

# **Sustainable Management of Shrimp Farming: A Case Study in Ninh Thuan, Vietnam**

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## **Abstract**

Here, a systems dynamics approach combines the environmental, economic and social aspects of intensive shrimp farming to construct a sustainability forecast. Intensive shrimp farming threatens to cause irreversible damage to water and land resources. High initial investments required are risky to small start-up farmers as ponds are prone to self contamination within a few years. This study is based in Ninh Thuan, one of the poorest regions in Vietnam. Since 1999, local people started to turn to intensive shrimp farming for quick profits. Causal loop diagrams presented focus on the individual shrimp farms and their collective effect at the municipal level. Modelling on the environmental aspect indicates that the current practice of intensive shrimp farming is not sustainable for Ninh Thuan. A combination of lowered stocking densities, pond cleaning and limitation on the land area converted to shrimp ponds will be beneficial for the local community in the long term.

## 1. Introduction

Worldwide aquaculture has been increasing rapidly in the last decade, including shrimp aquaculture. From a local perspective, shrimp aquaculture increases rural employment, but it also has negative environmental effects. Firstly, effluent discharge from the farms causes eutrophication (Patila et al., 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). The use of systems analysis will combine the environmental, economic and social aspects of intensive shrimp farming to construct a sustainability forecast. An overview of the shrimp commodity system has been modelled by Johnston, Soderquist and Meadows (2000). Arquitt, Xu and Johnstone (2006) have made a model based on the Thai shrimp aquaculture industry and its effect on mangroves. The contribution of this work is that it focuses on the individual shrimp farms and their collective effect on groundwater and land use at the municipal level. The aim of this paper is to show that current practices of shrimp farming in Ninh Thuan are not sustainable. The short and long term effectiveness of lowered stocking density, pond cleaning and a restriction on the land used for shrimp farming will be investigated.

### *Geographical, Social, Economic and Environmental background*

In 1986, Vietnam implemented Doi Moi, a shift to a market economy, which stimulated a 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). 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). With such a reliance on natural resources for economic growth, is important to investigate if current trends are sustainable to ensure long term prosperity and well being of the Vietnamese people.

Ninh Thuan is a coastal province in south central Vietnam with an area of 3352.27 km<sup>2</sup>, coastline of 105km and annual rainfall of 600mm (Centre for Rural Progress (CRP) and World Bank, 2003). The lack of alternative livelihoods in the rural regions, together with the abundance of cheap unused land, free access to groundwater, low labour costs and favourable climate were the ideal conditions for shrimp farming to expand. Shrimp farms

are mainly private investments practicing intensive cultivation methods. The year round warm temperatures makes it possible to have 3 growing seasons of shrimp.

The main the livelihood option of the population of Ninh Thuan was farm help 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 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.

## 2. Context characteristics and model description

This paper will focus on the municipal and individual shrimp farms levels, and omitting the international and national levels.

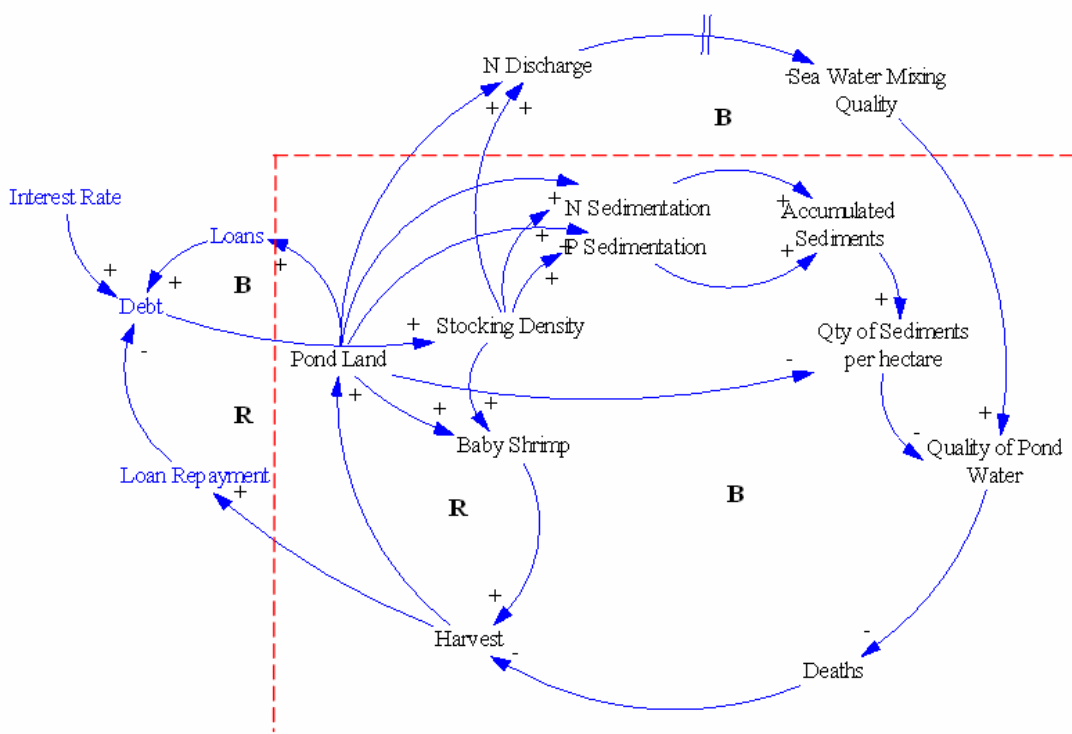


Figure 1: Causal Loop Diagram for the shrimp farming system at the Municipal Level

### *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). 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 *et al.*, 1998). In addition, the amount of water resources has 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, as appropriate levels of salinity and other water quality parameters for shrimps to mature will not be maintained. This result in a poor harvest and profits will decrease.

The prospect of quick and high profits 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. Interviews with the shrimp farmers in Ninh Thuan have confirmed 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. Figure 1 shows the causal loop diagram for the shrimp farming system at the municipal level.

### *Individual Shrimp Farm*

A good harvest will lead to higher profits and this will attract more investment and an increases the amount of land 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 *et al.*, 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 *et al.*, 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.

Shrimp farming requires high initial investment. Information from the interviews indicates that 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 cultivate as many shrimps as they can in order to profit from more harvest for debt repayment.

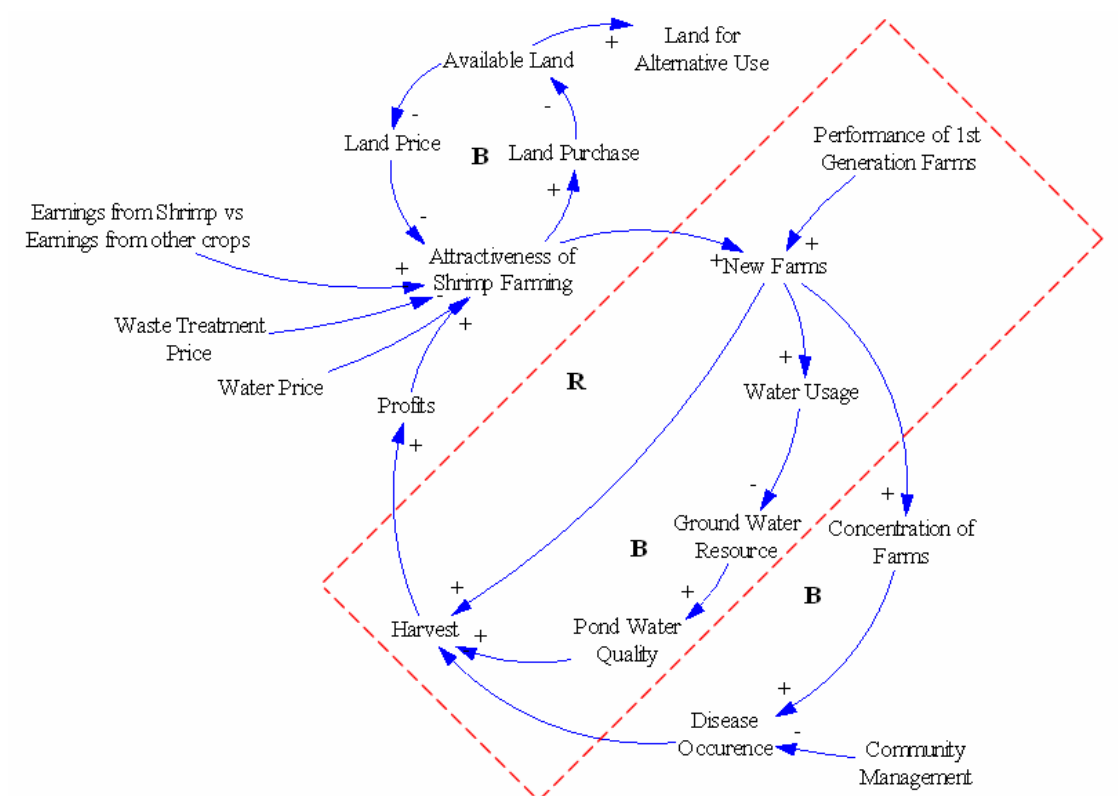


Figure 2: Causal Loop Diagram for the Individual Shrimp Farm

### *From Causal Loop Diagrams to Model*

The red dotted lines in figures 1 and 2 demarcate the modeling boundaries. The proliferation of shrimp farms were modeled as an array dependent on the performance of the farms established in the first year. New farms were only added at the start of the next year. This will cause the increase in the area converted to shrimp farms to follow a step-like trend. A lock was placed on the groundwater stock to limit the inflow of rainfall when it was depleted. This was done to show the delay in the accumulation of groundwater and its effect on the shrimp farms. The assumptions made are compiled in Appendix.

### *Solutions*

Four solutions are modeled and their results will be compared against the business as usual (BAU) scenario. First the ponds will be cleaned (Clean) and this can be modeled as an extraction from the stock of accumulated sediments. Second, a combination of the lowering of stocking and cleaning the ponds will be tested (Combi). Finally, a limitation on the land area converted into shrimp ponds will be imposed (Restriction).

## **4. Results**

### *Harvest*

The BAU scenario has a stocking density of 40 shrimps/m<sup>2</sup> 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 lifespan of the shrimp pond in this scenario was 19 seasons, which was comparable to 15 seasons in 5 years (Patil *et al.*, 2002). By the 15<sup>th</sup> season, shrimp farmers would have experienced a decline in their harvests and would intervene in an attempt to get better harvests. Cleaning action taken will prolong the lifespan of the pond to the 48<sup>th</sup> season, while a combination of lowered stocking density and cleaning action lengthens the lifespan to the 70<sup>th</sup> season. As the land use restriction is modeled based on the combination of lowered stocking density and cleaning action, it follows the same harvest trend. Figure 3 shows the harvest results.

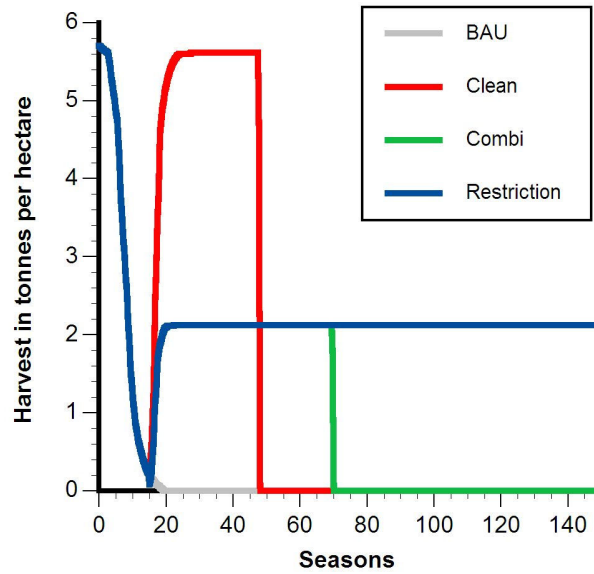


Figure 3: Harvest results for BAU, Clean, Combi and Restriction Scenarios

#### *Land Converted to Shrimp Ponds*

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. With cleaning activities, shrimp farming was attractive for 48 seasons, and a total area of 1518 hectares was converted into ponds. A combination of lowered stocking density and cleaning action lengthens the attractiveness of investing in shrimp farming for 70 seasons, and a total area of 1294 hectares was converted into ponds. It is implicitly assumed that local farmers are looking for a stable alternative livelihood, where the longer the viability of the business the more attractive it is to invest. When the limitation on the amount of land converted to shrimp ponds is imposed, the area of land converted to shrimp farms increase until that limit. An optimum area of shrimp ponds can be obtained for a given quantity of groundwater resource, its rainfall input, stocking density and the presence of cleaning activities. Figure 4 shows the amount of land converted to shrimp ponds.



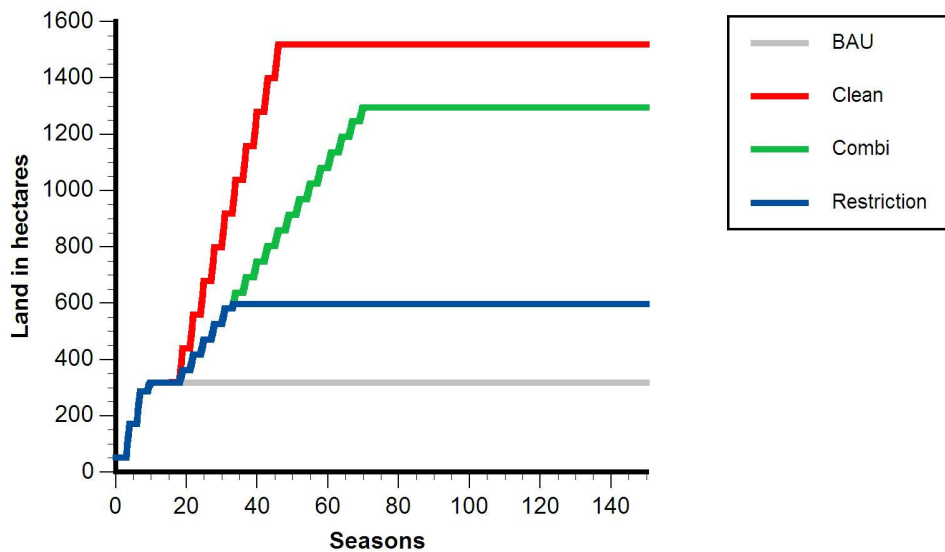


Figure 4: Amount of land converted to shrimp ponds for BAU, Clean, Combi and Restriction Scenarios

#### Groundwater

In the BAU scenario, groundwater resource was not the limiting factor. The ponds use less water than what is obtained annually from rainfall. When the shrimp ponds close down due to self contamination, the increase in groundwater resource is much faster. However, with cleaning activities, the number of shrimp farms increases and groundwater usage increases. More water is drawn out than collected from rainfall, causing the water resource to decline. When the groundwater resource is depleted, the farms cannot continue without freshwater and they close down. The combination of lowered stocking densities and cleaning follows the same trend as the cleaning scenario. The lower limit of groundwater restricts the inflow of rainfall after the stock of groundwater is depleted. In the scenarios without cleaning activities, the stock of groundwater is not depleted and is allowed to accumulate. With cleaning activities, the groundwater stock is depleted; restricting the groundwater stocks that stays zero. When the land use restriction is applied, the use of groundwater follows the increase in the total area of shrimp ponds and stabilises at the point where the restriction comes into effect. In this case, groundwater resource is not depleted. For the starting values of groundwater and rainfall in this model, the optimum area of land to be converted to shrimp ponds is 580 hectares. Figure 5 shows the level of groundwater resource.

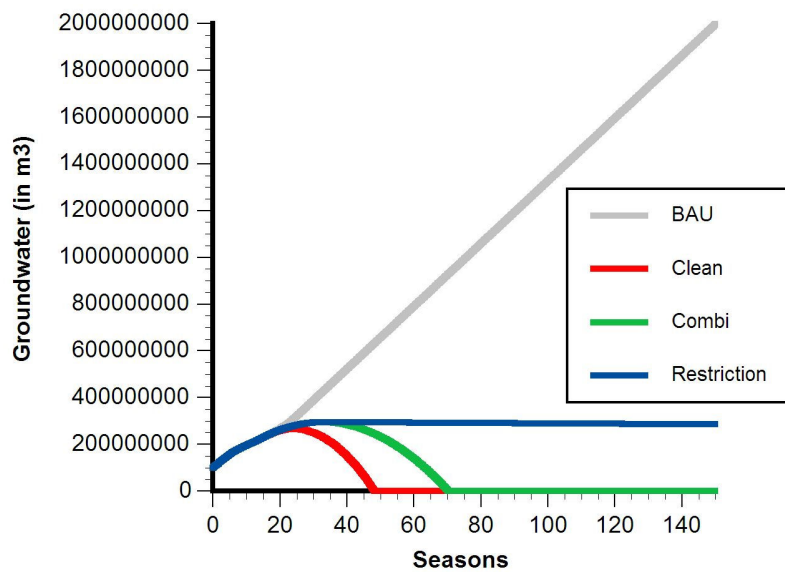


Figure 5: Level of groundwater resource for BAU, Clean, Combi and Restriction Scenarios

## 5. Discussion

Implementing cleaning practices or the combination of lowered stocking densities and cleaning at the individual shrimp farm level are inadequate solutions. Implementing restrictions on land use is the preferred alternative to ensure the long term survival of the shrimp farms and the sustainability of the groundwater resource.

### *Effectiveness of cleaning the ponds*

Cleaning activities increases the lifespan of the pond through controlling sedimentation. Costs will be incurred as cleaning activities would require more labour per hectare of pond. As more new farms adopt the new practice of cleaning, groundwater availability becomes the limiting factor. 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. Cleaning the ponds is an inadequate solution if implemented alone.

### *Effectiveness of lowering the stocking density and cleaning the ponds*

Cleaning the ponds helps to partially correct the problem of sedimentation, but the initial success of this management technique attracts more new farms imitating this farming practice which in the long term results in inadequate groundwater supply for all the farms. This scenario would not be attractive to shrimp farmers as it requires them to lower their stocking density which translates to a lower harvest per season. In addition, there

will also be an increase in the labour costs due to the manpower required to clean the ponds. This response from potential investors can be seen when total pond area in the combination scenario is lower than that of the cleaning scenario.

#### *Effectiveness of land use restriction*

The failure of lowered stocking densities and cleaning activities shows that end-of-pipe solutions are not always effective. It also shows that it is very important to limit the amount of land used for shrimp farming. A systems analysis approach allows the problem to be analysed at different levels over time. It helps to reveal the delay in the shortage of groundwater and that the limiting factor may not be on the same level as the individual ponds. Remedy action needs to be taken both at the individual and collective level. At the collective level, this implies that there is a need for an accurate assessment of groundwater and the optimal area of land converted to ponds. 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. Local people working as farm help are only concerned if they will have stable employment at the shrimp farms. Unfortunately they will also be the ones too poor to move away and have to endure the effects of polluted land and depleted groundwater supplies. The benefits and consequences of shrimp farming are divided unequally across different stakeholders. In addition, they hold varying decision making power at the collective level.

One way to implement land use restriction is to embed it in an export tax with rebate policy (Arquitt *et. al*, 2006). All farmers would be taxed and tax rebates will only be given to licensed farmers working in areas zoned for shrimp farming. Arquitt *et. al* (2006) have also highlighted the need for an ongoing assessment of the environmental carrying capacity by a transparent, qualified organization to regulate tax levels, shrimp farming zones and licenses. This policy and organization should be present before the proliferation of shrimp farming (Arquitt *et. al*, 2006), and implementing it halfway, as the situation is now, may not be as effective as it could have been.

Social and economic benefits from shrimp farming could be derived from a combination of variables in the model. The profitability of this business to the shrimp farmer is in proportion to the lifespan, harvest and stocking density. Estimation of the number of workers employed for cleaning activities could be made from the total pond area from the cleaning scenarios. The lifespan of the shrimp farm serves to indicate the workers' job stability. By obtaining the trend of land prices and the amount of land converted each year into shrimp farms, the

earnings from the sales of land, from the local community to shrimp farmers could be calculated. The quantity of groundwater water per capital could be used as an indication of the standard of living of the local community.

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 as flooding in the monsoon season. This emphasizes the need for accurate values of the rainfall input and the starting quantity of groundwater resource before promoting the shrimp farming industry. The sustainable use of ground water resource also has to take into account other factors outside the system boundary of this model, including the growth of population, the possible increase in water usage per person and usage from other crops.

## 6. Conclusion

Intensive shrimp farming is a good example of how closely the environment, social and economic aspects are intertwined. The economic driver of potential profit is so strong initially that it makes the possibility of exceeding the environmental carrying capacity a high risk. With the current technology and management practice, the initial benefits from shrimp farming will not be sustained in Ninh Thuan. The quality and quantity of land and water resources of the local community will be polluted and the local community 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 and cooperation and commitment of the stakeholders to restrict the land used for shrimp farming is required for the sustainable development of Ninh Thuan.

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## Appendix

Table A.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.                                                                |
| Stocking Density | 20-30 Shrimps/m <sup>2</sup> giving a harvest of 4-6 tonnes/ha/crop                                         | Boyd, 1998                     | 40 Shrimp/m <sup>2</sup>                                                                                                                                                                                                                 |
|                  | Open system ponds 60-100 Shrimps/m <sup>2</sup>                                                             | Funge-Smith, 1996              |                                                                                                                                                                                                                                          |
|                  | 29.9-115.1 Shrimps/m <sup>2</sup>                                                                           | ADB/NACA, 1996                 |                                                                                                                                                                                                                                          |
|                  | 15-50 Shrimps/m <sup>2</sup>                                                                                | 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     |                                                                                                                                                                                                                                          |

Table A.1b: Summary of the assumed values in the BAU scenario

| Variable              | Guideline                                                                                                                                                                                              | Source                     | Assumed Value in BAU                                                                                                                                                                                                                                                               |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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 |                                                                                                                                                                                                                                                                                    |
| Rainfall              | Total Area of Ninh Thuan: 3352.27 km <sup>2</sup><br>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 <sup>3</sup> 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 <sup>3</sup> per Ha per crop                                                                                                                                                                                                                                                |
|                       | 5-20% of pond volume daily                                                                                                                                                                             | Boyd, 1998                 |                                                                                                                                                                                                                                                                                    |
|                       | 6667 m <sup>3</sup> per ha per crop                                                                                                                                                                    | CRP and World Bank, 2003   |                                                                                                                                                                                                                                                                                    |

Table A.1c: Summary of the assumed values in the BAU scenario

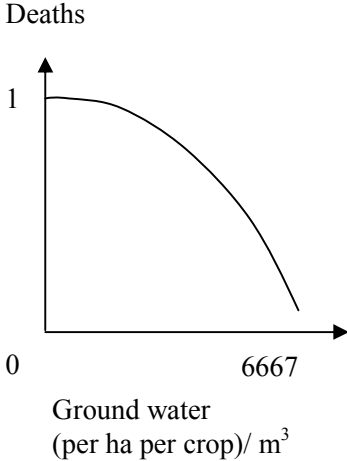
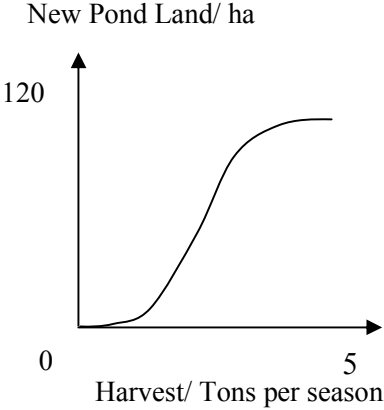
| Variable | Guideline                                                                        | Source                         | Assumed Value in BAU                                                 |
|----------|----------------------------------------------------------------------------------|--------------------------------|----------------------------------------------------------------------|
| 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<br>Lowest: Less than 1 ton per ha per season | Interviews with shrimp farmers |                                                                      |

Table A.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. |



Table A.2b: Summary of the assumed trends in the BAU scenario

| Relationships                                | Assumed Trend in BAU                                                                                                                                                                                                                                                                                                                                                                                                     | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ground Water: (Deaths vs Pond Water Quality) |  <p>The graph shows a downward-sloping curve. The vertical axis is labeled 'Deaths' and has a tick mark at '1'. The horizontal axis is labeled 'Ground water (per ha per crop)/ m³' and has a tick mark at '6667'. The curve starts at the point (0, 1) and curves downwards, becoming steeper as it approaches the x-axis at 6667.</p> | <p>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<sup>3</sup>, 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.</p>                                                                            |
| New Pond Land vs Harvest 1                   |  <p>The graph shows an S-shaped curve. The vertical axis is labeled 'New Pond Land/ ha' and has a tick mark at '120'. The horizontal axis is labeled 'Harvest/ Tons per season' and has a tick mark at '5'. The curve starts near the origin, rises steeply, and then levels off as it approaches the value of 120 on the y-axis.</p> | <p>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.</p> |