Sustainability of Intensive Shrimp Farming: A Case Study in Ninh Thuan, Vietnam

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Abstract

Intensive shrimp farming is known to be a high risk activity and polluting both to water and land. The high investments into intensive shrimp farming may prove to be unwise as the ponds are prone to self contamination within just a few years. This study takes the context of the Ninh Thuan, ranked as one of the poorest regions in Vietnam. Since 1999, locals have turned to intensive shrimp farming as a way to improve their financial situation, but the question of intensive shrimp farming being able to alleviate poverty remains unanswered. This study takes a systems analysis approach due to the interdisciplinary character of the problem. It combines the environmental, economic and social aspects of intensive shrimp farming for a balanced, dynamic analysis. Causal loop diagrams were constructed and translated into a model. The causal loop diagrams were based on literature review, interviews and data collection from non-governmental organizations, institutions, local farmers, officials and residents. With the model of the current scenario, different solutions and scenarios were tested. This study aims to prove that the current practice of intensive shrimp farming is not sustainable for the Ninh Thuan region and that lower stocking densities, pond cleaning and limiting the number of shrimp ponds in addition to capacity building and community cohesiveness will be beneficial for the locals in the long run.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BAU	Business As Usual
CLD	Causal Loop Diagram
Clean20	Scenario of cleaning at 20% efficiency
Clean40	Scenario of cleaning at 40% efficiency
Combine	Scenario of combining lowering the stocking density to 15 shrimps/m^2 and cleaning at 40% efficiency
CRP	Centre for Rural Progress
DANIDA	Danish International Development Agency
DPSIR	Drivers-Pressures-State-Impacts-Response
FAO	Food and Agriculture Organisation of the United Nations
GDP	Gross Domestic Product
NERI	National Environmental Research Institute
NGOs	Non-Governmental Organizations
RBP	Reference Behaviour Pattern
SD15	Scenario of lowering the stocking density to 15 shrimps/m^2
UNDP	United Nations Development Programme

1. Introduction

In 1986, Vietnam implemented Doi Moi, after years of economic hardship, which was a sign that the planned economy was not the way to prosperity. Doi Moi brought the shift to a market economy, and since, Vietnam has seen tremendous economic growth. Gross domestic product (GDP) per capita has increased from US$97 in 1986 (United Nations Statistics Division, 2003) to US$485 in 2003 (United Nations Development Programme, 2004). Agriculture, which includes the fisheries sector, makes up one fifth of the GDP (UNDP, 2004). With such a reliance on natural resources for economic growth, there is reason to worry if current trends are sustainable to ensure long term prosperity and well being of the Vietnamese people.

One aspect of the fisheries sector is shrimp aquaculture. Shrimp aquaculture brings with it the social and economic benefits of rural employment, but it has damaging effects that may take time to surface. Experiences in other shrimp producing countries have shown that shrimp farming is likely to cause pollution to water and land. There are three main negative effects on the environment. Firstly, effluent discharge from the farms causes eutrophication (Patil, Annachhatrea & Tripathi, 2002). Secondly, soil on which shrimp ponds are situated on becomes polluted due to the sediments accumulated during the farming period. Pond lands have high concentrations of salt and cannot be used for cultivation (Patila et al., 2002). Thirdly, salt water leaches from the pond to contaminate the groundwater beneath (Páez-Osuna, 2001).

There are signs that shrimp farming have exceeded the sustainable limit in Ninh Thuan. Groundwater levels in Vinh Truong village have dropped; the water has turned saline and is unfit for household use. Shrimp farmers have to build ponds to collect rainwater and pipes to channel freshwater from the mountains to ensure that there is enough water to run their business.

1.1 Shrimp faming in Vietnam and Ninh Thuan

The popularity of shrimp farming in Vietnam was catalysed by the impact the Doi Moi reforms in 1980s had on the fisheries sector (Ministry of Fisheries, 2004c). Since Doi Moi, fisheries exports have increased (Ministry of Fisheries, 2004a) and national aquaculture development programs have spurred the growth of aquaculture (Ministry of Fisheries, 2004b). Export targets of 2 million tonnes by 2010 have been set (Ministry of Fisheries, 2004b). In 1990, aquaculture export levels were 310 000 tonnes and by 2002 it was 976 000 tonnes (Ministry of Fisheries, 2004a). Shrimps fetch a higher selling price compared to other agricultural crops commonly grown in Vietnam. For example in 2002, frozen shrimps fetched US$5940 per ton (Food and Agriculture Organisation, 2004a) whereas rice fetched US$188 per ton (FAO, 2004b).

The lack of alternative livelihoods in the rural regions, together with the abundance of cheap unused land, free water, cheap labour and favourable climate were the ideal conditions for shrimp farming to expand. Shrimp farms are now found in mangrove, coastal and inland areas. The farms have varying characteristics, ranging from extensive, semi intensive to intensive and can be state owned enterprises or private investments. The northern regions, for example Cat Ba and Hai Phong, have mainly semi-intensive and extensive types of shrimp farming. Intensive shrimp farming can be found in the south central coastal regions. In the Mekong region, a combination of rice and shrimp farming is common.

1.2 Geographical, Social, Economic and Environmental background

The Ninh Thuan is a coastal province in south central Vietnam and its capital is Phan Rang. Please refer to Figure 1.1. The province is divided into different communes and within the communes there are villages. Ninh Thuan has an area of 3352.27 km2, 105km of coastline and annual rainfall of 600mm which mainly comes in the monsoon months between October and November (Centre for Rural Progress(CRP) and World Bank, 2003). The year round warm temperatures makes it possible to have 3 growing seasons of shrimp. The variety that is commonly cultivated is the *Peneaus monondon*, widely known as Black Tiger shrimp

Shrimp ponds are built on sandy soil near the coast. Other land uses are rice and grape cultivation and sheep rearing. The population of Ninh Thuan in 2002 was 539 000 and main the livelihood options is to work in farms, and more recently, as shrimp farm owners or labourers (CRP and World Bank, 2003). Shrimp farms were estimated to cover a land area of 320 hectares in 2003 (CRP and World Bank, 2003). 96 out of 250 shrimp farmers in were locals (CRP and World Bank, 2003). Ninh Thuan is one of the poorest region in Vietnam (CRP and World Bank, 2003), but there is expectation that shrimp farming will bring prosperity. Local social economic targets have been set and displayed on a local announcement board. Please refer to Figure 1.2. The translated information is shown in Table 1. Ninh Thuan aims to have an annual average economic growth rate between 9.5% and 10%, and to produce 20 000 tons of seafood annually.

According to the report written by CRP and the World Bank (2003), the environmental problems of Ninh Thuan include the lack of garbage disposal facilities and water pollution in 2002 by a factory that poisoning the locals and their livestock. There is also negligible application of environmental legislation or tax.

1.3 Aim and Scope of thesis

The aim of this thesis is to investigate if current practices of shrimp farming in Ninh Thuan are sustainable and serve to alleviate poverty. This study will not include the entire supply chain of shrimp production. The systems boundaries have been set in Ninh Thuan, and at the shrimp farm level that is illustrated by two causal loop diagrams (CLDs) in Figure 3.10. Using a systems dynamics approach, the CLDs were translated into a model to simulate the interactions between sedimentation, groundwater usage and the rise in the number of the shrimp farms. Different solutions had been tested on the model. The results show that the lowering of stocking densities and the cleaning of ponds are not effective in the long run as groundwater resource will still be exhausted. Analysis of the results indicates the need to control the number of ponds in an area and various methods to exercise this control are discussed.

Key:
Boundary of Vietnam
Hanoi
Ho Chi Minh City
Ninh Thuan

Figure 1.1: Map of Vietnam showing the different provinces.

Figure 1.2: Picture of an announcement board in Ninh Thuan showing socio-economic targets. (Picture by Mats G E Svensson, Ninh Thuan, November 11, 2003)

Table 1: Translated contents of announcement board.

Number	Item	Target
1.	Annual average economic growth rate	9.5-10%
2.	Agricultural, forestry and fishery output growth	4.9%
3.	Craft and industrial output growth	17.9%
4.	Growth of trade and services	8.8%
5.	Budget revenue	VND10 billion/year
6.	Food output	65000-70000 tonnes/year
7.	Seafood products	20000 tonnes/year
8.	Forestry plant	2600 hectares
9.	Proportion of households in poverty and hunger	5%
10.	Proportion of children completing lower secondary school	80%
11.	Child malnutrition rate	Lower than 25%
12.	Natural population growth	1.4%
13.	Proportion of cultural households	70-80%

2. Methodology

The approach of using causal loop diagrams and systems analysis was due to the interdisciplinary and dynamic nature of the problem. This study was conducted in several steps, with iteration within and between the steps. The steps are similar to the recommendations made by Luna-Reyes and Anderson (2003) and Vennix (1996).

2.1 Problem Identification and Model Purpose

As described in the introduction section, the hypothesis is that the business of intensive shrimp farming with the current technology and management practices will not alleviate poverty in Ninh Thuan. The purpose of building the model is to prove that this hypothesis is true, after which different solutions would be tested on the model to guide the policy analysis.

2.2 Model Formulation

2.2.1 Causal Loop Diagram

After the preliminary round of literature review, four CLDs were drawn. They include intensive shrimp farming at the household, municipal, national and international levels. The CLDs gave a very clear indication on the qualitative and quantitative inputs required by the model. This step had much iteration, especially after the field work, modelling and the testing of the validity of the model.

2.2.2 Questionnaire Design and Preparation for Interviews

The questionnaires were based mainly on the CLD at the household level. It aimed to verify the cause and effect relationships in the causal loop, and to identify other cause and effect relationships that were not found in the literature review and are specific to Ninh Thuan. Questions regarding other qualitative and quantitative inputs were included. Three questionnaires were designed for a semi-structured style of interview. The first was for shrimp farmers, the second for local officials and residents and the third for aquaculture experts. The semi-structured style was chosen as it focuses the discussion on the range of topics of interest to the researcher, but allows the interviewee to relate other qualitative information that may shed light on the cause and effect relationships of intensive shrimp farming. At this stage, it was also important to brainstorm the possible problems that may occur during the interviews and to take necessary precautions.

2.2.3 Preparation for Field Work

Field work, including site visits, data collection, translation and interviews, was arranged with the help of a local non-governmental organization, CRP and the Institute of Economics in Hanoi, Vietnam. They also provided access to reports written by Danish International Development Agency (DANIDA) and other information on Ninh Thuan.

2.3.4 Field Work

In addition to the collection of written material by different international aid agencies on shrimp farming in Hanoi, a site visit and trial interview was possible in Do Son, Hai Phong. This was an opportunity to build a good working relationship between the researcher and the translator, and to check if the questions were translated correctly during the interviews and to gauge the response from the Vietnamese. Due to the cultural and language differences between the researcher and the interviewees, this practice session was essential, so as to avoid mistakes in Ninh Thuan. Slight modifications to the questionnaire were made after this trial.

Other interviews were made with Vietnamese scientists and social scientists that have experience in aquaculture.

At Ninh Thuan, interviews were conducted at three villages: An Hai, Vinh Truong and Phuoc Dinh. Eleven intensive shrimp farmers, two local officials, two local residents and the project officer from the local branch of CRP were interviewed.

Interviews were not recorded on tape, but through pen and paper, as it would intimidate the interviewees and affect their response.

2.3.5 Modelling

After many refinements to the household CLD, it was translated into a computer model. Quantitative data which were required in the model and could not be obtained from the field work were assumed based on literature review. A model was first developed based on the "Business As Usual" (BAU) scenario and its results checked against the reference behaviour pattern (RBP) of the causal loop diagram. Modifications to the CLDs were made to ensure consistency between the model and the causal loops. At this point, the BAU could be used to test different solutions and scenarios.

2.4 Testing the Validity of the Model

The validity of the model was tested through a presentation of the model and its solutions to an audience consisting of Vietnamese and non-Vietnamese scientists and social-scientists that have experience in aquaculture and are familiar with the context of this study. Their criticisms and suggestions have been taken into account and modifications of the causal loops, model and solutions have been made.

2.5 Results and Analysis

In these sections, the results of the BAU model and solutions are analysed. Although the BAU model and solutions are based on the municipal-household level, the discussion of solutions at the national and international level will also be included, following the structure of a Drivers-Pressures-State-Impacts-Response (DPSIR) framework (NERI, 1995).

2.6 Recommendations and Conclusion

The thesis concludes with recommendations for the model and to the shrimp farming sector and policy makers that will guide the sustainable development of shrimp farming for poverty alleviation.

3. Modelling

3.1 Causal Loop Diagrams

This section will describe how the model is formulated through the use of CLDs. In order to have an orderly systems perspective, the problem was divided along the lines of the international and national level, national and municipal level, municipal level and the physical level. Each level is connected to the previous level by a relationship (denoted by an arrow or a variable), and contains both scientific and social-science variables. This hierarchy is illustrated in Figure 3.1. The connections have been highlighted in the diagrams below. This approach enables the identification of the driving and balancing forces at each level, and provides a clue to the solution.

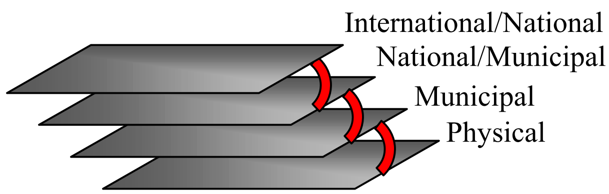


Figure 3.1: Hierarchy of CLDs

3.1.1 International and National level

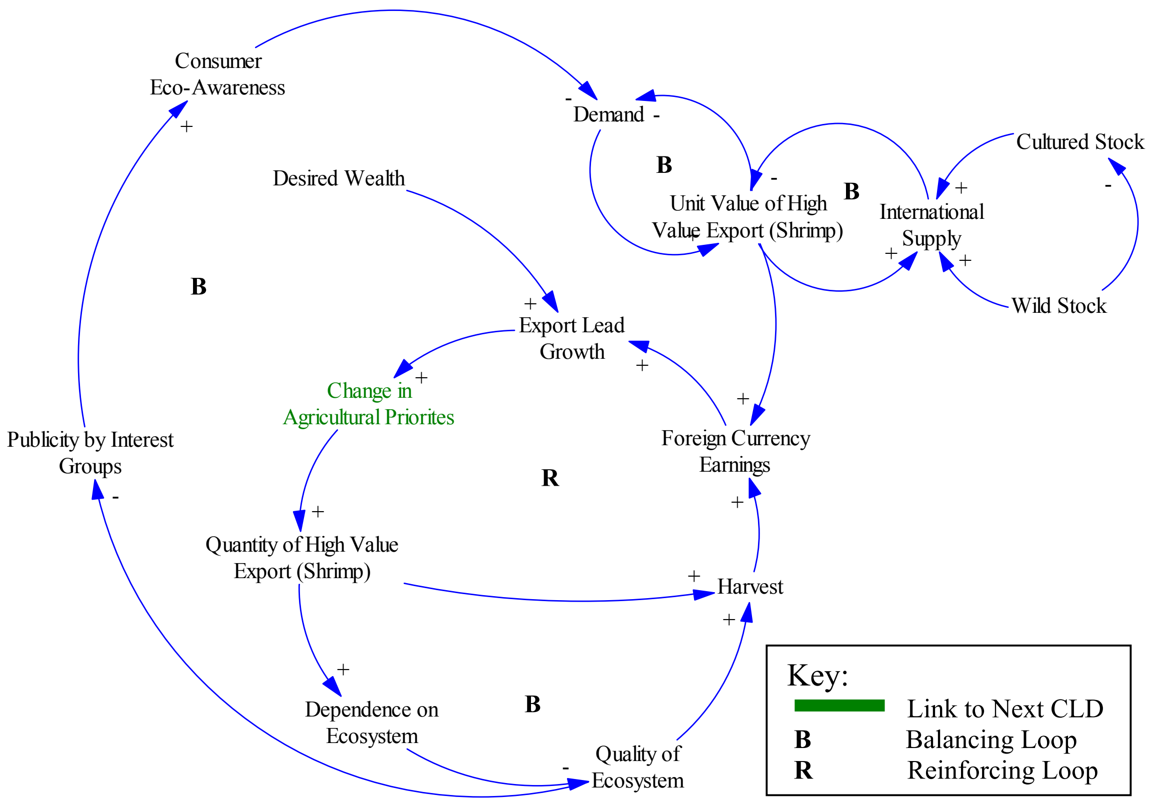


Figure 3.2: CLD for the International and National Level

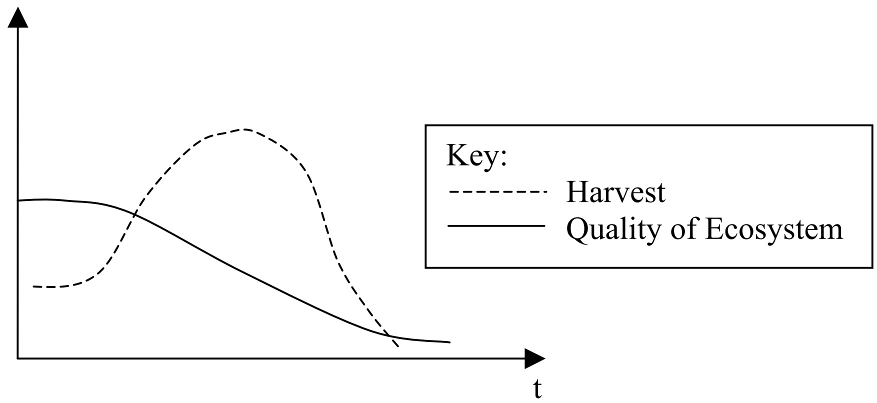


Figure 3.3: Reference Behavior Pattern for the International and National Level

Starting with the desire to create wealth, there is evidence that "Doi Moi" has encouraged export led growth in the fisheries sector. Doi Moi started in the 1980s and from then onwards fishery exports increased tremendously (Ministry of Fisheries, 2004c). In addition, it has been suggested by Flaherty and Vandergeest (1999) that an extended phase of financial difficulty may increase the probability that the government will encourage exports of cash crops to earn foreign currency. This may well be the case of shrimp farming in Vietnam, in the 1980s. Danish Fisheries Consultants (1997), Páez-Osuna (2001), Neiland, Soley, Varley and Whitmarsh (2001) have also echoed that foreign exchange earnings is a major driver at the national level for shrimp aquaculture. In the next step, export led growth gives rise to changes in the original agricultural aims: from subsistence farming to cash crop farming. Aquaculture area and production has increased (Ministry of Fisheries, 2004a). Shrimp exports have followed the same upward trend (Ministry of Fisheries, 2004a). This increase in shrimp production has a positive correlation to the dependence on the ecosystem as more inputs, including land and water are required. Discharges from the farms will affect the quality of the inputs and ultimately the production level. Once the carrying capacity of the environment is reached, a decrease in harvest is very likely. At the initial stages, the high levels of harvest would help to reinforce the idea that export led growth of the shrimp farming industry is a good method to increase wealth.

Vietnam is a price taker for shrimp in the world market (Danish Fisheries Consultants, 1997) and has little leverage in this aspect. Thus, its foreign currency earning in this sector will be affected by international demand and supply. Here, the basic economic theory of supply and demand applies: more demand leads to higher prices, higher prices leads to less demand, more supply leads to lower prices and lower prices leads to more demand. There are two forms of supply: wild stock and cultured stock. The falling supply of wild stock has been a major reason for the increase in production of cultured stock (Moberg and Rönnbäck, 2003; Burford et al., 2003).

In the context of the burgeoning interest in environmental and sustainability issues, consumer preference for eco-friendly products will affect the demand for shrimp. The deterioration of the quality of the ecosystem by anthropogenic causes attracts the attention of various interest groups, for example, non-governmental organizations (NGOs). These interest groups publicize such information and generate awareness to the general public. One such example was a documentary on ecological shrimp farming by Weidenbach (2002). Through this mechanism, public purchasing behavior is influenced.

3.1.2 National and Municipal level

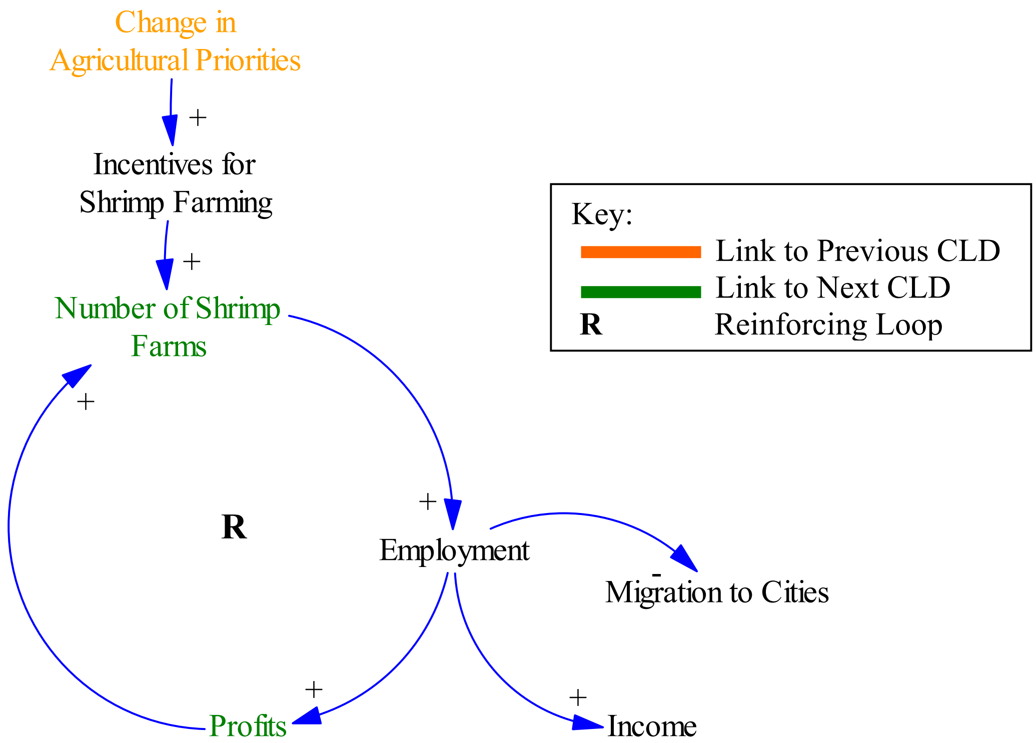


Figure 3.4: CLD for the National and Municipal Level

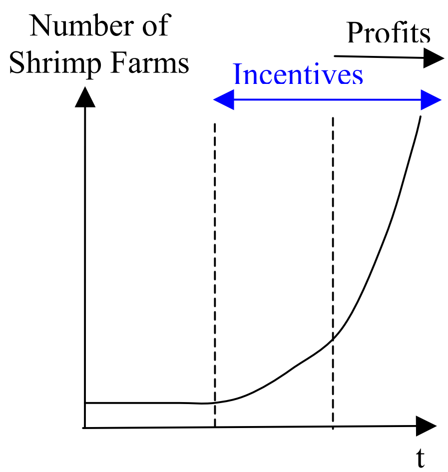


Figure 3.5: Reference Behavior Pattern for the National and Municipal Level

The change in agricultural priorities is manifested in the different targets and incentives for shrimp farming. Aquaculture targets at the national level from 1999-2010 aims to reach a total volume of 2 million tonnes and total export value of US$2.5 billion (Ministry of Fisheries, 2004b). In Ninh Thuan, the agricultural forestry and fishery output growth is targeted at 4.9% and the level of seafood produce at 20000 tonnes per year, for the time between 2000 and 2005 (Figure 1.2). Some examples of incentives that drive the increase in shrimp farms at the national level are the allotment of land, research and information dissemination on farming techniques and providing good quality seed supply (Danish Fisheries Consultants, 1997). Shrimp farming is encouraged in Ninh Thuan through general word of mouth and communication on the profitability and advice on farming techniques from the municipal officers (who may be shrimp farmers themselves), and the allotment of municipal land specifically for shrimp farming (Mai, D.K., personal communication, August 20, 2004; Ngo, V.N., personal communication, August 20, 2004). According to a survey made by CRP and the World Bank (2003), shrimp farming started in Ninh Thuan in 1999 and by 2003 there were 250 shrimp farm owners. This is an indication that more people are turning to shrimp farming as a means of livelihood. Furthermore, examples of successful shrimp farms serve as a motivation for others to start new shrimp farms or to intensify their farms.

The business of shrimp farming creates employment, as labour is required along the whole supply chain (Neiland et al., 2001). Examples of the forward and backward sectors include: production of shrimp seed, pond digging, daily maintenance, cleaning and processing. As the location of shrimp farms are mostly rural, an increase in local employment opportunities in these areas (Huitric, Folke & Kautsky, 2002) will reduce the number of people moving into the cities to look for jobs (Tran, V.N., personal communication, August 6, 2004). This also has the added benefit of raising the average income of the rural poor (Danish Fisheries Consultants, 1997; Neiland et al.).

3.1.3 Municipal level

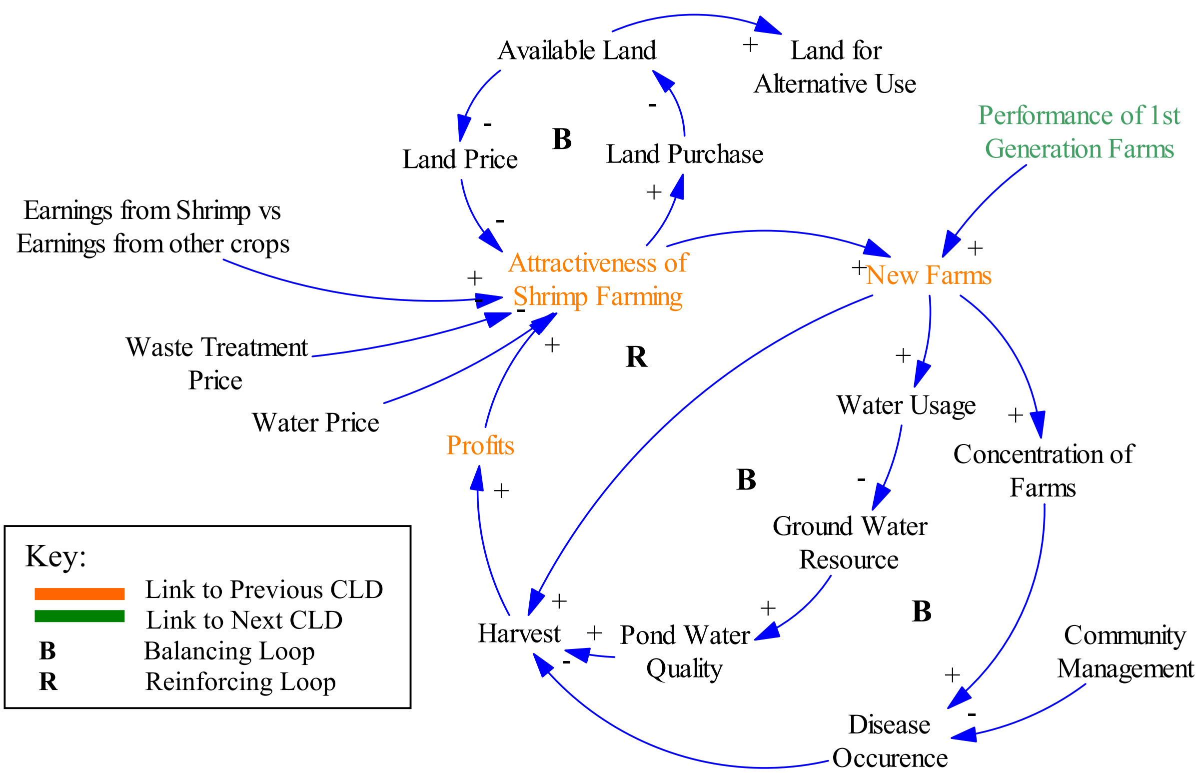


Figure 3.6: CLD for the Municipal Level

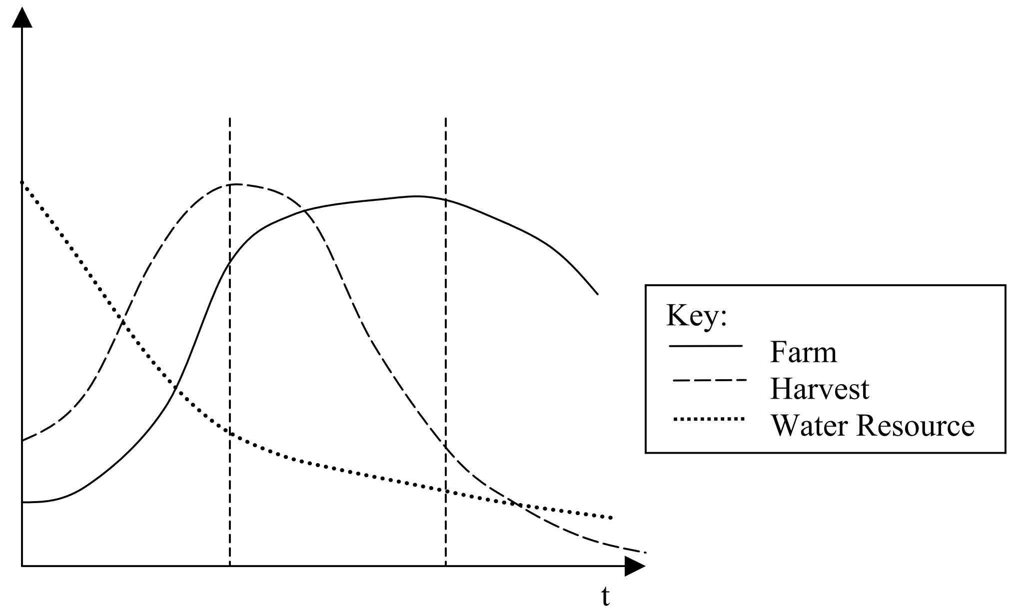


Figure 3.7: Reference Behavior Pattern for the Municipal Level

Profitability is the major driving force that determines the expansion of the shrimp farming sector (de Graaf and Xuan, 1998). Other factors include the relative profitability of shrimps to other crops (Flaherty and Vandergeest, 1999), "lack of regulations, cheap land, free water, incomplete implementation of existing regulations, and low sanctions" (Huitric et al., 2002). The site visit to Ninh Thuan revealed similar findings.

With more new farms in an area, there is a higher probability of disease occurrence and poor community management that will ultimately affect harvest and profits negatively (Shang, Leung & Ling, 1998). In addition to diseases, the amount of water resources has definitely been a limiting factor, especially in the Vinh Truong village in Ninh Thuan, where freshwater supplies have been contaminated and exhausted due to the large amounts used by the shrimp farms (CRP and World Bank, 2003). With freshwater supplies contaminated or exhausted, pond water quality will inevitably decrease. It would be very difficult to maintain appropriate levels of salinity and other water quality parameters without clean fresh water. If the conditions for shrimps to mature are not present, there will be little to harvest and profits will decrease.

The attractiveness of shrimp farming will lead to an increase in land purchase to construct ponds. This decreases the available land for other purposes. The demand for land will drive the price of the land upwards, making it more expensive and consequently less attractive to buy. It may come to a point that the land is too expensive and starting a shrimp pond is not as lucrative as it once was. There is evidence from interviews with the shrimp farmers in Ninh Thuan that land prices have increased and few have plans to expand their farms.

The performance of first generation farms plays an important role as it affects the number of new farms in such a way that as long as they perform well, they will attract others to invest in new farms. If otherwise, others will be more wary and less people may choose to invest.

3.1.3 Physical System

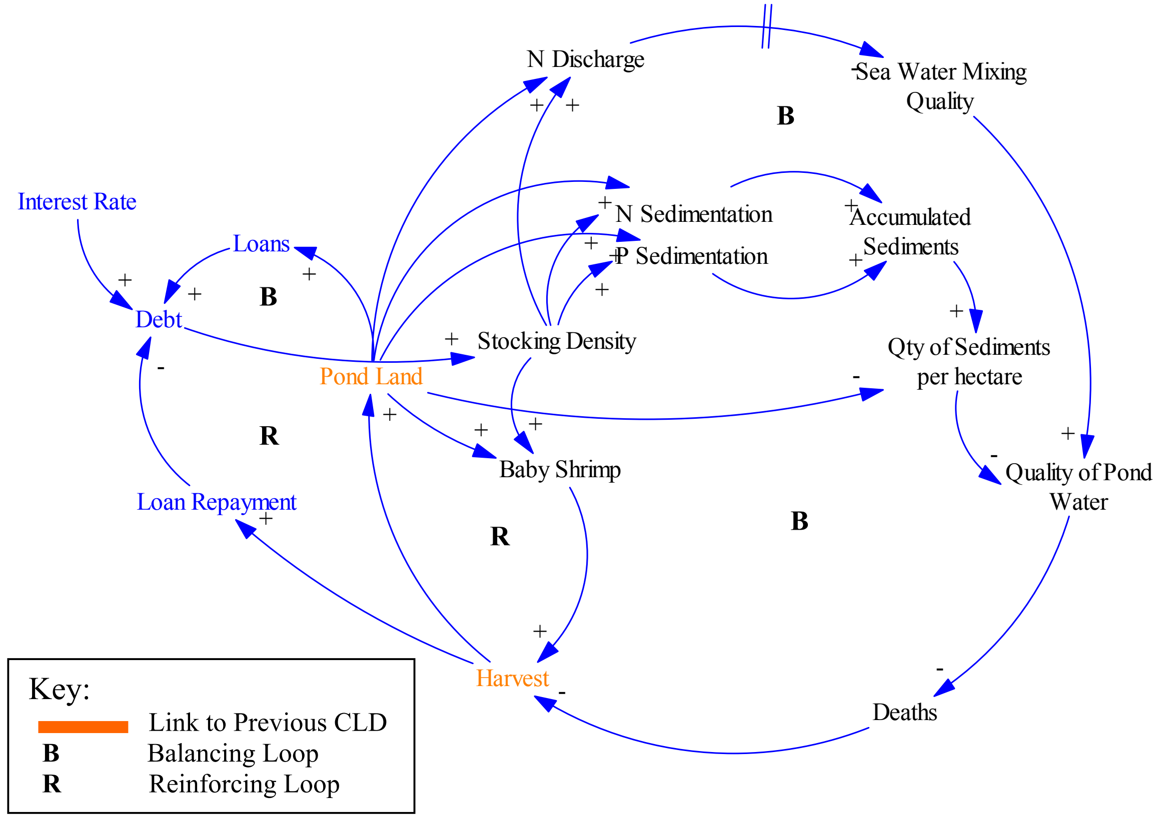


Figure 3.8: CLD for the Physical System

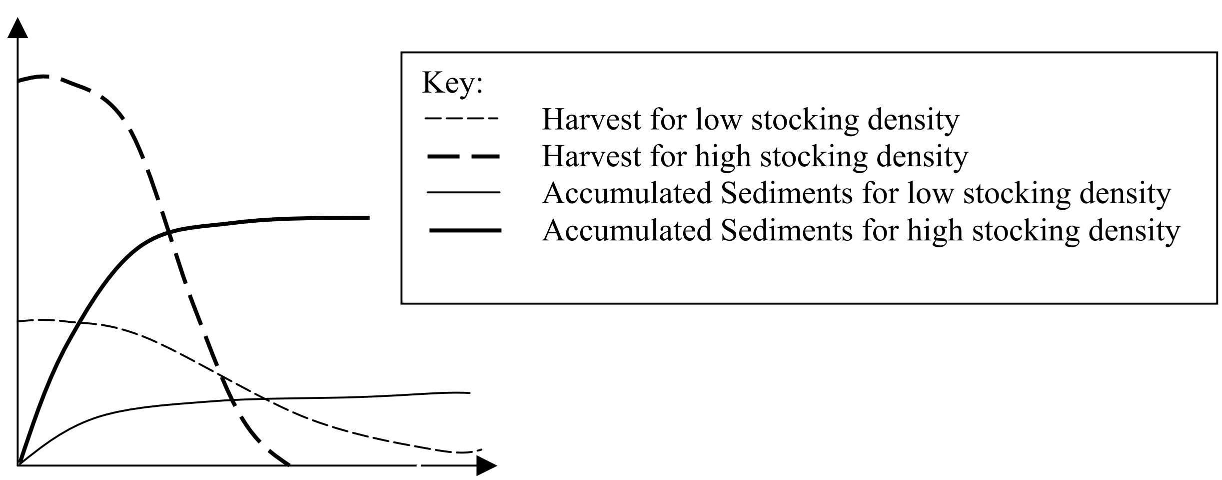


Figure 3.9: Reference Behavior Pattern for the Physical System

As mentioned previously, more harvest will lead to more profits and this will attract more investment and more land will be converted to shrimp ponds. Sedimentation is a process that will occur in shrimp ponds. They are mainly Nitrogen and Phosphorus compounds from shrimp feed (Hargreaves, 1998; Xie, Ding & Wang, 2004; Burford and Willliams, 2001; Funge-Smith and Briggs, 1998). Without proper feeding management and pond cleaning, the quantity of sediments per area will increase (Cripps and Bergheim, 2000; Funge-Smith and Briggs, 1998) adversely affecting the quality of the pond water and will lead to more shrimp deaths and less harvest (Cripps and Bergheim, 2000; Cowan, Lorenzen & Funge-Smith, 1999).

The quality of pond water is also affected by the input of seawater. In Ninh Thuan, the effluent is discharge directly into the sea. Depending on mixing, timing of discharge from other ponds, the availability of separate inlet and outlet drains and other factors the seawater input is likely to be contaminated, thus negatively affecting the quality of the pond water(Shang et al., 1998; Graaf and Xuan, 1998; Patil et al., 2002). Similar evidence was obtained in the interviews with shrimp farmers.

Another point of interest is the economic drivers at the household level of shrimp farming. The variables in this section is coloured in blue in Figure 3.8. The seemingly lucrative business of shrimp farming requires high initial investment. Most farmers would take a loan from friends or informal loan institutions. The more they loan, the more they are in debt. This debt is also determined by the interest rate. High interest rates would drive farmers to return the debt as soon as possible, and in order to do so they would try to stock as many shrimps as they can in order to profit from more harvest for debt repayment.

3.2 From CLD to model - Business As Usual scenario

Using the CLDs of the Municipal level and the Physical level, salient variables and relationships have been selected to be modeled. Please refer to the Appendix for the model. The system boundaries of the model are demarcated on the corresponding causal loop diagrams by a red dashed line in Figure 3.10. The parameters outside the system boundaries will be discussed qualitatively.

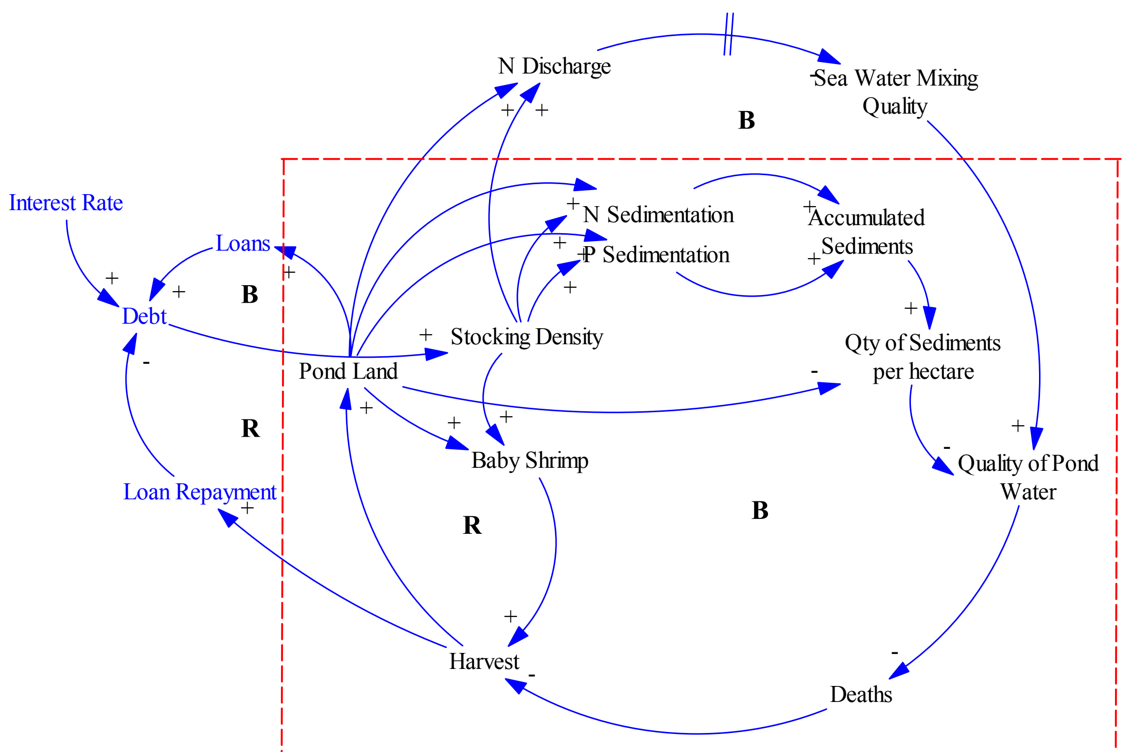


Figure 3.10a: System boundaries of the STELLA Model

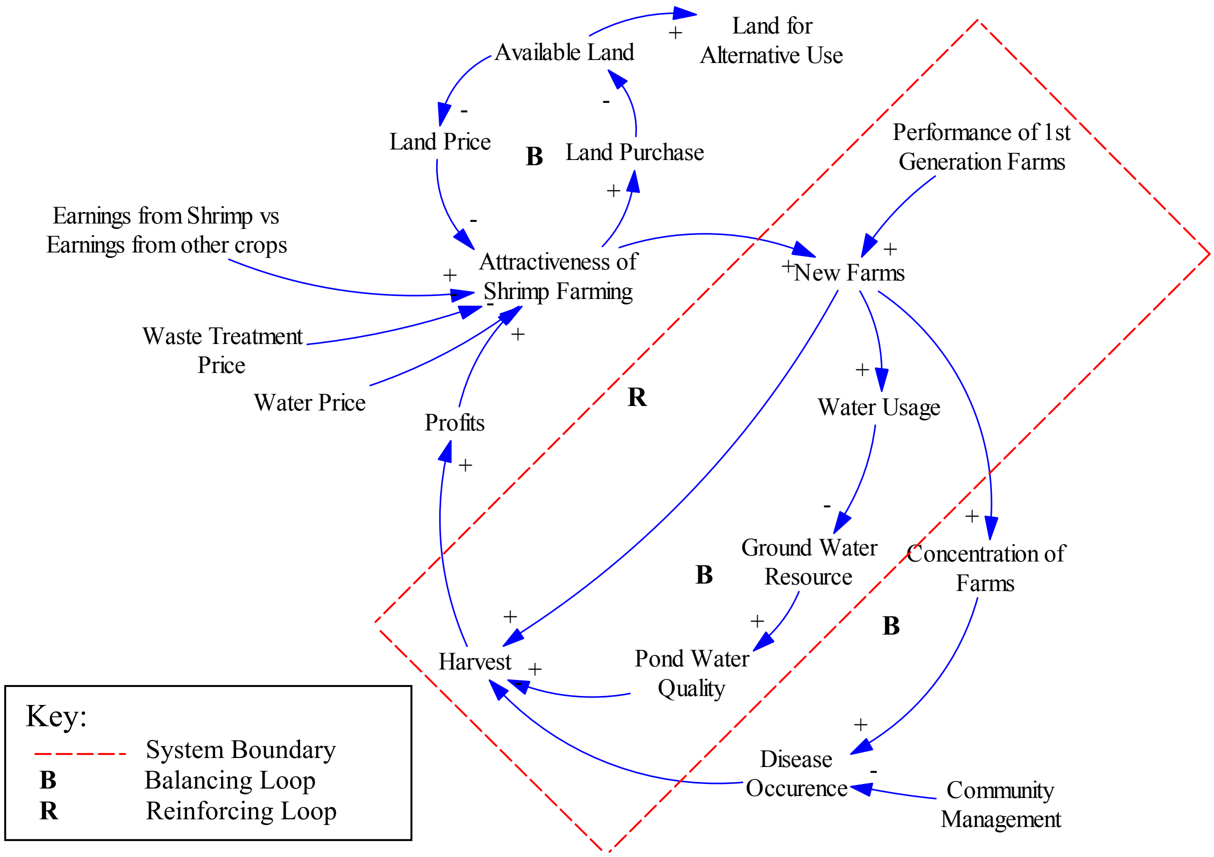


Figure 3.10b: System boundaries of the STELLA Model

3.2.1 Inputs and Assumptions

The inputs and assumptions made in the model have been derived from different guidelines from different sources. Where possible, inputs from local sources were used to ensure validity of the model.

Table 3.1a: Summary of the assumed values in the BAU scenario

Variable	Guideline	Source	Assumed Value in BAU
Pond Land	Shrimp Farming starts in 1999 and by 2003 there were 320 ha of shrimp ponds.	CRP and World Bank, 2003	The variable "New Pond Land vs Harvest 1" is adjusted such that the pond land increases from 0 to 320 hectares in 4 years. Initial pond land value is estimated at 50 ha.

Table 3.1b: Summary of the assumed values in the BAU scenario

Variable	Guideline	Source	Assumed Value in BAU
Stocking Density	20-30 Shrimps/m^2 giving a harvest of 4-6 tonnes/ha/crop	Boyd, 1998	40 Shrimp/m^2
	Open system ponds 60-100 Shrimps/m^2	Funge-Smith, 1996	
	29.9-115.1 Shrimps/m^2	ADB/NACA, 1996	
	15-50 Shrimps/m^2	Interviews with shrimp farmers	
N Sedimentation	17-58g N/kg shrimp (Smith, 1995)	Hargreaves, 1998	Feed is assumed to be the main source of N. Thus 24% of the N in the feed is used as the value for the amount of N sedimentation. The amount of feed used per hectare per crop is estimated by CRP & World Bank (2003) to be at 15 tons.
	No more than 70% to 75% of the N & P as not assimilated by the shrimps.	Boyd, 2003	
	Inorganic N found at 1.5mg per litre of sedimentation.	Xie et al., 2004	
	27% of N is discharged 24% were in the form of sediments. There is 70.8g of N (dry weight) in 1 kg of feed.	Funge-Smith & Briggs, 1998	
P Sedimentation	Inorganic P found at 0.024mg per litre of sedimentation.	Xie et al., 2004	Feed is assumed to be the main source of P sedimentation. Thus 26% of the P in the feed is used as the value for the amount of P sedimentation. The amount of feed used per hectare per crop is estimated by CRP & World Bank (2003) to be at 15 tons.
	No more than 25% to 30% of the N & P applied to ponds as fertilizers and feeds is recovered at harvest.	Boyd, 2003	
	Applied feed contributes to 51% of P in the system. 26% of the input P was assumed to be the eroded pond bottom. 10% of P was in the effluent water. There is 13.4g of P (dry weight) in 1 kg of feed.	Funge-Smith & Briggs, 1998	

Table 3.1c: Summary of the assumed values in the BAU scenario

Variable	Guideline	Source	Assumed Value in BAU
Rainfall	Total Area of Ninh Thuan: 3352.27 km^2 Average Rainfall: 600 mm per annum.	CRP and World Bank, 2003	2% of the rainfall is assumed to be collected as ground water resource. As rain mainly falls in the monsoon months and in a destructive manner there is more runoff than percolation.
Ground Water Resource			The starting value of ground water is estimated at 100000000m^3 such that it will not run out before 5 years, which is more than 7 times the annual rainfall input. Most villages are not at the stage of shortage, and the only example of shortage is in Vinh Truong.
Ground Water Usage	10-40% of pond water daily	Patil et al., 2002	6667 m^3 per Ha per crop
	5-20% of pond volume daily	Boyd, 1998	
	6667 m^3 per ha per crop	CRP and World Bank, 2003	
Harvest	9 Tons per ha per season	Cowan et al., 1999	Range of harvest is set between 0 and 6 tons per hectare per season.
	4-8 Tons per ha per year	de Graaf and Xuan, 1998	
	Highest: 8 tonnes per ha per season Lowest: Less than 1 ton per ha per season	Interviews with shrimp farmers	

Table 3.2a: Summary of the assumed trends in the BAU scenario

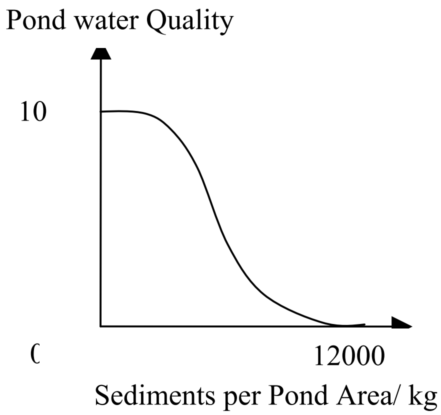
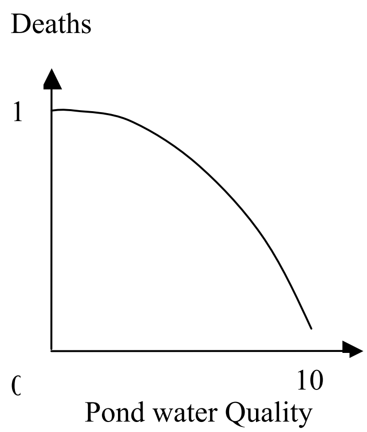
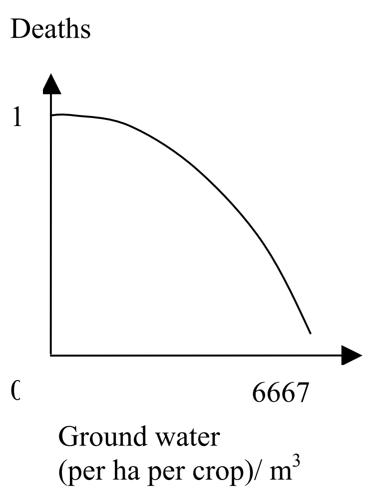
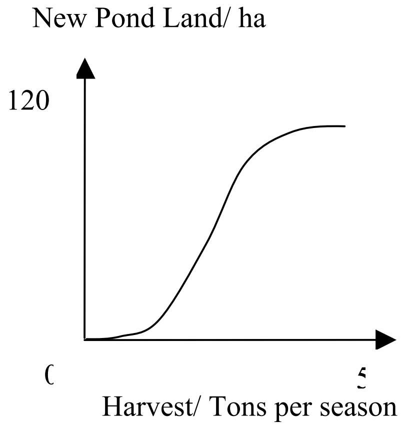
Relationships	Assumed Trend in BAU	Description
Pond Water Quality vs (Sediments: Pond Land)		Once the capacity of the pond to assimilate or break down the sediments is reached, pond water quality will decrease. Pond water Quality is measured on a scale of 1 to 10. Ponds start with a water quality of 10. It is possible that sediments will continue to increase but the quality will still remain as 0, which means that the minimum water quality required to farm shrimp has been exceeded.
Deaths		"Deaths" is measured as a proportion. "1" means that the whole population will die. As quality decreases the number of deaths increases. As shrimps are very sensitive to water quality, the number of deaths rises quickly when pond water quality drops from 10, thus the graph has a steep gradient at quality "10". There is a background death rate estimated to be 0.05, which can be attributed to the quality of shrimp seed.
Ground Water: (Deaths vs Pond Water Quality)		As groundwater decreases, there will be a lack of clean water available for diluting the sea water and cleaning. As shrimps are very sensitive to water quality, the number of deaths rises quickly when ground water availability drops from 6667 m^3, the ground water required for per ha per crop. Thus the graph has a steeper gradient at 6667. There is a background death rate estimated to be 0.05, which can be attributed to the quality of shrimp seed.

Table 3.2b: Summary of the assumed trends in the BAU scenario

Relationships	Assumed Trend in BAU	Description
New Pond Land vs Harvest 1		More land will be converted to shrimp ponds if the first generation shrimp farm are successful. The maximum amount of land to be converted in a year is set at 120 ha as this is more than twice of the starting value of 50 ha in the first year. It is reasonable to assume that the increase of farms between 1999 and 2003 is more in the initial years and less in the later years as the harvest of first generation farms have been decreasing. 5 tons per ha per season is definitely in the range of profits that will attract more investment.

Other assumptions include:
- There are no events of natural disasters: monsoon flooding or droughts.
- Rainfall has a uniform distribution of 200mm per season (4 months).
- The initial area of shrimp ponds in 1999 is 50 hectares.

3.3 Suggested Solutions

Three solutions are modeled and their results will be compared against the BAU model. First, the stocking density will be lowered from 40 shrimp/m^2 to 15 shrimp/m^2. Second, the ponds will be cleaned and this can be modeled as an extraction from the stock of accumulated sediments. Two levels of cleaning will be modeled, an extraction of 20% of sediments will represent a basic cleaning of ponds, flushing with water and rinsing the plastic cover sheets, which would require the minimum extra help of 1 worker per hectare. The extraction of 40% of sediments will represent a more through cleaning of ponds that may involve the digging up of sediments and relining the ponds and this will require at least the help of 2 extra workers per hectare. A run combining the lowering of stocking density to 15 shrimp/m^2 and cleaning the ponds of 40% of sediments will also be attempted.

3.4 Sensitivity Analysis

Stocking density and groundwater resource are chosen for sensitivity analysis. By varying the range of values of these inputs, it is possible to check if the model gives reasonable results for the range of values selected.

4. Results

4.1 Business as Usual

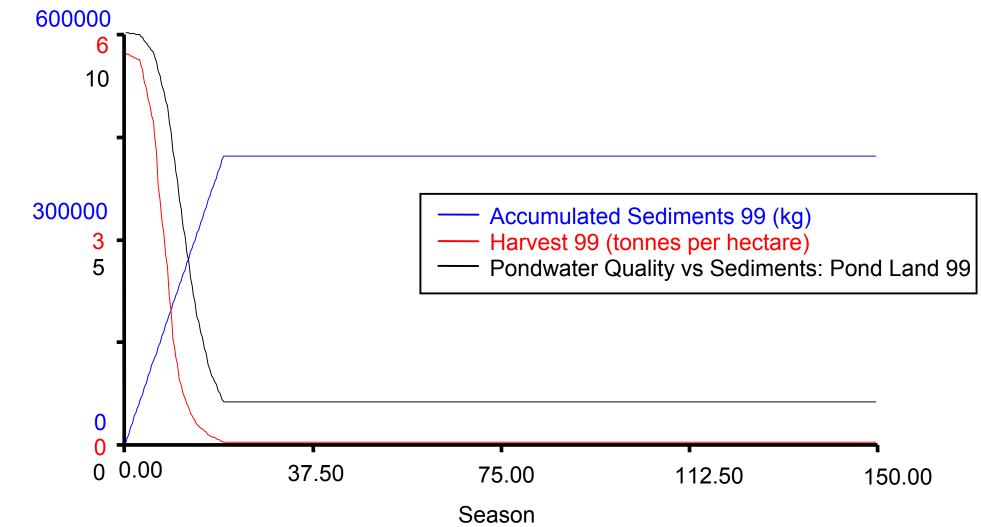


Figure 4.1:Business as Usual-
Accumulated Sediments, Pond Water Quality and Harvest of 1 Pond vs. Season

The BAU model has a stocking density of 40 shrimps/m^2 and no cleaning activities were assigned. The amount of accumulated sediments increases causing the pond water quality to decrease and the harvest to decline. The life cycle of the shrimp pond in this model is 19 seasons, which is comparable to 15 seasons in 5 years (Patil et al., 2002).

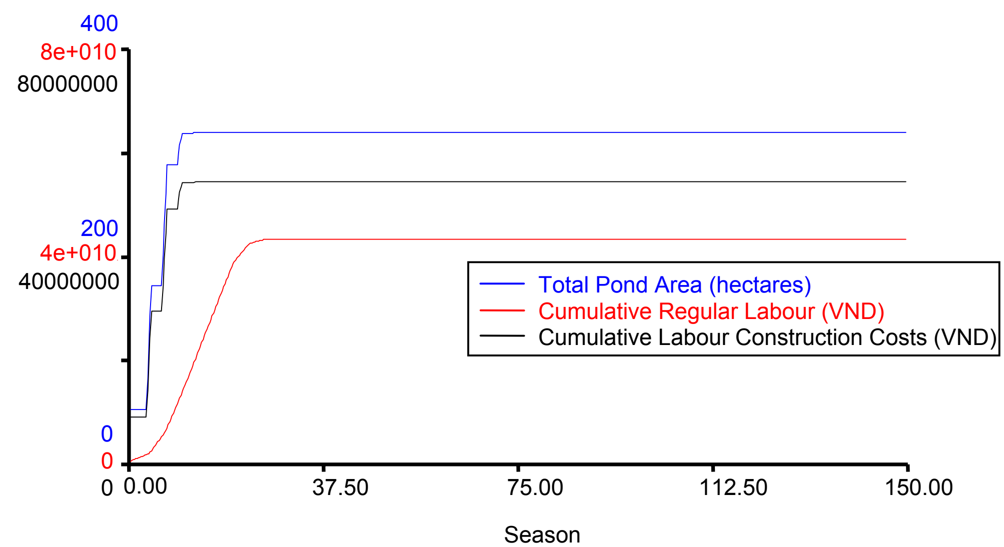


Figure 4.2: Business as Usual-
Total Pond Area, Cumulative Regular Labour, Cumulative Labour Construction Costs vs. Season

The harvest performance of the first generation ponds was able to attract shrimp farm investors for 12 seasons, and a total area of 317 hectares was converted into ponds. Employment in the BAU model stretches for 28 seasons, and the total amount of money earned by shrimp pond workers is more than VND 43,000,000,000.

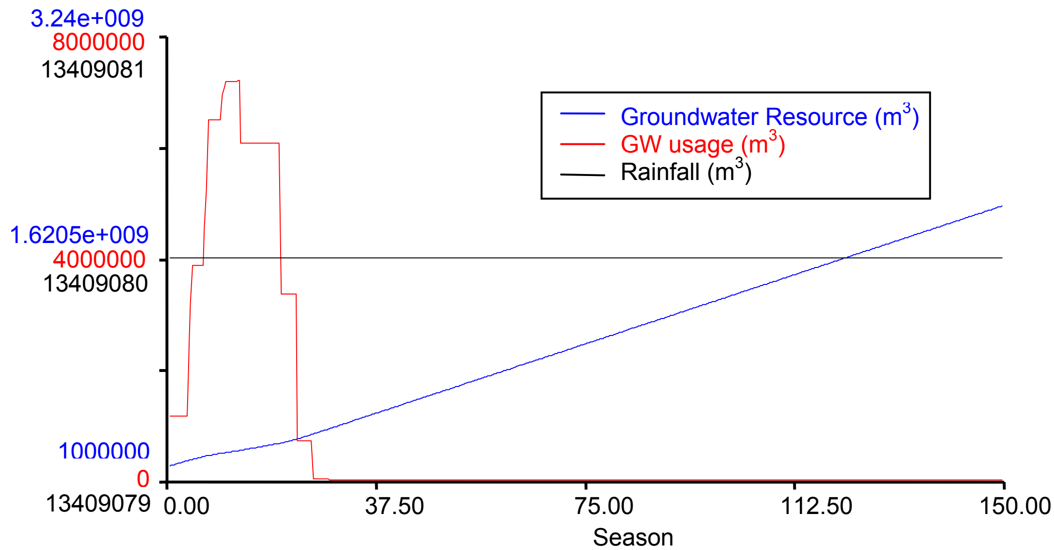


Figure 4.3: Business as Usual-
Groundwater Resource, Groundwater Usage and Rainfall vs. Season

In this case, groundwater resource was not the limiting factor as it increases steadily despite usage from the shrimp ponds. This increase is due to the constant rainfall input. When the shrimp ponds close down, the increase in groundwater resource is much faster.

4.2 Lowering the Stocking density

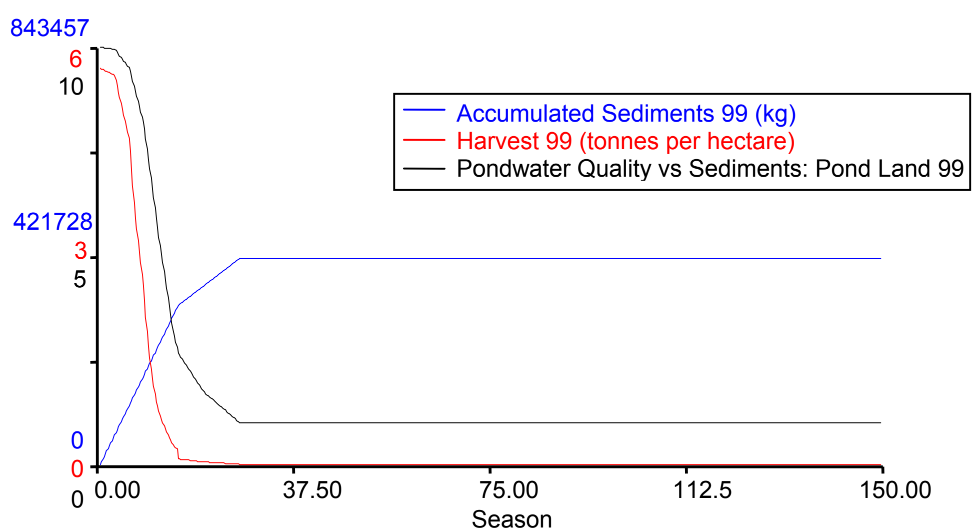


Figure 4.4: Lowering the Stocking Density-
Accumulated Sediments, Pond Water Quality and Harvest of 1 Pond vs. Season

The stocking density was lowered from 40 shrimps/m^2 to 15 shrimps/m^2 after the 15th season and no cleaning activities were assigned. The 15th season was chosen to be the time when the stocking density is lowered because by the 15th season, shrimp farmers would have experienced a decline in their harvests and some would try to lower the stocking density in an attempt to get better harvests. Another reason is that if this were to be recommended to Ninh Thuan now, as an option for sustainable development, there has already been five years (15 seasons) since the start of shrimp farming. Unfortunately, the amount of accumulated sediments continues to increase, although at a slower rate, while the pond water quality and harvest decreases. The life cycle of the shrimp pond is 25 seasons.

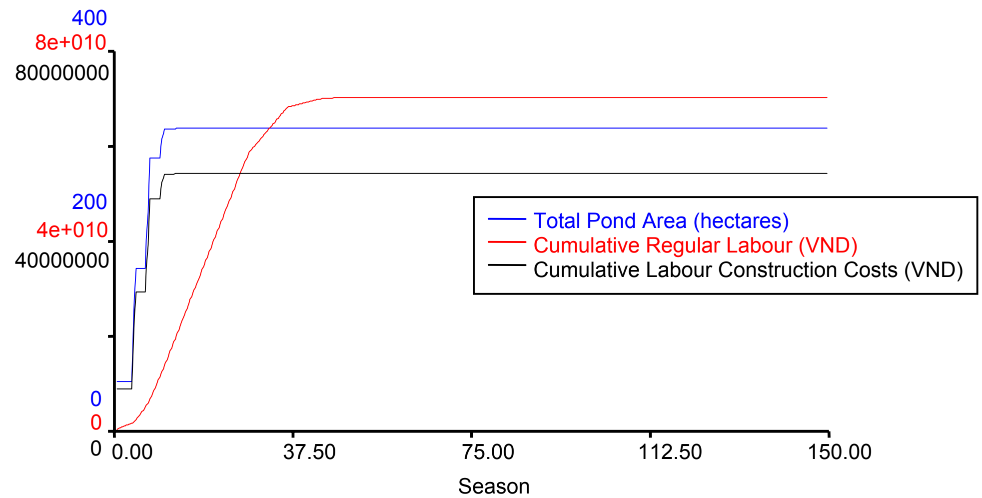


Figure 4.5: Lowering the Stocking Density-
Total Pond Area, Cumulative Regular Labour, Cumulative Labour Construction Costs vs. Season

The harvest performance of the first generation ponds was able to attract shrimp farm investors for 12 seasons, and a total area of 317 hectares was converted into ponds. Employment in stretches for 51 seasons, and the total amount of money earned by shrimp pond workers is more than VND 69,000,000,000.

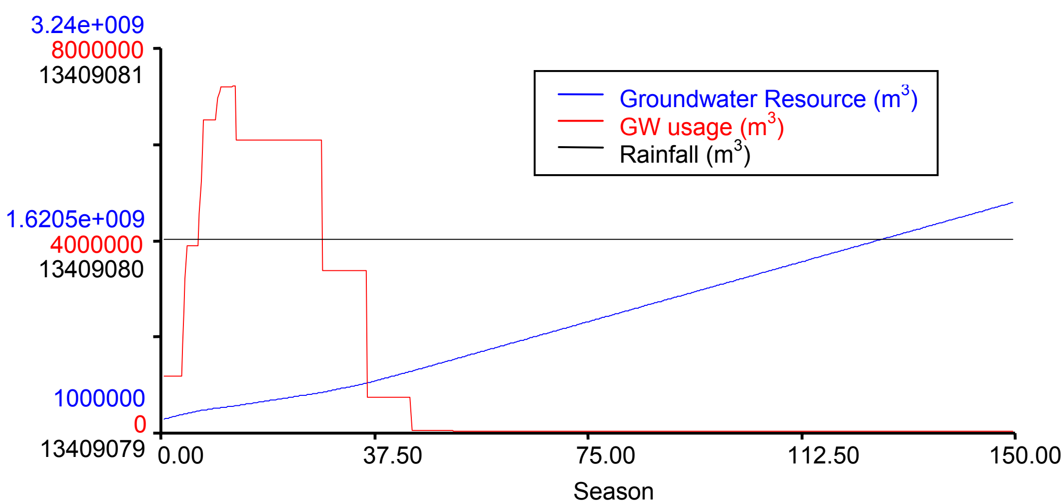


Figure 4.6: Lowering the Stocking Density-
Groundwater Resource, Groundwater Usage and Rainfall vs. Season

In this case, groundwater resource was not the limiting factor as it increases steadily despite usage from the shrimp ponds. This increase is due to the constant rainfall input. Once the shrimp ponds start to close down, the increase in groundwater resource is much faster.

4.3 Cleaning the Ponds of Sediments

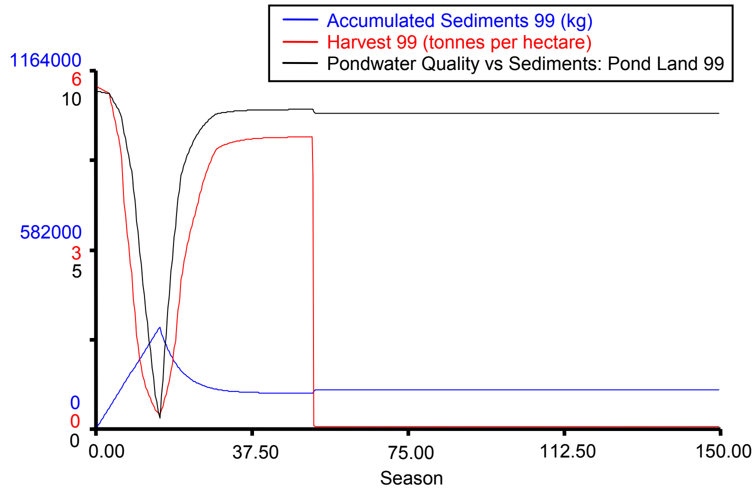


Figure 4.7: Cleaning at 20%-
Accumulated Sediments, Pond Water Quality and Harvest of 1 Pond vs. Season

Cleaning activities at 20% efficiency were assigned and the stocking density was maintained at 40 shrimps/m^2. The 15th season was chosen because shrimp farmers should have experienced a decline in their harvests by then and some would try to clean the ponds in an attempt to get better harvests. Another reason is that if this were to be recommended to Ninh Thuan now (2004), as an option for sustainable development, there has already been five years (15 seasons) since the start of shrimp farming. Initially, the amount of accumulated sediments will decrease; pond water quality increases and harvests improve. Although the accumulation of sediments is controlled at the farm level, the use of groundwater at the collective municipal level is not. Problems with groundwater availability start from the 52nd season. Freshwater availability declines and consequently decreasing pond water quality and harvest until the ponds have to close.

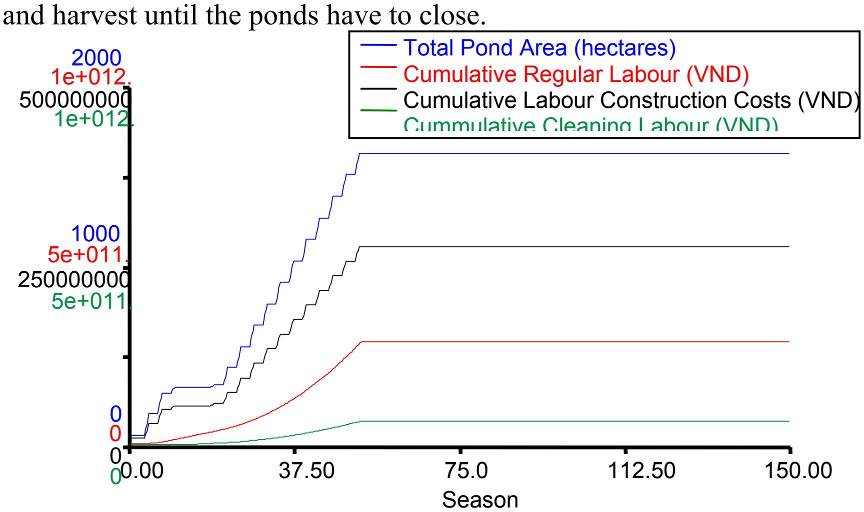


Figure 4.8: Cleaning at 20%-
Total Pond Area, Cumulative Regular Labour, Cumulative Labour Construction Costs vs. Season

The harvest performance of the first generation ponds was able to attract shrimp farm investors for 52 seasons, and a total area of 1624 hectares was converted into ponds. The increase in the number of shrimp farms leads to an increase in the number of shrimp pond workers employed. Employment on the shrimp farms is only possible for 52 seasons, and the total amount of money earned by shrimp pond workers is more than VND 350,000,000,000.

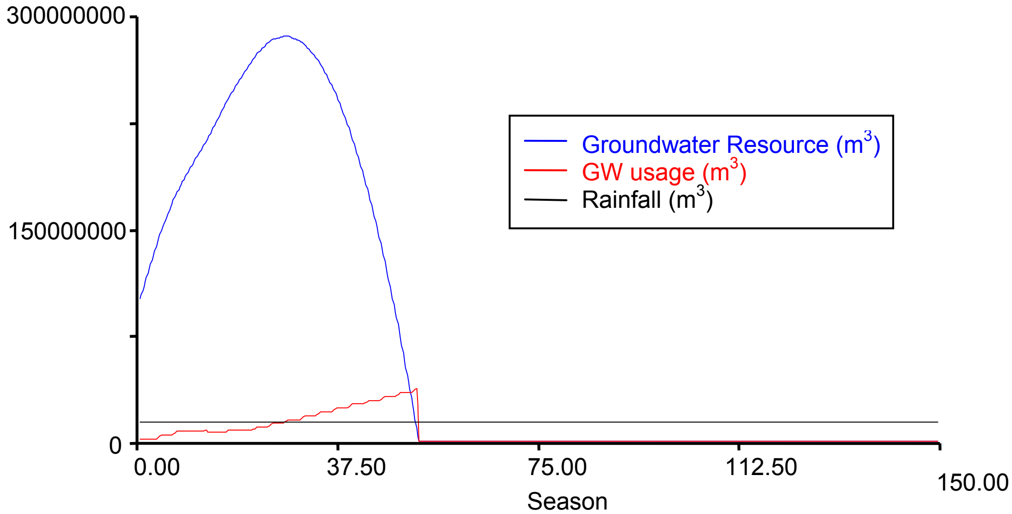


Figure 4.9: Cleaning at 20%-
Groundwater Resource, Groundwater Usage and Rainfall vs. Season

Initially groundwater resource increases because of the constant rainfall input, but as groundwater usage increases, more water is drawn out than collected, thus the water resource start to decline. When the groundwater resource is depleted, the farms cannot continue without freshwater and they close down on the 52nd season, thus groundwater usage drops to zero. The model is structured such that groundwater resource is not easily replenished once depleted.

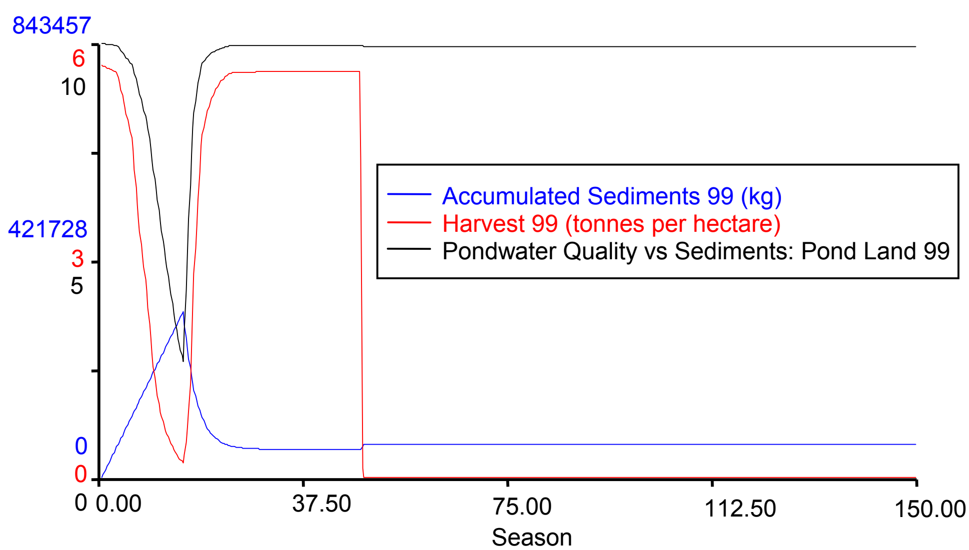


Figure 4.10: Cleaning at 40%-
Accumulated Sediments, Pond Water Quality and Harvest of 1 Pond vs. Season

Cleaning activities at 40% efficiency were assigned with stocking density maintained at 40 shrimps/m^2. 40% cleaning efficiency requires double the manpower as more cleaning, for example, digging out the sediments, is required. Labour costs for cleaning was correspondingly adjusted. The 15th season was chosen because shrimp farmers should have experienced a decline in their harvests by then and some would try to clean the ponds in an attempt to get better harvests. Another reason is that if this were to be recommended to Ninh Thuan now (2004), as an option for sustainable development, there has already been five years (15 seasons) since the start of shrimp farming. Initially, the amount of accumulated sediments will decrease; pond water quality increases and harvests improve. Although the accumulation of sediments is controlled at the farm level, the use of groundwater at the collective municipal level is not. Problems with groundwater availability start from the 48th season. Freshwater availability declines and consequently decreasing pond water quality and harvest until the ponds have to close.

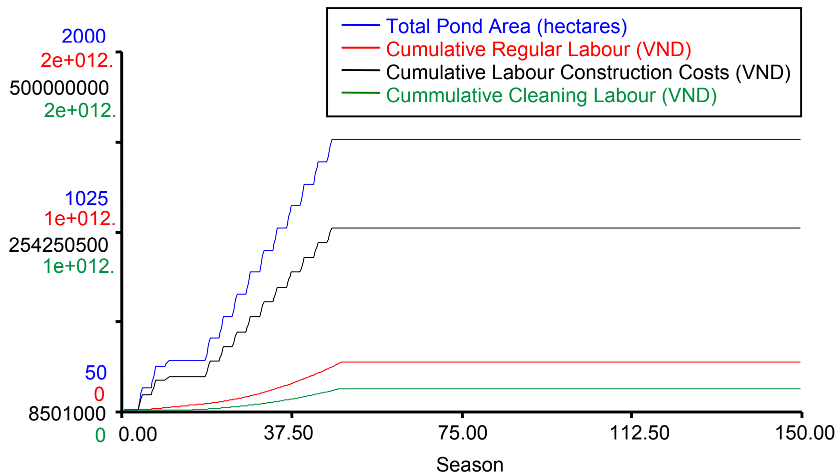


Figure 4.11: Cleaning at 40%-
Total Pond Area, Cumulative Regular Labour, Cumulative Labour Construction Costs vs. Season

The harvest performance of the first generation ponds was able to attract shrimp farm investors for 48 seasons, and a total area of 1518 hectares was converted into ponds. The increase in the number of shrimp farms leads to an increase in the number of shrimp pond workers employed. Employment on the shrimp farms is only possible up to the 48th season, and the total amount of money earned by shrimp pond workers is more than VND 380,000,000,000.

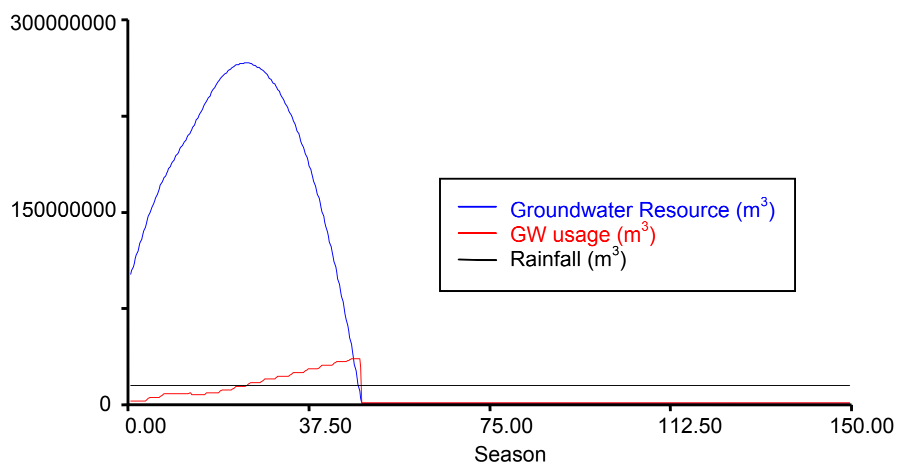


Figure 4.12: Cleaning at 40%-
Groundwater Resource, Groundwater Usage and Rainfall vs. Season

Initially groundwater resource increases because of the constant rainfall input, but as groundwater usage increases, more water is drawn out than collected, thus the water resource start to decline. When the groundwater resource is depleted, the farms cannot continue without freshwater and they close down on the 48th season, thus groundwater usage drops to zero. The model is structured such that groundwater resource is not easily replenished once depleted.

4.4 Lowering the Stocking Density and Cleaning the Ponds

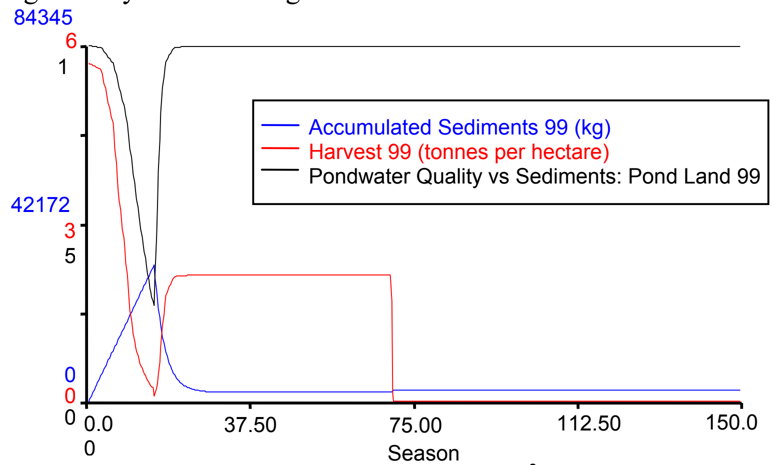


Figure 4.13: Stocking Density at 15 shrimps/m^2 and Cleaning at 40%-
Accumulated Sediments, Pond Water Quality and Harvest of 1 Pond vs. Time

Cleaning activities at 40% efficiency were assigned and the stocking density was lowered to 15 shrimps/m^2. The 15th season was chosen to be the time when the cleaning practice starts to imitate the reality in Ninh Thuan. The 15th season was chosen because farmers should have experienced a decline in their harvests and some have tried to clean the ponds and lower the stocking density in an attempt to get better harvests. Another reason is that if this were to be recommended to Ninh Thuan now (2004), as an option for sustainable development, there has already been five years (15 seasons) since the start of shrimp farming. Initially, the amount of accumulated sediments will decrease; pond water quality increases and harvests improve. Although the accumulation of sediments is controlled at the farm level, the use of groundwater at the collective municipal level is not. Problems with groundwater availability start from the 70th season. Freshwater availability declines and consequently decreasing pond water quality and harvest until the ponds have to close.

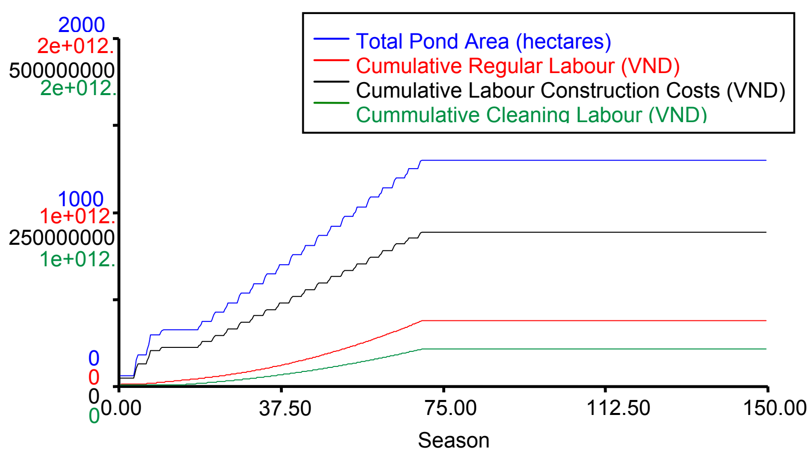


Figure 4.14: Stocking Density at 15 shrimps/m^2 and Cleaning at 40%-
Total Pond Area, Cumulative Regular Labour, Cumulative Labour Construction Costs vs. Time

The harvest performance of the first generation ponds was able to attract shrimp farm investors for 70 seasons, and a total area of 1294 hectares was converted into ponds. The increase in the number of shrimp farms leads to an increase in the number of shrimp pond workers employed. Employment on the shrimp farms is only possible up to the 70th season, and the total amount of money earned by shrimp pond workers is more than VND 540,000,000,000.

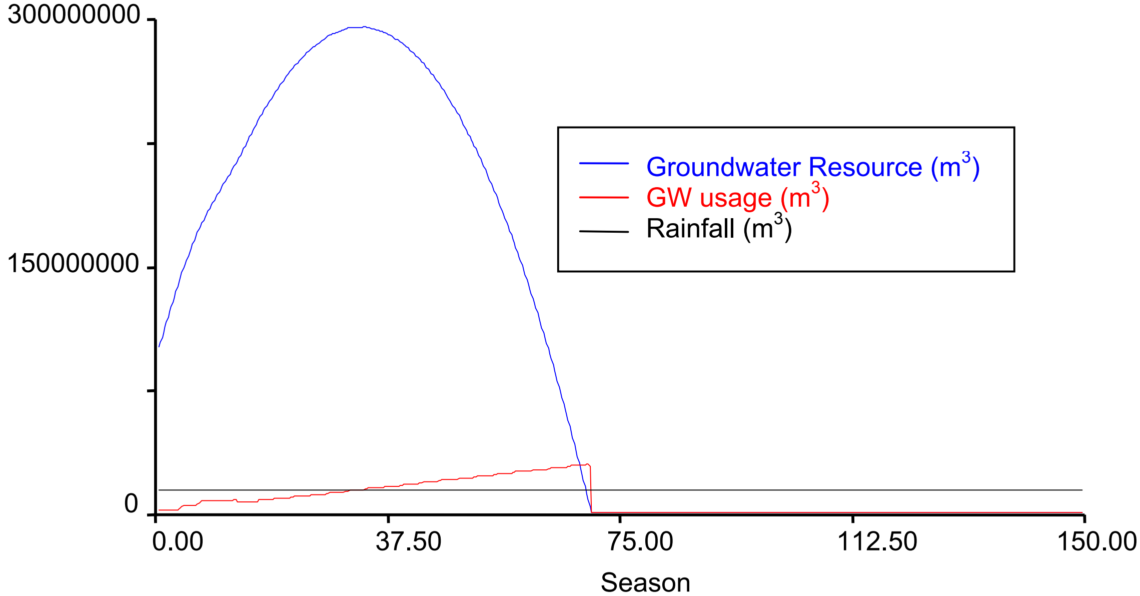


Figure 4.15: Stocking Density at 15 shrimps/m^2 and Cleaning at 40%-
Groundwater Resource, Groundwater Usage and Rainfall vs. Time

Initially groundwater resource increases because of the constant rainfall input, but as groundwater usage increases, more water is drawn out than collected, thus the water resource start to decline. When the groundwater resource is depleted, the farms cannot continue without freshwater and they close down on the 70th season, thus groundwater usage drops to zero. The model is structured such that groundwater resource is not easily replenished once depleted.

4.5 Summary of Modelling Results

The results are sorted and summarized in the form of column graphs, where comparison between the scenarios can be made using the categories: pond lifespan, groundwater availability, total pond area and combined labour costs. For pond lifespan, it is derived from the harvest performance of the ponds that were started in the first season. Ponds are considered closed once harvest declines to zero. Groundwater availability is counted from the start of the first season till the season when groundwater resource declines to zero. Total pond area will give an indication of how much land is converted into shrimp ponds. Combined labour costs are the addition of labour costs due to the construction of ponds, regular maintenance of ponds and cleaning of ponds. This gives an indication of the economic benefit of shrimp farming to the local community.

The scenarios have been abbreviated as such: Business as Usual as “BAU”, lowering the stocking density to 15 shrimps/m^2 as “SD15”, cleaning at 20% efficiency as “Clean20”, cleaning at 40% efficiency at “Clean40” and the combination of lowering the stocking density to 15 shrimps/m^2 and cleaning at 40% efficiency as “Combine”.

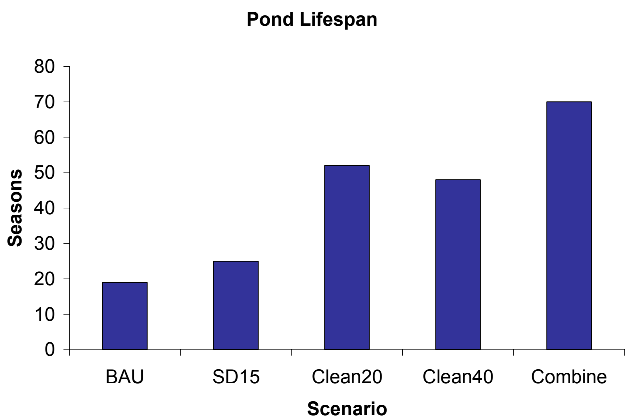


Figure 4.16: Comparison of Pond Lifespan

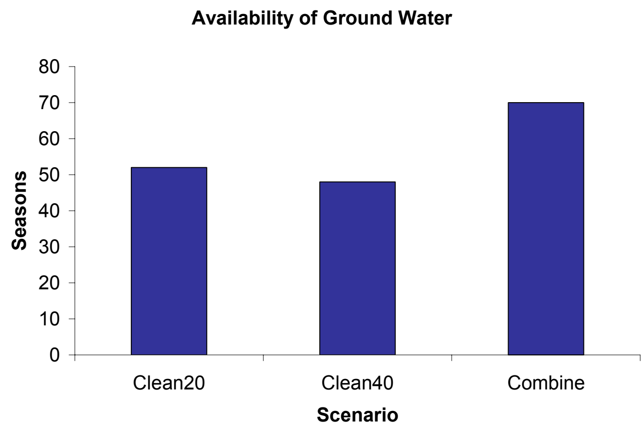


Figure 4.17: Comparison of the Availability of Groundwater

From Figure 4.16, it is evident that scenarios with cleaning activities have a longer pond lifespan than those without. Ponds in SD15 have a longer lifespan than in BAU as lower stocking densities would have less sedimentation and thus better pond water quality for a longer time. Ponds in Clean20 survive longer than in Clean40 as groundwater is available for a longer time in Clean20 than in Clean40, as shown in Figure 4.17 to ensure that water exchange and cleaning can be done to keep up the quality of the pond water. Although the Combine scenario outperforms the rest in terms of pond lifespan, it is still not a sustainable solution as in the long run it still fails. In Figure 4.17, the BAU and SD15 scenarios are not shown as groundwater does not run out.

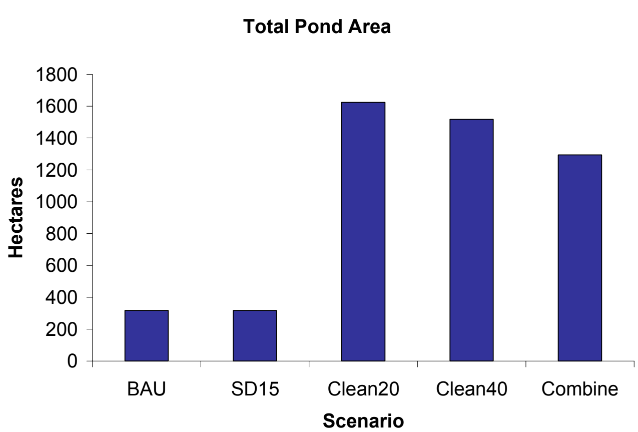


Figure 4.18: Comparison of Total Pond Area

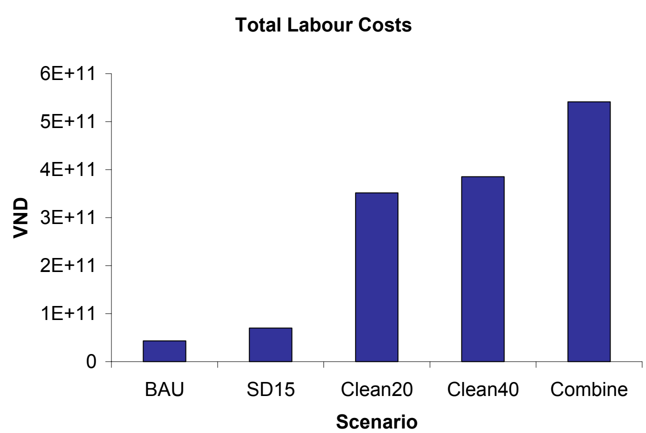


Figure 4.19: Comparison of Total Labour Costs

From Figure 4.16, it is evident that scenarios with cleaning activities result in significantly more land area converted to ponds. Between the cleaning scenarios, Clean20 has the most land area converted to ponds, followed by Clean40 and Combine. Similarly in Figure 4.19, scenarios with cleaning activities result in significantly higher levels of labour costs, which can be attributed to cleaning labour costs. Between the cleaning scenarios, Combine has the highest labour costs followed by Clean40 and Clean20.

4.6 Summary of Interview Results

In this section the interview responses from the different stakeholders will be summarized. The stakeholders are divided into three groups: shrimp farmers; aquaculture experts; local residents and officials and CRP officers.

4.6.1 Reponses from Shrimp Farmers

- farmers come from a variety of backgrounds, and most do not have prior training in aquaculture
- farmers were attracted to shrimp farming due to hearsay that it is a very profitable business
- all shrimp farmers had obtained loans from informal institutions
- the stocking density ranges between 15-50 Shrimps/m^2
- the output of the farm ranges between 1-8 tonnes per hectare per season
- all farmers sell their shrimp to middlemen
- most farms have experienced a decline in harvest
- a combination of groundwater and seawater is used for the ponds
- it is common that effluent is discharged without treatment
- farmers are aware that untreated effluent will cause harm to the environment
- it is common that the inlet and outlet drainage systems are the same channels which are shared by other farmers
- farmers would like to have: a local shrimp farmer association, measures to alleviate the effects of monsoon flooding that destroy their ponds and better quality of shrimp seed, as they think this is the reason for their bad harvest
- farmers believe that shrimp farming has brought employment and consequently a high standard of living to the local community
- farmers had mixed feelings if they would want their children to take over the business
- most farmers did not have the means to diversify their source of income, even if they have such plans
- farmers did not feel a strong sense of cooperation or competition between themselves. Only in Phuoc Dinh was cooperation demonstrated with the plan to construct an irrigation facility and a waste water treatment plant

4.6.2 Responses from Aquaculture Experts

- there is insufficient government funding for research activities, and different research institutions have to compete for the available funding
- aquaculture research is mainly on the science and technology to improve harvests and there is very little research done on the economic and social impacts of shrimp farming
- shrimp farming helps to increase the rural livelihood options and income, thereby reducing migration to the cities and increasing the rural standard of living
- at the national level , shrimp exports helps the country to earn foreign exchange
- shrimp farming is a risky business and it is important for potential farmers to evaluate their financial and technical capabilities and the resources available to them before starting
- the rise in the number of shrimp farmers can be attributed to the positive word of mouth on the business and the limited awareness of the risk involved in shrimp farming
- government can play a more active role in disseminating information on shrimp farming, and organizing shrimp farming communities to facilitate the sharing of common infrastructure and other collective action
- at present, there is not enough good quality shrimp seeds for everyone
- farmers are a conservative group of people, for them to make cost incurring changes to their usual practices, there must first be evidence of successful, profitable ponds with such changes
- it takes about two years of research to develop a standard model for farmers to copy
- farmer can learn and imitate new management practices within one season
- it is difficult for farmers to earn enough profits to expand their shrimp farming business

- laws and regulation on pollution caused by farms are not effective solutions as it is difficult to enforce and the people are too poor to pay fines

4.6.3 Reponses from Local Residents and Officials and CRP officers
- a proportion of communal land is allocated for shrimp farming
- local officials believe that shrimp farming has brought employment and consequently a high standard of living to the local community
- some local officials do not think that shrimp farming pollutes the land or is the reason for the decline in coastal catch
- local officials think that shrimp farming is a suitable business for the region and will be a long term venture
- in some areas, the drinking wells are the same wells that are used to irrigate shrimp farms and they are located nearby to the farms
- in some areas (but not in Vinh Truong), local officials have seen some signs of water contamination and shortage but claim that they are not significant
- CRP officers and locals in Vinh Truong said that the groundwater has been contaminated and is too saline for household use. Water from the mountains has to be piped to the village and is used sparingly.

4.7 Sensitivity Analysis

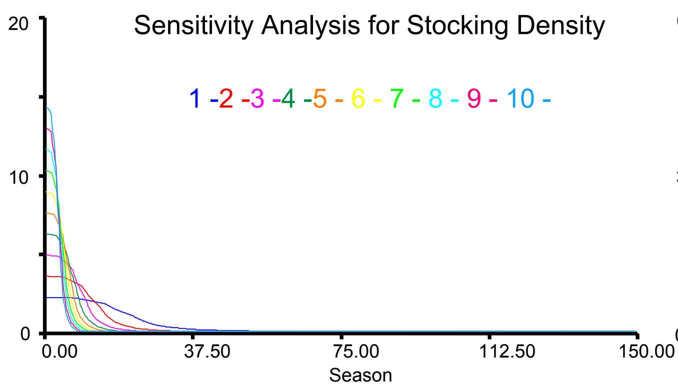


Figure 4.20: Sensitivity Analysis- Stocking Density on Harvest vs. Season

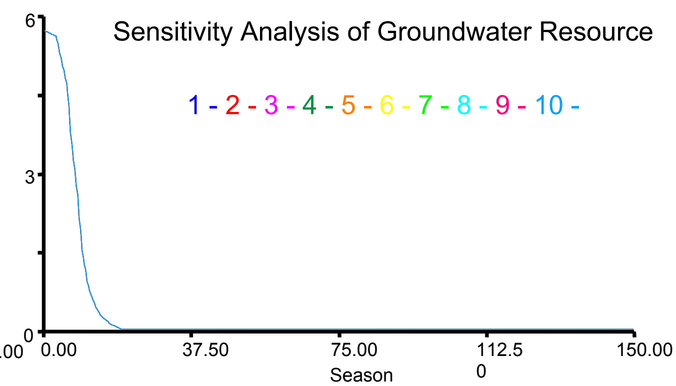


Figure 4.21: Sensitivity Analysis- Groundwater Resource on Harvest vs. Season

Harvest vs. Season was used as it represented the basic building block of the model: the dynamics of a farm. Other variables could not be chosen for sensitivity analysis because they are made up of assumed relationships in the form of graphs, but they have been noted in chapter 6 for further work.

10 values between 15 shrimps/m^2 and 100 shrimps/m^2 were used for the sensitivity analysis of stocking density on BAU. At lower stocking densities there were lower levels of harvests but a longer pond lifespan. Here, the effect of increase in the level of sedimentation can be verified. At higher stocking densities, the sedimentation process is more rapid and the pond water quality deteriorates faster which leads to the earlier closure of ponds due to bad harvest.

In the sensitivity analysis of groundwater resource (stock) on BAU, 10 values between 1 x 10^7 m^3 and 1 x 10^9 m^3 as initial values were used. There was no variation of the harvest. This has two implications. First, it verifies that at the farm level, sedimentation is the limiting factor. Secondly, it is very important to estimate the rainfall input into groundwater resource accurately to ensure that the limiting factor at the community level is the level of groundwater resource. This point is also reiterated in chapter 6.

5. Discussion and Analysis

This section will discuss the results presented in chapter four, starting with the validity of the model, followed by individual sections on the different types of scenarios and suggested solutions. Keeping in line with the aim of this thesis, the results will be used to evaluate if current practices of shrimp farming in Ninh Thuan are sustainable and serve to alleviate poverty. Further discussion and analysis would be done using the Drivers-Pressures-State-Impacts-Response (DPSIR) framework to put shrimp farming in Ninh Thuan in the larger context of Vietnam.

5.1 Evaluating the model

5.1.1 Validity of the model

Several steps were taken to ensure the validity of the model. First, the inputs to the model were taken as far as possible from local sources- interviews and reports published by the local NGO, CRP. Secondly, a dimensional consistency check (Vennix, 1996) was done to ensure that there is a real world meaning for every variable. Thirdly, a sensitivity analysis was performed for salient variables -stocking density and groundwater resource. These variables displayed the same pattern of behavior for the range of values tested.

The skewness of the input data and the model was reduced by gathering information from different stakeholders at different shrimp farming villages in Ninh Thuan. In addition, interview data was checked against published data. There was also an opportunity to present preliminary findings to an audience of Vietnamese and non-Vietnamese social and natural scientists for criticism to ensure face validity (Vennix, 1996). Their criticism and suggestions have been noted and the relevant changes have been made. This model was made with the purpose to investigate long term trends and to find leverage points in the system, so exact numbers are not the top priority.

5.1.2 Effectiveness of lowering the stocking density

Lowering the stocking density increases the life span of the shrimp pond (Figure 4.16) and attracts more new investments. In the SD15 scenario, sediments will accumulate at a slower rate, but the problems with water quality would still remain, only to appear at a later time. In this case, sedimentation is the limiting factor and not groundwater resource. Lowering the stocking density is an inadequate solution if implemented alone.

5.1.3 Effectiveness of cleaning the ponds

Cleaning increases the lifespan of the pond and attracts more new investments (Figure 4.18). Although the level of sediments is controlled groundwater availability becomes the limiting factor as more new farms are set up. New farmers would learn from the experience of older farms and think that by cleaning their ponds good harvests are assured. At the farm level, this can be true, but at the farming community level this is definitely not true as the groundwater is replenished at a constant rate. With the increase in the number of farms over the years, the groundwater usage will exceed the replenishment rate and groundwater resource will decrease. Consequently, all farms will face the same problem of a shortage of freshwater. The Clean40 scenario has a lower total pond area than the Clean20 scenario because the harvest levels of ponds from the Clean40 scenario are much better and the rate of increase of new ponds is much higher that drives the system to groundwater depletion much faster. Thus Clean40 stops at the 48th season as compared to Clean20 that stops at the 52nd season. The small difference of 4 seasons gives Clean20 enough time to attract more investors, and thus more land is converted to ponds. Local inhabitants can earn profits if they sell their land to investors. On the other hand, it is bad thing when ponds are abandoned as local inhabitants are the ones that have to endure the effects of polluted land and water. There is also a problem with the disposal of the pond sediments. It is very likely that these sediments are left on other plots of land without any treatment, creating problems of land contamination in other areas. Thus cleaning the ponds is an inadequate solution if implemented alone.

5.1.4 Effectiveness of lowering the stocking density and cleaning the ponds

In the Combine scenario, cleaning the ponds helps to partially correct the problem of sedimentation, but this success attracts more new farms to imitate this farming practice which in the long run results in inadequate groundwater supply for all the farms. Moreover, this scenario would not be attractive to shrimp farmers as it requires them to lower their stocking density and this means that they will have less harvest per season. This response from potential investors can be seen from Figure 4.18, when Combine is the scenario with the lowest total pond area when compared to the other scenarios with cleaning. In addition, farmers would have to pay the largest amount for labour costs (Figure 4.19) as cleaning labour is required throughout the lifespan of the ponds and in this case, the ponds have the longest lifespan (Figure 4.16). The failure of these three solutions shows that end of pipe, technical fixes are not always effective. It also shows that it is very important to limit the amount of land used for shrimp farming. This problem must be analysed at different levels, as the limiting factor may not be on the same level as the physical level. There is a difference between knowing the solution and how to implement the solution to obtain the desired effects. Furthermore, there is a need for an accurate assessment of groundwater and a backward calculation to find out the optimal number of ponds.

5.2 Evaluating the results in the context of Ninh Thuan and Poverty Alleviation

The shrimp farming business was encouraged in Ninh Thuan, as there are expectations that employment numbers and the stability (or length) of employment will increase. In addition to these two criteria for sustainable prosperity, the stock of groundwater, future flexible land use options, community cohesiveness and capacity building will be considered. This section analyses these criteria and their conflicts with environmental, social and economic interests. The merits, drawbacks, barriers and implications of different solutions will also be discussed.

- Employment numbers

As employment for the locals is usually in the form of labour, and labour required can be estimated by the area of the farm, the larger the pond area the more labour is employed. One interpretation of employment numbers is that it is an indicator of the number of opportunities for a local to increase his personal income. The scenario Combine had the largest total pond area of 1624 hectares. In the short term, more farms create employment, but it conflicts with the availability of groundwater resource in the long term. An increase in labour required per hectare is not possible as it conflicts with the farm owners' desire for profits.

- Stability of employment

A longer period of employment would mean job security for the local inhabitants. Clean40 had the longest pond life span of 70 seasons. This conflicts with the desire for high, short term profits for quicker debt repayment. Most farmers have taken loans with high interest rates as start up capital and there is a lot of pressure to be able to clear their debt as soon as possible. The presence of middlemen in the supply chain further impedes the possibility of high profits, as they fix the selling price of shrimp and this may hinder the farmers from getting more profits than they deserve and consequently affect the farmers' ability to repay their debts. A solution that results in a longer period of employment is complementary to the environment. The period of employment directly relates to the lifespan of the shrimp pond which in turn is dependent on the quality of the environment that supports the harvest level.

- Stock of groundwater

Maintaining a sustainable stock of groundwater is important to ensure that the quality of life of the locals is not threatened. In times of groundwater shortage, the purchase of water reduces the household income and this negative externality is shouldered by those who may not have benefited in any way from shrimp farming, but who just live in the vicinity, sharing the same source of groundwater. The issue surrounding the stock of groundwater is that of the tragedy of the commons. Water is free in Ninh Thuan, and the high profits from shrimp farming attract more shrimp farmers, who do not consider that there is a limited supply of groundwater. As succinctly phrased by Hardin (1968), "Each man is locked in a system that compels him to increase his herd without limit-in a world that is limited.".

The two scenarios that were not limited by groundwater resource was BAU and SD15, both without any cleaning activities. These scenarios are not beneficial for two very important reasons. First, the environment is harmed in another way, through sedimentation of the ponds. Ponds are abandoned when the concentration of sediments is too high for any profitable harvest and the land is too contaminated for other agricultural purposes. Secondly, it is not in the interest of the farmers who have invested a large proportion of their savings and taken loans at high interest rates to have ponds that have short lifespan. The lifespan must be long enough for them to repay their loans and to earn a decent living and not be worse off than when they started. The most ideal situation is when the lifespan of the pond is long enough for shrimp farmers to have profits to invest in other areas to diversify their income. It is common that most farmers are only reliant on shrimp farming as their source of income in the initial years as most of their savings are used as the start up capital for the shrimp farm. This is a very risky move, especially in Ninh Thuan, where in recent years; disease, heavy monsoon rains and flooding have destroyed many new ponds.

One solution is to limit the land area for shrimp ponds, if current pond management and pond technologies are unlikely to change. The challenge would lie in the implementation of land use restriction, especially to private lands. Enforcement of such restriction will be difficult. If enforcement is undertaken by municipal officers, conflicts may arise, as many of these officials are already shrimp farms owners. These conflicts may come in the form of bribery of officials or mistrust and resentment towards officials if they are owners but do not allow others to start their own farms.

Another solution would be the use of closed systems technology. However, it is likely that closed systems technology is too expensive to implement. There is also no incentive to use closed systems technology when water is free in Ninh Thuan. If loans are given out for such systems, there must also be other training programs to complement the loans. Successful closed systems are not only dependent on the start up capital but a through understanding and practice of the appropriate management techniques. Some may argue that the eco-labeling of shrimps from closed systems may fetch a higher selling price, and would be an incentive for closed systems technology, but genuine eco-labeling of products is dependent on many other factors, for example energy consumption per unit of product and the source of feed.

In the village Vinh Truong, where groundwater has been depleted, some farmers dug new ponds to collect rainwater to irrigate their shrimp ponds. This solution is possible if there is already a cooperative attitude between the shrimp farmers in the community, the shrimp ponds are located in close proximity to each other that makes sharing water easier and the number of shrimp farms is not too many that would require too much effort of pond digging. Currently, the shrimp farms still can manage by using the collected rainwater, but the locals in the community have to buy their water from other villages.

The problems with groundwater shortage are not easily resolved once they appear, especially so in Ninh Thuan where annual rainfall is only 600mm and this occurs mainly in the monsoon season and in the form of floods. This emphasizes the need to accurately estimate the groundwater resource before promoting the shrimp farming industry. It is easier to set a price for water usage before the industry takes off and not when the farmers already assume that water will be free. The sustainable level of ground water resource also has to take into account the growth of population, the possible increase in water usage per person, usage from other crops, and accessibility of the groundwater resource. Water trapped too deep in the soil strata or in too remote places from the villages will be expensive to pump.

- Future flexible land use options

Having more land use options in the future is a way to sustainable prosperity, especially for agrarian communities. It gives the option of future diversification of the local economy that can serve as a safety net if one type of agriculture fails. There are two main ways to ensure future flexible land use options. Firstly, allow only low impact activities on previously unused land. Secondly, reduce the pollution of the land currently in use.

The use of clay and plastic sheets as pond lining to prevent salinisation of the land and groundwater is currently inadequate. Evidence of groundwater being contaminated by the saline pond water can be found in Vinh Truong. Converting the brackish water ponds to cultivate fresh water shrimps is not a viable option either as Ninh Thuan is a dry region with limited fresh water supply. Even if salinisation of the land is not a problem, there will be a shortage of fresh water to support the local community.

There is clearly a need for the aquaculture research institutes to develop better brackish water pond design and techniques to reduce salinisation and sedimentation. The current emphasis is on disease prevention, quality of seed supply and the increase of yields (Tran, V.N., personal communication, August 6, 2004). Another approach would be to look for creative ideas to use the sandy areas in Ninh Thuan, other than for shrimp farming. It is myopic to exploit and environmentally degrade such areas because they have no other immediate anthropogenic use.

- Community Cohesiveness and Capacity Building

Community cohesiveness and capacity building has an important role in promoting sustainable prosperity. A higher level of community cohesiveness will increase the information flow between villages and within villages. In terms of shrimp farming, this means that there will be more opportunities to learn from the mistakes of others, at the physical level and at the municipal level. From the interviews in Ninh Thuan, it was surprising that respondents at An Hai and Phuoc Dinh did not view groundwater resource as a possible limiting factor. It was evident that they did not know of the problems shrimp farming had brought to Vinh Truong. If locals and farmers are not convinced that their groundwater resource will be threatened, it will be hard to implement preventive interventions in that village.

Within the same municipality, community cohesiveness can have other positive effects. In Phuoc Dinh, there is evidence of high cooperation levels between the shrimp farmers and a quick response to problems. A group of farmers have banded together to start building a shared irrigation system and waste treatment facility. This cooperation is partly due to the fact that some of the shrimp farm owners are also municipal officers who have more influence in the local community to make and expedite such decisions.

In An Hai, there is not much cooperation between shrimp farmers. One of the pioneer shrimp farmers complained that the irrigation facility that he built and paid for is being used by other new shrimp farmers and they use the same inlet irrigation channels to discharge their pond effluent. This contaminates the irrigation source and affects the rest of the ponds that are dependent on this source. The free rider effect and the high expense of constructing proper inlet and outlet irrigation channels and waste water treatment facilities deters individual farmers from taking steps to protect their farms. Some farms are not in cooperation with other because they are sited too far apart from each other to making sharing of facilities a cost effective endeavor. The environment suffers from the effluent discharge, which causes eutrophication in the coastal waters and subsequently a decline in coastal catch and will reduce the fishermen's income. The feedback from polluted seawater as the saline proportion of pond water takes a long time to appear as it is dependent on many other factors that influence the mixing of seawater with the effluent water.

In addition to community cohesiveness, capacity building for decision making at the municipal level and the individual level would promote sustainable development. At the municipal level, municipal officers should be trained in community management of common resources. The good for many individuals may not be the good for the collective. It is also important for the municipal officers to know when to apply rule of thumb advice and in which situations professional scientific advice is required. At the individual level, farmers and potential levels should be informed of and have to capacity to evaluate the risks involved in the different types of businesses (shrimp farming in this context). Some farmers are not aware that they do not have the capacity to take the risk of high initial investments using loans with high interest rates. This capacity building in individuals will reduce the number of people rushing into shrimp farming, and fewer shrimp farms (with good management practices) will reduce the risk of exceeding the carrying capacity of the environment, and ensure the long term economic viability of the shrimp farming business.

5.3 Analysis of modeled solutions and other solutions using the DPSIR framework

The DPSIR framework, developed by the National Environmental Research Institute (NERI) in Denmark in 1995, is used here to help locate the hierarchy of the solutions discussed above and to step away from the physical and municipal level to analyse the problem from a higher level to give a broader palette of solutions. This hierarchy gives an indication of how much leverage a solution has and facilitates the identification of the actors for the different solutions. The DPSIR framework also brings the discussion to a full circle as it takes into consideration the variables included in the CLDs at the stage of model formulation.

The drivers have been derived from the CLDs in chapter 3. Responses to the drivers are theoretically the most effective solutions as they address the root of the problem. The section on impacts summarises the problems with shrimp farming into three categories- groundwater shortage, contaminated land and reduced fishing harvest. In the model, groundwater shortage is the main stumbling block as end of pipe solutions can be applied for contaminated land or reduced fishing harvest, but not for groundwater shortage. Groundwater shortage can only be managed if the numbers of shrimp ponds are controlled. The DPSIR framework approach shows that there are other methods to control the number of shrimp ponds than implementing permits or dissuading potential investors using risk assessments. These methods are not miracles, they are theoretically sound but are difficult to implement, especially in the context of Vietnam. Their merits and shortcomings are discussed in the Analysis column.

Table 5.1: Drivers- Discussion and Analysis on Shrimp Farming

	Description	Response	Analysis
Drivers	Desired wealth through export led growth	Change in consumer behavior to buy ecological products	This promotes sustainability at the source of production but does not necessarily have direct sustainable benefits to the consumer. It takes a long time and a large combined effort of many states and stakeholders to achieve results.
	Change in agricultural priorities	Environmental legislature and policy developed for shrimp farming areas	It is difficult to implement, monitor, and enforce environmental legislature and policy (Tran, V.N., personal communication, August 6, 2004; Neiland et al., 2001). Contradictory policies between ministries may arise (Flaherty and Vandergeest, 1999; Huitric et al., 2002).
	Profitability of shrimp farming	Environmental tax levied on effluent discharge and water usage.	It is difficult to monitor and enforce (Tran, V.N., personal communication, August 6, 2004; Neiland et al., 2001).
		Increasing the relative profitability of other crops	This does not solve the problem of natural resource exploitation. Other forms of intensive agriculture may give the same negative effects.
	Performance of 1st generation farms	Limiting the entry of new investments through permits	It is difficult to have a full account of all the negative externalities (Harris, 2002) and in turn calculate an exact optimum number of permits. Corruption and bribery may give rise to problems with enforcement.
		Capacity building for individuals	Risk analysis will help the individual to decide if shrimp farming is a suitable business venture. This may reduce the overall number of potential investors.

Table 5.2: Pressures and State- Discussion and Analysis on Shrimp Farming

	Description	Response	Analysis
Pressure	Use of Ground water	Start to charge for water	The prevalent “free and abundant” water resource mentality will likely protest against paying for water. It is also hard to stop farmers from drilling their own wells, especially if the wells are on their own land.
		Capacity building in municipal officers for community and natural resource management	It is better to decentralize some parts of the problem solving process as local knowledge may be the winning factor for the solution to be customized and implemented effectively.
	Sedimentation and Salinisation	Closed systems	It is relatively too expensive to implement closed systems. (Tran, V.N., personal communication, August 6, 2004)
		Breed only fresh water shrimps.	The depletion of the freshwater resource is not resolved.
	Eutrophication	Compulsory effluent treatment	There is inadequate funding to build sufficient effluent treatment plants. Some ponds may not be situated near enough to be connected to a treatment plant. The setting up of common facilities on the farmers’ initiative would require and certain level of community cohesiveness. The proximity to sea is a very tempting factor to discharge there directly (Do, D. P., & Nguyen, T.D., personal communication, August 22, 2004).
State	Quantity and Quality of Ground water	Water recycling or treatment	It is too expensive to implement. Since water is free, it is cheaper to look for other sources when original sources are contaminated or depleted.
	Concentration of sediments/salt	Cleaning the ponds	The problem is not solved as the sedimentation process continues and problems with the disposal of sediments are likely to happen. The employment of cleaning labour would increase operating costs for farmers.
		Lowering the stocking density	This conflicts with the farmers’ desire for more profits.
	Concentration of N in adjacent coastal waters	Reduce N using biological methods	The problem is not solved as farms continue to discharge effluent. There is also a limit to the capacity of biological methods

Table 5.3: Impact- Discussion and Analysis on Shrimp Farming

	Description	Response	Analysis
Impact	Fresh water shortage	Look for new sources	There is a fixed replenishment rate for the groundwater resource and exceeding this amount will deplete even alternative sources. Furthermore, the sources may be located too deep or far to be cost effective to be pumped for use.
	Contaminated Land	Look for new land	There is a finite amount of uncontaminated land. Land is also needed for other forms of agriculture, housing and other infrastructure.
	Reduced fishing harvest	Work as paid labour on farms	Due to the eutrophicated waters, coastal catch will decline and fishing may no longer be a viable livelihood option. These fishermen may have to find work as paid labour on farms. The security of this job option is uncertain as shrimp farms are self polluting and may not be able to stay in business.

5.4 Recommendations for the sustainable development of Ninh Thuan

Making recommendation for the sustainable development of Ninh Thuan is not a straightforward process. The dynamic nature of the problem makes it important to consider the urgency to remedy the situation, and a combination of solutions from the discussion and DPSIR analysis would be required.

To control pollution at the farm level, there is a need to reduce stocking density and to have vigorous cleaning of ponds after each season. At the municipal or community level, local officials need to build their community management and natural resource management capabilities to plan future development, give appropriate advice and help farmers to organise themselves into groups to facilitate the sharing of common infrastructure. National level authorities should cooperate with local authorities to demarcate the land area allocated for shrimp farming, and enforce this land use criteria. This amount of land area will have to be based on a careful analysis of the carrying capacity of the local natural system. Similar recommendations of having complementary national planning, economic, social and environmental analysis for the particular area and "effective institutions and representative institutions" have been made by the FAO (2001) on sustainable coastal aquaculture development.

There are differences and similarities between these recommendations and those desired by the shrimp farmers. Farmers have emphasized during the interviews that they are hoping for better shrimp seed quality that would give them better harvests. However this is only one aspect of many that affects their harvest performance, and the hope for a miracle shrimp seed may not be realised during the lifespan of their ponds. In suggesting that a there should be a local shrimp farmers' association, the shrimp farmers are also pointing to the same direction of community cohesiveness. Although they have a different motive of cutting costs through sharing rather than environmental protection, the same aim of a wider collective good is achieved. This is where the different domains of the environment, economics and society have common ground and win-win-win solutions for sustainability can be achieved.

6. Future Work

6.1 Model Refinement

There are several ways to refine the model to get more accurate results. Since the model is made using different stages, possibilities for model refinement exist at every stage to improve the quality of the finished product.

- Derivation: Group CLD session

A group CLD session will create more opportunities for iteration of the CLDs. CLDs improves with iterations. A better CLD will translate to a better model. The discussion during the CLD session would also help the different stakeholders understand each other's roles and their interdependency. This understanding may be able to inspire solutions or motivate concessions from the stakeholders, which will facilitate the problem solving process.

- Expanding System Boundaries: Include more variables to have a better representation of economic sustainability

Shrimp farmers are the major stakeholders in this situation. The survival of their farms affects the economic sustainability of the community. If the model were to include more economic variables from the farmer's perspective, their decision making process that influences the stocking density and total number of farms, would be represented more accurately. Variables which are important are: how high is the interest rate on their loan and how much is required to break even. The former would help to determine the stocking density and the latter can be used to estimate the farm's profitability which in turn determines if other potential farmers will start shrimp farming and when the shrimp farm will have to close down. Furthermore, the ability to calculate the relative profitability of pond management practices can be used in combination with the concepts of environmental economics to investigate the appropriate level of environmental tax. However, it is very difficult to obtain such information, judging from the experience in interviewing shrimp farmers in Ninh Thuan.

- Improving Model Inputs:

Better estimates of ground water resource and rainfall contribution to ground water will help to give a more accurate back calculation of the optimal number of shrimp farms. The use of the pulse function to imitate the rainfall pattern may give a more severe scenario during the period of water shortage, but the general trends will stay the same.

Other variables and relationships that can be improved on are: the cleaning efficiency; the relationship between the concentration of sediments; pond water quality and deaths. With more accurate numbers, a quantitative cost-benefit analysis can be performed for the farm and for the community.

In this model, the appearance of new farms is solely dependent on the performance of the first generation ponds. This is true if there are no positive changes to pond management or technology, but when there is a change, it would be more accurate to link the appearance of new farms directly to the farm which was set up the same year as the implementation of these positive changes. This is because new farms would definitely want to imitate their success using such management or technology and this will spawn a generation of farms (another set of arrays) until the next set of positive changes.

- Adding Flexible options

This model has flexible modeling options, for example, modeling the effects of building ponds for rainfall collection and groundwater contamination. For the former, add a new rainfall flow to a new stock representing the pond water. Combine both groundwater resource and pond water to a new stock of usable water and add the outflow usage of water. For groundwater contamination, the stock of usable groundwater will decrease and this can be represented using an outflow from the groundwater resource.

However, there is a limit to how flexible this model can be as it was made for the purpose of fulfilling the aims of this thesis. New models developed from this model may be more suited to answer further research questions.

6.2 Comparative Studies on Intensive Aquaculture

Future work can move in the direction of developing strategies for controlling the number of farms. Comparative studies on the intensive shrimp farming in Thailand and intensive salmon farming in Norway may give insights into the factors and conditions influencing the success and failure of intensive aquaculture.

6.3 Development of a Risk Assessment Framework

Shrimp farming is a risky venture. The development of a risk assessment framework at the individual, municipal and national level will help the actors at the different levels to make informed decisions.

7. Conclusion

Intensive shrimp farming is a good example of how closely the environment, social and economic aspects are intertwined. The reinforcing social and economic loops run on shorter time cycles as compared with the balancing environmental cycle, which makes the possibility of exceeding the environmental carrying capacity a high risk. This thesis has fulfilled its original aims of proving that the business of intensive shrimp farming with the current technology and management practices will not alleviate poverty in Ninh Thuan. Working as paid labourers on the shrimp farms is an insecure job option and the quality and quantity of land and water resources of the local community will be threatened and locals may be worse off than before shrimp farming started. The failure of reducing stocking density and cleaning the ponds to safeguard the water resources indicates that there are no easy solutions. Unfortunately in Vinh Truong, irreversible damage has already been done, but these lessons are useful to prevent the same mistakes in other places.

This thesis has conceptualized the problem, gathered, organized and analysed the information and evidence, such that directions for the next steps are clear. There must be a limit to the area of land used for shrimp farming. The limit has to be calculated based on the carrying capacity of environmental resources and be implemented in an effective manner.

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Appendix

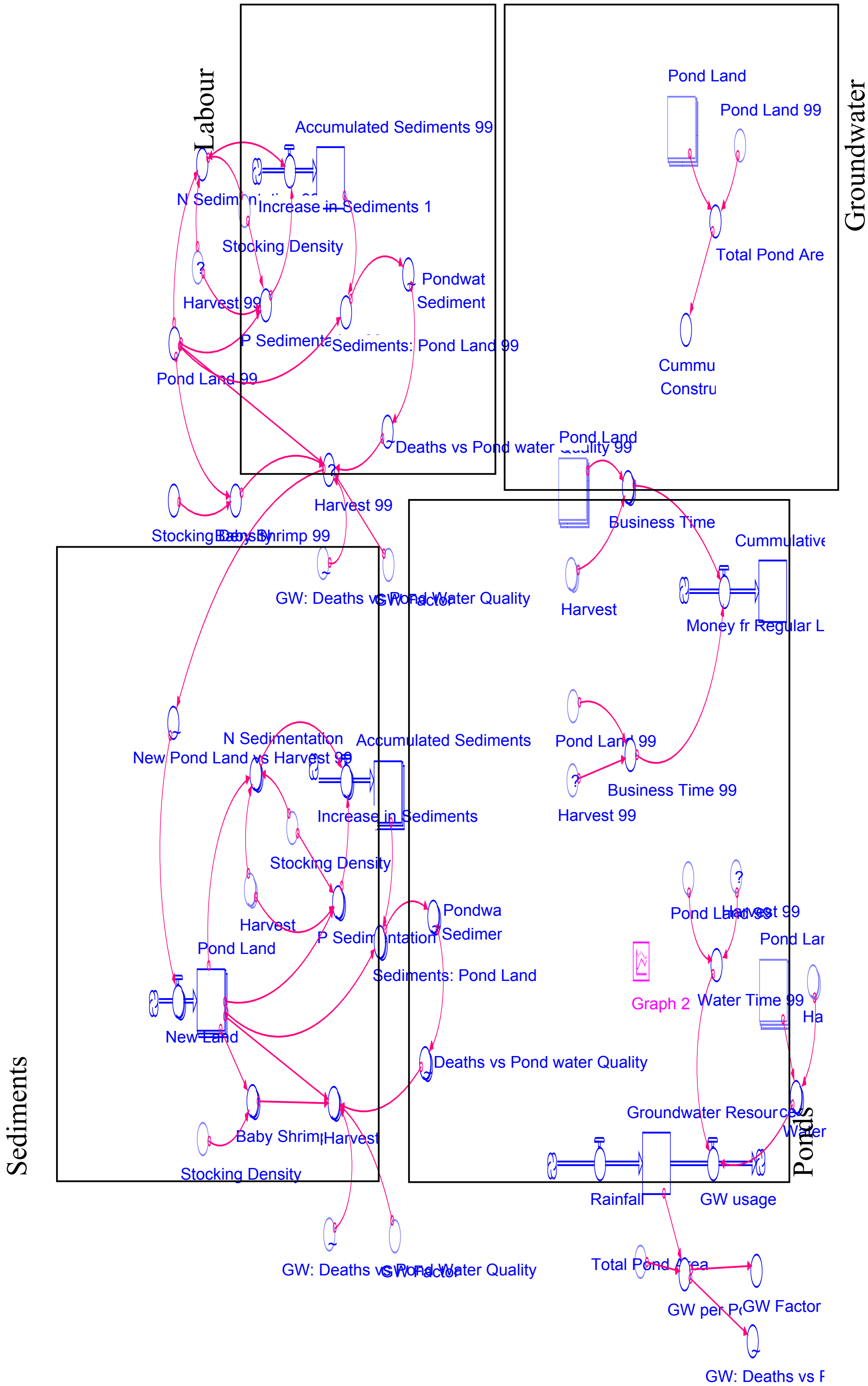

Figure A1: BAU model

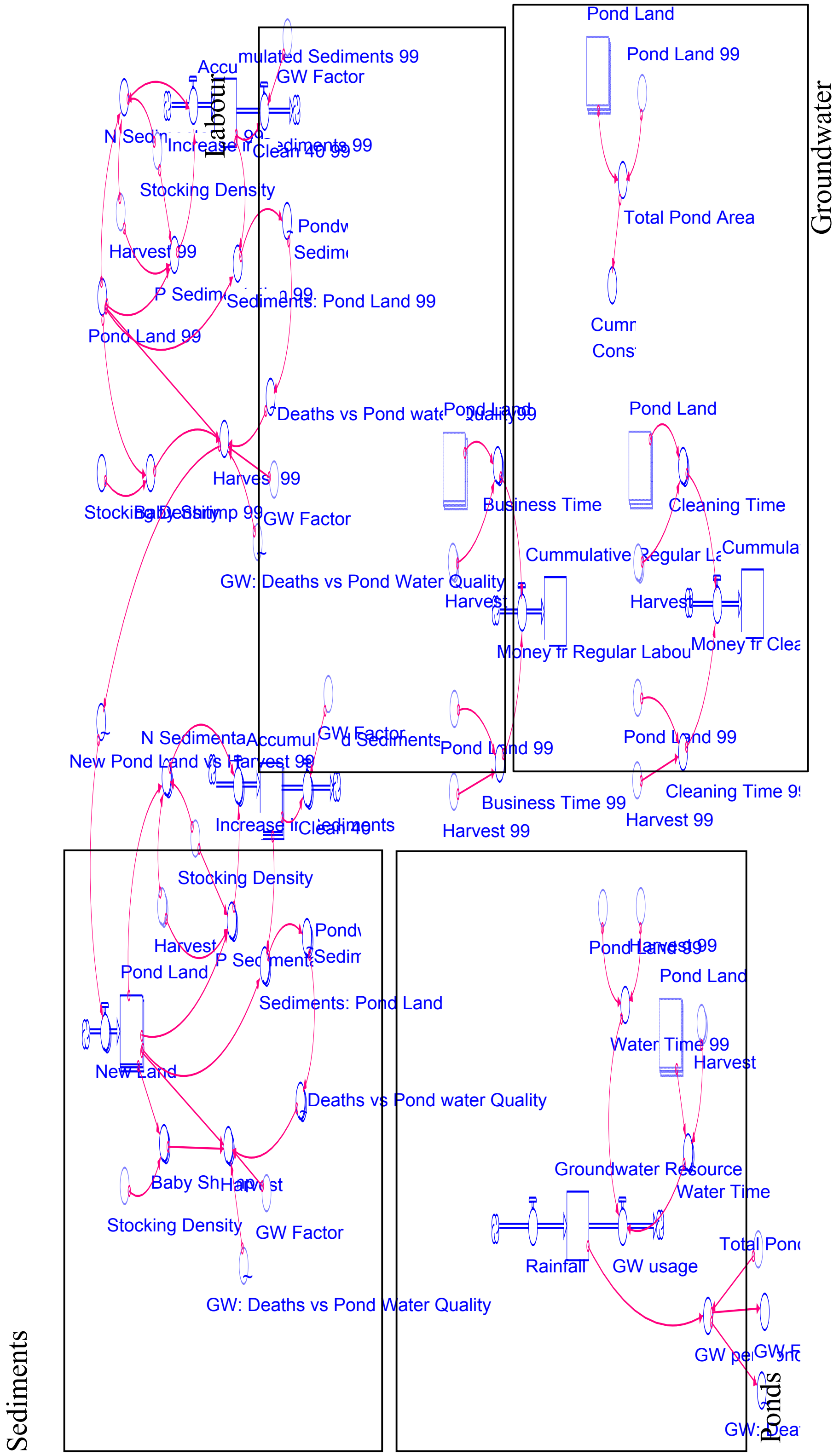

Figure A2: BAU model with suggested solutions