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RESEARCH REPORT

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Environmental Consequences of and Pollution Control Options for Pond "Tra" Fish Production in Thotnot District, Cantho City, Vietnam

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This EEPSEA study from Vietnam looks at the pollution problem caused by fish farming in the Mekong Delta (MD) and assesses a number of treatment options that could bring this pollution down to acceptable levels. The study is the work of a research team led by Ms Vo Thi Lang, from Cantho University in Vietnam. It finds that a trickling-filter system would be the most cost-effective response to this challenge. However such a system would cost farmers more than they currently pay to discharge their polluting wastewater. The study therefore suggests a number of policy options that would encourage fish farmers to reduce the amount of pollution they discharge and help them to meet the necessary clean up costs.

This study is timely and important because aquaculture is a thriving industry in Vietnam. Tra fish are the most popular catfish species bred in the region and they have become an important export item. As such they are an economically valuable product for many farmers. However, catfish farming is causing problems for the environment. Waste, especially wastewater, from fish farms is often not treated properly and is dumped into canals, creeks or rivers. This has a negative impact on local communities that rely on river water as their main water source. It also jeopardises the health of fish and the sustainability of the industry itself.

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June, 2009

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ENVIRONMENTAL CONSEQUENCES OF AND POLLUTION CONTROL OPTIONS FOR POND "TRA" FISH PRODUCTION IN THOTNOT DISTRICT, CANTHO CITY, VIETNAM

Vo Thi Lang, Ky Quang Vinh, and Ngo Thi Thanh Truc

EXECUTIVE SUMMARY

"Tra fish" or catfish production has been on the rise in many provinces in the Mekong Delta, Vietnam, and has brought significant profits to commercial fish farmers. However, it has also caused considerable pollution to surface water sources in the areas where catfish culture has taken place as the waste generated from pond fish breeding has been dumped into outside surface water bodies without proper treatment. As a result, the organic matter content (measured by the Chemical Oxygen Demand (COD) parameter) in these bodies has increased substantially, exceeding the legal surface water quality standards in Vietnam and adversely affecting the water bodies as well as threatening the livelihood of the fish producers.

This study examined the environmental consequences arising from pond "Tra" fish breeding in the Mekong Delta and explored technically and economically feasible wastewater treatment options for bringing water pollution down to an acceptable level in accordance with Vietnamese environmental standards. The research results showed that the farmers' practice of exchanging water between fishponds and outside water bodies was one of the main causes of surface water pollution in Tra fish-breeding areas. Water sample analysis results indicated that the COD concentration in Tra pond water was 34 mg/l, exceeding the limit of <10 mg/l according to Vietnam's surface water quality standards (TCVN 5942-1995, Class A). The pollution load rate in terms of COD per kilogram of fish produced was 0.098. To cope with the pollution situation more effectively, some technical pollution control options were proposed, of which the trickling filter technology was found to be the most cost-effective. Some policy recommendations to address the environmental pollution caused by pond Tra fish production in the Mekong Delta are also given.

1.0 INTRODUCTION

1.1 Research Problem

Aquaculture production is a thriving industry in the Mekong Delta (MD) of Vietnam. The industry has grown rapidly in the last two decades. Aquaculture production in the MD reached 625,397 tonnes in 2003 (Cantho Statistical Yearbook 2002; 2003). Tra fish (*Pangasius hypoththalmus*) and Basa fish (*Pangasius bocourti sauvage*) are two popular catfish species bred in the MD, of which the former is bred more than the latter. They can be cultured in floating cages or ponds. However, with ponds, farmers can breed the fish all year round whereas with cages/pens, they can only do so for six to seven months in a year. Thus, pond fish-breeding areas have mushroomed in the delta. Previously, Tra fish were bred in ponds as food stock for poor farming households, but with improvements in farming practices and technology, it has become an important export item in the form of fillet in recent years. Tra fish is exported to many Asian markets such as Hong Kong, Singapore, Taiwan, South Korea, and Japan as well as to Europe and North America. The total volume of catfish fillet exported by processing establishments increased from 7,000 tonnes in 1997 to 286,000 tonnes in 2006 (VASEP 2007). Tra fish has thus become an economically valuable product for many MD farmers as well as for processing companies. However, catfish farming and processing activities are causing problems for the environment, as waste, especially wastewater, from both are not treated properly and usually dumped into canals, creeks or rivers.

Surface freshwater sources in the Mekong Delta are being increasingly polluted. One of the largest polluting sources is the wastewater from aquaculture production and freezing operations, especially from Tra and Basa fish breeding and fillet freezing activities. These two activities have generated relatively high organic pollution loads, estimated around 50 kg of COD (chemical oxygen demand) per tonne of finished frozen fillet (Ky 2005). Fish producers discharge waste into local water sources and this adversely impacts local communities that rely on river water as their main domestic water source. In addition, polluted water discharged from fishponds can cause disease in fish. Due to the tides, a great amount of wastewater remains on site, subsumed in nearby water channels, lacking time to go far and so, ends up being eventually pumped back into fish ponds—this creates disease in the fish and increases antibiotic costs in breeding them. Furthermore, poor water quality can change the color of Tra fish meat from white to yellow, and this may cause the produce to fall below quality standards for domestic consumption and export. The deterioration of surface water conditions associated with catfish farming can be the result of many factors. Increased fish-farming areas, intensive farming with high densities of fish, excessive use of feed, over-use of antibiotics and other chemicals, and lack of wastewater treatment systems are among them.

The 2003 Cantho Statistical Yearbook reports more than 600,000 hectares of surface water in the MD being used for aquaculture. At a depth of one meter, the water volume for such acreage is around six billion cubic meters. If fish breeders substitute one-fourth of this volume of (pond) water per day using water from canals or rivers, one and a half billion cubic meters of wastewater per day or more than 540 billion cubic meters per year will be dumped into water bodies. As the COD concentration in wastewater from Tra and Basa ponds is around 118 mg/l (Ky 2004), then the annual flow of the Mekong River (500 billion cubic meters/year) cannot dilute it enough to meet the COD concentration limits in surface water (less than 10 mg/l for Class A) in accordance with TCVN 5942-1995. Given the situation, fish producers as well as the government need to take stronger action to reduce the adverse impacts of Tra fish farming on the environment.

1.2 Research Objectives

The general objective of this study was to provide an economic assessment of the environmental consequences of and pollution control options for pond Tra fish production in the MD.

The specific objectives were:

- To identify the environmental problems associated with the dumping of waste from pond Tra fish production.

- To identify cost-effective technological solutions.
- To recommend policy options to address the water pollution problems caused by pond Tra fish production.

1.3 Scope of the Study

Given the available resources, this study was confined to commercial Tra fish production at the household level and considered only the level of organic pollution with respect to the COD parameter. We identified feasible pollution reduction options only for commercial fish farms that sold their products to export companies.

2.0 LITERATURE REVIEW

This section consists of three parts. The first part deals with some theoretical concepts related to the subject. The second part covers empirical studies relating to the environmental consequences of pond catfish production. The third part is about aquaculture policies in Vietnam.

2.1 Theoretical Review

An external effect is said to occur when the production or consumption decisions of one agent affect the utility or production possibilities of another agent in an unintended way and when no compensation is given to the affected party. Economic behavior involves external effects. One of the major types of external costs is the cost associated with the use of environmental resources, especially when these resources have open access. In such cases, the producers of goods are only interested in their own production costs and often neglect the external costs to other people and the environment. If we are to have rates of output that are socially efficient, decisions about resource use must take into account both types of costs; private costs and external costs, to get the full social cost (Field and Olewiler 2005).

According to Kongkeo (2001), aquaculture has been rapidly developing in many parts of Asia in recent decades. Many types of aquaculture can contribute positively to environmental improvement. For example, rice-fish culture with integrated pest management can help farmers reduce the use of pesticides. However, according to Kongkeo (2001), negative impacts have been associated with intensive and monoculture systems. These can include nutrient and organic enrichment of recipient waters, resulting in a build-up of anoxic sediments, changes in benthic communities, and the eutrophication of lakes. The misuse of chemicals, collection of seeds from the wild, introduction of exotic species, and over-use of fishery resources as feed inputs are issues of concern. Such problems need appropriate management strategies.

According to Wurts (2000), there are biological limits in the production pond or aquatic environment. Stocking densities and harvest yields are finite and determined by pond carrying capacity. The availability of dissolved oxygen is the primary factor determining maximum biomass. Depending on temperature, salinity and atmospheric pressure, water can only hold a certain concentration of oxygen. Oxygen demand increases as the overall weight or biomass of a farmed species increases. When respiratory demand exceeds the rate of oxygen replacement from surface diffusion and photosynthesis, either aeration has to be employed or oxygen becomes depleted and the cultured species suffocates.

2.2 Empirical Studies on Catfish Farming

2.2.1 Environmental problems associated with catfish production

In the United States

According to Wurts and Wynne (1995), intensive aquaculture practices in the U.S. have pushed production to as high as 7,000–10,000 lb/acre, the objective of which has been to increase profitability by maximizing harvest weight (biomass) per unit volume or area of production system. However, these practices almost always exceed the biological carrying capacity of the production unit. High densities of fish usually lead to problems in terms of environmental degradation, disease, off-flavor (of aquatic animals), and a reduction in individual performance of the cultured species. The U.S. catfish farming industry has revealed some warning signs of reached carrying capacity limits. For example, widespread disease, antibiotic-resistant bacteria, off-flavor problems, and routine aeration have become common for intensive catfish farms. Also, according to the same authors, enteric septicemia of catfish (ESC) has developed in the crowded production ponds of Mississippi. Off-flavor results from dense phytoplankton (algae) blooms and micro-organisms which accompany the heavy nutrient and organic loads produced by fish waste (ammonia and manure) and uneaten feed.

In Vietnam

The Vietnamese catfish or Tra fish is the most commonly farmed fish species in Vietnam, especially in the Mekong Delta (MD). Previously this fish was reared in rural areas for domestic consumption, but now it has become a valuable export item. Due to high demand in the world market, many Vietnamese farmers are now choosing Tra fish farming as their main source of income. However, its unplanned development has led to many environmental problems caused by water use, fish feeding and the treatment of fish diseases.

Tu et al. (2004), when studying the causes of spotted liver disease in Tra fish, which caused great damage to the Tra fish farming industry in AnGiang, Dongthap, and Cantho Provinces, concluded that *E.ictaluri* bacteria was the agent and it was resistant to some antibiotics such as oxytetracylin, oxolini acid and sulphonamid. They suggested that this was due to the over-use of antibiotics on the fish by the farmers.

In a report on the results of a field survey conducted by some officers from the Southern National Center for monitoring the environment and preventing aquaculture disease in four provinces of the MD (Angiang, Dongthap, Cantho and Vinhlong) in June 2006, Ly (2006) reported that the water quality in the surveyed ponds in Vinhlong and Cantho were highly polluted. For example, in Tan Loc Commune, Thotnot District, Cantho City, due to uneaten fish feed, fish excrements left in the pond water and poor pond water exchange, pond pollutant contents were found to have increased in the February 2006 survey: total ammonia ranged from 3-6 mg/l in different ponds and COD ranged from 9.0-16.9 mg/l, which is a good environment for microbes to develop. In general, fish diseases showed typical symptoms for example, red spots/hemorrhages on the fins and spleens, swollen heads, white spots on the internal organs, and yellow meat. A great majority of fish farmers treated sick fish with antibiotics mixed with feed in order to reduce fish losses. In addition, ponds with sick fish were treated with salt, lime and chlorine. Another factor that caused pond water pollution was the practice by almost all the households in feeding the fish with home-processed food. Ly (2006) suggested that pH levels be kept within suitable ranges in order to prevent ammonia from being changed into poisonous forms that could harm Tra fish. She further recommended that there should be measures to treat environmental pollution and reasonable planning for Tra culturing areas so that the industry could develop in a sustainable manner in the years to come.

2.2.2 Common practices to improve pond water quality

In the U.S., catfish producers applied night-time aeration throughout the summer in order to improve pond water quality. Mechanical aeration has been used with increased frequency and magnitude. Aeration does not directly improve water quality parameters such as total ammonia-nitrogen, phosphorus, or nitrite-nitrogen concentrations (Wurts and Wynne 1995). Catfish producers often flush ponds with well water to dilute undesirable nutrient concentrations (Burtle et al. 1996). Kouka and Engle (1994) suggested some effluent treatments for catfish production: (a) reuse of water from catfish ponds for crop irrigation; (b) constructed wetlands; and (c) filter-feeding fish stocked in ponds paired with catfish ponds[1]. These treatment options will remove both dissolved nutrients and suspended solids.

In Vietnam, Bach, Nguyen and Nguyen (2005) conducted a study in Vinhlong Province in order to find a farming process that could produce white Tra fish meat for export. They suggested, among other measures, the use of mechanical aeration in combination with controlled water exchange to ensure stable pond water quality, with stocking densities from 15-22 fish/m^2.

Lagoons and chemical treatments are also recommended by the Ministry of Fisheries (Cantho Fisheries Department 2006). However, lagoons are not common because of land and treatment time constraints and lack of experimental studies to prove their effectiveness. As for chemical treatments, there are no chemicals that are proven effective at reasonable prices.

2.3 Vietnam's Policies on Aquaculture

On November 26, 2003, Vietnam's National Assembly passed the Fisheries Law. Aquaculture was mentioned in Chapter 4. Then, on October 11, 2005, the government issued Decree No. 128/2005/ND-CP stipulating sanctions for administrative violations by fisheries, including violations of regulations in aquaculture. The government had earlier

[1] Filter-feeding fish (like bighead carp) are reared to treat aquaculture effluents. Water from the catfish ponds is pumped into filter-feeding fish ponds for treatment.

enacted Decree 67/2003/ND-CP to reduce water environment pollution by instituting environmental protection fees on wastewater, in which industrial effluent fees ranged from 100-300 VND per kilogram of COD in wastewater.

The Ministry of Fisheries also issued some documents concerning water quality and catfish farming guidelines for aquaculture activities. For example, 28 TCN 176:2002 specifies requirements for surface water quality where catfish cages are to meet food hygiene and safety conditions, and 28 TCN 213:2004 stipulates technical processes to raise Tra fish intensively.

Vietnam is a developing country and most of its rural population is poor so the government has introduced some policies to encourage the development of aquaculture in the MD to create more jobs and income for MD farmers. For example, Decision No. 224/1999/QD-TTg issued by the Prime Minister, approves aquaculture development programs for the period 1999-2010; Decision No. 150/2005/QD-TTg by the Prime Minister approves plans for the conversion to a national agricultural production structure where forestry and fisheries will play a more prominent role by 2010; and Decision No. 10/2006/QD-TTg by the Prime Minister approves the Master Plan of Fisheries to the year 2010. Hence, Tra fish production has the opportunity to develop, especially in the MD, and bring in foreign exchange as well as create jobs and income for many Vietnamese families.

However, Tra fish production has encountered many environmental problems despite the laws enacted. The local government authorities in the MD have realized the serious effects of Tra fish production on water bodies. Therefore, they have been paying more attention to this sector through research activities to find out which practices can improve the situation. Up to now, the regulations have only applied to processing companies through effluent standards or charges. There have not been any environmental standards applied specifically to the pond Tra fish industry.

To minimize the environmental pollution caused by pond aquaculture, some specific regulations have been issued by the Ministry of Fisheries for the whole country and in Cantho City, by responsible agencies as well like the Cantho City People's Committee, Thotnot District People's Committee, and Cantho Fisheries Department. These regulations include the following: (a) Fish breeders should have pools—15-20% of the fishpond area—in size to contain wastewater and the mud generated from pond sediment removal; (b) Tra fish producers without extra land must reduce their fishpond size to build pools to hold mud and wastewater; (c) Prospective fish producers must get permission from the local government before digging fishponds and comply with state land use regulations. They should apply the fish farming guidelines issued by the relevant agencies; and (d) Some recommendations to raise fish safely and alleviate environmental pollution such as maintaining a stocking density of 15-20 fish/m^2 and a water depth not exceeding three meters, using industrial feed, and using drugs/chemicals according to regulations of the Ministry of Fisheries.

As for the local authorities, they have encouraged processing companies to cooperate with fish farmers to experiment with new models of raising fish to have a better environment for Tra fish production. In addition, local environmental management agencies are carrying out experiments on various technologies to find the most appropriate ones to recommend to fish farmers.

3.0 METHODOLOGY

3.1 Study Site Selection

Tra fish production is found in many provinces in the MD like Angiang, Dongthap, Cantho and Vinhlong, but Thotnot District of Cantho City (Appendix 1) is the most famous for it. According to the 2004 Cantho City Statistical Yearbook, of the eight districts of Cantho, Thotnot had the biggest area under Tra fish farming—318 hectares of Tra and Basa fish out of a total of 671 hectares under Tra fish farming in the whole city. Therefore, Thotnot was chosen as the representative site to study Tra fish farming practices as well as their environmental consequences. In addition, this study needed Tra fishpond wastewater samples for analysis so it was convenient to choose Thotnot for its proximity to the Cantho City Environmental Monitoring Station where the wastewater samples would be analyzed. Thotnot District has eight communes, of which two raise the most Tra fish, namely Thoi Thuan and Tan Loc. These two were amongst those selected for a household survey and water sampling. Besides these, three focus group discussions were also conducted in Thoi Thuan Commune.

Thotnot District (Appendix 2) lies along the Hau River. It has one town and seven communes. Its natural land area is 17,110.08 ha, with a population of 192,327 inhabitants and a population density of 1,124 persons/km^2 (Cantho Statistical Yearbook 2004). Aquaculture areas in past years have shown an upward trend, increasing from 209 ha in 2000 to 393 ha in 2004 and 484.4 ha in 2005, with pond Tra fish as the main species bred for export. The industry has flourished dramatically in the past three years since export demand rose in 2003.

Pond Tra fish areas totaled 30 ha in 2000, 210 ha in 2003, 318 ha in 2004, and around 393 ha (under some 487 Tra farming households) in 2005. In 2004, Thotnot produced 28,565 tonnes of Tra fish out of 41,383 tonnes of Cantho City’s total volume, and in 2005, it produced 51,131 tonnes (The Master Plan for Fisheries Development in Cantho City up to 2020, Service of Agricultural and Rural Development of Cantho City 2006). Tra fish is raised in all Thotnot communes situated along canals and the Hau River, but largest production areas are in the Thoi Thuan (154 ha) and Tan Loc Communes (136 ha).

3.2 Data Collection

3.2.1 Secondary data

Secondary data relating to Tra fish production and its environmental consequences was collected from the Cantho Service of Agriculture and Rural Development, Cantho University, and local management agencies. In addition, some foreign studies on catfish farming and feasible pollution control options were sourced from the internet. This data was used for the literature review section.

3.2.2 Primary data collection

Primary data was collected through focus group discussions, a household survey, and Tra fishpond wastewater sampling.

(a) Focus group discussions (FGDs)

FGD is a discussion with a selected group of four to eight people (chosen for having a background or knowledge relevant to the objectives of this study) following a set of detailed guidelines designed to generate discussion on a particular set of topics. To get general information on the opinions and perceptions of local communities about Tra fish farming and its environmental consequences, three focus group discussions were held with three groups of people in Thoi Thuan Commune. The first FGD consisted of 13 local leaders and heads of local organizations such as women's unions and farmer associations. The second FGD comprised seven Tra fish breeders while the third consisted of five farmers who did not raise Tra fish and lived along canals from which fish breeders took water to flush their ponds.

(b) Household survey

To collect more detailed primary data, a household survey using a structured questionnaire was conducted in the communes of Thoi Thuan and Tan Loc. Households living along the Hau River and canals (of different levels) were chosen for interview. The random sampling method was used to select farmers for personal interviews held at their homes. The total number of surveyed fish farmers was 131 (31 from Tan Loc Commune, 90 from Thoi Thuan, and 10 from the two nearby communes). The data collected from the household survey comprised socio-economic characteristics of the fish farmers, Tra fish breeding practices, Tra fish production costs, the advantages and disadvantages of fish breeding, pond wastewater treatment practices, the farmers' awareness of the environmental impacts of their activities and their responses to possible state regulations.

The survey was implemented in August 2006 with the help of the Vinh Thanh-Thotnot Fisheries Station staff and other local officers. Without the guidance of the local officers, we would not have been able to contact the household heads since the residents are usually doubtful and hesitant in dealing with interviewers asking questions related to Tra fish wastewater issues. The enumerators were young lecturers and senior students from Cantho University.

(c) Water sample collection

To assess the water pollution level caused by Tra fish farming, samples of Tra pond wastewater and river water were collected and analyzed. Five fish farmers were chosen (three from Thoi Thuan, one from Tan Loc, and one from Trung Kien commune) to sample inlet and outlet pond water throughout the fish rearing cycle (five months). The first water sampling was done on September 1, 2006, and the last was done on January 27, 2007. Water sampling was conducted once a week from five selected fish-farming households. A total of 178 water samples was collected from the households, and eight water samples were taken from the Hau River as control samples. Water quality analysis was done for five parameters: pH, SS, DO, COD, and NH3-N. The water sample collectors were from the Environmental Monitoring Station of Cantho City and the samples were analyzed at the station's laboratory. The pH was analyzed with analytical equipment PH 540-GLP, SS with LF197, DO with YSI-5000, COD with DR4000, and NH_3-N with DR 4000.

The inlet and outlet water quality analysis results were used to estimate the pollution loads and pollution load rates as well as compared with TCVN 5942-1995 (surface water quality standards). With the water quality analysis results, technical experts designed three technologies capable of treating the organic pollutants and then economic calculations were made.

3.3 Water Parameters Used

Aquaculture is water-dependent. The quantity and quality of the water supplied to aquaculture operations are key factors in production. Following are some of the water quality parameters used in this study:

- ***pH***

pH is a measure of the balance between acidity and alkalinity. It is measured exponentially on a scale between 0 and 14. A pH of 7.0 is neutral; above 7.0 is alkaline and below 7.0 is acidic. PH is important since it modifies the solubility and toxicity of many compounds.

- ***Dissolved Oxygen (DO)***

Dissolved oxygen is oxygen gas (O_2) that is dissolved in water. Fish can absorb oxygen directly from the water into their bloodstream via their gills. Most DO in ponds is produced during photosynthesis by aquatic plants and algae. DO increases during daylight hours, declines during the night, and is lowest just before daybreak. A concentration of 5 mg/l DO is recommended for optimum fish health. Most species of fish become distressed when the DO level falls to 2-4 mg/l. Mortality usually occurs at concentrations of less than 2 mg/l.

Oxygen depletion occurs when oxygen consumption exceeds oxygen production. Increases in oxygen consumption can be caused by an over-abundance of aquatic plants or algae in the ecosystem, increased organic waste entering the water, death and decay of organic matter, or by certain chemicals (e.g. formalin) that remove oxygen directly from the water column. DO can be monitored using an electronic meter or chemical test kit. Emergency aeration should be applied whenever the DO level falls below 4 mg/l or environmental conditions (as mentioned above) favor an oxygen depletion event (Floyd 2003).

In most pond culture operations, aeration offers the most immediate and practical solution to water quality problems encountered at higher stocking and feeding rates. Maintenance aeration systems are intended to prevent critical low oxygen levels from occurring. These systems include a low-pressure high-volume blower, PVC and/or polyethylene distribution pipe, and air releasers. Air is released near to bottom of the pond, aerating and mixing the water as it rises to the surface. These systems are relatively energy efficient and, when operated continuously, create and sustain an improved environment for fish production (McGee and Cichra 2006).

- ***Ammonia-nitrogen (NH_3-N)***

According to Alleman (1998), ammonia-nitrogen or free ammonia (NH_3-N) and ionized-ammonia (NH_4^+-N) represent two forms of reduced inorganic nitrogen which exist in equilibrium depending upon the pH and temperature of the waters in which they are found. Of the two, the free ammonia form is considerably more toxic to organisms such as fish. Ammonia-nitrogen is produced by deamination of nitrogen-containing compounds involving enzymes and micro-organisms and by hydrolysis of urea. Ammonia-nitrogen and ionized-ammonia are generally viewed as indicators that a given water body has been contaminated, usually in relation to the direct discharge of an ammonia-bearing waste (e.g., wastewater effluent, stormwater runoff, etc.). One important problem with the presence of reduced nitrogen in water is that its oxidation may impose an oxygen demand by nitrifying bacteria, which might then deplete the available dissolved oxygen concentration to a level which imposes stress on aquatic life

According to Wurts (n.d.), ammonia is a nitrogen waste released by aquatic animals into the production pond environment. It is a primary by-product of protein metabolism. Ammonia is excreted directly from the fish gills into the water. Ammonia concentrations are usually at their highest late in the production season when the biomass of the cultured species and the amount of protein fed are greatest. Ammonia is toxic to aquatic life and toxicity is affected by pond pH. Ammonia-nitrogen has a more toxic form, NH_3 (un-ionized-ammonia), at high pH, and a less toxic form, NH_4^+ (ionized-ammonia), at low pH. An un-ionized NH_3-N level of 0.019 mg/l would be considered acceptable for channel or pond catfish production. In addition, ammonia toxicity increases as temperature rises.

Photosynthesis and respiration have significant effects on pond pH. Because these processes affect pH, ammonia toxicity is affected also. When monitoring water quality, it is important for producers to understand the daily shifts in pH and their impacts on un-ionized- ammonia concentrations. PH and NH_3-N must be measured at the same time and should be tested late in the afternoon (Wurts n.d.).

- ***Chemical oxygen demand (COD)***

COD is a chemical measure of the amount of organic substances in water or wastewater. A strong oxidizing agent together with acid and heat are used to oxidize all carbon compounds in a water sample. Non-biodegradable and recalcitrant (slowly degrading) compounds, which are not detected by the test for Biochemical Oxygen Demand (BOD), are included in the analysis. The actual measurement involves a determination of the amount of oxidizing agent (typically, potassium dichromate) that is reduced during the reaction. The COD parameter reflects the entire amount of organic substances in water so it is chosen to denote the organic pollution level in water[2].

[2] Organic pollution is not toxic in small quantities but becomes a problem when there is an excess of organic matter, such as manure, sewage, or decaying plant matter in the water. When organic matter increases in a pond, the number of decomposers increases. These decomposers use a great deal of oxygen during their growth which is rapid. This leads to a depletion of oxygen which in turn can kill aquatic organisms. As the aquatic organisms die, they are broken down by decomposers and this leads to further oxygen depletion. (See http://www.mbgnet.net/fresh/pollute.htm for more information.)

- ***Suspended solids (SS)***

Suspended sediments are particles in the water such as silt. If there are high amounts of suspended solids in the water, it becomes turbid. Turbidity causes problems in that in order to use the water for drinking, the water must first be filtered. Turbidity measures the amount of suspended solids (dirt, algae, leaves, etc.) in the water. It is an important factor if the water is to be used for recreational purposes. If the water is too turbid, it can make recreational activities unsafe, for example, drowning victims may not be spotted in the water due to poor water clarity.

- ***Aesthetics***

Water should be free from offensive odors and colors and should prove pleasing to the user.

3.4 Pollution Load Measurements

3.4.1 Pollution loads

The organic pollution level in fishponds was measured by the COD parameter. The COD loads in a Tra fish production cycle were calculated using the following formula:

$$CODL\ (kg) = (CODoutlet - CODinlet)(g/m^3) \times Q_{ww}(m^3)/1000$$

where

CODL: Total COD load from a Tra fish pond for the entire production cycle (kg);

CODoutlet: COD concentration in Tra pond effluent water (g/m^3);

CODinlet: COD concentration in water put into Tra fishponds (g/m^3); and

Q_{ww}: wastewater volume exchanged between the pond and the river in a cycle (m^3).

It should be noted that the wastewater volume exchanged, Q_{ww}, was estimated based on the data collected from the five selected fish-farming households. COD concentrations were obtained from the water sample tests.

3.4.2 Pollution load rate

The pollution load rate (PLR) is the amount of COD generated from producing one kilogram of Tra fish. The equation used is as follows:

$$PLR = E/Ft$$

where

E: total COD load from fishpond water for the entire production cycle (kg)

Ft: fish growth for the entire production cycle (kg)

3.5 Economic Analysis

In this study, two economic tools were used: a costs and returns analysis (also called a financial analysis or profit and loss analysis) and a cost-effectiveness analysis (CEA).

The costs and returns analysis was used to assess the profitability of Tra fish production in Thotnot District. It calculated the profits that fish farmers earned after a production cycle. The purpose of this analysis was to ascertain the financial robustness of the fish farmers if they had to treat the COD effluents generated from their fishponds.

The CEA was done for proposed technical options to treat the COD effluents generated by pond Tra fish production as the second objective of this study was to identify cost-effective technological solutions to reduce the water pollution caused by Tra fish farming. To do this, we had to determine the abatement cost per unit pollutant of each option, and then compare the costs per option to find the one that had the least cost. The CEA is an analytical tool used by economists to evaluate environmental decisions (Field and Olewiler 2005). When there are several ways to attain a certain objective, CEA gives the costs of the various alternatives. The most cost-effective option is the one that achieves the given objective at the lowest cost among all possible options. Although a full cost-benefit analysis (CBA) is a superior tool, due to data limitations, especially difficulties in measuring the benefits, a CEA was the best option for this study. To identify cost-effective technological options to reduce the water pollution caused by Tra fish farming, the abatement cost per unit of pollutant of each control option were estimated and compared. Two measures were used; the abatement cost per kilogram of COD and the COD abatement cost per kilogram of fish growth. The procedures involved in the calculations are listed below.

(a) Calculating the abatement cost per kilogram of COD

(i) Determining the appropriate wastewater treatment technology

(ii) Determining the lifespan of the structure (years) (depending on type of materials used)

(iii) Determining the total capacity of the structure (L)[= lifespan (years) * abatement capacity per year (kg of COD abated/year)]

(iv) Determining the investment cost of the structure (C_1)

(v) Determining the discounted flow of annual operation and maintenance (O&M) costs for the structure’s lifespan (C_2)

(vi) Calculating the abatement cost per kg of COD using the following equation: $C = (C_1 + C_2)/L$

(b) Calculating the COD abatement cost per kilogram of fish growth

The COD abatement cost per kg of fish growth = C* PLR

4.0 RESULTS AND DISCUSSION

4.1 Stakeholders' Perceptions of Environmental Problems Caused by Tra Fish Farming

As discussed earlier, to obtain a general view of the environmental problems caused by Tra fish farming in Thotnot, three FGDs were conducted in Thoi Thuan with non-Tra fish farmers, Tra fish farmers, and local leaders, including the heads of local organizations.

4.1.1 Non-Tra fish farmers

This group complained a lot about the quality of local surface water sources. They said that river water was their main source of water and it had been degraded mainly due to untreated Tra fish wastewater being discharged into the river. A groundwater supply system had been constructed in the commune by the Cantho City Clean Water and Environmental Hygiene Center. Unfortunately, the groundwater supplied by the system was not clean because of the presence of alum and the quantity was also insufficient for the local people's needs even though they had to pay 2,500 VND for one cubic meter. The system was also not regularly cleaned. Water from this source was mainly used for bathing and washing. As for drinking water, the local people usually used rainwater, collected in big containers during the rainy season.

The non-Tra fish breeders felt that the river water was cleaner during the rainy season (from June to November) because the pollutants in it were diluted. However, the water was also opaque in the rainy season because of upstream water flowing in, carrying abundant alluvial matter. In the dry season, the water was clearer. The people also said that there were two inflows of water to the canals: a greenish one from the fishponds and an opaque one from the Hau River. Water from fishponds ran for a distance, then joined the Hau River to become one integrated source. Before 2000, the local people could use river water for cooking after removing the alum. Now the water quality was growing worse mainly due to Tra fish culture. Tra breeders usually exchanged water between canals and fishponds in order to reduce the pollutant content in the latter, resulting in heavy water pollution in the area.

Besides Tra fish farming, the people also named other sources that had contributed to the worsening of local water quality. For example, an alcohol factory located in the commune discharged its untreated wastewater into the river. The use of chemicals in rice production further contributed to water pollution, especially in November and December, the sowing months. The people said they wanted to have a cleaner water source instead of having to use river water from the canals.

4.1.2 Tra fish farmers

The Tra fish farmers cited that the available domestic water sources for them in the area were a mini water supply system, river water, rainwater, and home well water. Well water was used for washing and bathing, and rainwater and the mini supply system water were used for cooking. River water use was, however, limited of late. Of all the four, the mini supply system water was most preferred due to its cleanliness and convenience especially when compared to river water. Rainwater was preferred next because people believed that rainwater from the sky must be cleaner than river water that was polluted by fish rearing. Thus river water was the least preferred.

The Tra fish breeders said that fish farming had existed for 15 years in the area, but Tra fish culture had developed only in recent years and the practice of eliminating pond sediment periodically had just been applied in the past two years in order to prevent fish from contracting disease. They acknowledged that Tra fish farming was one of the causes of local river water pollution and admitted that they had limited the use of river water to bathing purposes.

When asked about the measures they took to reduce water pollution caused by dumping pond sediment, they reported that there was only one solution to the problem at the moment: building lagoons to contain the sediment. But this solution was not very feasible because of the lack of extra land. When asked about whether they were willing to apply wastewater treatment techniques that may cost them more money and land, one of them said that he would only accept an increase of 5% in cost while two others answered that they would not accept these kinds of costs. On the other hand, they had a suggestion: if they were forced to install waste treatment facilities, fish purchasing companies would have to recalculate their buying prices so as to absorb this increase in production costs in their contracts with the farmers.

The perceptions of fish farmers on local water quality and environmental regulations were also explored. When asked about what they thought would happen to the river water quality if many fish farmers discharged Tra fish wastewater into water bodies, 14% of the respondents said that the quality would be unchanged, 47% said it would be dirtier, 30% said it would be very dirty, and about 9% believed it would be unusable in the future (Appendix 3). When asked about the river water quality five years ago compared to the present time, the majority of the respondents said that the former was better than the latter. Only a small percentage of respondents thought that both were the same, but these people lived next to the Hau River, one of the two biggest rivers in the MD which could dilute pollutants easily due to its huge water volume.

Concerning environmental regulations, when asked what they would do if there were to be a state regulation banning the discharge of wastewater into public water bodies, 47% of the respondents said that they would stop rearing Tra fish while 32% said they would build lagoons. Others said they would discharge their wastewater into rice fields or orchards, do as other people do, go somewhere else with no strict rules to continue rearing fish, and so on (Appendix 4).

When asked what they would do if farmers had to treat their wastewater to meet Vietnamese water supply standards before releasing their wastewater into the environment by using some technique which would cost them 10% more land and increase their production cost by 10%, the majority of them (61.5%) had the same response: they would build lagoons. Others claimed that they could not afford these additional costs due to several reasons namely, (a) lack of land, (b) high treatment costs, (c) lack of land and high costs, and (d) high land prices (Appendix 5).

To explore the effects of polluted river water on the health of the local people in the survey sites, respondents were asked if they suffered any disease caused by using river water. Many people no longer used the water or swam in canals so they said that there was no effect on them. However, a small number of people who sometimes bathed in the canals when there was not enough water reserves at home revealed that they commonly suffered from itching and red/itchy eyes after doing so.

4.1.3 Local leaders

This group consisted of the Thoi Thuan Commune Chairman, the Thotnot District Environment and Resource Division Head, the Economics Division heads, and representatives of local people’s organizations. They were very interested in the environmental problems in their locality.

According to the Thoi Thuan Commune Chairman, aquaculture was only second to paddy in the commune and it had improved the local people’s economic conditions, but it had also brought about environmental problems in the area. Profit from Tra production was greater than rice. Consequently, many rice farmers had converted their rice fields to fish farms. Apart from the local inhabitants, a number of people from other provinces had come to the area to rent land to breed fish. Therefore, it was hard to keep these activities at a stable level.

According to the Thotnot District Environment and Resource Division Head, water pollution in the area had arisen from many causes, such as alcohol production without waste treatment, husks released from rice mills, waste from Tra production, domestic waste from households, and industrial waste from aqua-product processing companies. What people complained most about, though, was Tra fish and alcohol production which released a lot of wastewater into the main water bodies. Four activities in Tra fish farming were identified as the main causes of the pollution it produced.

The first was the digging of the fish ponds. A good pond had to be three to four meters deep, but some ponds along the Hau River bank reached six meters. When digging ponds, fish farmers tended to allocate more land to ponds and less to dykes. For example, a farmer with 1,000 m^2 of land will have 700 m^2 of surface land dug for ponds, leaving 300 m^2 for dykes. Therefore, the soil dug up was usually too much to be used for the dykes. If people living around the farm needed soil for their orchards or dykes, they could ask for the excess soil but if no one needed it and the landowner did not have space to keep it, the excess soil would be discharged into the nearby water canals. This was, however, prohibited by local regulations and subject to a fine if discovered. So the violators usually did the dumping at night.

The second activity was the discharging of Tra fish wastewater into outside water sources. If an alcohol factory with a water usage of around 1,000-2,000 m^2 discharges its wastewater into the canals, local officials could fine it and force it to build a wastewater treatment system. But in the case of hundreds or thousands of fish farmers discharging thousands of cubic meters of wastewater into water bodies per day, advising and controlling them represented a big challenge. Although the fish farmers knew that they were violating state regulations—since Vietnam has had the Fisheries Law since 2003—functional agencies had to advise them on how to correct the situation before fining them.

The third contributing activity was the use of chemicals/drugs in the production process to treat diseased fish. This is a common practice in aquaculture and adds to the pollutants in the wastewater discharged by the fish farms.

The last activity was the removal of sediment from the fish ponds and dumping it into the water canals. Sediment formed from fish feed leftovers and fish waste was usually taken out of fishponds several times during the production cycle and after harvesting the fish. Most fish farmers did not have much land so they usually discharged the sediment into water canals, making the water polluted and reducing the depth of water canals, hampering waterway transportation in the area. The People's Committee of Thotnot District has directed the district Economic Division to establish a rule that before digging fishponds, landowners had to allocate a land area equivalent to about 20% of the pond size to store sediment. Since this problem occurred on a smaller scale than the dumping of wastewater into the local water bodies, this rule was easier to enforce.

According to local officials, among the four practices above, how to treat fishpond wastewater was the greatest challenge for technical experts. The Thotnot District Environment and Resource Division had proposed using extra land to contain the wastewater in order for the solid waste in it to be settled, and then using chemicals to treat the wastewater before releasing it into the environment. If fish farmers only used the settling pond without chemical treatment, this would not be effective as the wastewater from each water exchange exercise was usually kept in the settling pond for only three to four hours before flowing out to make way for new wastewater[3]. Even if the pond was full of water hyacinth (which had the capacity to absorb some pollutants), it would take at least 24-48 hours for the waste to be absorbed.

Looking at Tra fish problems from an administrative angle, in 2003, due to increasing export demands, Tra fish price rose unexpectedly, pushing farmers to breed more Tra fish. In addition, due to the shifting economic structure in the rural areas, people began digging ponds all over the place without official approval or notification. This has made reporting land area by land use patterns more difficult.

In June 2005, the Thotnot People's Committee released a document specifying which areas were allowed to breed Tra fish. Anyone who wanted to dig new ponds or convert paddy fields into fishponds had to submit an application to the respective agencies so that it could be confirmed that his pond lay within the approved areas. According to this document, there are five areas in the district that are approved for Tra fish breeding: 300 m from the banks of the Hau, Cai San, Bo Ot, Thotnot, and Cantho Be-Thomrom Rivers. No fish ponds were allowed to be dug further than 300-m boundary.

One month later, the People's Committee issued another document requiring the agencies concerned to strictly fine anyone who dug a pond without the district's permission. Since then, there have been no spontaneous pond-digging cases.

[3] The time depends on the interval between each fishpond water exchange. The fishpond and the settling pond are connected by a pipe at the bottom of the fishpond. The water level in the fishpond is always higher than that in the settling pond. So when fish farmers pump fresh river water into the fishponds, the same amount of (old) fishpond water will flow out into the settling pond through the pipe and the wastewater in the settling pond will naturally overflow into nearby rice fields or surrounding public water bodies.

Due to the shortage of clean water for domestic purposes, partly because of Tra wastewater being discharged into water bodies, the local government authorities have asked fish breeders to pool their money to build small-scale water supply systems for the local inhabitants. However, this move is not a long-term solution to the water pollution problems in the area. If Tra fish wastewater continues to be discharged into water bodies, the assimilation capacity of these water sources will be soon depleted. Therefore, this situation needs more effective measures.

4.2 General Characteristics of the Surveyed Fish Farmers

To obtain detailed information about Tra fish production, a survey was conducted in two communes of Thotnot District, namely, Thoi Thuan and Tan Loc. Table 1 shows selected characteristics of the fish farmers and Tra production. The average fish farmer was 43 years old with level two (secondary school) education. The average years of residence varied from 2–67, with a mean of 38. Years of fish farming averaged five. Some people had reared fish for long but many of them had only started breeding Tra fish in recent years. The average farm size was about 1.7 hectares and the average fishpond area was about 5,300 m^2. The mean fishpond area in Tan Loc was greater than that in Thoi Thuan, 9,293 m^2 versus 4,023 m^2 (Appendix 6). As for pond size, among the surveyed fish-breeding households, 9% had ponds smaller than 1,000 m^2; 38% had ponds 1,000-3,000 m^2; 24% had ponds from 3,001-5,000 m^2; and 30% had ponds over 5,000 m^2 big (Appendix 7).

Table 1. Characteristics of surveyed farms

Farmers' characteristics	**Mean**	**Std. Deviation**
Age of respondents (years)	43.22	11.12
Education level (level)	1.97	0.95
Years of residence	37.82	16.38
Fish farming experience (years)	5.19	2.74
Household size (persons)	5.27	1.85
Females per household	2.42	1.18
Labor (persons)	3.72	1.79
Farm size (owned) (m^2)	17,836.37	14,390.89
Fishpond land area per farm (m^2)	5,300.11	8,142.33
Tra production characteristics		
Number of cycles/year	1.92	0.43
Breeding cycle (months)	6.58	1.22
Fishpond water surface area (m^2)	3,580.64	5,731.66
Water depth (m)	3.84	0.57
Distance from ponds to water source (m)	54.71	60.90
Stocking rates (fingerlings/m^2)	47.02	27.05

Source: 2006 survey

Rearing commercial fish requires a good knowledge of farming techniques, so local managerial agencies as well as feed or drug companies often give training courses to fish farmers in order for them to be able to raise Tra fish successfully. According to the survey results, over 70 per cent of the fish farmers had received lessons on fish culturing techniques.

Fish farmers can raise Tra fish throughout the year. Unlike rice production, there is no strict schedule in releasing fingerlings into ponds. Farmers can have two or three fish cycles per year by using several ponds. Tra fish culturing can last 3–10 months per cycle depending on several factors such as the release fish size or fish prices. Some farmers said that they alternated fish production across several ponds in order to actively respond to market price fluctuations. They often raised fingerlings in a pond in the first 2-3 months and then moved them to another pond to continue culturing for four more months before harvesting and selling.

Fishpond water area varied from several hundred to several thousand square meters, averaging 3,581 m^2 per pond. Pond water depth varied from 2–5 m, averaging 3.84 m. Fish production relies on water sources, so fishponds often lie along water channels. The distance from the ponds to water sources varied from 3–400 meters, averaging 55. Households situated near the Hau River or big canals enjoyed more favorable conditions for fish production since they had relatively cleaner inlet water than those located far from such large water sources. In addition, they could save costs related to transportation, the building of inlet pipelines, fuel for pumping water, and so on. The stocking density averaged 47 fingerlings/m^2.

Table 2 shows the kinds of inlet water sources that fish households can access: 23% of the fishponds surveyed had inlet water from the Hau River, 42% from Level 1 canals, 29% from Level 2 canals, and 5% from Level 3 canals. There were some fish households rearing Tra fish on a large scale near the Hau River but they were very busy working and not willing to be interviewed.

Table 2. Inlet water sources for Tra fish farming

	Frequency	**Percentage**
The Hau River	30	23.1
Level 1 canal	55	42.3
Level 2 canal	38	29.2
Level 3 canal	7	5.4
Total	130	100.0

Source: 2006 Survey

4.3 Tra Fish Farming Practices

To engage in Tra fish production, farmers had ponds constructed. Earth removed from pond digging was used to build dykes around the pond or laid on land. Inlet water pipelines were built to take water from outside water bodies into the ponds.

4.3.1 Pond preparation

Work relating to this item covered dredging pond bottom sediment before each Tra fish production cycle and adjusting the dykes. Removal of the sediment was done mainly by hired labor using machines. During the Tra fish culturing process, pond sediment was removed several more times in order to reduce toxins that could affect fish health.

4.3.2 Pond treatment

Before fish stocking, fish farmers often treated their ponds with lime ($CaCO_3$ or CaO), salt, and other chemicals.

4.3.3 Fish stocking

Fingerling size varied from 1-5 centimeters. Fish farmers tended to stock their fish at very high rates, averaging 47 fingerlings/m^2 versus the rate of 15-20 fish/m^2 recommended by the Ministry of Fisheries in 28 TCN 213:2004 (or even that of 15-25 fish/m^2 proposed by Duong n.d.).

4.3.4 Feeding

The survey revealed that fish farmers fed their small Tra fish 1-5 times/day, usually 2-3 times. For big fish, common feeding times numbered 1-3 according to the farmer's aim. If he wanted his fish to grow fast, feeding times would be increased. Fish feeding hours were usually from 8-9 a.m. and from 4-5 p.m. The feed quantity varied according to the fish body weight or was adjusted based on the feed quantity eaten the previous day. When the fish were small, farmers usually used commercial feed produced by feed companies (e.g. Cargill, Gimbo, Con co, Mekong, etc.). This feed can float on the water for a while so it does not pollute the water much and is used effectively. However, due to its high price, this feed was only used when the fish were small. When the fish became bigger, in order to save feed costs, fish farmers usually used home-processed feed with high protein content. Its composition was diverse. It usually consisted of rice bran or broken rice (30%), marine fish or Tra fish meal (40-50%), and soybean (15-20%). In addition, fish farmers often put a Vitamin C, sorbitol, enzyme, and mineral premix into the feed to strengthen the resistance of the fish to disease.

4.3.5 Preventing and treating disease

Fish farmers used a variety of chemicals to deal with pond water quality problems and fish disease. In addition, they often used the method of changing pond water with outside water to reduce water pollution in the ponds as well as to prevent disease.

4.4 Environmental Impacts of Tra Production

4.4.1 Tra fish disease

Raising fish with high stocking rates makes them prone to disease due to oxygen competition among the fish or polluted water associated with fish excrement and uneaten feed. According to the survey results, common Tra fish diseases affected fish organs like the liver (77%), kidney (70%), gill (41%), skin (63%), head (25%), and swimming-bladder and intestines (3%) (Table 3). The farmers interviewed said that these diseases occurred due to weather changes (49%), polluted water sources (72%), parasites and bacteria in water (17%), and home-processed feed (5%) (Appendix 8). When farmers saw their fish get sick, they usually took the fish to the local aquaculture station or a veterinary clinic for them to be diagnosed and then bought drugs for treatment. These medicines were either mixed with feed or water and the mixture was then dumped into the ponds. In addition, the farmers also resorted to exchanging greater quantities of pond water with outside water to dilute the concentration of organic pollutants.

Table 3. Statistics of some common Tra fish diseases in the survey sites

Fish Diseases	Frequency	Percentage
White spots in liver	97	77.0
White spots in kidney	88	69.8
Red spots in gill	52	41.3
White skin	79	62.7
Swimming-bladder & intestine disease	4	3.2
Swollen head	32	25.4

Source: 2006 Survey
Note: n = 126

4.4.2 Pond sediment

Pond sediment elimination is now common practice in Tra fish production. Table 4 shows the percentage of farmers dumping waste into the surrounding environment and their awareness of its consequences and of the local regulations. Almost all of the farmers (96.9%) said that they had their ponds dredged several times; once after harvesting the fish and preparing the ponds for the new stock, and two to three times during the culturing process. One farmer had his pond dredged 18 times. The dredged sediment was dumped in several places like dikes, orchards, containment ponds, or water channels. Based on the survey results, these places could be grouped into three categories: public water sources (33%), private land (61%), and both (6%) (Appendix 9).

Table 4. Farmers' behavior and awareness related to the dumping of waste

	Percentage of respondents	
	Yes	No
Discharged pond sediment	96.9	3.1
Discharged wastewater	100.0	0
Know the consequences of the above actions	23.0	77.0
Know local regulations regarding the above actions	24.4	75.6

Source: 2006 Survey

When asked whether the act of dumping polluted the environment, only 23% of the fish farmers said "yes". Pollution in this case was in the form of polluted surface water and a bad smell emanating from the water. Besides creating water pollution, dumping was contributing to the reduction of canal depth, which threatened the navigation of vessels and the transportation of goods in the area and created/increased canal dredging costs.

To deal with this problem, the district and commune authorities passed a regulation to ban the dumping of pond sediment into water channels. However, only 24.4% of the respondents said that they were aware of the regulation.

4.4.3 Wastewater

During the Tra fish production process, uneaten feed, especially home-processed feed, and excrement pollute the pond water, which can cause disease in the fish. All the respondents reported that to cope with this problem, they regularly flushed the fishponds with water from external sources such as rivers and canals, as advised by technical agencies (Table 5). This measure helped improve the quality of the pond water but caused problems for the external water bodies.

According to the survey results, 25.9% of the farmers discharged pond effluents into the Hau River, 34.3% into canals, 5.6% into settling ponds, and 34.3% into paddy fields. Most of the respondents (60.2%) reported they dumped wastewater into public water sources and 39.8% dumped it onto private land. A great majority of the farmers (92.2%) used pumps to drain off the wastewater and pump river water into their ponds while 7.8% relied on natural flows during high tide (Appendix 10). When asked why they changed pond water, the reasons given were that they wanted their pond water to be clean so that their fish could be healthy and have a good appearance (white meat) at the time of sale.

Table 5. Wastewater receiving bodies

Receiving bodies	Frequency	Percentage
The Hau River	28	25.9
Canals of various levels	37	34.3
Lagoons	6	5.6
Paddy fields	37	34.3
Total	108	100.0

Source: 2006 Survey

The number of pumping times varied according to fish size. When the fish were small, this was every 0-4 days and the average water quantity exchanged was 25% while the time for exchanging water averaged 2.17 hours. When the fish became bigger, the number was from 1-3 times/day, averaging 1.4 times/day, with an average exchanged water quantity of 56% and the time for exchanging water lasting from 2-15 hours/time, averaging 5 hours/time (Appendix 11).

Wastewater exchange in Tra fish-breeding areas polluted the public water bodies and caused a nuisance to the local people as it reduced their clean water supply, aggravated the shortage of clean water in dry seasons, decreased their in-stream use for swimming and bathing, and lowered the environmental aesthetics. Meanwhile, the local government struggled to find a sustainable solution. Building settling ponds was one of the immediate measures that local agencies told fish farmers to take. But the survey results showed that only 13 out of 127 fish farmers (10.2%) did so. The main reason was the lack of land. Land prices were also high so many fish farmers could not afford to purchase more land. Furthermore, to treat wastewater effectively, the wastewater had to be kept in the pond for many hours for the pollutants in it to decompose before being released into the environment, but due to fish farmers changing the water almost every day, this measure alone was not effective in treating the wastewater.

The farmers did not use any devices to check the river water quality before taking it into their ponds. They just observed the color of the water and pumped it into their ponds during high tide. They had no choice but to use outside water, no matter how dirty it was, because the fish needed fresh water. Although many farmers did not check the river water quality, the majority of them (73.4%) checked their pond water quality regularly (Appendix 12), either using pH meters (60.7%) or making visual inspections (23.6%) or both (15.7%) (Appendix 13).

Some fish farms/ponds were located far from the Hau River and downstream along small canals. The risk the farmers of these faced was that they could not receive water from the big canals; rather they had to receive discharged wastewater from other fish farmers' ponds located upstream. Consequently, downstream canal fish farmers had to bear more risks than upstream canal farmers.

In summary, the main environmental consequences associated with the dumping of great quantities of pond sediment and untreated effluents carrying chemicals, uneaten home-made feed, and fish excrement into water bodies were the following:

- Reduced domestic water supply quality and quantity, which badly affected the local people's living conditions.
- Adverse effects on human health and aquatic life through the polluted water, especially in areas far from the Hau River.
- Decreased inland navigation due to shortened depth of canals.
- Reduced aesthetics of the local water bodies and people's recreational facilities due to polluted water in the canals.

4.5 Costs and Returns Analysis of Tra Fish Production

4.5.1 Operating costs

Operating costs consist of expenditure for pond preparation, pond treatment, fingerlings, feed, chemicals, labor, fuel for exchanging water and making home-processed feed, harvesting, loan interest, and other items. These inputs yielded about 450 tonnes of Tra fish/ha (or 45 tonnes per 1,000 m^2). Feed costs accounted for the greatest percentage (78%) followed by the costs of fingerlings (6.7%) and chemicals (5%) (Table 6). For one Tra fish cycle in 2005, the total operating cost was estimated at VND 476 million/1,000 m^2 or VND 4.76 billion/ha[4]. The operating cost per kilogram of Tra fish was VND 11 thousand, equivalent to USD 0.69/kg.

Table 6. Operating costs per 1,000 m^2 of pond water surface area for one cycle in 2005

Unit: '000 VND

	N	Mean	Percentage of total
Pond preparation	126	2,319	0.49
Pond treatment	125	3,406	0.72
Fingerlings	126	32,100	6.74
Feed	126	371,000	77.94
Chemicals	126	23,400	4.92
Labor	125	14,100	2.96
Fuel	126	13,100	2.75
Harvesting	126	2,810	0.59
Operating interest	126	14,500	3.05
Other cost	126	156	0.03
Total variable cost	126	476,000	100.00
Yield (tonnes)	126	45	
Operating cost per kg of Tra fish	126	11	
Catfish sales	126	551,000	

Source: calculated from survey data
Note: * = average for the whole sample

4.5.2 Fixed costs

Fixed costs are those associated with the total initial investment in equipment and the construction of ponds, pipelines, and storehouses. The depreciation of fixed investments was calculated by using the straight-line method on the estimated economic life of the initial investment (ponds, pipelines and storehouse/s: 10 years, equipment: 5 years) with zero salvage value of the items. Tra fish is harvested, on average, twice per year. The value of fixed inputs varied depending on farm scale and type of building materials and equipment. Due to lack of accurate data on the fixed costs/initial investment, total depreciation here may be underestimated. Table 7 shows that the fixed costs per hectare of water surface area for one cycle in 2005 totaled about VND 32.34 million.

Table 7. Fixed costs per 1,000 m^2 of pond water surface area for one cycle in 2005

Unit: '000 VND

Depreciation	N	Mean	Std. Deviation
Pond	95	994	1,631
Pipeline	83	273	296
Equipment	85	1,482	1,002
Storehouse	87	317	289
Total depreciation	67	3,234	2,839

Source: Calculated from survey data

[4] 1 hectare = 10,000 m^2

4.5.3 Net returns from Tra fish farming

Aquaculture is a risky industry since it is heavily dependent on natural conditions. For that reason, not all fish farmers are better off in this occupation. There were losers among the surveyed Tra fish producers. Therefore, to take a closer look at the profitability of this activity, surveyed farmers were divided into two groups: gainers and losers.

The total cost of Tra fish production was estimated by summing the costs of operating and fixed inputs. These cost estimates did not include the opportunity cost of the capital owned by the fish farmers. On average, fish farmers with positive profits produced about 52 tonnes of marketable Tra fish per 1,000 m^2 of water surface area and received VND 12.6 thousand/kg. Total sales were VND 649 million, total costs were VND 525 million, and net returns were VND 124 million per 1,000 m^2 of water surface area (Table 8).

Table 8. Costs and returns per 1,000 m^2 of pond water surface area for one cycle in 2005 (gainers)

Unit: '000 VND

Cost and Returns	N	Mean	Std. Deviation
Yield (tonnes)	52	52	73
Tra fish sales per kg	52	12,6	1,3
Tra fish sales	52	649,000	869,000
Fixed costS per crop	52	3,225	3,145
Operating costs	52	521,000	732,000
Total costs	52	525,000	735,000
Cost per kg of Tra fish sold	52	10	1,8
Net returns	52	124,000	154,000
Net returns per kg	52	2,5	1,6

Source: Calculated from survey data

On average, fish farmers with negative profits produced about 37 tonnes of marketable Tra fish per 1,000 m^2 of water surface area and received VND 11 thousand/kg. Total sales were VND 410 million, total costs were VND 465 million, and net returns were –VND 56 million per 1,000 m^2 of water surface area (Table 9).

Tra fish production in Thotnot District endured similar disadvantages as many other economic activities in Vietnam such as unstable prices and lack of capital. In addition, Tra fish production is water-dependent, so polluted water is a big disadvantage for this industry. Among the disadvantages listed by the respondents, price fluctuations caused them the most anxiety. Next was lack of capital, which was a chronic problem farmers had to face. As for polluted water, not many of them were as concerned over this as the first two disadvantages. This could be because they felt that they were addressing the problem by doing the water exchange.

Table 9. Costs and returns per 1,000 m^2 of pond water surface area for one cycle in 2005 (losers)

Unit: '000 VND

Cost and Returns	N	Mean	Std. Deviation
Yield (tonnes)	15	37	14
Tra fish sales per kg	15	11	1,5
Catfish sales	15	410,000	182,000
Fixed costS per crop	15	3,000	1,000
Operating costs	15	462,000	201,000
Total costs	15	465,000	202,000
Cost per kg of Tra fish sold	15	12,5	1,7
Net returns	15	-55,500	41,200
Net returns per kg	15	-1,5	1,0

Source: Calculated from survey data

4.6 Pollution Load Calculations for Tra Fish Production in Thotnot District

The calculation of pollution load was based on the COD parameter or the amount of oxygen needed to oxidize the entire organic matter in a fishpond (in this case). The more COD there is in the water, the more the amount of organic matter in it, that is, the water is more polluted.

To avoid fishpond water pollution, farmers usually change fishpond water. The changing of pond water is carried out during the fish culturing cycle. Depending on the fish growth stage, fish weight, and the practices of individual farmers, 5%–50% of pond water volume is changed per day. Pond water is changed in two ways. For fishponds located in the areas far from the Hau River, farmers pump water into the ponds from small nearby canals. For fishponds situated near the Hau River, farmers let water flow freely into ponds during high tide.

Fishpond water is usually polluted due to organic matter and certain substances in fish feed. However, organic matter is the main ingredient that causes fishpond water pollution. Treatment technologies to clean pond water are primarily chosen to remove organic pollutants but pollutants other than organic compounds could also be treated.

For this study, the Hau River water, the main source of water to the Mekong Delta, was taken as the control water sample. The control water samples were collected in the middle of the Hau River near Tan Loc islet.

Five Tra fish farming households were selected in the study sites as samples, of which three were located inland and far from the Hau River, and the other two were located near the Hau River. The study sites are shown in a map in Appendix 2. The households had their own fish farming practices (way of feeding, feed types, initial fish sizes, pond area, pond depth, etc.), but they had one common trait, that is, they had at least five years' experience in fish culturing.

Due to study time constraints, the water analysis stage barely covered five months from September 2006 to January 2007. In addition, it was hard to control the private fish raisers' culturing schedules so the research team chose the ponds which had fish in the development stage, which was the fastest growing stage in the Tra fish development cycle. This is the stage during which fish have a weight of 10-800 grams each. Stages where the weight is less than 10 grams or above 800 grams are considered as very slow growth rate stages.

4.6.1 COD load results

(a) Control river water quality (Hau River)

There were eight water samples taken from the middle of the Hau River at different times during the study period. Table 10 shows the results of the Hau River water analysis.

Table 10. Hau River water quality (Tan Loc islet, September 2006 to January 2007)

Date	**Tested Parameters**				
	pH	**SS**	**DO**	**COD**	**NH_3-N**
TCVN 5942-1995 Class A	6-8.5	≤20 mg/l	≥6 mg/l	<10 mg/l	≤0.05 mg/l
01/09/2006	7.91	76	5.2	4.0	0.050
23/09/2006	7.16	51	3.6	14.0	0.060
14/10/2006	7.09	115	5.2	11.0	0.100
28/10/2006	7.19	112	3.2	6.0	0.120
18/11/2006	6.38	58	2.9	9.0	0.247
16/12/2006	6.65	87	3.1	12.0	0.147
13/01/2007	7.16	61	3.2	10.0	0.098
27/01/2007	6.85	22	3.3	5.1	0.163

Source: Water sample analysis results from the Cantho Environmental Monitoring Station

- pH values varied from 6.38-7.91, most of which were within Vietnamese environmental standards (TCVN 5942-1995). Specifically, the 18/11/2006 water sample pH had the lowest value of 6.38, violating the TCVN standard of 6.5, but the violation level was not high and was still within normal range compared to previous Hau River water monitoring results.
- Suspended solids (SS) in the samples varied according to sampling times with the highest value of 115 mg/l in October 2006, thereafter decreasing until the end of January 2007 with the lowest value of 22 mg/l. Hence, at the beginning of the study stage, the amount of SS was high due to the flood season with abundant silt, and at the end of the study period, the amount of SS was low because of the start of the dry season in the MD.
- Dissolved Oxygen (DO) amount in the water varied from 2.9-5.2, usually hovering between 3.1 and 3.6 mg/l. The DO values of the Hau River water were lower than that of TCVN 5942-1995, Class A (>6mg/l), showing that the water was being polluted by organic matter. Low DO levels affect aquatic life.

- Organic content, represented by the COD parameter, varied from 4-14. The COD values were greater than the allowed rate of TCVN 5942-1995, Class A (<10mg/l) four times.
- The NH3-N content in the samples often exceeded the TCVN 5942-1995, Class A standard of 0.05 mg/l. It showed a tendency to increase significantly at the end of 2006 and at the end of the study period. In September 2006, the NH_3-N content in the water was 0.05 mg/l, equal to the allowed level. In November 2006, NH_3-N had the highest concentration of 0.247 mg/l, exceeding the permissible limit by nearly five times.

In summary, the Hau River water had better quality at the beginning of the study period than at the end. It can be concluded that the Hau River water was polluted due to organic matter, more so in the late months of 2006.

(b) Inlet and outlet water quality at water sampling sites in Thotnot District

The inlet and outlet water quality analysis results of the five households are presented in Appendices 14, 15, 16, 17 and 18. These results were compared to the specifications in TCVN 6774:2000 on Fresh Water Quality Guidelines for the Protection of Aquatic Life (pH of 6.5-8.5, DO of 5 mg/l, and SS of ≤100 mg/l); and 28 TCN 176:2002 on aquaculture standards (COD of <10 mg/l, and NH_3-N of <1 mg/l). In general, pH values of inlet and outlet water at the five fishponds were still within TCVN 6774:2000. The pH values of the outlet water tended to be lower than those of the inlet water.

- SS measured at the five ponds varied from 28-303 mg/l while the allowed level in TCVN 6774:2000 is equal to or less than 100 mg/l.
- The DO values in inlet and outlet water were much lower than the allowed standard in TCVN 6774:2000 (5 mg/l). DO amounts in the outlet water were far less than those in the inlet water, varying from 0.8-6.8 but generally less than 4.1. Perhaps too high stocking rates (33-120 fingerlings/m^2), coupled with uneaten feed and fish feces contributed to this. Due to high population densities and lack of oxygen, fish loss rates were also high at 19-50 % of initial stocking rates.
- As for COD values, the water sample analysis results showed that the COD content in the outlet water was much higher than that in the inlet water and often exceeded the allowed COD standard (<10 mg/l). The difference in COD contents between inlet and outlet water samples is the COD amount generated from Tra fish production, which is subsequently released in the wastewater into the outside water environment.
- NH_3-N in Tra fish culture tended to increase with Tra fish farming over time. The NH_3-N content in the inlet water was within the permitted range, but in the outlet water, it was often beyond 1 mg/l.

4.6.2 Pollution Load Rate (PLR) results

The PLR was used in the calculation of COD abatement costs per kilogram of fish. Table 11 shows the summary of the water sample analysis and PLR results for the five households (see also Appendix 19).

Table 11. Summary of the wastewater analysis results for the five fish-farming households

Households	**Fish growth (kg)**	**Pond volume (m^3)**	**Wastewater volume exchanged (m^3)**	**COD load (kg)**	**PLR (kg COD/kg of fish growth)**
1	416,500	32,000	925,290	45,126	0.108
2	56,000	4,800	66,000	4,625	0.083
3	40,800	4,000	60,125	3,933	0.096
4	157,000	25,000	452,500	13,601	0.087
5	173,600	36,000	954,000	15,835	0.091
Total/Average	843,900	101,800	2,457,915	83,120	0.098

Source: Calculated by the technical expert

The average PLR for the five fish-breeding households was estimated at 0.098 kg COD/kg of fish growth, that is, one kilogram of fish yielded 98 grams of COD. On the other hand, the average COD amount in Tra pond wastewater effluents that needed treating was 0.034 kg/m^3 or 34 mg/l. This was the additional COD quantity generated from breeding Tra fish beyond the COD amount available in the input water. This concentration is small compared to that of other industrial activities like processing aquaculture products where the COD amount may reach over 1,000 mg/l of wastewater. However, in Tra fish production, the wastewater volume dumped into the environment is huge and so it has caused significant pollution of the local water resources. If this situation continues unchecked, Tra fish production could become unsustainable in the near future.

4.7 Technical Options to Reduce COD Loads in Tra Fish-farming Wastewater

At present, to reduce the pollution in Tra fishpond water, fish farmers in Thotnot District usually replace pond water with river water to dilute the pollutant concentrations in fishponds. Some fish farmers also use lagoons to reduce water pollution. However, in Thotnot District, this method is not common because of insufficient land (Appendix 20).

To address the risk of potentially polluted river water being used in catfish culturing, guidelines by the Ministry of Fisheries as well as the Cantho Fisheries Department, urged fish farmers to build settling pools from which settled water can then be taken into fishponds, while effluents from fishponds have to be treated in treatment pools before being released into external water bodies. Some guidelines have been given for treatment pools, namely: (a) using hyacinth to absorb organic nitrogen; (b) putting in tra fish at a density of 3 fish/m^2 for them to aerate pond bottoms and reduce algae; (c) using aerators to disturb the bottoms of ponds so that toxic gases are released; and (d) when necessary, using approved chemicals to treat the wastewater (Cantho Fisheries Department 2006). In addition to these measures, recommendations on stocking densities, feed types, and chemical use have been also given to reduce Tra fish-related water pollution. Nevertheless, the guidelines have not indicated how much water pollutants can be reduced from these measures and the length of time wastewater has to stay in treatment pools before being safely released to the outside environment.

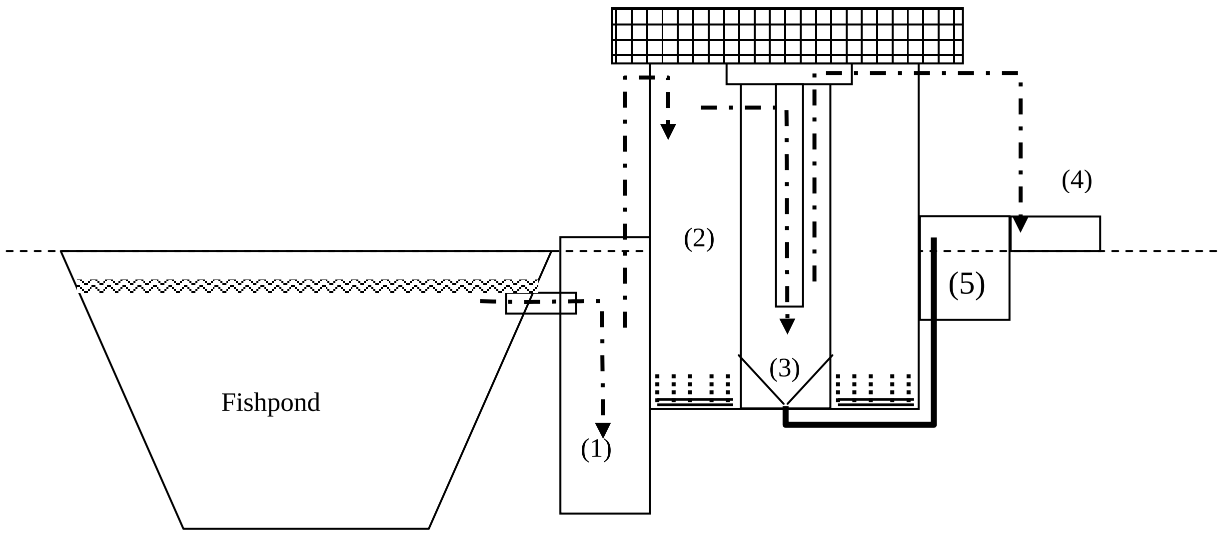
Through the water sample analysis results (Table 11), although the COD concentration in Tra fish wastewater was not as high (34 mg/l) as other industries, the organic pollutants in the fishpond water in the survey sites were nevertheless considerably in excess of the Vietnamese environmental standards for surface water quality (<10 mg/l). If this situation is common for most other fish breeders in Thotnot as well as in other localities in the MD, the domestic water supply quality in the MD could be severely compromised, especially in densely populated areas, threatening the welfare of thousands of people as well as the Tra fish export potential of Vietnam due to diseased fish, etc. To reduce organic pollutants from pond Tra fish production being discharged into outside water bodies, three technical control options were proposed: the aeration system, the trickling filter, and constructed wetlands. The aeration system is being applied in aqua-product processing plants (Meko and Binh An in Cantho Industrial Zone) while the trickling filter system is installed at the Ha Tien II Cement Factory in Cantho City to treat domestic wastewater from workers' activities and kitchens. Constructed wetlands have so far not yet been applied in Cantho City, but this system is going to be installed to treat wastewater from the students' dormitory at Cantho University.

4.7.1 Description of technical options

The three options are explained and illustrated below.

(a) Aeration system

In this system, wastewater from fishponds will be pumped into a temporary tank (1). Then, the water will be pumped into an aeration tank (2). After a specific time for aeration, the water will flow into a sediment tank (3), then to a sterilizing tank (4), and finally return to the fishponds or flow out to local surface water bodies. After 3–6 months of operation, there will be some sludge settling at the bottom of the bio-filter tower. This sludge must be pumped to the sludge-storing tank (5) for other uses.



Key

- - ▸ : Wastewater flowing route
(1) : Temporary tank
(2) : Aeration tank
(3) : Sediment tank
(4) : Sterilizing tank
(5) : Sludge-storing tank

Figure 1. Aeration system

(b) Trickling filter system

Wastewater from the fishponds will be pumped into a temporary tank (1). Then, the water will be pumped to the top of the bio-filter tower and sprayed for leaching through the filter material to the sediment tank at the bottom (2). After a few selected cycles of the bio-filtering process, the water will flow into a sterilizing tank (3) and then return to the fishponds or flow out to local surface water bodies. After 3–6 months of operation, there will be some sludge settling at the bottom of the bio-filter tower. This sludge should be pumped into the sludge-storing tank (4) for other uses.

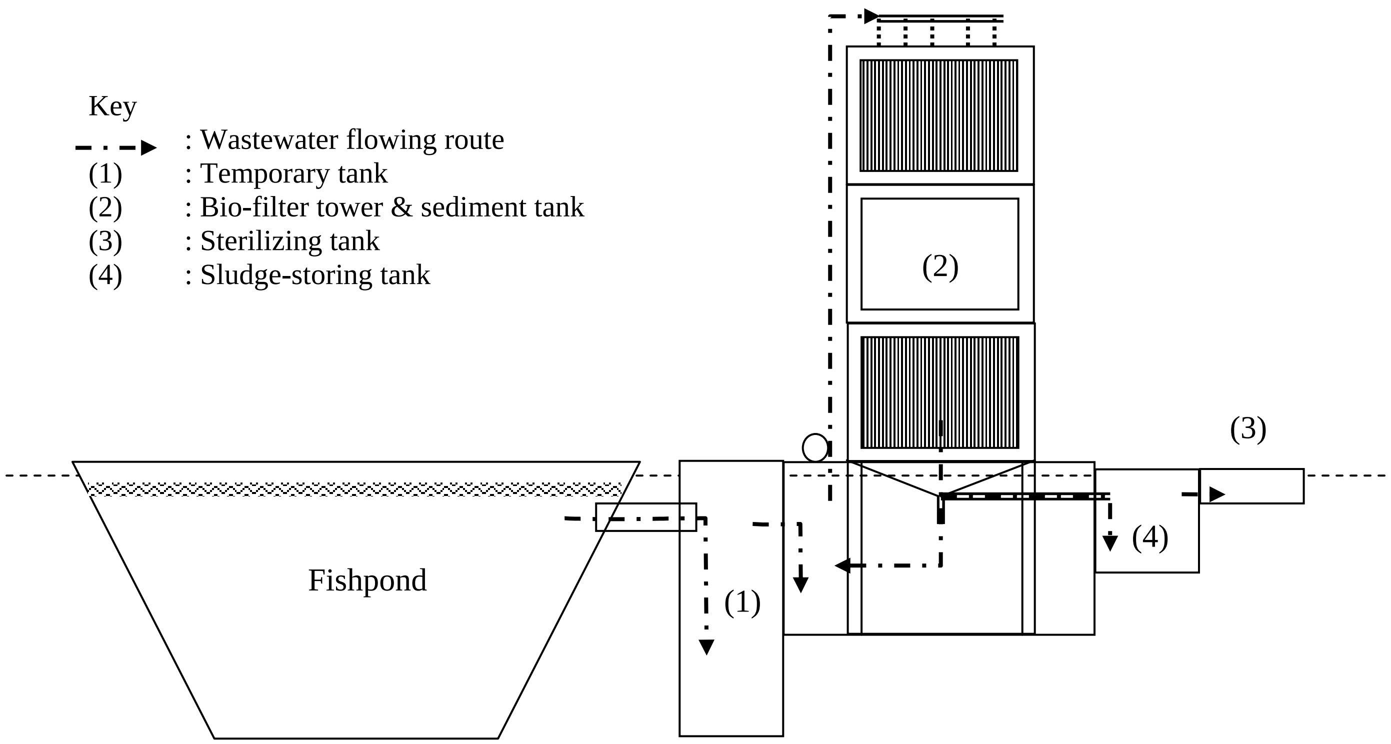


Figure 2. Trickling filter system

(c) Wetland system

Wastewater from the fishponds will be pumped into a temporary tank (1). Then, the water will be pumped to eject about 50 cm over the top of the wetland bio-filter tank (2) to fall and leach through the filter material. It will then flow to the temporary tank (1) again through a collecting pipe system at the bottom of the bio-filter tank. After a few selected cycles of the bio-filtering process, the water will be poured into a sterilizing tank (3) and then return to the fishponds or flow out to local surface water bodies. The workers must check the system every day for any operational problems. After 3–6 months of operations, there will be some sludge settling at the top of the wetland bio-filter tank. The filter must be cleaned and the sludge transferred to the sludge-storing tank (4) for other uses.

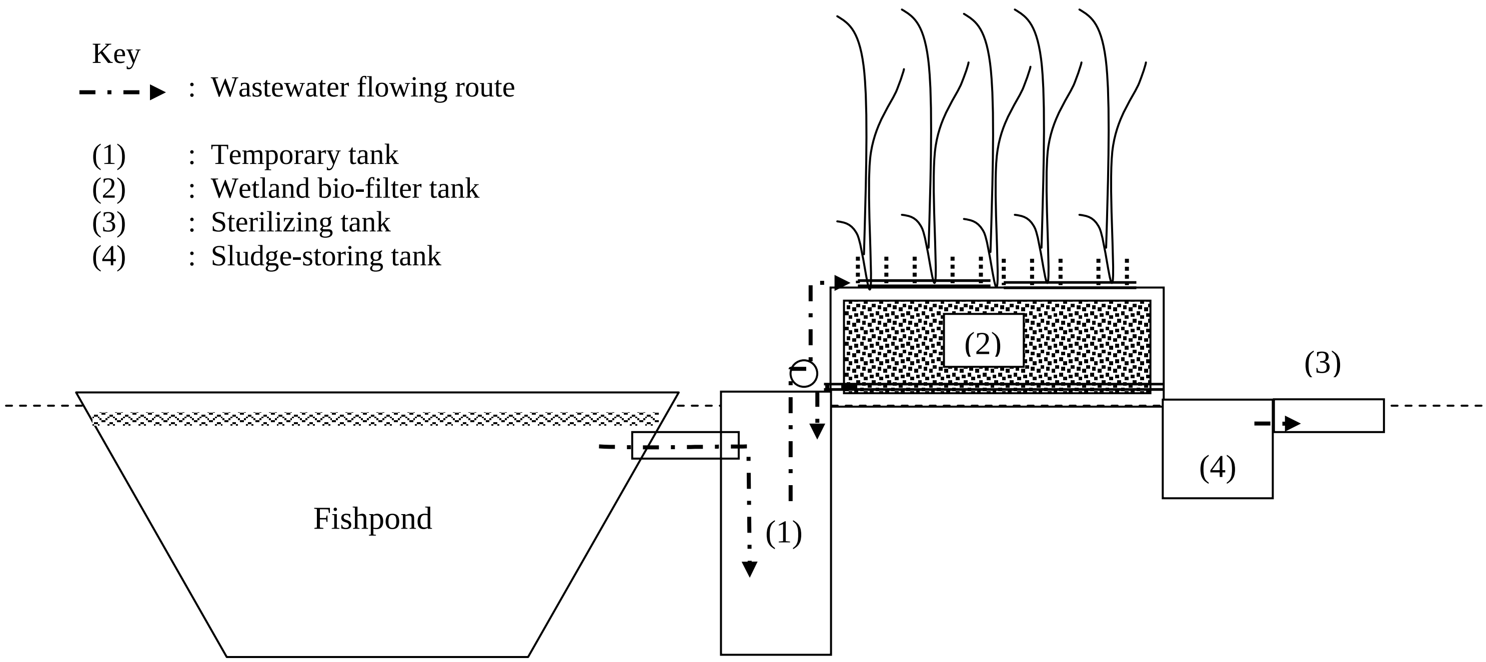


Figure 3. Wetland system

4.7.2 Cost-effectiveness analysis of the proposed technical options

The assumptions for this analysis were as follows:

- Pond water surface area: 5,000 m^2 (average pond area in Thotnot District)
- Pond volume: 20,000 m^3 (pond water depth of 4 meters)
- Daily discharged wastewater: 6,000 m^3 (average discharge rate of 30%)
- COD concentration (needing treatment) per cubic meter of wastewater: 0.034 kg/m^3
- Daily COD load (needing treatment): about 200 kg (= 6,000 m^3 * 0.034 kg/m^3)
- Pollution load rate (PLR): 0.098 kg of COD/kg of Tra fish growth
- Lifespan of aeration and trickling filter systems: 30 years
- Lifespan of constructed wetland system: 10 years

4.7.3 Calculation results

Table 12 shows the estimated costs of the three wastewater treatment systems. For a pond 5,000 m^2 in size, the land area needed for the aeration system is 915 m^2; for the trickling filter system, 1,300 m^2; and for the constructed wetland system, 1,300 m^2. The investment cost of the aeration system is the highest while that of the constructed wetland is the lowest. The operating cost of the aeration system is also the highest and that of the trickling filter system is the lowest. Of the three systems, trickling filters have the least treatment costs per kilogram of COD abated and per kilogram of fish growth. Therefore, the trickling filter system appears to be the most cost-effective of all. These calculations were based on current input prices. If the input prices increase, the COD abatement costs will be higher.

Table 12. Estimated costs of the three wastewater treatment systems for a pond 5,000 m^2 in size

Unit: '000 VND

Costs	Aeration system	Trickling filter system	Constructed wetland system
1. Investment Costs	**1,871,581**	**975,658**	**812,158**
Construction area (m^2)	915	1300	1300
Land	137,250	195,000	195,000
Materials (iron, cement, etc.)	972,281	242,125	191,169
Pumps:			
- Wastewater	69,943	69,943	69,943
- Sludge	28,876	14,438	9,625
- Aeration or filter matter	63,000	234,000	144,000
Electric and mechanical system	200,000	40,000	60,000
Labor for construction	400,231	180,152	142,421
2. Annual Operating Costs	**151,728**	**89,040**	**138,000**
Operating labor	36,000	36,000	72,000
Electric power	109,728	51,840	64,800
Maintenance cost	6,000	1,200	1,200
3. Present value (@ 10%)	Lifespan: 30 years	Lifespan: 30 years	Lifespan: 10 years
Investment cost	1,871,581	975,658	812,158
Total operating costs	1,430,327	839,372	847,950
Total Present Value	**3,301,908**	**1,815,030**	**1,660,108**
4. COD amount that needs treating (kg)	2,190,000	2,190,000	730,000
5. Treatment cost/kg of COD	**1.508**	**0.829**	**2.274**
6. PLR (kg COD/kg fish produced)	0.098	0.098	0.098
7. Treatment cost/kg of fish produced (Item 5*PLR)	**0.148**	**0.081**	**0.223**

Source: Calculated by the technical expert and authors

Note: 1 USD ≈ VND 16,000

4.7.4 Comparative summary of the three options

Table 13 shows the comparison of some of the main characteristics of the three options with common advantages as well as disadvantages. It appears that trickling filters have the most preferred characteristics.

Table 13. Comparison of some financial and technical characteristics of the three options

Characteristics	Aeration system	Trickling filter system	Constructed wetland system
1. Investment costs	High	Low	Lowest
2. Annual operating costs	High	Low	Medium
3. Electric power	High	Lowest	Low
4. COD abatement costs	Medium	Low	High
5. COD treatment capacity	95-98%	90%	75-80%
6. Lifetime	30 years	30 years	10 years
7. Advantages	- High treatment capacity - Automated, easy to operate - Effective in treating high concentrations of organic pollutants - Reliable performance - Biological process - Can reuse treated wastewater	- Rather high treatment capacity - Automated, easier to operate - Effective in treating high concentrations of organic pollutants - Simple, reliable - Biological process - Can reuse treated wastewater - Durable process elements - Low power requirements	- Biological process - Automated, easiest to operate
8. Disadvantages	- High investment - Needs more land (18% of pond area), which is a constraint in the study area - Consumes a lot of electric power, relying on state power supply, which is big constraint - Needs technicians in case the system goes out of order	- High investment - Needs more land (26%), which is a constraint in the area - Consumes electric power, relying on state power supply, which is big constraint - Needs technicians in case the system goes out of order	- High investment - High labor requirement to run the system - Needs more land (26%), which is a constraint in the area - Only treats wastewater with low pollutant concentrations and must go through several rounds - High COD abatement costs - Consumes electric power, relying on state power supply, which is big constraint - Needs technicians in case the system goes out of order

4.7.5 Farmers' opinions of the proposed technical options

After the calculations were done, a seminar was organized in Thotnot District to collect the farmers' opinions of the proposed technologies as well as other information. Twenty-two people attended the meeting, of which 14 were fish-breeding farmers and the rest were local officials of related agencies. At the meeting, the study results of the environmental consequences of Tra fish production were presented first, and then proposed technical options with their associated costs were described by the technical expert. After that, the study team asked the participants to assess the technical and financial feasibility of the options. Local officials were interested but the fish farmers were reluctant to consider the prospect of having to treat their wastewater with costly technologies. The fish farmers' views on the proposed options were as follows:

(a) The options depended heavily on the State's electricity supply which could not even meet national demands—this was a big constraint.

(b) The options were only suitable for concentrated fish culture planned zones, not for separate fish-breeding households, due to the lack of extra land on which to build the treatment structures. Moreover, if only some households applied these systems while the others did not, the former would still face the problem of unclean input water if they supplemented pond water with water from the local canals which were already polluted not only by Tra fish effluents but also by other polluting sources.

(c) The State should invest in a pilot project involving these options for a few years for farmers to see the results before they made any decisions.

(d) Due to the relatively big investments required, if these systems could be funded by some organization or cooperative, then the fish farmers would be willing to pay this organization for clean input water and treatment fees.

(e) The profits from the Tra fish industry were shared among many stakeholders such as input suppliers, so why did only the fish farmers have to bear the environmental costs?

(f) Tra fish prices often fluctuated, depending on export prices, that is, on international Tra fish demand. If fish prices go up, then so will input prices. However, if fish prices go down, input prices may not follow suit, which may lead to financial losses for the farmers. Since the farmers were struggling with increasing operating costs, they could not afford any significant investment in wastewater treatment systems. Therefore they were more inclined to resort to chemical treatment since they thought that this was less costly.

Among the five surveyed fish-breeding households, one had installed an aeration system in his pond to provide oxygen for his fish. He reported to the group that although the COD amount and the number of dead fish in his pond had decreased, so did the fish growth rates. Since he had spent a significant amount of money on this treatment system, he could not consider any alternative treatment.

In response to the farmers' opinions, the technical expert explained that applying aerators directly in ponds reduced the COD content and increased oxygen, but it also increased ammonia (NH_3) which could reduce fish growth or kill fish if levels rose too high. Therefore, aerators should be placed outside the pond. In regard to chemical treatment, the technical expert revealed that his agency had tested some chemicals to treat wastewater in fishponds but the results showed that their performance was not as good as the three options proposed (they only treated about 70% of the COD). Moreover, the prices of the chemicals were very high since they were imported from the U.S. His view was that treating pond water with chemicals increased the chemical quantity in ponds while not strictly solving the pollution problem. As for input water problems, he said that fish farmers could reuse the treated water instead of releasing it into water channels or they could use the systems to treat the input water. The technical expert added that while treating wastewater would raise fish production costs, the farmers would save on fuel expenditure for pond flushing at the same time.

In all, farmers realized the consequences of Tra fish production on local water quality but due to land and financial constraints, they responded poorly to the proposed technical options.

4.7.6 Farmers' option ranking

As the above fish farmers were not eager to receive these technologies due to their personal constraints, option ranking was necessary to make a more objective judgment on the three technologies. Therefore, the same fish farmers were invited to another meeting and asked to rank the options using the preference ranking method. This method of ranking is not complex. People are asked to choose between each pair of options in turn, using a two-way choice matrix. The option that appears in the two-way choice matrix the most often is given the highest rank. People were also asked to give reasons for their choices. Table 14 lists the ranking results.

Table 14. Results of preference ranking of options

Most preferred option	Number	Percentage
1. Aeration system	5	36
2. Trickling filter system	7	50
3. Constructed wetland system	0	0
4. No ranking	2	14
Total	14	100

Source: synthesized from individual fish farmers' matrices

Table 14 shows that 36% of the participants chose the aeration system as their most preferred option, 50% chose trickling filters, none chose wetlands, and 14% refused to rank the options. Their reasons for choosing or not choosing an option are given below.

(a) Choosing the aeration system

- High treatment capacity.
- Structure of high investment signifies high quality.
- The COD abatement cost is not significant compared to the fish unit production cost.

(b) Choosing the trickling filter system

- The COD abatement cost is the lowest.
- Effective treatment.
- Saves money in not having to aerate the wastewater.

(b) Not choosing the constructed wetland system

- Low treatment capacity.
- Needs a lot of labor to operate and clean the system, but labor price is high and labor supply is short in the region.
- The COD abatement cost is the highest.

(c) Refusing to rank the options (not trusting in their feasibility)

- Need to see the performance of the systems before making judgments on them.
- The structures required more land area for construction (18-26%) than they expected (10%).
- Input water quality is important to fish health but these options place more focus on treating effluents, not adequately solving their input water concerns. Their ponds are located far from the Hau River so water supply is not abundant and there is river water competition among fish producers in this area. Therefore, they do not think that Tra fish-farming in these areas will last long, due to the increasingly polluted input water.
- Governments should strictly address other large polluting sources like alcohol production, aqua-product processing activities, etc., first.
- Do not believe that the power demand will be met.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Tra fish production in Thotnot District in particular and the MD in general has brought many benefits to fish-breeding farmers as well as to the nation namely, by improving the incomes of the farmers, providing nutritious food to the population, and earning foreign income for the country through export. Fish producers in Thotnot District earn profits of about VND 2-2.5 thousand/kg of fish.

However, Tra fish culture has caused water pollution. The study uncovered the following problems: (a) Earth removal from fishpond digging and periodic dumping of pond sediment into external water bodies have polluted these bodies and reduced their depth, affecting water quality and navigation; (b) Wastewater from Tra fishponds has been released into rivers and canals without proper treatment. The organic content in the wastewater was high. The average COD quantity released from Tra fish raising processes into outside water bodies was about 34 mg/l of wastewater or 98 g/kg of fish produced; and (c) High stocking rates, coupled with unhygienic home-made feed, polluted input water, abuse of antibiotics, etc., have led to high fish losses due to lack of dissolved oxygen in the water.

To reduce the pollution in Tra fishponds, fish breeders often exchange some of the water with fresh water from outside sources as a means of diluting the pollutant concentration in the ponds in order to prevent fish loss. This practice is of grave concern to the local government as well as the people. It also contravenes Vietnam’s Law on Environmental Protection 2005 which stipulates regulations for production/business activities, aquaculture, etc., such as treating wastewater before discharging it into the environment. If this situation is not arrested, the areas breeding Tra fish will soon lack clean water for the local people’s needs and the Tra fish-farming industry will also suffer great losses due to polluted water.

Currently, some fish-farming households use additional ponds to hold the wastewater for some time before releasing it into public water bodies, but these ponds are small and the water retention time allocated by the farmers is too short, so this measure is not effective. To treat effluents more effectively, the study team proposed three possible technical options to reduce water pollution from Tra fish farming: (a) the aeration system; (b) the trickling filter system; and (c) the constructed wetland system. Among these, trickling filters was the most cost-effective option. The treatment cost per kilogram of COD estimated was VND 1.51 thousand (≈USD 0.09) for the aeration system; VND 0.83 thousand (≈USD0.05) for the trickling filter system; and VND 2.27 thousand (≈USD 0.14) for constructed wetlands, much greater than the environmental protection fee of VND 0.3 thousand/kg of COD in wastewater presently imposed by the government on industrial as well as domestic wastewater as specified in Decree 67/2003/NĐ-CP. Industrial wastewater refers to water discharged into the environment from industrial production establishments and agricultural, forestry and aquatic product processing establishments.

The treatment costs per kilogram of fish produced were VND 0.148 thousand for the aeration system, VND 0.081 thousand for trickling filters, and VND 0.223 thousand for constructed wetlands, equivalent to 7.5%, 4%, and 11% of fish production profits, respectively. All three options needed extra land (about 18-26% of pond water surface area), adequate power supply, and considerable investment, which are all significant constraints to fish producers.

To assess the social acceptability of the three options, two focus group discussions were organized. The first provided general judgments and the second ranked the options through the preference ranking method. Not all of the participants chose the most preferred technology based on the criterion of cost-effectiveness. Instead, their choices were based on their preferences. Consequently, 50% chose trickling filters, 36% chose aeration systems, no one chose constructed wetlands, and 14% refused to rank. All of them suggested that the State install these systems as a pilot project on a certain plot to demonstrate their performance and if they proved to be good, then a collective organization should be set up to manage wastewater treatment in the area and the farmers would be willing to pay for clean input water as well as Tra fish wastewater treatment fees.

5.2 Policy Recommendations

To continue economic development without sacrificing the natural environment, national laws as well as other government action are needed to address the externalities of economic activities. From the above conclusions, we can see that the dumping of great quantities of Tra fish waste into public water channels by fish farmers has considerably jeopardized the health of the fish being reared as well as the domestic water supply of the local people. The Ministry of Fisheries has laid down specific guidelines for pond construction and land requirements for the storing of pond sediment and wastewater. However, in reality, fish farmers do not abide by the latter and still discharge untreated wastewater into local waters. This study proposed three wastewater treatment technologies to treat wastewater more effectively than settling pools, but the COD treatment costs were rather high. Some policy recommendations that would help in reducing water pollution caused by Tra fish production are given below.

Firstly, it is necessary to implement the establishment of Tra fish planned zones in Cantho City. These zones have been planned but not yet established. They would pave the way for concentrated wastewater treatment systems to be set up, which will help reduce COD treatment costs.

Secondly, it is essential to set emission standards for Tra fish pond wastewater released into public water bodies. This will spur the application of efficient technologies to reduce organic matter concentration in the wastewater to acceptable levels. Fish farmers will only think of waste treatment if standards are set by state law and enforced by capable agencies. At present, environmental protection fees apply only to the shrimp industry, not to the Tra fish industry.

Thirdly, due to the high initial investment costs of the treatment technologies, farmers are unwilling to implement them without support. Thus, local governments should set up an environmental fund to provide long-term loans with preferential interest rates to fish farmers to enable them to build treatment systems. In addition, governments should think of establishing state-financed pilot waste treatment systems capable of treating input and output water to demonstrate the usefulness of these systems to farmers.

Fourthly, to make fish producers accept treatment costs more willingly, local governments should investigate pond Tra fish production costs, taking into account the treatment cost per kilogram of fish produced (which should be included in the production costs), before setting a floor buying price for Tra fish bought from farmers.

The fifth recommendation is for agricultural agencies to study and formulate clean Tra fish culture processes in accordance with national food safety and hygiene standards, and then enforce them strictly.

While there are not yet effective measures to curb water pollution, responsible agencies should pay more attention to finding feasible clean water supply alternatives to alleviate the local people’s hardship due to lack of clean water.

The COD treatment costs estimated in this study are high compared to the environmental fees specified by the state in Decree 67/2003/NĐ-CP—this will not encourage individual farmers to apply technical options. Therefore, state agencies should compare current environmental fees with the COD treatment costs of different technologies and adjust them if they are too low.

5.3 Future Research

To reduce the environmental consequences arising from Tra fish production, it is necessary to apply diverse technologies to the pond Tra fish industry. This research has proposed three technical options to treat fishpond pollutants. However, the results were based on reports from private fish-farming households and a limited number of water samples within a short time frame. This study has provided the statistics for COD concentrations (mg/l) in wastewater, pollution load rates, treatment costs per kilogram of COD, and treatment costs per kilogram of fish produced. These are the estimates based on a household survey. If policy-makers wish to formulate environmental standards for or impose environment protection fees on Tra fish producers, a more complete investigation should be conducted experimentally with state-owned aquaculture establishments or more (voluntary) households to obtain more accurate data.

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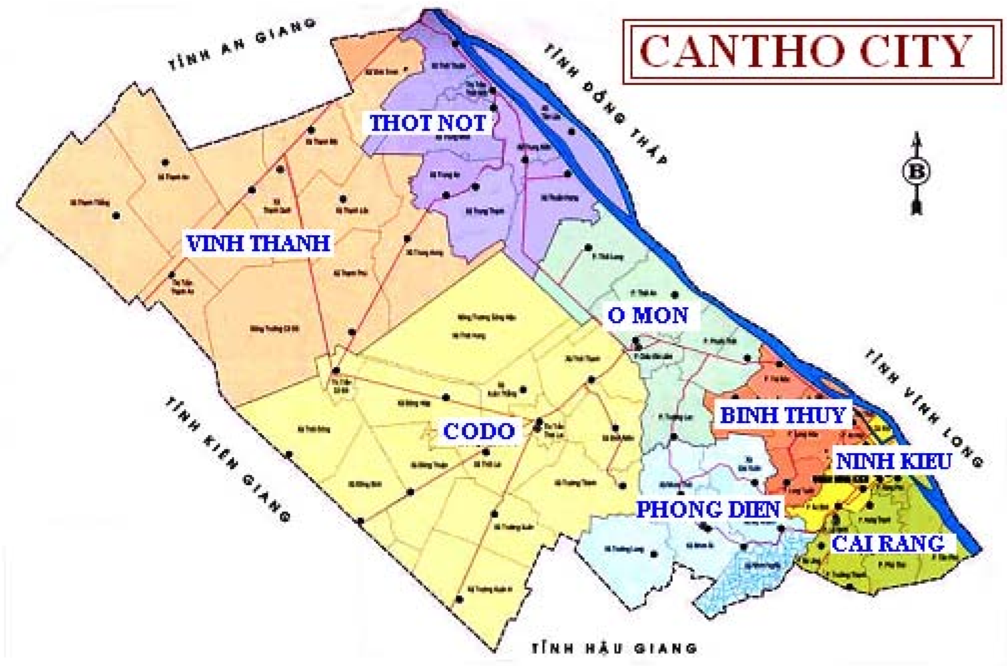
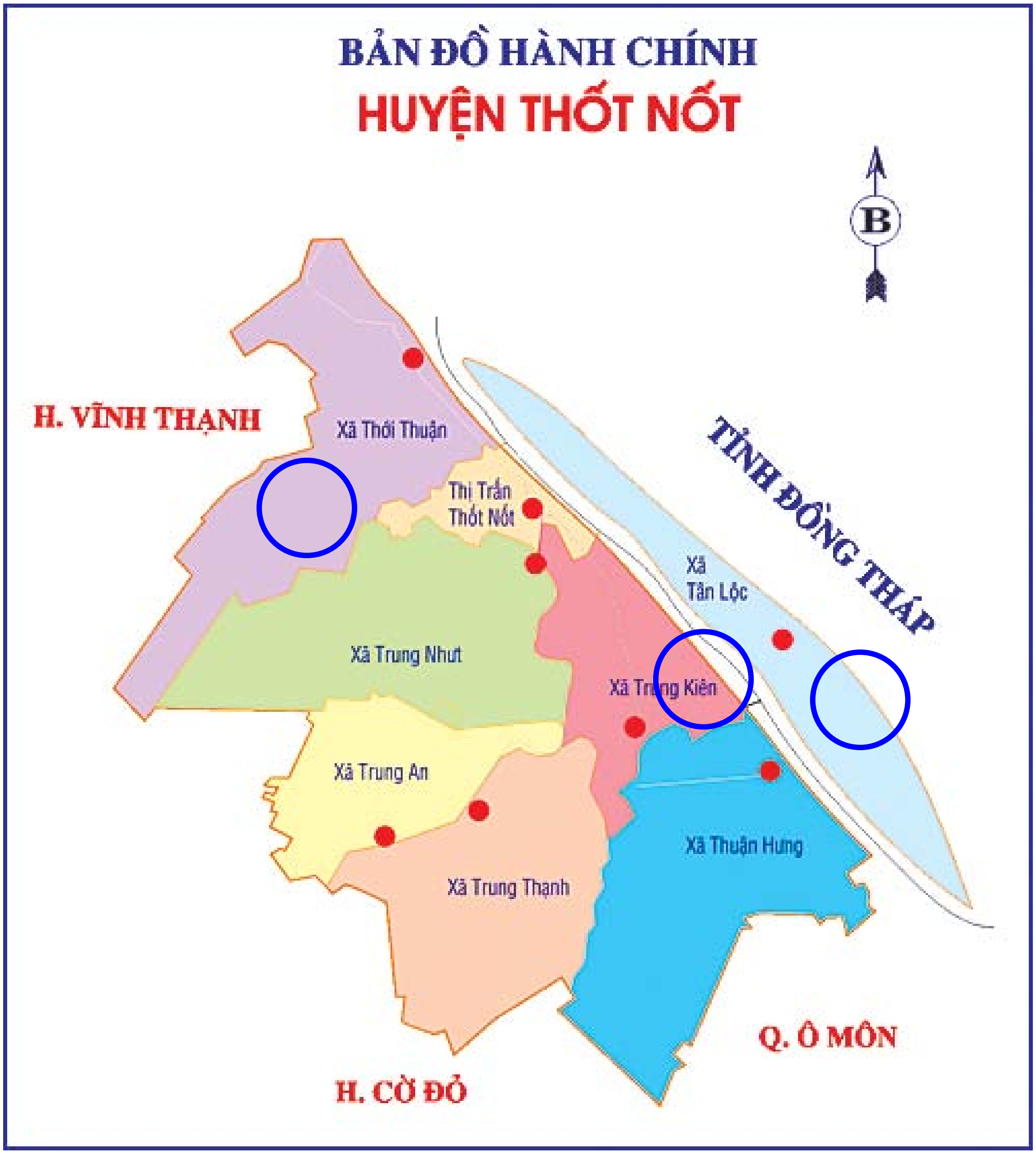
APPENDICES

Appendix 1. Map of Cantho City



Appendix 2. Map of Thotnot District, Cantho City



Note: ◯ Study sites

Appendix 3. Farmers' opinions about the effect of dumping wastewater on the quality of river water

River water quality	Frequency	Percentage
Unchanged	18	14.2
Dirtier	60	47.2
Very dirty	38	29.9
Unusable in the future	11	8.7
Total	127	100.0

Source: 2006 Survey

Appendix 4. Fish farmers' reactions to the possibility of a ban on the discharge of wastewater into public water bodies

	Frequency	Percentage
Stop rearing fish	59	47.2
Build lagoons	40	32.0
Others	26	20.8
Total	125	100.0

Source: 2006 Survey

Appendix 5. Fish farmers' reactions to the possibility of higher treatment costs

	Frequency	Percentage
Farmers' opinions about the higher treatment costs		
Disagree	47	38.5
Agree	75	61.5
Total	122	100.0
Farmers' reasons for not accepting the higher treatment costs		
Lack of land	10	22.2
High treatment cost	18	40.0
Lack of land & high cost	12	26.7
High land price	3	6.7
Not discharging into channels	2	4.4
Total	45	100.0

Source: 2006 Survey

Appendix 6. Mean fishpond area by commune (2006)

Commune	Mean (m^2)	N (cases)	Std. Deviation
Tan Loc	9,292.58	31	14,895.925
Thoi Thuan	4,022.72	90	3,567.665
Trung Nhut	1,500.00	1	.
Vinh Trinh	4,744.44	9	4,623.341
Total	5,300.11	131	8,142.330

Source: 2006 Survey

Appendix 7. Size of fishponds in the fish farms in the study sites (m^2)

Pond size	Frequency	Percentage	Cumulative Percentage
<1,000	9	6.9	6.9
1,000-3,000	50	38.2	45.0
3,001-5000	32	24.4	69.5
>5000	40	30.5	100.0
Total	131	100.0	

Source: 2006 Survey

Appendix 8. Causes of fish diseases as reported by farmers

	Frequency	Percentage
Weather changes	37	48.7
Polluted water source	55	72.4
Parasites, bacteria in water	13	17.1
Home-processed feed	4	5.3

Source: 2006 Survey

Appendix 9. Sediment receiving bodies

Receiving bodies	Frequency	Percentage
Public water sources	41	33.1
Private land	76	61.3
Both	7	5.6
Total	124	100.0

Source: 2006 Survey

Appendix 10. Methods used to exchange pond water with river water

	Frequency	Percentage
Natural flows (tide)	10	7.8
With pumps	118	92.2
Total	128	100.0

Source: 2006 Survey

Appendix 11. Characteristics of pond exchange

	N	Min.	Max.	Mean	Std. Dev.
1. **Small fish**					
Number of flushing times (days/time)	117	0	4	2.60	0.60
Water quantity changed (% of pond water volume)	111	0	80	25.39	13.26
Length of time (hours/time)	107	0	7	2.17	1.22
2. **Bigger fish**					
Number of flushing times (times/day)	117	1	3	1.40	0.52
Water quantity changed (% of pond water volume)	110	1	100	55.94	21.34
Length of time (hours/time)	101	2	15	5.06	2.52

Source: 2006 Survey

Appendix 12. Pond water quality checks by households

	Frequency	Percentage
Without check	34	26.6
With check	94	73.4
Total	128	100.0

Source: 2006 Survey

Appendix 13. Methods used by the fish farmers to check pond water quality

	Frequency	Percentage
pH meter	54	60.7
Visual	21	23.6
pH & visual	14	15.7
Total	89	100.0

Source: 2006 Survey

Appendix 14. Water sample analysis results of Household 1

Time	Date	Inlet water					Outlet water					Exchanged water volume	Load	
		Ph	SS	DO	COD	NH3-N	pH	SS	DO	COD	NH3-N		COD	NH3
			mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	m^3	kg	kg
1	**01/09/2006**	7.57	99	4.7	9.1	0.042	7.11	41	1.5	23.1	0.092		0	0
2	**09/09/2006**	7.22	113	4.0	10.4	0.074	6.87	60	1.6	27.3	0.174	3,075	52	0
3	**16/09/2006**	6.87	110	4.1	12.3	0.173	6.60	119	2.3	33.5	0.260	8,000	170	1
4	**23/09/2006**	7.07	70	3.5	15.3	0.062	6.83	106	1.0	49.4	0.262	8,000	273	2
5	**30/09/2006**	6.73	87	4.1	16.1	0.130	6.92	101	1.2	37.2	0.530	32,000	675	13
6	**07/10/2006**	7.07	98	3.9	11.5	0.075	6.89	76	1.0	33.1	0.950	32,000	691	28
7	**14/10/2006**	7.15	113	4.2	14.8	0.075	6.80	106	1.2	54.8	0.220	48,000	1,920	7
8	**21/10/2006**	6.73	147	3.7	11.7	0.078	6.89	136	1.3	46.5	0.620	32,000	1,114	17
9	**28/10/2006**	7.48	113	3.6	12.6	0.072	7.15	134	1.1	45.2	0.420	40,000	1,304	14
10	**04/11/2006**	6.21	46	3.5	17.4	0.047	6.07	54	0.8	52.4	0.570	40,000	1,400	21
11	**11/11/2006**	6.73	35	3.5	19.2	0.024	6.45	53	2.1	65.2	0.130	40,000	1,840	4
12	**18/11/2006**	6.45	47	3.1	20.1	0.088	6.22	34	1.0	50.1	0.109	40,000	1,200	1
13	**25/11/2006**	6.10	45	3.6	26.9	0.095	6.17	64	2.2	57.3	0.563	48,000	1,459	22
14	**02/12/2006**	6.23	87	2.4	23.4	0.089	6.41	75	1.6	82.8	0.690	48,000	2,851	29
15	**16/12/2006**	6.34	99	2.9	20.5	0.117	6.26	46	1.2	115.2	0.370	48,000	4,546	12
16	**23/12/2006**	6.42	78	3.0	19.7	0.096	6.31	47	1.3	103.2	0.430	64,000	5,344	21
17	**30/12/2006**	6.51	69	3.2	18.2	0.036	6.27	55	1.1	78.4	0.203	64,000	3,853	11
18	**06/01/2007**	6.69	56	2.8	26.1	0.168	6.54	67	1.0	111.6	0.790	64,000	5,472	40
19	**13/01/2007**	6.77	81	2.1	24.2	0.102	6.17	77	1.4	77.5	0.385	64,000	3,411	18
20	**20/01/2007**	6.87	61	2.4	19.3	0.075	6.75	54	1.0	80.7	0.550	64,000	3,930	30
21	**27/01/2007**	6.62	76	2.4	13.9		6.18	25	1.1	70.5	0.870	64,000	3,622	56
												851,075	**45,126**	**347**

Appendix 15. Water sample analysis results of Household 2

Time	Date	Inlet water					Outlet water					Exchanged water volume	Load	
		pH	SS	DO	COD	NH3-N	pH	SS	DO	COD	NH3-N		COD	NH3
			mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	m^3	kg	kg
1	**01/09/06**	7.56	85	4.4	11.2	0.110	7.27	189	6.8	44.3	0.242		0	0
2	**23/09/06**	7.09	76	3.5	17.4	0.004	6.59	70	0.3	59.1	2.784	960	40	3
3	**14/10/06**	7.15	107	3.2	10.1	0.002	6.97	85	2.5	45.5	0.161	960	34	0
4	**21/10/06**	6.80	58	3.7	8.2	0.187	6.63	93	1.1	50.4	6.823	960	41	6
5	**28/10/06**	7.33	89	3.5	11.6	0.055	7.17	148	2.3	46.7	3.326	1,200	42	4
6	**04/11/06**	6.17	85	3.2	11.9	0.001	5.86	58	0.3	67.6	0.035	2,400	134	0
7	**11/11/06**	6.71	45	2.8	10.2	0.028	6.38	54	2.6	87.8	2.572	2,400	186	6
8	**18/11/06**	6.84	172	1.8	25.7	0.823	6.32	127	1.6	107.9	6.011	2,400	197	12
9	**25/11/06**	6.19	48	3.4	14.6	1.154	6.04	78	1.9	119.4	3.758	2,880	302	7
10	**02/12/06**	6.39	155	1.4	21.5	0.002	6.51	90	1.9	91.5	0.554	4,320	302	2
11	**16/12/06**	6.24	227	2.1	35.1	0.972	6.30	50	1.5	92.1	2.446	4,320	246	6
12	**23/12/06**	6.51	61	2.4	17.2	0.419	6.30	41	1.7	110.2	1.566	5,760	536	7
13	**30/12/06**	6.62	78	2.8	19.6	0.178	6.35	64	1.2	114.1	3.066	9,600	907	28
14	**06/01/07**	6.58	52	2.6	16.4	0.287	6.47	55	0.9	96.7	7.776	4,800	385	36
15	**13/01/07**	6.45	136	1.7	25.1	1.188	6.21	86	1.4	108.2	8.376	9,600	798	69
16	**20/01/07**	6.83	57	2.1	19.3	0.761	6.79	63	0.9	85.7		5,700	378	-4
17	**27/01/07**	6.56	143	2.1	14.8	2.412	6.45	50	0.9	31.7	10.68	5,700	96	47
												63,960	**4,625**	**183**

Appendix 16. Water sample analysis results of Household 3

Time	Date	Inlet water					Outlet water					Exchanged water volume	Load	
		pH	SS	DO	COD	NH3-N	pH	SS	DO	COD	NH3-N		COD	NH3
			mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	m^3	kg	kg
1	**01/09/06**	7.54	82	4.2	10.0	0.049	7.26	99	6.0	20.1	0.112		0	0
2	**23/09/06**	7.10	68	3.6	20.4	0.059	6.66	89	0.8	35.2	0.961	263	4	0
3	**14/10/06**	7.20	92	3.3	11.2	0.080	7.09	129	0.9	31.3	0.523	263	5	0
4	**21/10/06**	6.70	53	3.6	7.2	0.120	6.75	155	1.3	48.2	0.537	600	25	0
5	**28/10/06**	7.29	96	3.3	10.4	0.043	7.09	164	1.1	55.3	0.264	600	27	0
6	**04/11/06**	6.14	89	3.0	11.1	0.010	5.97	134	0.7	62.7	0.370	800	41	0
7	**11/11/06**	6.78	57	2.9	9.3	0.084	6.59	50	2.4	69.5	2.086	1,600	96	3
8	**18/11/06**	6.84	172	1.8	23.7	0.281	6.37	78	2.6	58.2	2.044	1,600	55	3
9	**25/11/06**	6.17	52	3.2	17.5	0.172	6.01	72	1.1	80.8	2.599	2,400	152	6
10	**02/12/06**	6.39	155	1.4	22.4	0.220	6.38	84	2.1	97.6	2.685	4,000	301	10
11	**16/12/06**	6.24	214	2.2	38.2	0.350	6.27	45	1.3	80.7	2.171	8,400	357	15
12	**23/12/06**	6.49	69	2.3	16.2	0.372	6.29	52	1.1	102.8	1.392	8,400	727	9
13	**30/12/06**	6.58	61	2.7	18.2	0.162	6.41	72	0.9	78.4	2.458	8,400	506	19
14	**06/01/07**	6.61	48	2.5	14.3	0.244	6.57	52	0.6	74.8	2.976	7,200	436	20
15	**13/01/07**	6.63	147	1.8	27.4	0.250	6.53	68	2.2	82.2	1.712	7,200	395	11
16	**20/01/07**	6.82	52	2.1	20.4	0.230	6.87	37	1.0	70.6	2.130	8,400	422	16
17	**27/01/07**	6.56	143	2.1	14.8		6.53	75	1.7	60.6	2.016	8,400	385	17
												68,525	**3,933**	**129**

Appendix 17. Water sample analysis results of Household 4

Time	Date	Inlet water					Outlet water					Exchanged water volume	Load	
		pH	SS	DO	COD	NH3-N	pH	SS	DO	COD	NH3-N		COD	NH3
			mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	m^3	kg	kg
1	**01/09/2006**	7.35	203	3.2	9.0	0.100	6.93	35	2.9	22.0	0.633		0	0
2	**23/09/2006**	7.05	91	3.0	21.0	0.030	6.85	50	1.0	27.3	0.982	6,250	39	6
3	**14/10/2006**	7.07	52	2.6	12.0	0.108	6.79	90	1.9	30.5	0.371	12,500	231	3
4	**21/10/2006**	6.55	88	3.0	7.0	0.089	6.90	89	1.5	35.1	0.234	12,500	351	2
5	**28/10/2006**	7.38	140	2.9	7.2	0.046	7.11	101	2.3	38.4	1.923	12,500	390	23
6	**04/11/2006**	6.13	88	3.1	10.7	0.081	6.00	120	1.5	38.7	1.172	18,750	525	20
7	**11/11/2006**	6.67	33	2.9	11.5	0.112	6.57	136	2.5	48.6	1.253	22,500	835	26
8	**18/11/2006**	6.72	97	2.7	18.7	0.187	6.19	78	2.1	46.7	1.154	22,500	630	22
9	**25/11/2006**	6.23	96	2.5	15.4	0.274	6.01	140	2.0	56.3	1.380	37,500	1,534	41
10	**02/12/2006**	6.56	121	1.8	22.9	0.101	6.10	89	1.1	50.6	0.720	37,500	1,039	23
11	**16/12/2006**	6.21	156	2.1	62.7	0.273	6.25	143	1.3	75.7	2.504	37,500	488	84
12	**23/12/2006**	6.67	93	1.7	23.7	0.214	6.35	89	0.9	65.2	2.417	37,500	1,556	83
13	**30/12/2006**	6.51	115	1.9	21.4	0.154	6.28	95	1.0	62.8	2.216	45,000	1,863	93
14	**06/01/2007**	6.68	71	2.0	22.4	0.294	6.45	89	0.9	45.3	2.345	45,000	1,031	92
15	**13/01/2007**	7.01	124	2.2	20.4	0.250	6.34	109	1.2	50.2	2.198	52,500	1,565	102
16	**20/01/2007**	6.91	72	2.1	17.2	0.230	6.78	45	1.0	35.7	2.549	52,500	971	122
17	**27/01/07**	6.71	63	1.8	12.7	0.047	6.43	46	0.7	37.3	11.30	22,500	554	253
												475,000	**13,601**	**996**

Appendix 18. Water sample analysis results of Household 5

Time	Date	Inlet water					Outlet water					Exchanged water volume	Load	
		pH	SS	DO	COD	NH3-N	pH	SS	DO	COD	NH3-N		COD	NH3
			mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l	m^3	kg	kg
1	**01/09/2006**	7.51	81	4.4	11.5	0.070	7.69	31	4.1	20.0	0.160		0	0
2	**23/09/2006**	7.01	114	4.0	16.3	0.055	7.02	33	2.4	17.0	0.230	72,000	50	13
3	**14/10/2006**	7.10	121	5.0	12.6	0.040	6.81	36	3.1	23.5	0.250	54,000	589	11
4	**21/10/2006**	6.80	57	3.7	10.9	0.360	6.78	44	1.7	18.9	0.620	72,000	576	19
5	**28/10/2006**	7.37	303	4.8	12.4	0.040	7.18	107	2.3	27.1	0.150	54,000	794	6
6	**04/11/2006**	6.89	245	4.4	14.6	0.080	6.57	120	2.5	23.7	0.230	72,000	655	11
7	**11/11/2006**	6.77	45	3.9	22.5	0.120	6.21	33	2.1	33.2	0.270	54,000	578	8
8	**18/11/2006**	6.43	56	3.5	16.8	0.360	5.97	49	1.0	27.6	0.680	72,000	778	23
9	**25/11/2006**	6.57	101	3.5	14.2	0.299	6.11	28	2.7	31.4	0.390	72,000	1,238	7
10	**02/12/2006**	6.67	44	3.4	15.7	0.256	6.29	61	0.8	29.7	0.420	54,000	756	9
11	**16/12/2006**	6.78	66	3.3	9.2	0.315	6.31	40	1.1	24.3	0.620	72,000	1,087	22
12	**23/12/2006**	6.88	41	3.7	17.9	0.246	6.79	53	1.3	46.2	0.380	54,000	1,528	7
13	**30/12/2006**	6.91	52	3.5	16.2	0.115	6.81	62	1.2	50.5	0.210	72,000	2,470	7
14	**06/01/2007**	6.87	47	3.3	12.8	0.156	6.72	71	1.0	42.8	0.490	54,000	1,620	18
15	**13/01/2007**	7.14	84	3.0	21.6	0.254	7.34	115	1.1	35.4	0.470	72,000	994	16
16	**20/01/2007**	6.84	68	3.2	15.1	0.398	6.79	28	2.0	27.9	0.550	54,000	691	8
17	**27/01/2007**	6.79	51	3.2	10.4	0.084	6.50	34	1.0	36.9	2.640	54,000	1,431	138
												1,008,000	**15,835**	**322**

Appendix 19. Summary of the PLR results of the five fish-farming households

A. Groups of households far from the Hau River

1. Household 1 (Thoi Thuan Commune)

- Pond area of 6,400m^2, pond depth of 5 m, pond volume of 32,000 m^3.
- Number of initial fingerlings about 600,000 with average individual weight of 0.060 kg/fingerling; about 490,000 fish at the end of the study stage with average weight of 0.850 kg/fish.
- Initial stocking rates of about 93 fingerlings/m^2, population density at selling time about 76 fish/m^2. Fish loss rate was 19%.
- Feed conversion rate was about 1.4 kg of feed /kg of fish produced.
- PLR: 0.108 kg COD/kg of fish produced.

2. Household 2 (Thoi Thuan Commune)

- Pond area of 1,200 m^2, pond depth of 4 m, pond volume of 4,800 m^3.
- Number of initial fingerlings about 100,000 with average individual weight of 0.010 kg/fingerling; about 70,000 fish at the end of the study stage with average weight of 0.800 kg/fish.
- Initial stocking rates about 83 fingerlings/m^2, population density at selling time about 58 fish/m^2. Fish loss rate was 30%.
- Feed conversion rate was about 1.7 kg of feed /kg of fish produced.
- PLR: 0.083 kg COD/kg of fish produced.

3. Household 3 (Thoi Thuan Commune)

- Pond area of 1,000 m^2, pond depth of 4 m, pond volume of 4,000 m^3.
- Number of initial fingerlings about 120,000 with average individual weight of 0.010 kg/fingerling; about 60.000 fish at the end of the study stage with average weight of 0.600 kg/fish.
- Initial stocking rates about 120 fingerlings/m^2, population density at selling time about 60 fish/m^2. Fish loss rate was 50%.
- Feed conversion rate was about 1.6 kg of feed /kg of fish produced.
- PLR: 0.096 kg COD/kg of fish produced.

B. Group of households near the Hau River

4. Household 4 (Trung Kien Commune)

- Pond area of 5,000 m^2, pond depth of 5 m, pond volume of 25,000 m^3.
- Number of initial fingerlings about 230,000 with average individual weight of 0.010 kg/fingerling; about 165,000 fish at the end of the study stage with average weight of 0.800 kg/fish.
- Initial stocking rates about 46 fingerlings/m^2, population density at selling time about 33 fish/m^2. Fish loss rate was 29%.
- Feed conversion rate was about 1.4 kg of feed /kg of fish produced
- PLR: 0.087 kg COD/kg of fish produced.

5. Household 5 (Tan Loc Commune)

- Pond area of 9,000 m^2, pond depth of 4 m, pond volume of 36,000 m^3.
- Number of initial fingerlings about 300,000 with average individual weight of 0.010 kg/fingerling; about 217,000 fish at the end of the study stage with average weight of 0.800 kg/fish.
- Initial stocking rates about 33 fingerlings/m^2, population density at selling time about 24 fish/m^2. Fish loss rate was 28%.
- Feed conversion rate was about 1.5 kg of feed /kg of fish produced
- PLR: 0.091 kg COD/kg of fish produced.

Appendix 20. Percentage of surveyed households with lagoons

	Frequency	**Percentage**
Without lagoons	114	89.8
With lagoons	13	10.2
Total	127	100.0

Source: 2006 Survey