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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).