represent the population to be served with the migration system of the present study. In papers published on this in [18] and [19], they considered the migration of young recruits ranging from coastal water to fresh water. These works were focused in terms of swimming speed (m.s^{-1}) and swimming endurance (s). Otherwise, [20] studied the effect of effort in swimming on glucose levels in lymph freshwater prawn. The aforementioned aspects of these works done were taken into account in order to have a better sizing migration step for river prawn and reduce to a minimum the effect of their migratory movement. Given that there are no migrations step works on prawn, were taken as reference background fish. As noted [7], one of the main factors for the design of the fishway is swimming performance, resulting in the hydraulics of a staircase in a barrier when the flow rate exceeded the capacity of swimming the species.

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B. Architectural and Hydraulic Characteristics Prawn Pass

A migration staircase will be well dimensioned, if it allows the passage of the total population of migrant prawn in a period corresponding to the period of natural migration time, in such a density that prevents cause damage to each other, and without suffering physiological changes in the effort to transit the migration steps. On the one hand, has been stressed that the ability of swimming expressed in terms of speed and swimming endurance is an important design [21] factor. On the other hand, it is necessary to ensure, compatibility between the hydraulic operating conditions of the migration passage with the displacement capabilities of the species, in order to achieve the design functionality [22].

Among the variety of types of stairs, the pool-weir model adopted in this study is considered a good solution, which is recommended where several migratory species [11] exist, therefore, in our opinion it was the most appropriate given the lack of knowledge of aquatic species that exist in the Ocoña River. In addition it should be noted the behaviour observed in prawn during their displacement, facing obstacles in the river bed, opting to overcome them by crawling out of the water to wet surfaces, for several minutes (Fig. 3b). Due to this capacity of the species, was considered a maximum water depth of 0.10 m to the sides of the notches, in the weirs of the migration ladder (Fig. 5a) [23], describes the water flow characteristics in rectangular weir with notches in straight type, found stagnant regions where the flow velocity was almost zero, creating behind the weir a resting place, which is an additional advantages of the current design.

In relation to the water flow calculated for fish passage, reference [24] notes that should represents 1 to 5 per cent of the water flowing out of the way of migration, which in this case corresponds to the ecological flow, that will pass through the bypass dam gates, estimated flow rate between 6 and $10 m^3.s^{-1}$. While the results meet the above percentage, in the case of prawn, paying attention to its ability to creep, it is rather the surface (m^2) displacement, the dimension that defines the ability of migration because it is a benthic species. A bad sizing of water flow or changes in the management of the dam and inadequate dimensions associated with excessive turbulence, currents, water column, the presence of material clogging or lack of maintenance [6], will lead to a wrong migration step operation.

In relation to hydraulic fishways, modelling with Hec-Ras, allowed to obtain dimensioning values close to those recommended by [11], indicating falling 0.45 m corresponding to a maximum speed of $3.0 m.s^{-1}$ dimensions, and pool length (L) within the range 7 to 12 times the dimension of the recess located in the landfill (Fig. 4). Regarding the water column in the pool, the design meets what recommended by [11] for water free falls between pools, a minimum of twice the level difference between them. Regarding the rate of energy dissipation, [25], under laboratory conditions, found a maximum value of 105 W. m^{-3} for 54 $L.s^{-1}$ and 220 W. m^{-3} with flow rate of 615 $L.s^{-1}$, and has been 150W. m^{-3} accepted for trout [26]. These values are lower than the values of this study (433.56 W. m^{-3}), probably because it laboratory scale model.

V. CONCLUSIONS

It is concluded that the appropriated type for the migration passes, for *C. caementarius*, is the so-called “pool and weir”, equipped with rough surfaces so that the prawn can be to climbing the slopes between pools. This designed passage on the diversion dam on the Ocoña River is an important contribution to the conservation of a species of crustacean, commercial and environmentally valued and at the same time is a tool to make the most friendly hydropower projects to environment. Taking into account the knowledge of the species biology and hydraulic characteristics of its habitat, it is concluded that the architecture and dimensioning defined in this study are a good approach to design that fits population densities of the species in the area of study, not only to cope with hydraulic calculation, but also because it responds to population densities and to the travel habits in their natural environment.

It is advisable, based on the progress made in the fish passes design for several species, to begin studies on fresh water prawn, based on the physiology of its displacement and the hydraulic parameters of the built structures for migration and modeling of water currents, in order to do not affect them during their migration. Finally, perform migration tests using physical models of traditional migration structures as well as those of recent developments, such as meander-type fish passes.

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REFERENCES

[1] A. Mendiola, C. Aguirre, O. Aguilar, S, Castillo, G.Giglio, and W. Maldonado, “Power Generation Projects in Peru: Hydroelectric Power Plants or Thermal Power Plants?” Development Management Series 28, ESAN University. Lima, Peru, 130p., 2012.

[2] J. S. Baron, N. Le Roy Poff, P. L. Angermeier, C. N. Dahm, P. H. Gleick, N.G. Hairston, R. B. Jackson, C. A. Johnston, B. D. Richter, and A. D. Steinman, “Meeting Ecological and Societal Needs for Freshwater,” *Ecological Applications*, 12(5), pp. 1247-1260. 2002.

[3] C. Katopodis and J.G. Williams, “The Development of Fish Passage Research in a Historical Context,” *Ecological Engineering*, vol. 48 (November), pp. 8-18. 2012.

DOI: 10.5963/JWRHE0601001

[4] P. Baumann and G. Stevanella, “Fish passage principles to be considered for medium and large dams: the case study of a fish passage concept for a hydroelectric power project on the Mekong Mainstemin Laos”, *Ecological Engineering*, vol. 48 (November), pp. 79-85. 2012.

[5] C. Katopodis, “A review of recent advances in ecohydraulics”, *E-Proceedings of the 36th IAHR World Congress 28 June - 3 July 2015*, The Hague, The Netherlands, 2015.

[6] M. Larinier, “Fishways” - General Considerations. Bulletin Français de la Pêche de la Pisciculture, vol. 364, supplément, pp. 21-27.

[7] J. Puertas, L. Cea, M. Bermúdez, L. Pena, A. Rodríguez, J. R. Rabuñal, L. Balairón, A. Lara, and E. Aramburu, “Computer application for the analysis and design of vertical slot fishways in accordance with the requirements of the target species,” *Ecological Engineering*, vol. 48 (November), pp. 51-60.

[8] G.L. Ziemer, “Fish Transport in Waterways”. Alaska Dept. of Fish and Game, 10p, 1961.

[9] W.A. Evans and F.B. Johnston, “Fish migration and fish passage: a practical guide to solving fish passage problems,” USDA Forest Serv., Region 5, 43p, 1980.

[10] G. S. Armstrong, M. W. Aprahamian, G. A. Fewings, P. J. Gough, N. A. Reader, P. V. Varallo, “Environment Agency Fish Pass Manual: Guidance Notes on the legislation, selection and approval of fish passes in England and Wales”, Document GEHO 0910 BTBP-E-E. United Kingdom, Nov. 2010.

[11] M. Larinier, “Pool Fishways, Pre-Barrages and Natural Bypass Channels”. Bulletin Français de la Pêche et de la Pisciculture, vol. 364 supplément, pp. 54-82.

[12] National Service of Meteorology and Hydrology of Peru. 2015. website. [Online]. Available: http://www.senamhi.gob.pe/main_mapa.php?t=dHi.

[13] ECSA Ingenieros. “Limnological Fisheries Assessment in the Influence Area of the Ocoña Hydroelectric Project”. Lima-Perú. 128 pp. 2011.

[14] J. Wasiw G. and V. Yépez P. “Population Assessment of the *Cryphiops caementarius* Shrimp in Rivers of the Southern Coast of Peru”. Rev. investig. vet. Perú, 26(2). Lima, Apr. 2015.

[15] V. Yépez y R. Bandín, “Estimation of shrimp population, *Cryphiops caementarius* Molina 1782 (Natantia, Palaemonidae), in the Ocoña, Majes-Camaná and Tambo rivers”, Inf. Prog. Inst. of the Peruvian Sea 43: 3-31, 1996.

[16] Zacarías R., S., and Yépez P., V. Monitoring of river prawn population. Estimation of adult abundance in rivers of the South Central Coast. Annual Report 2007, Inst. of the Peruvian Sea, 2008.

[17] V. Yépez, and R. Bandín. “Evaluation of the resource *Cryphiops caementarius* shrimp in the rivers Ocoña, Majes, Camaná and Tambo”, Inf. Prog. Inst. of the Peruvian Sea, 77, 76p, 1997.

[18] C. Flores-Coto, J. Becerril-Martínez, G. A. Zavala-García, and John S. Burke, “Shrimp postlarvae immigration during the high current velocity period of the flood tide in the Southern Gulf of Mexico”. *Hidrobiológica*, 20(1), pp. 1-12. 2010.

[19] A. Wakida-Kusunoki, A. González, M. Medellín, and F. Arreguín-Sánchez. “Emigration assessment of the Brown Shrimp *Farfantepenaeus aztecus* through Mezquital Inlet, Tamaulipas, Mexico”. *Hidrobiológica*, 20(3), pp. 256-65, 2010.

[20] R. T. Bauer, “Amphidromy in Shrimps: A Life Cycle between rivers and the Sea”, Studies on Freshwater Decapods in Latin America, Lat. Am. J. Aquat. Res., 41(4), pp. 633-650, 2013.

[21] M. Larinier, “Biological Factors to be taken into account in the design of Fishways”, The Concept of obstructions to upstream migration. Bulletin Français de la Pêche et de la Pisciculture, No. 364, supplément, pp. 28-38, 2002.

[22] J. M., Santos, A., Silva, C. Katopodis, P. Pinheiro, A. Pinheiro, J. Bochechas, and M. T. Ferreira, “Ecohydraulics of Pool-Type Fishways: Getting Past the Barriers,” *Ecological Engineering*, vol. 48 (November), pp. 38-50, 2012.

[23] J. H. Kim, “Hydraulic characteristics by weir type in a pool-weir fishway”, *Ecological Engineering*, vol. 16, pp. 425-433, 2001.

[24] M. Larinier, “Location of Fishways”, Bulletin Français de la Pêche et de la Pisciculture, No. 364, supplément, pp. 39-53, 2002.

[25] O. Yagci, “Hydraulic aspects of pool-weir fishways as ecologically friendly water structure”, *Ecological Engineering*, 36(1), pp. 36-46, 2010.

[26] R., T. Teijeiro, A. J. Puertas, M. L. Peña, and G. E. Peña, “Evaluating Vertical-Slot Fishway. Designs in Terms of Fish Swimming Capabilities”, *Ecological Engineering*, 27(1), pp. 37-48, 2006.

DOI: 10.5963/JWRHE0601001