DOI: https://doi.org/10.25100/iyc.v19i2.5298

ENVIRONMENTAL ENGINEERING

Water footprint messure method for tilapia, cachama and trout production: study cases to Valle del Cauca (Colombia)

Metodología para la medición de la huella hídrica en la producción de tilapia, cachama y trucha: estudios de caso para el Valle del Cauca (Colombia)

Mario A. Pérez-Rincón[§1], Isabel C. Hurtado[1], Sergio Restrepo[1], Sara P. Bonilla[2], Héctor Calderón[2] , Andrés Ramírez[2]

[1]Instituto CINARA, Universidad del Valle. Cali, Colombia.
[2]Federación Colombiana de Acuicultores (FEDEACUA). Bogotá DC., Colombia.
mario.perez@correounivalle.edu.co, isabel.hurtado.s@correounivalle.edu.co, sergio.restrepo@correounivalle.edu.co, bonillasp@FEDEACUA.org, hector.calderon@FEDEACUA.org, andres.ramirez@FEDEACUA.org

(Recibido: Noviembre 29 de 2016 - Aceptado: Junio 20 de 2017)

Abstract

The pisciculture sector in Colombia, has grown 13% annually between 1988 and 2013, and it is the sixth major water user. Considering the influence that pisciculture has over the water resources, the water footprint of pisciculture was studied as a sustainability indicator, a method was developed to estimate the water footprint of the sector, which include not only the direct and indirect components, but also the green, blue and grey water footprint. The method was applied to the three most produced species in the country: tilapia (Oreochromis mossambicus), cachama (Piaractus brachypomus) and trout (Oncorhynchus mykiss), to corresponding case studies in Valle del Cauca, Colombia. It was found that the water footprint of tilapia culture is 5,486 m^3/Ton, cachama culture is 6,193 m^3/Ton, and trout culture is 19,854 m^3/Ton. The highest total water footprint for tilapia was that of the concentrated feed, followed by the blue water footprint, associated with the amount of water that remains stored in the ponds, whereas for the cachama and trout, the highest water footprint was grey, due to the high concentrations of solids and nutrients present in fish excretions and unconsumed feed.

Keywords: *Method, pisciculture, sustainability, water footprint, water resources.*

Resumen

El sector piscícola en Colombia creció en promedio 13% anual de 1988 a 2013 y es el sexto mayor usuario de agua en el país. Considerando la presión que ejerce la producción piscícola sobre las fuentes de agua, se estudió la huella hídrica (HH) de la piscicultura como un indicador de sostenibilidad. Para ello se desarrolló una metodología que mide la HH en el sector, que incluye sus componentes directos e indirectos, así como las huellas hídricas verde, azul y gris. La metodología se aplicó a las tres especies piscícolas más producidas en el país: tilapia (*Oreochromis mossambicus*), cachama (*Piaractus brachypomus)* y trucha (*Oncorhynchus mykiss*), para sendos casos de estudio en el Valle del Cauca, Colombia. Se encontró que la HH total del cultivo de tilapia es de 5,486 m^3/Ton, la del cultivo de cachama de 6,193 m^3/Ton y la del cultivo de trucha de 19,854 m^3/Ton. La huella hídrica total más alta para la tilapia fue la del alimento concentrado, seguida por la huella hídrica azul, asociada a la cantidad de agua que permanece almacenada en los estanques; en la cachama y trucha la mayor huella hídrica total fue la gris, relacionada con las altas concentraciones de sólidos y nutrientes, presentes en las excretas de los peces y en el alimento concentrado no consumido.

Palabras clave: *Colombia, huella hídrica, metodología, piscicultura, recurso hídrico, sostenibilidad.*

1. Introduction

Colombia is the seventh country in the world with greater availability of water resources and the second in South America (1). From the total water used in the country during 2012, the demand for pisciculture was 4.6% (1.654 Mm^3), placing this sector as the sixth largest user of water in the country after agriculture (46.6%), energy (21.5%), livestock (8.5%), domestic (8.2%) and industrial (5.9%) sectors (2). The productive dynamics of the pisciculture sector grew around 13% each year since 1988, driven by the external demand which grew 250% annually in the last 10 years (3, 4). The production growth of this sector in Colombia in the last decade was 9.3% annual average, reaching a production of 103,114 tons in 2015, from which 61.3% were Tilapia (*Oreochromis mossambicus*), 20.2% Cachama (*Piaractus brachypomus*), 15.4% Trout (*Oncorhynchus mykiss*) and 3.1% of other species (5). The global foresight for the year 2030 indicates that 62% of fish will come from aquaculture (6), resulting in an increase in the pressure on water resources exerted by this sector.

Reducing this pressure improves the competitiveness of the pisciculture sector by reducing costs and increasing sustainability. Sustainability assessment is carried out through indicators that allow the transformation of ambiguous concepts into tangible and concrete forms, making it possible to guide resource management strategies and policies (7).

Among the indicators of sustainability are those of pressure over the environment (8), one of them is the water footprint (WF). The WF is an indicator of water consumption that can be represented as an aggregate number in units of volume, able to consider different types of consumption and water pollution as a function of time and space (9).

The method used in this study is the one proposed by the Water Footprint Network (WFN) (10), in which the total WF of a product consists of: i) direct WF (dWF), which refers to water consumed and contaminated in all stages of production of the product, and ii) indirect WF (iWF) which refers to water consumed and contaminated in the production of goods and services used in the production stages of the product (10), where consuming water generates opportunity costs for others social groups and ecosystems that demand the resource, while their use does not generate them (11).

In the pisciculture sector, the dWF measures the amount of water consumed directly in the production of the product. Its components are the green WF (WF_v), the blue WF (WF_b) and the gray WF (WF_g). The WF_v is the volume of water from precipitation, which would reach the natural ecosystem, but instead is captured and consumed in the fish production process. WF_b is the volume of fresh water collected from surface or underground sources. This considers the water that evaporates in the production, the water incorporated in the product, the water that does not return to the same catchment area from where it was extracted and the water that does not return to the body of water in the same climatic period. The WF_b of fish production consists of i) the volume of evaporated water (V_{Ev}) which is the amount of water leaving the system by evaporation, ii) the volume of water contained in ponds (V_{Ac}) which is the amount of water that remains physically accumulated in them, iii) the volume of water incorporated in the product (V_{Bio}) which is the amount of water in the biomass of the fish, and iv) the volume of water used for maintenance (V_{Mant}), which is the water used to wash ponds and installations. The WF_g is the volume of water from the source required to dilute the contaminating effluent loads of the fish production process, which corresponds to the contaminant that requires the most amount of water to be diluted.

The iWF in fish production can also be defined as WF_v, WF_b and WF_g. Based on previous research (14), the main components of iWF for the sector are WF of concentrated feed (WF_{cf}), WF of electric power (WF_e) and WF of hatching eggs (WF_h), where each of them includes the components WF_v, WF_b and WF_g. The WF_e is generated in the production of the electric energy consumed during the production process, and depends on the generation technology used (12). The WF_{cf} is the volume of water consumed in the production of the concentrated feed, which is different for each species (13). The WF_h is generated in the production of the eggs, larvae or fingerlings.

The method of WFN (10) has been applied in Colombia in few experiences in the pisciculture sector, where two stand out: a study of the WF for trout farming in Antioquia (14) and a study for cachama in Meta (15). Both cases show that the main determinants of WF are iWF and WF_g, both related to the concentrated feed used in fish production.

The general perception is that fish-farming projects are sources of pollution that damage the water quality of rivers; this can identify the sector as a water-intensive consumer. In this regard, institutions in Colombia have changed their concept: in the National Water Study - ENA 2010 (16), the sector was classified as a *consumer* and in the 2014 edition (2), as a *user of water*. The character of user or consumer of water for the fish sector is clarified by measuring the volume of water consumed, which corresponds to the WF. In the current work the WF of tilapia, cachama and trout crops was measured within the framework of a project developed by the CINARA Institute of Universidad del Valle, in association with the Colombian Federation of Aquaculture - FEDEACUA. The resulting method fills a gap in the research of WF for sectors or productive activities worldwide, since there was no specific method for the pisciculture sector.

After this introduction, the method developed to estimate the fish water footprint is presented. Afterwards, the results obtained and the analysis of the application of this method in tilapia, cachama and trout cultures are presented for three case studies in the Valle del Cauca, Colombia. However, the method can be applied in other basins and regions of the world. Conclusions are presented at the end.

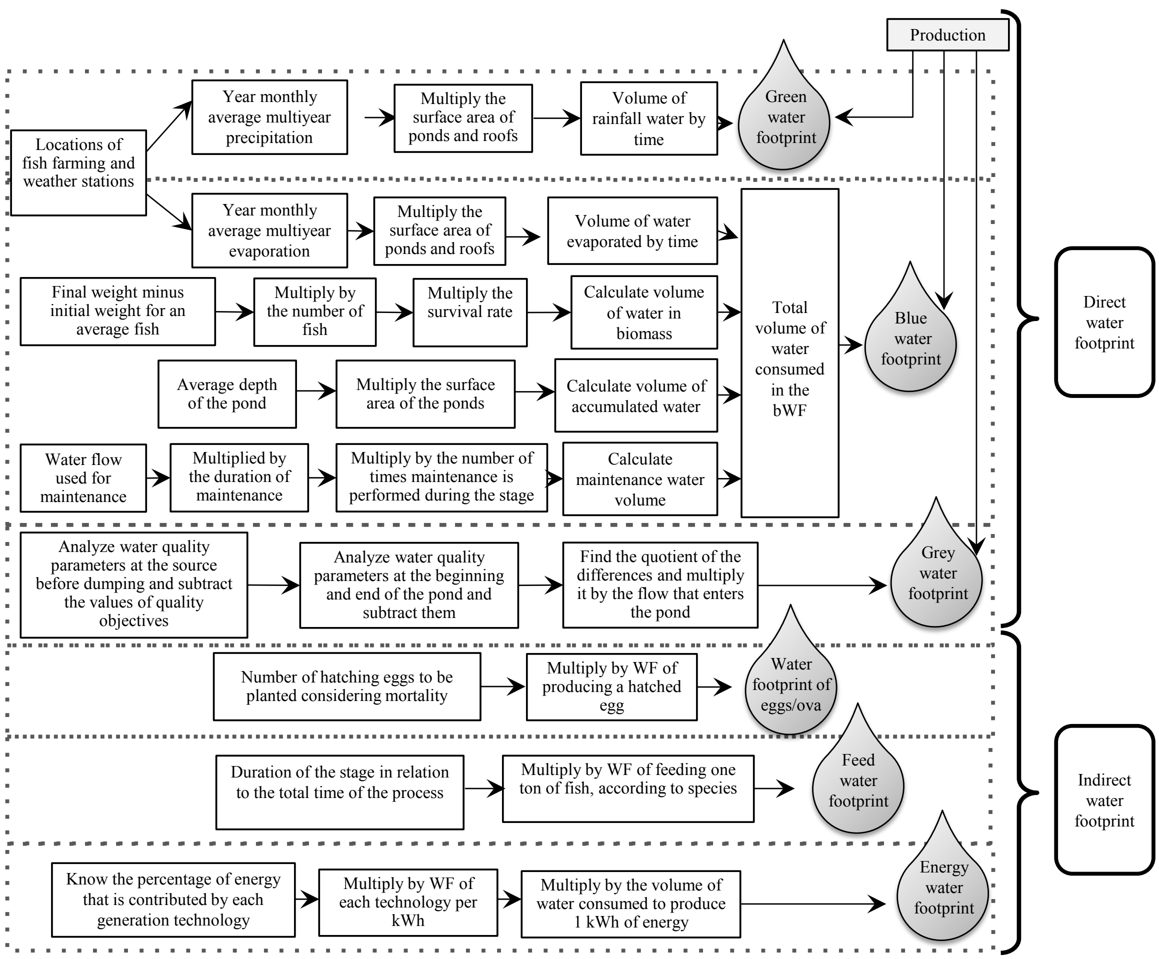

Figure 1. *Methodology to estimate the fish-farming water foot print.*

2. Methodology

The stages in which the production of the species under study are developed vary according to their life cycle and productive parameters. The production of tilapia, cachama and trout was grouped in three stages: seed (2-3 months), fattening (5-7 months), slaughter and processing (1-2 days). The TotalWF corresponds to the sum of the dWF and the iWF corresponding to the three stages of production for one ton of final product. In Figure 1, the method developed to estimate the fish WF by stage is presented in detail. This method was applied in the three annotated case studies. The cases were selected for the same region (Valle del Cauca, Colombia) and for the same river basin (Cauca river), since they were in productive interaction (Figure 2). For each case study, we randomly selected: i) a pond with fish in seed stage; Ii) two ponds with fish in the fattening stage (one in the first months and another in the last month of the stage); and, iii) a day of sacrifice and prosecution. The method was used as described below.

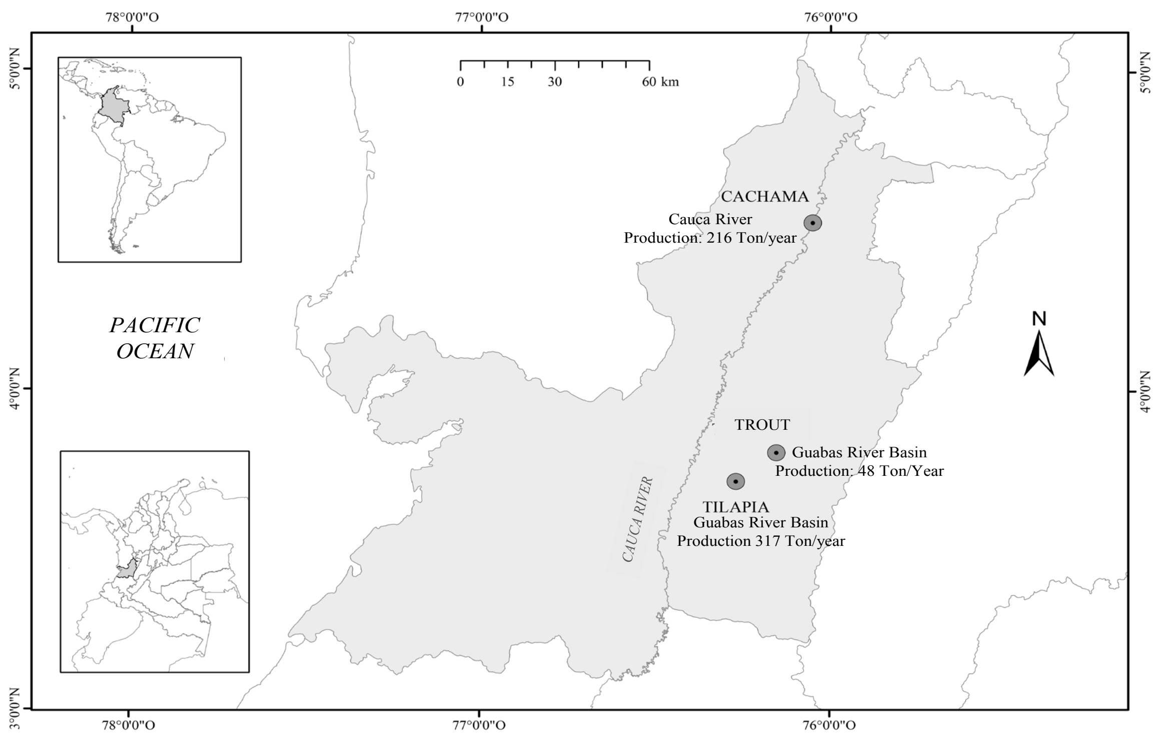

Figure 2. *Map of the study area, cultures of tilapia, cachama and trout.*

2.1 Direct water footprint

2.1.1 Green water footprint (WF_v)

The WF_v was estimated for the seed and fattening stages from historical precipitation data (1980 to 2014), recorded by 25 weather stations located within a radius of less than 33 km around the case studies in the municipalities of Geneva, El Cerrito, Buga, Yotoco, La Victoria, La Unión, Toro, Zarzal, Obando and Roldanillo (17). With these data a spatial interpolation was performed by the Inverse Distance Weighting (IDW) method, and monthly “rasters” of multiyear precipitation averages were obtained. The volume of precipitation was found to be the product of the pond area and the water column that fell on them during the months corresponding to each stage (Figure 1).

$$WF_v = \frac{\sum \text{Volume of water captured from rainfall}}{\text{Production of the product of the stage}} \quad (1)$$

2.1.2 Blue water footprint (WF_b)

The water volume of the WF_b was calculated based on Eq. v:

$$WF_v = \frac{V_{Ev} + V_{Bio} + V_{Ac} + V_{Mant}}{Producción\ del\ producto\ de\ la\ etapa} \quad (2)$$

Where: V_{Ev} is the volume of water evaporated; V_{Ac} the volume of water accumulated in ponds; V_{Bio} the volume of water incorporated in the biomass of the fish, and V_{Mant} the volume of water used for the maintenance and cleaning of the ponds.

V_{Ev} was found using the same steps as for WF_v, but with evaporation information, which was recorded only in five climatological stations within a radius of less than 33 km, in the municipalities of: Buga, Yotoco, La Victoria and La Union (2 stations). The V_{Ac} was calculated as the wet volume of the pond according to its geometry, during the seed and fattening stages, since it is the life support medium of the fish and remains approximately constant throughout the stage (Figure 1).

El V_{Ev} se halló usando los mismos pasos que para la HH_v, pero con información de evaporación, la cual fue registrada solo en cinco estaciones climatológicas dentro de un radio menor a 33 km, en los municipios de: Buga, Yotoco, La Victoria y La Unión (2 estaciones). El V_{Ac} se calculó como el volumen húmedo del estanque según su geometría, en las etapas de semilla y engorde, pues es el medio de vida de los peces y permanece aproximadamente constante durante toda la etapa (Figure 1).

V_{Bio} was found using the average biomass increase of the fish at each stage and the body moisture content by species: tilapia 72.3-76.9%; cachama 74.8-79.3% and trout 69.8-75.9% (18), Eq. (3):

$$V_{Bio} = \left(P_{Bio_f} - P_{Bio_i}\right) \times \%A \times N_{fish} \quad (3)$$

Where: (P_{Biof}) is the weight of the fish at the end of the stage; (P_{Bioi}), the weight of the fish at the beginning of the stage; (% A) is the body moisture content per species, and (N_{fish}) is the number of fish.

V_{Mant} was calculated with information provided in each case study according to the maintenance practices used, Eq. (4):

$$V_{mant} = \sum Flow\ rate \times \text{maintenance time} \times \text{number maintenance per stage} \quad (4)$$

2.1.3 Gray water footprint (WF_g)

The WF_g was estimated from Eq. (5) (see Figure 1). The concentrations of the quality parameters in the tributaries and effluents for all the stages of the process, and for the water source before receiving any type of dumping, were obtained by means of a monitoring campaign conducted in condition of low rains (December).

$$WF_v = \frac{\left(\frac{C_{effl} - C_{afl}}{C_{máx} - C_{nat}} * Effl\right) * T}{Production\ of\ the\ product\ in\ the\ stage} \quad (5)$$

Where: (C_{max}) is the maximum concentration of contaminants according to river quality objectives, (C_{nat}) is the concentration of contaminants in the water source before receiving discharges, (C_{afl}) is the concentration of contaminants at the beginning of stage, (C_{effl}) is the concentration of contaminants at the exit of the stage; (Effl) is the flow of the stage and (T) is the time in which the dumping occurs.

Samples were taken for three consecutive days, four times per day in each case study; the sampling schedules were defined considering the incidence of sunlight and the feeding and digestion schedules of the fish. 360 samples were taken, for a total of 5,358 laboratory analysis including: pH, dissolved oxygen, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total organic carbon (TOC), total suspended solids (TSS) , total nitrogen or TKN, ammoniacal nitrogen, nitrites, nitrates, total phosphorus, fats and oils, fecal coliforms, total coliforms and sedimented solids (11). Concentrations of the quality parameters were normalized in order to use Eq. (5). The limit concentration was found in the quality objectives of different water sources in the country (Table 1).

Table 1. *Concentration limit values for the quality parameters used in the estimation of the gray water footprint.*

Quality Parameters	Units	Limit	Quality objectives
Biochemical oxygen demand (BOD_5)	mg/L O_2	7	Agreement 043 of CAR. Quality objectives of Bogotá River
Total Suspended Solids (TSS)	mg/L	50	CRC. Quality objectives of Cauca River in Popayán
Dissolved Oxygen (OD)	mg/L O_2	6	
Fecal coliforms	NMP/100mL	200	CARDER Resolución 252. Otún River quality objectives
Total coliforms	NMP/100mL	1,000	
Nitrites (NO_2)	mg/L N-NO_2	10	CVC Resolución 0686. Cauca River quality objectives
Nitrates (NO3)	mg/L N-NO_3	10	Agreement 043 of CAR. Quality objectives of Bogotá River

Source: (11).

The results of the WF_g were analyzed by determining the time required by the body of water receiving the shed to return to its initial conditions. To do so, the method proposed by Streeter and Phelps in 1925 was used. This method describes variations in the concentration and oxygen demand when water receives shedding (19).

2.2 Indirect water footprint

2.2.1 Water footprint of electric power (WF_e)

The WF_e was estimated from the energy matrix of the Colombian National Interconnected System, composed of: hydroelectric power (72%) and thermal energy (28%) (20). The WF of each type of electric power generation technology (12) was multiplied by the corresponding percentage (Figure 1) and by the number of kWh consumed in the production unit during the process; then divided by the fish production stage (Table 2).

Table 2. Summary of Indirect Water Footprint for the production of inputs used in fish farming.

Indirect WF		WF Input unit	Input units Used
WF_e	Tilapia (1)	0.0394 m^3/kWh	30,666 kWh
	Cachama (1)	0.0394 m^3/kWh	15,306 kWh
	Trucha (1)	0.0394 m^3/kWh	888 kWh
WF_l	Tilapia (2)	2,250 m^3/Ton	1 Ton
	Cachama (2)	2,250 m^3/Ton	1 Ton
	Trucha (2)	1,500 m^3/Ton	1 Ton
WF_h	Tilapia (3)	0.088 m^3/egg	55,960 eggs
	Cachama (3)	0.00234m^3/egg	40,000 eggs
	Trucha (4)	0.5222m^3/egg	45,000 egg

Source: 1. (12) y (20); 2: (13); 3: (21-23); 4: (24).

2.2.2 Water Footprint of Concentrated Food (WF_{cf})

The WF_{cf} was only estimated for the stages of seed and fattening because in sacrifice and processing there is no feeding. The duration of seed and fattening stages was multiplied by the WF of fish food production. For tilapia and trout it was taken from Pahlow et al. (13), and for cachama the value used was the same as for tilapia since they consume the same food (Table 2).

2.2.3 Water footprint of hatched eggs (WF_h)

The WF_h was calculated as the product of the number of hatching eggs required to produce one ton of final product and the amount of water consumed in the production process of these eggs from reproduction (Figure 1). For this estimation, we considered: (i) direct blue WF; (ii) direct green WF; and (iii) indirect WF of the concentrated feed consumed by breeding fish for growth (Table 2).

3. Results and analysis

3.1 Water footprint obtained in each case study

The WF values obtained for the three species under study are presented in Figure 3.

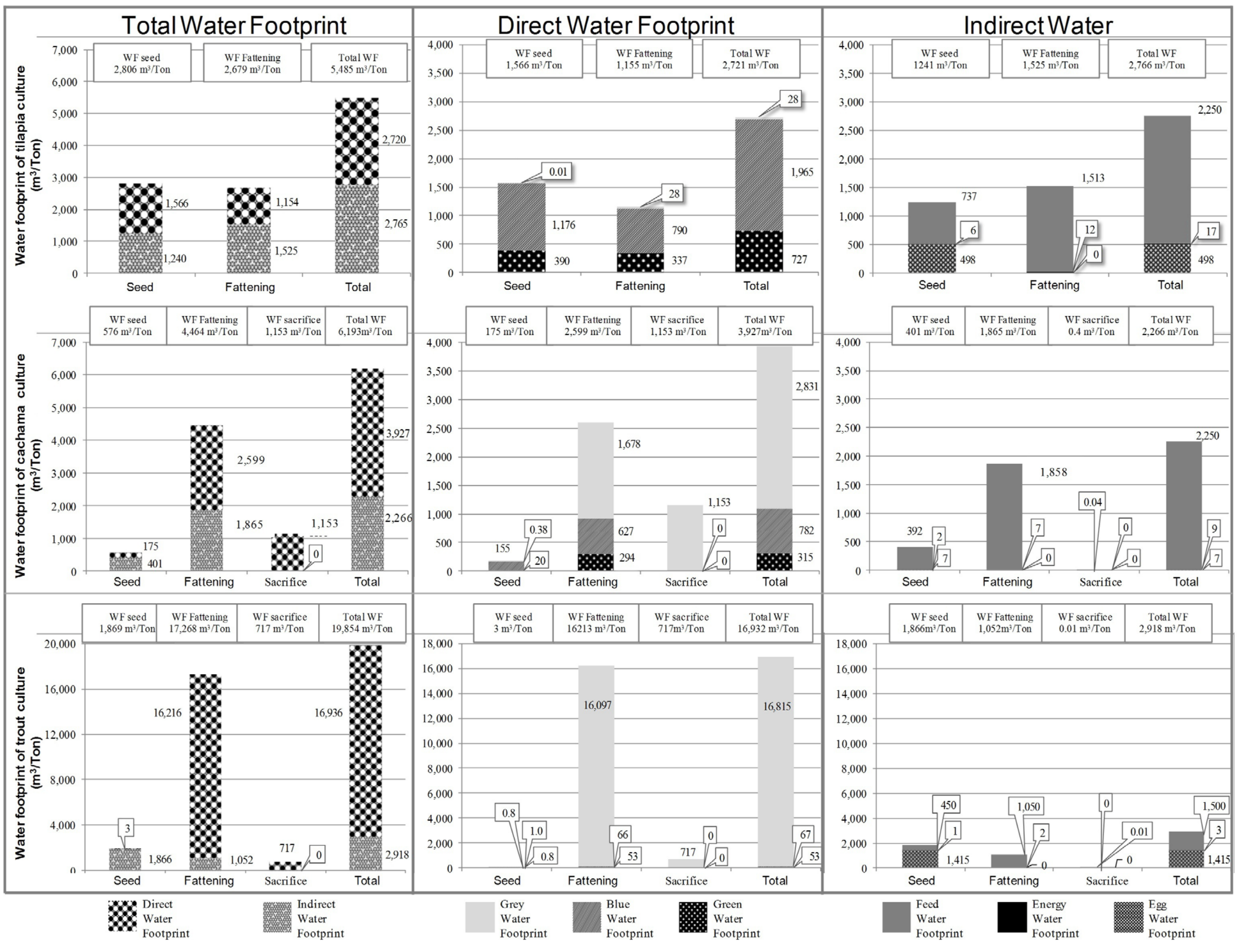

***Figure 3**. Water footprint obtained for three case studies of tilapia, cachama and trout. Note: The case study of tilapia does not have a slaughter and processing stage.*

3.2 Analysis of tilapia culture results

The TotalWF in tilapia culture reached 5,486 m^3 / Ton, where 50% is dWF, consisting mainly of the WF_b. The volume of water that contributes most to the WF_b (1,965m^3/Ton) is the water content accumulated in the ponds, which remains approximately constant throughout the stage. The second most important volume in WF_b is the amount of water that evaporates from the ponds; This depends directly on the surface area, the solar radiation (location) and the duration of the stage, all from which also depends the WF_v (727m^3/Ton).

The WF_g in tilapia (27.6 m^3/Ton) is determined by the quality parameters that generate greater affectation to the water resource: BOD_5 and fecal coliforms, which increased their concentration (Table 3), since the fish feed is rich in organic matter that is excreted in the metabolic process, increasing the coliform bacteria count and the concentration of biochemically oxidizable organic compounds. The high densities of seeded fish, low water exchange and limited maintenance of pond bottoms, raise the concentration of ammoniacal nitrogen and BOD_5 in water, contributing to an increase in WF_g.

The iWF (2,765 m^3/Ton) is mainly due to the WF_{cf} (2,250 m^3/Ton), which depends on the duration time of the stage, and the latter will be proportional to the size reached by the fish. The WF_h (497 m^3/Ton) is only counted in the seed stage, but constitutes an important contribution to TotalWF, 9.1%.

Tabla 3. *Quality parameters that determined the grey water footprint.*

Species	Seed		Fattening		Sacrifice and processing	
	Parameter	Increase that defined the WF_g	Parameter	Increase that defined the WF_g	Parameter	Increase that defined the WF_g
Tilapia	BOD_5	30 – 34 mg/L	BOD_5	30 – 34 mg/L	BOD_5	34 – 390 mg/L
	Fecal coliforms	89 – 222 MPN/100mL	Fecal Coliforms	22 – 88 MPN/100mL	Fecal Coliforms	10 – 59,000 MPN/100mL
Cachama	BOD_5	25 – 34 mg/L	BOD_5	25 – 34 mg/L	BOD_5	34 - 390 mg/L
	TSS	80 - 95 mg/L	SST	80 - 95 mg/L	SST	55 – 1,418 mg/L
Trout	TSS	0.8 – 2.8 mg/L	SST	63 – 98 mg/L	SST	2 – 271 mg/L
	BOD_5	9 - 23 mg/L	Fecal Coliforms	14 – 22 MPN/100mL	BOD_5	4 – 305 mg/L
	NH_3	0.36 – 0.47 mg/L	-	-	TKN	3.8 – 114 mg/L

The WF_v and the WF_b depend to a large extent on uncontrollable climatic factors, limiting the management aimed at reducing it in favor of the sustainability of the water resource. Management actions to reduce WF_g in tilapia cultivation should focus on improving the maintenance of ponds, and on developing schemes to optimize food supply and ration unconsumed food. The management for the reduction of the WF_{cf}, requires finding a point of balance in the relation food-weight, that allows to determine the optimal time for the harvest of fish, maintaining the profits of the producers.

3.3 Analysis of Cachama culture results

TotalWF of cachama reached 6,193 m^3 / Ton, of which 63% is dWF determined by the WF_b and mainly by the WF_g. This is consistent with the results of the study for the same kind of crop in Restrepo (Meta) (15). The largest component of WF_b is the volume of water accumulated in the ponds. In the case of the WF_g (2,831 m^3/Ton), which represented 72% of the dWF, it is due to the increased concentrations of BOD_5 and SST (Table 3). Both coming from fish excreta and organic waste from the slaughter and processing stage. The iWF (2,266 m^3/Ton) accounted for 37% of TotalWF, basically explained by the WF_{cf} (Figure 3).

Although it has a lower contribution, the WF_g for the seed stage poses a potential threat associated with the concentrations of carbon (C) and nitrogen (N) in water, from proteins and carbohydrates contained in the fish feed (25).

In line with the results found, actions for sustainable water management should focus on: i) assessing the reduction of water in ponds to reduce WF_b, without impairing animal welfare or fish production; ii) implement final effluent treatment systems to reduce the WF_g generated during the slaughter and processing stage (although the reduction of WF_g in the fattening stage has the highest value, it depends on the duration of the stage: 5 months, so there is a metabolic and market limitation to manage the reduction of this WF); and iii) optimize fish food supply, given its significant contribution to WF_g and iWF associated with WF_{cf}.

3.4 Analysis of trout culture results

The TotalWF for trout, with final product as butterfly cut was 19,854 m^3/Ton, of which 85% count as dWF. The iWF reached a value of 2,918 m^3/Ton, equivalent to 15% of TotalWF and explained by the WF_{cf} and the WF_h.

The largest contribution of dWF is the WF_g (16,815 m^3/Ton) explained by the fattening stage (16,097m^3/Ton).These results are lower than those found by Toro (14) in Antioquia, which reported a TotalWF of 610,000 m^3 / Ton in trout fillets. In the current study the WF_g is due to the concentrations of SST and fecal coliforms in the fattening stage, whereas in the stages of seed and slaughter and processing this is due to the concentrations of SST, N and BOD_5 (Table 3).The nutrients are contained in the food of the fish and their excreta, providing fecal coliforms, organic matter and settleable solids. The major component of SST is COT, while P and N are the major components in dissolved solids (26).

The value of the WF_g is directly proportional to the input flow and to the difference between the output and input concentrations (Eq. 5); Thus, when the concentration difference is low between the entrance and the exit of the stage, as in the case of the trout crop, the value of the flow has a greater influence on the WF_g. Reducing the inflow to ponds would reduce the WF_g of this crop. The total flow in the case study (139 L/s) was between 2 and 7 times higher than the theoretical minimum required by the species: 18 to 57 L/s (27).

If the input flow to the ponds were the theoretical (18 L/s) during the fattening stage in the trout crop, TotalWF would decrease to 5,841 m^3 / Ton, showing that the optimization of flow rates is relevant in this crop. The flow entering seed and fattening ponds in the case study is turbulent (Reynolds Number: 121,170), causing solids from unconsumed food and fish excreta to remain in suspension. Thus, the optimization of flow rates would have a dual purpose: i) to reduce the WF_g associated to the concentrations of suspended and sedimented solids and, ii) to reduce the WF_g associated to all flows higher than the optimum.

The Streeter and Phelps model in the trout study case showed that the receiving water body needs between 8 minutes and 1.9 hours to recover from the loading and return to the BOD_5 level prior to dumping. The Streeter and Phelps model in the trout study case showed that the receiving water body needs between 8 minutes and 1.9 hours to recover from the loading and return to the BOD_5 level prior to dumping. The above reflects a conceptual and methodological limitation of the WF_g estimation: the WF_g concept quantifies the impact of dumping on the water quality of the receiving body, regardless of the context in which it occurs. That is, it does not analyze the availability of water in the basin and the capacity of assimilation of the environment. This is a limitation that could be overcome with sustainability analysis (10), not included in this work.

In the case of trout, just as for tilapia and cachama crops, the implementation of treatment systems and the optimization of feeding according to the duration of the stage and the weight gain of the fish (feeding curve) would reduce the WF_g that determines the dWF. Additionally, it determines the WF_{cf} which is the highest of the iWF (Figure 3). These recommendations were also made by a study for the department of Cauca (27), according to which the concentration of these pollutants can be reduced by optimizing the feeding, favoring the sedimentation of particles in the pond and using treatment processes; although the high flow rates used in production, limit their management by conventional wastewater processes (26).

3.5 Integral analysis

In the integral analysis of the results it is found that dWF is the main component of TotalWF in the three species: 50% in tilapia, 63% in cachama and 85% in trout. In the cachama and trout cultures, the major component of the dWF was the WF_g, while in the tilapia culture was the WF_b. However, the latter is also important in the cultivation of cachama. In these last two crops, the WF_b is due to the volume of water accumulated in the fish ponds for several months. This generates an opportunity cost for the use of the resource in other ecosystem services, downstream of the fish production unit. In all cases WF_g is associated with nutrients in water, which are found as residues of unconsumed food and fish excreta. The stabilization of these substances, considered pollutants, consumes the OD of the water and favors the presence of algae, which also contribute to the concentration of SST and BOD_5. The highest total and direct water footprint is observed in the production of trout, despite that effluent concentrations are low. However, the high flow rates and their continuous nature for up to seven months, accumulate high pollutant loads.

The contribution of iWF to TotalWF is 50% in tilapia, 36% in cachama and 15% in trout. The management of iWF is of low governance for the fishery sector, where it is limited to the optimal use of the inputs: eggs (or roe and alevin), concentrated food and energy. However, in a broader perspective that encompasses the life cycle of the production chain, and includes input producers, management actions could be found for these entrepreneurs. The reduction of TotalWF should incorporate strategies of industrial ecology, in which interaction between all the sectors involved generates synergy between by-products and residues, changes from linear production systems to cyclical systems and imitation of natural ecosystems functioning (29).

4. Conclusions

The WF estimation for the three studied species allowed the identification of the technical and operational conditions that require changes in each stage of the productive process, in order to reduce WF and thus to soften the impact of fishery activity on water resources. An environmental management strategy to reduce the gray water footprint of trout crops, responsible for the largest WF in the sector, is the use of optimum flow rates and the optimization of wastewater treatment systems. In tilapia and cachama crops, the reduction of the water level in the ponds can be evaluated, in order to reduce the accumulated volume, as long as the living conditions of the fish are not damage.

The study showed that WF is an indicator of process analysis, by involving water consumption and contamination. The research filled a gap in the studies of WF, by developing a method for its measurement in the fish sector. The use of this method should be applied in the zones of greater fish production in Colombia, as well as in different technological schemes. This would help to validate the method and consolidate global information of the country's WF fishery. The research evidenced limitations of the method proposed by the WFN to estimate the WF in three aspects: i) assuming that any type of pollutant load can be reduced by diluting it in water; ii) not considering the assimilation capacity of the receiving water body, generating an imaginary in overestimation of WF_g, which oversizes the environmental problem; and iii) not incorporating the vision of a product life cycle, makes its management recommendations exclusively limited to the sector, losing effectiveness where governance is low. In the first case, the WFN is developing new methods that address these limitations. In the second and third cases, the incorporation of the ecosystem approach proposed by industrial ecology, promotes a broader sustainability analysis that incorporates different scales, dimensions, levels, and sectors users of the water resource at the basin level.

5. Acknowledgments

To the National Aquaculture and Fisheries Authority - AUNAP for the financial support under the agreement No. 203-2015 signed with the Colombian Federation of Aquaculture - FEDEACUA. The fish farmers of the area: Hacienda la Esperanza, Piscícola del Valle and Piscícola Santa Cecilia, all contributed to the development of the measurement of water footprint. And to the evaluators who with their valuable observations contributed to the good development of this article.

6. References

1 Arévalo D. Una mirada a la agricultura de Colombia desde su huella hídrica. Cali: WWF Colombia; 2012. 48 p.

2 IDEAM (Instituto de Hidrología Mete-orología y Estudios Ambientales de Co-lombia). Estudio Nacional del Agua 2014. Bogotá D.C.: IDEAM; 2015. 493 p.

3 Merino M C, Bonilla S P, Bages F. Diagnóstico del estado de la acuicultura en Colombia. Bogotá: MADR (Minis-terio de Agricultura y Desarrollo Rural); 2013. 163 p.

4 FEDEACUA (Federación Colombiana de Acuicultores). Plan de Negocio Sectorial de la Piscicultura Colombiana. Bogotá DC: PTP; 2015. Document prepared as an instrumento of Programa de Trans-formación Productiva.

5 FEDEACUA (Federación Colombiana de Acuicultores) [On-line]. Bogotá DC: FEDEACUA; 2016. Versión revisada en la revista Acuicutores en el artículo Creado el Registro Pecuario de los Establecimientos de Acuicultura. Available: http://www.FEDEACUA.org/revista-acuicultores/

6 World Bank. Fish to 2030: Prospects for fisheries and aquaculture. Washington DC: World Bank; 2013 dec. Report number 83177-GLB

7 Kharrazi A, Kraines S, Hoang L, Yarime M. Advancing quantification methods of sustainability: A critical examination emergy, exergy, ecological footprint, and ecological information-based approaches. Ecological Indicators. 2014;37(Part A):81-89.

8 Fezzardi D, Massa F, Avila-Zaragoza P, Rad F, Yücel-Gier G, Deniz H, Hadj Ali Salem M, Hamza HA, Ben Salem S. Indicators for sustainable aquaculture in Mediterranean and Black sea countries. Guide for the use of indicators to monitor sustainable development of aquaculture. Roma: FAO; 2013. 68 p.

9 Vanham D, Bidoglio G. A review on the indicator water footprint for the EU28. Ecological Indicators. 2013;26:61-75

10 Hoekstra AY, Chapagain AK, Aldaya MM, Mekonnen MM. The water footprint assessment manual: setting the global standard. London: Earthscan; 2011. 228 p.

11 CINARA (Instituto de Investigación y Desarrollo en Abastecimiento de Agua, Saneamiento ambiental y Conservación del recurso Hídrico). Desarrollo de una metodología específica para medición de la huella hídrica como indicador de sostenibilidad en la producción de tilapia, trucha y cachama, con implementación en un proyecto demostrativo en el Valle del Cauca. Cali: CINARA; 2015. Document prepared for Federación Colombiana de Acuicultura, FEDEACUA.

12 Mekonnen MM, Gerbens-Leenes PW, Hoekstra AY. The consumptive water footprint of electricity and heat: a global assessment. Environmental Science.Water Researche & Technolgy. 2015;1(3):285-97.

13 Pahlow M, van Oel PR, Mekonnen MM, Hoekstra AY. Increasing pressure on freshwater resources due to terrestrial feed ingredients for aquaculture production. Science of The Total Environment. 2015;536:847-57.

14 Toro C. Proyecto piloto huella hidrica produccion de trucha en colombia. Centro Nacional de Producción Más Limpia. Medellín: Centro Nacional de Producción Más Limpia; 2012.

15 Castro GV. Contribución a la determinación de la huella hídrica del cultivo de cachama blanca (Piaractus brachypomus) en etapa de ceba, en Estaciones Piscícolas del Muni-cipio de Restrepo - Meta [Masther's The-sis]. Villavicencio: Universidad de los Llanos; 2014.

16 IDEAM (Instituto de Hidrología Meteorología Y Estudios Ambientales). Estudio Nacional del Agua 2010. Bogotá D.C.: IDEAM.

17 CVC (Corporación Autónoma Regio-nal del Valle del Cauca). Boletín Hidro-climatológico 2014. Cali: CVC; 2015. Document prepared for Grupo de Sistemas de Información Ambiental de la Dirección Técnica Ambiental de CVC.

18 Perea A, Gómez E, Mayorga Y, Triana CY. Caracterización nutricional de pescados de produccion y consumo regional en Bucaramanga, Colombia. Archivos Latinoamericanos de Nutrición. 2008;58(1):91-97.

19 Von Sperling M. Introducao a qualidade das aguas e ao tratamento de esgotos. Belo Horizonte: Departamento de Engenharia Sanitária e Ambiental – Universidade Federal de Mina Gerais; 2005. 243 p.

20 XM [On-line]. Medellín: Informes Anuales; 2015. Versión revisad en el Informe de operación del SIN y administración del mercado. Oferta y generación. Available: http://informesanuales.xm.com.co/2014/SitePages/operacion/2-6-Capacidad-efectiva-neta.aspx

21 SAGARPA (Secretaría de Agricultura Ganadería Desarrollo Rural Pesca y Alimentación) [On-line]. Veracruz: FUNPROVER; 2008. Versión revisada en el documento Manual de Producción de Tilapia con Especificaciones de Calidad e Inocuidad. Available: http://www.funprover.org/formatos/cursos/Manual%20Buenas%20Practicas%20Acuicolas.pdf

22 Rodríguez J, Giraldo L. Aproximación al manejo zootécnico en la reproducción de Cachama blanca, Piaractus brachipomus, mediante inducción hormonal [dis-sertation]. Villavicencio: Universidad de los llanos; 1999.

23 Villarreal-Valbuena RD, Rosado-Puccini R, David-Ruales CA. Relación entre factores dimensionales y de composición en la determinación de la calidad del huevo en tilapia roja (Oreochromis spp). Revista Lasallista de Investigación. 2013;10(1):27-37.

24 Universidad Católica del Norte [On-line]. Antofagasta: Universidad Católica del Norte; 2009. Versión revisada en el documento Planificación de la producción de alevines de 7cm (4.5 g) de Trucha Arcoiris. Available: http://www2.produce.gob.pe/RepositorioAPS/1/jer/PROPESCA_OTRO/actividades_convenios/UCN%20PELT%20Informe%20Parcial(1).pdf

25 Barreto-Curiel F, Durazo E, Viana MT. Growth, ammonium excretion, and oxy-gen consumption of hybrid red tilapia (Oreochromis mossambicus × Oreochromis aureus) grown in seawater and freshwater. Ciencias Marinas 2015;41(3):247-54.

26 Fernández, J. Nuevo desarrollo tecnológico para la producción mas limpia de trucha arco iris [PhD Thesis]. Cali: Universidad del Valle; 2014.

27 Fernández J, Cruz C, Caicedo J. Aspectos de contaminación y control del recurso hídrico en cultivo de trucha. In: Gallego-Ropero MC, Ceballos-Sarria VE, Alvear-Narváez L, editors. La gestión del riesgo y la restauración de ecosistemas acuáticos continentales. Popayan: GEF; 2015. p. 88-100.

28 Blanco MC. La trucha: Cría industrial, 2.ª ed. España: Mundi-Prensa; 2014.

29 Torre-Marín C, Granados S, Herrera R, Martínez R. Ecología industrial y desarrollo sustentable. Ingeniería. 2009;13(1):63-70.