# Impact of shrimp pond wastewater on the estuaries and the issue of salinity intrusion in the Quang Tri Province


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# Acknowledgements

On the 15th of September 2007, I was in for the biggest adventure of my life so far. I hadn't been outside of Europe before, so Vietnam would be my first real big trip. I was very exited about it, though I was a bit worried about how the differences in cultures would affect me and also my research. From the first day the content of my research changed over and over again. After a couple of weeks I finally had my definite planning made, ready to start my research. After 3 months of doing research I can't say that I'm fully satisfied with my results. At first I would do both a qualitative and quantitative analysis, but because of several circumstances, my research ended with only the qualitative analysis. Still I think that the results are very much applicable, though more research and especially funds for the measures are needed.

The study has given me a very good insight of how shrimp farms operate and what kind of problems the people at the shrimp farms have to fight. I hope that my report, although it will be a very small part in a very large study case, can be of help for both the people and the government in the Quang Tri Province, so that a more stable economic environment can be created.

This research could not have been possible without the help of a large number of people. First of all I want to thank dr. Nguyen Tien Giang, dr. Jean-Luc de Kok and dr. Tran Ngoc Anh for the direct help for me on this study case. Dr. Giang helped me in many ways, of course he helped me with my research a lot, but he also took me on a fieldtrip, showed me around on the university and he was the first one who took me on a motorbike. Dr. Anh also helped me on a day to day basis for my research, but he also took me to the football pitch where we had a lot of fun playing football with the department. The department on which we were warmly welcomed by Assoc. Prof. Dr. Nguyen Hun Khai. I also want to thank dr. de Kok who helped me by communicating via email to give me his opinion on the progress and the direction I was following. The final two weeks I was helped by dr. Augustijn because of health problems of dr. de Kok, so although it was a short period, I want to thank him to for guiding me as well.

The 3 months I lived in Hanoi, I stayed in a home with mrs. Lieu and mr. Tuyet. They have made my life in Hanoi a lot easier. Mrs Lieu cooked for us all day, every day and helped us out with all our basic needs. Mr. Tuyet showed us how great an evening with his friends in Hanoi can be, by having a beer, having a laugh and playing chess. Although the communication was difficult at times, I think that in the end we understood each other pretty well.

Next I have to thank a person who I didn't know at all before I went to Vietnam, but who I now consider to be a friend, my companion Jorik Chen. We had 3 months of pure fun going from one adventure to another. Going out for a beer, going on a trip to a temple or hanging out with local people. He also helped me where I needed him for my report; when I was stuck, asking sentences in English etc.. Thank you so much, I couldn't have found a better match.

And last but most certainly not least my dear friend Dung Hoang. I met Dung when I needed someone to translate articles for my report from Vietnamese to English. Although she has been a great help for me with that, she conquered a special place in my hart by taking us to so many great places, from a Vietnamese wedding to a karaoke evening with her friends. She showed me the way Vietnamese people live, something an average tourist would never experience. I will cherish those moments for all my life, and I hope that we will meet each other again someday.

Hanoi 13th of December 2007

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# Summary

Quang Tri Province is located in the central part of Vietnam. Quang Tri has very special geographic characteristics, with mountains in the west and a very flat east side. The east side has a coastal zone which has two main rivers, the Ben Hai river and the Thach Han river. These two rivers have many tributaries and finish in the South China Sea. The two estuaries of these rivers, Cua Tung and Cua Viet are very good sites for aquaculture to take place, because of the brackish environment. That's the main reason that many shrimp farms are located near or at the estuaries.

Shrimp production could be a very good economic resource for the Quang Tri Province, but the last couple of years problems are occurring at the shrimp farms concerning diseases. In 2006 at some farms up to 80% of the production of shrimps was lost. The main reason for the diseases to occur is that the farmers take in water directly from the river. The water quality of the rivers are often not suitable for shrimp farming. The water gets polluted by industries, agriculture and shrimp ponds themselves.

Water is taken in at the beginning of each production period, but it is also taken in more frequently during production because of the high evaporation at that time, which effects the salinity rate of the water in the ponds. Salt water can only be taken in at high tides, but at high tides the polluted water that is discharged by farms at the end of a harvesting period tends to flow back upstream of the river.

In this research a literature study is done about similar problems that occurred years ago in Thailand, Indonesia, Bangladesh and China. In these countries the problems have largely been solved. This information in combination with new research information about water quality problems, provided enough information about possible measures.

The measures have been evaluated with the help of a Multi-Criteria Analysis. And as the best result the combination of better management, a fresh water reservoir and a reservoir with a culture in it seemed to be the most suitable. Though after the fieldtrip of November 2007, it became clear that because of the wide diversity of the structure of shrimp farming communities, a closed circuit biofilter seemed to be more useful for the smaller communities. Better management will include, better equipment for water quality measurement, simple tools to prevent external factors to affect the shrimp ponds, and policies by the government to be able to make a better structure for the shrimp farming in the province.

In this research the problems and the possible impact of solutions would be modeled in the MIKE11 model, but unfortunately because of the delay of the fieldtrip in which a lot of important data was gathered, time didn't allow me to use the model for this thesis already. So this should be done in the next project for this case.

The recommendations are to make a complete quantitative analysis with more and specific data about the water quality around the shrimp ponds, to make a study about the quantitative impact of all the proposed measures, Simple measures should be applied immediately and step by step the Quang Tri province should work towards a stable economic environment for the brackish aquaculture, this will require a lot of effort from the government, but also from the farmers,

# Table of Contents

# List of Figures

# List of Tables

# 1 Introduction

In recent years the production of tiger shrimps worldwide has increased exponentially. Especially for developing countries it is a very attractive market, to increase the economic wealth and export to other countries.
Though with the growth of the industry more problems occurred in the last couple of years. In one of the central provinces in Vietnam, namely Quang Tri, farmers lost a lot of their production, sometimes even up to 80% of their harvest. Most of the dead shrimps had symptoms of several diseases, for example red skin disease and white spot disease.
The question however was what caused these diseases? Apparently the water quality of the water taken in wasn't good. There we're a lot of polluting substances in it, which strangely came from shrimp farms themselves and of course from other industries.
The farms that produce these tiger shrimp need certain salinity, so only at high tides water could be taken in. Because of the high tides however, the discharged (polluted) water from shrimp farms flowed back towards the shrimp farms, leading them to take in polluted water.
The Hanoi National University of Science is asked by the province of Quang Tri to provide measures to solve these problems.

## 1.1 Goal

The goal of this research is to examine what structural and non-structural measures can and should be taken to improve the water quality in the shrimp ponds and the estuaries.

## 1.2 Research Questions

- What are the characteristics of the Quang Tri Province?
- What are the current problems with the farming of shrimps in Quang Tri Province?
  - What is the state of the art of brackish pond culture in the coastal area of the Quang Tri Province?
  - What is the impact of shrimp pond cultures on the water quality of the estuaries?
  - What is the impact of the water quality and the salt intrusion in the estuaries on the shrimp pond culture?
- What are the possible measures for environmental protection and socio-economic development in the coastal area of the Quang Tri Province regarding the shrimp pond culture?
- Which measures are most suitable for the researched area in Quang Tri Province?

## 1.3 Methodology

To answer the first research question, available information about shrimp ponds in Vietnam and specifically in the Quang Tri province should be read. There have been several fieldtrips already to the shrimp ponds in the research area; data was collected about the way the shrimp ponds operate and the size of different shrimp farming types. Eventually on the last fieldtrip (November 2007) the exact location of every shrimp pond in the coastal area of the province have been written down and added to a map of the province.
There is a lot of information available about the problems that are occurring these last years in Vietnam. Similar problems have occurred in lands like Thailand, Indonesia, Bangladesh and China. So literature available covering the problems that occurred in these countries needed to be gathered to answer the second and third research questions. This includes the difficulties with the salinity intrusion.
After the possible measures have been gathered, a Multi Criteria Analysis has been applied to determine which of these measures are most effective in the research area. The effectiveness is determined by the chosen criteria and boundaries, which are mostly found by choosing which goals should be achieved, and determining which of the criteria have the highest priority. In this way a certain weight is given to each criterion, though when further research will be done, these weights should be determined in a more specific and detailed way.

# 2 Characteristics of Quang Tri Province

The Quang Tri Province is located in the central part of Vietnam. It covers a total area of 4.592 $km^2$ and it has a large river network that provides a useful place for aquaculture. This research will cover only the coastal part of the Quang Tri Province, because this is where the shrimp ponds for this research are located.


*Fig. 2.1 Location of Quang Tri Province*

## 2.1 Geographic

The Quang Tri Province can be divided in two different geographical parts. The east part which is relatively low and ends at the coast line at the South China Sea. The western part which is a mountain area and is relatively high (between 1400m and 2000m). The difference in height between the east and west has a major effect on the weather conditions. They can be completely different from each other at the same time. Also the mountain area can cause rain and winds in the eastern (coastal) part.

*Fig. 2.2 Satellite image of Quang Tri Province*

In the estuaries and also some of the tributaries of the rivers this sea is of great influence. The land is relatively flat so the tidal regime causes the salt seawater to intrude far into the land.
Once a month the tide reaches a peak which allows salt water to intrude very far upstream of the river. In this peak there are two high tides. So the farmers choose one of these high tides to take water in, incase the water is (visually) polluted too much. The tidal regime graphs can be found in appendix A.

## 2.2 Hydrologic

As shown in the figure 2.2 and 2.3 there are two main river estuaries in the coastal area. These estuaries are the end of a complex river network. The two main rivers are the Ben Hai river (North) and the Thach Han river (South). The largest tributaries of these rivers are shown in table 2.1. The two rivers each flow towards their own estuary. The Ben Hai river flows into the Cua Tung estuary, the Thach Han river flows into the Cua Viet estuary.

| Main River | Tributary |
|---|---|
| Ben Hai | Sa Lung<br>Ben Xe |
| Between BH and TH | Canh Hom |
| Thach Han | Cam Lo<br>Vinh Phuoc |

*Table 2.1: Main Rivers in Quang Tri with most important tributaries*

The rivers in the northern parts of Quang Tri are in the region where the rainfall is high. Annually the Ben Hai river discharge water to sea with a total amount of 1.35 billion $m^3$ with an average discharge of 43.170 $m^3$/s.
The Thach Han river discharges water to sea with a total amount of 3.145 billion $m^3$ with an average discharge of 128.25 $m^3$/s. However the annual flow is variable. In some years the water amount can be 1.5-1.6 times higher than the annual average. (Source: Quang Tri Province, year unknown)
Flow in a year is divided into two seasons, flood season and dry season. In the upper part of Thach Han river rainy season comes earlier, it starts in July and ends in December. The month which has the

greatest flow is September. The months with the lowest flow are April and July. In the lower part of Thach Han river the flood season starts in September and ends in December or in January, the greatest discharge concentrates in October or November.
The estuaries are very complex because of the large amount of tributaries. In the estuaries the salt water of the sea can intrude up to 24 km into the land. So there is an important process of mixing of freshwater and saltwater, making it a brackish environment. The flow channels change much because of the large differences in water discharges. (Source: Quang Tri Province, year unknown)

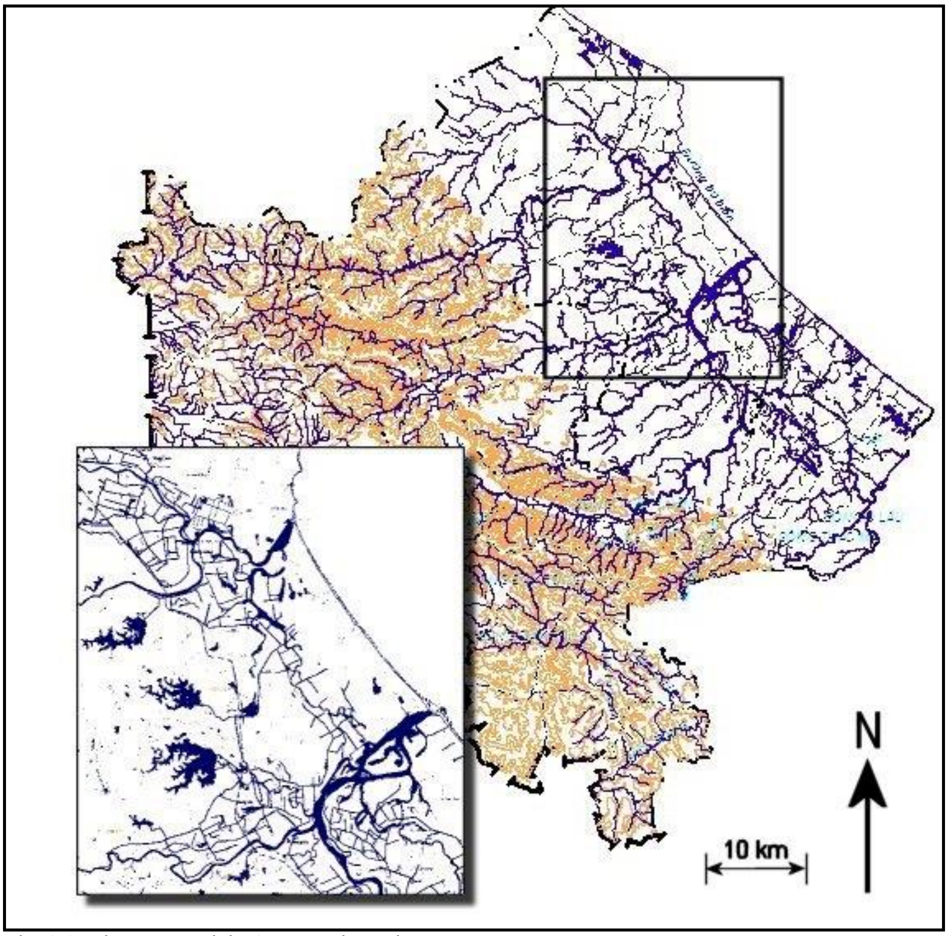


*Fig. 2.3: River Network in Quang Tri Province*

## 2.3 Climate

Vietnam has a very humid climate. In a year the average rainfall is 2000-3000 mm. The wettest months are from August to December. The dry “season” is from February to July. In the summer the air in the Quang Tri Province can be very dry. This is caused by winds which come over the mountain area and drop towards the lower parts in the province. The rainfall per month can drop to 40mm.
The largest rainfall occurs from September to November, these are the months in which typhoons are regular. Also the combination of warm air from the south and cold air from the north causes much rain.
The amount of sunshine in the Quang Tri Province varies from extremely high in the summer to extremely low in the winter. The amount of sunshine (hours) in the summer is so high that the evaporation is about 2.5-3 times larger than the precipitation, causing great draught.
At Dong Ha (near the Thach Han river) the monthly evaporation is measured. The results are shown in table 2.2. At plain regions the average evaporation is much higher then mountainous regions. The highest monthly evaporation at Dong Ha station is 219 mm/month. The highest daily evaporation is observed in July, daily evaporation can then reach 7 mm.

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dong Ha (measuring station) | 53.5 | 49 | 54 | 71.5 | 126 | 195 | 219 | 189 | 100 | 90 | 71 | 61 | 1279 |

*Table 2.2: Monthly and annual evaporation at Dong Ha station*

The annual average temperature is about 24.3 °C. The daily difference of temperatures lies between 7-10 °C. The monthly temperatures at Dong Ha are shown in table 2.3.

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dong Ha (measuring station) | 19.2 | 19.3 | 22.5 | 25.6 | 28.2 | 29.3 | 29.6 | 28.8 | 27.1 | 25.1 | 22.5 | 19.9 |

*Table 2.3: Monthly average temperatures at Dong Ha station*

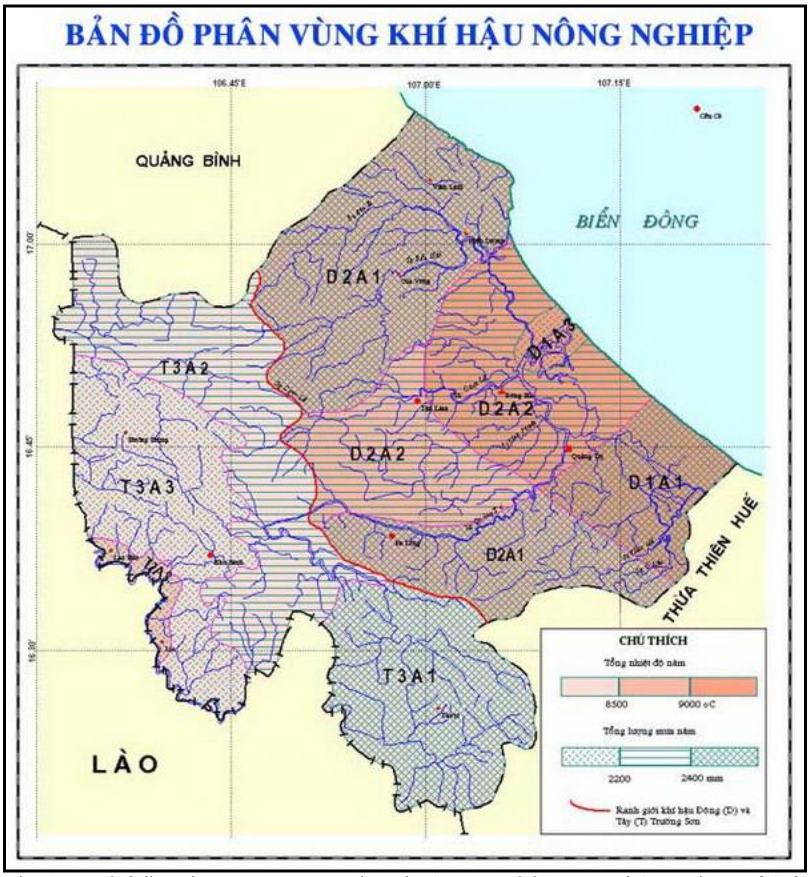


*Fig. 2.4 Rainfall and Temperature regions in Quang Tri (Quang Tri Committee of Science and Technology, source: internet)*

The characteristics of storms and tropical cyclones in Quang Tri vary with each storm and each storm period. In some years there where no tropical storms and cyclones, 1963, 1965, 1969, 1986, 1991, 1994. For other years there were 3 storms, 1964, 1996 and one year 2 storms 1999. On average there are more then 1 tropical storms each year. (Source: Quang Tri Province, year unknown)
Storms get to the inlands with a wind velocity of 10-12 Beauford (Bfd). Sometimes it reaches over 12 Bfd. The period of strongest winds in a storm lasts for 8-10 hours. But the stormy rainfall often occurs for 3 days. (Source: Quang Tri Province, year unknown)
The Typhoon season causes many and severe flooding, which is one of the reasons the development of the economy in Quang Tri is slowed down. In this time of the year shrimp production is stopped, because the ponds would flood as well.

## 2.4 Socio-economic

In Quang Tri the standard of living is still very low, or old-fashioned. People live with very old traditions which are shown in the way they work; they rely on old-fashioned experience based ways of working. People mostly live in communes with their families.
The majority of income in the Quang Tri Province is determined by agriculture and industry. Agriculture mainly consists of plantations on which several vegetables are grown. The breeding and keeping of animals hasn't developed yet as a large source for income. Animals are only kept for families and communes themselves, not as a trade product. Other land uses are rice fields, forestry and aquaculture. The last type includes fisheries and shrimp ponds. Though fishing on a large scale at the coast still hasn't emerged yet. (Source: People Committee dep. Quang Tri, 2004)
There is a reasonable large industry in Quang Tri, which covers around 1/3 of the total income. There are 5659 processing factories including the production of food, sewing, wooden products, paper, chemicals, rubber, metal, and machines and instruments. There are 320 exploiting factories for fuel and water and there are 2 power plants. The industry in Quang Tri is still in a developing state. The industries discharge their wastewater on the same rivers that are used by the shrimp farms. (Source: People Committee dep. Quang Tri, 2004)

For tourism, there are the Cua Tung swimming beach and the beach in Cua Viet, but only local people come there in the summer. Entertainment facilities haven't been built yet. Quang Tri province also has famous revolutionary spots (where the Vietnam war has played a major role) like Lang Vay, Chien khu Ba Long, Dia Dao Vinh Chap etc. There is also an eco-tourism region in Ta Long, but none of these spots are widely exploited by domestic and international tourists. (Source: People Committee dep. Quang Tri, 2004)

# 3 Problem Diagnosis

This chapter will give insight on how shrimp farms operate and on what the current problems are. First there will be a short introduction about the location of the farms in Quang Tri, next the way shrimp farms operate and what kind of different layouts and types there are will be presented. Finally the current problems that the farms are suffering from will be presented.

## *3.1 Current state of the art of shrimp farms*

### *3.1.1 Type of shrimp farms in Quang Tri Province*

In the Quang Tri Province there are three types of shrimp farms: intensive, semi-intensive and improved extensive. The differences between these types are based on the way they use a confined environment for the shrimp production. The intensive shrimp farms use an almost completely closed environment where they control every aspect, the only thing that makes the environment not completely closed is the fact that they dispose the sludge from the shrimp ponds outside of the farms. The improved extensive shrimp farms don't influence the shrimp production that much and let nature go its way. For example, an intensive shrimp farm uses nets to prevent birds from getting into the water of the ponds. The improved extensive ponds and semi-intensive ponds don't always take that kind of measures. In reality it is difficult to determine the difference between improved-extensive and semi-intensive shrimp farms. Some ponds operate differently from each other while both are of the same farming type. For example one farm uses bird nets while the other one doesn't, and the other one uses a freshwater reservoir while the first one doesn't. Therefore in this thesis when ponds are examined there will not be distinguished between semi-intensive and extensive shrimp farms.
It is known that there are some aspects from the intensive way of farming, which semi-intensive and improved extensive farms both tend to use. To prevent sickness they both tend to use antibiotics, and they both use foils on the bottom of the pond to prevent the sludge and its contents to leave the pond through the ground. This is to prevent the groundwater to get polluted, often though the foils are in a very bad condition. (Fieldtrip 2006)

### *3.1.2 Location of the shrimp farms in Quang Tri Province*

There is only one intensive shrimp pond located in the Quang Tri Province, but because it's well managed there aren't any major problems right now. So for this research the focus will be on the semi-intensive and improved extensive shrimp farms, which are located at or near the estuaries of the Ben Hai river and the Thach Han river.

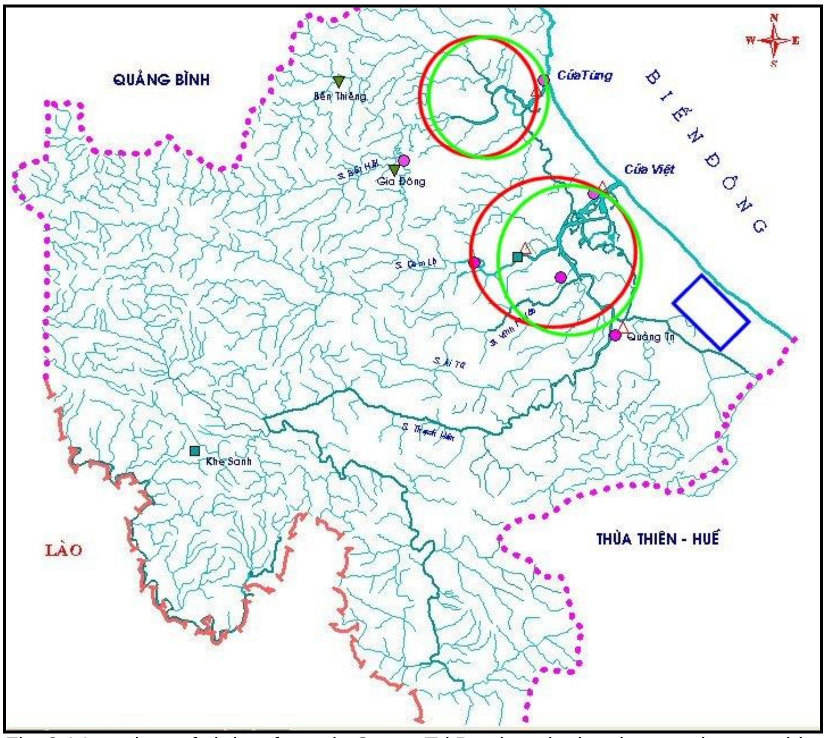

*Fig. 3.1 Locations of shrimp farms in Quang Tri Province (red and green show semi-intensive and improved extensive ponds, blue shows the intensive pond)*

Locations of improved extensive shrimp ponds near the Cua Viet estuary are: Pho Hoi Village, Trieu An commune and the Trieu Phong district. There are also farms located in Vinh Thai village (Vinh Linh district), in Gio Mai (Trung Hai, Gio Linh district), the Hai Ba commune (in Hai An, Hai Lang district), and some districts near Dong Ha town.
On the fieldtrip of November 2007  for the first time all of the shrimp farms we’re put on a map by the use of GPS, the results are shown in figures 3.2 and 3.3.

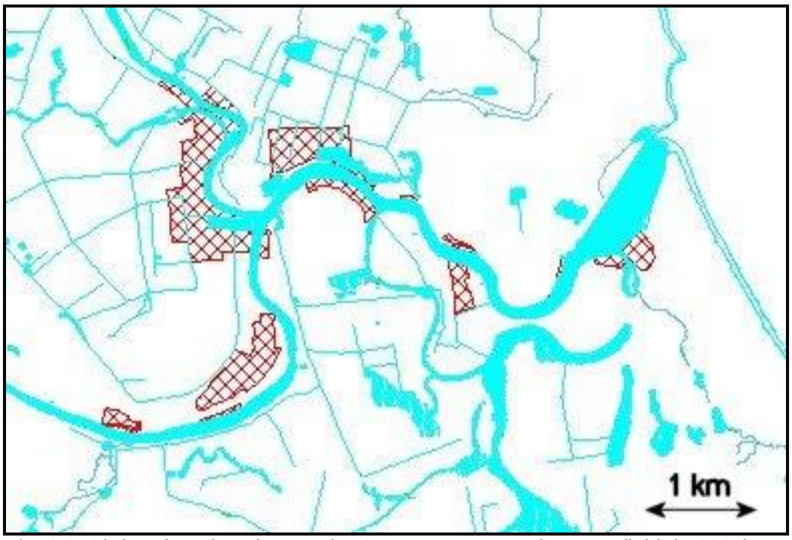

*Fig. 3.2: Shrimp farm locations at the Cua Tung estuary (Source: fieldtrip 2007)*

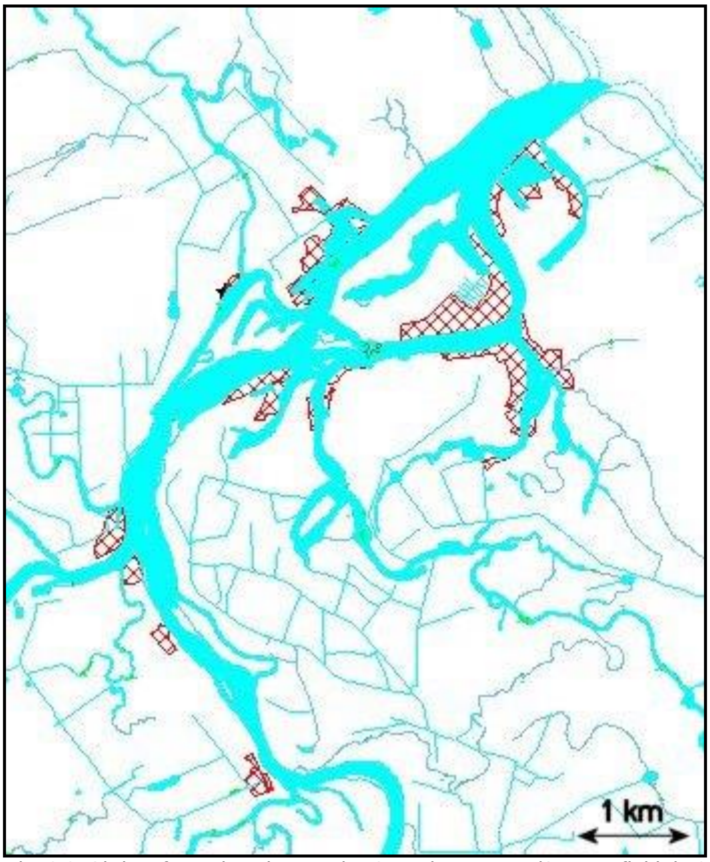

*Fig. 3.3: Shrimp farms locations at the Cua Viet estuary (Source: fieldtrip 2007)*

The shrimp farms located nearest to the river mouth are settled on top of sand on the river banks. The shrimp farms located more upstream of the rivers are mostly build on clay soil layers.

### *3.1.3 Shrimp farmers*

In general shrimp farmers don't have a large income. In 2004 a research was done in which farmers were interviewed about their annual profit. At that time the interviewed farmers were still very optimistic, since there were no diseases yet. 35% of the farmers said that they earned about 50% on top of their initial investment, 40% answered between 50-100%, and 25% said more than 100%. Most farmers even used shrimp farming as a subordinate income, most of them were also in agriculture like farming rice. Only 6.3% of all the shrimp farmers were fully focused on shrimp farming alone (people committee dep. of aquaculture in Quang Tri, 2004). Though at the time the research was done shrimp farming was still very much undeveloped. Nowadays almost every farmer is fully focused on shrimp farming.
The initial investment needed to build a shrimp farm is around 10 mil. VnD for building the pond and 21 mil. VnD for other facilities. So in total 31 mil. VnD or around 2000 dollar. To get this amount of money farmers often get a loan from the bank. They often get loans which they have to pay back in 1 year, but 30% of the farmers get a loan which they can pay back in 5-7 years. Of all the farmers 87.5% would like to have a loan with a longer term for paying back. The loans have an interest rate of around 0.45-0.9% per month (people committee dep. of aquaculture in Quang Tri, 2004).

### *3.1.4 Production of shrimps*

The average area of a pond is about 0.5 ha. Most ponds are owned by families, so that each family has one pond. The shrimp that is grown here is the Tiger Shrimp. Each pond has a drainage channel which is connected downstream to the river, this is where the wastewater is discharged. To take fresh water in there used to be a reservoir, but because of bad production numbers in the years that the farmers used these reservoirs, the reservoirs aren't used as often anymore, and fresh water is drawn directly from the river into the ponds with a water pump or by the use of a sluice or intake channel. A shrimp pond has a gentle slope, with an average depth of 1.0-1.2 m and a deepest point of 1.6 m. The base of each pond is covered by a net which has a height of 0.6 m, to prevent crab and other species to enter the pond. However the net is often in bad quality. As written before, in contrary to the intensive ponds, there is not a net to prevent birds to enter the pond.

In figure 3.4 the basic layout of a shrimp farm community is drawn. Actually the communities have several different layouts. The smaller ones have only 5 to 6 ponds located next to each other, the larger communities often have up to a hundred shrimp farms located next to each other both vertically and horizontally. There is also a third type of shrimp pond community which consists of one large intake channel surrounded by several ponds. This is shown in figure 3.5. (Fieldtrip November 2007).

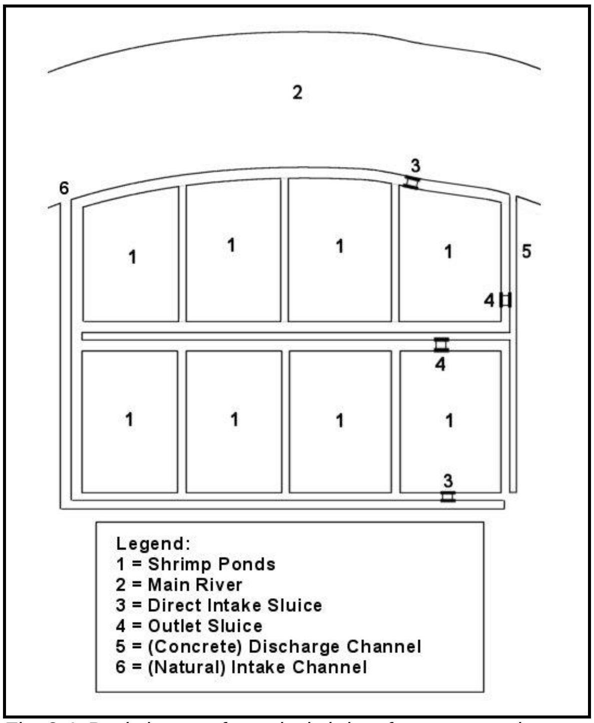


*Fig. 3.4: Basic layout of a typical shrimp farm community*

There are several ponds drawn, but to give an example of how one operates, only some ponds in the figure have sluices and a drainage channel, in reality every pond has inlets and outlets (Fieldtrip November 2007). The ponds located directly alongside the river are more expensive than the ponds located further from the river. This is because these ponds don't need discharge channels or intake channels; they can get the water directly from the river. Farmers do not have to invest into the channels, and so they can also save space.

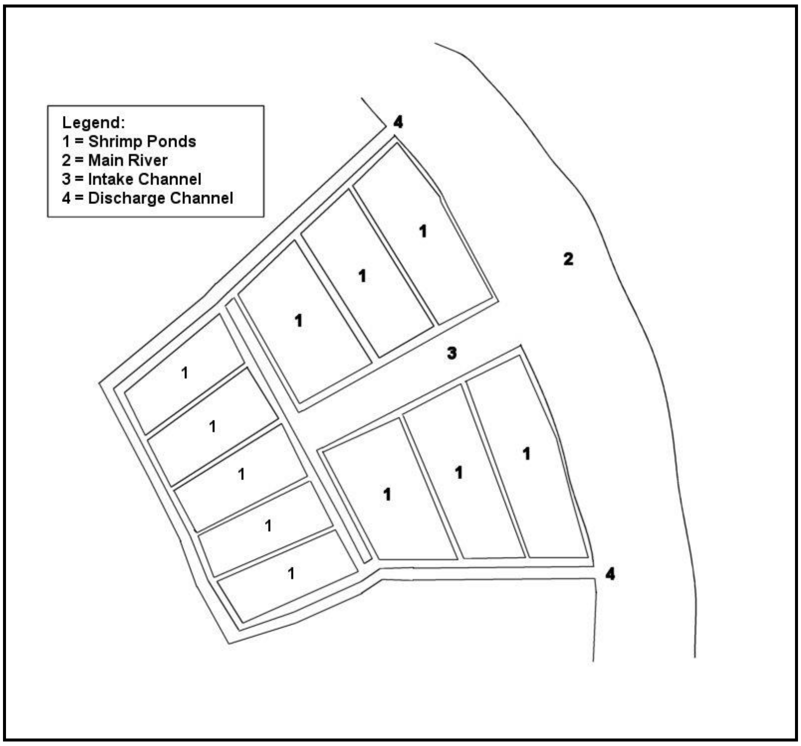


*Fig. 3.5: Layout of a shrimp farm community with a main channel surrounded by several shrimp ponds*

Shrimps are produced from seeds (post larvae), these seeds are first stockpiled in a reservoir. These reservoirs are not always located next to the shrimp farms, and so not always operated by the shrimp farmers themselves. The quality of the water in which the post-larvae are grown also influences the way diseases affect the shrimp pond production. The stronger the larvae, the less they are affected by diseases. The density in which the seeds are cast is 5 shrimps/$m^2$. (Fieldtrip 2006)
There are two possible crop seasons, though not every shrimp farmer uses both periods to produce shrimps. The periods are:

- Seeding of first crop: early March to mid- March
  Harvesting of first crop: early July
- Seeding of second crop: early July to mid-July
  Harvesting of second crop: from early October to mid-October

Shrimps are fed 4 times a day, from 6 am to 9 pm, every 5 hours. The amount of food increases with the growth of the shrimps:

| | |
|---|---|
| First week: | 10-12 kg/day/pond |
| Second week: | 15-20 kg/day/pond |
| Second and third month: | 100-150kg/day/pond |
| Near harvesting time: | 250 kg/day/pond |

A basket is used to "measure" the amount of food that is left after each feeding time. When there is too much food left in the basket, the next time the amount is lessened. Shrimps also eat less when the weather is rainy and it gets colder.
The average production of the first harvest is 1 ton/ha/crop. The second harvest is less than 1 ton/ha/crop. (Fieldtrip 2006)

### *3.1.5 Water quality standards in shrimp farms*

Tiger shrimps grow best in brackish water with a salinity of 15-25$^0/_{00}$. It's hard to keep the salinity at a steady level because of the major evaporation in the production period. That's why the farmers let fresh water in each 2 or 3 days.
The water quality in shrimp farms is tested in many ways. First of all the pH value is measured, secondly the salinity is tested. Some farmers also test the Dissolved Oxygen (DO) level. To improve the DO-level farmers use fans in the first or second month. But the farmers mostly rely on visual aspects. They look at the watercolor and to improve it they add animal faeces, they think that if the water has a blue colour it is of good quality (Fieldtrip 2006).

| Parameter | Vietnam |
|---|---|
| | Most Suitable |
| Temperature (ºC) | 29-30 |
| Salinity (‰) | 15-25 |
| pH | 7.5-8.5 |
| DO (mg/l) | >5 |
| BOD (mg$O_2$/l) | 5-10 |
| COD (mg$O_2$/l) | 10-15 |
| $H_2S$ (mg/l) | 0.1 |
| $NH_3$ (mg/l) | 0.1 |
| $NO_2$ (mg/l) | 0.1 |
| Total N (mg/l) | 2 |
| Dissolved $PO_4$ (mg/l) | 1 |
| Total $PO_4$ (mg/l) | 0.5 |
| Total Fe (mg/l) | 0.15 |

*Table 3.1:Water quality standards applied for shrimp farming in Vietnam (Ms. Quan Thi Quynh Dao 2002)*

Research has been done at intensive and semi intensive shrimp farms in the past in Thailand to see which substances in the water cause which problems, or which problem is caused by which aggressor. In table 3.2 the results are presented.

| Characteristics | Sources/ Causes |
|---|---|
| Physical properties | |
| • color | Decomposition organic mater; algae population; leaching of inorganic. |
| • odor | Decomposition of organic matter from uneaten feeds and metabolites. |
| • solids | Uneaten feed particles; detritus; coagulated/ flocculated products of dead organisms. |
| Chemical constituents | |
| • BOD | Carbohydrates, proteins, fat from feed and metabolites. |
| • pH | biological and chemical reactions. |
| • Nitrogen | feed, metabolites and dead organisms. |
| • Phosphorous | Decomposing of organic matter, dead plants/animas, feed and fertilizer. |
| • Drugs and chemicals | Antibiotics, feeds and disinfectants. |
| Biological constituents | |
| • Planktonic organisms | Phyto-/zooplankton flourishing in ponds. |
| • Pathogens | Bacteria and viruses. |

*Table 3.2: Summary of physical, chemical and biological characteristics of intensive shrimp pond effluents (R.M.U. Senarath 1998)*

After harvesting the ponds are drained and cleaned with $CaCO_3$, to improve the pH value and to remove nutrients. But research has shown that the soil (sludge) in the ponds doesn't get cleaned properly, so much of the pollution remains in the farms (Fieldtrip 2006).

### *3.1.6 Wastewater*

Wastewater is discharged directly into the river, or estuary. Water discharge occurs once a month when 50-60% of the water in the shrimp pond is exchanged. This process is quite slow because of the use of a pump with a very small capacity. That's why changing the water is a process of many hours sometimes even days. The impact on the water quality in the river is extensive because of the large number of ponds. (Fieldtrip 2006)

### *3.1.7 Diseases*

Recently there have been severe problems with the production of shrimps. In some shrimp farms more then 80% of the shrimp population died before harvesting. The most common diseases are the red body disease and the white spot disease.
The red body disease is caused by bacteria called vibrio parahaemolyticus, the white spot disease is caused by the baculo virus. Both the virus and the bacteria can live in the shrimp ponds because of the remaining food in the soil of the pond and the anaerobic conditions created by the amount of nutrients in the water.
To prevent diseases antibiotics are added to the water every time shrimps start showing symptoms of diseases (Appendix B). To hamper an outbreak every 7 or 15 days antibiotics are added to the water. The problem with these antibiotics is that much of it isn't absorbed by the shrimps. Only 20-30% is absorbed, which means that the other part will get into the wastewater or sludge in the bottom of the pond. The more intensive a shrimp pond is operated, the more antibiotics are used and the more the mud (especially) gets polluted. First of all this is bad for the environment, but secondly the bacteria surrounding the ponds which cause the diseases tend to get immune to the antibiotics (Ms. Quan Thi Quynh Dao 2002).

## *3.2 Current state of the estuaries*

### *3.2.1 Salinity intrusion*

Because of the tidal regime water in an estuary is both influenced by the freshwater of the river and the salt water of the sea. This creates a brackish environment. The intrusion length thus the amount of salt in the estuaries mostly depends on the discharge of the river and the tidal regime, but also the amount of wind and its direction.

### *3.2.2 Water quality*

The water quality in the estuaries is determent by the salinity, but is also influenced by the concentrations of polluting substances in the water of the river. Obviously the pollution is caused by the waste water of shrimp ponds, factories and wastewater of other types of land uses. The biggest problems are the amount of nitrogen and phosphorus in the water, but also dissolved oxygen (DO) and BOD are causing problems. Further more there are some heavy metals in the water and the pH value tends to fluctuate. (Quan Thi, 2002)

## 3.3 Current problems

An estuary is located near the end of a river near the ocean. So if the land is relatively flat, the water in an estuary is severely influenced by tides, and salt water. Shrimp farms need brackish waters, but because of the tides, wastewater which is disposed is able to flow back. Therefore when a shrimp farm takes in new water, it gets polluted with wastewater from itself or other ponds and also with wastewater from land use. This is probably one of the major causes of the diseases which lately occur in the shrimp ponds.
The ponds rely on the tidal regime to make sure that water is taken in with a suitable salinity. To make sure that no polluted water is taken in, the farmers look at the color of the water.
The production period is in the months where the evaporation is at its peak and so every 3 or 4 days fresh water is added to reduce the salinity in those periods. Most of the time this fresh water is taken directly from the river without any preparation.

# 4 Qualitative Analysis of the pollution in shrimp ponds

In this chapter an analysis will be made of the current problems occurring in the Quang Tri province. Which actors are involved, which objectives should be achieved and finally a systems diagram will present the interaction between all of these factors which are important for this study case.

## 4.1 Current and future problems

The last couple of years several diseases occurred in the shrimp ponds located in or near the estuaries of Cua Viet and Cua Tung. These diseases are caused by polluted water which is taken in by the shrimp farms. The water is polluted because it is often drawn directly from the river without filtering. The river water is polluted mostly with wastewater from the shrimp farms themselves, but also from other wastewater for example from industry and agriculture.
Another problem for the shrimp farms is to keep a decent salinity for growing tiger shrimps. This salinity rate changes heavily because of the tidal regime. So only at certain periods water with the correct salinity can be taken in by the farms.
The tides also affect the way in which the wastewater of the ponds is spread in the estuaries and in the river with its tributaries, because of the tides the polluted water from the shrimp farms flows back and will be taken in by the farms as being fresh water.

## 4.2 Actors

- Shrimp pond farmers: these are the people who are affected the most, because of the diseases their production is minimal and so they have more costs than profit.
- Industry: their wastewater also affects the water quality of the river and its estuaries.
- Agriculture: this type of land use often influence the discharge channel of shrimp farms because they are located close to the shrimp farms. In many cases the shrimp farmers themselves are also into agriculture.
- Local government: they have plans for the future to increase the amount of shrimp farms in Quang Tri because of the economic profit, and so they are also affected by the problems, and most probably they are the ones that have to support measures financially.

## 4.3 Objectives

Shrimp pond farmers want to make a living, they need to maintain their families or even whole communities. Also because of the relative large initial costs they are in depth and have to repay the banks in very short terms.
Solving the shrimp pond problems will not affect the industry in a positive way, but industries cause pollution in the rivers and estuaries. Actually the same goes for agriculture, but as mentioned before the agricultural farmers are often the same as the shrimp farmers, so they will be easier to persuade in changing their way of working.
The local government wants a growing economy in Quang Tri, and shrimp farming is a great opportunity for that, certainly in the lower parts of Quang Tri, because of its unique brackish environment.

Major objective for the provincial government:

- achieve a more stable economic environment for the province

In trying to achieve this goal, sub-goals should be reached like:

- better water quality in the river and it’s estuaries
- better water quality in the shrimp ponds
- better economic wellbeing of farmers and their families/the communities
- better functioning of all the land uses in the surroundings together with the shrimp farming

## 4.4 Boundary conditions

There are several boundary conditions that need to be mentioned related to the problems and possible solutions of the wastewater problems near shrimp farming ponds. These are:

- Spatial boundaries:
    - The location of the shrimp farms has to stay near the river estuaries.
    - The available space for a production pond remains 0.5 ha, because there is no space available to enlarge the current ponds.
- Time boundaries:
    - The time in which measures should be implemented can be no longer then half a year (from January to June), because otherwise farmers would loose more than one harvesting period.
- Social boundaries:
    - The standard of living for the farmer’s communities may not be lowered.
- Ecological boundaries:
    - The water quality in the ponds should meet the standards for the farming of Tiger Shrimps.
    - Water quality in the river and in the estuaries should be improved.
    - No measures may have negative effects on the environment.

### *4.4.1 Extra Demands/Wishes*

- Governmental:
    - The government has to subsidise measures where possible/needed.
- Educational:
    - Farmers should be guided for the implementation of measures, so that they can operate on their own.
    - Farmers should be guided for the maintenance of measures, so that they will be effective for longer periods of time

## *4.5 Criteria*

To choose criteria that are also useful for the multi-criteria analysis several aspects are kept in mind. First of all the systems diagram, to see which aspects can influence the water quality in the river, estuaries and shrimp ponds. Secondly the actors, every actor has his it’s main interest, which are important to find a measure, or combination of measures that is/are suitable for all the actors.
And finally the main objectives for this research.

- Costs of implementation, this criteria is quite logical, as it will both be important for the farmers and the local government that a measure will be affordable.
- Time of implementation, this is mostly important for the farmers. Many farmers are already in dept because of the loans they took for their initial investment costs. Still for the local government it is also important to have a quick solution for the issues at the farms as the shrimp farming industry itself has great economic potential.
- Manageability by farmers, it is important that the measures are not too difficult to implement, but certainly that they are not too difficult to maintain and operate.
- Economic benefits, this is of course the main goal of this research. If measures are successfully implemented they should really contribute to a more stable economic environment for both the farmers and the government.
- Effect on production, the amount of shrimps that will survive will increase differently per measure or in some cases another type of culture can be added to the production.
- Effect on diseases, if substances in the water are reduced to the needed or desired water quality standards, the occurrence of diseases will decrease.
- Environmental impact, measures can be taken at the input of water for the shrimp farm, or at the outlet. In this way the impact can be different per measure.
- Needed policies, depending on the chosen measure the government will need to apply policies to the area in which the measure has its effect. This cost time, money and effort.
- Large scale effectiveness, measures can be applied for an area or for only one pond for example. It is important to see how large the influence of a measure can be, mostly for the future planning of aquaculture in the Quang Tri Province.

## *4.6 Uncertainties*

There are some uncertainties which are important to know when the measures are analysed:

- The exact water quality in and around the researched shrimp ponds
- The exact influence of pollution on the water quality in the estuaries
- The way the pollution spreads
- The way in which the pollution flows back towards the shrimp ponds
- The usability of natural resources for each shrimp farming community
- The availability of instruments to improve the water quality in shrimp farms for each farming community
- The willingness of the local government to invest in measures
- The possibilities for the local government to get funds for the application of measures
- The willingness of outside investors, maybe from other countries, to invest in the shrimp production
- The exact time needed to apply measures
- The available knowledge of shrimp farmers

Most of these uncertainties cover the part of good quantitative analyses. This is one important thing that should be done following this initial research. There were plans at the time of this research to gather new measurements when the new production season of shrimps starts in 2008.

## *4.7 Diagrams*

The issue with the research area is that the complexity of the problem is quite large. To focus on the problems for this case, only the key factors should be included in the diagrams. That's why first a flow diagram is made with all the aspects in the area relevant for shrimp farming in estuaries (Appendix C). Secondly a systems diagram is made with the key aspects of the problems which are being studied. Each diagram consists of blocks which represent an aspect of the system. Each block has an input side (left) and an output side (right), the numbers show a relation between two aspects. (De Kok, 2001)


*Fig. 4.1: systems diagram of the key problems*

The only part still missing is the part of measures which should be taken and their effect on the problems. To find the most suitable measures a Multi-Criteria-Analysis will be made for available measures which have been used on other locations, but also newly developed measures.

# 5 Possible measures

In this chapter all possible measures will be presented, both structural and non-structural. Where structural implies measures which need a certain structure to be build. Non-structural measures will mostly focus on management issues.

## 5.1 Introduction

To reduce the amount of pollution discharged into the river via wastewater there are three possible types of measures:

- **reduce** the amount of pollution
- **reuse** the polluted water for other purposes
- **recycle** wastewater for the same shrimp ponds
- a combination two or more of the above

Measures reducing the pollution problems will affect the input of the shrimp ponds. For example reduce the amount of food.
Measures that reuse the wastewater will affect the output of shrimp farms. The nutrition in the wastewater can be used by other types of aquaculture, or in some cases the water can be used for agriculture, for example the rice cultures.
Recycling measures will try to reduce the pollution in the wastewater by for example filtering so it can be used again by the same or other farms.

The problem with the salinity can probably only be solved by better management together with a reservoir where water with a good salinity is stored. This can be done in combination with measures that are used for the pollution problem in the farms. If an extra reservoir is created for example to filter the polluted water, this reservoir can also be used as a measure for the salinity problem. In other words the issues with salinity can be solved by applying a measure which solves the pollution problems. If a measure works well enough to reduce every amount of pollution to the required standards, water can be taken in at any time, even at high tides.

## 5.2 Structural Measures

### 5.2.1 Measures on wastewater pollution

In Indonesia similar pollution problems occurred a couple of years ago as they occur now in Vietnam. One structural measure that seems to be working is by creating poly cultures. This means that the first period of shrimp production will remain the same as before, but the second production period (July to October) will be used to not only produce shrimp but also another culture, like oysters, crabs, mussels, fish etc. In this way there will be two profits: the nutrients in the water from the first period of production will be used in the second period, and the farmers will have more economic certainty, because they can bet on two different horses.
Though because of the lack of knowledge and lack of economic capability of the farmers, the government will need to invest in this measure to make it work. This could be a good long term plan for the development of aquaculture in the Quang Tri Province.

Another structural measure is by making filters for the wastewater. This can be done in several ways:

- Natural filters and non-natural filters, for example making mangroves or other bio-filters which are made in the wastewater channel or near the intake so that the water will be filtered before it is used.
- Treatment by filtering with chemicals, electrolysis etc.

The easiest way of creating a natural biofilter is by building several reservoirs which filter the water in different stages. There will be at least two reservoirs needed, one sedimentation reservoir and one reservoir with bacteria or a culture in it, for example oysters or mussels. The sedimentation reservoir will remove all the floating larger particles, the reservoir with a culture in it will remove nutrients and BOD. The culture should be replaced after a while, but in case the cultures are oysters or crabs for example, they can be sold and increase the economic benefits. One problem that occurs by using a

culture is that cultures replace nutrients by forming ammonia. This problem can be solved by adding a plant like seaweed which removes ammonia from the water. Currently some of the shrimp farms in the Quang Tri province already use several ponds to filter the water before shrimp ponds use it. The cost of the complete construction of several reservoirs and pipelines in total is 15.000.000 VnD, which is approximately 900 USD (People Committee dep. of aquaculture in Quang Tri Province, 2004). The current reservoirs are only used for the intake of water, to improve the water quality in the rivers the water being discharged after usage in the ponds should be treated as well. This could be done by creating separate reservoirs for the outlet of water, but maybe in some cases the reservoirs for the intake can be used as filters for outlet water as well.
This solution could also provide a good start for long term planning with polycultures, because currently research is done at combining shellfish cultures with shrimp production in the same pond (Tendencia, 2007).

A study already has been made about combining the shrimp farming industry with the placing of mangroves in Colombia (Gautier, 2002). The costs of placing a mangrove bio-filter will be around 100000 dollar, which seems to be a lot, but it can be a solution for many related actors at once (Gautier, 2002). Also the replacement of natural mangroves by shrimp ponds has been and still is a major problem in many countries where shrimps are produced. By creating a mangrove at certain places this problem can be solved, and also mangroves can offer a great chance for tourism. Most of the mangroves which are currently still available in the area are not located near the farms which have the water quality problems. The mangroves are located further downstream of the farms with the problems.

A natural filter which is currently being studied is the use of a so called wetland. A wetland for example can be a swamp or a mangrove. The wetland is located near the shrimp ponds and consists of soil with a certain slope and obstacles in it, so that water will flow through it in a certain direction. In this way the water gets cleaned before it reaches the discharge channel (Rogers et al. 2001). The great benefit of the wetland is that water can also be recycled for the shrimp pond itself and because of the size of a wetland it can also be used by the surrounding agriculture. The cost of a constructed wetland depends on the size of the wetland needed, which of course on itself depends on the amount of wastewater which needs to flow through it. The costs are around: $35,000 to $150,000 per acre (Argonne National Laboratory, The University of Chicago for the U.S. Department of Energy, year unknown).

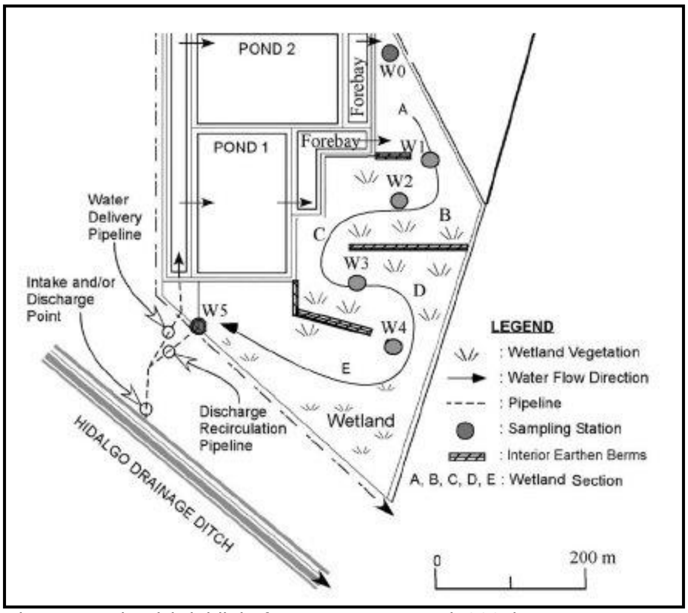

*Fig. 5.1 Wetland (Highlight from D. Rogers et al. 2001)*

On the fieldtrip it became clear that in the main rivers several wetlands could be used for the shrimp farms. Though the numbers of available wetlands are small.

In Germany a company has developed a bio-filter which consists of a couple of tanks in which bacteria and natural filters are used to remove polluting substances from municipal and industrial wastewater. According to the company the filter is relatively cheap, and the great benefits of this filter are that it can work completely on its own and that it will change the way it is functioning to the amount of pollution. (Source: http://www.ircnet.lumatchingcompleterec.cfmBBS_ID=11568&org=0)

In a similar way as the German bio-filter, research has been done at the functioning of a completely closed bio-filter used for the production of tiger shrimps (Menasveta et al., 2000.). The filter not only filters the water, but also makes it reusable. It functioned pretty well, all concentrations of polluting substances stayed in allowable limits and the shrimps developed in a normal way to economic profitable size. There were some problems with keeping the pH at a high enough level, which caused the shrimps to turn to cannibalism. According to the researchers this could be prevented by letting freshwater in more often then they had done during the research periods (Menasveta et al., 2000).

A non-natural way of treatment is by using electrolysis to remove heavy metals from wastewater. This is a possible solution in combination with filters like the sedimentation reservoir.
Other ways are by using chemical substances to react with polluted substances. So that for example the pollution precipitates, so that it can be filtered more easily.

If the intake channel is located at a bigger distance from the output channels from other farms, the amount of polluted water taken in can be reduced, but still the timing of intake and discharge is the major problem, in combination with the tidal regime.
Another problem is that the channels are not only used by the shrimp ponds, but also by agriculture and industries. So by making different input and output channels the general wastewater problems will not be solved completely, because the discharge of the other industries will remain the same. And this measure doesn't match the boundary set where measures should improve the water quality in both estuaries and rivers.

### 5.2.2 Measures on salt water intrusion

A reservoir with saltwater to retain the needed salinity can be a good solution to lessen the amount of times shrimp ponds take in freshwater, because of a drop or raise in the salinity. This will also partly solve the problem with taking in polluted water. If water isn't taken in to frequently, the timing with discharging of other ponds nearby can be managed better.

## 5.3 Non-structural Measures

### 5.3.1 Measures on wastewater pollution

Based on studies in China, Indonesia, Mexico and Bangladesh one of the most logic measures is better management of the inputs for the shrimp ponds. The major problems with nutrients and BOD are caused by feeding the shrimps more then they can eat. Shrimps are also given too many antibiotics. The excess of these substances will remain in the water and will also get into the soil on the bottom of the shrimp ponds. By reducing the feeding and the amount of antibiotics, fewer substances will get into the wastewater. By cleaning the sludge or removing it completely the water quality will also improve.
It is also very important that the post-larvae which are used as the seeds for the shrimp ponds are grown in a good water quality environment. Then the production can start with cleaner water and healthier shrimps resulting in a higher production.
To maintain a good water quality more measurements should be taken during production. In this way the amount of food, antibiotics and other added substances, like chemicals, can be adjusted better to the needs of the shrimps and the needed water quality parameters. One already used measure to reach the required dissolved oxygen level is by using a fan in the water. These kinds of simple techniques should be used in a more efficient way. The same goes for using certain chemicals or other additives like $CaCO_3$. The farmers should be better educated in using these kinds of water quality measures.
In this case management will also include adding nets to prevent birds from coming in the pond, small dikes between reservoirs and natural waters to prevent other cultures to enter the main production pond and the nets that form a layer between the soil and the water underneath the ponds should be of better quality, maybe even made from plastic to prevent any interaction.

By reusing the wastewater for agriculture like rice fields, the problem with pollution can be partially solved. The wastewater from the shrimp farms is not discharged directly in the river anymore, but then again the wastewater of rice fields and agriculture is also pumped in the channels. So although the pollution is less then when it's discharged directly out of the shrimp ponds, there will still be some pollution in the water. This solution maybe useful in combination with filtering.

The same goes with recycling. The wastewater should be filtered first, before it can be used again by the same shrimp ponds.

Reducing the number of times that water is taken in from the river should have a positive effect on the amount of polluted water taken in by farms. A clean water reservoir near the shrimp farms with good quality water can help reducing the number of times water is taken in directly from the river. Though not changing the water often enough may have negative effects on the chances of diseases (P. Leung et al. 2000).

In general a lot can be done by improving the conditions of the shrimp ponds. For example better measuring devises and nets to prevent birds from getting in the shrimp ponds. All of these improvements can be called intensifying. Though the farmers should be careful with the intensification of the shrimp farming, because as soon as the farms also intensify their production, the wastewater will be polluted even more then in the current situation. The problems with pollution at intensive shrimp farms are bigger than the problems at improved-extensive and semi-intensive farms, but not so much for the farms themselves. The pollution is so severe that the water quality of the rivers, estuaries or even the sea is influenced badly.

### *5.3.2 Measures on salt water intrusion*

The timing of the intake of clean water should be changed together with the output of wastewater, not only from shrimp farms but also the wastewater output of industries and agriculture. When these two events occur too fast after each other, shrimp farms will take in polluted water. So there should be a policy that wastewater may not be discharged on the river around the time that shrimp ponds have to take in fresh water. Obviously it is pretty difficult to determine the exact period in which the pollution is spread around the farms. More research and modeling will be needed before such a policy can be implemented. Also in combination with such a policy shrimp ponds themselves should improve the amount of times that they need fresh water. So a combination of policies against discharging of wastewater in certain high tide periods and reservoirs near the ponds which can hold saltwater may be a possibility.

## *5.4 Systems Diagram including possible measures*

Now that the possible measures are know, the systems diagram can be expanded.

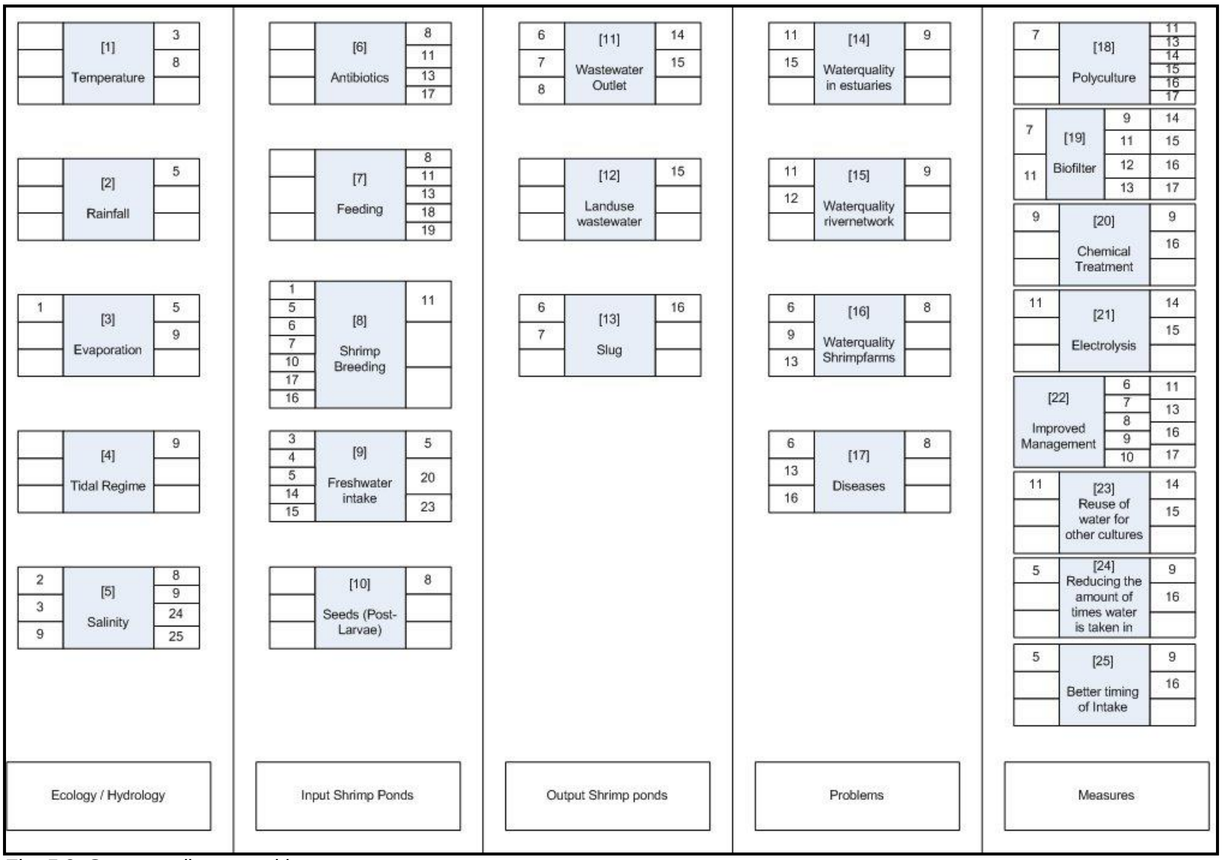

*Fig. 5.2: Systems diagram with measures*

## *5.5 Measures to analyze*

### *5.5.1 Structural*

A1: Polyculture
A2: Biofilter:

- A2.1 Closed biofilter
- A2.2 Mangrove filter
- A2.3 Wetland
- A2.4 Sedimentation reservoir + reservoir with culture (oysters, crabs)

A3 Chemical treatment
A4 Electrolysis

### *5.5.2 Non-structural*

B1 Improved management (better measurements, less feeding, less antibiotics)
B2 Reuse of water for other cultures
B3 Reducing the amount of times fresh water is taken in
B4 Better timing of taking water in (also for salinity)

# 6 Effectiveness Measures

On the fieldtrip done in November 2007 it became clear that the implementation of certain measures would require a lot of effort and time from the local government and farmers. For example the reuse of water for other cultures like rice in that area would require a lot of changes in the water infrastructure. Also the implementation of a freshwater reservoir would only be possible if some of the shrimp ponds would be completely used only as a freshwater reservoir or as a sedimentation pond or as a pond with other cultures in it. The problem is that each pond is operated by one family, and so if one pond is completely changed, this would imply that one family would lose its total income. Then again with good policies from the government it should be possible that these farmers can also profit from other farmers' income, because one fresh water pond could provide fresh water for more then one shrimp pond. Maybe the production will not be done by several ponds at once, but because of better management and policies the production of shrimps can be much more lucrative and a more stable economic environment can be created.
In this chapter the effectiveness of the most suitable measures are presented. In the Multi-Criteria Analysis this effectiveness and applicability will be used. Not all the measures are taken into account in this chapter, because some measures are applicable on every location, for example the use of chemicals.

## 6.1 Effectiveness structural measures

On the fieldtrip it became clear that it is impossible to say that one measure is applicable for the complete coastal zone area in Quang Tri. This is because the shrimp farms are not structured in one typical way, it differs per area. So to make clear where to apply which measure for the shrimp farms, there will be three different designs depending on the alignment of the ponds, the number of ponds in the communities and the available space.

When there are only a small number of ponds next to each other, and when they are all located near the riverbank. The solution of the closed biofilter seems to be the most suitable one. The filtering tanks can be placed on the sides of the ponds, so that every pond stays operational for shrimp farming. The biofilter will have a limited capacity because of the lack of space, but with only 4, 5 or maybe 6 ponds next to each other this shouldn't be a problem.

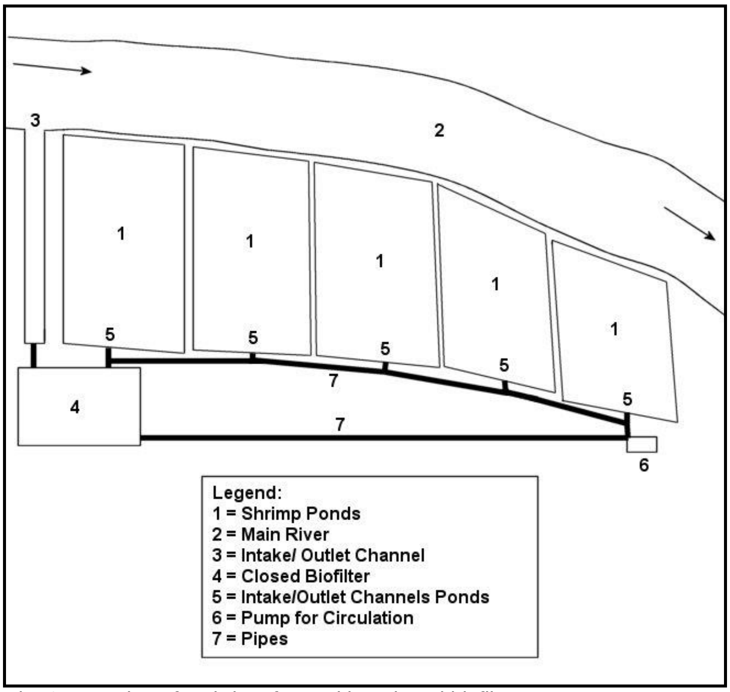


*Fig. 6.1: Design of a shrimp farm with a closed biofilter*

The high costs will need to be covered by a sponsorship program which the government should construct. The government should also take care of the maintenance of the biofilter. This shouldn't be much more then once or twice per year.

When there are several ponds lying next to each other both vertically and horizontally, the implementation of a closed biofilter won't be as interesting anymore, because of the lack of capacity, or very high costs when the capacity is met.
In this case the combination of sedimentation reservoirs and a reservoir with a culture in it is likely to be more effective. The ponds which are located directly on the river banks will keep being used for shrimp production, because they are more expensive then the ponds located further from the river. The ponds located further can be changed into the needed reservoirs. Depending on the number of ponds located next to each other more then one or two ponds may have to be redesigned. To filter the water before it is discharged in the river again, another reservoir should be constructed for the outlet. Maybe the Intake reservoirs can be used for the outlet filtration too, but only at the end of the second season. Otherwise the intake reservoirs are still filled with good quality water to add to the ponds, when the water evaporates.

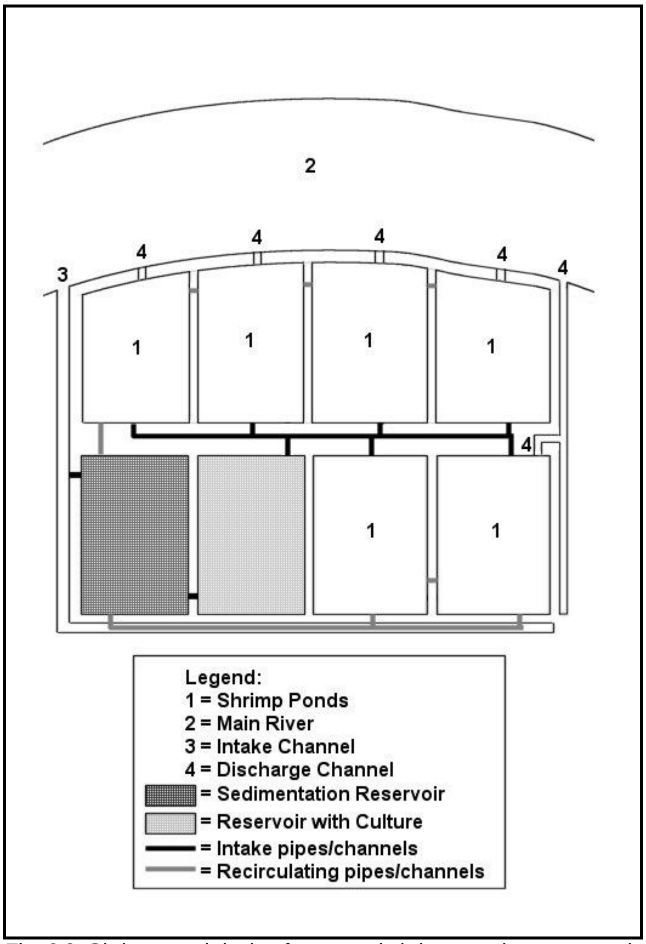


*Fig. 6.2: Shrimp pond design for several shrimp ponds next to each other vertically and horizontally*

In the coastal area of Quang Tri there are still some shrimp farmers who also use the ponds or the areas surrounding their ponds for agriculture (for example rice fields). Though on the fieldtrip the locations showed that more changes actually have to be made than first thought. Mostly to transport the water from the ponds to the agriculture areas.

The final type of shrimp ponds communities is the one where several ponds are located near each other, but where they use a large intake and discharge channel, instead of dispersing the water over the several ponds by using sluices. In this case the measure of the natural filter using several reservoirs might also be applicable depending on the number of ponds located next to each other, if not the closed biofilter again might prove to be the best alternative.

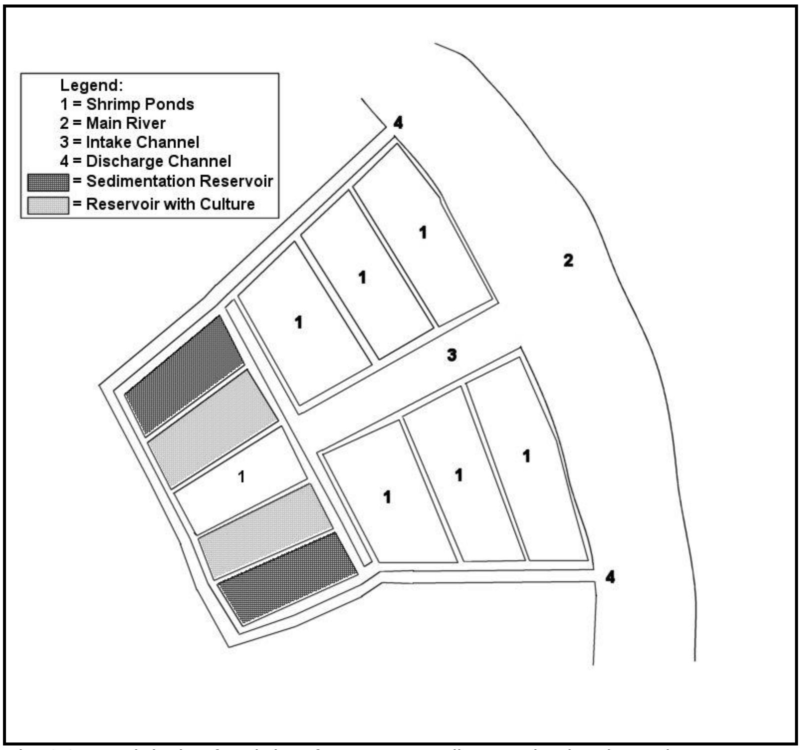


*Fig. 6.3: Pond design for shrimp farms surrounding one intake channel*

Furthermore on the fieldtrip the possibilities of using wetlands and mangroves proved also to be applicable. The problem is that there are very few mangroves and wetlands near the shrimp ponds with the problems. So only very few communities could be helped with such a measure.

## 6.2 Effectiveness non structural measures

The structural measures on its own will not be sufficient enough as a complete solution for the pollution problems. They have to be combined with better management of the pond itself.
There should be a better structure on how ponds have to operate. The government needs to guide the farmers where needed.

First of all the ponds all need good measurement equipment, this can be a large investment, but it will be very important for determining what the status of the water quality is. Next to that all the ponds need basic equipment that is needed to prevent unwanted species to be able to come inside of the pond. Also ponds need good measures that prevent the pollution from getting into the soil underneath the pond.
Other improvements that are very important are:

- using post-larvae which have been produced in reservoirs with good water quality
- cleaning the sludge on the bottom of the pond, or removing it completely after each harvesting period

All these measures are applicable in a very short amount of time, and could be very useful for the production of shrimp farming.

# 7 Multi-Criteria Analysis (MCA)

Now a Multi-Criteria Analysis can be made, but first a number of steps have to be made, to make sure that the measures are evaluated correctly with respect to each other. First of all the way the scoring has been determined, after that, the scores have to be standardized, to be able to compare different ways of scoring with each other. A certain weight is given to each of the criteria, because not every criterion is evenly important. The weight is determined by using common sense. It was not possible yet to quantify or verify all the criteria.
Now the actual analysis can be made. First an analysis was done for every measure on its own, and then logical combinations of measures were evaluated to make clear which measures are most suitable in the researched area.

## *7.1 Scoring for Criteria*

As mentioned before these are the criteria for which the measures will be analyzed:

- Costs of implementation, how much money will it cost to implement the measure
- Time of implementation, how much time will it take to implement the measure
- Manageability by farmers, how easy will it be for farmers to understand and operate the respective measure
- Economic benefits, how much will a farmer (and the government) benefit from the respective measure
- Effect on production, how positive will the measure effect the production
- Effect on diseases, how much the measure will decrease the amount of diseases. How well will the water quality in the ponds be positively influenced.
- Environmental impact, how positive will the measure effect the environment. How well will the water quality in the rivers and estuaries positively be influenced
- Needed policies, how much does the government have to invest (time, money, education) to make the measures work properly
- Large scale effectiveness, will the measure have an effect on only a small area or on a large area.

The way in which the scores are handed to the criteria will be as followed:

| Criteria | Scale | Levels |
|---|---|---|
| Costs of implementation | ordinal | in US dollar |
| Time of implementation | ordinal | number of months |
| Manageability by farmers | nominal | hard/medium/easy |
| Economic benefits | nominal | high/medium/low |
| Effect on production | nominal | high/medium/low |
| Effect on diseases | nominal | high/medium/low |
| Environmental impact | nominal | high/medium/low |
| Needed policies | nominal | high/medium/low amount |
| Large scale effectiveness | nominal | high/medium/low |

*Table 7.1: Scoring card for criteria. The costs of implementation are not known for every measure. For some measures the costs will be estimated in relation to the highest and lowest costs*
.

The meaning of each level is as follows:

- Costs of implementation: the lower the score the better
- Time of implementation: the lower the amount the better
- Manageability by farmers: the easier the better
- Economic benefits: the higher the better
- Effect on production: the higher the effect the better
- Effect on diseases: the higher the effect the better
- Environmental impact: the higher the better
- Needed policies: the lesser the amount of policies needed (or guidance by the government) the better

- Large scale effectiveness, the higher the scale the better

## 7.2 Standardisation

To be able to compare all the scores for each criteria with each other a standardisation for the scores is needed.

| Criteria | Levels | Amount | Standardisation |
|---|---|---|---|
| Costs of implementation | high/medium/low | Highest known cost is 0 | 0 |
| | | Other costs are estimated between 0 and 1 | 0.001-0.999 |
| | | Lowest known cost is 1 | 1 |
| Time of implementation | number of months | 4 or more months | 0 |
| | | 2-3 months | 0.5 |
| | | 1-2 months | 1 |
| Manageability by farmers | hard/medium/easy | | 0/0.5/1 |
| Economic benefits | high/medium/low | | 1/0.5/0 |
| Effect on production | high/medium/low | | 0/0.5/1 |
| Effect on diseases | high/medium/low | | 1/0.5/0 |
| Environmental impact | high/medium/low | | 1/0.5/0 |
| Needed policies | high/medium/low amount | | 0/0.5/1 |
| Large scale effectiveness | high/medium/low | | 1/0,5/0 |

*Table 7.2: Standardisation scoring card*

## 7.3 Scoring card

| | Measure | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Criteria | A1 | A2.1 | A2.2 | A2.3 | A2.4 | A3 | A4 | B1 | B2 | B3 | B4 |
| Costs of implementation | est: 2000 | est: 50000 | 100000 | est: 60000 | est: 900 | est: 500 | est: 500 | est: 0 | est: 200 | est:0 | est: 0 |
| Time of implementation | 2-3 | 1-2 | >4 | >4 | 1-2 | 1-2 | 1-2 | 1-2 | 1-2 | 1-2 | 1-2 |
| Manageability by farmers | medium | easy | medium | medium | medium | medium | hard | medium | medium | medium | medium |
| Economic benefits | high | medium | medium | medium | medium | low | low | medium | high | low | medium |
| Effect on production | high | high | medium | high | medium | low | low | medium | high | medium | medium |
| Effect on diseases | medium | high | medium | high | medium | low | low | medium | low | medium | medium |
| Environmental impact | medium | low | high | medium | low | low | low | low | high | low | low |
| Needed policies | medium | low | medium | medium | low | low | high | medium | low | low | high |
| Large scale effectiveness | low | low | high | medium | low | low | low | low | low | low | medium |

A1: Polyculture
A2: Biofilter:
A2.1 Closed biofilter
A2.2 Mangrove filter
A2.3 Wetland
A2.4 Sedimentation reservoir + reservoir with culture (oysters, crabs)
A3 Chemical filter
A4 Electrolysis

B1 Improved management (better measurements, less feeding, less antibiotics)
B2 Reuse of water for other cultures
B3 Reducing the amount of times fresh water is taken in
B4 Better timing of taking water in (also for salinity)

*Table 7.3: Scoring card*

Now the standardized values for the costs of implementation can be calculated.

| Costs of implementation | |
|---|---|
| Score | Standardized |
| 2000 | 0.98 |
| 50000 | 0.5 |
| 100000 | 0 |
| 60000 | 0.4 |
| 900 | 0.991 |
| 500 | 0.995 |
| 500 | 0.995 |
| 0 | 1 |
| 200 | 0.998 |
| 0 | 1 |
| 0 | 1 |

*Table 7.4: Standardisation of costs of implementation*

## 7.4 Weight

The weight chosen for each criterion is mostly based on the main objectives of this research. Of course the main objective is creating a more stable economic environment for the farmers and government. Right now most of the farmers are already in dept, so economic profit should be achieved on a short period of time.
Other objectives are improvement of the water quality in shrimp ponds, rivers and estuaries. Finally the impact and area of impact are important for the whole collaboration of aquaculture, agriculture industries and other land users.

| Criteria | % |
|---|---|
| Costs of implementation | 10 |
| Time of implementation | 20 |
| Manageability by farmers | 5 |
| Economic benefits | 15 |
| Effect on production | 10 |
| Effect on diseases | 15 |
| Environmental impact | 15 |
| Needed policies | 5 |
| Large scale effectiveness | 5 |
| Total: | 100 |

*Table 7.5: Weight of Criteria by percentage of total*

As written before, this way of applying a certain weight to each criterion is very variable. More exact information is needed to change the weight to the demands of the Province of Quang Tri. This should be done in a following research project.

## 7.5 Order of Measures according to scoring

The results:

| | Measure | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Criteria | A1 | A2.1 | A2.2 | A2.3 | A2.4 | A3 | A4 | B1 | B2 | B3 | B4 | Weigth |
| Costs of implementation | 0.98 | 0.5 | 0 | 0.4 | 0.991 | 0.995 | 0.995 | 1 | 0.998 | 1 | 1 | 0.1 |
| Time of implementation | 0.5 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.2 |
| Manageability by farmers | 0.5 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.05 |
| Economic benefits | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0.5 | 1 | 0 | 0.5 | 0.15 |
| Effect on production | 1 | 1 | 0.5 | 1 | 0.5 | 0 | 0 | 0.5 | 1 | 0.5 | 0.5 | 0.1 |
| Effect on diseases | 0.5 | 1 | 0.5 | 1 | 0.5 | 0 | 0 | 0.5 | 0 | 0.5 | 0.5 | 0.15 |
| Environmental impact | 0.5 | 0 | 1 | 0.5 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0.15 |
| Needed policies | 0.5 | 1 | 0.5 | 0.5 | 1 | 1 | 0 | 0.5 | 1 | 1 | 0 | 0.05 |
| Large scale effectiveness | 0 | 0 | 1 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0.05 |
| Total | 0.648 | 0.68 | 0.45 | 0.515 | 0.5741 | 0.3745 | 0.2995 | 0.55 | 0.775 | 0.5 | 0.55 | |

*Table 7.6: Results of the MCA*

So the best alternatives would be:

- A closed bio filter
- A sedimentation reservoir + a reservoir with a culture in it
- Improved management

## 7.6 Combinations of Measures

A number of alternatives (especially the non-structural) would still be very useful if they are implemented together with other alternatives. For example, if there is a better timing of when and how much water to take in, this will help with the amount of polluted water taken in. This in combination with a certain filter would have a bigger impact then the two alternatives separately.
The same goes for using a number of chemicals in combination with another filter. Though using chemicals by farmers might result in the same problems as there are now with the antibiotics, in other words they might end up using too much.

## 7.7 Scoring Card

To research possible combinations another Multi-Criteria Analysis is made, in which several combination are evaluated. Not every combination is logical, for example polycultures plus the reuse of water in another culture.

| | Combination of Measures | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Criteria | A1+A2.1 | A1+A2.4 | A1+B1 | A1+B4 | A1+B1+B4 | A2.1+A2.2 | A2.1+A2.3 | A2.1+A3 | A2.1+B1 |
| Costs of implementation | est: 52000 | est: 2900 | est: 2000 | est: 2000 | est: 2000 | est: 150000 | est: 110000 | est:50500 | est: 50000 |
| Time of implementation | 2-3 | 2-3 | 2-3 | 2-3 | 2-3 | >4 | >4 | 1-2 | 1-2 |
| Manageability by farmers | medium | medium | medium | medium | medium | easy | medium | medium | medium |
| Economic benefits | high | high | high | high | high | medium | medium | medium | high |
| Effect on production | high | high | high | high | high | high | high | medium | high |
| Effect on diseases | high | medium | medium | medium | medium | high | high | medium | high |
| Environmental impact | medium | medium | medium | medium | medium | high | medium | medium | low |
| Needed policies | medium | medium | medium | medium | medium | medium | medium | low | medium |
| Large scale effectiveness | low | low | low | low | low | high | medium | low | low |

| Criteria | A2.2+A2.4 | A2.2+A3 | A2.2+B1 | A2.3+A2.4 | A2.3+A3 | A2.3+B1 | A2.4+A3 | A2.4+B1 | A2.4+B1+B2 |
|---|---|---|---|---|---|---|---|---|---|
| Costs of implementation | est: 100900 | est: 100500 | est: 100000 | est: 60900 | est: 60500 | est: 60000 | est: 1400 | est: 900 | est:1100 |
| Time of implementation | >4 | >4 | >4 | >4 | >4 | >4 | 1-2 | 1-2 | 1-2 |
| Manageability by farmers | medium | medium | medium | medium | medium | medium | medium | medium | medium |
| Economic benefits | medium | medium | medium | medium | medium | medium | medium | medium | high |
| Effect on production | medium | medium | medium | high | medium | high | medium | medium | high |
| Effect on diseases | medium | medium | medium | high | medium | high | medium | medium | medium |
| Environmental impact | high | high | high | medium | medium | medium | low | low | medium |
| Needed policies | low | medium | medium | medium | medium | medium | high | high | low |
| Large scale effectiveness | high | high | high | medium | medium | medium | low | low | low |

*Table 7.7: Scoring card of combination of measures*

| Costs of implementation | |
|---|---|
| Score | Standardized |
| 150000 | 0.000 |
| 110000 | 0.273 |
| 100900 | 0.333 |
| 100500 | 0.336 |
| 100000 | 0.339 |
| 60900 | 0.600 |
| 60500 | 0.603 |
| 60000 | 0.606 |
| 52000 | 0.659 |
| 50500 | 0.669 |
| 50000 | 0.673 |
| 2900 | 0.987 |
| 2000 | 0.993 |
| 2000 | 0.993 |
| 2000 | 0.993 |
| 1400 | 0.997 |
| 1100 | 0.999 |
| 900 | 1.000 |

*Table 7.8: Standardization of costs of combinations*

## 7.8 Results of the Multi-Criteria Analysis

The three best combinations appear to be:

- A sedimentation reservoir + a reservoir with a culture in it + improved management + reuse of water for other cultures
- A closed bio-filter + improved management
- A shrimp farm with polycultures + closed bio-filter

| | Combination of Measures | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Criteria | A1+A2.1 | A1+A2.4 | A1+B1 | A1+B4 | A1+B1+B4 | A2.1+A2.2 | A2.1+A2.3 | A2.1+A3 | A2.1+B1 | Weigth |
| Costs of implementation | 0.659 | 0.987 | 0.993 | 0.993 | 0.993 | 0 | 0.273 | 0.669 | 0.673 | 0.1 |
| Time of implementation | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 1 | 1 | 0.2 |
| Manageability by farmers | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 0.5 | 0.5 | 0.5 | 0.05 |
| Economic benefits | 1 | 1 | 1 | 1 | 1 | 0.5 | 0.5 | 0.5 | 1 | 0.15 |
| Effect on production | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 1 | 0.1 |
| Effect on diseases | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1 | 0.5 | 1 | 0.15 |
| Environmental impact | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 0.5 | 0.5 | 0 | 0.15 |
| Needed policies | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 0.5 | 0.05 |
| Large scale effectiveness | 0 | 0 | 0 | 0 | 0 | 1 | 0.5 | 0 | 0 | 0.05 |
| Total | 0.691 | 0.649 | 0.649 | 0.649 | 0.649 | 0.600 | 0.502 | 0.617 | 0.717 | |

| Criteria | A2.2+A2.4 | A2.2+A3 | A2.2+B1 | A2.3+A2.4 | A2.3+A3 | A2.3+B1 | A2.4+A3 | A2.4+B1 | A2.4+B1+B2 | Weigth |
|---|---|---|---|---|---|---|---|---|---|---|
| Costs of implementation | 0.333 | 0.336 | 0.339 | 0.600 | 0.603 | 0.606 | 0.997 | 1 | 0.999 | 0.1 |
| Time of implementation | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0.2 |
| Manageability by farmers | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.05 |
| Economic benefits | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 0.15 |
| Effect on production | 0.5 | 0.5 | 0.5 | 1 | 0.5 | 1 | 0.5 | 0.5 | 1 | 0.1 |
| Effect on diseases | 0.5 | 0.5 | 0.5 | 1 | 0.5 | 1 | 0.5 | 0.5 | 0.5 | 0.15 |
| Environmental impact | 1 | 1 | 1 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0.5 | 0.15 |
| Needed policies | 1 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 0.05 |
| Large scale effectiveness | 1 | 1 | 1 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 | 0.05 |
| Total | 0.508 | 0.484 | 0.484 | 0.535 | 0.410 | 0.536 | 0.575 | 0.575 | 0.775 | |

*Table 7.9: Results of MCA of combinations of measures*

The positive and negative sides of each combination are shown in table 6.10.

| A sedimentation reservoir + a reservoir with a culture in it + improved management + reuse of water for other cultures | |
|---|---|
| Positive: | Fast and cheap implementation, economic benefits |
| Negative: | Small scale, difficult to manage shrimp farmers |

| A closed bio-filter + improved management | |
|---|---|
| Positive: | Easy to manage by shrimp farmers, impact on shrimp water quality |
| Negative: | Small scale, high costs |

| A shrimp farm with polycultures + closed bio-filter | |
|---|---|
| Positive: | Economic benefits |
| Negative: | High costs, difficult to manage by shrimp farmers, small scale |

*Table 7.10: Positive and Negative sides of the 3 best combinations*

## 7.9 Sensitivity/Uncertainty of the MCA

The major problem with a MCA is that depending on the weight, the chosen criteria and chosen scores, the outcome can be completely different. Obviously this is a general problem with MCA's, but with this research the variability of the MCA proved to be quite a lot.

A lack of information or up to date information caused the scoring to change from before the fieldtrip to after the fieldtrip. The weight was mostly based on common sense; what are the major needs and goals.

In a next research there should be more specific information available, and the weight should be based on the demands of the local government. In this way the outcome of the MCA should be more reliable and permanent. Still the MCA in this case gave a good idea of which measures should be the most interesting to look after.

# 8 Conclusions and Recommendations

For each type of shrimp farming community a possible measure is made. For the smaller communities a closed biofilter seems to be the best solution, for the larger communities the sedimentation reservoir and the reservoir with a culture in it seems to be a suitable solution. There is still a lot of research that can and should be done before any of these measures are applied.

First of all a complete quantitative analysis should be made, including the impact of all the proposed solutions. This can only be done when measurements are taken around the shrimp ponds during the production season. This will be done in the year 2008.
The size of the filters and the changes in management are depending on the amount of water that needs to be filtered and the intensity in which it needs to be filtered.

Further research is also needed at applicability of measures for different areas. For example maybe the reuse of water for agriculture can be a suitable solution for some areas. Also some of the measures mentioned in this research were still in development, for example the mangrove biofilter. After more research and testing it could well be that one of these measures could be very well applied on some of the locations in the research area.

For now changes already should be made at the shrimp farms as soon as possible. The changes in management and a freshwater reservoir can solve the problems for a large part already. With a freshwater reservoir the salinity problem can already be solved, a reservoir can also already be used as a part of a filter, by using it as a sedimentation reservoir and/or by growing a culture in it. Better management can solve a large part of the diseases. The bacteria which cause the diseases can live of remaining food in the water and in the sludge at the bottom of the pond, if this is cleaned more properly this could change a lot. Also the tools to prevent external factors to enter the pond like birds should be applied immediately.

For future planning the government might want to look at the use of polycultures in the brackish aquacultures. This solution did not come out of the MCA as the best measure at first because of the long application time, and the difficult manageability by the farmers. Still if a biofilter is implemented consisting of a reservoir with a culture in it, this can be the first step towards the use of polycultures, because the culture in the filter can also be sold, and should also be changed during the production period. The use of polycultures can also lead to a good structure for the brackish aqua cultural environment and the most important part of polycultures is that they are used in a very successful way in countries that have suffered from the same problems as Vietnam right now. So it is proven to be a good method.

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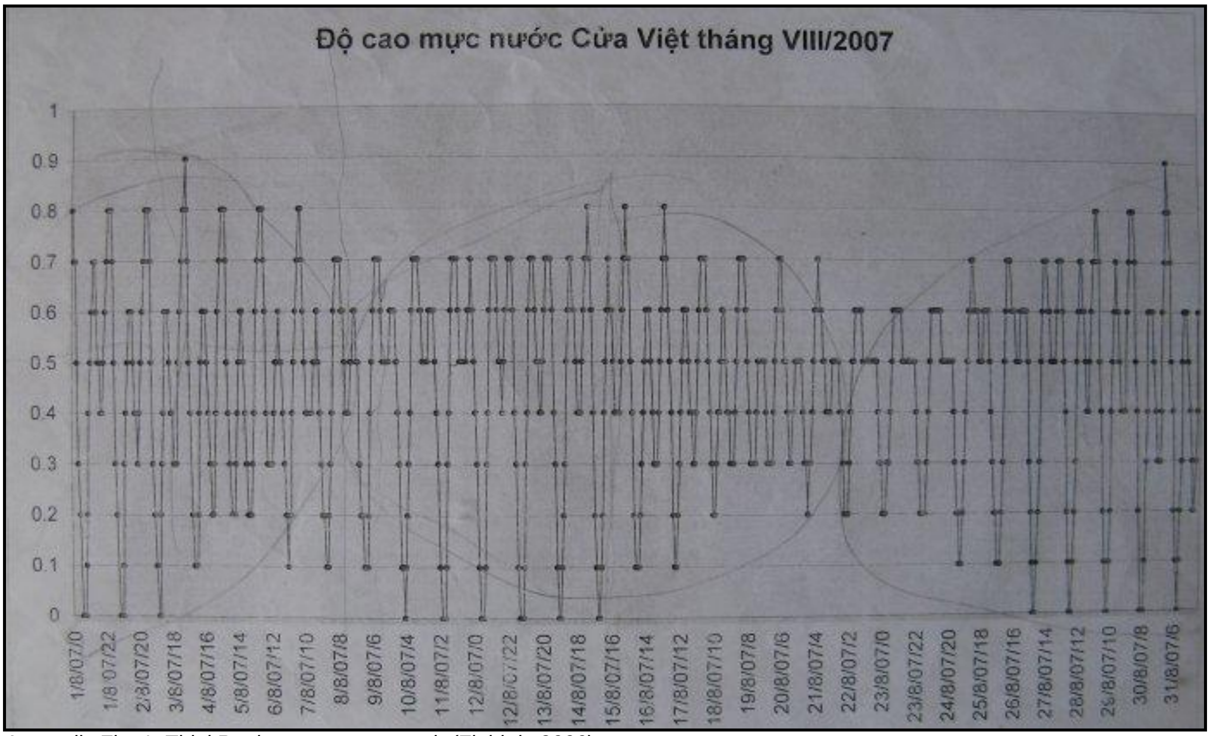
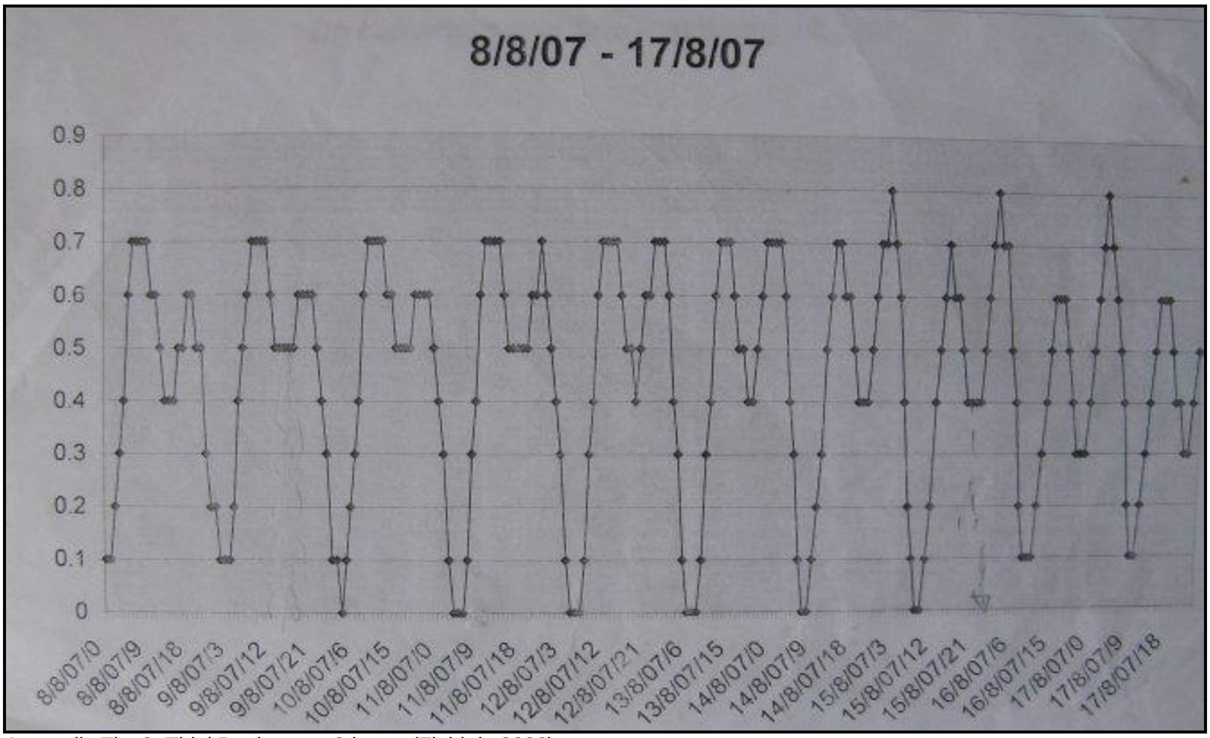
# Appendix A. Quang Tri Province

## *Tidal Regime*

The tidal regime has been measured on one of the fieldtrips. It was unknown though what the unit was of the vertical axis. The horizontal axis however shows the date and time. This graph gave global insight in the tidal regime, the most important part was the period in which high tides occur.




*Appendix Fig. 1: Tidal Regime over one month (Fieldtrip 2006)*




*Appendix Fig. 2: Tidal Regime per 9 hours (Fieldtrip 2006)*

# Appendix B. Problem Diagnosis

## *Comparison measured/calculated values with standards*

When looking at the measured values for improved Extensive farms and the canals, research shows that on average (in a growing season) there are hardly any problems. The biggest problems occur in the months where the shrimp start to grow fast, and the input of food and antibiotics etc. is far more then the shrimps need or can process.

| Parameter | Canal | | Improved Extensive | | Intensive | | Vietnam |
|---|---|---|---|---|---|---|---|
| | Average | Min-Max | Average | Min-Max | Average | Min-Max | Most Suitable |
| Temperature (ºC) | 29.3 | 23.1-32 | 29.3 | 23.2-32.1 | 28.8 | 23.3-31.6 | 29-30 |
| Salinity (‰) | 18 | 10-27 | 21 | 13-28 | 22 | 18-28 | 15-25 |
| pH | 7.7 | 6.9-8.2 | 7.6 | 7.1-8.3 | 7.8 | 7.3-8.1 | 7.5-8.5 |
| DO (mg/l) | 5.2 | 2.2-6.8 | 4.76 | 2.4-7.0 | 4.9 | 2.9-6.5 | >5 |
| BOD (mg$O_2$/l) | 5.8 | 4.1-9.1 | 5.7 | 3.4-9.5 | 7.7 | 2.4-12.6 | 5-10 |
| COD (mg$O_2$/l) | 6.9 | 5.3-10.2 | 6.8 | 3.9-10.9 | 8.8 | 4.2-12.6 | 10-15 |
| $H_2S$ (mg/l) | 0.103 | 0.003-0.25 | 0.138 | 0.025-0.300 | 0.126 | 0.020-0.220 | 0.1 |
| $NH_3$ (mg/l) | 0.073 | 0.005-0.240 | 0.091 | 0.012-0.360 | 0.069 | 0.008-0.240 | 0.1 |
| $NO_2$ (mg/l) | 0.026 | 0.003-0.055 | 0.025 | 0.001-0.052 | 0.074 | 0.003-0.250 | 0.1 |
| Total N (mg/l) | 0.56 | 0.23-0.84 | 0.87 | 0.63-1.12 | 1.21 | 0.72-1.78 | 2 |
| Dissolved $PO_4$ (mg/l) | 0.016 | 0.008-0.038 | 0.02 | 0.009-0.034 | 0.036 | 0.007-0.088 | 1 |
| Total $PO_4$ (mg/l) | 0.12 | 0.016-0.212 | 0.206 | 0.082-0.241 | 0.274 | 0.072-0.433 | 0.5 |
| Total Fe (mg/l) | 0.18 | 0.1-0.3 | 0.18 | 0.07-0.34 | 0.17 | 0.1-0.32 | 0.15 |

*Appendix Table 1: comparison of measured values and most suitable values for farming tiger shrimp (Ms. Quan Thi Quynh Dao 2002)*

## *Antibiotics*

| Type of antibiotics | Improved Extensive | | Intensive | |
|---|---|---|---|---|
| | Water | Mud | Water | Mud |
| Sulphamethoxazole (‰) | 0.055 | 0.02 | 0.205 | 1.52 |
| Trimethoprim (‰) | 0.27 | 0.07 | 0.115 | 2.45 |
| Oxolinic Acid (‰) | 0.09 | 0.01 | 0.1 | 0.004 |
| Norfoxacin (‰) | 0.02 | 0.03 | 0.7 | 3.35 |

*Appendix Table 2: Antibiotics measurements in North Vietnam (Ms. Quan Thi Quynh Dao 2002)*

# Appendix C. Qualitative Analysis

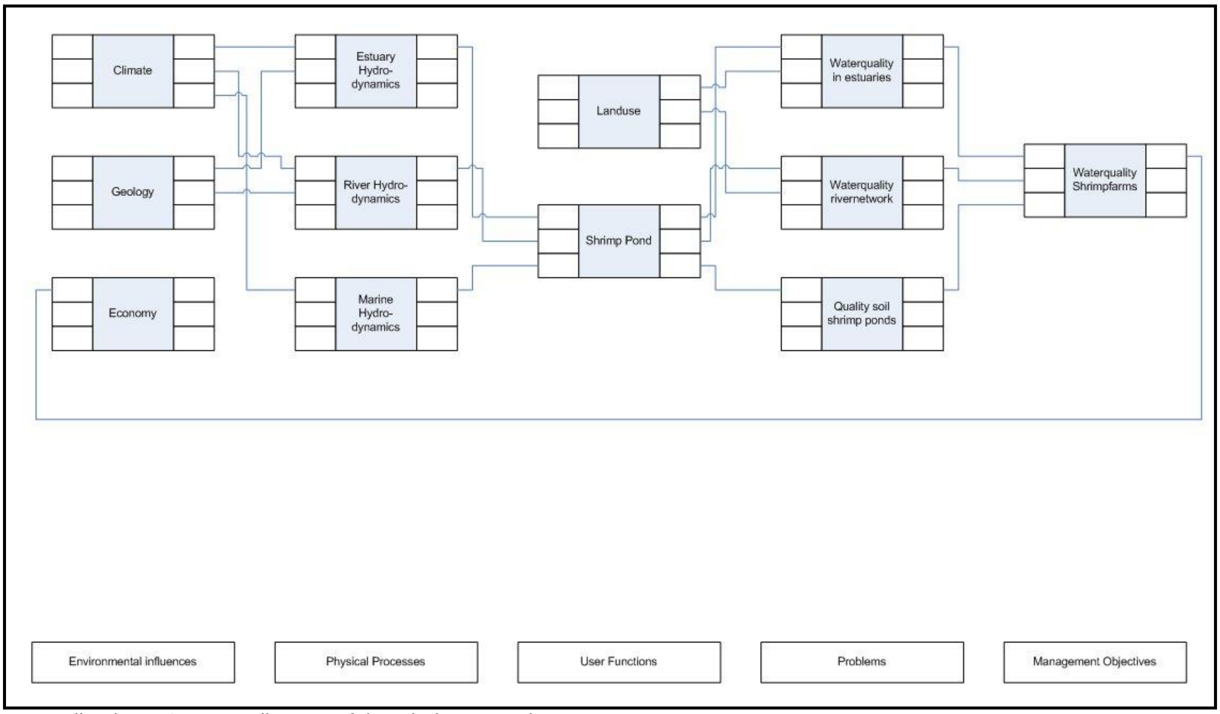
## *Flow Diagram*

The flow diagram was made, to get insight into every aspect involved for this problem. It was also very usable to see which aspect was useful for this research.


*Appendix Fig. 3: Flow diagram of the case study*

## System Diagrams

To summarize the flow diagram, the detailed aspects have been pulled together on a more global level. In this way it's easier to see the relations.




*Appendix Fig. 4: Systems diagram of the whole research assessment*