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Assisted management of water exchange in traditional semi-intensive aquaculture ponds

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ABSTRACT

Grid gates with multiple sharp-crested rectangular orifices are used to control manually water discharge from branch channels to semi-intensive aquaculture ponds. Experimental and analytical analysis related to the discharge characteristics of these grid gates under submerged flow conditions have been presented in this paper with the objective to integrate the results in an support system to control the water exchange management. Experimental analysis was carried out in the laboratory using a scaled model. Steady-state hydraulic data were measured and collected for each tested grid gate considering different orifices number and flow rates. Multiple linear regression (MLR), factorial regression (FR), polynomial regression (PR), hybrid model (PR + FR) and generalized linear model (GLM) were evaluated to determine the relationship between the coefficient of discharge C_d and the non-dimensional parameters ω/h_1^2, b/h_1 and h_3/h_1 (ω is the total cross section of discharge; h_1 is the upstream water level of the grid gate; h_3 is the downstream water level of the grid gate; and b is the width of the channel) which were obtained by the analysis dimensional. Of all these approaches, the best fits were obtained using a FR + PR hybrid model and a GLM model with only two non-dimensional parameters ω/h_1^2 and h_3/h_1 as independent variables. These models produced errors not higher than ±3%. The best GLM model and the aquaculturist knowledge in relation to the management of water exchange were integrated in a computer program namely 'Gate management' which was implemented in the ACUIGES system.

1. Introduction

More than 40% of aquaculture worldwide production is carried out in semi-intensive facilities with diversion earth ponds which are usually built by excavating pits and building dikes (Lekang, 2007). In Southern Spain (Andalucía region), the fish rearing systems in traditional earth ponds (namely 'esteros') is approximately the 60% of aquaculture production (Gutiérrez-Estrada et al., 2012) which has significantly contributed in the last years to the regional economy. In a near future, this traditional aquaculture sector should be positioned like as a solid and developed industry able to get a competitive and sustainable yield. For this adaptation it will be required to improve the efficiency and cost-effectiveness of existing plants (Pulido-Calvo et al., 2008; Liu et al., 2013). Therefore, processes that facilitate the fishfarm management while satisfying system performance criteria should be implemented. Particularly, in this type of systems, one of the processes that can be assisted is the water exchange in the ponds.

Currently, water exchange management in these semi-intensive systems is carried out manually by means of a gates system namely 'grid gates'. For this, the aquaculturist puts between two guides located in the pond input a series of grids and planks made of wood to control roughly the water discharge to the pond. The number of grids and planks to put in the guides is depending only on the experience and knowledge of the aquaculturist whom makes a heuristic decision in function of the values of several water quality parameters as water temperature, ammonia, turbidity or dissolved oxygen concentration. Therefore, there is a need of a support system for the water exchange management, which would significantly reduce the risk of a failure in the system as a consequence of a human contingence.

Three steps are necessary to develop this type of support systems: (a) to capture the experience and knowledge of the aquaculturist concerning the operation of the water exchange in the ponds for maintaining the water quality; (b) to know the flow discharge through the grid gates used in these semi-intensive aquaculture ponds for what is necessary to obtain its discharge equation; and (c) to implement the modeled knowledge of the aquaculturist and the discharge equation in a computer program. This would permit us replace the traditional grid gates by a set of penstock gates motorized.

In relation to the first step, Gutiérrez-Estrada et al. (2012) modeled efficiently the behavior of the aquaculturist in this water

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exchange process using Neural networks and Fuzzy logic controllers. Concretely, the models developed by these authors provided levels of correlation between 0.73 and 0.75 which is suitable considering the complexity of the decision making in these yield systems.

The second step is one of the main difficulties to develop the support system for the water exchange process due to the nonexistence of a specific discharge equation for this type of grid gates in open channels. To know the flow discharge of the traditional grid gates used is a key factor to integrate the modeled behavior of the aquaculturist with a new system of motorized gates.

The hydraulic behavior and the discharge capacity of different type of weirs, sluice gates and orifices in open channels have been investigated extensively in the specialized literature (Swamee et al., 1993; Ojha and Subbaiah, 1997; Muslu, 2002; Ghodsian, 2003; Sepúlveda et al., 2009; Bilhan et al., 2010; Hussain et al., 2010, 2011). In these researches, a physical hydraulic model is commonly used and is usually a smaller-size representation of a hydraulic flow situation (i.e. the prototype or the full-scale structure). The model is investigated in a laboratory under controlled conditions. Dimensional analysis and similarity theory can be used in these experiments with models to estimate the behavior of prototype flow situations (Munson et al., 2002).

Therefore, discharge capacity of the traditional grid gates (with multiple sharp-crested rectangular orifices) used in semi-intensive fishfarms in the Southern Spain has been investigated through experimentation and analytically in this paper with the objective to obtain an analytical approach to relate the water discharge to the pond and several geometrical parameters of the grid gate. This is a basic topic if we want integrate the modeled behavior of the aquaculturist in a support system to control the water exchange management.

Finally, the aquaculturist behavior modeled by Gutiérrez-Estrada et al. (2012) and the analytical equation of the traditional grid gate obtained in this work have been integrated in a new computer tool of the ACUIGES program. ACUIGES is a modular program developed in Microsoft Visual Basic© which integrates different aspects about engineering design, biology, management and control of several reared species (Pulido-Calvo et al., 2006; Pulido-Calvo et al., 2008).

2. Material and methods

2.1. Study area and general procedure

In order to test the methodology developed in this study, the ‘Langostinos de Huelva S.A.’ semi-intensive fishfarm located in Southern Spain was selected. This fishfarm is located in the province of Huelva (Southern Spain) and is devoted to gilthead seabream (*Sparus aurata*) production. One of the main reasons for which this fishfarm was selected was that during several years, the production of this fishfarm has been to the limit of its carrying capacity which is an indicative of a proper general operation. Concretely, in relation to the water management, firstly the water is pumped from a tributary of the Piedras River to two regulation reservoirs. From these reservoirs, the water is manually regulated to the ponds by distribution channels. As noted above, this management is carried out exclusively in function of the acquired experience of the workers during the last years. The details of how this knowledge was modeled (step 1) can be checked in Gutiérrez-Estrada et al. (2012).

In a step 2, we built to scale (1:9) traditional planks and grid gates to experimentally obtain a discharge equation by mean dimensional analysis. This process is described in detail in the Sections 2.2–2.4 of this work. Finally, in a step 3, the modeled behavior of the aquaculturist and the discharge equation of the traditional grid gates were implemented in a tool (Gates management) which was integrated in the ACUIGES system (Section 2.5). Fig. 1 shows a scheme-resume of the steps followed to automate the water exchange process.

2.2. Discharge equation for rectangular orifices

For a small rectangular orifice with constant pressure distribution over the flow area, it is possible derive, using the energy conservation equation, the following widely known discharge expression:

$$Q = C_d \omega \sqrt{2g(h_1 - h_3)} \tag{1}$$

where Q is the flow discharge, ω is the area of the rectangular orifice, h_1 is the upstream water level, h_3 is the downstream water level, g is the acceleration due to gravity and C_d is called the discharge coefficient which integrates geometric, viscous and surface tension effects.

In the study case of a discharge through a grid gate with multiple rectangular orifices, Eq. (1) may think that could be modified considering ω as the total cross section of all the orifices (Fernando-Cadena and Magallanez, 2005; Bryant et al., 2008).

In most practical situations in different type of weirs, sluice gates and orifices in open channel, the viscous and surface tension effects may be neglected for fluids of moderate viscosity (Ranga-Raju and Asawa, 1977; Ballester and Dopazo, 1994) and therefore C_d can be considered exclusively as a function of the geometric parameters (USBR, 1997; Munson et al., 2002; Martínez et al., 2005; Sepúlveda et al., 2009). So, it is found that probable variables affecting the discharge coefficient C_d for a grid gate are: (a) the total cross section ω of discharge of all the orifices; (b) the width b of the channel; (c) the upstream water level h_1 of the grid gate; and (d) the downstream water level h_3 of the grid gate. The functional relationship for the discharge coefficient C_d may, thus, be written as:

$$C_d = f_1(\omega, b, h_1, h_3) \tag{2}$$

Taking h_1 as the repeating variable for the dimensional analysis, the functional relationship for C_d in terms of non-dimensional parameters may be written as:

$$C_d = f_2\left(\frac{\omega}{h_1^2}, \frac{b}{h_1}, \frac{h_3}{h_1}\right) \tag{3}$$

Data collected in the present experimental study were analyzed to investigate the effect of the above non-dimensional parameters on C_d.

2.3. Experimental setup

Hydraulic data were obtained by carrying out experiments in the Fluid Mechanics Laboratory of Huelva University, Spain. Experimental set-up consists of a zero-slope channel with a rectangular cross section and the following dimensions: 2.5 m length, 0.082 m width and 0.25 m depth (Fig. 2a). The channel consists of a smooth well-painted steel bed and it has vertical glass sidewall. It has an upstream head reservoir to supply water at a constant level and a rectangular weir at the downstream end to control flow depth. The planks and grids of the tested gates were made of balsa wood and the guides of aluminum. The dimensions of a grid are $8.2 \times 4 \times 0.275$ cm and the dimensions of the orifices are $1.7 \times 0.33 \times 0.275$ cm (ϕ_i) and $3.85 \times 0.33 \times 0.275$ cm (Φ_j) (Fig. 1, step 2 and Fig. 2a).

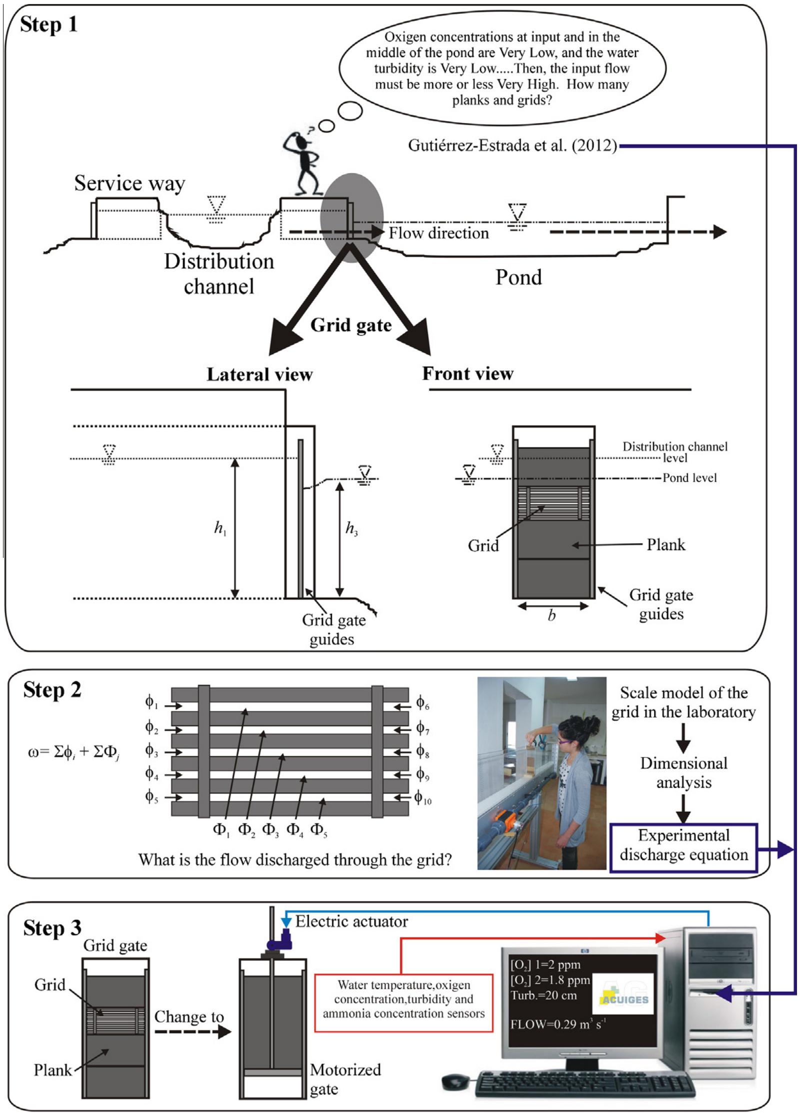

Fig. 1. Schematic representation of the steps followed to develop the support system for water exchange in semi-intensive aquaculture ponds. h_1 is the upstream water level of the grid gate, h_3 is the downstream water level of the grid gate, b is the width of the grid gate, ϕ_i is the discharge area of the rectangular orifice i, Φ_j is the discharge area of the rectangular orifice j and ω is the total cross section of discharge of all the orifices.

Water was supplied to the channel through a PVC supply pipe 32 mm in diameter. Water was pumped from a tank with 250 l capacity using a horizontal centrifugal pump (flow range from 20 to 120 l/min; energy head range from 9 to 22 m; frequency of 50 Hz; rotation speed of 2900 rpm). The flow was controlled by a gate valve and the discharge was measured to an accuracy of ±0.05 l/s by means of a KOBOLD MIK magneto-inductive flowmeter installed in the supply line.

Flow depths h_1 and h_3 (Fig. 2b) were measured with a precision manual millimeter having an accuracy of ±0.1 mm. Steady-state hydraulic data (water levels and flow rates) were measured for each grid gate considering different orifices number and flow rates. These different flow rates (approximately variations of 1 l/min) were obtained opening gradually the valve installed in the supply line. These experiments were carried out with the grid gates submerged. This hydraulic condition was assessed by visual inspection. The various degrees of submergence were achieved by varying the rectangular weir at the downstream end of the channel.

The range of data collected in the present study is given in Table 1. For each grid gate tested (gate with one grid – with 15 orifices and gate with two grids – with 30 orifices), the relationship between the difference of water levels h_1–h_3 and the flow rates Q is presented in Fig. 3. As can be seen, there is no discontinuity over the whole range of flows.

2.4. Fitting of the equation of the discharge coefficient C_d

The coefficient of discharge C_d is computed for each data set collected in the present study for known values of ω, h_1 and h_3 using Eq. (1). The relationship between C_d and the non-dimensional parameters ω/h_1^2, b/h_1 and h_3/h_1 obtained by the dimensional analysis (Eq. (3)) is evaluated using multiple linear regression (MLR), factorial regression (FR), polynomial regression (PR) and generalized linear model (GLM) (Green and Silverman, 1994).

The aim of multiple linear regression (MLR) analysis is to obtain a linear equation that allows the dependent variable or criterion y, to be estimated when the values of the q independent or predictive variables $x_1, \ldots, x_q$ are known:

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_q x_q \tag{4}$$

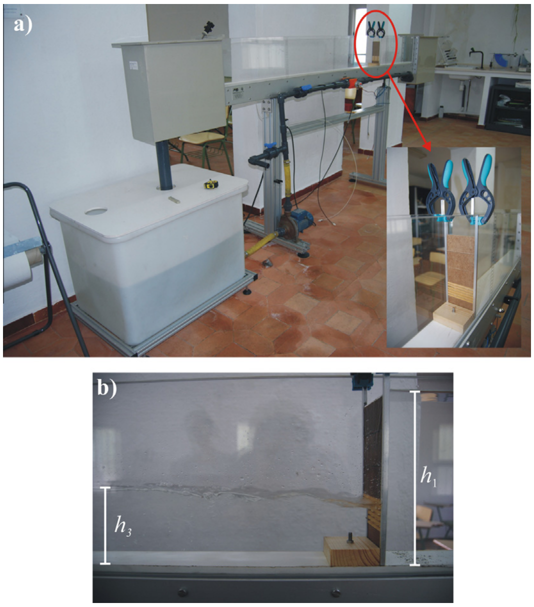

Fig. 2. (a) Detail of the experimental channel. (b) Detail of a grid gate model (scale 1:9). h_1 is the upstream water level of the grid gate and h_3 is the downstream water level of the grid gate.

Table 1
Range of data collected in the present study.

Parameter	Unit	Range data	
		Minimum	Maximum
Gate with one grid (15 orifices with ω = 0.0011 m^2) – 44 data collected			
Discharge through the grid gate Q	l/min (m^3/s)	14.5 (0.0002)	56.6 (0.0009)
Grid gate upstream water level h_1	m	0.083	0.205
Grid gate downstream water level h_3	m	0.080	0.159
Gate with two grids (30 orifices ω = 0.0022 m^2) – 55 data collected			
Discharge through the grid gate Q	l/min (m^3/s)	32 (0.0005)	107 (0.0018)
Grid gate upstream water level h_1	m	0.120	0.243
Grid gate downstream water level h_3	m	0.096	0.165

where the parameters β_0, β_1, …, β_q represent the contributions of each independent variable to the estimation of the dependent variable.

Factorial regression (FR) is defined as a design in which all or some possible products of the continuous predictor variables are represented. For example, the full-factorial regression design for two continuous predictor variables x_1 and x_2 would include the first-order effects of x_1 and x_2 and their two-way x_1 and x_2 interaction effect:

$$y = \beta_0 + \beta_1 x_l + \beta_2 x_2 + \beta_3 x_1 x_2 \tag{5}$$

Factorial regression (FR) designs can also be fractional, that is, some effects can be omitted from design. Polynomial regression (PR) designs contain main effects (i.e. the first-order effects) and higher-order effects for the continuous predictor variables but do not include interaction effects between predictor variables. For example, the polynomial regression design to degree two for two continuous predictor variables x_1 and x_2 would include the first-order effects of x_1 and x_2 and their quadratic effects (i.e. second-order effects):

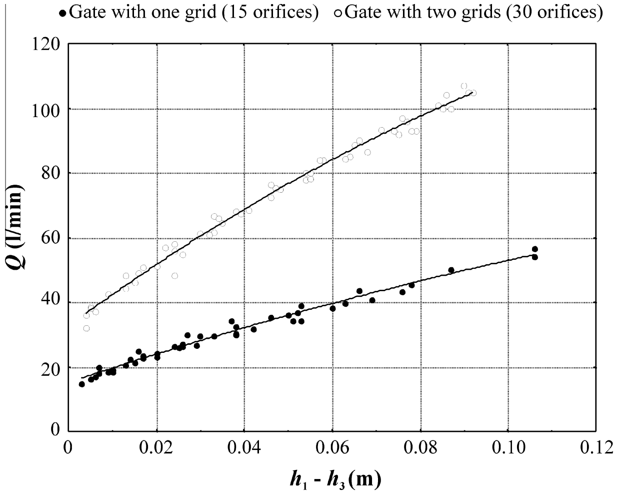

Fig. 3. Relationship between the difference of water levels h_1–h_3 and the flow rates Q for each grid gate tested (gate with one grid – with 15 orifices and gate with two grids – with 30 orifices).

$$y = \beta_0 + \beta_1 x_l + \beta_2 x_l^2 + \beta_3 x_2 + \beta_4 x_2^2 \tag{6}$$

Polynomial regression (PR) designs do not have to contain all effects up to the same degree for every predictor variable. Hybrid designs (PR + FR) with characteristics of both polynomial regression (PR) and factorial regression (FR) have been also evaluated. For example, the hybrid model for two continuous independent variables x_1 and x_2 would include the first-order effects of x_1 and x_2, their quadratic effects and their two-way x_1 and x_2 interaction effect:

$$y = \beta_0 + \beta_1 x_l + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_l^2 + \beta_5 x_2^2 \tag{7}$$

The generalized linear model (GLM) differs from the multiple linear regression (MLR) in that the dependent variable values are predicted from a linear combination of predictor variables (independent variables), which are 'connected' to the dependent variable via a link function. The relationship in the generalized linear model (GLM) is assumed to be:

$$y = g(\beta_0 + \beta_1 x_l + \cdots + \beta_q x_q) \tag{8}$$

where $g(\ldots)$ is a function. The inverse function of $g(\ldots)$, that is $f(\ldots)$, is called the link function and so:

$$f(mu_y) = \beta_0 + \beta_1 x_l + \cdots + \beta_q x_q \tag{9}$$

where mu_y stands for the expected value of y. Various link functions can be chosen as ln link [$f(mu_y) = \ln(mu_y)$], power link [$f(mu_y) = (mu_y)^a$ for a given a] and logit link [$f(mu_y) = \ln(mu_y/1 - mu_y)$].

For all models, a backward stepwise method was selected to obtain the coefficients β_i. For selecting the best-fit equation that represents the agreement between the observed and estimated values, three accuracy measures were used: the coefficient of determination or the square of the Pearson's product-moment correlation coefficient (r^2), the square root of the mean square error (RMSE) and the mean absolute percentage error (MAPE) (Legates and McCabe, 1999; Pulido-Calvo and Portela, 2007; Sepúlveda et al., 2009; Hussain et al., 2010).

2.5. Integration of aquaculturist behavior and the equation of the discharge in the ACUIGES program

The aquaculturist behavior modeled by Gutiérrez-Estrada et al. (2012) and the analytical equation of the traditional grid gate obtained in this work have been integrated in a new tool (Gates

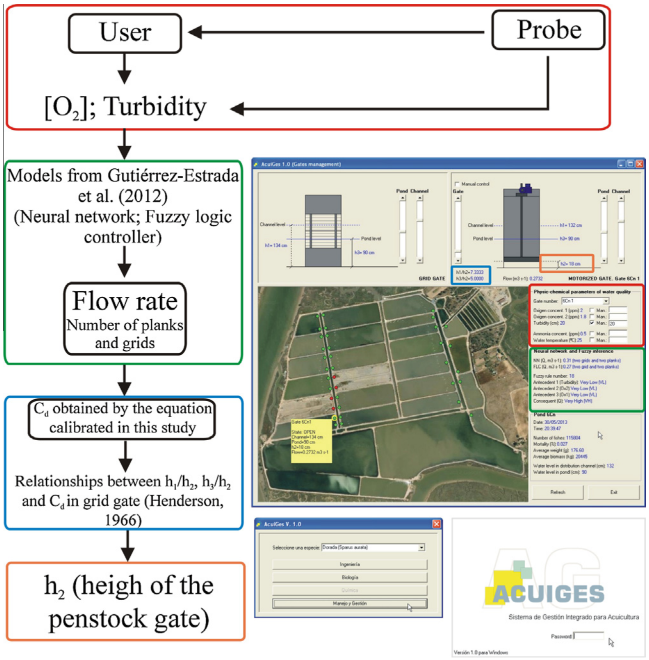

Fig. 4. Main window of 'Gate management' module of ACUIGES system and flow chart of the integration process of the calibrated models by Gutiérrez-Estrada et al. (2012) and the best approach to obtain the discharge coefficient of grid gates.

management) of the ACUIGES program (Fig. 4). ACUIGES is a modular program developed in Microsoft Visual Basic© which integrates different aspects about engineering design, biology, management and control of several reared species (Pulido-Calvo et al., 2006; Pulido-Calvo et al., 2008).

The 'Gates management' tool searches the equivalence between the flow discharged through a traditional grid gate (in which, the number of grids and planks is inferred by the models calibrated by Gutiérrez-Estrada et al. (2012); see Fig. 4, box entitled Neural network and Fuzzy inference) and the height at which a penstock gate should be elevated so that the same flow is discharged. For that, seven experimental curves obtained by Henderson (1966) relating the pond level (h_3) and the penstock gate height (h_2) (h_3/h_2; see Fig. 4; Munson et al., 2002) and comprising a range of the relationship channel level (h_1) and penstock gate height (h_2) (h_1/h_2, see Fig. 4; Munson et al., 2002) between 0 and 16 were plotted and integrated. From the experimental relationships between h_3/h_2 and h_1/h_2 is possible to calculate the discharge coefficient (C_d) of a penstock gate. For any C_d, knowing the channel level and the discharging flow, the penstock gate height can be calculated as:

$$h_2 = \frac{Q}{bC_d\sqrt{2gh_1}} \quad (10)$$

3. Results and discussion

A thorough evaluation of the results of the analysis of multiple linear regression (MLR), factorial regression (FR), polynomial regression (PR) and generalized linear model (GLM), revealed that the non-dimensional parameters ω/h_1^2 and h_3/h_1 are the predominant parameters which affect the discharge coefficient C_d. For all fits tested, including all the possible effects (FR: effects of first-order and of interaction; PR: effects of first-order and of second-order; PR + FR and GLM: effects of first-order, of second-order and of interaction), the non-dimensional parameter b/h_1 was non-significant (significance level $p > 0.05$). In the calibration of the GLM models, the link functions ln, power (with $a = 2$) and logit were evaluated.

These results indicate that the models identified the variability associated with the width b of the channel contained in the total cross section ω of discharge of all the orifices and in the upstream and downstream water levels (h_1 and h_3) of the grid gates. This situation was expected since similar conclusions have been obtained in other studies in which geometric variables, initially considered in the dimensional analysis, did not have an effect predominant about the discharge coefficient C_d calculated of experimental data (Hussain et al., 2010, 2011). This effect, named proxy effect, has been reported previously in ecological modeling and water resources management studies (Czerwinski et al., 2007; Gutiérrez-Estrada et al., 2007, 2008; Watts and Worner, 2008; Pulido-Calvo et al., 2012). These have shown that candidate model inputs having a strong relationship with the model output are redundant because the same information is already provided by another input variable.

In Table 2 are shown the summary of the best-fits for the relationship for the discharge coefficient C_d for each analytical analysis

Table 2
Summary of the best models that describe the relationship between C_d and the non-dimensional parameters obtained by the analysis dimensional.

Multiple linear regression (MLR)		
$r = 0.67$; $r^2 = 0.46$; $F(2,96) = 40.135$; $p < 0.001$; RMSE = 0.07; MAPE = 5.00%		
	Coefficients β_i	Significance level p
Intercept	0.2958	<0.001
Independent variables		
ω/h_1^2	0.9591	<0.001
h_3/h_1	0.3390	<0.001
Factorial regression (FR)		
$r = 0.79$; $r^2 = 0.62$; $F(3,95) = 51.684$; $p < 0.001$; RMSE = 0.06; MAPE = 4.22%		
	Coefficients β_i	Significance level p
Intercept	0.7985	<0.001
Independent variables		
ω/h_1^2	8.0027	<0.001
h_3/h_1	−0.2889	0.0099
$[\omega/h_1^2]\cdot[h_3/h_1]$	10.9006	<0.001
Polynomial regression (PR)		
$r = 0.87$; $r^2 = 0.75$; $F(3,95) = 96.191$; $p < 0.001$; RMSE = 0.05; MAPE = 3.52%		
	Coefficients β_i	Significance level p
Intercept	1.9198	<0.001
Independent variables		
ω/h_1^2	0.9006	<0.001
h_3/h_1	−4.0856	<0.001
$[h_3/h_1]^2$	2.9340	<0.001
Hybrid model [factorial regression (FR) + polynomial regression (PR)]		
$r = 0.90$; $r^2 = 0.81$; $F(4,94) = 101.7426$; $p < 0.001$; RMSE = 0.04; MAPE = 2.94%		
Intercept	1.7985	<0.001
Independent variables		
h_3/h_1	−3.6854	<0.001
$[\omega/h_1^2]\cdot[h_3/h_1]$	5.2149	<0.001
$\left[\omega/h_1^2\right]^2$	−20.3941	<0.001
$[h_3/h_1]^2$	2.4565	<0.001
Generalized linear model (GLM)		
$r = 0.92$; $r^2 = 0.85$; deviance = 0.1254; degrees of freedom = 94; RMSE = 0.03; MAPE = 2.72%		
Intercept	1.4097	<0.001
Independent variables		
h_3/h_1	−5.9050	<0.001
$[\omega/h_1^2]\cdot[h_3/h_1]$	7.9634	<0.001
$[\omega/h_1^2]^2$	−30.6570	<0.001
$[h_3/h_1]^2$	3.9374	<0.001

proposed in this research (MLR, FR, PR, FR + PR, GLM). The best results of the accuracy measures were obtained with a generalized linear model (GLM), with a link function ln, that considers effects of first-order (h_3/h_1), of second-order ($\left[\omega/h_1^2\right]^2$ and $[h_3/h_1]^2$) and of interaction $\left(\left[\omega/h_1^2\right]\cdot[h_3/h_1]\right)$ for the independent variables. For this best model, the accuracy measures reached values quite satisfactory ($r = 0.92$; $r^2 = 0.85$; RMSE = 0.03; MAPE = 2.72%). So, the r^2 value indicates that this model explains 85% of the variability of the observed C_d values and the MAPE value indicates that this model is producing very smaller percentage errors, that is, of 2.72%.

Also the schematic representation of the observed C_d values (calculated using Eq. (1)) as a function of the estimated C_d values using the relationships obtained with the best MLR, FR, PR, FR + PR and GLM models (Table 2) (scatter plots between observed and estimated C_d) showed that the MLR model presented the highest dispersion along the line 1:1 (that would correspond to a perfect adjustment) while the GLM model denoted a higher approximation of observed and estimated C_d values. Scatter plots for the best MLR, FR, PR, FR + PR and GLM models are presented in Figs. 5 and 6. Notice mainly the tendency of the MLR and FR models to underestimate the high values of C_d ($C_d > 0.7$). The observation of these scatter plots supports the improvement in the percentage errors using FR + PR and GLM models (with percentage errors less than 3%) versus MLR, FR and PR models (with percentage errors in the range 3.5% < MAPE ⩽ 5%) (Table 2).

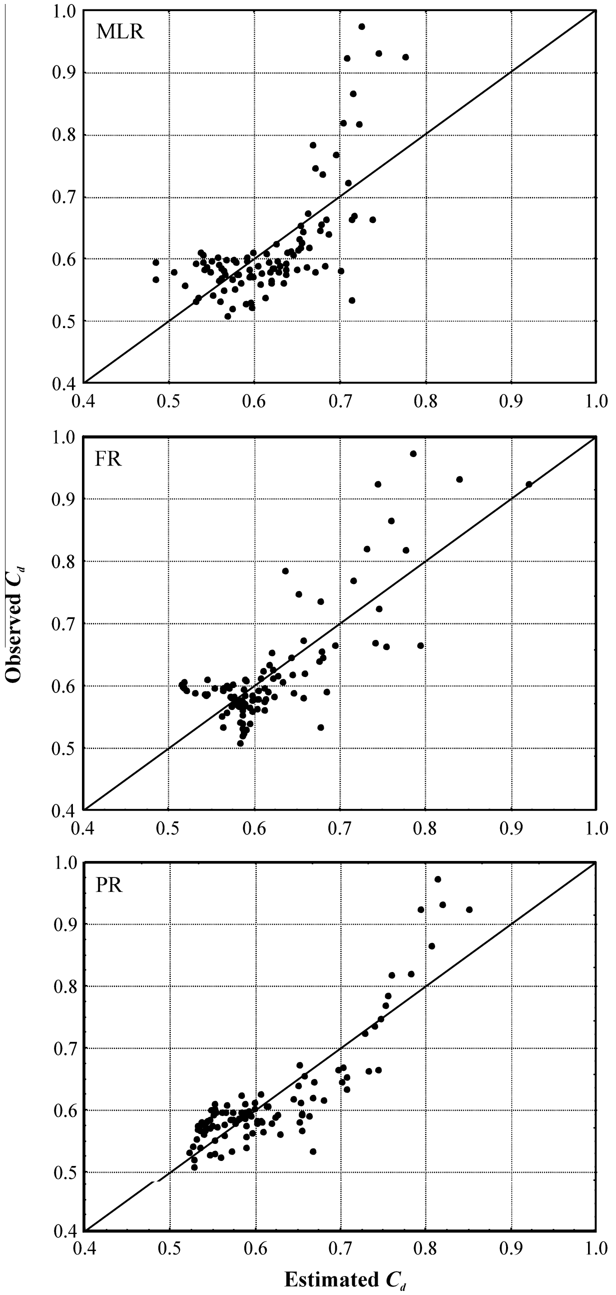

Fig. 5. Scatter plots between observed and estimated discharge coefficients C_d for the best models: multiple linear regression (MLR), factorial regression (FR) and polynomial regression (PR).

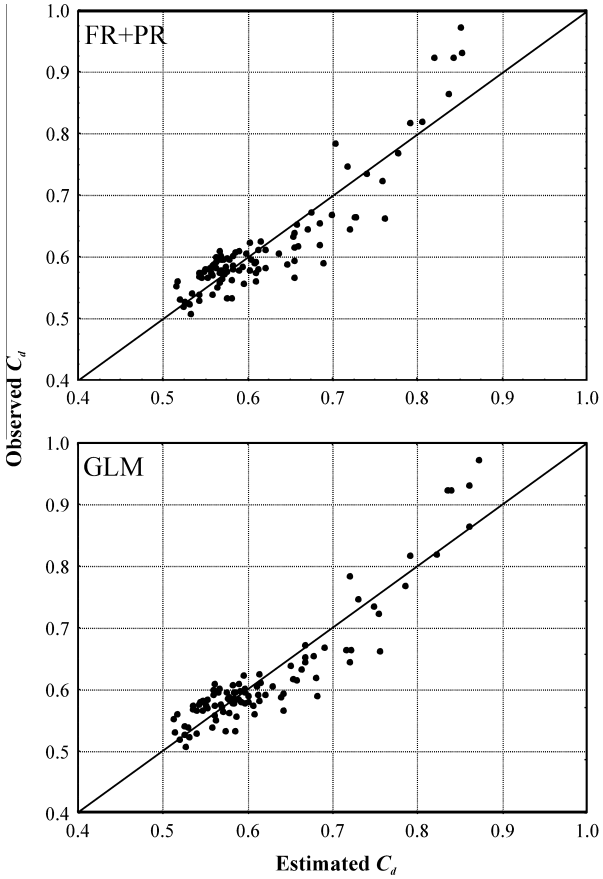

Fig. 6. Scatter plots between observed and estimated discharge coefficients C_d for the best models: hybrid model (FR + PR) and generalized linear model (GLM).

The grid gates were calibrated in the laboratory using a scaled model to avoid the difficulty of calibrating the prototypes in the aquaculture ponds. The prototypes considered as examples in this study were the grid gates used in the semi-intensive fishfarm, 'Langostinos de Huelva S.A.'. Based on the laboratory dimensions, a geometric scale of 1:9 ($\lambda = 1/9$) was chosen. In the study case (open-channel flow), the relationship between the flows in model Q_m and prototype Q_p can be obtained by applying the Froude number similarity (Munson et al., 2002), and as the gravitational conditions in model and prototype are the same, the resulting equation is $Q_p = \lambda^{2/5} Q_m$.

On the other hand, we have to point out that the experiments carried out in the laboratory were made with freshwater (with a mean temperature about 20 °C) while the aquaculture ponds are filled from brackish streams or lakes, and therefore in the aquaculture ponds the fluid is saltwater. The period of maximum frequency of water exchange rate in aquaculture ponds is usually performed when the mean water temperature are about 20 °C

(Gutiérrez-Estrada et al., 2012). At this temperature, the viscosity and surface tension of freshwater and saltwater are very similar, and therefore, seems sufficiently approximate considering the Froude number similarity between model and prototype.

These above considerations imply to disregard the effects of surface tension and viscosity on the discharging capacity of the grid gates studied, which can be supported by the researches for different weirs of Ranga-Raju and Asawa (1977), where for fluids of moderate viscosity, found that these effects can be neglected when the product $R^{0.2}W^{0.6}$ is greater than 900. Here $R = g^{1/2}h_1^{3/2}/v$ and $W = \rho g h_1^2/\sigma$, where g is the local acceleration due to gravity, h_1 is the weir head, v is the kinematic viscosity, ρ is the density and σ is the surface tension. In the present study, the product $R^{0.2}W^{0.6}$ is greater than 900 for all the data sets (range between 915 and 2775). Moreover, Ballester and Dopazo (1994) showed that the effects of viscosity had a significant influence on the discharge of heavy oils through nozzles when diameters were lower than 0.45 mm. As the orifices dimensions of the grid gates tested in this work are significantly higher to this value and the viscosities of freshwater and saltwater are significantly lower to the viscosities of heavy oils, the hypothesis considered in the analytical analysis developed can be accepted.

Gutiérrez-Estrada et al. (2012) used several different techniques to model the aquaculturist knowledge in relation to the water exchange process in the fishfarm in study. Between these, the best results were obtained with an artificial Neural network with two hidden layers with 10 and 5 neurons per layer and a Fuzzy Logic Controller in which the input and output variables were composed of three partitions. In both cases, the input variables were the turbidity and the oxygen concentration at the input and output of the pond. Both models were implemented in the 'Gate management' tool in such a way that the aquaculturist can select the model that the 'Gate management' will work or he/she can to obtain a combined result from both models (see Fig. 4, box entitled Neural network and Fuzzy inference). Obviously, in function of the results obtained in this work, the discharge coefficient of the grid gate was estimated using a GLM with a link function ln, that considers effects of first-order (h_3/h_1), of second-order ($[\omega/h_1^2]^2$ and $[h_3/h_1]^2$) and of interaction $\left(\left[\omega/h_1^2\right]\cdot[h_3/h_1]\right)$ for the independent variables. Therefore, this model was also integrated in the software developed.

4. Conclusions

A support system to control the water exchange management in semi-intensive aquaculture ponds has been presented in this paper. This system has been developed in three phases: (a) Characterization of the experience of the aquaculturist in relation to the knowledge of the water exchange management; (b) Determination of a relationship for the discharge coefficient of traditional grid gates; and (c) Integration of the previous phases in a computer program that allows the automatic control of motorized penstock gates.

The performance of several calibration methods for the relationship for the discharge coefficient of submerged grid gates using experimental data of a laboratory canal has been tested. The results indicated that the discharge coefficient depends mainly on the total cross section of discharge of the multiple orifices and the upstream and downstream water levels of the grid gate. It has been found that the best models of all the calibration methods proposed presented mean errors not higher ±5%. It is recommended to use the generalized linear model (GLM) proposed because this model is producing the lowest percentage error of 2.72%.

Our findings suggest that gate discharge can be estimated with high accuracy and reliability using the equation proposed in this paper. This equation was easily implemented in a new tool namely 'Gate management' which was integrated in the ACUIGES system.

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