MODELING SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF SHRIMP FARMING IN MEKONG DELTA, VIETNAM

By

THUY THI HONG NGUYEN

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To the faculty of Washington State University:

The members of the Committee appointed to examine the thesis of THUY THI HONG NGUYEN find it satisfactory and recommended that it be accepted.

Andrew Ford, D.E., Chair

Barry Moore, Ph.D.

Gregmar Galinato, Ph.D.

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MODELING SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF SHRIMP FARMING IN MEKONG DELTA, VIETNAM

Abstract

By Thuy Thi Hong Nguyen, M.S
Washington State University
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Chair: Andrew Ford

Intensive shrimp farming is well-known worldwide as not only a highly profitable business but also a risky business. The excessive use of industrial feed, chemicals and antibiotics of this industry has imposed a great impact on the environment. In order to explain the economic incentive leading to dynamic land use and the interaction between this industry and the environment, a dynamic model is built for the case of Dai Hoa Loc Commune in the Mekong Delta of Vietnam. The model includes two modules of Shrimp land and Nitrogen, running from 1999 to 2019. Initial simulations suggest that model results match with stories from the field. Additional analysis reveals the risky nature of the shrimp industry which lies in the choice of starting stock density. Farmers tend to begin with high stock density to obtain huge profit in the first few years without knowing that the corresponding nutrient input will result in precipitous yield drop in subsequent years. Meanwhile, a low stock density brings low profit at first but makes the business sustainable. In the case of a constant stock density of 40 fry/m^2, the business will close down in nine years. Reducing stock density from 40 to 25 fry/m^2 in 2008 helps sustain the system for 20 years at a yield of 0.75 tons/ha. Further testing combining this method with introducing treatment ponds in the same year results in a yield of 1 ton/ha at the end of the period. The best policy is combining lowering the stock density and improving the channel

system to reduce nitrogen load in the channel system. This strategy creates a yield of 1.6 tons/ha from 2014 to the end of the time horizon. Shrimp supply and profit from this policy are both high suggesting that infrastructure development is necessary and practical.

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This thesis is dedicated to my mother and father for their unconditional love and emotional support

CHAPTER ONE

INTRODUCTION

1.1. Shrimp farming in Vietnam

a. A brief history

Vietnam is one of the most populated countries in the Southeast Asia with a population of 85 million in 2007 (General Statistics Office, 2007). It has borders with China to the north, Laos and Cambodia to the west and the Pacific Ocean to the east which is also called the South China Sea or East Sea. The coastline of 3,200 km stretching from the north to south is one important factor for developing navigation, fishery, tourism and aquaculture.

In spite of favorable natural conditions and a large labor force, none of the aforementioned industries developed until the 1990s. Vietnam's economy was in dramatic crisis for 10 years after the reunion event in 1975. In 1986, "Đổi mới" (or Renovation) policy was issued with its main focus on replacing bureaucracy with a multi-component economy, promoting market-based economy and shifting industrialization from heavy industry to light industry to produce more food, consumer goods and export goods (Le, Trinh & Mach, 2006, p.148). The shift in policy resulted from a series of events in previous years such as serious deficiencies in food and consumer goods supply, excessive imports compared to exports and severe inflation.

In the 1980s, aquaculture or more specifically shrimp farming was primarily practiced for subsistence based on existing ponds and recruitment natural stock with little care. Thanks to the infrastructure development, transportation and communication were improved which subsequently enhanced free trade both nationally and internationally. The world demand for shrimp was then well recognized, and farmers started to turn to this business. Intensive shrimp farming first emerged in the South Central area of Vietnam and gradually spread to other regions.

The climate and water quality of Central Vietnam are very favorable for tiger shrimp farming. Khanh Hoa is the leading province in this industry. Starting in 1998, this province has provided half of the fry quantity for the whole country. The farming method based on the Thai technique was first applied here and then promulgated to neighboring provinces such as Ninh Thuan, Binh Thuan, Phu Yen, etc. The Mekong Delta where salinity intrusion occurs annually about half of the region is also suitable for tiger shrimp farming. Unlike Central Vietnam, the farming methods in this region are very diverse including: modified extensive in mangrove forest, rice-shrimp, semi-intensive and intensive. Ca Mau and Bac Lieu provinces which have the greatest intrusive area, have the largest shrimp farming land nationwide. Northern Vietnam is the least suitable place for shrimp farming. Its cold winters and wide range of temperature variations between seasons inhibit the growth of shrimp and the productivity reduces accordingly (Agriviet, 2004).

Generally speaking, Vietnam is a late comer in the world shrimp market. From Figure 1, it is clear that in 1995 most leading exporting countries like Thailand, China, Indonesia, India, Bangladesh and Philippines experienced boom and burst patterns in production. The decline in production was due to disease outbreaks which were the inevitable consequence of intensive farming without proper care for the environment. The longer shrimp farming is practiced, the more pollution accumulates. In 1995, Vietnam had the advantage of a newcomer; it could learn from the advantage of farming methods with lower stocking density and zero-exchange of water. But the general governmental policy of encouraging aquaculture development without good planning and inadequate infrastructure has created some problems. This haste reflected the hope of improving the standard of living by the appealing profit from intensive shrimp farming which dominated the special attention to its aftermath. In recent years, when intensive shrimp farming is widely practiced throughout the country, both the government and farmers are starting to pay more attention to the effect of the environment on shrimp yield.

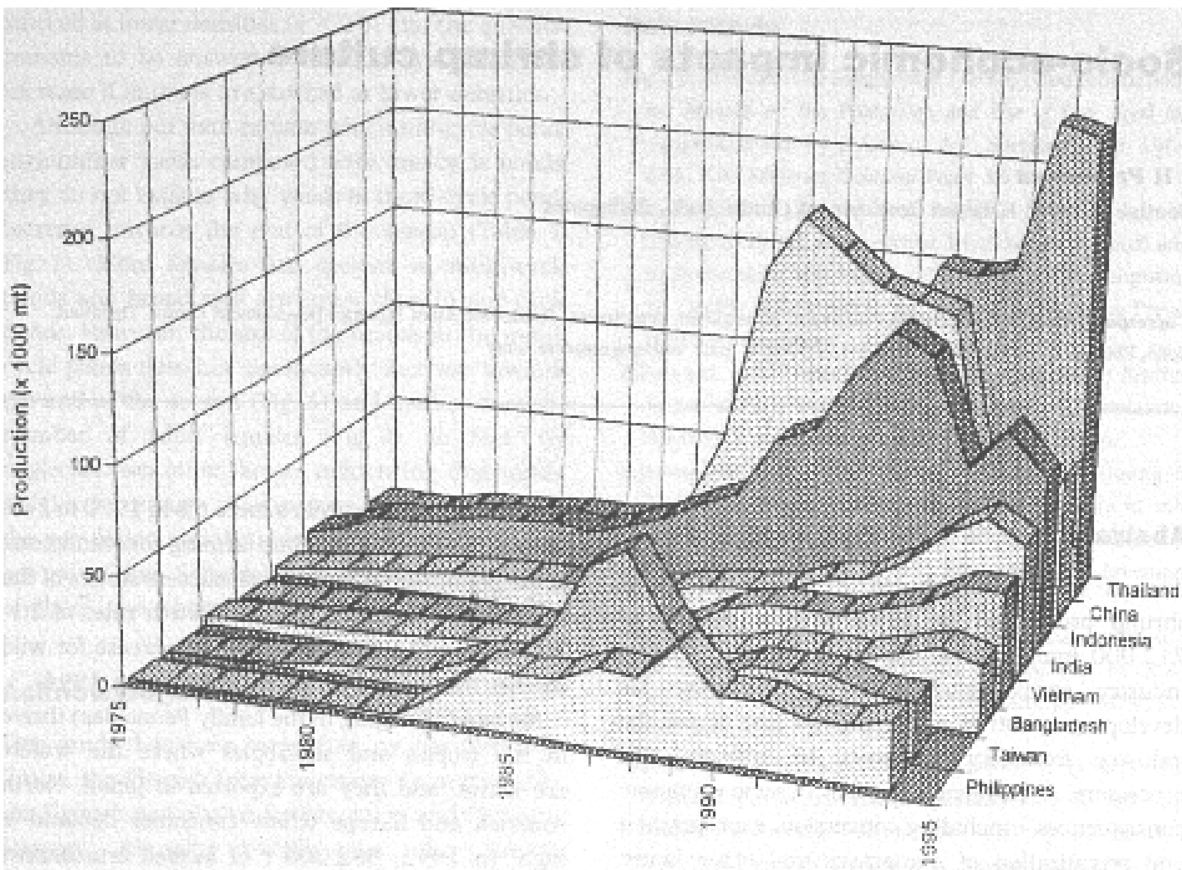


Figure 1: Production in thousand tons of cultured shrimp in leading Asian countries (Primavera, 1997).

b. Shrimp farming practice in Vietnam

In order to understand the environmental impact of shrimp farming, it is useful to know the actual practices of farmers. The procedure is illustrated by the flow chart in Figure 2. In this procedure, a farmer starts by choosing a farming method. In general, there are four main methods: extensive, improved extensive, semi-intensive and intensive. The difference of these methods can be determined based on stocking density, use of aeration, shrimp yield and level of management and capital investment. Farming method classification is summarized in table 1 below (Ninh Thuan, 1999).

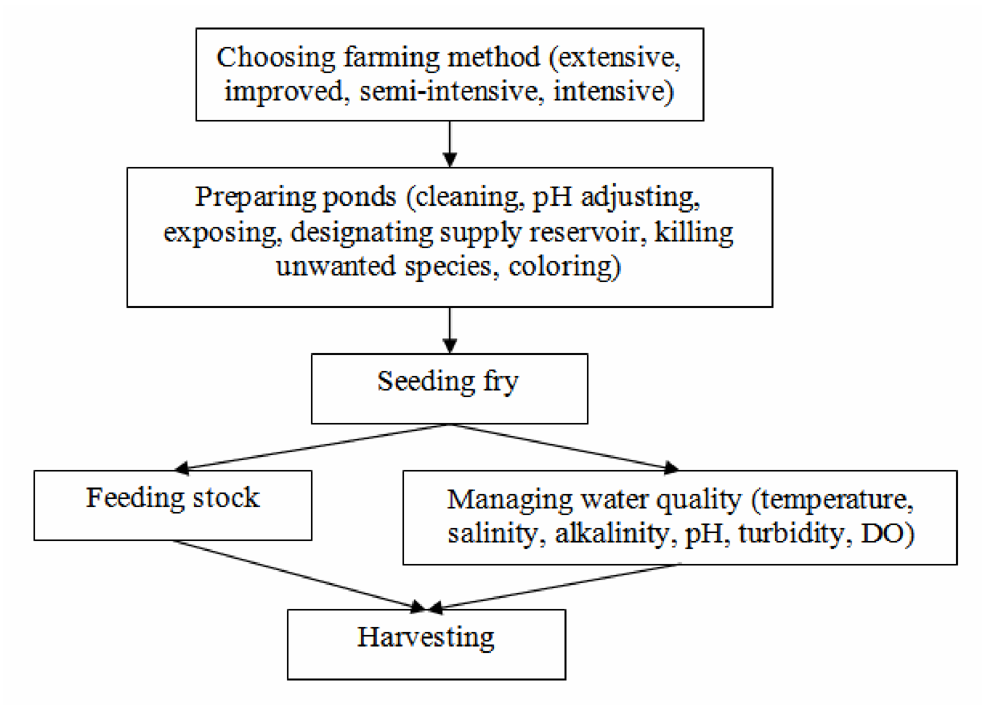


Figure 2: A brief procedure of shrimp farming

- Extensive farming makes use of large land area, natural stock and natural feed. Today, most farmers supply more fry with low stock density but they still depend totally on natural feed. This method is mainly applied in Ca Mau Province, Mekong Delta.
- Improved extensive farming is very popular in the Mekong Delta and the Northern Vietnam. Shrimp can be cultivated as a mono crop or rotated with rice or salt.
- Semi-intensive and intensive methods require higher stock density, aeration, advanced level of management and investment so they produce higher yield. These methods are applied in most areas of Vietnam.

Table 1: Classification of shrimp farming methods

Farming method	Stocking density PL_{15} (fry/m^2)	Aeration Yes/ no (+/-)	Average yield (tons/ha/harvest)	Investment & management level
Extensive	-	-	-	+
Improved-extensive	5 -10	-/+	≤ 1	+ +
Semi-intensive	15 - 20	+	1 - 3	+ + +
Intensive	>20	+ +	>3	+ + + +

Source: Ninh Thuan (1999)

After deciding which method to use, the farmers prepare the pond. This step is repeated before each harvest to ensure proper conditions for the shrimp. Pond cleaning is done by using pumps for sucking sediment or using tool/machines for dredging the sediment. Ponds are then filled with water, left standing overnight and flushed many times to get the actual pH value. Chemicals such as lime are usually employed to adjust to the desired pH. Later, ponds are exposed to the sun from one to two weeks to kill bacteria and germs. Pond area is divided into two parts: supply reservoir and main pond. The supply reservoir covers 30 – 50% of the total area and serves as a preliminary water treatment unit (Figure 3). Water is fed to the supply reservoir, stands for three days and some chemicals such as Saponine and Chlorine are added to kill unwanted species such as eggs of other fish and crabs. Water flows into the main pond to the depth of 1 – 1.2 meters and fertilizers are added to facilitate the growth of algae and phytoplankton. This source of food is very important for shrimp fry in their early days in earthen environment.

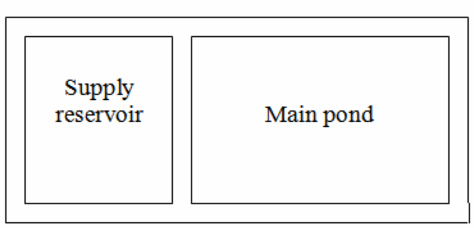


Figure 3: Diagram of a shrimp pond

When the ponds are ready, shrimp fry are cultured with varied density depending on the method chosen. In intensive method, stock density usually ranges from 25 – 45 fry/m^2. Besides natural feed in the pond, home-made or industrial feed is also applied. At the same time, water quality is monitored closely in terms of temperature, salinity, pH, turbidity, dissolved oxygen (DO) and toxins (NH_3, H_2S, NO_3, heavy metals, etc.). During this period, shrimp might become diseased due to climatic factors or infection of viral diseases. Farmers, therefore, have to apply antibiotics to keep the shrimp healthy. After 3.5 – 4.5 months, the shrimp are ready for harvest.

c. Environmental and socio-economic impacts of shrimp farming

In Vietnam, most farmers practice zero-exchange method which means that during a harvest, no water is exchanged with the environment. This method helps reduce nutrient loss and maintain acceptable water quality (Thakur & Lin, 2003). However, throughout the farming procedure, many chemicals and nutrients are intentionally added to the pond. Chemical pollution affects and kills non-targeted species. These chemicals are very persistent so their impact is unpredictable. Nutrient pollution causes eutrophication in the channel systems and waterways. Viruses from shrimp ponds and dead shrimp without proper treatment in a nutrient-rich environment enhance the growth of water-borne diseases. In turn, these impacts decreases shrimp yield and cause the farming system to fail after a period of time.

The environmental impacts of shrimp farming are even more serious in areas near mangrove forests, coral reefs and sea grasses, Melaleuca forests and freshwater wetlands (Environmental Justice Foundation, 2003). Biodiversity loss of these ecosystems is the main cause leading to system malfunctioning. This phenomenon adds more severity to natural disasters in these regions. Furthermore, shrimp farming also induces groundwater and soil salinization.

Resource use conflict, mainly water use, happens between farmers growing cash crops such as rice or sugarcane and shrimp farming farmers. Oftentimes, people share the same channel system and the effluent from shrimp farms with high salinity reduces the yield of rice/sugarcane crops significantly. This seems to be not very serious because the fraction of rice or sugarcane area in shrimp farming regions is relatively small compared to shrimp farms.

The profit from intensive shrimp farming is more than 30-fold greater than profit from rice farming. A harvest is considered successful when both yield and price are high. With a successful harvest, farmers can earn tens of thousand of dollars per hectare. This profit enables them to repay loans, reinvest in the next harvest and improve their standard of living. In contrast, an unsuccessful harvest traps them in the spiral of debt due to high investment. From a research of assessing poverty in Tra Vinh province in the Mekong Delta, Oxfam Great Britain modeled the socio-economic impact as shown in Figure 4. Most farmers abandon their land after several failed harvests. Some of them rent or sell their land and work for others but this does not improve their situation. Adding more risk into this business is the habit of most farmers of not building a saving account.

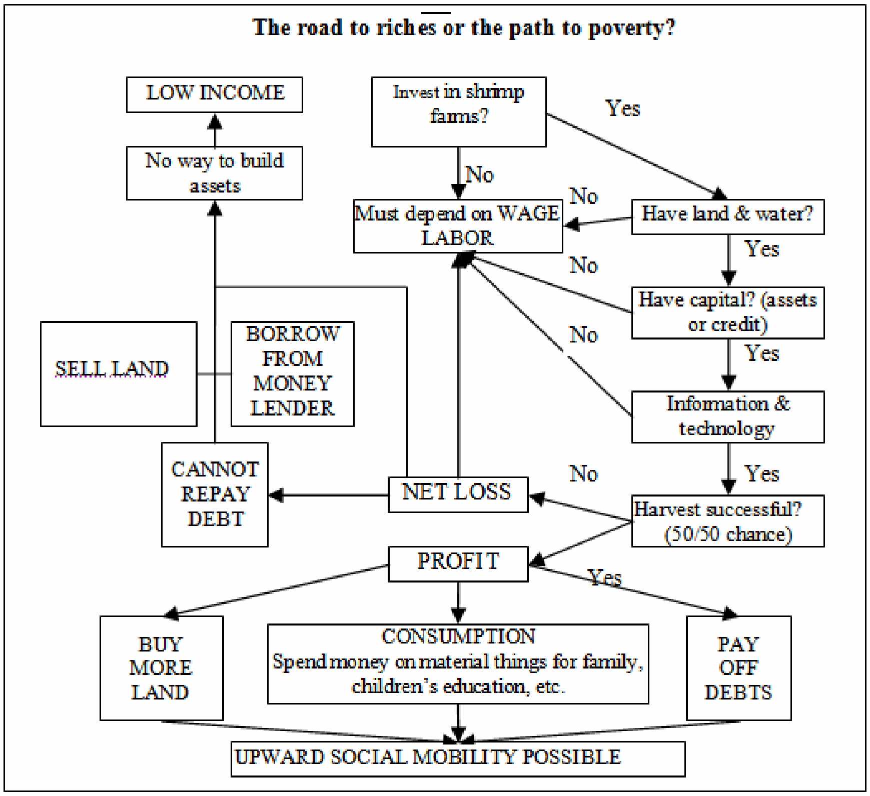


Figure 4: Diagram of social impact of shrimp farming EJF (2003) quoted from Oxfam GB, Hanoi (1999)

d. Problems of shrimp farming in Vietnam

Disease is the primary tangible cause of shrimp harvest failure in Vietnam. Environmental conditions, climatic factors, poor quality post larvae (fry), inappropriate feeding regimes/overfeeding and inadequate channel systems are some reasons contributing to disease outbreaks (EJF, 2003). Intensive use of chemicals and nutrients pollutes the water. Coupled with undeveloped channel systems, water stagnates and water intake is therefore from the same source as the receiving body. When the water is already infected by viruses in a nutrient-rich environment, the new harvest will very likely experience viral diseases. If, for some reasons, the shrimps do not get diseased, the yield will be much lower than normal because of the slow growth. This is one of the major reasons explaining why shrimp farms fail after several years. For extensive shrimp farming, productive harvests can last for 10 – 20 years. The semi-intensive method only works for about 5 – 10 years and intensive systems fail after 5 years (EJF, 2003).

Shrimp are quite sensitive to temperature changes and Vietnam is a tropical country with two distinct seasons. Temperatures vary from 10 – 12^0C between dry and rainy seasons whereas a variation of 5 – 6^0C can cause shrimp to die.

Post larvae quality is also a big concern because not all regions can produce fry locally. Traveling long distant induces stress for young shrimp. Farmers often use their naked eye to test fry quality which is often misleading due to the hatchery's use of antibiotics. Only some farmers send the fry to be tested. As a result, for the most part, farmers are not provided with good quality fry.

The feeding regime is another important aspect in shrimp farming. Shrimp should be caught and weighed every 7 – 10 days to determine survival rates and body weight. Based on these parameters, the amount of feed is calculated accordingly. Feeding must follow a strict schedule. Poor farmers feed their shrimp poorly when they have little money and feed shrimp excessively when they have enough money. Some always overfeed their shrimps hoping to get higher yield. These inappropriate practices cause the shrimp to be unhealthy and greatly reduce the yield.

Shrimp production is known by many farmers as a profitable and risky business. High levels of investment require high reinvestment because most costs lie in feed cost and other operating costs. Unsuccessful farmers abandon their farms because converting back to rice is difficult. It is difficult in a sense that farmers have to invest to transform the deep pond into the shallower field. Shrimp ponds have accumulated high levels of salinity so they need to be flushed many times before growing rice. As a result, the first few crops of rice will have a very low yield. Shrimp production is also risky because fry and feed quality provided by separate sellers is unknown although this is not always the case in every region. The marketing channel is mainly driven by collectors or middlemen who have some power to influence the price because most shrimp farms are in the coastal zone far away from the main market. Figure 5 illustrates a marketing channel in Phu Tan in Mekong Delta (EJF quoted from Nguyen Van Be). This structure reveals the monopsony power of middlemen or collectors in the market. In order to maximize their net benefit from purchasing shrimp, they purchase a smaller quantity at a lower price compared to that of the competitive market. As a result, monopsony makes the buyers better off and the sellers worse off. The resulting deadweight loss is the source of inefficiency if there is no market failure due to some sources of externalities.

The government has a regulation specifying when to grow shrimp and how to treat infected dead shrimp. However, regulation violation occurs in several places. People tend to grow two harvests per year instead of one which is the recommended level of the government and do not treat the dead shrimp thoroughly. The second harvest often produces a lower yield and has a greater chance for the shrimp to be infected. These two practices cause the farming system to fail more quickly.

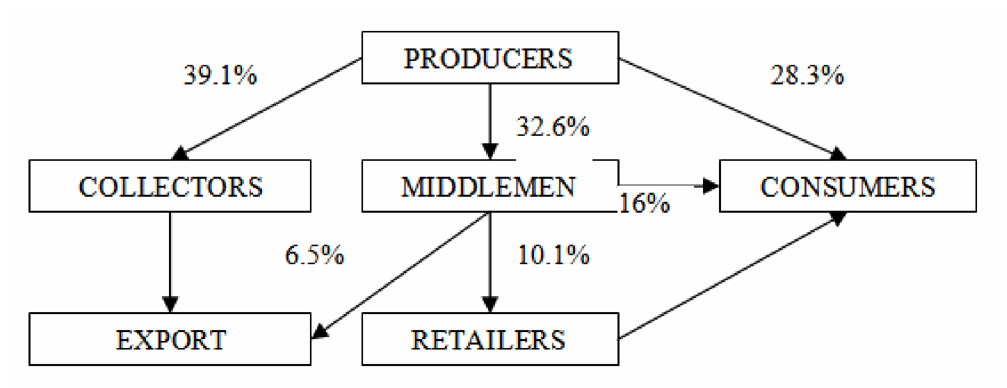


Figure 5: Shrimp marketing channel in Phu Tan (EJF (2003) cited from Nguyen Van Be (2000))

1.2. The study area

Dai Hoa Loc Commune, Ben Tre Province covering an area of 2,356 ha is the focus area of this study. Its population in 2008 is 8,625 with 2,150 households. More than 90% of the population are farmers. This area has a monsoon climate with two distinct seasons: rainy season from May to November and dry season from December to April. In the past, this region experienced six months of intrusion in the dry season. Before the year 2000, most people grew rice, made salt and went fishing for subsistence. In 2000, the government constructed Ba Lai Dam and Sluice Gate over the Ba Lai River at the upper bound of this commune to prevent salinity intrusion. The upstream from the dam has freshwater all year round and it was planned to grow three rice crops per year. The downstream from the dam has saline water in all seasons and was planned for developing aquaculture. Construction and operation of the dam has led to dynamic change of land use in this area.

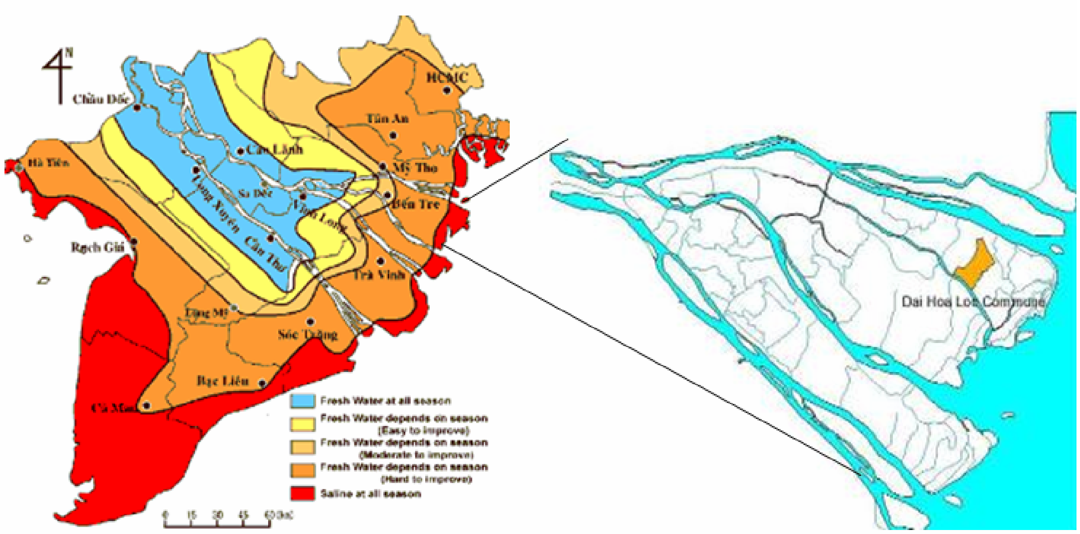


Figure 6: Map of the Mekong Delta (Akira Yamashita, 2004) and the study area

In 2003, when the construction of the dam completed, there was a mass conversion to shrimp. Salt pans no longer existed. Today, the shrimp land covers about 82% and rice land covers 10% of the total arable land. Following is the land statistics from 2005 – 2007 (Table 2) and population data from 2006 to 2008 (Table 3).

Table 2: Land use in Dai Hoa Loc from 2005 to 2007 (People's Committee of Dai Hoa Loc, personal communication, 2008)

Year Land category	2005	2006	2007
Arable land (ha)	2,055	2,057	2,057
Aquaculture (ha)	1,677	1,679	1,694
Rice (ha)	233	233	217
Total land	2,356	2,356	2,356

Table 3: Population of Dai Hoa Loc from 2006 to 2008 (People's Committee of Dai Hoa Loc, personal communication, 2008)

	2006	2007	2008
Male	3634	3658	4307
Female	4443	4462	4318
Total	8077	8120	8625
Growth rate	0.027	0.005	0.062

1.3. Objectives of the study

The focus of this paper is the driving force of land use change, the effect of shrimp farming practice on the environment and how that influences shrimp yield in return. Farmers in this region observed the profit per ha from pilot shrimp farms then they compared with the profit per ha from rice and decided to change. It takes people some years to realize the profit and learn the new farming technique. When more farmers are capable of shrimp technique, they shift to shrimp faster. Under the monopsony power of the market, the price of shrimp decreases due to the large amount of supply, and the profit per ha of land decreases. On the other hand, the more shrimp land grows, the more nitrogen is discharged into the environment in the form of sediment and drainage water. Some of the nitrogen content is transported by tide, and the rest stays in the channel system. Because the water supply channel is also the receiving body, nitrogen remaining in the channel finds its way to the shrimp pond. High nitrogen content in the pond at subsequent harvest reduces shrimp yield. Farmers evaluate the risk of shrimp by counting the years they earn low profit. Several years of low profit retard the conversion process. All of these complex interactions will be represented in a simulation model.

Sensitivity analysis of the model will show how different stocking density affects shrimp yield and channel pollution. The model will also be used to show how the borrowing period and the tidal removal rate affect the conversion process. The main purpose of the model is policy testing. Policy tests include stock density reduction, the introduction of treatment ponds and the investment to improve the channel system. The cost of these policies is compared with the benefit of reducing nitrogen content in the channel system to see if sustainability would be obtained.

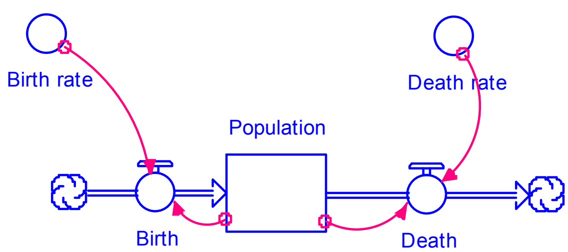
CHAPTER TWO

METHODOLOGY

2.1. System Dynamics:

System Dynamics is a method of analyzing problems over time to help understand system components' interaction and the interplay between the system and the environment (Coyle, 1977). This methodology was first developed in the 1960s by Jay Forrester. It is very useful in revealing complex feedback loops within the system, and this knowledge helps improve the system's performance.

In this paper, Stella 9.1 is used to model the system and conduct numerical simulations. The building blocks of the model are stocks and flows as illustrated in the following diagram:



Population (t) = population (t-dt) + (birth - death) dt
Birth = Birth rate * population
Death = Death rate * population

Figure 7: A schematic diagram of a simple population model

In Figure 7, the box representing "Population" is called a *stock*, the circle representing "Birth" and "Death" is *flow*. The incoming flow brings material into the stock and the outgoing flow takes material away from the stock. Each flow is further clarified by *converters* containing information to help explain the flows. An example of the stock in this paper is Nitrogen concentration in the channel. This stock keeps track of the accumulation of nitrogen in the channel fed by the flows of nitrogen concentration from upstream and nitrogen concentration in the drainage water, and the flow of the tide removing the nitrogen out of this stock.

The stock accumulates material over time. Sometimes, material does not accumulate but temporarily stays in the system for a short period of time. In this case, a special stock called *conveyor* is used. Figure 8 depicts the number of students in school who will graduate after several years and be replaced by new students. The learning process of farmers in this model happens in the same manner. It takes about a year for farmers to learn the shrimp farming technique so a conveyor is used to observe the land belonging to farmers in training.

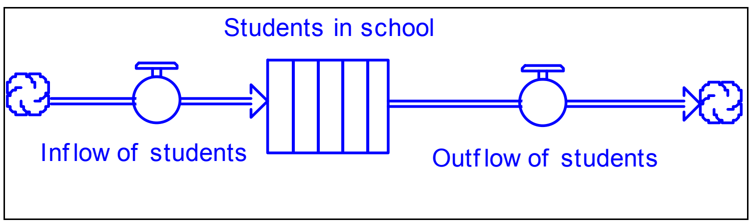


Figure 8: Diagram of a conveyor stock

In showing the relationship among variables and the direction of interaction, a causal loop diagram is used (Figure 9). Unlike the schematic diagram of the model, only names of variables are shown. In this diagram, arrows connect related variables. The plus sign at the end of the arrows shows that the two variables change in the same direction, and the minus sign shows that they go in opposite directions. A positive (or reinforcing) feedback loop is assigned when the number of minus signs is even and the loop is assigned negative (or balancing) feedback loop when the number of minus signs is odd. A positive loop means that any change in the loop will be magnified over time whereas a negative loop means that any change in the loop will be negated. In brief, positive feedback loops show the growing part of the system and negative feedback loops show the force to keep the system in balance.

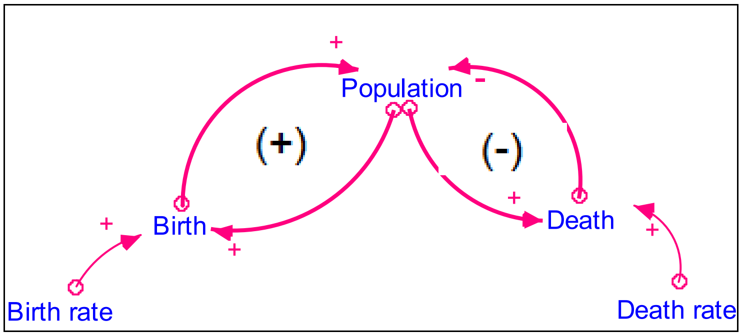


Figure 9: A causal loop diagram for the population model

For more information about System Dynamics application, readers can refer to Sterman (2000) for business dynamics, and Ford (1999) and Deaton & Winebrake (2000) for environmental system dynamics.

2.2. Application of System Dynamics in some shrimp related research:

Several studies in shrimp have applied this methodology successfully. Franco, Ferreira and Nobre (2006) developed an individual growth model for panaeid shrimp using Powersim software. Main physiological processes were described such as: ingestion, assimilation, feces production, respiration and female reproduction. Based on the quantification of these processes, the authors examine the effect of food availability and water temperature on shrimp weight. Sensitivity analysis results of the model showed that a 10% change in juvenile food availability did not induce any difference in shrimp yield. However, a 10% variation in temperature affected shrimp final weight considerably.

In a study of the Guayas River estuary in Ecuador, a model from an ecological perspective of shrimp production was built by Twilley et al. (1998) using Stella II version 3.0.5. The model aimed to address the environmental impact of shrimp farming on mangrove forests by keeping track of water quality parameters such as salinity, suspended sediment and total nitrogen in response to land use change. Three scenarios of land use were tested at 100%, 50% and 10% of 1989 baseline river flow corresponding to the construction of a dam:

(1) 100% mangrove, (2) 50% mangrove and 50% shrimp pond and (3) 100% shrimp pond. Water quality remained good due to the low residence time in the estuary because of high water flow and tidal exchange rate. However, with a 90% reduction in mangrove forest due to converting to shrimp pond, total nitrogen concentration increased five times. Nitrogen concentration even became 60 times higher if river discharge decreased to 10%. The topography and hydrograph of the estuary also influenced water quality as nitrogen concentration of the upper estuary region increased more quickly while it did not change much in the lower region. The authors believed that the integration of this model into economic analysis would better evaluate the economic impacts of coastal zone management policy.

In line with studying the impact of shrimp farming on mangrove forests, Arquitt, Honggang and Johnstone (2005) developed a model for the case of Thailand, one of the world's largest shrimp production countries. The model tried to shed light on the interaction among market demand, shrimp production and the environment by constructing inventory, production and ecology sectors. Simulating the model for 50 years with a time step of 0.125 years showed the overshoot pattern of Total Thai Production, Thai Mangrove Farm Production and Thai Inland Coastal Farm Production. This pattern happened as a result of over-investment in shrimp farming when the demand was high which caused tremendous mangrove forest loss. Three policies of Technology, Eco-taxes and Export Tax with Rebate were considered to test if it is possible to maintain the benefit from shrimp while preserving the mangrove forests. The Export Tax with Rebate turned out to be the best. The idea of this policy is to tax each unit of exported shrimp and rebate to farmers certified with sustainable practice. Three tax levels of $1, $2 and $3 per kg were applied for the sensitivity test. Results showed that the overshoot pattern started to decrease at the tax level of $2 and gradually shifted toward a sustainable pattern at the level of $3. Combining the tax of $3 and technological improvement indicated a sustainable trend of Thai production and Mangrove Farm. The production rate in this case was higher than the rebate fee alone. Coupled with the rebate fee, this policy enabled farmers to restrict themselves in developing new farms on susceptible areas. However, for the case of Thailand, this policy did not work well as Thai mangrove was highly degraded at the time of the research. The authors would like to consider this policy as a learning experience which should apply for unexploited mangroves in Asia, Africa and Latin American.

For the context of intensive shrimp farming in Ninh Thuan –Vietnam, Soo (2005) built a model revealing the development of shrimp farms and its effect on land price, revenues, and ground water quantity and pond water quality. The propagation of shrimp farms was based on the performance of first generation farms in 1999. The more pilot farms performed well, the more attractive shrimp production became. This attractiveness increased land prices which in turn reduced the rate of converting to shrimp ponds. The increase in shrimp farms also led to an increase in nitrogen and phosphorous sediment in ponds and a decrease in groundwater storage. Coupled with high stocking density, high sediment load worsened pond water quality which affected shrimp survival and yield. The groundwater quantity was calculated based on precipitation and used to test if it was one of the limiting factors to shrimp farming. Results showed that with a stocking density of 40 fry/m^2 and no cleaning action, the life time of the shrimp pond was 19 seasons. From a starting area of 50 ha, after 12 seasons, 317 ha of land was converted to shrimp farms. Reducing stocking density from 40 to 15 fry/m^2 in the 15^{th} season would extend the system performance for 10 more years.

Keeping the stock density at 40 fry/m^2 and cleaning the pond in the 15^{th} season with 20% removal efficiency, 1624 ha of land was converted to ponds within 52 seasons. In this scenario, groundwater storage declined tremendously and was depleted in the 52^{nd} season which closed down the business. Increasing the cleaning efficiency to 40% in 15^{th} season, within 48 seasons, 1518 ha of land was converted. Groundwater became the limiting factor in the 48^{th} season. Combining the low stock of 15 fry/m^2 and cleaning activity of 40% efficiency, the groundwater problem occurred in the 70^{th} season and 1294 ha of land was converted.

Although the four studies in shrimp cover different scales and aspects of this industry, they have some common features: researching complex dynamics, containing a lot of uncertainties and providing practical simulation analysis. In an effort to apply the same methodology to shrimp farming in Dai Hoa Loc Commune, this paper will be based heavily on some concepts in the paper by Soo (2005).

CHAPTER THREE

THE MODEL

3.1 Model structure and description:

The model includes two modules: Shrimp land and Nitrogen. The interaction between these modules can be described as follows. When more shrimp land is developed, more nitrogen is discharged into the environment. The nitrogen will deteriorate water quality, reduce shrimp yield and shrimp profit, and slow down the development of shrimp land. This is a typical pattern of development reaching the carrying capacity of the environment. As mentioned in the introduction chapter, farmers tend to do two harvests per year. However, for simplicity, in this model we count only one harvest a year.

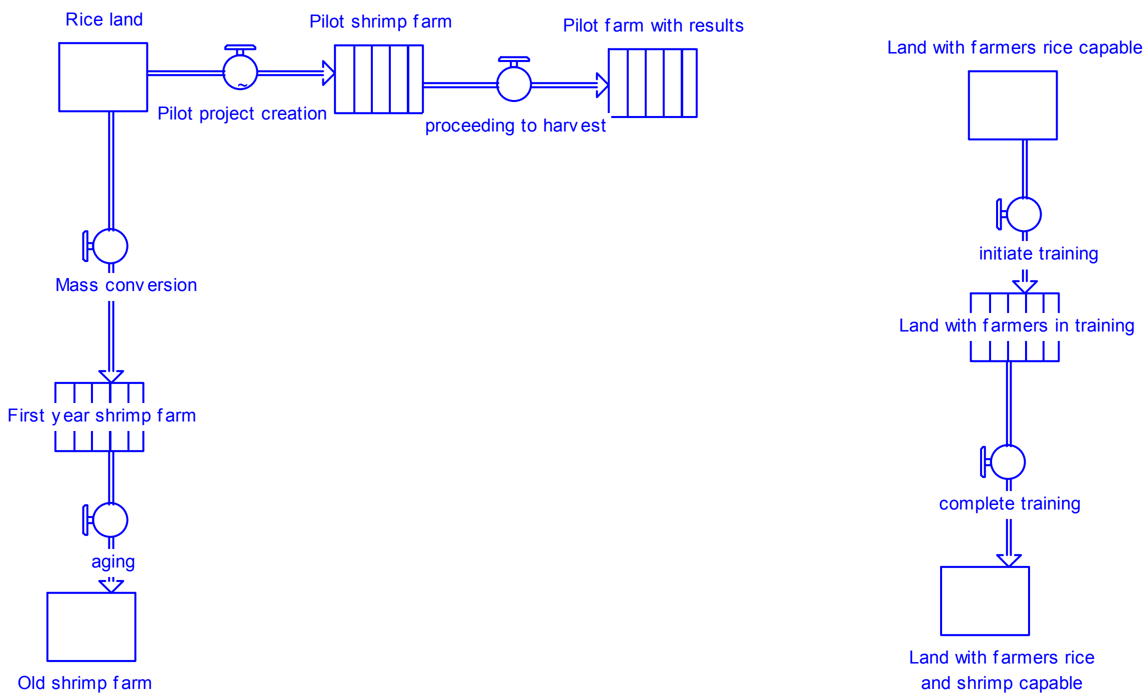


Figure 10: Stock and flow diagram of Shrimp land module

The Shrimp land module describes the conversion process from rice land to shrimp land. The process begins when some pilot farms are created. People observe the profit from these farms, compare with the profit from rice and start being interested in shrimp farming. In this model, rice price is fixed for easier comparison. It takes the farmers a while to observe the profit and this is represented by the lag time in observing. When the high profit of shrimp farming becomes well-known, rice farmers begin to learn the new farming technology. It takes them about one year to take training courses and learn from neighbors. At the same time of observing profit, they also count the bad years when there is no net benefit or even is a net loss. After gaining the necessary technique and lessons, they make the decision to convert to shrimp, the mass conversion process in Figure 10. The separation of first year shrimp farms from old farms serves for cost calculation purpose only. In the first year, the investment is higher than subsequent years due to the fixed cost of preparing/creating the pond. To most farmers, this cost is calculated once and this explains why the profit from the first year is not very high. There are additional operating costs such as labor cost, equipment operation cost, seed and feed costs. Seed and feed costs are dependent on the stocking density. In addition, most farmers borrow money from the bank and they have to pay off the debt. The typical borrowing period ranges from 1 – 5 years. The revenue from shrimp is computed based on the shrimp yield and shrimp price which is driven by the monopsony market. In calculating the shrimp supply, only effective land is taken into account. Effective land is the actual area of the main pond without the supply reservoir. The annual average income from both rice and shrimp is also tracked to see if the community is better off or worse off when shifting to shrimp. There are four variables of this module connecting to the next module: stock density, feed applied, shrimp yield and total effective shrimp land. The full diagram of this module is in figure 11.

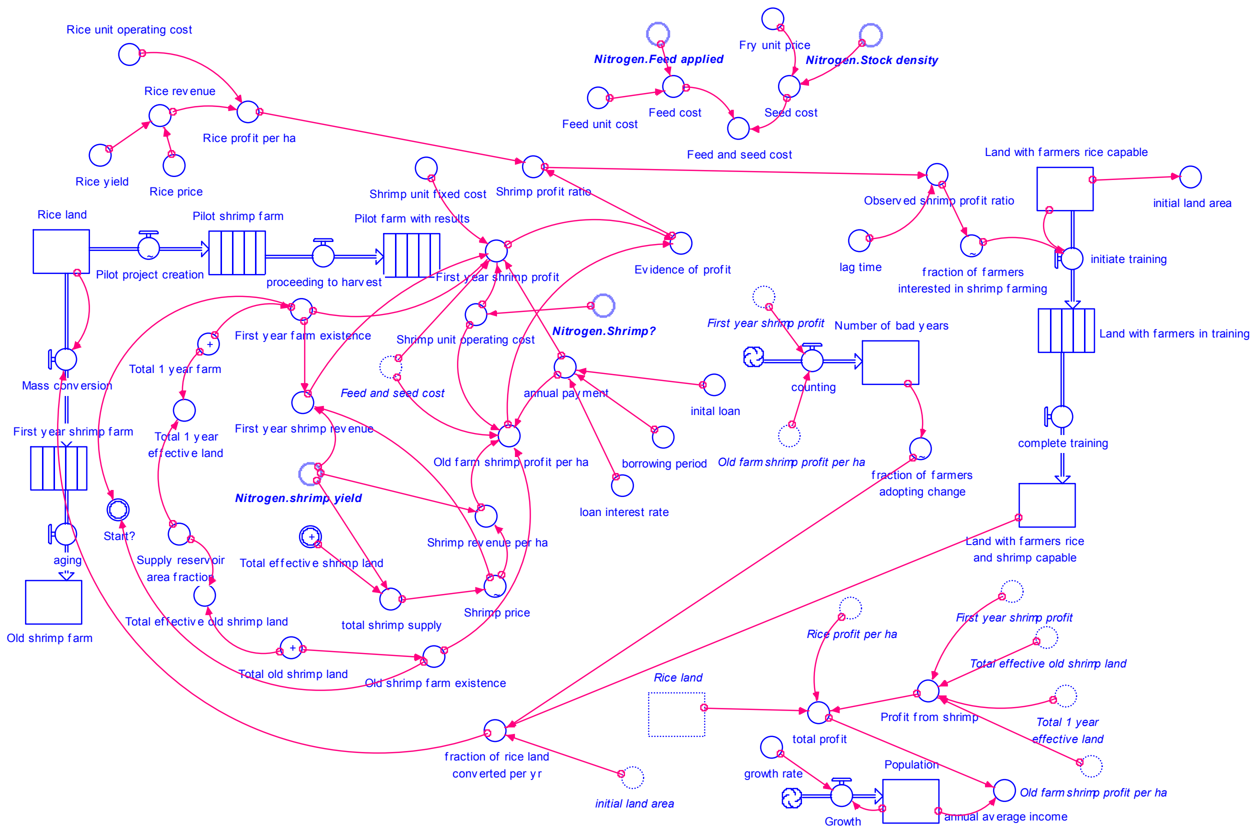


Figure 11: Full diagram of the Shrimp land module

The Nitrogen module keeps track of Nitrogen of both the water and sediment phase from the pond to the channel system (Figure 12). The source of Nitrogen includes fertilizer, seed, intake water and feed. While fertilizer is a fixed amount for each ha of the shrimp pond, feed is dependent on the stock density. The amount of feed applied is calculated based on an average feeding scheme. Most nitrogen ends up in the pond sediment in the form of dead shrimp, feces, excess feed, plankton and bacteria. The remaining nitrogen is in the harvested shrimp, removed by drainage water when harvested or lost in the form of gases such as NH_3, N_2 or N_2O. About 90% of the sediment is dredged out of the pond after harvest and discharged into the channel.

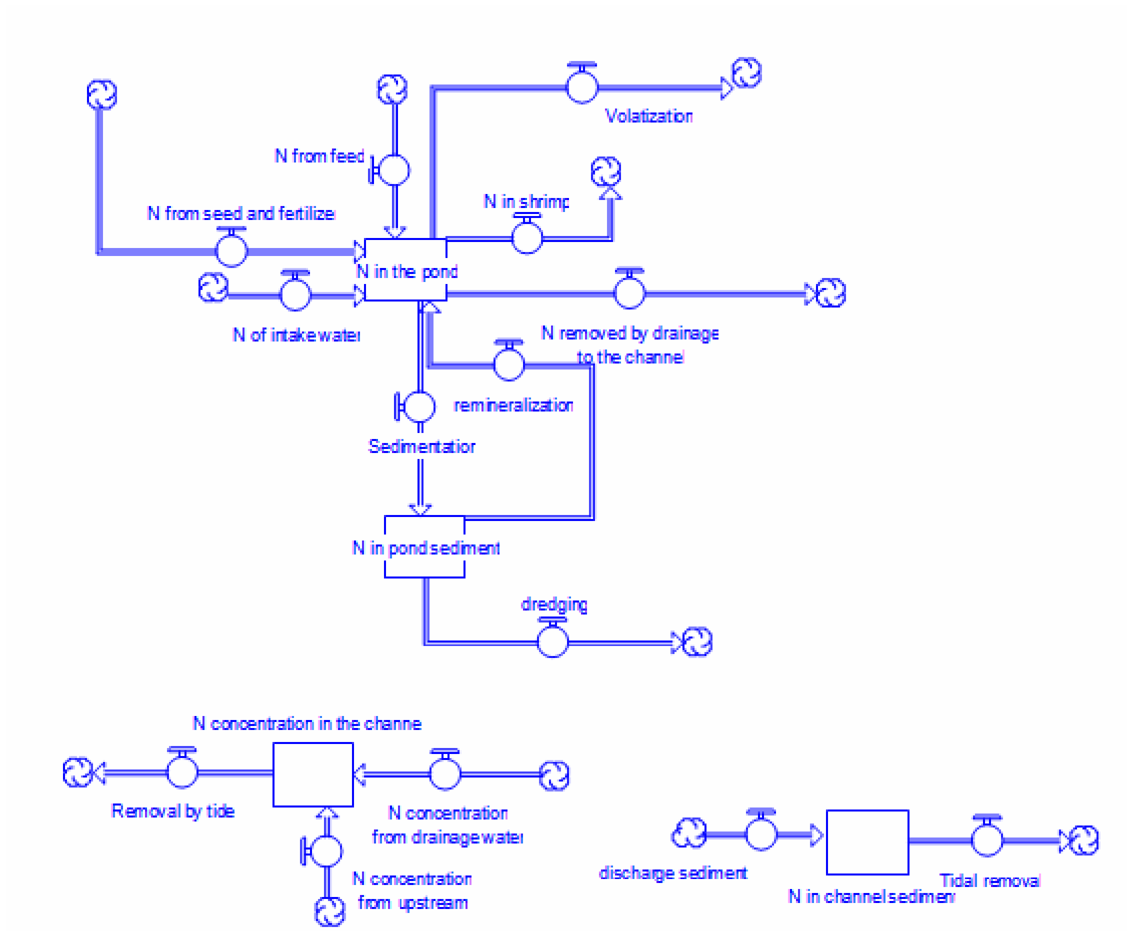


Figure 12: Stock and flow diagram of Nitrogen module

A small fraction of nitrogen in pond sediment goes back to the water phase during the remineralization process. Once the nitrogen makes its way to the channel, two main processes take place: biodegradation and tidal removal. In this region, the tidal pattern is semi-diurnal which means there are two high tides and two low tides each day. Due to the frequent and continual tidal action, tidal removal is more important than biodegradation. As a result, only the tidal effect is taken into account in the model. The nitrogen in the channel is supplemented by the agricultural and domestic water use upstream. The intake water is withdrawn from the channel. In this module, the nitrogen is calculated based on one ha of shrimp land (main pond area) so the total pollution is multiplied by Total effective shrimp land. The water flow demand is the water volume that should be maintained during shrimp farming in each ha of main pond. The typical value for water level ranges from 1 – 1.5 m so we take the average value of 1.2 m for calculation. This means that for one ha of main pond, there should be 12,000 m^3 water. In addition to keeping track of nitrogen, shrimp survival is also observed. Shrimp survival rate depends on not only the stock density but also other environmental factors. Making use of the information of ammonia toxicity, we consider the nitrogen concentration in the shrimp pond as the limiting factor to shrimp growth. In reality, farmers may use aerators or chemicals to control pH and thereby adjust ammonia concentration, hence the effect of ammonia is not serious. However, because viruses and other physical parameters are random and hard to keep track of, this is a much simpler way to account for the environmental impact. The full diagram of this module is shown in Figure 13.

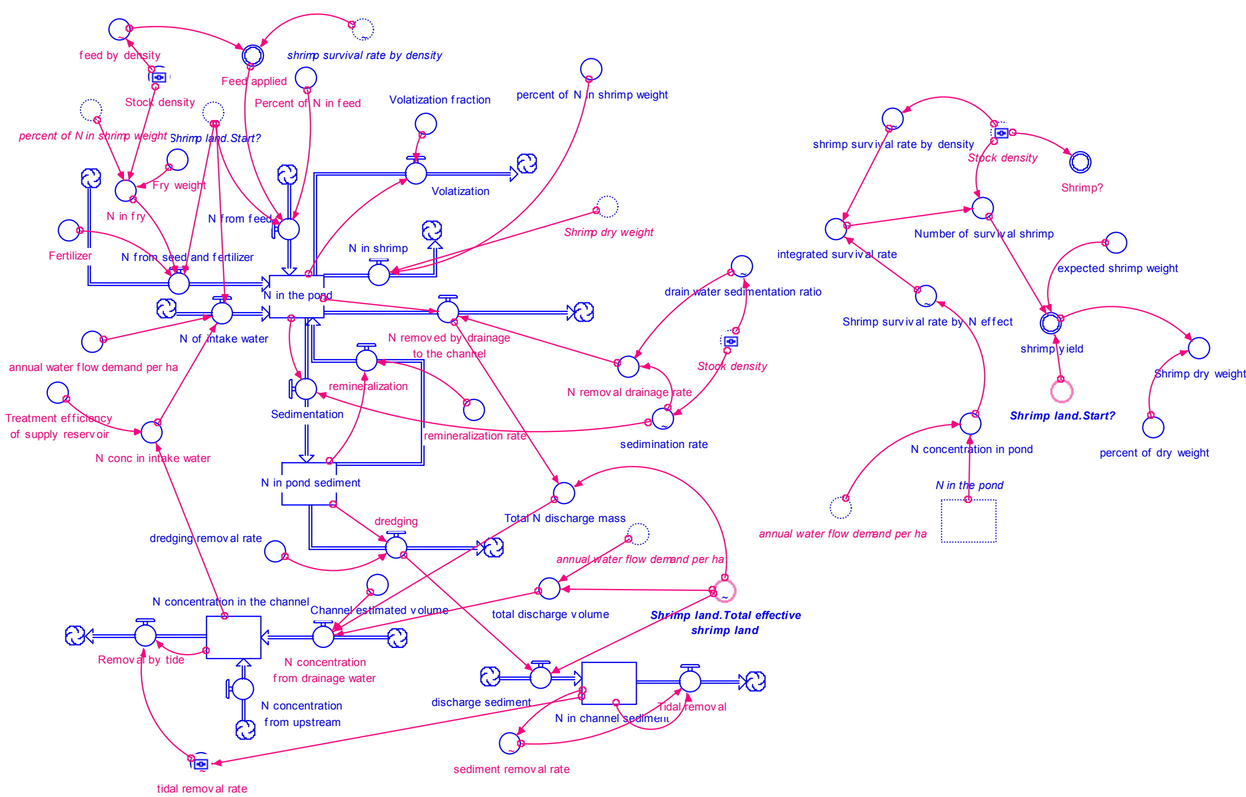


Figure 13: Full diagram of the Nitrogen module

3.2 Causal loop diagram

From a farmer's perspective, the Profit responding loop is the most easily seen (Figure 14). This is a negative loop in the Shrimp land module. When there are more shrimp farms, shrimp supply increases which causes the shrimp price to fall. Accordingly, shrimp profit decreases which influences the shrimp profit ratio. After a lag time, people observe the fall in the shrimp profit ratio and the fraction of farmers interested in shrimp farming declines. There are fewer people attending training courses and becoming capable of both rice and shrimp farming. The fraction of rice land converted annually will drop. There would be less land conversion from rice to shrimp.

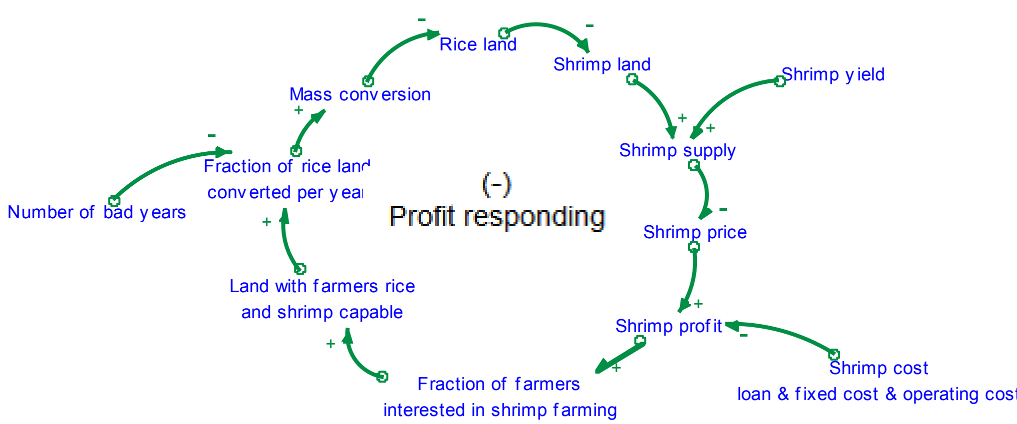


Figure 14: The Profit responding loop

The other three main loops in the Nitrogen module (Figure 15) are harder to observe. The first positive loop involves nitrogen cycling. When the concentration of nitrogen in intake water is high, the nitrogen content in the pond is also high. The more water is drained into the channel, the more nitrogen is discharged. Nitrogen ends up in the channel causing an increase in nitrogen concentration of the intake water.

The second positive feedback loop involves sediment cycling in the pond. A large amount of nitrogen in the pond enhances the sedimentation process and deposits more nitrogen in the pond sediment. On the other hand, remineralization increases when nitrogen content in the sediment gets higher and higher. This process adds more nitrogen content into the water phase.

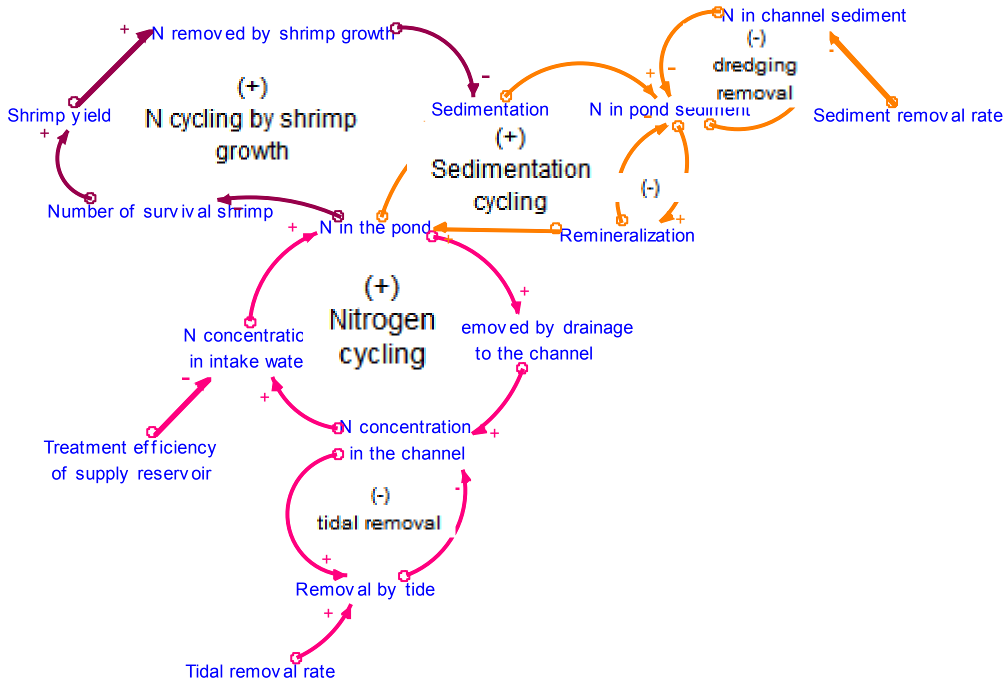


Figure 15: Causal loop diagram of the Nitrogen Module

The third positive loop in the Nitrogen module involves nitrogen cycling by shrimp growth. When the nitrogen content in the water phase of the pond is high, shrimp become poisoned and reduce their population. Accordingly, shrimp yield is low and the nitrogen content removed by shrimp growth is low, leaving a large amount of nitrogen in the pond water. The fact that this is a positive loop may cause some counterintuitive opinions. However, the main interpretation of this loop is that adding more nitrogen into the pond does not help increase the shrimp yield but increase the nitrogen in the water phase of the pond.

The key loop in the model joining the two modules together is the density control loop (Figure 16). The dash line connecting Shrimp supply and the Stock density represents the implicit link in the model by experimenting with the slider to change stock density. This key loop is negative indicating that this is a controllable system. When farmers start with a high stock density, they apply a large amount of feed and cause the nitrogen in the pond to increase. The increased concentration is lethal to shrimp and reduces the number of survival shrimp. Shrimp yield drops leading to a decrease in shrimp supply. In response, the farmers have to reduce the stock density. In fact, the accumulation of nitrogen in the system takes time which induces delayed response to the high stocking density. By the time the shrimp yield has fallen, the land conversion has been completed. This loop shows that choosing the right density to start is vital to the performance of the whole system.

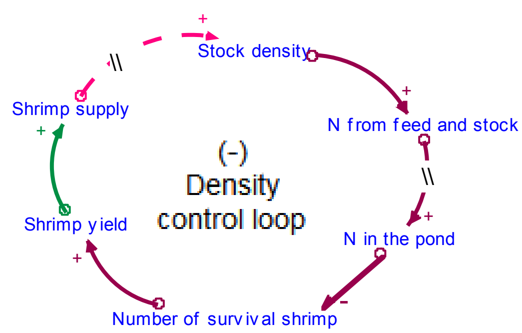


Figure 16: The key loop in the system

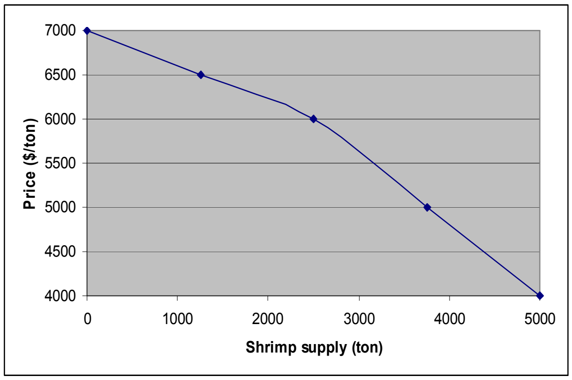
3.3 Model parameters:

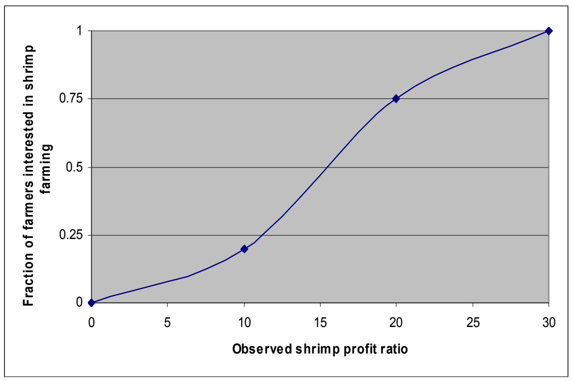
Most of the values of main stocks and converters are based on calculations or estimations from fieldwork. The fraction of farmers interested in shrimp farming and the fraction of farmers adopting change are estimated based on their desire. Sediment removal rate and tidal removal rate are assumed due to data deficiency. Volatization fraction, sedimentation rate, shrimp survival rate by density, and drain water sediment ratio are quoted from the experiment of intensive shrimp culture in the closed system by Thakur and Lin (2003). The percent of nitrogen in feed and percent of nitrogen in shrimp weight are cited from the study of Funge-Smith and Briggs (1998). Data on toxicity of ammonium to shrimp by Chen, Liu and Lei (1990) are used to calculate the survival rate of shrimp. Table 4 and Table 5 show the main parameters of the two modules in more detail:

Table 4: Main parameters of the Shrimp land module:

Variable	Unit	(Initial) Value	Note
Stocks			
Rice land	ha	2,000	Approximate number of arable land of Dai Hoc Loc Commune
Pilot shrimp farm	ha	0	Transit time = 1
Pilot farm with results	ha	0	
First year shrimp farm	ha	0	Transit time = 1
Old shrimp farm	ha	0	
Land with farmers rice capable	ha	2,000	
Land with farmers in training	ha	0	Transit time = 1
Land with farmers rice and shrimp capable	ha	0	
Number of bad years	years	0	
Population	persons	6,500	Estimated based on 2005 – 2007 population
Converters			
First year farm existence		0 or 1	
Old shrimp farm existence		0 or 1	
Start?		0 or 1	
Shrimp unit fixed cost	$/ha	10,000	Cost for creating ponds
Shrimp unit operating cost	$/ha	2,000	Labor costs ($1000/ha) and equipment operating costs ($1000/ha)
Fry unit price	$/10,000 fry	30	
Seed cost	$/kg	0.5	
Initial loan	$/ha	10,000	
Borrowing period	Years	1 – 5	
Loan interest rate	%/year	14.4	
Supply reservoir area fraction		40%	About 30 – 50% of shrimp land is designated as supply reservoir
Rice price	$/ton	300	
Rice yield	tons/ha	3.5	
Rice unit operating cost	$/ha	500	Seed, fertilizer, labor costs
Lag time	Years	1	
Growth rate	%/yr	3	Estimated based on 2006 – 2008 population

VARIABLE	UNIT	VALUE	NOTE
Shrimp price	$/ton	(see chart 1 below)	Estimated based on monopsony market
Fraction of farmers interested in shrimp farming		(see chart 2 below)	Estimated based on local people's stories
Fraction of farmers adopting change		(see chart 3 below)	Estimated based on local people's stories





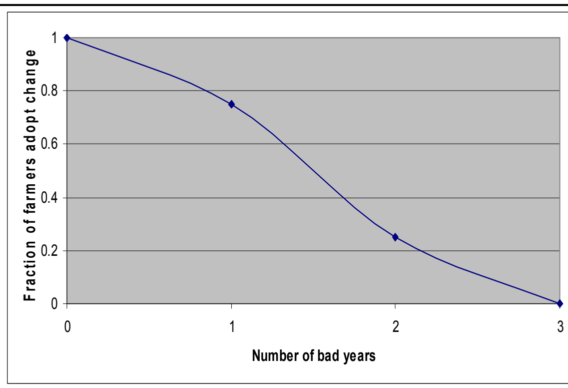
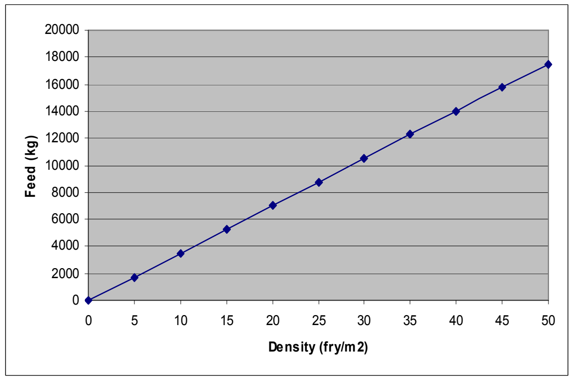
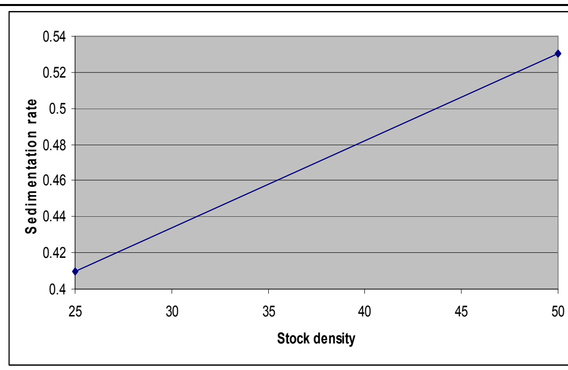
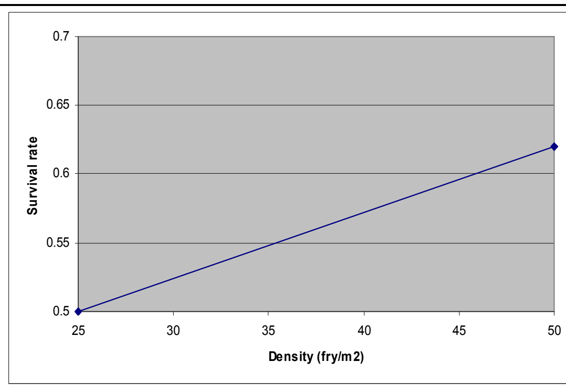
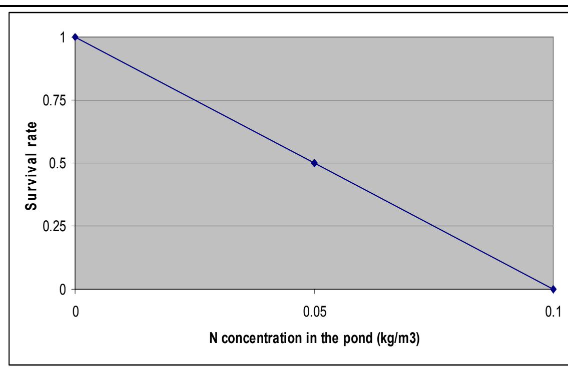
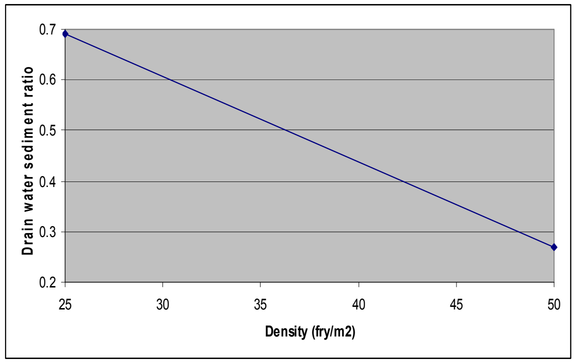
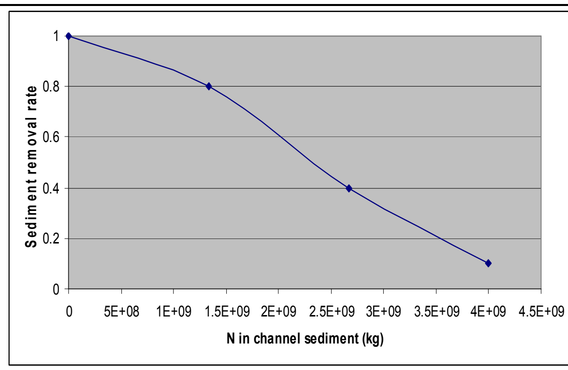
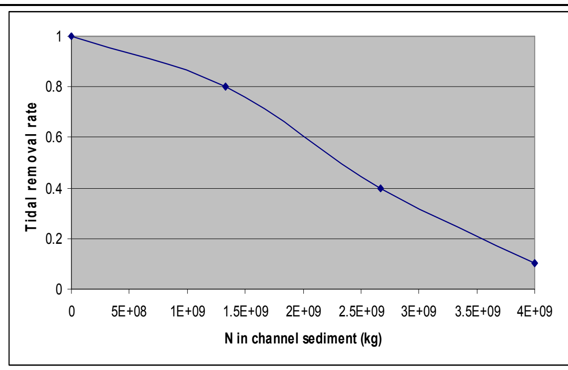


Table 5: Main parameters of the Nitrogen module:

Variable	Unit	(Initial) Value	Note
Stocks			
N in the pond	kg/ha	0	
N in pond sediment	kg/ha	0	
N in channel sediment	kg	0	
N concentration in the channel	kg/ m^3	5E-5	TCVN 5942: 1995 Vietnam standard: Water quality, surface water standards
Converters			
Fry weight	g/fry	1	
Stock density	Fry/m^2	25 – 50	
Fertilizer	kg/ha	20	28TCN 171 The procedure for intensive culture of Tiger shrimp specified 20 – 25 kg Urea
Percent of N in feed		0.07	Funge-Smith and Briggs (1998), table 1
Volatization fraction		0.06	Thakur and Lin (2003), table 3: 5.2 – 7.9%
Remineralization rate		0.06	Burford (2004), table 1: remineralization rate ~ volatilization rate
Percent of N in shrimp weight		0.11	Funge-Smith and Briggs (1998), table 1
Percent of dry weight		0.27	Calculated from table 1, Funge-Smith and Briggs (1998)
Expected shrimp weight	g/fry	30	
Annual water flow demand per ha	m^3/ha	12,000	
Channel estimated volume	m^3	2E6	Channel area ~ 1,330,000 m^2, 1.5 m depth
Treatment efficiency of supply reservoir		0.3	
Dredging removal rate		0.9	Assumed that all farmers clean their ponds almost completely after each harvest
Shrimp?		0 or 1	

Variable	Unit	Value	Note
Feed by density	kg/ha		Calculated based on an initial survival rate of 70%, FCR (Food conversion ratio) 1.67, then converted to 100% survival rate
Sedimentation rate			Thakur and Lin (2003), table 3
Shrimp survival rate by density			Thakur and Lin (2003), table 2. The values in this table are much higher than in reality so a multiplier of 0.8 is used.
Shrimp survival rate by N effect			Chen, Liu and Lei (1990), consider N as TAN (Total ammonium)

Variable	Unit	Value	Note
Drain water sediment ratio			Thakur and Lin (2003), table 3
Sediment removal rate			Assumption
Tidal removal rate			Assumed that tidal removal rate equals sediment removal rate

It is important to notice that the discount rate in this model is set to zero which means that the value of benefit or cost for each hectare of land from the beginning to the end of the period is the same. With a higher discount rate, the objective of businessmen is to maximize the profit without paying for the cost of externalities. As a result, they tend to obtain as much profit as they can from the beginning of the horizon. With an emphasis on sustainability, the objective here is different which leads to different results of recommendations for policy tests from those of a discount rate greater than zero.

CHAPTER FOUR

BASE CASE SIMULATIONS

In intensive shrimp farming in Vietnam, the commonly used stock density ranges from 25 – 45 fry/m^2, and the higher density is more prefered by farmers. This chapter gives two base case simulations of high and low stock densities to provide a brief comparison. The time horizon covers 20 years from 1999 to 2019 with the assumption that pilot farms started in 2000. All the runs are conducted with a dt of 0.25 years.

4.1 High stock density simulations

With a stock density of 45 fry/m^2, the yield in the first year is very promising at 8 tons/ha. After two years, the yield is cut in half and no yield is observed in 2009. The profit from shrimp is very high at first but it falls precipitously in following years (Figure 17).

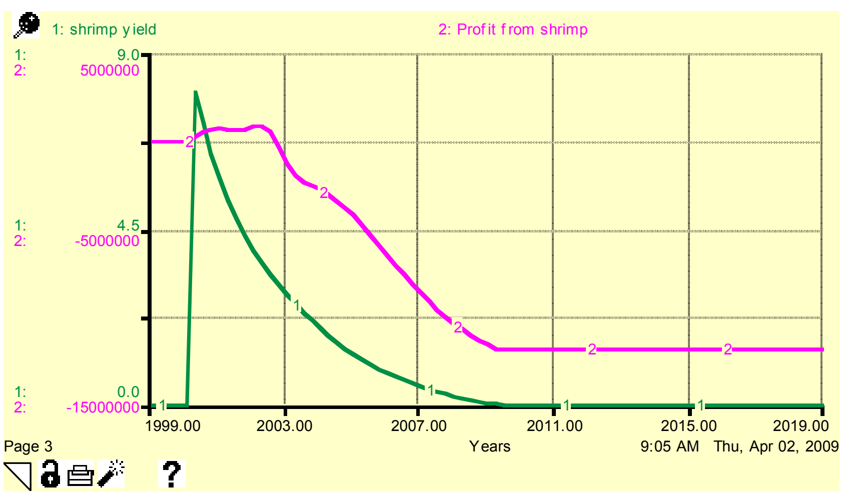


Figure 17: Graph of Shrimp yield and Profit from shrimp at a stock density of 45 fry/m^2

When observing the high profit in the first few years, farmers convert to shrimp quickly with a peak in 2003 at 860 ha. The mass conversion completes in five years resulting in 1719 ha of shrimp land in 2005 (Figure 18). Total shrimp supply also peaks in 2003, leading to a major fall in shrimp price in the same year (Figure 19).

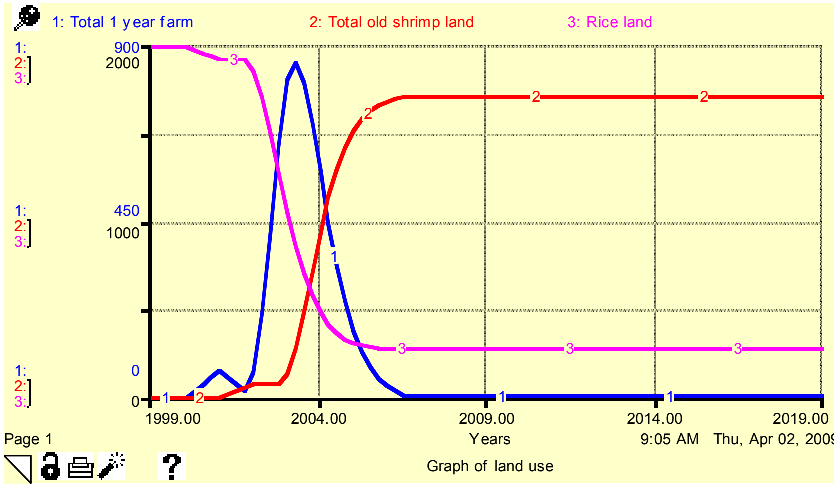


Figure 18: Graph of Land use at a stock density of 45 fry/m^2

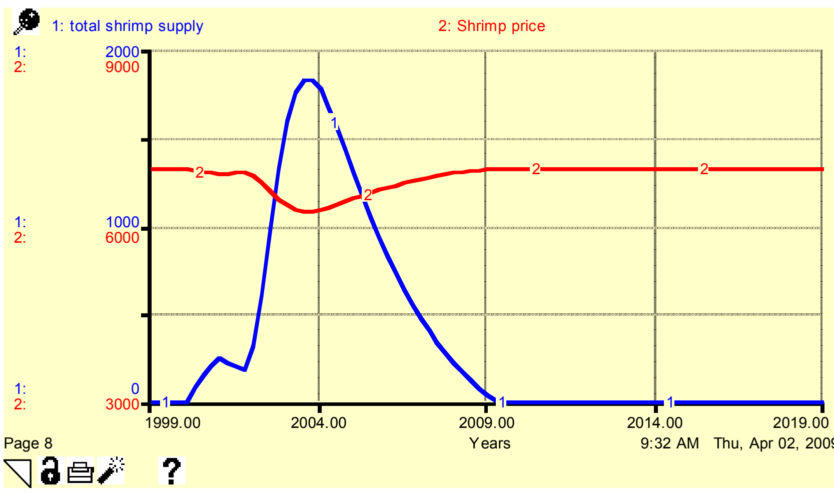


Figure 19: Graph of Total shrimp supply and Shrimp price at a stock density of 45 fry/m^2

The intensive practice causes nitrogen to accumulate substantially in the pond at an equilibrium value of 1238 kg/ha (Figure 20). The nitrogen increase in the channel water is somewhat harder to discern as the equilibrium value is small (0.2 kg/m^3 ~ 200 mg/L).

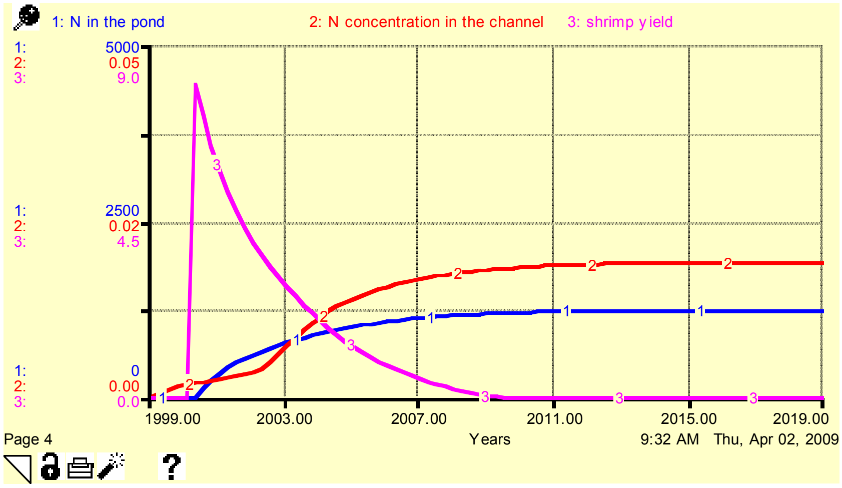


Figure 20: Graph of Nitrogen in the pond, Nitrogen concentration in the channel and Shrimp yield at a stock density of 45 fry/m^2

4.2 Low stock density simulations

When farmers begin with a low stock density of 25 fry/m^2, they get an average yield of 3.8 tons/ha. The yield drops slightly in ten years and the equilibrium yield is 2 tons/ha. The profit from shrimp increases gradually and remains stable in the long term (Figure 21).

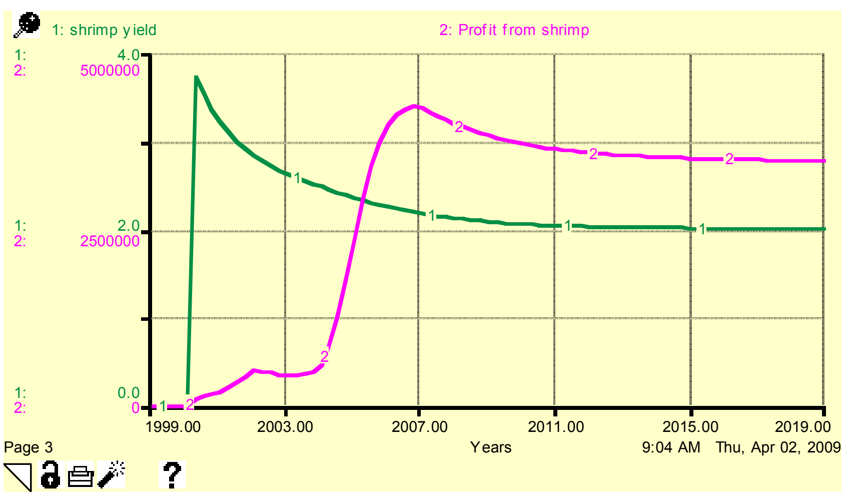


Figure 21: Graph of Shrimp yield and Profit from shrimp at a stock density of 25 fry/m^2

Due to the unattractive profit from the pilot farms, land conversion occurs slowly and peaks in 2004 at 566 ha. The process finishes in six years with 1298 ha of shrimp land

(Figure 22). Total shrimp supply also peaks in 2004, leading to a fall in shrimp price in the same year (Figure 23).

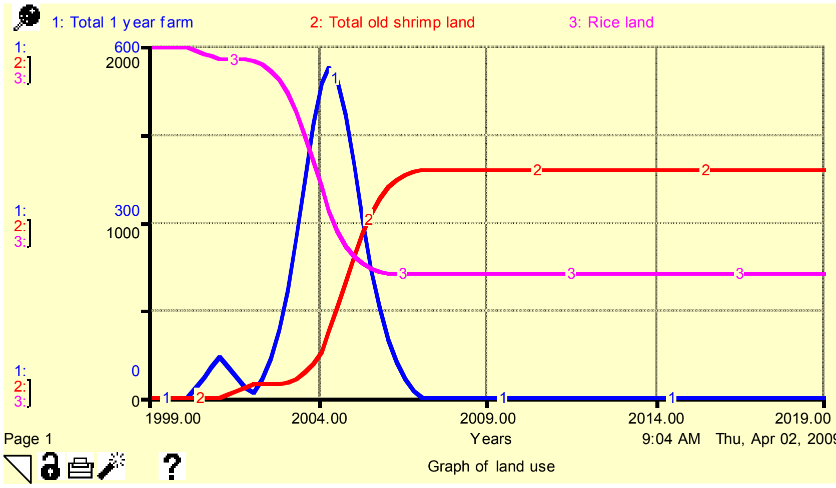


Figure 22: Graph of Land use at a stock density of 25 fry/m^2

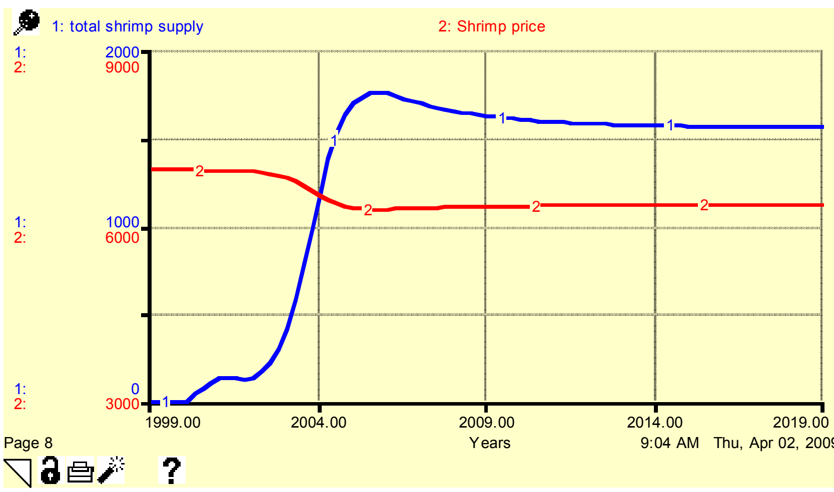


Figure 23: Graph of Total shrimp supply and Shrimp price at a stock density of 25 fry/m^2

With a low stock density, the shrimp farming practice is not highly intensive. The nitrogen content in the pond is around 550 kg/ha and nitrogen concentration in the channel is also low, roughly 0.01 kg/m^3 (100 mg/L). Due to the low accumulation of nitrogen in the system, the yield is sustainable till the end of the horizon*.

* Although this practice is good for the environment, this may not be the preferable practice in the case of a positive discount rate.

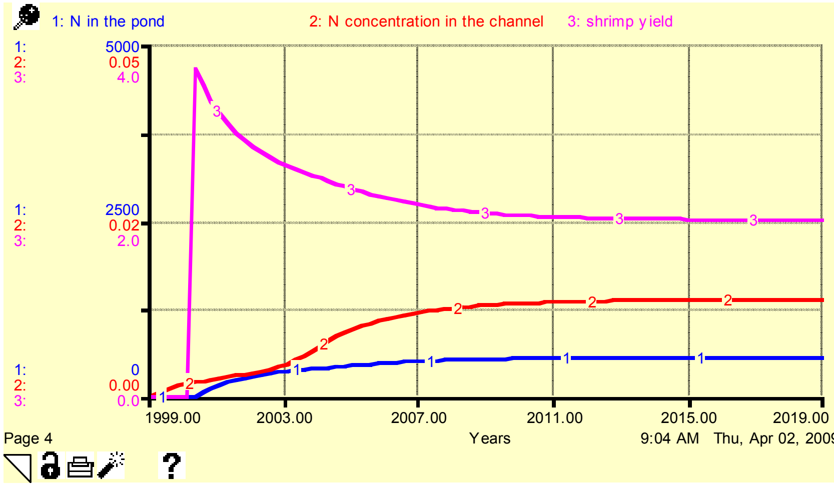


Figure 24: Graph of Nitrogen in the pond, Nitrogen concentration in the channel and Shrimp yield at a stock density of 25 fry/m^2

From the two base case simulations, it is obvious that higher stock density gives a higher yield at first and speeds up the conversion process. However, the unsustainable practice endangers the system by introducing too much nutrient content and puts farmers into trouble with no yield in the long run.

CHAPTER FIVE

SENSITIVITY ANALYSIS

5.1 Stock density

Three different stock densities of 25, 35 and 45 fry/m^2 (corresponding to runs 1, 2 and 3) were tested to see the effect of stock density on shrimp yield, shrimp land, shrimp supply, nitrogen in the pond, nitrogen in pond sediment, nitrogen in channel sediment and nitrogen concentration in the channel.

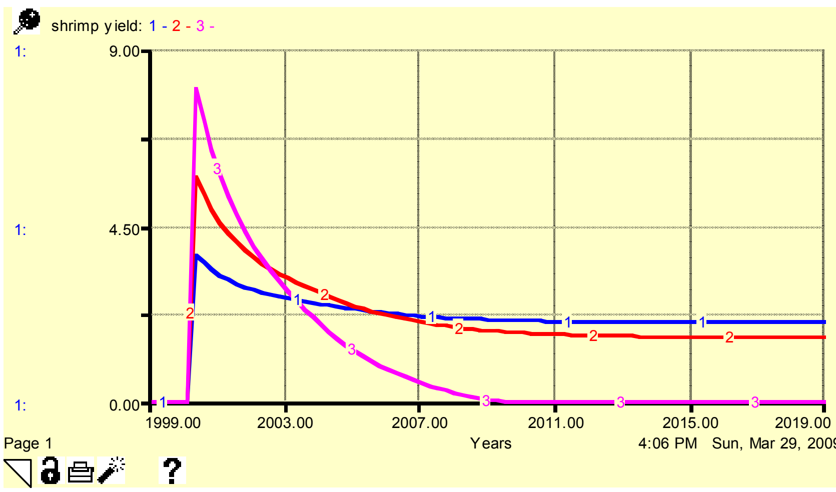


Figure 25: Sensitivity graph of shrimp yield corresponding to stock density of 25, 35 and 45 fry/m^2

From the graph (Figure 25), in the first few years, higher stock density creates higher yield. As the density increases, the equilibrium yield decreases. When the density gets too high, the yield plummets after six years and no yield is observed in the long run. This finding is very important as most people believe that they will get a higher yield with higher stock density. However, due to the action of the positive feedback loop (Nitrogen cycling by shrimp growth illustrated in Figure 15), the yields become lower when more Nitrogen is added to the system.

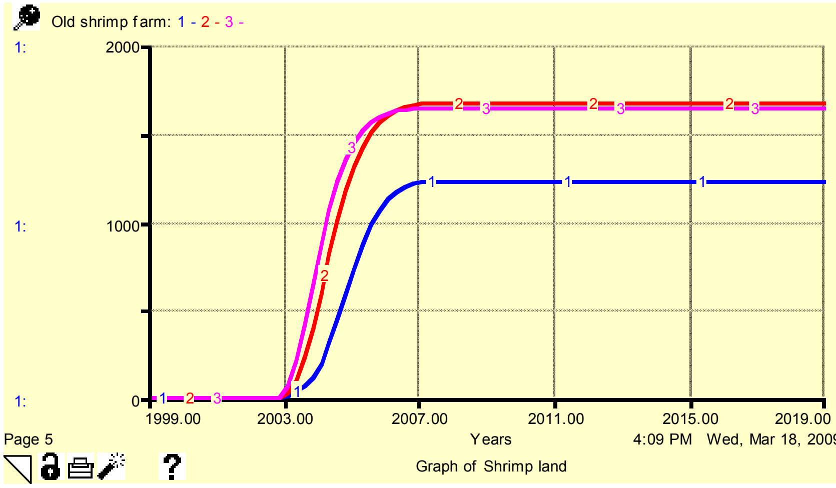


Figure 26: Sensitivity graph of shrimp land corresponding to stock density of 25, 35 and 45 fry/m^2

Due to the higher yield of higher stock density, people rush to shrimp farming sooner. However, in the long run, there's not much difference in the final shrimp land area between the stock density of 35 and 45 fry/m^2 (Figure 26). With a low density of 25 fry/m^2, less land is converted to shrimp farms as the profit is not attractive enough. This effect is controlled by the negative feedback loop of Profit responding (Figure 14).

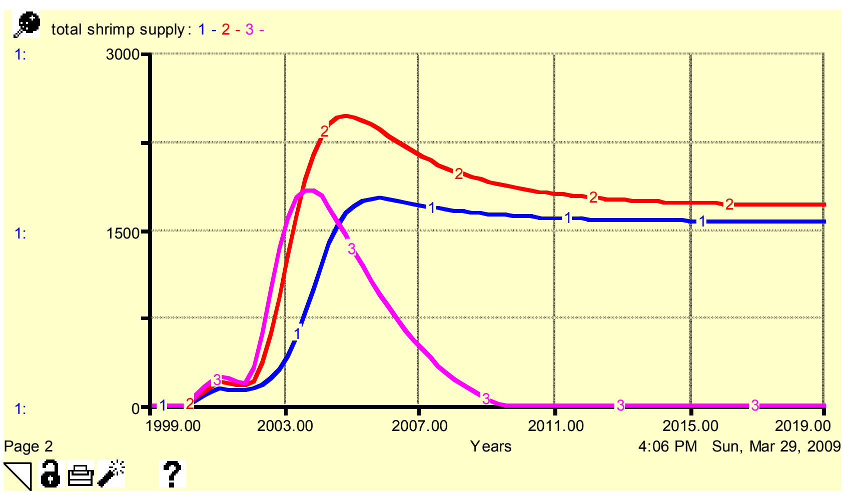


Figure 27: Sensitivity graph of shrimp supply corresponding to stock density of 25, 35 and 45 fry/m^2

Among the three runs shown in Figure 27, the total shrimp supply from the highest density is the lowest within the time frame. Though the higher yield provides extra quantity at the beginning, its declining supply for the remaining period is significant. A stock density of 35 fry/m^2 is the most reasonable as it yields the highest supply of the three densities.

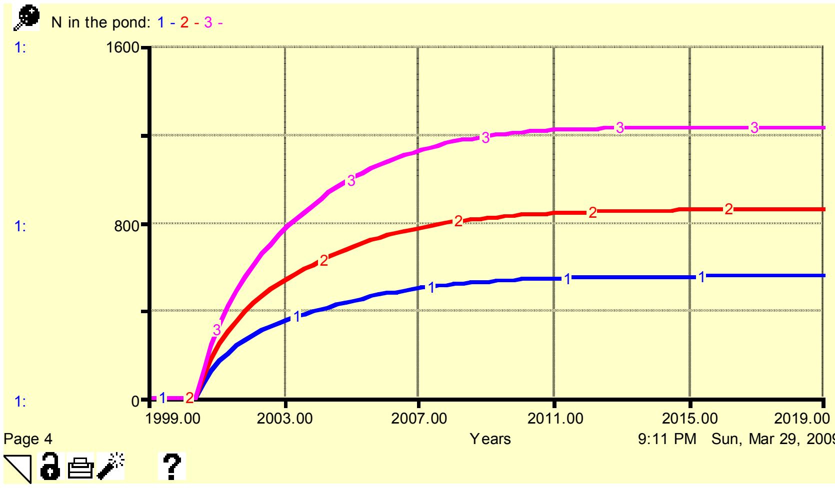


Figure 28: Sensitivity graph of nitrogen in the pond corresponding to stock density of 25, 35 and 45 fry/m^2

Figure 28 shows the intensive input of nitrogen into the pond. The nitrogen content is twofold when we increase the stock density from 25 to 45 fry/m^2. Correspondingly, nitrogen content in the pond sediment increases almost threefold (Figure 29). The accumulation of Nitrogen in the system is driven by two positive feedback loops of Sedimentation and Nitrogen cycling (Figure 15).

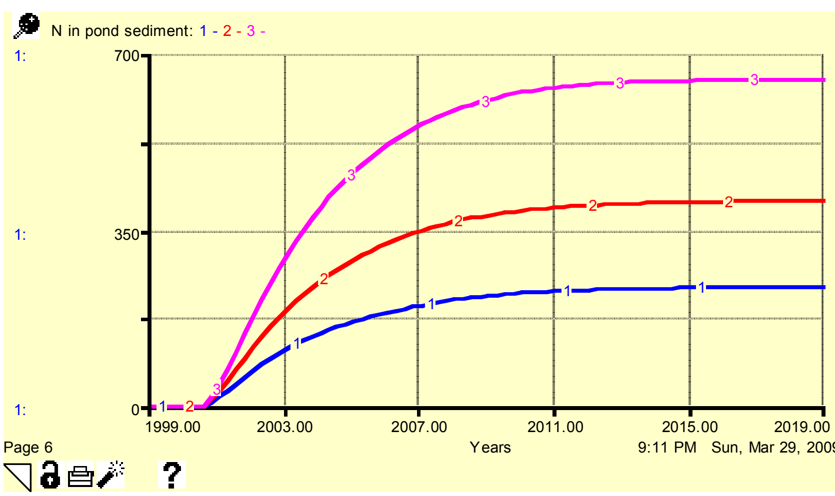


Figure 29: Sensitivity graph of nitrogen in pond sediment corresponding to stock density of 25, 35 and 45 fry/m^2

Since 90% of the pond sediment is dredged and discharged into the channel, more nitrogen content in channel sediment accumulates when stock density is increased (Figure 30).

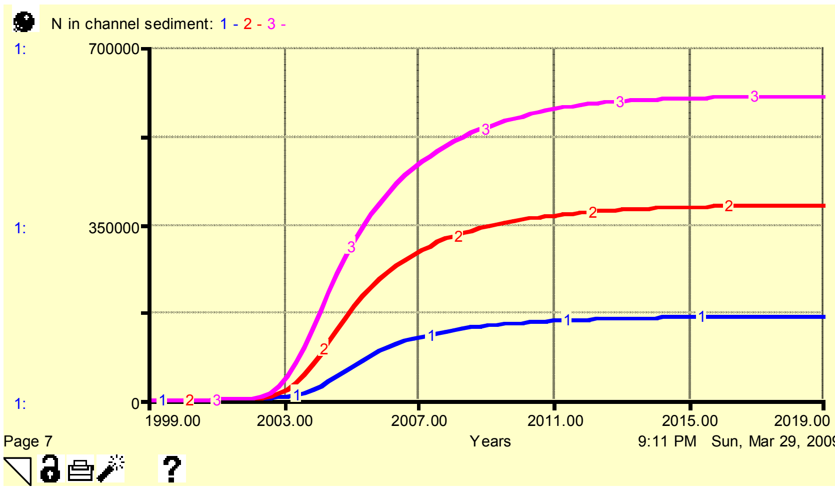


Figure 30: Sensitivity graph of nitrogen in channel sediment corresponding to stock density of 25, 35 and 45 fry/m^2

Although the discharge from higher density ponds is more intensive, nitrogen concentration in the channel water does not vary much due to the large volume of water in the channel (Figure 31). In this case, water volume is assumed to be constant regardless the season of the year.

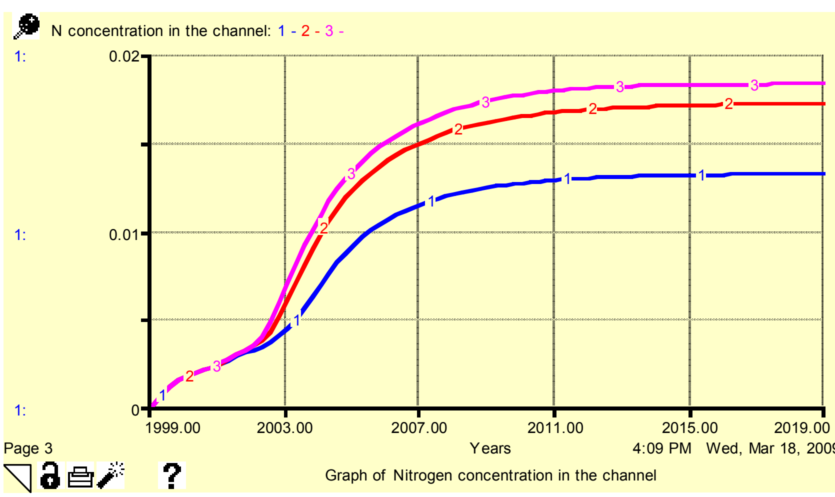


Figure 31: Sensitivity graph of nitrogen concentration in the channel corresponding to stock density of 25, 35 and 45 fry/m^2

5.2 Borrowing period

In order to test the significance of the borrowing period to the farmer's decision on shrimp farming investment, a stock density of 35 fry/m^2 is used. Based on the local bank's policy, borrowing periods range from 1 to 5 years.

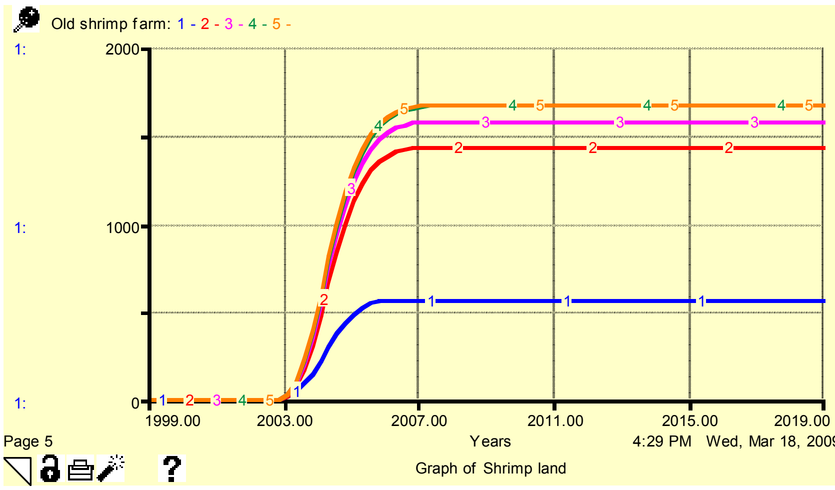


Figure 32: Sensitivity graph of shrimp land corresponding to borrowing period of 1 – 5 years

Results show that more land is converted when the period is longer (Figure 32). In this model, the annual interest rate is fixed so the annual payment is lower in response to the longer borrowing period. In addition, with a one year loan, farmers are more reluctant to convert to shrimp because the initial investment in the first year for creating ponds is high. Approximately 1,400 ha are kept as rice land when farmers can only get a one year loan. However, there is no major difference in shrimp land among borrowing periods of 2, 3, 4 and 5 years. This suggests that two years is the starting point to boost the shrimp industry. Shrimp profit is also higher when the period is longer (Figure 33).

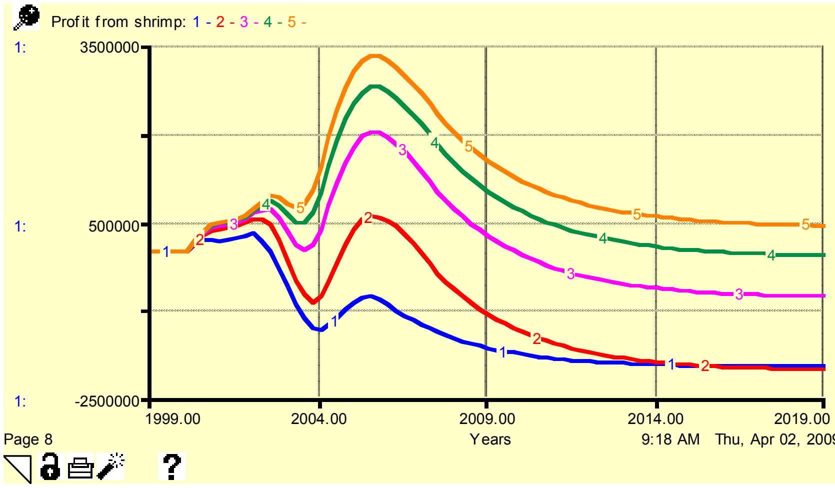


Figure 33: Sensitivity graph of shrimp profit corresponding to borrowing period of 1 – 5 years

5.3 Tidal removal rate

Tidal removal rate is considered for testing because it helps decrease the nitrogen content in channel water and consequently reduces the nitrogen content in intake water. However, there is little knowledge on the tidal removal rate in this region. It is also not easy to judge whether the tidal removal rate depends on sediment load in the channel and hence it also depends on sediment removal rate. Two main scenarios are built for this test: (1) tidal removal rate depends on sediment load in the channel and (2) tidal removal rate is independent of sediment load in the channel. For the first scenario, three cases are considered: (1) tidal removal and sediment removal rates are equal, (2) tidal removal rate is linearly dependent on sediment load and (3) tidal removal rate is hyperbolic dependent on sediment load. A stock density of 35 fry/m^2 and a borrowing period of 5 years are used in this test.

For the first scenario, there is no difference in shrimp yield among the three cases (Figure 34). This shows that the interdependence between tidal removal rate and sediment load is negligible.

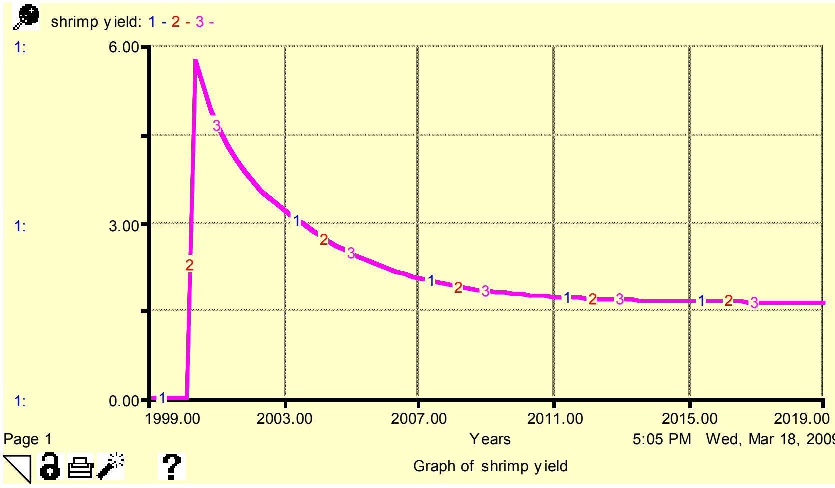


Figure 34: Sensitivity graph of shrimp yield corresponding to different tidal removal rate scenario 1

For the second scenario, sensitivity runs are conducted for three tidal removal rates of 0.1, 0.5 and 0.9 corresponding to runs 1, 2 and 3. With a very low removal rate of 0.1, farmers get no yield in six years because the high nitrogen content builds up in the system. At a rate of 0.5, no yield will be observed in 2009. At a high removal rate of 0.9, the yield drops from 6.9 tons/ha to 1.5 tons/ha in seven years and 0.7 tons/ha is the equilibrium yield (Figure 35).

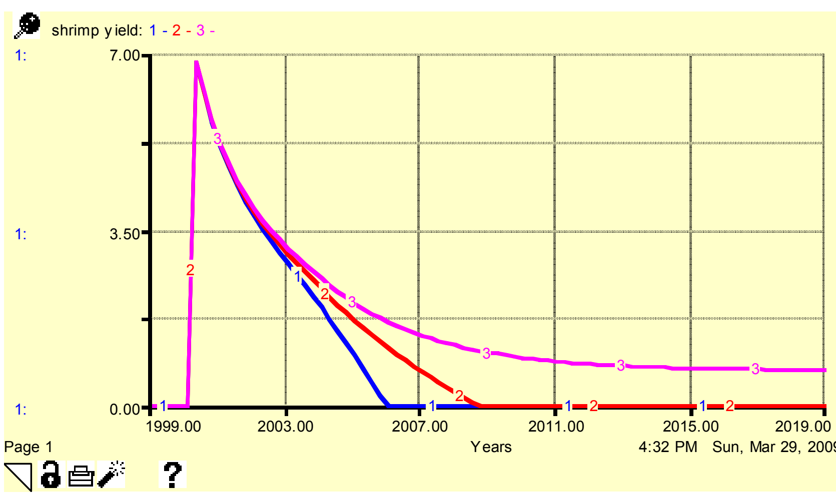


Figure 35: Sensitivity graph of shrimp yield corresponding to tidal removal rate of 0.1, 0.5 and 0.9

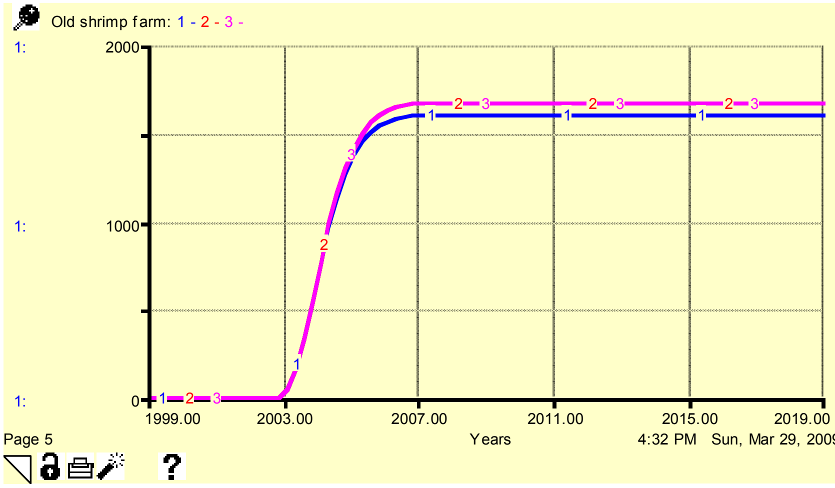


Figure 36: Sensitivity graph of shrimp land corresponding to tidal removal rate of 0.1, 0.5 and 0.9

There is no significant difference in shrimp land because the conversion takes place excessively in the first few years (Figure 36). However, due to the yield difference, shrimp supply varies substantially among three runs (Figure 37). Nitrogen concentration in the channel reaches 0.366 kg/m^3 (366 mg/L) at a rate of 0.1, 0.047 kg/m^3 (47 mg/L) at a rate of 0.5 and 0.020 kg/m^3 (20 mg/L) at a rate of 0.9 at the end of 20 years (Figure 38). For further runs on policy testing, the average rate of 0.5 will be used for comparison.

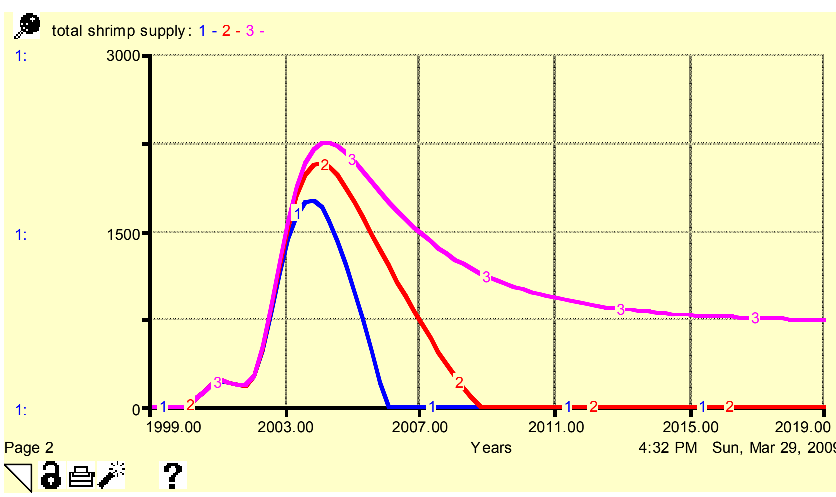


Figure 37: Sensitivity graph of shrimp supply corresponding to tidal removal rate of 0.1, 0.5 and 0.9

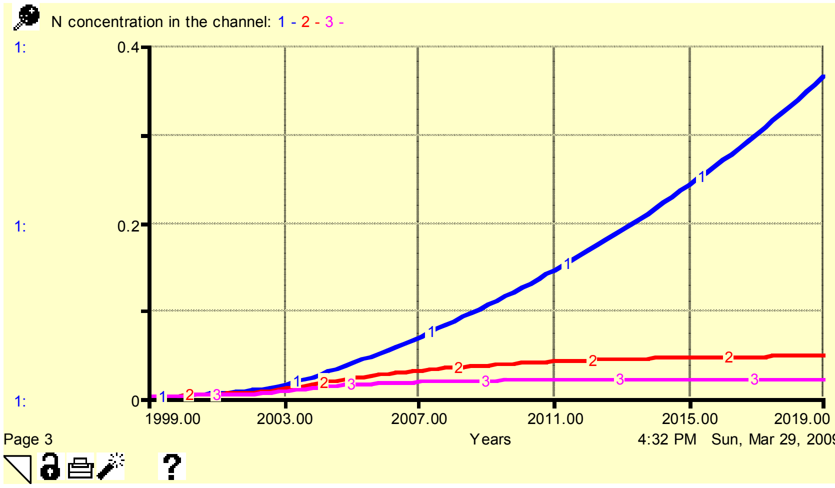


Figure 38: Sensitivity graph of nitrogen concentration in the channel corresponding to tidal removal rate of 0.1, 0.5 and 0.9

CHAPTER SIX

LEARNING THE RISK

6.1 The story of land use change:

Although land statistics are only available from 2005 to 2007, the people in Dai Hoa Loc Commune have their own story about land conversion since the year 2000. In 2000, about 70 ha of land was converted to shrimp ponds. The mass conversion occurred very quickly in 2003 and 2004. In 2005, the conversion was almost finished and shrimp land dominated the area as shown in Table 2. To confirm their story, the model is run with the following inputs: 70 ha of the pilot area in 2000, stock density at their commonly-used level of 40 fry/m^2, borrowing period of 5 years, tidal removal rate at 0.5 and a time frame from 1999 to 2007.

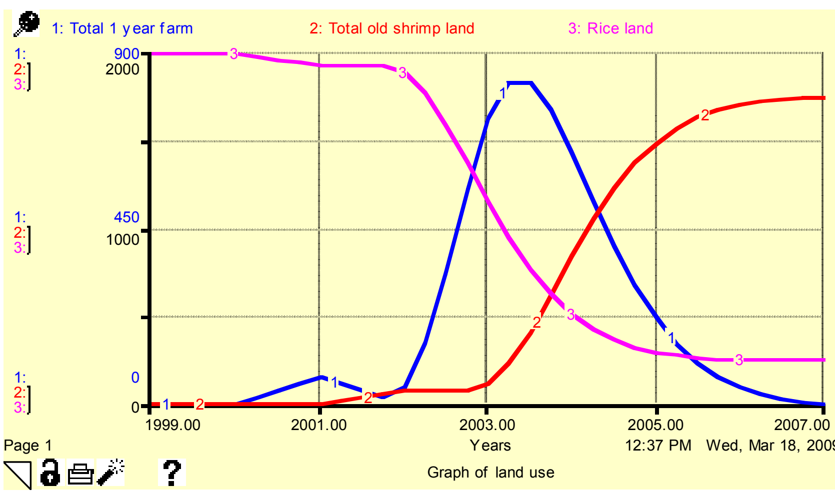


Figure 39: Graph of land use from 1999 to 2007 of Dai Hoa Loc Commune

Figure 39 retells the story quite well with a sharp increase in land conversion from 2003 to 2005. The total area of remaining rice land in 2007 is 249 ha which is slightly higher than the statistical data.

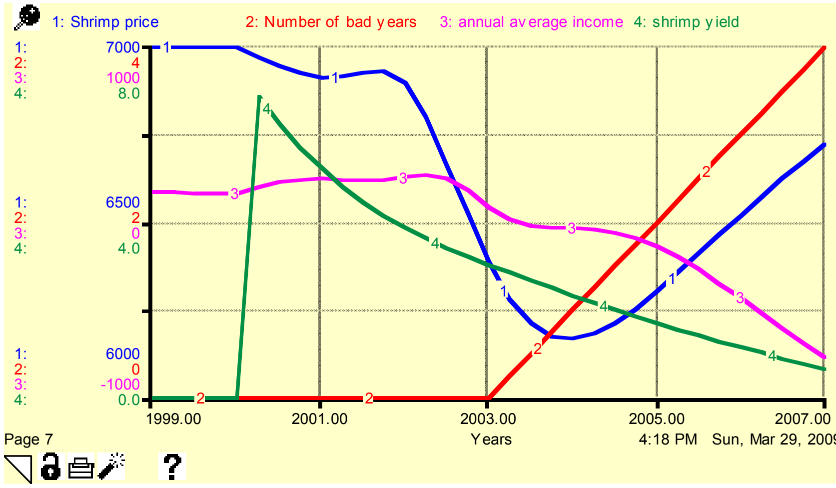


Figure 40: Graph of Shrimp price, Shrimp yield, Annual average income and Number of bad years

From 2000 to 2007, average yield declines from 6.9 tons/ha to 0.7 tons/ha, the lowest shrimp price is observed in 2004 at $6,167/ton. Annual average income is highest in 2002 at $272/capita from rice and shrimp alone, and four bad years are counted (Figure 40). From the local people's estimate, the highest annual average income was about $300/capita in 2003 and 2004. The difference between the model's result and the actual story was due to the transition conversion. Most people practiced extensive farming first to see how they were doing. When they saw the great benefit from shrimp compared to rice, they decided to convert their fields into ponds. Because extensive farming mainly utilizes natural stock and feeds, there is not enough information to integrate into the model.

It is also noticed that for extensive shrimp farming, all the land is effectively used while in intensive farming only 50 – 70% of the land is effectively used because 30 – 50% is reserved for the supply reservoir. Farmers already took this tradeoff into account and that's why only 20% of the farmers are interested in shrimp farming when the profit ratio of shrimp to rice per effective ha is 10. In addition, conversion from shrimp to rice is difficult which makes farmers count the number of bad years before making the decision on permanent conversion.

6.2 The risky nature of shrimp business

Now most people in the region have shifted to shrimp and they have experienced some bad years due to the declined yield. To maintain the business, they have tried several things. Some abandon their farms after a few years and continue when they mobilize enough capital for investment. Some reduce the stock density.

Figure 41 shows the shrimp yield and profit from shrimp when farmers abandon the ponds for two years and restart in two years. Starting in 2008, farmers stopped their activities. In 2010, they will restart cultivating and get a yield of 3.4 tons/ha. In 2011 the yield will decline to 1.7 tons/ha. Their next trial in 2014 will result in 3.6 tons/ha and the yield in 2015 will be 1.8 tons/ha. Restarting the business in 2018 gives a yield of 3.7 tons/ha and the yield in 2019 will be 1.9 tons/ha. From the test, it is obvious that pausing cultivation does make the situation better because the tidal effect helps reduce nitrogen content in the system. The profit from these recovering years is high. However, due to the high load of nitrogen already accumulated in the channel water, the nitrogen amount in the pond reaches its previous level after two years of cultivating. As a result, the yield only partially recovers and then rapidly declines (Figure 42).

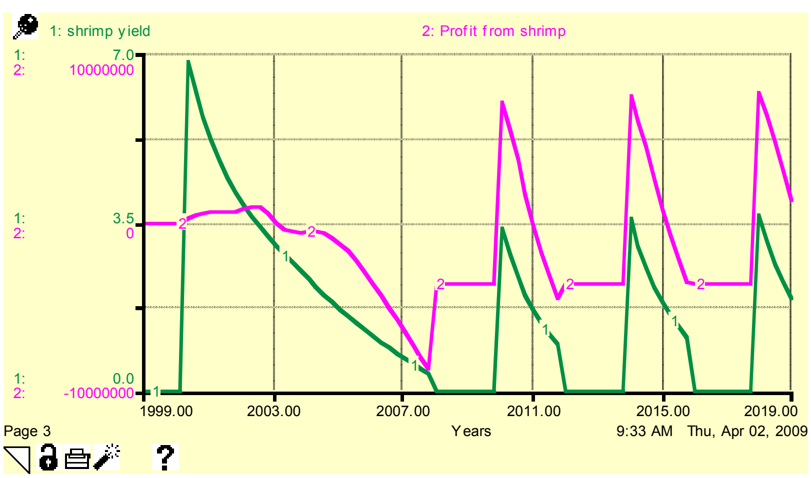


Figure 41: Graph of Shrimp yield and Profit from shrimp corresponding to two year pausing period

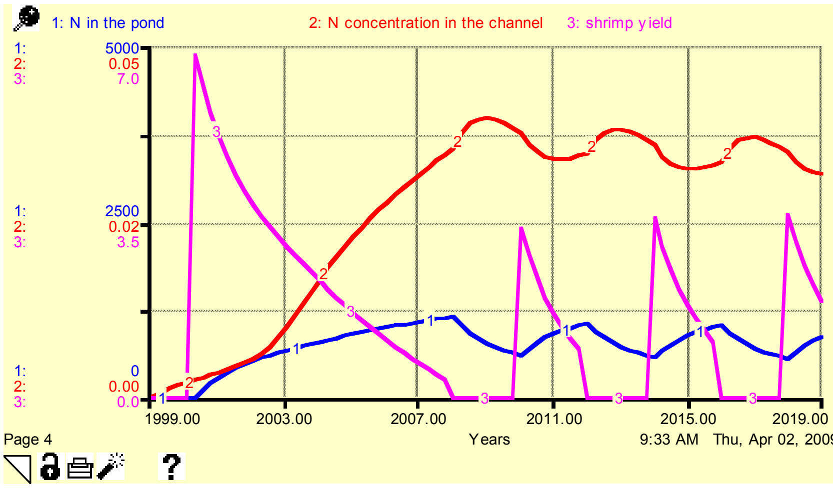


Figure 42: Graph of Nitrogen in the pond, Nitrogen concentration in the channel and Shrimp yield corresponding to two year pausing period.

Based on the sensitivity tests of stock density, the alternative of reducing stock density is promising. But would the yield increase immediately when they do so? If not, how long would it take to recover to a profitable yield? From my observation, only farmers with low capital do this because they no longer have enough money to pay high feed costs. Assuming that all the farmers lower the stock density when they observed a decline in yield to 0.7 tons/ha, the model is run thrice for better comparison: (1) keeping stock density constant at 25 fry/m^2 during the horizon, (2) keeping stock density constant at 40 fry/m^2 during the horizon and (3) switching from 40 to 25 fry/m^2 starting in 2008.

Figure 43 shows that if farmers keep cultivating at 40 fry/m^2, their business will be closed in nine years. If they reduce the stock density in 2008, the yield continues to drop to 0.13 tons/ha (almost no yield). In 2009, the yield increases to 0.6 tons/ha. One more try in 2010 creates a yield of 0.7 tons/ha. In 2011, the yield reaches equilibrium at 0.75 tons/ha. This yield is lower than the yield of a constant low stock density of 1 ton/ha. Farmers might get frustrated at this point because they will no longer obtain the profitable yield that they used to have.

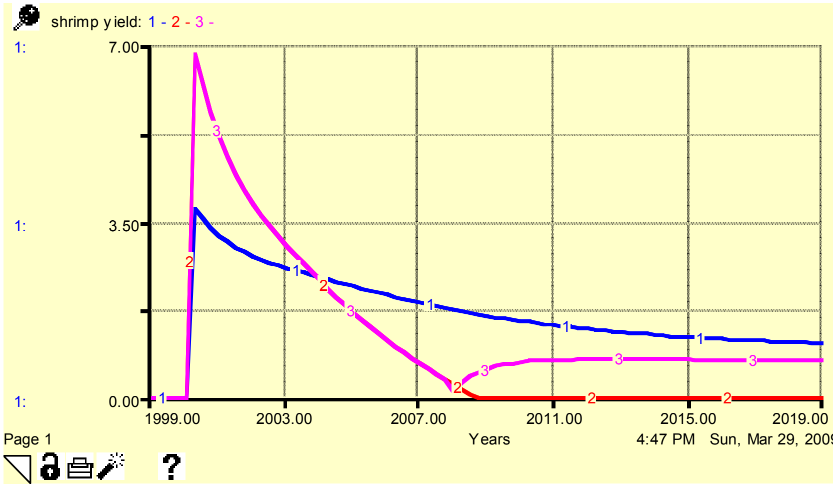


Figure 43: Comparative graph of shrimp yield among consistent stock density of 25 fry/m^2, 40 fry/m^2 and a switch from 40 to 25 fry/m^2 in 2008.

Figure 44 shows the shrimp supply from three runs. The stock density of 25 fry/m^2 provides the highest supply. The approach of reducing the stock density does increase the supply at the end but the earlier and higher supply at the beginning of the high stock density approach cannot offset the loss later on. This indeed explains the risky nature of the shrimp business.

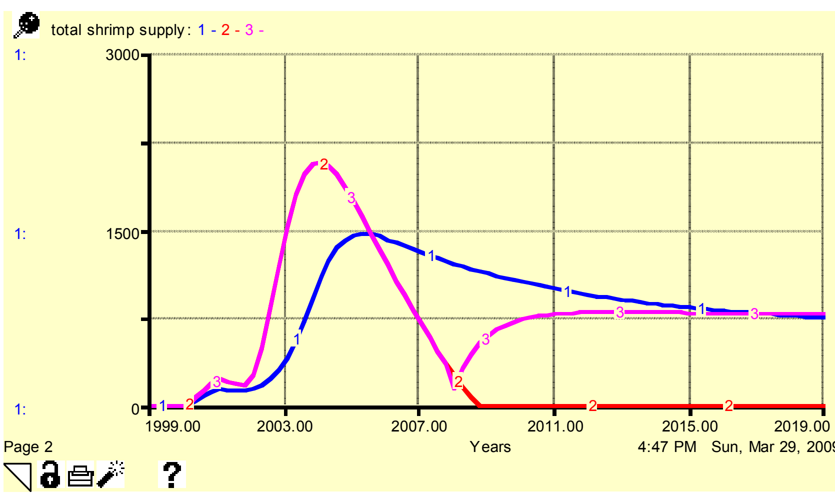


Figure 44: Comparative graph of shrimp supply among consistent stock density of 25 fry/m^2, 40 fry/m^2 and a switch from 40 to 25 fry/m^2 in 2008.

For most people, the shrimp industry has improved their standard of living. Others believe rice farming is more sustainable although the benefit is much smaller. In shrimp farming, once they fail in two consecutive years, they fall into a spiral of debt. Back to the question of Oxfam (1999): Is shrimp farming a path to riches or a road to poverty? Figure 45 shows the pattern of annual average income from both activities: (1) rice farming, (2) shrimp farming at a stock density of 40 fry/m^2, (3) shrimp farming with a stock decrease from 40 to 25 fry/m^2 in 2008 and (4) shrimp farming with a stock density of 25 fry/m^2. Due to population increase, the income from rice decreases from $169/capita to $93/capita. Among the three runs of shrimp farming, the lowest stock density brings highest annual average income of $423 in 2006. At this stock density, the overall income seems better than rice farming although the income at the end of the horizon is negative. The three runs 2, 3 and 4 confirm that shrimp farming is not a sustainable practice compared to rice if we totally rely on natural attenuation.

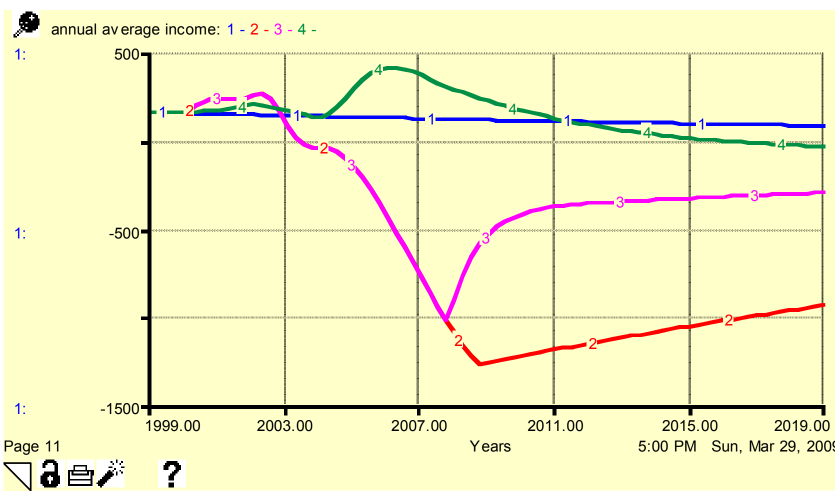


Figure 45: Comparative graph of annual average income from shrimp farming and rice farming

CHAPTER SEVEN

POLICY TESTING

Scientists believe that farmers have to assign treatment ponds to treat the drainage from harvest before discharging into the environment and that the channel system should be improved to facilitate this industry. In this section, these two recommendations are considered for testing.

7.1 Improving the channel system

The purpose of improving the channel system is to enhance the tidal removal rate and subsequently reduce the nitrogen concentration in the channel. Due to the crisscrossing channel system in this area, the hydraulic condition is very complicated. Investment in infrastructure development is costly so the model will be used to test if this investment is worthwhile.

Suppose that the tidal removal rate increases from 0.5 to 0.75. Four runs are conducted for comparison: (1) stock density is kept constant at 40 during the horizon and tidal removal rate is set to 0.75 in 2008, (2) in 2008 stock density is reduced from 40 to 25 and tidal removal rate increased from 0.5 to 0.75 (3) stock density is kept constant at 25 and tidal removal rate is 0.5 and (4) stock density is reduced from 40 to 25 in 2008 keeping the tidal removal rate at 0.5.

Results show that improving the channel without reducing the stock density creates the lowest yield of 0.15 tons/ha at the end of the 20-year run. Lowering the stock without improving the channel system helps sustain the yield at 0.75 tons/ha. The best strategy is to improve the channel and lower the stock density at the same time to maintain the yield at 1.6 tons/ha (Figure 46). Correspondingly, the supply of the second run is highest (Figure 47).

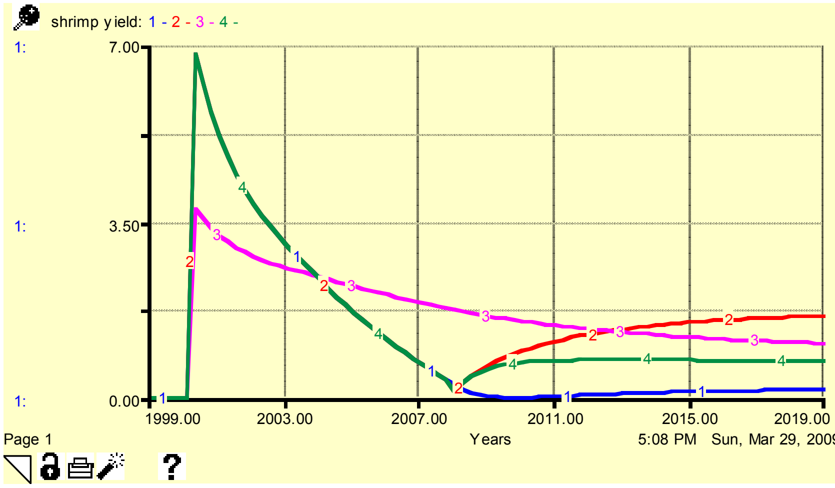


Figure 46: Graph of Shrimp yield in the test of improving the channel system

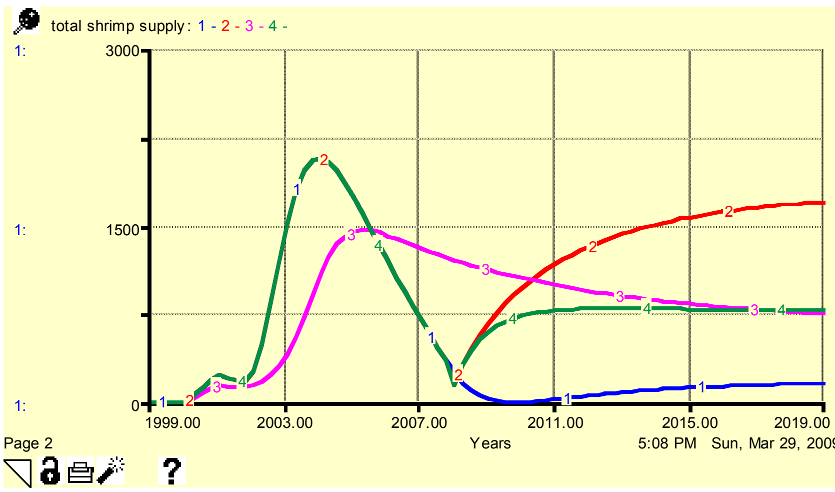


Figure 47: Graph of Shrimp supply in the test of improving the channel system

From the profit perspective, only profit from improving the channel and lowering stock is considerable. The profit of this strategy at the end of the period is around 2 million dollars. From Figure 46, the yield of this approach is sustainable so the profit is also sustained in Figure 48. The profit in the long term is so large that it is worthwhile to invest in infrastructure development. In reality, such a large project can only be managed by the government and the process may take a long time. Another approach is that each farmer has his own treatment pond to treat the drainage water before discharging into the channel.

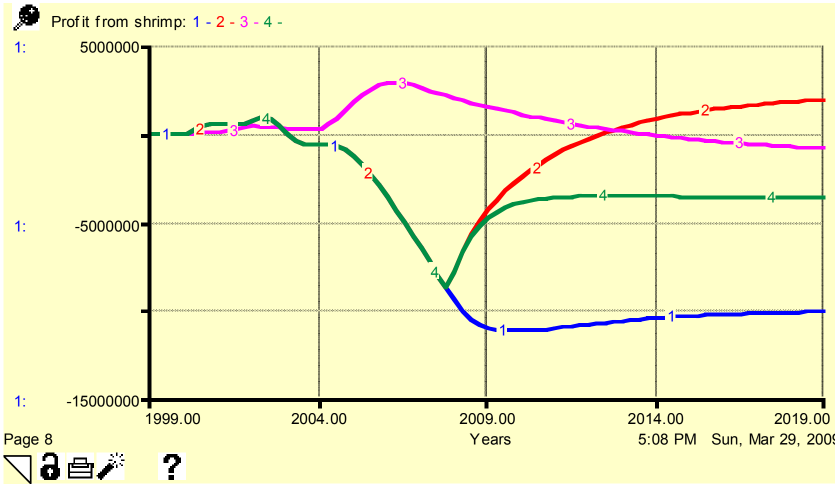


Figure 48: Graph of shrimp profit in the test of improving the channel system

7.2 Assigning treatment pond

By standard 28TCN 171 (2001), each farm should reserve 20 – 25% of the land for a supply reservoir, 10 – 15% for a treatment pond and the rest is used for growing shrimp. In practice, farmers reserve 30 – 50% of their land for a supply reservoir instead of dividing the land into two different ponds. Suppose that we change from the current practice to strictly comply with the standard, the treatment efficiency of the supply reservoir is reduced by half, i.e., from 30% to 15%. According to Teichert-Coddington, Rouse, Potts and Boyd (1999), the treatment pond helps reduce 7% of total nitrogen in the pond or its treatment efficiency is 31%. In this analysis, two base runs of stock density of 25 and 40 without any change are maintained for comparison. Two new runs are added: (3) keep the stock density constant at 40 and introduce the treatment pond in 2008 and (4) while introducing a treatment pond in 2008, reduce the stock density from 40 to 25.

Results show that with a stock density of 40, the introduction of treatment ponds does not help improve the situation. Combining treatment ponds with lowering the stock density recovers the yield to 1 ton/ha – the level of applying a constant low stock density at the beginning (Figure 49). Yield recovery increases shrimp supply (Figure 50) and shrimp profit

(Figure 51) and the total amount of shrimp supply is quite close to that of a low stock density practice.

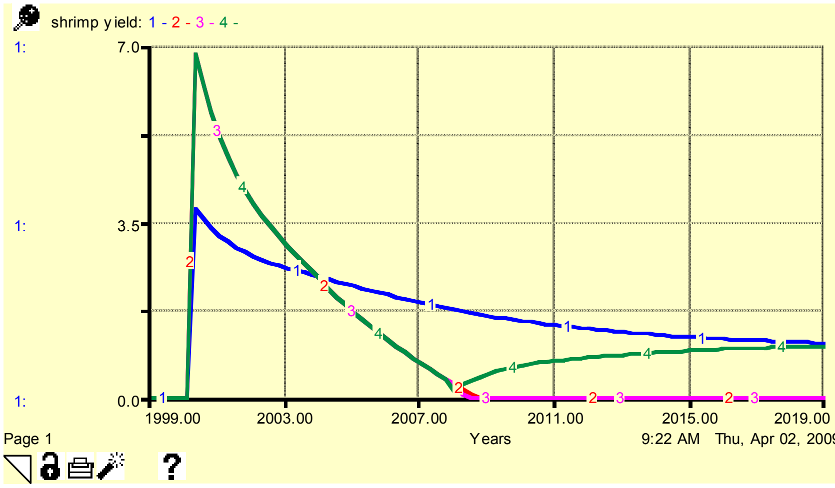


Figure 49: Graph of shrimp yield in treatment pond introduction test

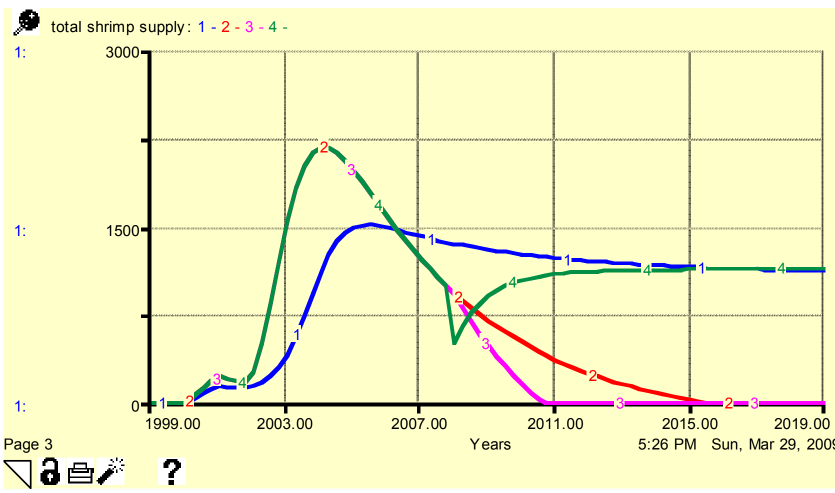


Figure 50: Graph of shrimp supply in treatment pond introduction test

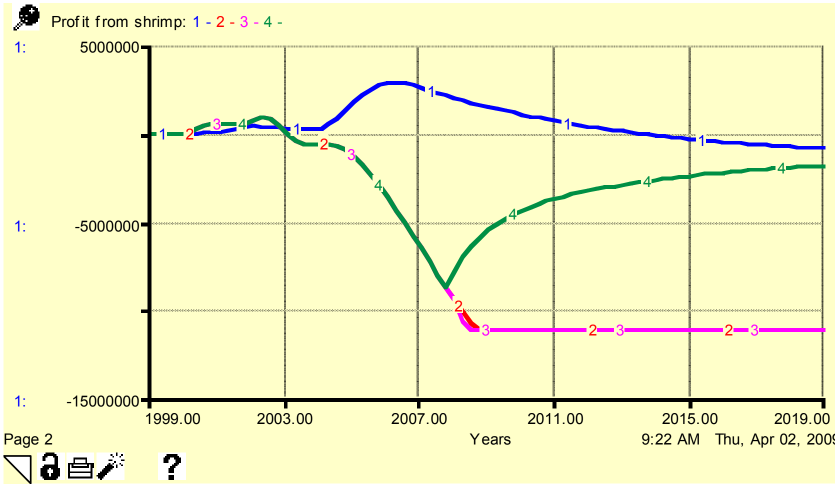


Figure 51: Graph of shrimp profit in treatment pond introduction test

Comparing this policy test with the previous one, the former is more profitable but also more costly and time consuming. From all the tests, it is obvious that lowering stock density is beneficial but this method alone only slightly improves the yield. The reason is that nitrogen has already accumulated substantially in the environment from the early years and lowering the stock is one way to reduce the incoming pollution load. The method per se does not help reduce the existing pollution. Alternatively, if farmers practiced low density stocking from the beginning, their business would be sustained for 20 years. This is to say the investment in shrimp is not only about farming technique or capital mobilization but also about long term planning. As long as people consider the shrimp industry a highly profitable business but a costly business, we will still have unsustainable shrimp farming. The inevitable consequence is that farmers are trapped in the spiral of debt.

CHAPTER EIGHT

FURTHER WORK AND CONCLUSION

8.1 Further work

There are opportunities to discuss some interesting issues in the future version of the model such as the relationship between monopsony market and externalities, and the application of taxing in regulating farmers' practice. With the monopsony power, buyers purchase a smaller quantity compared to that of a competitive market. This quantity shifts toward the quantity of a market where externalities are partially accounted for shrimp price. This is to say monopsony structure in the presence of externalities can reduce the deadweight loss. In addition, based on the results of this model, the government might want to impose a low stock density use. This could be done in several ways and taxing on fry is a promising approach. Theoretically, this tax should be equal to the marginal value of externalities so that externalities are internalized in shrimp farming. In reality, the success of such policy depends on many factors and the answer can only be found in future research.

8.2 Summary and conclusion

The model built for the case of Dai Hoa Loc Commune has shed light on the economic incentive for local farmers to shift from rice to shrimp farming which has led to dynamic land use change in the last 10 years. In addition, modeling the interaction of shrimp farming and the environment also reveals the risky nature of the shrimp industry. Although farmers are very careful in taking training courses and observing the number of bad years before deciding to change, high profit is only obtained in the first few years. When there is a major decline in shrimp yield due to the cumulative impact of nutrient pollution in the system, most people fall into the spiral of debt. The serious problem here is that the higher stock density used at the beginning, the shorter time the system lasts. Another issue is that converting back from shrimp to rice is difficult and considered to be impractical. Once the move to shrimp is made, they are trapped in this business forever.

In order to improve the system, two policies were tested. Results show that a combination of lowering the stock density from 40 to 25 fry/m^2 and introducing treatment ponds helps sustain the business within the horizon. A better approach is to improve the channel system in addition to lowering the stock density. This strategy shows that the system can become sustainable with high profits and the investment in infrastructure development is worthwhile.

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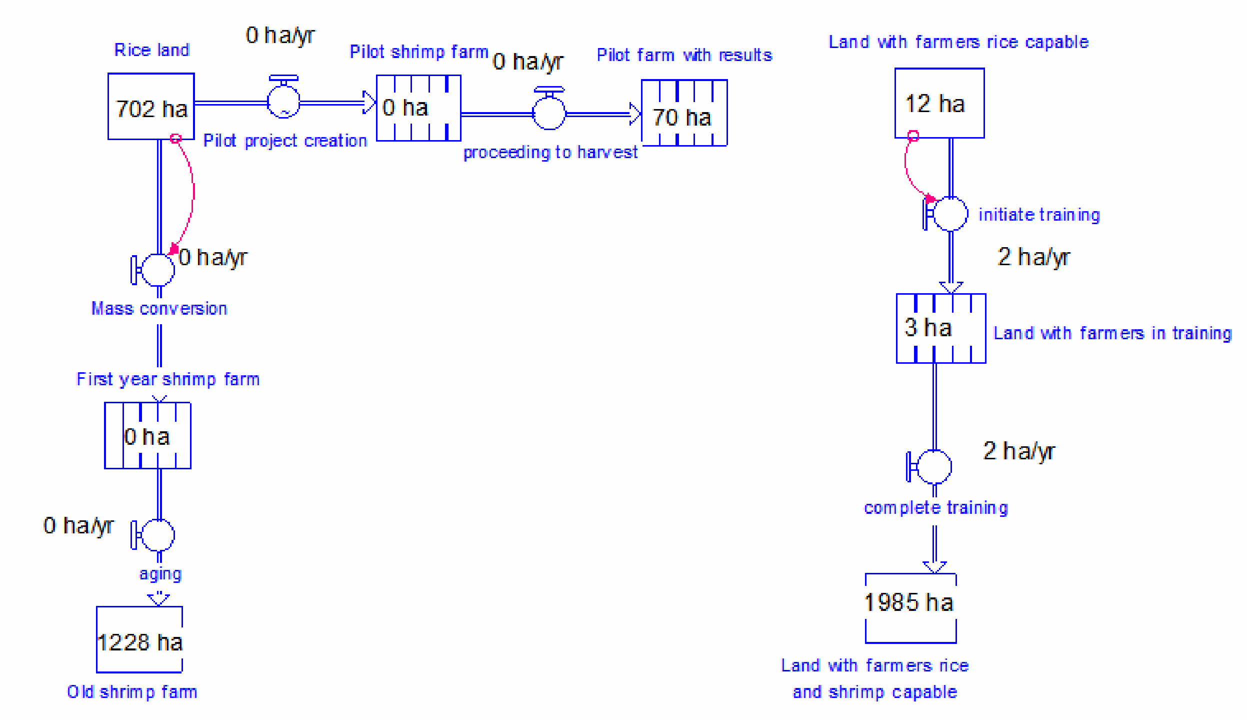
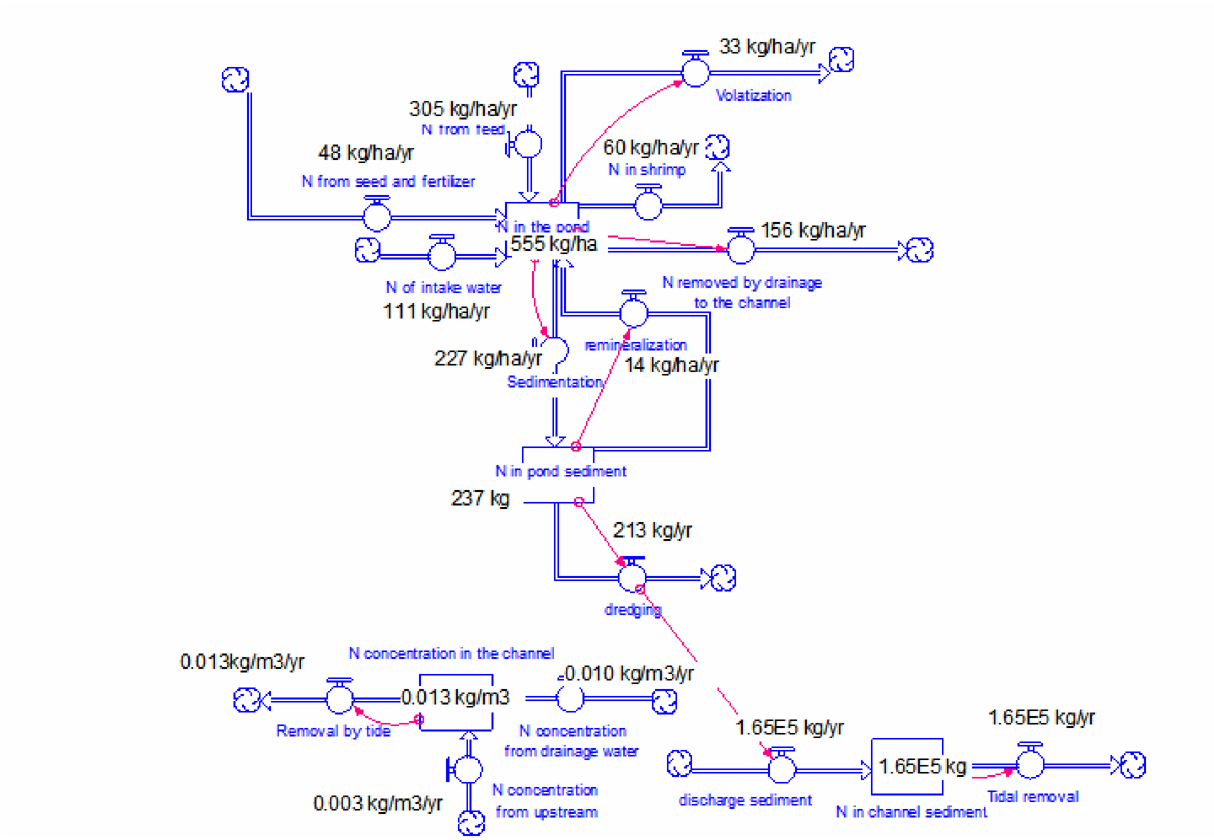
APPENDICES

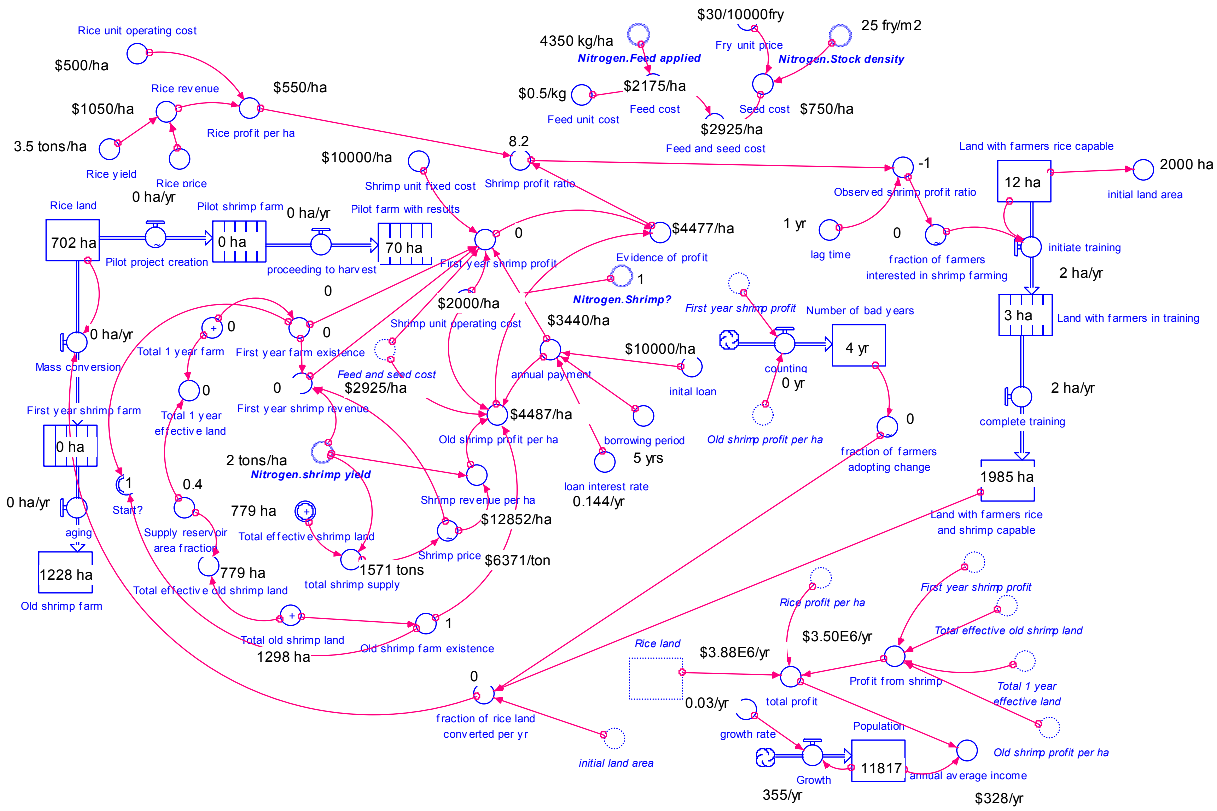
Appendix 1: Stock and flow equilibrium diagram of the Shrimp land module for the base case of 25 fry/m^2



Appendix 2: Stock and flow equilibrium diagram of the Nitrogen module for the base case of 25 fry/m^2



Appendix 3: Full equilibrium diagram of the Shrimp land module for the base case of 25 fry/m²



Appendix 4: Full equilibrium diagram of the Nitrogen module for the base case of 25 fry/m²