RESEARCH REPORT

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Pollution Control and Sustainable Fisheries Management in Songkhla Lake, Thailand

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Hundreds of thousands of people rely on the fisheries of Thailand's Songkhla Lake for their livelihoods. Unfortunately, effluent from factories and farms in the region is heavily polluting the lake, which lies on the east coast of the country. Now a new EEPSEA study looks at the pollution in the lake and its impact on fishery production. It also assesses technological and policy options to improve water quality and so boost the lake's ecological health and its economic productivity.

The study is the work of a team of researchers led by Kunlayanee Pornpinatepong from Prince of Songkla University, Hat Yai, Thailand. It finds that two key market-based mechanisms could give polluting firms a real incentive to adopt appropriate clean-up technology and so reduce the amount of pollution they produce. It therefore recommends that a tradable discharge permit (TDP) system should be applied to large firms and farms, while an emission charge system (ECS) would better suit small- and medium-scale firms and farms.

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Pollution Control and Sustainable Fisheries Management in Southern Songkhla Lake, Thailand

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EEPSEA was established in May 1993 to support research and training in environmental and resource economics. Its objective is to enhance local capacity to undertake the economic analysis of environmental problems and policies. It uses a networking approach, involving courses, meetings, technical support, access to literature and opportunities for comparative research. Member countries are Thailand, Malaysia, Indonesia, the Philippines, Vietnam, Cambodia, Lao PDR, China, and Papua New Guinea.

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After attending the training course in Policy Analysis provided by EEPSEA in 2006, Vietnam, I became inspired to apply this in my research to address serious environmental problems such as in Songkhla Lake. The five-day training was a valuable experience that has had much positive impact on my research. I have found that policy analysis is not only a systematic, standardized tool providing powerful information for decision-making, but it is also a problem-based research tool which helps to ensure a positive outcome. I would like to thank Dr. David Glover and Dr. Herminia Francisco for the opportunity to attend the course and also for the funding support of this policy analysis research.

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This research will have been successful if it is used in any way to bring about more effective policies for environmental protection.

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EXECUTIVE SUMMARY

The major objective of this study was to develop appropriate water quality control policies for a sustainable fishery in Southern Songkhla Lake (Southern Lake) so the impact of water pollution on fishery production in the lake was the first consideration. The three major components of this study were: (i) the identification of the situation and trends in fishery production associated with water quality in the lake, using secondary data and statistical analysis, (ii) the evaluation of technological options to improve water quality using secondary data and cost-effectiveness analysis, and (iii) the analysis of proposed policy alternatives for better water quality.

In order to identify the current situation and trends in fishery production associated with water quality in Southern Lake, the natural shrimp catch was used as an indicator of water quality deterioration while the water quality composite index (WQCI) was used as the indicator of the relationship between water quality and pollution from various sources.

Our statistical analysis indicated that the water quality changes in the lake had a significant impact on shrimp production, i.e., one unit increase in the WQCI at U-Tapao would lead to a shrimp productivity increase of 3.4% (significant at the 0.05 level), and one unit increase in the WQCI at Pag-ro would lead to a shrimp productivity increase of 10% (significant at the 0.01 level). Also, an analysis of 12 years of water quality data (1992-2004) found that the amount of nitrogen and phosphate discharged into Southern Lake had increased over time at every river mouth. In particular, the total amount of nitrogen at the U-Tapao river mouth had increased significantly.

Nitrogen was found in farm effluents and in both domestic and industrial waste and in large amounts, which was very harmful to aquatic animals. Therefore, in order to control and improve the water quality of Southern Lake, the wastewater from the various sources needs to be well managed in order to increase the fishery value of the lake.

There were two types of methodologies identified which affected treatment costs for basic technology options. First, land use applications had a higher fixed cost due to land use but lower operating costs, while technology-based applications, such as the Up-flow Anaerobic Sludge Blanket (UASB) or Activated Sludge (AS), had lower land use costs but higher operating costs. With high technology options, however, there was no particular cost pattern.

The results of the cost-effectiveness analysis (CEA) showed that the effectiveness of a treatment technology was sensitive to the size of the plant and the influent load. It was less effective for businesses with a lower influent load or a smaller size to invest in individual treatment plants while it was more cost-effective for small-scale polluters to share a common treatment plant.

For domestic treatment facilities at the municipal level, the CEA showed that the cost of treating the biological oxygen demand (BOD) per kilogram was very high even at full capacity. Large-scale domestic treatment facilities tended to be ineffective due to under-utilization and such operations required effective administrative management. Smaller-scale domestic treatment facilities are recommended because these are easier to operate effectively and also offer more flexibility for future development.

The command and control (CAC) policy is the current water pollution management system in Southern Lake. Overall, this study found that the CAC policy was deficient in encouraging the participation of all stakeholders and that they were not sufficiently aware of their responsibilities in environmental protection

Based on our literature review and survey, it became evident that firms and farms had the potential to improve their wastewater treatment technologies but there were no incentives for them to do so. Market-based instruments have many advantages over CAC regulations. However, each instrument has different advantages and disadvantages. Therefore, three policy alternatives were carefully compared: the command and control (CAC) system, emission charge system (ECS) and tradable discharge permit (TDP) system. There were ten criteria selected to compare the different policies, namely, public acceptability, legal feasibility, implementation complexity, effectiveness, capital costs, operating costs, transaction costs, impacts, equity, and decentralization.

In order to select the best alternative, the study suggests that policy-makers apply different weights to the different criteria depending on their desired goals. Moreover, some congruence among the advantages of each policy option can also be considered. For example, due to the high outcome effectiveness of the TDP and high capital costs, it could best be applied to large-sized firms and farms, while the ECS would better suit small and medium-scale firms and farms because it involves lower capital costs. Whichever combination of policy options is ultimately selected, further studies will be needed to determine the effectiveness of such combinations.

1.0 INTRODUCTION

Songkhla Lake is a lagoon in south Thailand which is made up of three interconnected lakes. The southernmost lake of the lagoon, called Southern Songkhla Lake or Southern Lake, is facing a significant decline in its once thriving fishery industry. Two main factors which have led to this decline are water quality degradation and an increase in fishing activity. This study was undertaken to develop policy recommendations for a sustainable fishery in Southern Lake with the aim of such policies being extended to Songkhla Lake. However, it deals only with the pollution aspects of the problem as extensive consultations with local stakeholders indicated that any talk about controlling fishing activities was a very sensitive issue in the local community and the fisherfolk would be more likely to be cooperative about establishing pollution controls in the area.

This report begins by providing a simple conceptual model of the existing usage and economic value of Southern Lake. The policy options are examined next, taking into consideration policy problems and their impacts on water quality and primary solutions, stakeholders' opinions, and the assessment of economics and fishery experts.

The results and recommendations of this study will be valuable to decision-makers attempting to formulate practical policies aimed at sustaining fishery production in Southern Lake. In addition, the study will be useful to those interested in understanding the value of the fishery industry in Songkhla Lake.

1.1 Research Problem

Southern Songkhla Lake, known locally as *Thale Sap Songkhla*, is one of the three interconnected lakes which form Songkhla Lake. It is located in Songkhla Province, in the southeast coast of Thailand, and covers an area of about 180 km^2 with brackish and salt water.

Southern Lake empties into the Gulf of Thailand through a small channel which also serves as the harbor entrance to the town of Songkhla. Tidal currents carry seawater into the lake all year long and it mixes with freshwater from several streams and small rivers that flow into the three lakes. Southern Lake has a season-dependent salinity—its water is brackish to salty in the dry season (February – April) when freshwater input is minimal, but is mostly fresh during the wet season from November to March when freshwater input is high.

The lake plays a unique role because it acts as the lungs for the inland harbor at the town of Songkhla. Due to the tidal currents, the depth of the harbor and its channel are maintained at six to eight meters. The seasonal fluctuations in the water level of the lakes wash away new sediments and remove the isolated patches of water hyacinth after the plants have died because of the saline water. The current situation of having an open lagoon is essential for all forms of aquatic life in the lakes because open water, wind, and waves effectively put oxygen in the water. An open lagoon with an undisturbed circulation of fresh and brackish water is a prerequisite for a stable and healthy ecosystem. Any change in the quality of the water, whether from natural or man-induced actions, is likely to affect the whole system.

Songkhla Lake is facing serious water pollution as a result of human activity and industrial development. In 2001, domestic wastewater (from Hat Yai City, the most populous and largest business center of the Songkhla Lake basin) containing 3,375 kg BOD [1] /day was discharged into the lake daily. Pesticides and fertilizers from agricultural activities, nutrients from shrimp farming and livestock waste, and oil and grease from shipping and other activities in the harbor also accumulate in the lake (ONEP 2004). The direct impacts of these pollutants on the fishery industry increase year by year. A sewage treatment plant was opened in Hat Yai in 1999, but has only had a small impact in mitigating pollution.

In 2005, the Department of Pollution Control reported that there were 1,567 factories around Songkhla Lake. Half of these are large factories, with equipment of more than 50 horsepower. About 63% of them are centered around Southern Lake, with their accumulated discharge having serious detrimental impacts on the water quality.

[1] BOD = Biological Oxygen Demand

The shrimp fishery is the most profitable economic activity in Southern Lake. On average, the income from the shrimp catch is almost ten times that of other catch. Presently, however, the shrimp catch in Southern Lake has decreased severely in terms of both amount and number of species. Sirimontaporn, Choonhapran and Tansakul (1999) reported that there were 30 species of shrimp found in Songkhla Lake in the early '80s (most of which were found in Southern Lake), but a later study in 2002 found only 11 species (Mabuntham 2002). A related study found that the shrimp catch from standing traps, the most common local fishing trap, decreased from 3.6 kg/day in 1996 to 0.9 kg/day in 2003 (ONEP 2004).

Although there has been a great deal of concern over these problems, they have not yet been solved. This study was thus undertaken to determine appropriate policy options for more effective water quality management in developing a more sustainable fishery industry in Southern Lake.

1.2 Objectives of the Study

The general objective of the research was to develop appropriate water quality control policies to ensure a sustainable fishery in Southern Lake. The impact of water pollution on fishery production in the lake was top priority in the investigation.

The specific objectives of the research were:

- To identify the current situation and trends in fishery production in Southern Lake.
- To estimate recent decreases in the economic value of Southern Lake associated with fishery and other human activities.
- To identify appropriate policy options for sustainable fishery resource use in Southern Lake.
- To analyze and evaluate the main policy options.

1.3 Research Questions

The research questions were:

- What is the current situation and what are the trends in fishery production in Southern Lake?
- What are the effects of the major human activities in Southern Lake on the environment?
- To what extent does water pollution affect the economic value of Southern Lake?
- What are appropriate policy options for water quality control management in Southern Lake?

1.4 Study Site and Scope of the Study

This study selected Southern Lake as the study site out of the three lagoons in Songkhla Lake because it has the richest biodiversity, most intensive economic activities and highest population density. The shrimp fishery was selected as the indicator of both the environmental quality and economic value of the lake as shrimps were the highest priced product in the seafood market and abundant in Southern Lake.

1.5 Methodology

1.5.1 Identification of existing conditions and problems

The study undertook a thorough review of the existing situation using the following steps.

(a) Data collection

There were three main categories of information gathered: biological conditions, physical conditions, and economic activities and fishery production. The biodiversity of the lake was determined with the help of an experienced biologist. The historical trends and current physical conditions were also investigated, focusing on water pollution and the major sources of pollution.

(b) Constructing a profile of the existing system

Using data from (a) above as well as from consultations with ecologists and focus group discussions with experienced fishermen, a profile of the existing biological, physical and economic system of Southern Lake was constructed in the form of a simple conceptual model.

(c) Identifying quantitative cause-and-effect relationships between the main activities and the economic value of the lake

The cause-and-effect relationships were roughly estimated and presented in two components. The first was a descriptive review of how the main activities contributed to water pollution, which in turn led to lower fish and shellfish populations in the lake. The second component examined the relationship between the lake’s productivity and the sources of pollution using statistical analysis. Shrimp productivity was used as the dependent variable.

(d) Reporting

All the above data together with the results of the pre-analysis done in (c) above provided the input for a short preliminary descriptive report on “Southern Lake: Functions, Status and Recent Trends”. This report described the existing situation in terms of the relevant problems and trends in fishery production in the lake and was the principal reference in considering the best policy options.

1.5.2 Policy alternatives

(a) Identification of potential policy alternatives

Base on the input from 1.5.1, the links between environmental problems, the impacts on water quality, specific policies, and primary solutions were made. Potential policy alternatives were then identified.

(b) Focus group discussions

The report and draft policy alternatives were presented to the various stakeholders, specifically (i) the polluters for example, the manufacturing industries, and shrimp and pig farmers; (ii) community leaders and representatives from related government agencies; and (iii) external agencies such as NGOs and academic institutions. Once the stakeholders had had a chance to study the report and draft policy alternatives, focus group discussions (FGDs) were conducted to investigate how they perceived the situation and obtain their comments and suggestions. With this feedback, the details of each alternative were adjusted.

(c) Assessment and ranking of the policy alternatives

Assessment criteria were set based on the input from the FGDs. In order to assess and compare the different policy alternatives using these criteria, one person from each stakeholder group was selected for small group discussions and in-depth interviews. Finally, the results were interpreted by the research team and experts together and a ranking of the policy alternatives was made.

2.0 THE FISHERY INDUSTRY IN SOUTHERN LAKE: FUNCTIONS, STATUS, AND RECENT TRENDS

This section served as the baseline report for investigating policy options for sustainable fishery use in the Songkhla Lake system. The report was aimed at providing information on the current situation of resource utilization in Southern Lake to local communities and relevant government agencies.

In order to understand the Songkhla Lake system, its profile in terms of bio-physical properties and the existing usage of the three lakes was described. The problems and causes of the current environmental degradation affecting fishery production in Southern Lake were illustrated in a simple model. This report focused on Southern Lake as the study area because it had the most intensive economic activities, richest biodiversity, and highest population density in the Songkhla Lake basin.

We selected three sets of variables (shrimp catch, water quality, and salinity) to describe the links between human activities and their adverse effects on fish and shrimp catching and cultivation, and on the productivity of fishery activities. The key issue was the deterioration of the lake's water quality which caused a reduction in the economic value of the lake and affected the livelihoods of the people that depended directly on it.

Of the various sources of pollution, the most critical one was the major human activity, which was fishing, in the study area. The most popular fishing methods were chosen as typical activities in the lake. In order to discuss the water pollution in the lake, a set of general water quality parameters was selected in the construction of a "Water Quality Composite Index (WQCI)". The productivity of the shrimp fishery was selected as the indicator of the economic value of the lake. This choice was based on the fact that shrimps were the most abundant catch and also the highest priced product in the seafood market. Salinity was also selected as an environmental factor which had an impact on the value of the fishery.

2.1 Physical Aspects of Songkhla Lake

Songkhla Lake (Figure 1) is located on the southeast coast of Thailand. The Songkhla Lake system covers parts of three provinces: Songkhla, Phatthalung, and Nakorn-Srithammarat. The overall basin covers an area of 8,729 km^2, of which the lake proper has a water surface area of about 1,040 km^2 (ONEP 2005).

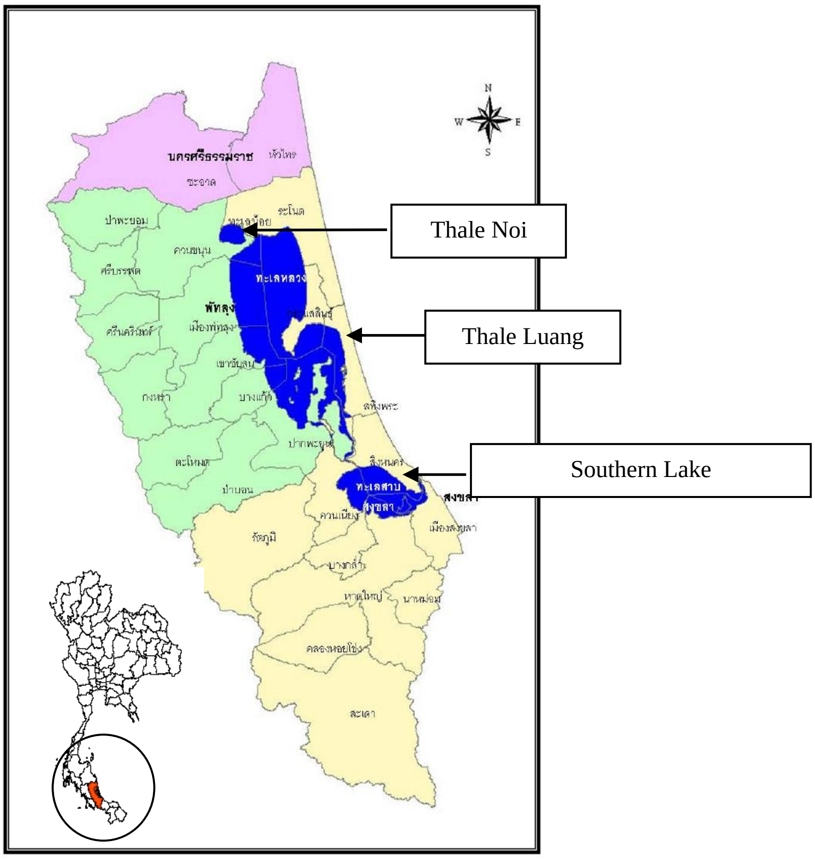

Figure 1. The physical and administrative areas of Songkhla Lake

Note: Part 1 is Thale Noi, Part 2 is Thale Luang, and Part 3 is Thale Sap Songkhla (Southern Lake).

The lake is classified as a lagoon system comprising three inter-connected parts, from the north to the south as follows**:**

(a) Thale Noi, with an area of 30 km^2, containing mainly freshwater.

(b) Thale Luang, which is further divided into two parts; with the northern part connected to Thale Noi with a surface area of 459 km^2, and the southern part with a surface area of 377 km^2. Both parts contain brackish water, with salinity concentrations depending on the season.

(c) Thale Sap Songkhla (Southern Songkhla Lake or Southern Lake), is about 180 km^2 in surface area with brackish to salt water. Southern Lake is connected to the Gulf of Thailand at the point where Songkhla Town is located, which serves as the entrance to the inland harbor.

2.2 Climate of the Songkhla Lake Basin

The climate of the Songkhla Lake area is governed by two monsoons; the southwest monsoon and the northeast monsoon. There are two seasons (ONEP 2005): (a) The rainy season, from May to January, under the influence of the southwest monsoon from May to September and the northeast monsoon from October to January. The heaviest rains usually occur in November; and (b) The dry season, from February to April. The hottest month is normally April (ONEP 2005). During this dry season, the amount of freshwater flowing into Songkhla Lake is substantially lower than the rest of the year.

2.3 Physical Description of Southern Lake

Southern Lake (Figure 2) has an average depth of about 1.5 m. The deepest area is around the lake entrance at 12-14 m (ONEP 2005). The hydro-dynamics of Southern Lake are mainly driven by tidal flow and river runoffs which cause variations in water level and quality. Uncertain weather also occasionally impacts physical conditions. Tidal fluctuations in the lake from Ko Yo to Pag-ro[2] vary significantly from 21 cm to 11 cm, respectively (Pornpinatepong 2004). In the dry season, a current velocity of about 1 m/s is the norm at the lake entrance. The flow then separates into two paths as it approaches Ko Yo. Maximum velocities north and south of Ko Yo are approximately 0.6 m/s and 0.4 m/s, respectively. In the rest of the water body upstream of Ko Yo and in the mid-portion of Southern Lake, the water is normally relatively calm until it reaches Pag-ro Channel where the passage narrows and the water velocity suddenly increases up to 0.5 m/s.

Complete mixing of seawater and freshwater can be found throughout Southern Lake, except for the deeper sections such as around Pag-ro, Ko Yo, and the lake entrance, where salinity stratification occurs. Normal sea salinity is 32-35 ppt and the seawater flow can cause salinity of up to 31 ppt at Ko Yo in the dry season.

[2] Ko Yo is an island in Southern Lake, close to the entrance of the lagoon, and Pag-ro is the connecting channel between Southern Lake and Thale Luang. Figure 2 refers.

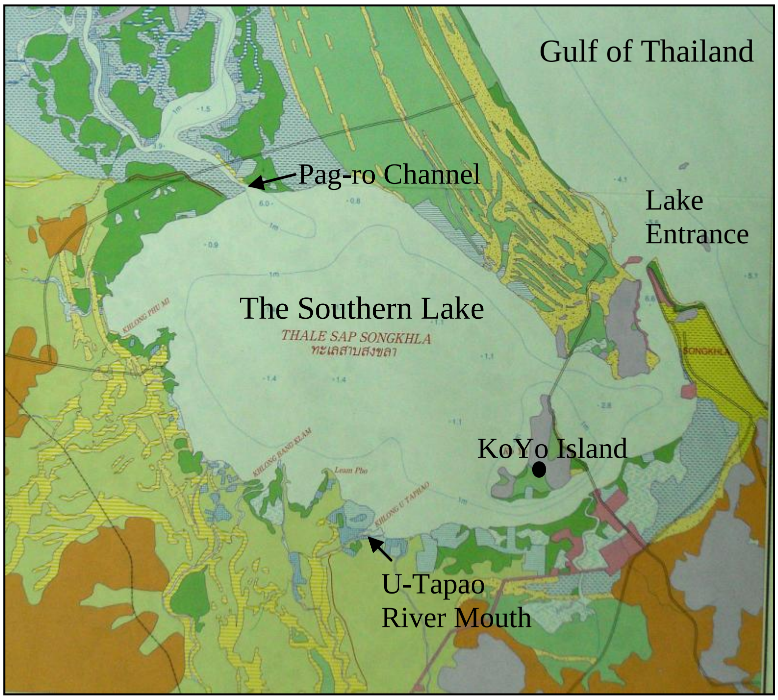

Figure 2. A map of Southern Lake

In the late and heavier rainy season, from October to January, large amounts of freshwater flush out most of the saltwater and the waters of Southern Lake often become almost completely fresh on the surface, although salinity stratification can persist in the deeper portions of the lake. For example, to the north of Ko Yo, the stratification at 3 m deep has been found to result in a difference in salinity of 12 ppt between the water surface and the bottom of the lake as compared to 22 ppt at the lake entrance (Pornpinatepong 2004).

Taylor et al. (1986, cited in Pornpinatepong 2004) reported that Songkhla Lake received a sediment load of 60-75 tonnes/km^2/year, an average rate of 0.4 mm/year. With increased deforestation and erosion since then, it is suspected that the sedimentation load must now be much higher. Most of the lake bed is muddy, except at the lake entrance where sand is predominant, with a gradual mud-sand gradient at the end of the entrance channel.

2.4 The Ecosystem of Southern Lake

The characteristics of the Southern Lake ecosystem are quite unique, especially the variations in salinity due to seasonal changes and distance from the mouth of the lake. In the rainy season, freshwater and nutrients from the watershed area around the lake are discharged into it and flush the seawater outwards to the Gulf of Thailand. However, in the dry season when less freshwater is discharged into the lake, seawater intrudes well into the lake, bringing the larvae of sea animals, and various shrimp species in particular into the lake which then serves as a nursery for these animals. At the same time, this seawater intrusion also kills certain aquatic weeds that might otherwise become over-abundant and thus helps maintain the equilibrium of the lake's ecosystem. This situation of having freshwater, brackish water, and seawater all in the same body gives Southern Lake a highly diverse and rich ecosystem and provides fishery resources composed of freshwater, brackish and marine animals all year long.

According to the Encyclopedia of Southern Thailand Culture (Sirimontaporn, Choonhapran and Tansakul 1999), 450 fish species and 30 shrimp species can be found in Songkhla Lake and it also serves as an important nursery ground for many economically important species of fish, crabs, and shrimps (Sookchareon 1965; Choonhapran 1994; Sirimontaporn, Choonhapran and Tansakul 1999; and Mabuntham 2002).

The most economically important species found in Southern Lake are:

(a) Shrimps *(both freshwater and marine species)*

There are various marine shrimp species which migrate from the sea to grow in Southern Lake throughout the year, of which the important ones are: banana shrimp (*Penaeus merguiensis*), black tiger shrimp *(P. monodon),* green tiger prawn *(P. semisulcatus),* yellow shrimp *(Metapenaeus brevicornis),* stork shrimp *(M. tenuipes*) and pink shrimp *(M. moyebi).*

(b) Brackish water fishes *(from both capture and culture fisheries)*

The major brackish water fish species are sea bass (*Lates calcarifer*), greenback mullet (*Liza subviridis*), sea catfish (*Plotosus* spp.), and spotted scat (*Scatophagus argus*).

(c) Freshwater fishes

The most important freshwater fish species are catfish (*Clarias* spp.), yellow mystus (*Mystus nemurus*), snakehead murrel (*Channa striata*), and butter catfish (*Ompok bimaculatus*).

2.5 The Socio-Economic Structure of the Southern Lake Area

Southern Lake has always been rich in fishery resources, and fishing is the major occupation, using local fishing equipment. People also collect forest products and cultivate food crops such as paddy and fruits. With the exceptions of Hat Yai and Songkhla, the bigger cities in the area where large businesses are located, these natural resources are the main source of livelihood and food for the many small communities around Southern Lake. The population around the lake is approximately 800,000, in 9 out of the 16 districts of Songkhla Province.

Recently, however, industrial operations, encouraged through government policy, have increased along with the population. Unfortunately, this has led to environmental degradation. The traditional culture of sharing and exchanging goods has been replaced by business competition and one of the externalized costs has been the environment. The people's way of life has changed and many have had to move away to find jobs in town.

Since the catchment areas of Southern Lake are mostly located in Songkhla Province, the latter's economic structure is directly and indirectly related to the natural production system of Southern Lake. Songkhla's economy mainly depends on the fishery and agricultural production sectors, and non-agricultural sectors such as wholesale, retail trade, and services. In 2005, the Gross Provincial Product (GPP) of Songkhla was 136,663 million baht and the Gross Provincial Product (GPP) per capita was 103,785 baht (Table 1). From 2001-2005, the fishery sector's economic contribution to the province decreased while that of most other sectors increased.

Table 1. Gross Provincial Product (at current market prices) by economic activity (2001- 2005)

Sectors	**2001**	**2002**	**2003**	**2004**	**2005**
Agricultural	24,987	26,465	29,502	33,663.50	34,785
- *Agriculture*	*9,061*	*11,563*	*16,118*	*20,110*	*21,515*
- *Fishery*	*15,926*	*14,902*	*13,384*	*13,553*	*13,270*
Non-Agricultural	76,606	80,833	86,565	93,278	101,877
- *Goods*	*48,835*	*51,394*	*56,160*	*59,938.30*	*65,351*
- *Services*	*175,415*	*185,157*	*201,729*	*220,543*	*236,798*
GPP (baht)	101,593	107,298	116,067	12,6941.5	136,663
Per capita GPP (baht)	78,848	82,824	89,076	96,843	103,785

Source: Office of the National Economic and Social Development Board (2006)

There are a wide range of non-agricultural occupations throughout the basin, such as rubber and seafood industries, tourism, transportation, and restaurants. The major agricultural occupations are:

(a) Fishery

Most people who live around Southern Lake, especially along the shores, earn their income from fishing. In recent years, however, because of declines in aquatic catch, many fishermen have been forced to find new occupations in the cities as factory workers and so on. Some have stopped fishing but remain living by the lake, providing boat tours for tourists.

(b) Aqua-farming

Shrimp farming was introduced to Southern Lake in 1987. It grew rapidly and has since expanded to freshwater areas, even displacing some rice farms. The wastewater from shrimp farms is discharged into the lake. Fish farming in Southern Lake began in 1971. The most popular fish farmed is sea bass, which is a brackish water fish.

(c) Rice farming

Rice farming is a traditional occupation of the people living around the edge of Southern Lake, and on nearby alluvial plains. However, in recent years, as a result of floods, droughts, and farmers moving to other occupations, most paddy fields have been converted to alternative uses such as shrimp farming, rubber planting, or residential areas.

(d) Orchards and rubber plantations

Rubber has been one of the most important economic crops in the province for a long time. The amount of land around the lake basin used for rubber planting has been increasing every year because of a substantial rise in the world price of rubber. Most fruit orchards around Southern Lake are mixed orchards, with various types of trees grown together in the same area, depending on the suitability of the land and demand.

(e) Pig farming

Pigs are an important source of meat in Thailand and there are many pig farms around Southern Lake. Most pig farms are small in size, run by household labor.

2.6 The Economic Value of Southern Lake

2.6.1 Concept of the economic value of lakes

In order to identify the economic value of a lake, two central factors have to be considered: a clear-cut boundary must be established for the lake system, and the means used to define ‘economic value’ must be defined.

(a) Boundary of the lake system

A lake is a natural system within its shoreline, largely dependent on and related to the surrounding systems. If a lake is sufficiently old, it will generally have its own specialized, indigenous plant and animal species. Lake ecosystems cannot survive without the inflow of water. Therefore, the physio-chemical and ecological attributes of any lake system depends largely upon the natural environment, including the human population and its activities within the catchment area. Lakes can only be environmentally stable as long as their catchment areas maintain ecologically sound conditions. These were the guiding principles in framing the recommendations for this study.

(b) Concepts of the economic value of the environment

Concepts of the economic value of a given environmental area are based on the underlying concept of welfare economics. Economic value and changes in it resulting from changes in environmental resource systems are measured in terms of their effects on human welfare. The use of resources or the taking of resources from other uses will affect the well-being of the people in the area of concern in terms of the benefits from and the costs of consuming such resources. These benefits and costs determine the economic welfare of the community affected. Individuals can value the survival of species in a certain environment not only because of the uses people make of them for say, food and recreation, but also because of altruistic or ethical concerns, which in economic terms are defined as existence or non-use values (Freeman 1993).

In terms of asset value, the value of natural resource services can be defined as the sum of the discounted net present values of the monetary flows attributable to those services (Freeman 1993). Changes in the flows of any given service due to public policy or damage caused by pollution or human intervention are translated into changes in the net present value of that service. It is for this reason that all changes of resource flows influence or cause changes in the economic value of the environmental resource system.

(c) The economic value of lakes

The economic value of a lake can be measured using human utilization as a reference. It is necessary to consider all human activities involving lake services in the downstream and catchment areas which affect the natural equilibrium of the lake. The economic value can be categorized according to use or non-use values.

Use values would be the values of goods and services directly provided by the lake system, on-site, to people. Examples of such use values would be the lake's fisheries, vegetation, recreational benefits, and mariculture (fish farming).

Because lake ecosystems, particularly lagoon systems such as Songkhla Lake, provide habitats for a large diversity of aquatic life, they contribute to the economic on-site value of the lake and to the fish populations that can be caught many miles away from the lake (offshore fishery value). Hence the use of a lake has in such cases an indirect use value.

One type of use value is "option value". This applies to resources that are likely to be used some time in the future. People may be willing to pay to maintain the existence of these things in order to reserve the option of using them in the future (Bateman et al. 2002). Such option values for Southern Lake could be the indigenous species of fish for eco-tourists who wish to admire them or the recreational value of some areas around the lake.

Non-use value or passive-use values refer to the willingness of the public to pay to maintain some goods and services provided by, in this case, the lake in existence even though there is no actual or possible use to such persons (Freeman 1993; Bateman et al. 2002). For instance, someone who never visits the lake or is never likely to may hold a passive-use value because she values nature in general. Non-use values can be of various types, including existence values, altruistic values, and bequest values.

(d) The total economic value of Southern Lake

The total economic value of a lake can be measured as the sum of all the types of economic values it carries. In the case of Southern Lake, it would be quite challenging to calculate the different types of values. Therefore, this study mainly considered the cause-and-effect relationship between water quality and the economic value of the lake as most households around the lake made their living from fishery. The shrimp fishery was selected as the single collective indicator to measure the productivity of the lake, as mentioned in the Introduction Section.

2.6.2 Fishery value

The National Institute of Coastal Aquaculture (NICA 2003) evaluated the kinds and quantities of fishery catch at fishing landing sites around Songkhla Lake, and divided the fishery catch into three groups: fish, crabs, and shrimp/mantis-shrimp. In Southern Lake, the largest percentage of the catch by weight in 2003 was found to be shrimp/mantis-shrimp at 83%, followed by fish at approximately 14%, with only 3% for crabs (Figure 3). The most common species of shrimp was pink shrimp (74%) with smaller proportions of banana shrimp (22%), white leg shrimp (3%) and others (1%) (Figure 4). In 2003, shrimps provided the highest economic value at about 31,558,850 baht, with fish and crabs much lower at 2,527,725 baht and 1,156,850 baht respectively.

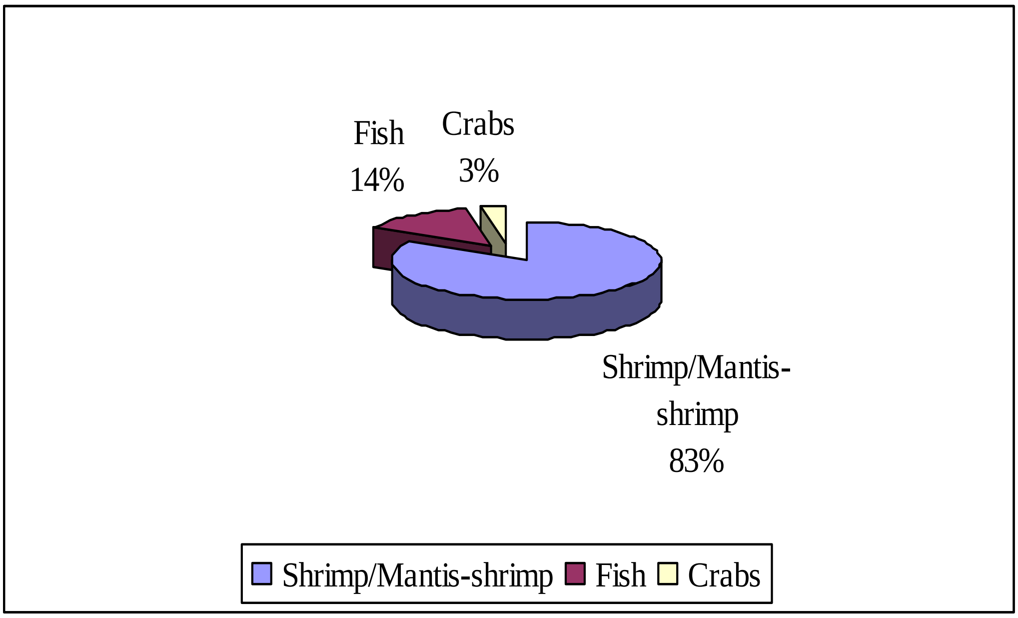

Figure 3. Structure of fishery products in Southern Lake (2003)

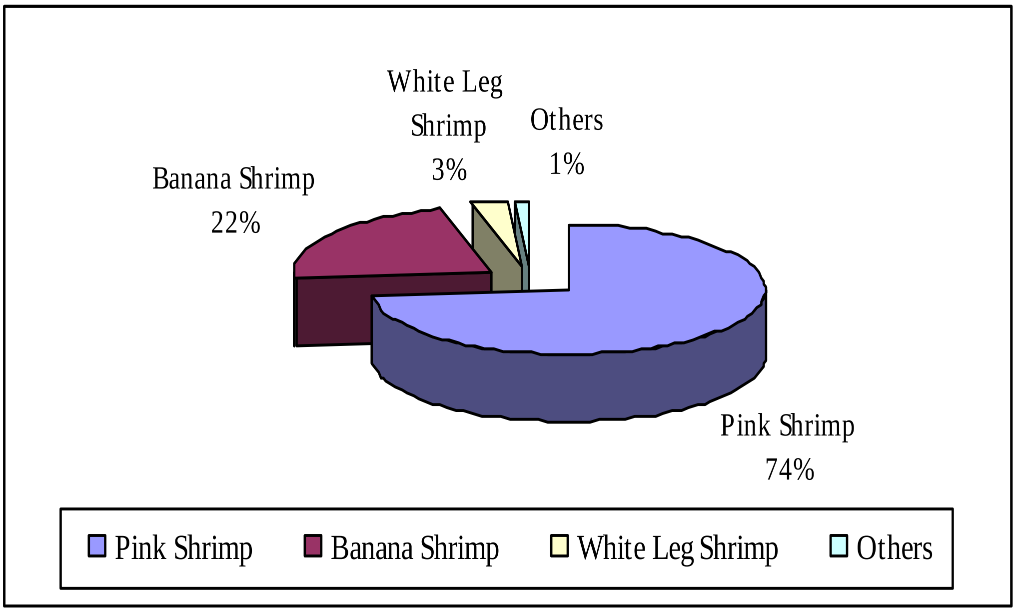

Figure 4. Fishery catch by species in Southern Lake (2003)

Mariculture

Sea bass is one of the most popular kinds of fish cultured in Southern Lake. The areas with a high density of sea bass culture are Ko Yo, Singhanakorn District, and Kaunneang. Due to its high value, sea bass culture is a popular occupation. In 2001, there were about 1,272 sea bass culturing operations with about 5,878 pens, and a total economic value of approximately 826,593,750 baht per year (Songkhla Provincial Fisheries Office 2005).

2.7 Problems and Causes of Environmental Degradation in Southern Lake

2.7.1 Fishery productivity

In order to determine fishery productivity in Southern Lake, this study used the total catch of key species as indicators. There have been several studies on aquatic animals and fisheries resources in Songkhla Lake, but the results have varied in both species diversity and fisheries production due to differences in sampling methods. The different ways of measuring fishery productivity of the lake which have been used can be divided into two groups: fishing traps and docking statistics.

(a) Using fishing traps

This process starts with surveys to find out the number of fishing households and fishing traps per household. Then, another survey is done to determine catch per fishing trap and thus, the total catch.

Using this method, Tookwinart et al. (1986) found that from 1984 to 1986, the total catch in Southern Lake was about 2,480,000 kg per year. Using the same method, Choonhapran et al. (1996) found that the total catch from 1994 to 1995 had increased (compared with the Tookwinart et al. 1986 study) by 35.6% to about 3,361,100 kg per year (Table 2). The researchers believed that this increased catch was likely due to the increased number of fishing traps, especially standing traps, in the lake (for more details, see section 2.7.3)

Table 2. The total catch in Southern Lake estimated from the catch per fishing trap

Study	**Years**	**Catch (kg. per year)**
Tookwinart et al. (1986)	1984-1986	2,480,000
Choonhapran et al. (1996)	1994-1995	3,361,100

(b) Using docking statistics

In this method, the total catch is estimated by the amounts sold at the landing sites of the fishing boats. These estimations may, however, be under-estimated for a number of reasons. Firstly, there are some fishermen who sell their catch at other fish landing sites, outside the scope of the study. Secondly, most fishermen keep some of the fish caught for their own consumption before selling the rest at the fish landing sites. Finally, there are some people living around the lake who catch fish for consumption only. Thus, they don't sell any of their catch at the sites.

This method was used by Tookwinart et al. (1985) to determine the amount of fish sold by fishermen at five docking sites. The study found that in 1985, 345,938 kg of fish were caught. Sirimontaporn and Chaiwatcharakul (1987) collected data from three fish landing sites and found that, from 1977 to 1986, there was an increasing trend in the total catch. NICA (2003) collected data from seven fish landing sites and found that in 2003, 300,477.50 kg of fish were caught.

Even though several studies have tried to estimate the fishery productivity of Southern Lake, most of them collected data for only a single year and had different ways of gathering the information and estimating productivity. This makes it difficult to compare the different findings and results.

ONEP (2004) reported that the total number of fish caught in the standing traps was decreasing. The average amount of fish caught in 2003 was four times lower than in 1996 (from an average of 3.6 kilograms per day in 1996 to 0.9 kilograms per day in 2003). Mabuntham (2002) also found that most fish caught in Southern Lake were of a smaller size than in earlier times.

In conclusion, the total catch data of Southern Lake showed an increasing trend from 1977 to 1995 although these findings may be due to the rise in the number and types of fishing instruments in the 1990s. However, NICA (2003) estimated the fishery productivity of Southern Lake in 2003, and their results indicated that the productivity of the entire lake had slightly decreased.

2.7.2 Deteriorating water quality

Water quality is one of the critical factors affecting the productivity of Southern Lake. Changes in water quality are due primarily to human activity such as water pollution from households and industries, and deforestation of the catchment areas. The sources of pollution, monitoring of the water quality, the current water quality situation, eutrophication, and deforestation are discussed below.

(a) Sources of pollution

The major sources of pollution in Southern Lake are the industrial sector, the agricultural sector, and lakeside or nearby communities. The factories which release wastewater into the lake are mainly rubber and food industries. The Industrial Office of Songkhla reported that in 2003, at least 75 factories had released wastewater into a canal which flowed into Southern Lake (ONEP 2006).

For the agricultural sector, the major sources of agricultural pollution are shrimp farms, pig farms, crop farms, and rubber plantations which contaminate the lake with wastewater, pesticides, fertilizers, and other toxic substances.

The other important sources of pollution are human communities around the lake. The Office of Environmental Policy and Planning (ONEP 2006) reported that in 2005, the most important source of BOD was local communities, and the load from this source had increased in 2006 (Table 3).

Table 3. The amount of BOD (kg/day) released into Southern Lake (2005–2006)

Year	**Sources of pollution (BOD kg/day)**					
	Communities	**Factories**	**Livestock**	**Shrimp farming**	**Harbor**	**Total**
2005 (%)	7,058 (64.43)	1,406 (12.07)	1934 (16.60)	805 (6.91)	-	11,653 (100)
2006 (%)	8,461 (75.86)	726.50 (6.51)	535.70 (4.80)	560.80 (5.03)	869 (7.79)	11,153 (100)

Source: ONEP (2006)

(b) Monitoring

The water quality parameters data was collected according to seasons and catchment areas. The Office of Environmental Policy and Planning (ONEP 2006) determined the parameters by which the water quality would assessed, such as biological oxygen demand (BOD), dissolved oxygen (DO), salinity, and acidity/alkalinity (pH). Since 1998, five monitoring stations have been set up around Southern Lake in areas of special attention to collect data three times a year based on the season: November (heavy rainy season), March or April (summer), and July or August (light rainy season).

The reason for collecting data three times a year is to assess changes related to the quantity of rainfall, which has a major influence on lake conditions, especially salinity which affects the proliferation and diversity of all aquatic species.

(c) Current water quality situation

In Figure 5, the DO in the third period, just before the major rainy season, indicated slight fluctuations in the Pawong River Mouth, Pak-ro Channel and Wat Suwankere Temple stations. The levels in these three areas suit aquatic animals. At the Samrong River Mouth and Tinnasulanont Bridge, the DO levels showed strong fluctuations, however, the levels of DO at the Samrong River Mouth were lower than needed by aquatic animals to survive. For the U-Tapao River Mouth station, the DO trend was downward, which is a sign of deteriorating water quality.

Because the monitoring is conducted only during the day, and DO fluctuates during the day, being high in the afternoon but lower during the night (Tanaka et al. 2006), the actual DO status may be more severe, and using only static DO measurements might bias the conclusions.

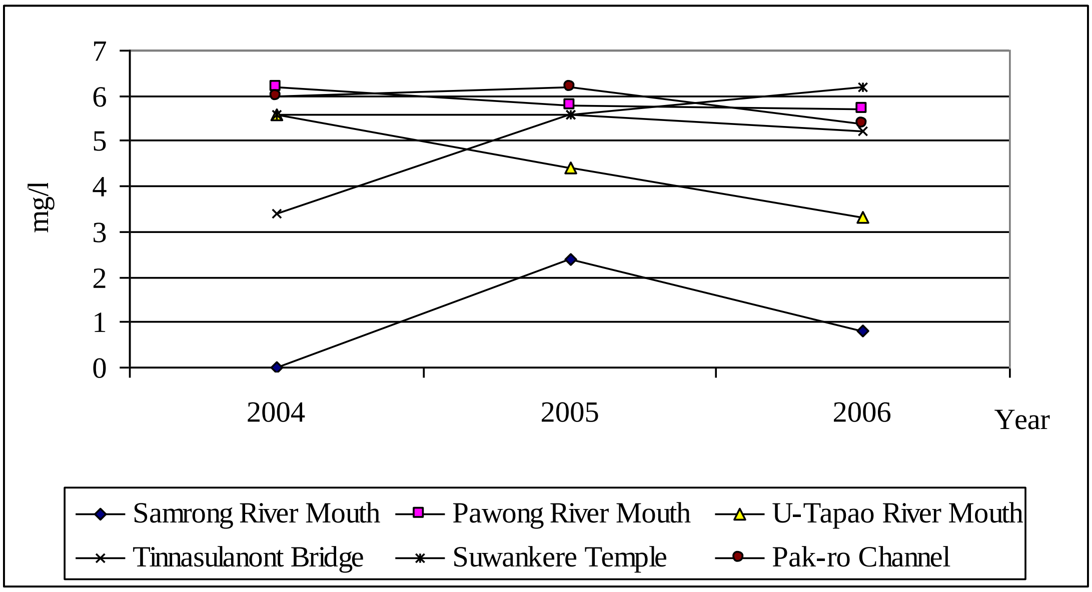

Figure 5. Dissolved Oxygen (DO) values at stations around the lake (third period readings, 2004-2006)

(d) Eutrophication

Eutrophication is the situation that results when a body of water has a large supply of nutrients which encourages plankton overgrowth. The DO decreases, which affects the survival of aquatic life. Decreasing DO causes aquatic animals to die or move to better waters.

The eutrophication in Songkhla Lake arises from high nitrogen and phosphorus levels, which result primarily from the release of wastewater from human activities in the catchment areas. In an extensive study from 1999-2003, NICA (2005) reported that the nitrogen levels at the U-Tapao River Mouth was three times higher than in other areas, and the amount of phosphorus at both the U-Tapao and Pawong River Mouths was higher than in other areas as well.

In November 2001, a sudden fish die-off occurred in Southern Lake. It was found that the amount of Chlorophyll A[3] was 164 mg/l, which indicated serious eutrophication (Laoongsiriwong et al. 2004). In June 2004, the amount of Chlorophyll A in Southern Lake was 339 mg/l (Laoongsiriwong et al. 2004) which again indicated serious eutrophication, severely damaging aquatic survival, particularly the sea bass culture operations at Ko Yo. Therefore, eutrophication is another reason for decreasing lake productivity.

(e) Deforestation of upstream watershed areas

In 1991, the forest areas of the upstream Songkhla Lake watersheds comprised about 617,108 rai (98,737 ha)[4], but by 2002, this area had decreased to 523,511 rai (83,762 ha), a decrease of approximately 1.38% per year (Chareonjiratragul et al. 2005).

Because of the deforestation of upstream watershed areas, heavy rains directly hit the soil surface and flush large amounts of soil into the rivers, causing them to become shallow and turbid. Eventually the lake itself, into which they flow, will also suffer the same fate.

2.7.3 Fishing efforts in Southern Lake

Since Southern Lake is connected directly to the ocean, saltwater-preferring species can freely move into and out of this section of Songkhla Lake in summer, the dry season, when incoming seawater creates higher salinities. Freshwater animals, however, dominate during the rainy season when the water has lower salinity. This special characteristic gives the lake a wide variety of fishery animals, with only shrimps being found throughout the year.

As shrimps fetch a high price, many people around the lake are shrimp fishermen. The proportion of fishing families out of the total number of families around Songkhla Lake is about 40.42% of which 73.29% do not have other sources of income (Choonhapran et al. 1996).

However, the fishery in Songkhla Lake is not well managed, as evidenced by an increase of prohibited fishing equipment such as Fyke nets (Table 3). Moreover, the lake is becoming overcrowded with standing traps[5] and there is an increasing use of illegal fishing methods such as electric shocks and fishing nets with smaller mesh sizes. The large and growing quantity of fishing equipment in Southern Lake, especially the standing traps, is putting shrimps and other aquatic animals at risk of extinction. They also create obstacles to fish moving freely around in the lake.

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[3] Chlorophyll A, which is used to measure primary production of plankton in a water column, can be used as an indicator of eutrophication. More than 10 mg/l of Chlorophyll A in a water body usually indicates eutrophication (Nedwell et al. 2002).

[4] 1 ha = 6.25 rai

[5] Standing traps are the most popular type of fishing equipment in Songkhla Lake as they are designed for shrimp catching. A standing trap is a box about 1.5-2 meters high, 0.6-0.8 meters wide and 1 meter long. Each side of the box is covered with a fishing net. To enlarge the trap's entrance, fishermen also add a 25-30 meter-long net to the trap entrance in order to enhance the efficiency of the standing trap in guiding the shrimp into it.

Surveys show that there is no more space left for fishing traps. By law, the space between rows of fishing traps must be at least 300 m. With this restriction, given the surface area of Southern Lake (180 km^2) and the area needed for each trap (15,292 m^2), the approximate maximum number of traps should not exceed 12,000. However, 29,604 traps were recorded in the year 2003. In a focus group discussion with fishermen and representatives from twelve related local government agencies, it was reported that all the traps were less than 300 m apart. With this information, and considering the number of standing traps existing now, it can be concluded that the number of traps reached saturation point by 2003 and have most likely remained so since. Some fishermen have chosen to sell their traps in some areas.

Table 4. Most common fishing equipment in Southern Lake

Years	Number of standing traps	Number of Fyke nets
1984[1]	900	NA
1995[2]	5,250	603
1997[1]	8,500	NA
2003[1]	29,604	2,074
2004-2007[3]	Possibly constant at 2003 figures	NA

Sources: [1] ONEP 2005
[2] Choonhapran et al. 1996
[3] Focus group discussion (2007)

2.8 Relationship between the Problem and the Causes

Fishing production and other economic activities in the watershed area affect the water quality of Southern Lake, leading to deterioration of the environment, and thus decreased economic value of the lake. This relationship is presented in a simple model (Figure 6).

As the figure shows, the main problem the study addresses is decreasing fishery productivity in Southern Lake. The model identifies three factors affecting fishing catch. The first factor is water quality, measured by the Water Quality Composite Index (WQCI). The second is the fishing efforts measured by the total number of items of fishing gear/equipment used and the number of fishing households. The third is the salinity in parts per thousand (ppt) units. The model also includes positive and negative factors affecting water quality, such as rainfall, which dilutes water pollution, and human activities, such as settlement, industry and farming, which discharge waste loads into the water basin.

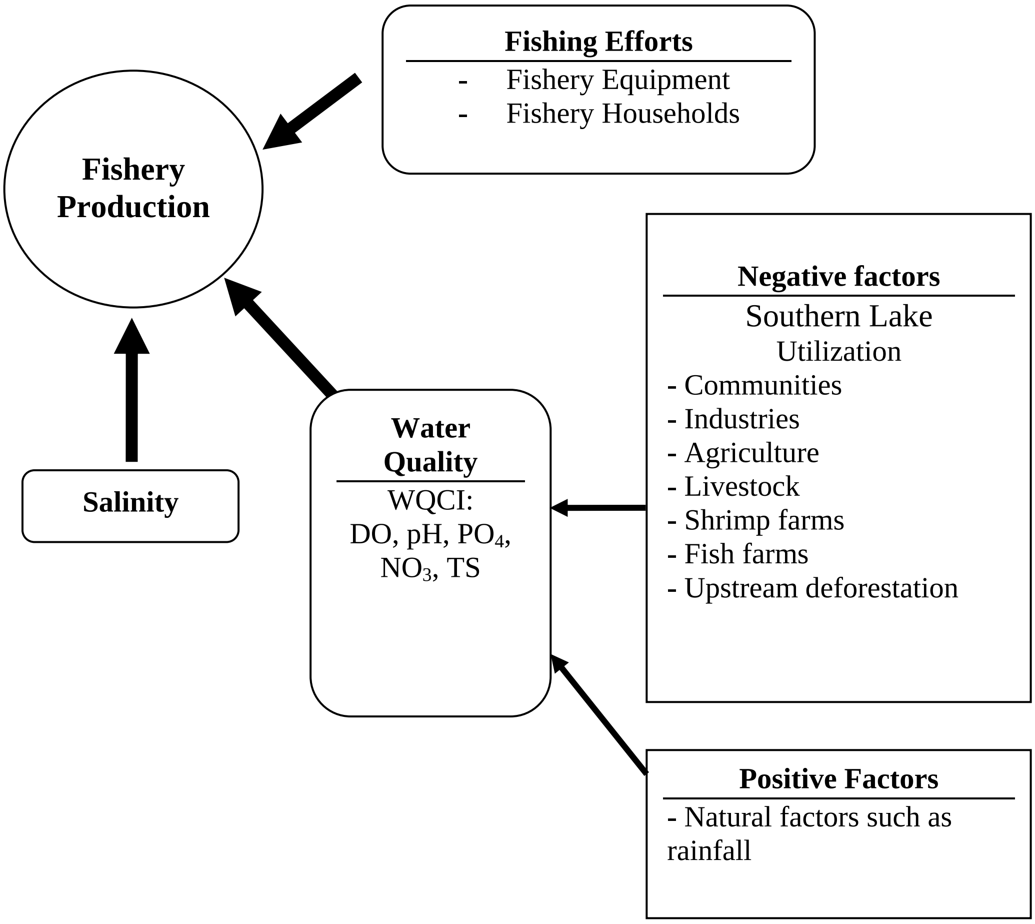

Figure 6. Simple model showing the factors impacting fishery productivity in Southern Lake

3.0 ANALYSIS AND RESULTS

3.1 Empirical Model

For the factors impacting fishing catch, the study used the following production function:

$$Q = f\,(WQCI, S, E) \qquad (1)$$

where Q = fishery productivity (pink shrimp catch)

WQCI = water quality composite index

S = salinity (ppt.)

E = efforts assumed as a constant

3.2 Description and Specifications of Variables

3.2.1 Fishery Productivity (Q)

In order to simplify the process, the pink shrimp species was selected to represent the fishery productivity of Southern Lake. This decision was justified due to the following reasons:

(a) Pink shrimp was the type of shrimp caught in the largest numbers in the lake.

Pink shrimp is a small shrimp, around 10 cm in size. It is the dominant catch of standing traps (Choonhapran and Intaramontry 1998) which are widely used across the lake and are associated with many fishery households. The catch is good all year long and generates regular income for the fishing households (Choonhapran and Intaramontry 1998).

(b) Pink Shrimp is a local and natural shrimp, not augmented by any artificial means.

Many government agencies, such as the Songkhla Provincial Fisheries Office, release a number of aquatic species every year into Southern Lake to increase fishery production for temporary durations. However, there is no release of pink shrimp (NICA 2005) hence the quantity of the shrimp is solely natural. From this perspective, using pink shrimp as the proxy for the overall fishing catch has the advantage of reflecting the natural conditions of Southern Lake.

(c) The sets of data on fishing catch for Southern Lake are not complete and continuous.

Many sets of data on the total fishery productivity of the lake are derived from research papers which have used different kinds of measurement methods and had differing purposes and so do not lend themselves to reliable time-series analysis. This limitation does not apply to the pink shrimp, however, as there is data for many years available from NICA surveys on seasonal shrimp catches in Southern Lake.

3.2.2 Water Quality Composite Index (WQCI)

To study the relationship between water quality and pollution from various sources, water quality is measured using the water quality composite index (WQCI). The WQCI consists of five factors: DO, pH, PO_4, NO_4, and TSS, which were selected from the general water quality parameters[6] specified and used by the Department of Pollution Control. The WQCI was calculated on the basis of the composite index

[6] The general water quality parameters specified by the Department of Pollution Control are DO, pH, PO_4, NO_4, TSS, TU, BOD, and fecal coliforms.

method in that each of the parameters was weighted according to its importance to water quality and aquatic animals. The equation for each value of WQCI is:

$$WQCI = 0.4\,DO + 0.25\,[1/(\text{absolute value of }(7- pH)] + 0.125\,(1/PO_4) + 0.125(1/NO_3) + 0.1\,(1/TSS) \qquad (2)$$

where

DO = Dissolved Oxygen (mg/l). A DO value of less than 4 mg/l causes the death of most aquatic animals.

pH = A measure of acidity or alkalinity of a solution (MPN/100 ml). A pH in water of 7 means a neutral solution, good for aquatic life forms. A value below 7 means the water tends to be acid and a value over 7 denotes that the water is alkaline.

PO_4 = Phosphate in the water (mg/l). The main sources of phosphate are fertilizers and detergents. Too high phosphate content leads to eutrophication, as described earlier, which is a dangerous phenomenon for aquatic animals.

NO_3 = Nitrates in the water (mg/l). NO_3 comes mainly from ammonia. Their sources are farming, domestic waste, and industrial waste. In a lake, NO_3 may cause eutrophication similar to phosphates.

TSS = Total Suspended Solids (mg/l). An increase in suspended solids comes, for instance, from deforestation in the upstream watershed, which generates excessive deposits in the lake bed when rainfall washes the soil out of the local watershed area into the lake. A high amount of impenetrable material obstructs both the breathing of aquatic animals and their growth.

The relationship between WQCI and catch quantity (Q) is positive i.e., a higher WQCI would give rise to a higher catch quantity.

3.2.3 Salinity

The relationship between salinity and shrimp productivity should be expressed in quadratic form, because, all other factors being equal, shrimp productivity will increase with higher salinity, but decrease when the salinity becomes too high. Southern Lake is an open lagoon with brackish to salty water in which the salinity is not too high. For the relevant range of salinity, the relationship between salinity and shrimp productivity can be represented in positive linear form.

3.2.4 Fishing Efforts

Unfortunately, there was no available fishing traps data for the years after 2003 for use in this study. However, most of the fishermen and government officers, we interviewed indicated that the quantity of catch from fishing traps in Songkhla Lake had not changed significantly between 2003 and the writing of this report in 2007.

Thus, in the regression analysis carried out in this study, it was assumed that fishing efforts remained constant.

3.3 Data Sources and Description

We used mainly secondary data, including time series on shrimp catch, water quality, and sources of pollution. The data sources were gathered from two government agencies; the National Institute of Coastal Aquaculture (NICA 2007) and the Office of Environmental Policy and Planning, Division 16 (ONEP 2007). The types of data used in the regression analysis can be described as follows:

(a) Shrimp catch (pink shrimp)

The seasonal shrimp catch data was collected from one of eight docking sites around Southern Lake for the years 2004-2006.

(b) Water quality parameters

The WQCI was constructed using Equation 2 and calculated from seasonal water quality data for the years 2004-2006 with selected water quality data taken at five stations in and around Southern Lake (Tinnasulanont Bridge, U-Tapao River Mouth, Pawong River Mouth, Samrong River Mouth, and Pak-ro Station). This information was the basis for tracing which sources of pollution primarily affected shrimp production, and, by extension, the overall productivity of the lake.

(c) Salinity

The salinity data from Pak-ro Station was selected for the analysis because this was a station located a good distance from the mouth of the lake, so if significant salinity intruded as far as Pak-ro Station, it could be assumed that much of the lake would also have high salinity, which would benefit shrimp growth.

3.4 Results of the Impact of the WQCI on Shrimp Productivity

3.4.1 Empirical model

(a) Testing for multicollinearity

The analysis in Table 5 shows that the WQCIs at the Tinnasulanont Bridge, U-Tapao River Mouth, and Pawong River Mouth Stations had a strong and significant correlation with each other while the Samrong River Mouth Station had a slightly less significant correlation with these three stations. The WQCI at Pag-ro Station, where Southern Lake connects to Thale Luang (the Middle Lake), was not correlated with the data from the other four stations. Therefore, the WQCI at U-Tapao River Mouth Station and Pag-ro Station were selected for the analysis as these two stations could represent the areas of severe water quality degradation. Also the WQCIs of these two stations were uncorrelated with each other. The investigation also found that the salinity at Pag-ro was not correlated to other variables. Therefore, the salinity data from Pag-ro Station was selected for the analysis.

Table 5. The correlation coefficients of the WQCIs

Stations	$WQCI_{PR}$	$WQCI_{SR}$	$WQCI_{TN}$	$WQCI_{UT}$	$WQCI_{PV}$	S_{PR}
WQCI at Pag-ro ($WQCI_{PR}$)	1	-.124	.296	.275	.248	.050
WQCI at Samrong ($WQCI_{SR}$)	-.124	1	.763*	.744*	.774*	-.659
WQCI at Tinnasulanont Bridge ($WQCI_{TN}$)	.296	.763*	1	.996**	.996**	-.207
WQCI at U-Tapao ($WQCI_{UT}$)	.275	.744*	.996**	1	.998**	-.149
WQCI at Pawong ($WQCI_{PV}$)	.248	.774*	.996**	.998**	1	-.199
Salinity (S_{PR})	.050	-.659	-.207	-.149	-.199	1

Source: Calculated using data from ONEP 2007.
Notes: * Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

(b) Model

The equation of the cause and effect of changes in the WQCI on shrimp productivity in Southern Lake was estimated using Ordinary Least Squares (OLS) in semi-log form. Table 6 shows the different forms of relationship used, namely linear, quadratic, and time lag for salinity (salinity in one period will effect shrimp production in following periods).The linear form of the salinity analysis performed better than the other two forms using standard statistical tests, such as R-square, F-value, and sign of coefficients and t-statistics. The results are shown below in Table 6 and written as Equation (3) below.

$$LN\_SHRIMP = 5.368 + 0.034\, WQCI_{UT} + 0.10\, WQCI_{PR} + 0.185\, S_{PR} \qquad (3)$$

t = 24.238**   t = 3.875*   t = 8.446**   t = 13.571**

Based on Equation 3, one unit increase in water quality at the U-Tapao River Mouth ($WQCI_{UT}$) would result in an increase of 3.4% in shrimp productivity while the same increase at Pag-ro ($WQCI_{PR}$) would result in an increase of 10% in shrimp productivity. In addition, one ppt increase in salinity at Pag-ro would lead to an increase of 18.5% in shrimp productivity.

Table 6. Functional form of the models

Variables	Models ($WQCI_{UT}$, $WQCI_{PR}$, S_{PR})		
	1. Linear (S_{PR})	**2. Quadratic (S_{PR})**	**4. Time lag (S_{PR})**
LN_Shrimp			
R_sq	0.987	0.987	0.9863
F-value	99.979**	58.691**	35.9347*
Autocorrelation test			
D	2.701	2.466	2.6834
du (α=0.05)	2.287	-	-
dl (α=0.05)	0.368	-	-
	indecisive zone		
Coefficients			
Constant	5.368**	5.364	5.3599**
$WQCI_{UT}$	0.034*	0.034*	0.0324
$WQCI_{PR}$	0.1**	0.106	0.1023*
S_{PR}	0.185**	0.147	0.1837*
S_{PR}^2	-	0.002	-
SPR_Lag	-	-	0.006

Notes: **Significant at the 0.01 level; * significant at the 0.05 level.

3.5 Trends of Water Quality in Southern Lake

The data for our investigation is only for three years due to the limitations in available information on shrimp catch. The results (using regression analysis) were, fortunately, significant. There were other observations and evidence of water quality from other sources which support the results of our regression analysis:

(a) Some of the water quality parameters have changed over time and this has had a negative effect on the overall water quality. Monitoring data from both NICA (2004) and ONEP (2006) show that the amount of nitrogen and phosphate discharged into the lake in general has increased over time in every river mouth station. Particularly, the total amount of nitrogen at the U-Tapao River Mouth has increased significantly (Figure 7). Changes in the amount of DO were unclear at most stations. Only the data from Pag-ro station was clear, and showed that the amount of DO had decreased steadily over time (Figure 8). There was also a marked increase in the total solid contents of the water at the Pawong and Samrong River Mouths in recent years.

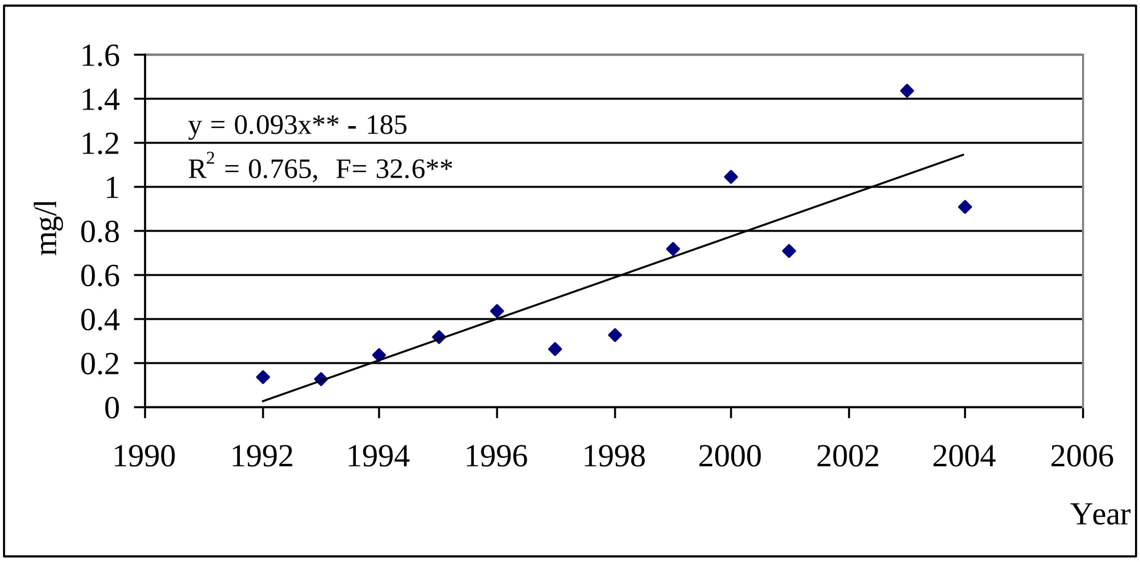

Figure 7. Total nitrogen in the water at U-Tapao River Mouth (1992-2004)

Note: ** Significant at the 0.01 level

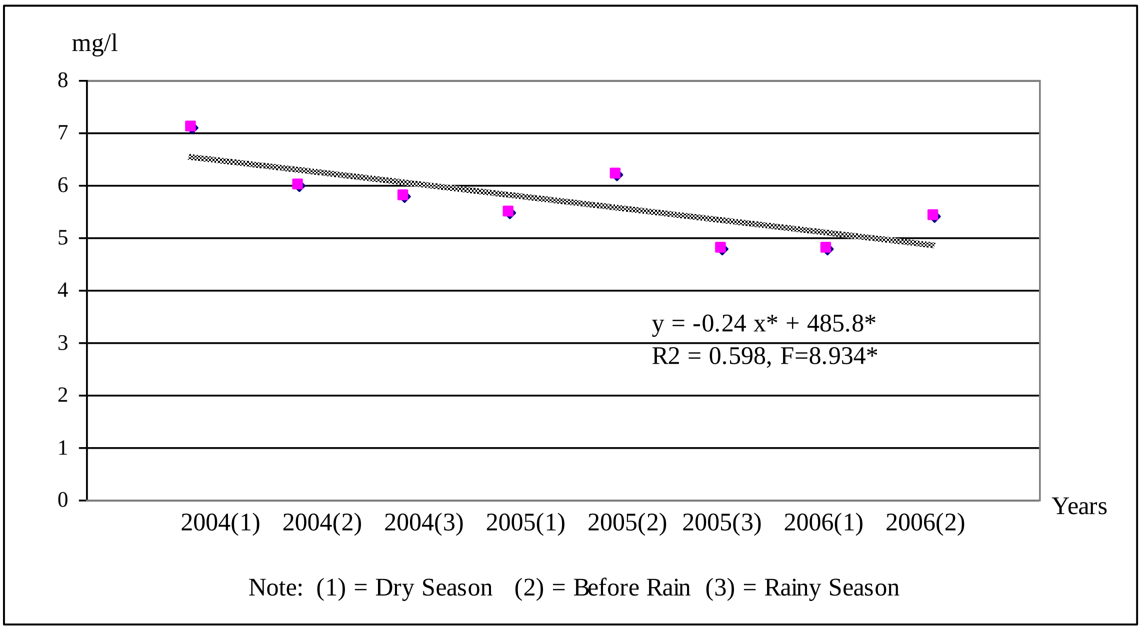

Figure 8. The decreasing DO in the water at the Pag-ro Channel (2004 -2006)

Note: * Significant at the 0.05 level

(b) The water quality of the lake is expected to continue to deteriorate over time particularly in U-Tapao catchment area because of the increasing population, the expansion of shrimp and pig farms, and the increasing number of industries which release polluting materials, as shown in Table 7.

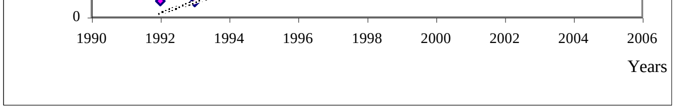

Table 7. Number of farms and population in the Southern Lake watershed

Year	Pig farms (units)		Shrimp farms (rai)		Population	
	U-Tapao	SL Watershed	U-Tapao	SL Watershed	U-Tapao	SL Watershed
2004	28,907	56,350	1,771	4,232	520,862	836,469
2005	12,638	34,322	2,077	5,121	506,917	888,996
2006	13,574	42,321	3,698	6,346	581,930	807,085

Source: ONEP (2006)

3.6 Conclusions on the Status of the Fishery in Southern Lake

Our research findings and estimation results on the situation of Southern Lake in regard to the effect of water quality degradation on the value of the lake fishery can be summarized as follows.

- The biodiversity of Southern Lake, particularly of fish and shrimp species, has been decreasing. The literature shows that the overall fish size has become smaller and the catch of less economic value (Mabuntham 2002). Also, the evidence indicates that the average amount of fish caught in 2003 was only a quarter of that in 1996, averaging 3.6 kg per day in 1996 compared to 0.9 kg per day in 2003 (ONEP 2004).
- Our statistical analysis indicates that water quality changes in the lake have had significant impacts on shrimp production, i.e., the better the water quality, the higher the economic value of the lake. The study found that one unit increase in the WQCI at U-Tapao would lead to a shrimp productivity increase of 3.4% (significant at the 0.05 level), and one unit increase in the WQCI at Pag-ro would lead to a shrimp productivity increase of 10% (significant at the 0.01 level) (See Equation 3).
- Our analysis indicates that the major sources of pollution affecting the water quality and fishery produce in Southern Lake are from the U-Tapao River where a high density of factories and pig farms are found. Another important source is the Pag-ro River where there are a large number of shrimp ponds.
- Our analysis of 12 years of water quality data (1992-2004) confirmed that the amounts of nitrogen and phosphate discharged into the lake have increased over time at every river mouth in Southern Lake. In particular, the total amount of nitrogen at the U-Tapao River Mouth has increased significantly. Nitrogen was found in farm discharge and in both domestic and industrial waste, and in large amounts, it is very harmful to aquatic animals.

4.0 MANAGEMENT OPTIONS FOR WATER QUALITY CONTROL

4.1 Theoretical Concept of Water Quality Management

When producers emit pollutants into a nearby river, they create negative externality problems. The government can respond in at least two ways. First, it can regulate polluters' behavior directly (command and control policies), or second, it can provide incentives so that polluters will choose to solve the problem on their own (market-based policies).

4.1.1 Command and control policies

Command and control policies, referred to as standards or regulations, are the most common form of environmental policies in both advanced and developing countries. As the name implies, the command and control approach consists of a "command", which sets a standard (the maximum level of permissible pollution) and a "control", which monitors and enforces the standard. In general, there are two types of standards; ambient standards and emissions standards. Ambient standards set the minimum desired level of air or water quality, or the maximum level of a pollutant that must be maintained in the environment. Conversely, an emissions standard specifies the maximum level of permitted emissions.

Emissions standards can be performance-based standards or technology-based standards. Performance-based standards are the most common type. They stipulate emissions limits that each polluter should not exceed. Technology-based standards not only specify emission limits, but also the "best" technology that must be used.

To design good standards, government regulators need to know various details about specific polluters and also have some understanding of alternative technologies available for those polluters to adopt. This information is often difficult for government regulators to obtain.

4.1.2 Market-based policies

Instead of regulating behavior in response to an externality, the government can use market-based policies to align private incentives with social efficiency. There are two principal market-based approaches: corrective taxes and tradable pollution permits.

(a) Corrective taxes

The government can internalize the externality by taxing activities that have negative externalities. Taxes enacted to deal with the effects of negative externalities are called corrective taxes, sometimes also called emission charge[7]. An ideal corrective tax (per unit of pollutant discharged) would equal the marginal damage cost caused by the pollutant concerned.

(b) Tradable pollutions permits

The tradable pollution permit is another kind of market-based mechanism. These permits allow pollution up to the level of a pre-determined standard. As the name suggests, these permits can be traded between polluters. With such a system, polluters

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[7] Some studies, like Panayotou's (1994), distinguish charges from taxes. In these studies, charges are defined as payments for the use of resources and services while taxes are not payments for "services" but a means of raising fiscal revenue. However, corrective taxes may be thought of as a charge for the use of the environment's assimilative capacity (a natural resource) and hence, analogous to a charge. This study uses the terms "corrective taxes" and "emission charges" interchangeably.

whose abatement costs are relatively high have an incentive to bid for available permits. Permit buyers therefore tend to pollute more than permit sellers, yet overall environmental standards remain unaltered because just enough permits are issued to achieve the standard in aggregate. Trading permits between polluters thus minimize the overall cost of complying with the standard.

***(c) Corrective taxes versus tradable pollutions permits*[8]**

Although reducing pollution using pollution permits may seem quite different from using corrective taxes, in fact the two policies have much in common. In both cases, polluters pay for their pollution. With corrective taxes, polluters must pay a tax to the government. With pollution permits, polluters must pay to buy a permit. Even polluters who already own permits must pay to pollute: the opportunity cost of polluting is what they could have received by selling their permits on the open market. Both corrective taxes and pollution permits internalize the externality of pollution by making it costly for polluters to pollute. In both cases, there is an economic incentive for polluters to implement abatement measures.

4.2 Available Management Options to Improve the Water Quality in Southern Lake

4.2.1 Command and control policies

(a) Overview of Thailand's environmental plan

Since the last century, many major water resources in Thailand have been degraded through human activity from a burgeoning population, resulting in water contamination from domestic discharge, agricultural and industrial sectors, and the development of coastal zones for aquaculture. These activities have affected the coastal water quality as well as marine ecosystems.

Since 1961, the Thai government has developed five-year National Economic and Social Development Plans that establish the overall priorities and policy framework for the country's development. In the seventh plan (1991-1995), the government started to promote sustainable economic development that protected the environment, which continues to the present day. For instance, the recent ninth plan (2001-2005) focused on the management of natural resources and the environment by enhancing the participation of all sectors in society, empowering communities, incorporating strong and useful regulations, and encouraging practical research.

(b) Water pollution management in Thailand

Several governmental agencies play major roles in environmental management. The Ministry of Natural Resources and Environment (MONRE) is the main

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[8] This section is drawn extensively from Gregory (2004).

governmental agency responsible for environmental quality and management at the national level. Under the Ministry, three major offices are responsible for environmental management:

- The Office of Natural Resources and Environmental Policy and Planning (ONEP) is mainly responsible for the establishment of environmental policy and planning for the enhancement and conservation of national environmental quality. Some examples of ONEP plans are the Water Pollution Management Plan and the Twenty-Year Perspective Plan (1997-2016).
- The mandate of the Department of Environmental Quality Promotion (DEQP) is to conserve and enhance environmental quality by supporting environmental research, providing training courses to authorities and the general public as well as encouraging the development of environmental networks among parties concerned and promoting public awareness on environmental issues.
- The Pollution Control Department (PCD) is chiefly in charge of the conservation of the country's environmental areas. The key responsibilities of this department are to establish national environmental pollution management plans and to recommend standards for environmental parameters and pollution discharges.

Besides MONRE, other core governmental organizations involved in environmental management include the Office of the National Economic and Social Development Board (NESDB), the Department of Public Works and Town and Country Planning (DTCP), and the Department of Local Administration (DLA)[9]. The regulatory agencies in charge of monitoring water quality attempt to limit pollutant loads at current levels and reduce them as soon as possible in the future. All the stakeholders such as factories, pig and shrimp farm entrepreneurs, and municipalities must comply with the various acts and regulations listed in Table 8. The management agencies are deeply concerned over heavy pollutants such as BOD, COD, and Total Kjeldahl Nitrogen (TKN), and minimum concentration-based discharge requirements are strictly enforced (see Table 9).

[9] NESDB is under the Office of the Prime Minister. DTCP and DLA are under the Ministry of Interior.

Table 8. Water pollution legislation

Legislation	Regulated Activities	Responsible Ministries	Remarks
Enhancement and Conservation of National Quality Act (ECNQA 1992)	Regulates specified point sources for wastewater discharges into public water resources, or the environment, based on effluent standards.	Ministry of Natural Resources and Environment (MONRE)	Key environmental law in Thailand
Factories Act of 1992	Limits levels of effluents discharged and restricts concentration levels of chemical and/or metal pollutants	Ministry of Industry (MOI)	Issues Ministerial Regulations and Notifications to govern any or all types of factories
Public Health Act of 1992	Regulates nuisance activities related to water pollution such as odors, chemical fumes, wastewater discharge systems of buildings, factories or animal feedlots that cause harmful health effects.	Ministry of Public Health (MOPH)	Decentralized implementation by local government agencies
Building Control Act of 1979	Regulates discharge of water pollution from buildings	Ministry of Interior (MOINT)	Decentralized implementation by local government agencies
Fisheries Act of 1947	Prohibits dumping or discharging of hazardous chemicals into water resources reserved for fishing.	The Ministry of Agriculture and Co-operatives (MOAC)	

Source: partly from WEPA 2007

Table 9. Effluent standards in Thailand

Parameter (unit)	**Industries**	**Pig Farms**		**Shrimp Farms**	**Housing Estates**	
		Large Farms (Note 3)	**Medium and Small Farms** (Note 3)		**100-500 units**	**>500 units**
BOD (mg/l)	Not more than 20 mg/l depending on the receiving water body or type of industry. The PCC may allow BOD levels to exceed 20 mg/l but not 60 mg/l.	60	100	20	30	20
COD (mg/l)	Not more than 120 mg/l depending on the receiving water body or type of industry. The PCC may allow COD levels to exceed 120 mg/l but not 400 mg/l.	300	400		-	-
TKN (mg/l)	Not more than 100 mg/l depending on the receiving water body or type of industry. The PCC may allow TNK levels to exceed 100 mg/l but not 200 mg/l.	120	200		35	35

Source: partly from WEPA 2007

Notes:
(1) BOD = Biological Oxygen Demand; COD = Chemical Oxygen Demand; and TDK = Total Kjeldahl Nitrogen
(2) PCC = Pollution Control Committee
(3) Based on Standard Methods for the Examination of Water and Wastewater (APHA, AWwA and WEF)
(4) Large farms = >5,000 units; medium and small farms = $\leq$ 5,000 units

(c) Limitations of command and control policies

From our investigations, we found that the command and control policies for Southern Lake have resulted in inefficiencies because of several limitations.

- Command and control policies do not encourage industries to improve their production processes and wastewater treatment systems in order to reduce pollution emissions.
- Concentration-based discharge standards alone are not sufficient to control pollution; there should also be control over waste discharge volumes.

- Monitoring procedures are somewhat inefficient due to insufficient enforcement officers, which limits enforcement to random inspections every two months or so for large and medium factories and farms, and the general neglect of smaller operations such as backyard pig farms.

- The management structure of many of the relevant government agencies is not well organized and there are many overlapping authorities and tasks, which causes confusion among the entrepreneurs in terms of timing and budgeting arrangements. For example, several government agencies separately oversee waste load discharges (BOD or COD).

- The punishment for those who exceed pollution standards is quite light and not strictly enforced. For instance, if polluters dispose of effluents at a higher rate than the set standards, they are asked only to pay an emission charge which is often lower than the cost of pollution treatment.

- Command and control policies are deficient in encouraging the participation of all stakeholders, such as manufacturers and communities, in that they are not made sufficiently aware of their responsibilities in environmental protection.

4.2.2 A market-based instrument: effluent charges

Although the command and control system is currently employed in water pollution management in Thailand, because of inefficiencies with this system, there are plans for changes in order to control pollution as much as possible. Towards this end, the Department of Industrial Works conducted a study in 2007 on “The Application of Economic Instruments in Industrial Pollution Management”, which was supported by the government of the Federal Republic of Germany.

The study was designed to determine the pollution load coefficients[10], for example, the pollutant load per unit of product or per unit of raw material, for five industries that generate significant BOD loads. These coefficients were then used as constants in the calculation of the emission charges. The study concluded that emission charges were the most appropriate economic instruments for use in Thailand to minimize pollution, and these tools should be used in the application of economic instruments in hazardous waste management by related government agencies.

An emission charge (EC) is a charge calculated from the pollution a factory discharges. The funds collected will be utilized as a circulating fund to provide assistance or support for the implementation of industrial pollution management measures and for environmental quality monitoring of industrial activities. All factories that discharge wastewater to their surroundings will be obliged to pay ECs. The factories will be divided into two types: “flat rate” type and “variable rate” type.

[10] The coefficients were divided by type and production scale of the factory. See Department of Industrial Works (2007).

(a) Flat rate type factory

This type of factory is classified by a BOD Load of Influent[11] of less than 100 kg per day. Most factories are medium and small-scale ones that discharge relatively small amounts of wastewater, hence ongoing effluent monitoring is not required. The effluent BOD load of the factory is calculated from the multiplication of the pollution load coefficient of each industry type and the production quantity, as shown in the equation below.

$$\text{BOD load (kg/yr)} = A \times B \qquad (4)$$

where

A = pollution load coefficient of the industry type (e.g. effluent BOD per standard production unit)

B = production capacity per year (standard production unit)

(b) Variable rate type factory

This type of factory will be classified by a BOD Load of Influent greater than 100 kg per day. Most of such factories are relatively large-scale factories which generate considerable volumes of wastewater, hence effluent monitoring is required. The effluent BOD load of the factory is calculated from the multiplication of the effluent BOD concentration and the effluent flow rate determined from the monitoring (Equation 6).

$$\text{BOD load (kg/yr)} = \text{average BOD load per day} \times \text{working days per year} \qquad (5)$$

$$\text{Average BOD load per day (kg/day)} = (\text{BOD concentration (mg/l)} \times \text{average effluent flow rate } (m^3/\text{day}))/1{,}000 \qquad (6)$$

The calculation of annual ECs for both flat and variable rate types is shown in the equation:

$$\text{Annual emission charge (baht/year)} = f \times c \times B \qquad (7)$$

where

f = adjustable coefficient based on the severity of pollution determined by the Department of Industrial Works

c = basic emission charge rate (35 baht/kgBOD)

B = BOD load (kg/year)

[11] BOD Load of Influent is the amount of BOD in wastewater produced from the production process. Effluents are the wastewater from factories and other activities discharged into the environment with or without treatment.

Although the charge system is designed primarily to control the pollution caused by factories, the system can be extended to include other polluters such as shrimp farms, pig farms, and households, with the same systematic procedures. This proposed extended charge system is compared to command and control and tradable permit systems in the next section.

4.2.3 Other water pollution management programs in Southern Lake

Government agencies use other methods besides regulation and legislation to attempt to control the pollution in Southern Lake. As there are many sectors which are involved in the release of pollutants to the lake such as industry, agriculture and communities, the relevant government agencies have to apply different programs for each sector. Nevertheless, these can be categorized into three groups as described below.

(a) Environmental promotion programs for entrepreneurs

Entrepreneurs have been compelled to control their pollution emissions through environmental legislation, but unfortunately without much success. To effectively encourage small entrepreneurs to better manage their pollution emissions, government agencies are introducing other programs in parallel, mainly various ‘green-technology’ operations, which have the goal of reducing pollution before it becomes a problem by focusing on production lines. As an incentive, a factory joining this program will be certified by the government as a ‘production friendly business’ to improve its reputation in the local community, which could then improve its business.

(b) Public awareness and education programs

The concept behind these programs is to encourage collaboration between the environmental agencies and communities located around the lake in being vigilant about any threats to the quality of the water. For instance, the Beautiful and Clean Canals Project was created to provide technical knowledge so that more people could be aware when their water quality was deteriorating and help them take steps quickly to stop the problem. Vigilant committees have now been set up in every community in the lake area and regularly communicate and exchange information with one another. In particular, people are trained to observe simple parameters of water quality, such as DO, so that they can immediately report any undesirable changes to the proper authorities.

(c) Future operations

The government agencies are planning a study on the overall carrying capacity of Songkhla Lake so that credible plans for sustainable utilization of the lake can be drawn up and implemented. This will provide baseline data and other criteria that will assist in monitoring and controlling the levels of all major parameters. In addition, zoning the areas around the lake will also be a key management strategy so that any activities impacting the water quality can be easily monitored. Economic instruments, such as the emission charges discussed in this paper, are among the instruments being considered.

4.3 Tradable Discharge Permits as an Alternative Approach

4.3.1 Tradable discharge permits for water quality control in Southern Lake

As is known, market–based instruments have many advantages over command and control regulations. Also, each instrument has different advantages and disadvantages. For example, if we compare the EC system and the tradable discharge permits (TDP) system, both of them provide incentives to polluters to reduce pollution at the least possible cost. ECs might be applicable for all sizes of firms but it is difficult to define an optimal fee level. If the fee is too low, it would not provide sufficient incentive for pollution control. Even if the fee was at an optimal level, there would always be distortions existing in the behavior of both the enterprises and the regulatory bureaus, which would lower the incentive for pollution control (Yun 1998).

Problems might also arise in the case of ECs, which although can potentially raise large amounts of revenue, are not seen as a means of cost recovery or payment for services or resource use but perceived as taxes connected to the national budget. Environmental ministries prefer to view pollution/emission charges as user fees and want the revenues earmarked for environmental investment to be used to abate pollution and rehabilitate degraded areas of the environment while finance ministries prefer to view ECs as taxes and hence as a source of general revenue to be allocated among alternative uses in order to maximize the social rate of return regardless of the origin of the revenue. Earmarking is simply viewed as a distortion (Panayotou 1994).

Interestingly, a TDP system provides great flexibility for firms to meet their discharge targets. It offers industrial firms the option of avoiding having to meet stringent effluent standards by purchasing effluent credits/permits from other firms which can reduce their effluents at a lower cost. This concept is very applicable to the Southern Lake watershed because there are various industries with different abatement costs, and therefore the potential gains from trading effluent credits/permits are likely to be proportionately large. However, on the negative side, a TDP system might be limited by the high monitoring and transaction costs between a large number of small firms.

An effective way to initiate a market-based system for the Southern Lake watershed would be to begin by introducing a TDP system for large domestic and foreign firms as well as public utilities, such as public wastewater treatment facilities. Also, the implementing agency can work with the local industry associations, community organizations, and related government agencies to set up a monitoring and enforcement system.

4.3.2 Specifications of TDP for water pollution control in Southern Lake

Due to the advantages of the TDP system, one was carefully designed by this study as part of a water pollution control management program for Southern Lake. The

U-Tapao catchment area, a sub-watershed located in the Southern Lake basin, was selected for an initial demonstration of this system. Here, there is a high density and large variety of firms, including large domestic and foreign firms. According to the Office of Environmental Policy and Planning, Division 16 (2006), the amounts of water utilization and wastewater, and BOD loads from this area were the highest among all the catchment areas in Southern Lake and also in the Songkhla Lake basin as shown in Figure 9. Here local communities are relatively strong and very interested in the conservation of community water resources. The basin's water quality and environment are, and have been for many years, systematically monitored by the Office of Environmental Policy and Planning, Division 16.

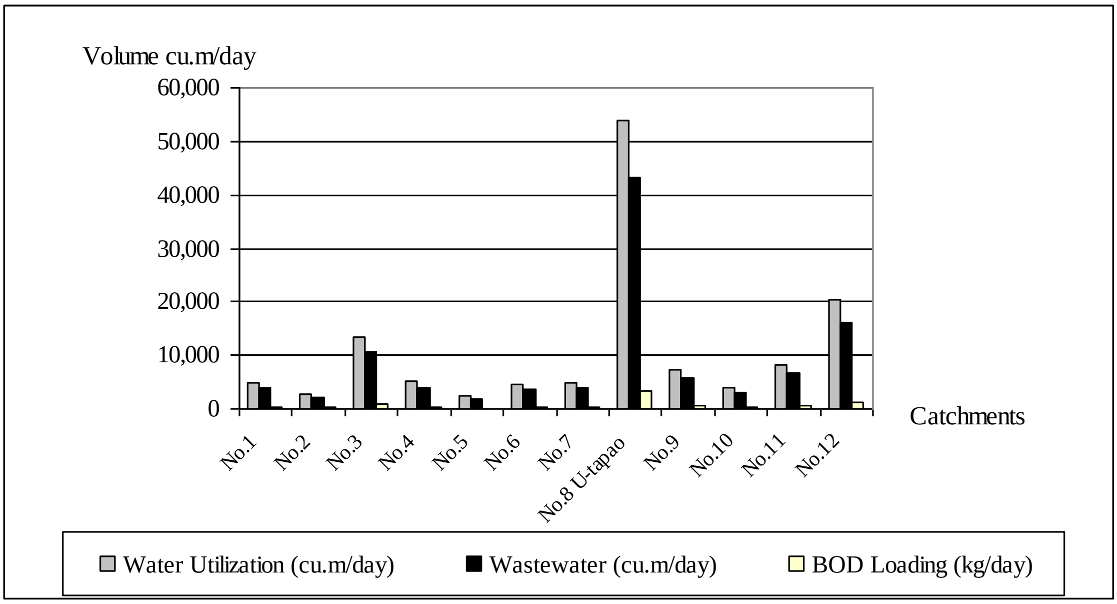


Figure 9. The amount of water utilization and wastewater in each catchment area in the Songkhla Lake basin (2006)

Discussion and brainstorming sessions were conducted with concerned policy-makers, government officers, academicians, and NGOs, aiming at drafting a TDP policy for a water quality control program in Southern Lake. The details arrived at are outlined below.

(a) Objectives

The objectives of establishing a demonstration TDP system for the U-Tapao catchment area were set as follows:

- To effectively achieve the total water pollution reduction targets for Southern Lake.
- To provide an incentive system to stimulate firms, which have the potential to develop their abatement technologies, to install new technologies; and to provide flexibility for firms confronted with different constraints.

(b) Steps in the TDP demonstration program

There were three crucial steps in implementing the TDP system in the U-Tapao catchment area.

- Preparatory Stage: Firstly, legal preparations to encourage desired activities, such as incentive mechanisms and punishments in cases of violation of the regulations, were required. Secondly, we had to get an estimate of the total amount of allowable discharge permits (kgBOD/year) for the area. The amount of discharge permits for sub-zoning in the area also needed to be identified.
- Initial Stage: This was the period of establishing the particular incentives for firms to facilitate their restructuring, for example, establishing a revolving fund to benefit participating polluters who chose to voluntarily reduce their effluents. This stage should take at least two years. Initial rights would be allocated at the beginning of the first year based on fair distribution mechanisms.
- Development Stage: In this stage, water quality improvements due to pollution reductions based on the established targets should be observable. To ensure proper monitoring, the pollution reduction targets need to be set systematically.

(c) Initial management of the program

The BOD discharge rate was proposed as the key parameter for the U-Tapao TDP system, covering existing large-scale point pollution sources and public utilities. Allowing new point pollution sources would be considered based on available discharge permits.

In terms of issuing production permits and controlling effluent discharge, each type of production currently involved different government sectors. For example, factories, shrimp farms, and pig farms were separately supervised by the Departments of Provincial Industry, Fishery and Provincial Cattle, respectively, and the pollution control standard regulations of all three departments were different.

In order to clarify the administrative management protocols, an independent environmental protection organization (IEPO) was proposed for the program, which would be a combination of government agency supervision with industrial associations and community organizations. The IEPO would work as the overall administrative agency, with the main tasks of (a) providing facilities for the trading process, and (b) keeping track of the number of permits in the possession of each source and the quantity of emissions from each source in order to estimate the cumulative emissions. The purpose of these two tracking programs was to keep the emissions at a level no greater than the total number of discharge permits in the possession of the polluter. Therefore, the IEPO would have the authority to make spot checks and make reports suggesting appropriate penalties in cases where the emissions exceeded the level on the permit. Routine monitoring would still be conducted by the appropriate government agency.

(d) Allocation of initial rights

Field and Field (2002) determined that the success of the TDP approach in controlling pollution depends critically on limiting the number of permits in circulation as individual polluters will ask for their maximum allocation at the first distribution. It is expected that this will lead to considerable controversy and competition among the concerned industries in establishing which formula should be used for the original distribution of emission rights. Distributing the permits equally among the existing sources which register for the program may be perceived as unfair by some because of large differences in the sizes of the firms and their production types, such as rubber factories and pig farms. Moreover, some firms have already effectively reduced their emissions, and thus may not be starting on an equal footing with firms which have not yet reduced their emissions, and the program must not discourage those that have been working hard already on pollution abatement.

In principle, it does not matter whether the rights are given away, sold or auctioned, as long as the permits are distributed fairly and widely. Subsequent market transactions will redistribute them in accordance with the relative marginal abatement costs of polluters whatever the original distribution may have been (Field and Field 2002). The crucial issue for this initial stage is for policy-makers to find some widely accepted and workable compromise for the initial distribution.

In order to ensure appropriate allocation of the permits to the firms, the amount of discharge allowed in the permit (kg/year of BOD) for each participant is calculated based on three factors: (a) firm production capacity, (b) a coefficient specified by the Department of Industrial Works (see 4.2.2), and (c) total reduction targets in the catchment area.

In this initial stage, participants may receive a certain discharge amount (kg/year of BOD) for free in their permits. If they want additional permits they can participate in an auction to obtain additional permits or pay a small surcharge for them. The selection of either an auction or a surcharge will depend on the agreement among the firms managed by the IEPO.

(e) Participants

The intended participants of the program are the following: (a) large domestic and foreign firms (which release equal to or above 100 kg of BOD per day) in the U-Tapao catchment area—this includes industries such as food factories, rubber factories, shrimp farms, and pig farms, (b) public utility bodies such as community sewage treatment plants or combined sewage treatment plants of small pig farms (home backyard farms) in the community, and (c) medium or small-sized firms and farms (which release less than 100 kg of BOD per day) which are required to connect with a domestic treatment plant. All participants will be required to install discharge monitors on their premises.

(f) Trading rules

There are several important points in the trading rules. Firstly, the permits can be traded and held by participants via the IEPO only within the specified limits of BOD loading in sub-zones. Private citizens, environmental groups, other types of business enterprises, local administrative bodies, and so on will also be allowed to hold permits for a certain level of discharge related to the projected rate of future reduction targets. Secondly, each permit is for a particular year, but it can be used either in that year or 'banked' for use in any subsequent year. Thirdly, at the end of each year, the IEPO will deduct the amount of emissions from the permitted level and if the licensee does not hold enough permits to cover its emissions, it will be subject to a fine based on the excess. It will also have to buy an emergency discharge permit to cover the excess. Fourthly, the IEPO will reserve a certain number of TDPs for emergency cases, which should not be more than 5% of the total available TDPs.

The proposed TDP was presented to the stakeholders together with ECs and CAC. Comparisons were conducted using selected criteria (see 5.2).

4.4 Technological Options to Improve the Water Quality in the U-Tapao Catchment Area

Since the U-Tapao catchment area has many pollution sources, technological options for sewage treatment systems were the first issue of concern. In this section, we give an overview of available sewage treatment technologies at different stages of the wastewater treatment process and the cost effectiveness of each. A comparison is then made.

4.4.1 The wastewater treatment process

The wastewater treatment process and the different technological options available at each stage are illustrated in Figure 10.

(a) Primary treatment

The process starts with the physical removal of suspended solids and organic matter. The steps involve a coarse/fine screen or grit chamber, pH neutralization, grease trap tank/skimming devices, and primary sedimentation tank. The waste from this process is primarily wastewater with a small amount of sediment.

(b) Secondary treatment

This involves reducing BOD by anaerobic digestion or fermentation of bio-degradable materials, which is essential for highly polluted wastewater. There are four major technological alternatives: anaerobic pond, anaerobic covered lagoon, fixed dome, and Up-flow Anaerobic Sludge Blanket (UASB). The three latter technologies also generate biogas. The facultative system is an aerobic-anaerobic digestion mechanism, to be used as necessary in an additional pond. (For more information on this, please go to the website of the Pollution Control Department at: www.pcd.go.th)

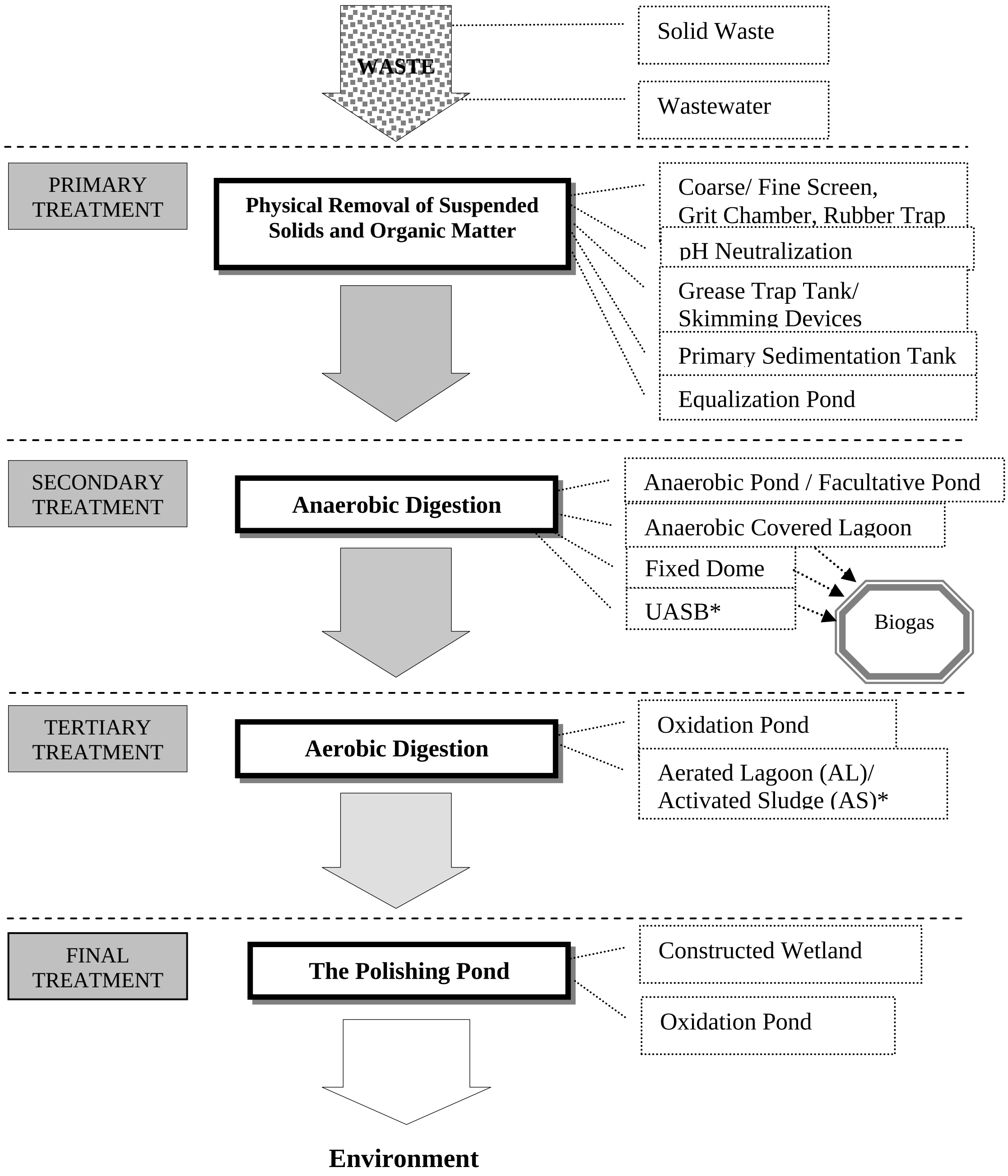


Figure 10. The wastewater treatment process

Note: * high technology

(c) Tertiary treatment

The wastewater after anaerobic digestion is generally still of poor quality and requires more treatment. The tertiary process involves aerobic digestion aimed at increasing the level of oxygen and further cleaning up any remaining organic matter. One treatment technology is an oxidation pond less than two meters in depth, which allows sunlight to reach the bottom, encouraging macro-algae growth through photosynthesis. Such ponds have more natural oxygen which facilitates aerobic chemical reactions.

The second alternative technology is the aerated pond and the third is activated sludge. The aerated pond depends mainly on oxygen generators while activated sludge also uses a generator and adds more aerobic microorganisms to increase the rate of digestion. Activated sludge is considered as high technology.

(d) Final treatment

The wastewater finally flows to a polishing pond before being released to the natural environment. The options for this final treatment are a simple oxidation pond or a natural or constructed wetland. The constructed wetland is an artificial marsh or swamp, created for anthropogenic discharge, such as wastewater, and acts as a biofilter, removing sediments and pollutants such as heavy metals and nitrogen from the discharge.

All the alternatives for each process described above can be mixed or expanded to more ponds or tanks as the case may be depending on the amount of pollution to be dealt with.

4.4.2 Cost-effectiveness of the selected technological options for wastewater treatment

Even though it is agreed that there will be substantial benefits from investing in wastewater treatment facilities, the costs are quite high and must be considered in light of the benefits expected from each of the different options. In order to provide information to assist entrepreneurs in selecting the most appropriate treatment technology, this section gives an overview analysis of the cost effectiveness of each technical option in terms of the cost of reducing one kilogram of BOD.

(a) Technological options for sewage treatment plants in the different sectors

The technological options for sewage treatment plants for analysis were selected from major point pollution sources, namely industry, farm, and domestic treatment facilities. Because of the limitations of a cost-effectiveness analysis (CEA), which ignores scale effects, we attempted to categorize all the different cases according to plant size. The list of the case studies together with their treatment processes is given in Table 10.

Table 10. Technological options for sewage treatment plants in each sector

Technologies	Factories: Rubber (CRSFs)[6] /Food/Others					Pig Farms			Communities				
	Basic Technology			High Technology		Model/Size			Villages		Municipalities		
	Yoong Thong[1]	Model 1994[2]	Model 1995[2]	UASB[3]	AS[3]	A[4] Large	B[4] Medium	C[4] Small	Sadao[5]	Klong Ree[5]	Songkhla[5]	Hat Yai (Dry)[5]	Hat Yai (Rain)[5]
1. Primary Treatment													
Coarse/fine Screen Grit Chamber				x	x				x	x	x	x	x
Rubber Trap	x	x	x										
pH Neutralization		x	x	x	x								
Grease Trap Tank/Skimming Sedimentation													
Primary Sedimentation Tank				x	x				x	x	x		
Equalization Pond				x					x	x			
2. Secondary Treatment													
Anaerobic Pond/Facultative Pond	x						x	x		x		x	x
Anaerobic Covered Lagoon	x		x			x							
Fixed Dome							x	x					
UASB				x									
3 Tertiary Treatment													
Oxidation Pond						x	x	x		x		x	x
Aerated Lagoon (AL) / Activated Sludge (AS)		x	x	x	x				x		x		
4. Final Treatment													
Constructed Wetland	x			x	x					x		x	x
Oxidation Pond	x	x	x								x		

Source: [1] Pollution Control Department 2008
[3] Klinpikul 2008
[5] Hatyai Local Government 2008 (personal communication)

Notes:
[2] Model 1994 and Model 1995 are the sewage treatment plant model for rubber factories specified by Office of the Rubber Replanting Aid Fund (ORRAF 2007)
[4] The size of pig farms specify by the number of pigs in the farm which are: the number of pigs > 5,000 pigs is large-size farms, the number of pigs = 500 – 5,000 pigs is medium-size farms, and the number of pigs< 500 pigs is small-size farms (Pollution Control Department. 2007)
"x" is mean technology use.
[6] CRSFs stand for cooperative rubber sheet factories.

(b) Cost-effectiveness analysis (CEA)

There were three cost items to consider: capital, operations, and land use. Capital costs in this study included initial construction and equipment costs. All items were considered to have been incurred in a single year. For the cost of land use, the revenue of growing rubber trees was selected for the opportunity cost of land per year, which was 15,510 Baht/rai. It was calculated using data obtained from interviewing the experienced farmers who grew rubber trees in the U-Tapao catchment area.

The effectiveness of each sector was estimated in terms of the capacity to reduce BOD loading and in the differences in BOD loads between influents and effluents. Then the cost-effectiveness ratio was calculated by dividing the total cost per year by the amount of the reduction in BOD loading per year. The results are shown in Table 11.

The CEA suggests the following:

- According to the cost structure, Yoong Thong, Model 1994 and Model 1995 are low cost options and UASB and AS are high cost options for the basic technology cases. The land use applications have a higher fixed cost due to land use and lower operating costs while the technology-based applications have lower land use but involve higher operating costs. With the high technology cases, however, there is no particular pattern for the two technologies.
- The effectiveness of the different technologies is a function of the size of the treatment plant and the volume of influents. Individual treatment plants are less effective for smaller firms with lower discharge, and such firms should consider setting up common treatment plants in cooperation with other dischargers.

For domestic treatment facilities, the CEA indicates that the cost of treating BOD per kilogram is very high in the current situation (331.7 - 52.7 baht/kgBOD) and still high even when used to full capacity (42 baht/kgBOD during the rainy season at HatYai) if compared to the 35 baht/kgBOD, the basic effluent charge rate specified in the study of the Department of Industrial Works (2007). The reason is that the BOD discharged from the communities in the current situation is much lower than the full capacity of the system. Because the size of the plants was based on future growth of the community, therefore, the BOD discharged from community is lower in the early stages. This indicates that larger domestic wastewater treatment systems are at a high risk of inefficiency, and thus reduced cost-effectiveness. The details of advantages and disadvantages of the different sewage treatment plants are shown in Table 12.

Table 11. Cost-effectiveness analysis of technological options for sewage treatment plants in each sector

Period: one year

Sector	**Capital Costs** (1,000 baht)	**Land Costs** (1,000 baht)	**Operating Costs** [5] (1,000 baht)	**Total Costs** (1,000 baht)	**Effluent** (BOD (kg/year)	**Effectiveness**[5] (baht/kgBOD)	**Biogas**
Factories: Rubber (CRSFs) / Food / Others							
Basic Technology							
Yoong Thong [1]	526.9	182.6	55.5	765.0	498.2 [8]	1,535.4 [8]	Yes
Model 1994 [1]	531.9	109.4	1,800.9	2,442.3	50,000 [6] 498.2	48.9[7] – 4901.9[8]	-
Model 1995 [1]	342.6	109.4	1,106.3	1,558.3	50,000 [6] 498.2 [8]	31.2[7] – 3127.8 [8]	Yes
High Technology							
UASB [3]	1,339.9	35.8	1,437.5	2,813.2	492,750.0 [8]	5.7 [8]	Yes
AS [3]	693.2	51.1	5,274.0	6,018.3	492,750.0 [8]	12.2 [8]	-
Pig Farms							
A (Large) [2]	502.8	268.7	111.0	882.5	120,656.2	7.3	Yes
B (Medium) [2]	26.4	2.9	55.5	84.8	13,578.0	6.2	Yes
C (Small) [2]	5.3	2.4	55.5	63.2	2,894.1	21.8	Yes
Communities							
Small-scale: Villages							
Sadao [4]	125.0	0.7	89.0	214.7	2,428.2 [8]	88.4 [8]	-
Klong Ree [4]	60.0	23.3	60.7	144.0	15,300.0 [8]	9.4 [8]	-
Large-scale: Municipalities							
Songkhla [4]	15,000.0	2,728.7 (176 rai)	6,000.0	23,728.7	1,022,000 [7] 71,540 [8]	23.2 [7] – 331.7 [8]	-
Hat Yai (Dry season) [4]	93,368.2	31,628.2 (2,040 rai)	8,966.7	133,963	3,777,750 [7] 1,231,875 [8]	35.5 [7] – 108.8 [8]	-
Hat Yai (Rainy season) [4]	93,368.2	31,628.2 (2,040 rai)	8,966.7	133,963	3,189,932 [7] 2,542,833 [8]	42.0 [7] – 52.7 [8]	-

Source: [1] ORRAF 2007
[2] Dumrungwattanapokin 2004.
[3] Klinpikul 2008
[4] Hatyai local government 2008
[5] Calculation by researcher
[6] Assumptions by an expert

Notes:
[7] Full capacity
[8] Current situation (from survey in 2008)

Table 12. Advantages and disadvantages of each type of sewage treatment plant

Sector	Disadvantages	Advantages
Factories: Rubber (CRSFs) / Food / Others		
Basic Technology		
Yoong Thong	Big space required.	Low construction cost. Low maintenance cost. Biogas generation. No odor.
Model 1994	Big space required High cost of electricity. Bad?? odor	Low construction cost. Low maintenance cost.
Model 1995	Big space required High cost of electricity.	Low construction cost. Low maintenance cost. Biogas generation. No odor.
High Technology		
UASB	High construction cost	Low maintenance cost. Small space required. Biogas obtained. No odor. High efficiency
AS	High cost of electricity. High sludge disposal. High maintenance cost.	Low initial construction cost. High efficiency.
Pig Farms		
A (large)	High construction cost. Big space required.	Low maintenance cost. Biogas generation. No odor. High efficiency
B (medium)	_	Low construction cost. Low maintenance cost. Small space required. Biogas generation. No odor. High efficiency
C (small)	Low efficiency	Low construction cost. Low maintenance cost. Small space required. Biogas generation. No odor.
Communities		
Small-scale: Villages		
Sadao	High construction cost. Sediment remains.	Low operation space. Low maintenance cost. Easy to in store Consume less electricity.
Klong Ree	Large space required. Bad odor from sewage pond.	Low construction cost. Low maintenance cost. No electricity needed.
Large-scale: Municipalities		
Songkhla	High construction cost. Big space required.	Low operating cost. High system efficiency.
Hat Yai (Dry season) Hat Yai (Rainy season)	Big space required. High construction cost.	Simple technology. Low operational cost.

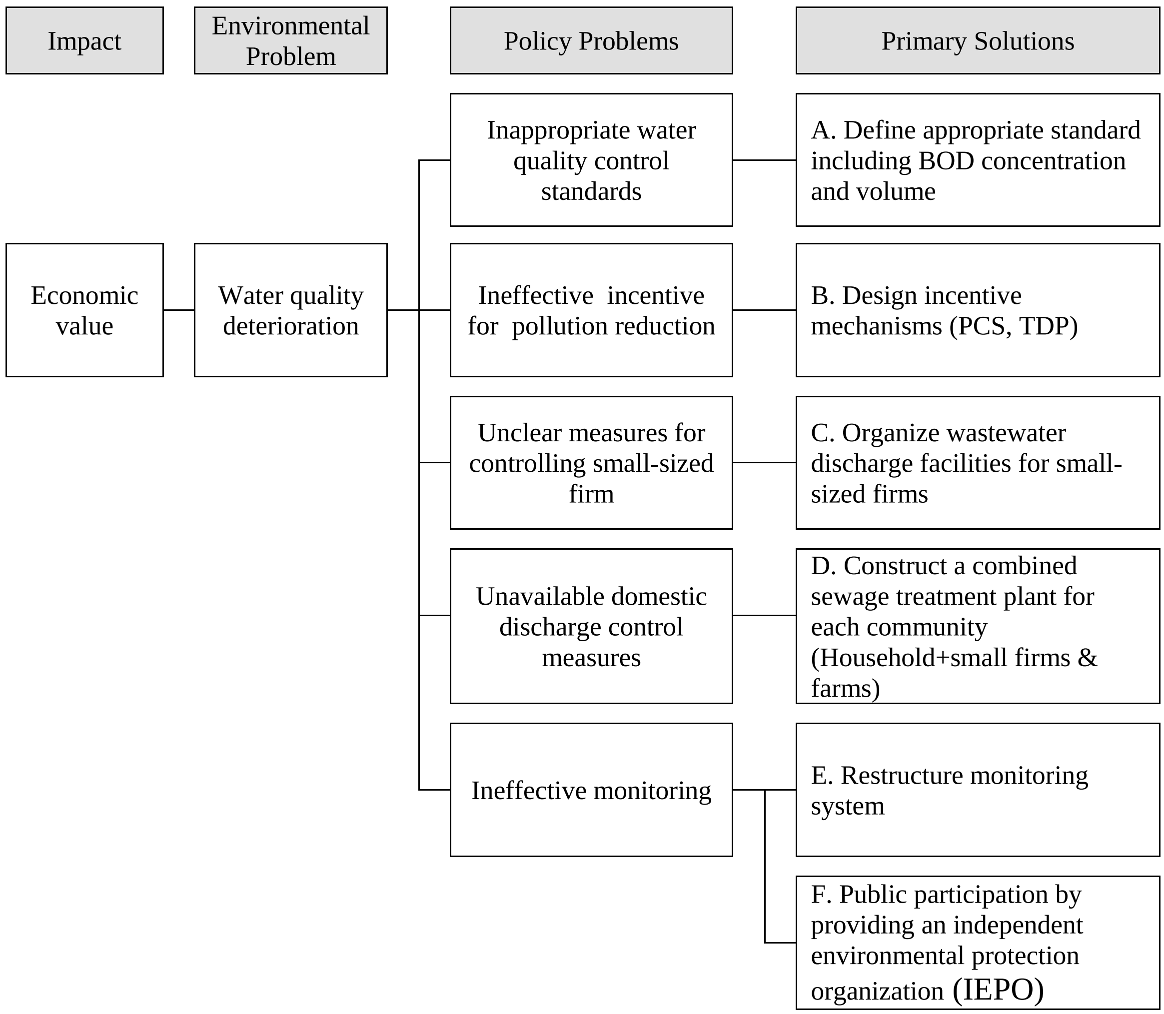
5.0 ECONOMIC EVALUATION OF POLICY OPTIONS FOR A WATER QUALITY MANAGEMENT PROGRAM: A CASE STUDY OF U-TAPAO CATCHMENT AREA

In this section, we focus on the formulation of policy alternatives with the achievement of a better level of water quality as the objective. An economic evaluation of the policy options was performed using the eight-fold path to more effective problem-solving recommended by Bardach (2000). Data mentioned in the previous sections was analyzed together with stakeholder and expert opinions. The U-Tapao catchment area was selected as the representative site for Southern Lake because it contained a high density of polluters, a good monitoring plan overseen by responsible agencies, and communities that were aware of the problem. The details are discussed below.

5.1 Construction of Comprehensive Policy Options

The environmental problems and related policy problems facing Songkhla Lake and Southern Lake have been clearly defined in previous sections. The policy goal here was to effectively achieve the desired total water pollution reduction targets with sustainable water resources utilization. The links among the environmental problems, policy problems, impacts, and primary solutions are shown in Figure 11.

Figure 11. The links among environmental problems, policy problems, impacts, and primary solutions related to Southern Lake



Based on the information collected (Figure 11), the policy options were designed. The characteristics of each policy alternative are shown in Table 13.

- **Policy Option 1:** Strengthening the enforcement of the existing command and control system (CAC)
- **Policy Option 2:** Implementing the emission charge system (ECS) (details given in Section 4.2.2 as modified from the study of the Department of Industrial Works, 2007)
- **Policy Option 3:** Implementing the tradable discharge permit system (TDP) (details given in Section 4.3)

Table 13. The characteristics of the three policy options

Policy Option	Primary Solutions						Policy Description
	A	B	C	D	E	F	
CAC	/			/			Status Quo + Changes in pollution evaluation and strengthening the enforcement of the monitoring system
ECS	/	/	/	/		/	Charges on large and small firms enforced as set out in the regulation
TDP	/	/	/	/	/	/	- Large firms and domestic treatment facilities forced to enroll in the TDP system - Small firms forced to pay for their pollution via district or municipality or combined sewage treatment systems and enroll in the TDP system - Households pay via the domestic treatment facilities system

Note: For primary solutions A to F, please see Figures 12 - 14.

5.2 Criteria Selection

In order to evaluate the three policy alternatives, certain criteria were selected. These are described in Table 14.

Table 14. Criteria selected for the evaluation of the three policy options

Criteria	Description	Measures	Evaluation Methodology
1. Public Acceptability	The acceptance level among key stakeholders, local administrative authorities, and government agencies.	The degree of acceptance (strongly disagree /disagree /agree / strongly agree)	Focus group discussions
2. Legal Feasibility	The existing legislative framework to permit the policy options.	Easy/ somewhat easy / somewhat difficult / difficult	Historical data / Expert judgment
3. Implementation Complexity	Extent of regulatory and legislative requirements	Degree of complexity (very high / high / low / very low)	Historical
4. Effectiveness	Extent to which the proposed policy options address the six factors in proper water quality control management	1 - Provide incentive mechanisms for pollution reduction	Expert judgment /Focus group discussions *(continued)*

		2 – Interaction among and coordination of stakeholders for water quality improvement 3 - The outcome effectiveness of the water quality control policy 4 - Appropriate water quality control standards 5 - The control of all sizes of firms 6 – Availability of domestic discharge control (high/ moderate/ low /none)	
5. Capital Costs	Monetary costs of the initial investment in required equipment	1 - Number of activities needed 2 - Comparing the cost of each activity	Expert judgment
6. Operating Costs	Monetary costs of operating the option on a yearly basis		
7. Transaction Costs	Monetary costs incurred in firm to firm interaction		
8. Impacts 8.1 Positive impacts 8.2 Negative impacts	 Impacts on aquatic environment, natural fishery, & aquaculture fishery The loss of competitiveness due to higher production costs	 The change in the economic value of the lake (Fish productivity / recreational value). The impact on output price	 Expert judgment
9. Equity	Polluter pays principle	Number of dischargers included in the system (high/moderate/low /none)	Historical data
10. Decentralization	Firms make decisions on pollution reduction	Number of firms which potentially reduce pollutants and set up plans for pollution reduction	Historical data/ Expert judgment

5.3 Evaluation of the Three Policy Options

Criterion 1: Public Acceptability

Public acceptance is essential to the success of any system of resource management or environmental protection. To measure the community acceptance level of the options put forward in this study, we assessed the various stakeholders' level of agreement with the CAC, ECS, and TDP systems. The three key stakeholder groups selected for the survey were: (a) the major polluters, such as the rubber industry, food industry, shrimp farms, pig farms, and municipalities which treated domestic sewage; (b) community leaders, NGOs and elected local administrative authorities; and (c) representatives from related government agencies. All together, there were 33 respondents. They were asked to rate the three policies using a four-point scale ranging from 1 (strongly disagree) to 4 (strongly agree). The results are shown in Table 15.

Table 15. Public acceptability of the three policy options

Stakeholders	CAC	ECS	TDP
1. Polluters (12)	3.10	2.82	2.75
2. Communities (16)	2.94	2.75	1.94
3. Government officers (5)	2.20	2.80	2.60
Mean (total 33)	**2.87**	**2.78**	**2.33**

Note: The rating scale was: 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree. To get the mean: <1.49 = strongly disagree, 1.5-2.49= disagree, 2.5-3.49=agree, and >3.50= strongly agree.

Although the polluters were expected to be the most negatively impacted stakeholders from the implementation of any of these policies, a higher agreement level from them was reflected in the higher public acceptability of each policy. The results show that polluters rated all three policy alternatives in the "agree" range; however, the CAC was rated higher than the ECS or TDP.

The CAC was preferred by the polluters to the ECS because, with the introduction of the latter, pollution rights would be entirely relocated from the polluters to the government, and polluters would have to pay taxes even after having reduced their emission levels. In contrast, the CAC leaves the pollution rights to the remaining emissions with the polluters. Therefore, if the polluters cannot expect the charged revenue to be paid back to them, they will always favor the CAC option. On the other hand, if revenues were redistributed in a lump sum to the polluters, they would prefer the ECS (Felder and Schleiniger 1999).

From the community point of view, the three policy alternatives were all in the "agree" range and in similar order as the polluters. Government officers were slightly different in that they disagreed with the CAC and agreed with the ECS. The possible reason was that these officials were more familiar with both options and understood through routine contact with both systems how inefficient the CAC could be and how the ECS provided more incentives to reduce pollution. They agreed with the TDP option but at a lower level than for the ECS, perhaps because TDP was new to them, and thus, they were less familiar with its concepts.

Interestingly, the public acceptability of the key stakeholders of the TDP option was overall in the "disagree" range. This is perhaps because the TDP is a new concept for Thais. Moreover, it appeared that most respondents were generally unclear about the TDP, and thus gave it the lowest rating.

Although both the CAC and ECS were in the "agree" range, the ECS scored lower, and the reason was that both communities and government officers believed that it carried the risk of generating more opportunities for corruption in the system.

Criterion 2: Legal Feasibility

The legal feasibility criterion focused on the availability of current regulations to accommodate the suggested policy options and the complexity of the process of establishing new regulations or legislation to adopt the policy options in case they did not already exist. Using historical data on the available regulations/legislation together with consultations with a lawyer as an expert advisor, the legal feasibility of the options was assessed using a four-level rating scale (1 = difficult to 4 = easy). The results are shown in Table 16.

Table 16. Legal feasibility of the three policy options

Legal Feasibility	**CAC**	**ECS**	**TDP**
Availability of current laws and the complexity of the process of establishing new regulations/legislation to adopt the policy options	Easy (4)	Somewhat easy (3)	Somewhat difficult (2)

Source: expert's assessment

Note: The rating scale was: 1 = difficult, 2 = somewhat difficult, 3 = somewhat easy, and 4 = easy

The TDP was deemed to be somewhat difficult while the ECS was seen as somewhat easy, and CAC as easy. The lawyer explained that the CAC proposal was effectively the current situation, thus no new regulations or legislation would be required. Also, under the ECS, the Municipal Law on Controlling, Collecting and Treating Sewage (2000) under the National Environmental Improvement Legislation (1992) was already in place and provided opportunities to implement pollution charges in any area that had been declared as an environmental quality control area, as requested by any municipal or district administration. The actual pollution charge or fee could be proposed later.

The TDP, on the other hand, was judged to be somewhat difficult to implement, because it would require additional legislative options to become active, and therefore the National Environmental Improvement Legislation (1992) would need to be first amended to accommodate it. The process afterwards would then be similar as for the ECS.

Criterion 3: Implementation Complexity

Criterion 3 examined the implementation complexity of the three policy alternatives, measured by the "extent of regulations" in terms of having government officials, organizations, and legislative requirements (such as regulation rules and laws) to run each policy. A rating scale was used to measure the level of implementation complexity (1 = very high to 4 = very low).

The assessment of this criterion was undertaken by relevant government officers together with the researchers of this study whose assessment depended on a review of related literature. The assessment results are shown in Table 17. The least complex policy was deemed to be the CAC, which generally needed only pollution loading regulations and supervision. The ECS was deemed complicated because it required regulations, supervision, and additional resources to collect the charges from the polluters, and the most complex policy was found to be the TDP, which had the same requirements as the ECS, but also a system of permit trading and fee collection.

Table 17. Implementation complexity of the three policy options

Criterion	**CAC**	**ECS**	**TDP**
Scale of implementation complexity	Low (3)	High (2)	Very high (1)

Source: assessed by researchers and government officers

Note: The rating scale was: 1= very high, 2 = high, 3 = low, and 4 = very low

Criterion 4: Effectiveness

The effectiveness criterion was evaluated based on four assumptions about the policy design.

- BOD loading was used as the basis for water quality control standards, and applied to all the three policies (CAC, ECS, and TDP).
- In the case of the ECS, firms which discharged more than 100 kg BOD/day would be forced to participate in the ECS program using a variable rate while firms which discharged less than or equal to 100 kg BOD /day would be charged a flat rate. In the case of the TDP, firms which discharged more than 100 kg BOD/day would be forced to participate in the TDP program while firms which discharged less than or equal to

100 kg BOD/day would be allowed to discharge their wastewater through municipality sewage treatment plants.

- All three policy designs included domestic discharge for all sizes of firms, using the same water quality control standards. Therefore, evaluation items 4, 5, and 6 are equal for all alternatives (see Table 18).

Using the expert opinions of two academicians and six researchers, with a four-level rating scale (1 = none to 4 = high), the results shown in Table 18 were arrived at. It should be noted that because the experts who evaluated these policy alternatives were mainly economists, their opinions were most likely based on economic concepts.

Table 18. Effectiveness of the three policy options

Criteria	**CAC**	**ECS**	**TDP**
1. Provides incentive mechanisms for pollution reduction	1	2.57	4
2. Interaction and coordination of stakeholders for water quality improvement	1.43	1.43	3.57
3. The outcome effectiveness of the water quality control policy	1.57	2.43	4
4. Appropriate water quality control standards	4	4	4
5. Controlling all sizes of firms	4	4	4
6. Domestic discharge control available	4	4	4
Mean	**2.67**	**3.07**	**3.93**

Source: assessed by researchers and experts

Note: The rating scale was 1 = none, 2 = low, 3 = moderate, 4 = high. To get the mean rating, <1.49 = none, 1.5 – 2.49 = low, 2.5 – 3.49 = moderate, and >3.50 = high.

In terms of providing of incentive mechanisms for pollution reduction, the TDP was deemed to be highly effective while the ECS was moderately effective and the CAC deemed as practically non-effective. The possible reason is that both the TDP and ECS provide self-incentives to reduce pollution at the least possible cost, but with the ECS, it is difficult to define an optimal fee which would provide sufficient incentive for pollution control. As a result of this uncertainty concerning the fee level, the ECS was rated as having only a moderate incentive with low outcome effectiveness.

The TDP, on the other hand, received a high outcome effectiveness rating because this system provides great flexibility for firms to meet their discharge targets using the market mechanisms of tradable discharge permits. Because there are a variety of firms with different abatement costs in the area, the potential gains from trading effluent permits are potentially significant. This situation can stimulate firms to develop the most effective sewage treatment technologies for their businesses. Therefore, the conclusion was that the

TDP was the most effective policy, with both the ECS and CAC rated as moderately effective (Figures 12, 13 and 14).

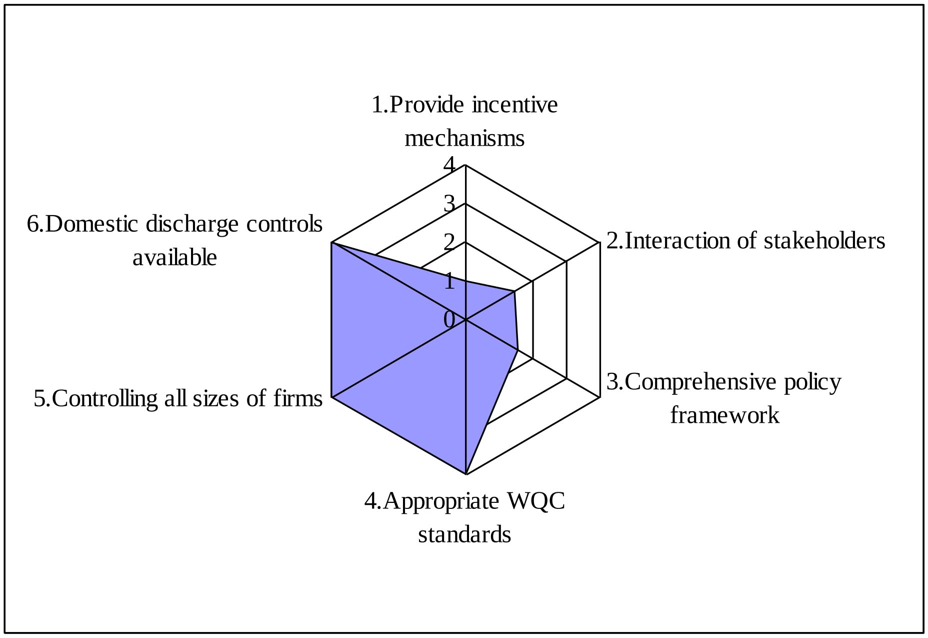


Figure 12. Effectiveness of the CAC

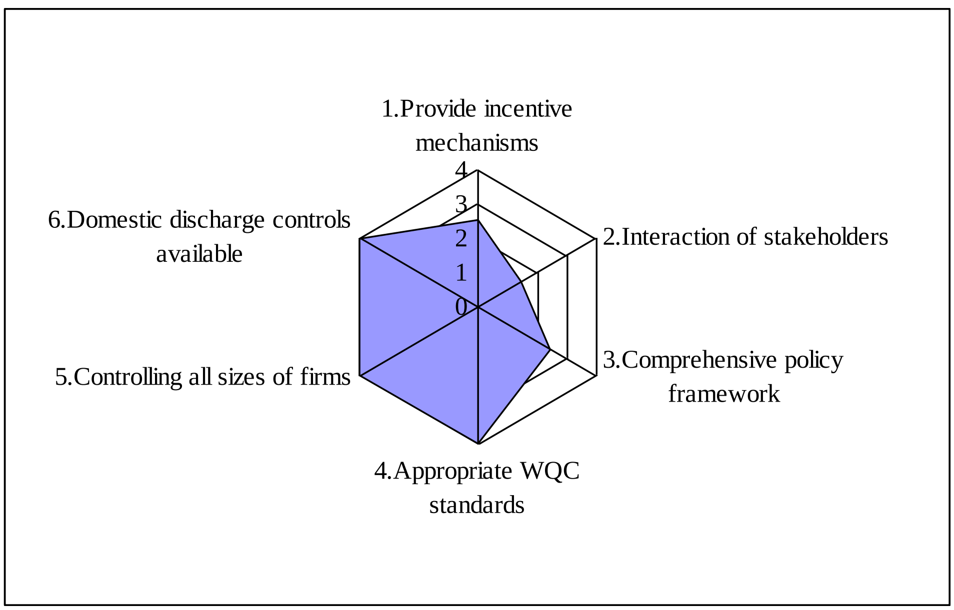


Figure 13. Effectiveness of the ECS

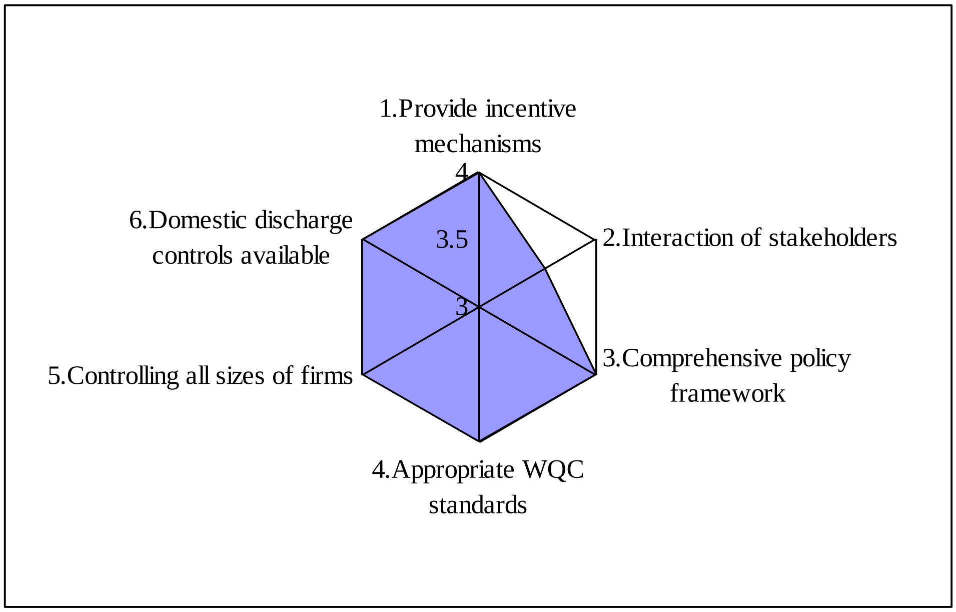


Figure 14. Effectiveness of the TDP

Criterion 5: Capital Costs

The capital cost of each policy, from the point of view of the polluters, was similar because each requires the same things of them. In the beginning, the polluters are required to invest in a treatment system and monitoring machines which satisfy the legislation. However, the state may mitigate these costs by offering some offsetting incentives such as reducing corporate taxes or providing low interest rate loans.

However, the estimation of capital costs differed for the policy-makers. The TDP program demands a higher investment than the ECS because the state has to establish a market for trading permits as well as institutions and new government agencies to control the complicated market and recoup the costs of assessing and distributing the initial permits to all involved parties.

To run the ECS program, the government has to invest in official costs such as a new computer system to report charge data, monitor the transactions and calculate the appropriate rates. The CAC does not have these capital costs, thus, the required initial investment is highest for the TDP, lower in the ECS, and lowest in the CAC.

Criterion 6: Operating Costs

Like the capital costs, the operating costs for electricity, water, maintenance, etc. were not deemed different between the different options from the polluters' point of view, but they were deemed different by the policy-makers. The ECS and TDP users face equal expenditure because the TDP requires a trading mechanism and a controlling institution, and the ECS also has related costs, especially in monitoring the operating charge system which is expected to be higher than the TDP. The CAC has the lowest implementation and operating costs because it requires only monitoring, which is the minimum requirement for any program.

Criterion 7: Transaction Costs

Businesses in the TDP option must deal with costs related to their trading transactions whereas in the ECS, they deal only with service charges such as late fees or bank fees if they pay by account. So the transaction costs were highest for the TDP, high for the ECS, and low for the CAC.

Criterion 8: Impacts

The impacts of the three policy alternatives were divided into positive and negative impacts. Positive impacts related to impacts on the aquatic environment, natural fishery, and aquaculture fishery and can be quantified as follows:

*Positive impact = Total amount of waste reduced * increase in benefits resulting from one unit of waste reduced*

The positive impact generated by each policy is equal to the total amount of waste reduced as a result of that policy multiplied by the benefit increases (in terms of increases in fish productivity) from one unit of waste reduction. Since one unit of waste reduction from the CAC, ECS or TDP generates the same amount of benefits, the latter part of the above equation is the same for each policy. The comparative positive impact of each policy then depends solely on the total amount of waste reduction resulting from each policy. Using the effectiveness criterion to represent the total amount of waste reduction achieved by each policy, the positive impact of the TDP is more than the ECS, and the positive impact of the ECS is more than the CAC.

The negative impacts of the options can be defined as the loss of competitiveness of the producers due to higher production costs. This loss depends on at least two factors. The first is the ratio of the cost of waste reduction to the total cost of each firm[12]. The other major factor is the degree of competitiveness of the market. Other things being constant, an increase in the first factor will decrease the competitiveness of the firm. Considering the degree of competitiveness; the more competitive the environment, the higher the loss of competitiveness faced by the firm due to increased waste management costs. In view of the fact that the policies considered in this study would not affect the degree of competitiveness of the market, this study examined only the ratios of the costs of waste reduction to the total costs of the firms.

[12] Assuming there is no negative impact on communities

The proposed policies aimed at forcing polluters or providing incentives to them to reduce their waste. To reduce waste, firms inevitably face increased costs, thus, in the short run, applying the CAC, ECS or TDP will increase the ratio of the cost of waste reduction to the total cost of each firm in the same way. Other things being equal, every firm will lose its competitiveness at the same level for all three policies, thus the implementation of any of the alternatives will not affect the competitiveness of the firms in relation to one another.

There is also a positive side, as although firms may find their competitiveness affected from increasing treatment costs, they could gain the opportunity to sell their products in a new market. Some countries have environmental restrictions for many imported goods, and shrimp production is high on most such lists. This naturally affects Thai shrimp and other products which are denied access to those countries not because of quality, price or lack of demand, but because their production fails to comply with environmental restrictions. Therefore, in complying with the CAC, ECS or TDP policy, the benefits include not only waste reduction and an improved local environment, but also improved access to new markets, which will alleviate the negative impact of implementing such policies.

Rahim (1991, quoted in Panayotou 1994) found that Malaysia's palm oil export sector lost only 5% of the value of their output as a result of environmental regulations (ECS) from 1982-1986 that reduced allowable BOD discharges by 90%. Vincent (1993, quoted in Panayotou 1994) also found that in Malaysia, the crude palm oil sector lost only about 1% of the value of production despite the highly competitive nature of the world palm oil market.

Since the ECS and TDP provide incentives to polluters to reduce their waste, the firms will have increased interest in R&D in mitigation technologies. The more waste is reduced, the more money is saved (and may be the more money gained from the TDP). With the CAC, firms develop their technology only to the level necessary to comply with regulations. Thus, in the long run, the ratio of the cost of waste reduction to the total cost of firms complying with ECS or TDP regulations will be smaller than for the CAC option due to the decreasing costs of waste reduction from R&D in mitigation technologies.

Criterion 9: Equity

Equity refers to fairness in terms of (a) equity among polluters and those negatively impacted by the pollution, and (b) equal discharge standards or abatement costs among polluters. The evaluation was based on the "polluter pays principle," which states that whoever causes pollution is responsible for the costs of repairing the damage it causes. Equity was measured using a four-level rating scale (1 = none to 4 = high). The assessments were done based on literature reviews.

Table 19. Equity of the three policy options

Criterion	CAC	ECS	TDP
Scale of Equity	Low (2)	High (4)	High (4)

Source: assessed by the researchers of this study

Note: The rating scale was: 1 = none, 2 = low, 3 = moderate and 4 = high.

In the case of point source pollution, the CAC was found to have a low level of equity because industries do not pay unless they discharge more pollution than allowed by the emission standards. The ECS and TDP options, however, are based on the “polluter pays principle”, which involves the assumption that people living near the polluters have the legal right to be free of harmful emissions; thus polluters have to pay for the ‘right’ to pollute.

Equity issues in the context of ECS center on the charge rate, which should be high enough to effectively induce changes in behavior. Violators are willing to pay fines when the rate is set at low levels rather than comply with the CAC; in the other words, higher costs make the ECS less attractive to polluting industries.

Concerning the TDP, a significant pre-condition for the success of such schemes is the initial distribution of permits. Government auctions of marketable permits can achieve equity, but clearly this would not hold when permits are allocated freely, because the permits in this case would represent a windfall gain for the receiving firms (Norregaard and Reppelin-Hill 1999).

Therefore, if the permits are auctioned and there is an optimal charge for the ECS, then both the TDP and ECS are equivalent and can achieve the same equity outcome. If the permits are given out freely, however, they represent a windfall gain for the receiving firms and may create a bias against new firms entering the market since existing firms will have gotten their permits free while new firms must buy them. In this respect, the ECS would be preferred.

Criterion 10: Decentralization

Decentralized policies are policies that permit the individuals involved in a case of pollution to work it out themselves (Field and Field 2006). This criterion examined the degree of decentralization of the three policy alternatives, measured by the number of firms which could potentially reduce pollutants and set up plans for pollution reduction.

For the CAC, since some standards are strictly dictated by the regulator, polluters must follow them, even though they might be able to achieve efficient abatement with lower costs by other means. Therefore, there is no incentive for the polluters to find new and creative ways to further reduce their own pollution emissions. Due to such disadvantages with the CAC, incentive-based environmental policies that decentralize the decision-making process, such as the ECS and TDP, have been designed.

With the ECS, emitters can find the best means to abate emissions by themselves. For instance, if the charges are set at very high levels, the industries affected will attempt to find cost-saving methods to control their waste or improve their end-process treatment systems. The ECS, however, is not a perfectly decentralized system as interaction between polluters and public authorities is still necessary. Some central public authority must be in charge of establishing the charge rate, monitoring the performance of each polluter, and then collecting the fees (Field and Field 2006).

The TDP is preferred to the ECS in this respect because it maintains the desired level of emissions without intervention by the regulators. The adjustment responsibility in the face of change is borne by the firms in the permits market. It allows firms to buy additional permits as needed if they fail to meet their targets internally and to sell off excess permits if they exceed their internal pollution reduction targets (Norregaard and Reppelin-Hill 1999). The polluters are also more interested in R&D and technological treatment improvements to pursue the gains from permit trading.

In sum, the most decentralized policy is the TDP, followed by the ECS and CAC, the policy with the least degree of decentralization. No matter what system is used, it is necessary to improve the flow of information to all stakeholders (the public's right to know) in order to improve decision-making. Often, lack of public awareness on the importance of water pollution prevention and low participation in improvement efforts contributes to deterioration of the environment and pollution problems (World Bank 1998).

Summary of the evaluation results

A summary of the ten criteria applied to each policy is shown in Table 20. The results indicate that CAC has several advantages and disadvantages compared to TDP and ECS. Under CAC it would be difficult to solve water pollution control problems because of disadvantages in crucial areas, such as effectiveness, positive impacts, equity, and decentralization.

Based on effectiveness, which was considered to be the most important criteria, ECS was found to be less effective than TDP because of the difficulty of defining an optimal fee level for the Songkhla Lake area, and also because of the complexity of implementation. Therefore, there is no guarantee that ECS would achieve its goals if it was applied at the Southern Lake.

The assessment shows that TDP would be effective in the Songkhla Lake watershed. This is because there are a variety of industries in the region, all with different abatement costs. The potential gains from trading effluent credits or permits are therefore likely to be significant. However, there would be some disadvantages with TDP. Putting TDP in place would require various legislative issues to be resolved. Implementing TDP would be complex so would demand a greater initial investment and incur higher transaction costs. In addition, TDP has a low public acceptability rating because people do not currently understand how such a system functions. Therefore, in order to implement TDP in a community situation, outreach and education work would be required. Finally, TDP could best be applied to large-scale firms and farms because of its high outcome effectiveness and high capital costs.

ECS would be better suited to small- and medium-scale firms and farms, including businesses and households. In order to select the best alternative for each business, farm or household, different weights could be given to the various criteria depending on desired goals.

Table 20. Summary of the evaluation results of the three policy options

Criteria	CAC	ECS	TDP
1. Public Acceptability	Agree (2.87)	Agree (2.78)	Disagree (2.33)
2. Legal Feasibility	Easy (4)	Somewhat easy (3)	Somewhat difficult (2)
3. Implementation Complexity	Low (3)	High (2)	Very High (1)
4. Effectiveness	Moderate (2.67)	Moderate (3.07)	High (3.93)
5. Capital Costs	Low	High	Higher
6. Operating Costs	Low	Higher	High
7. Transaction Costs	Low	High	Higher
8. Impacts			
8.1 Positive impacts	Low	High	Higher
8.2 Negative impacts	Low	Low	Low
9. Equity	Low (2)	High (4)	High (4)
10. Decentralization	Low	Moderate	High

6.0 CONCLUSIONS AND POLICY IMPLICATIONS

6.1 Southern Lake: Situation and Trends

In order to identify the current situation and trends in fishery production in Southern Lake, a literature review and synthesis of secondary data were conducted. Past studies reported a significant economic value for the lake in terms of the value of the natural shrimp catch, which was then used as an indicator of water quality deterioration. Our statistical analysis indicated that the water quality changes in the lake had a significant impact on shrimp production, i.e., one unit increase in the WQCI at U-Tapao would lead to a shrimp productivity increase of 3.4% (significant at the 0.05 level), and one unit increase in the WQCI at Pag-ro would lead to a shrimp productivity increase of 10% (significant at the 0.01 level) as shown in section 3.4.

The major sources of pollution affecting water quality and fishery production in Southern Lake are from the U-Tapao River and the Pawong River which have a high density of factories and pig farms. Another important source is the Pag-ro Channel where there are a large number of shrimp ponds. An analysis of 12 years of water quality data (1992-2004) found that the amount of nitrogen and phosphate discharged into Southern Lake had increased over time at every river mouth. In particular, the total amount of nitrogen at the U-Tapao River Mouth had increased significantly. Nitrogen was found in farm effluents and in both domestic and industrial waste, and in large amounts, which was very harmful to aquatic animals. This is also closely related to the BOD (kg/day) discharge into the lake. Therefore, in order to control and improve the water quality of Southern Lake, the wastewater from the various sources needed to be well managed in order to increase the economic value of the lake.

Intensive over-fishing is also known to be a cause of fishery degradation. However, this study dealt only with the pollution aspects, as extensive consultations with stakeholders indicated that controlling fishing efforts was a very sensitive issue with the communities and the fishermen would be more likely to be cooperative after pollution controls were in place. Also, the limited data on the full impact of fishing in Southern Lake did not allow us to fully assess the empirical relationship between fishing efforts and fishery values in the current situation. Therefore, the issue of controlling fishing efforts should be considered in a separate study.

6.2 Available Management Options to Improve Water Quality

The ‘Command and Control’ (CAC) policy is the current water pollution management system in Thailand. The regulatory agencies in charge of monitoring water quality attempt to limit pollutant loads within current levels and reduce them in the future. According to the various laws and regulations, all the stakeholders such as factories, pig and shrimp farm entrepreneurs, and municipalities must comply with the effluent standards set. The management agencies are deeply concerned about heavy pollutants such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Kjeldahl

Nitrogen (TKN) and concentration-based discharge requirements for particular point source polluters are strictly enforced.

The main problems of the current CAC policy are: (a) it does not encourage the industries to improve their production processes and wastewater treatment systems in order to reduce pollution emissions; (b) effluent standards that focus on concentration-based discharge are not really adequate in controlling wastewater disposal; (c) monitoring procedures are somewhat inefficient, with random inspections of large and medium factories and farms every two months or so, and no regular inspections of smaller operations such as backyard pig farms; and (d) the punishments for those who exceed pollution standards are quite small and not strictly enforced. Overall, this study found that the CAC policy was deficient in encouraging the participation of all stakeholders, and that they were not sufficiently aware of their responsibilities in environmental protection.

In consideration of the inefficiencies of the CAC policy, the Department of Industrial Works conducted a study on “The Application of Economic Instruments for Industrial Pollution Management” in 2007. It introduced an emission charge system (ECS) and recommended pollution management fees as the most appropriate economic instrument to minimize pollution in Thailand. Two different types of pollution/emission charges were designed: (a) the flat rate type for medium and small-scale factories, and (2) the variable rate type for large-scale factories. The basic emission charge rate was set at 35 baht/kg BOD.

6.3 Technological Options to Improve Water Quality in the U-Tapao Catchment Area

There were several types of polluters identified in the U-Tapao catchment area, based on the type of waste products, type of factory, and size of the local community. A variety of pig and shrimp farm operations were identified as polluters in the area. All polluters had similar wastewater treatment system processes from primary treatment stage through to the final treatment stage, with the major differences being the size of the treatment plant and the level of technology applied.

Investment in wastewater treatment plants always involves a high cost and therefore, most dischargers avoid such investments where possible, leading to a large amount of wastewater from firms and farms being directly released into the environment by up to 91% of the pig farms and 100% of the open-system shrimp farms in the area. Such operations have no incentive at all to reduce their effluent discharge and therefore, the U-Tapao catchment area is in serious need of incentive mechanisms to encourage polluters to do so.

There were two types of methodologies identified which affected treatment costs for basic technology options. The land use applications, such as the basic technology model which was used at the Yoong Thong factory, had higher fixed costs due to land use but lower operating costs, while technology-based applications, such as the UASB or AS, had lower land use costs but higher operating costs. With the high technology options, however, there was no particular cost pattern.

The results of the cost-effectiveness analysis (CEA) showed that the effectiveness of a treatment technology was sensitive to the size of the plant and the influent load. Firms had to take into account the appropriate size, technology, and consistency of the amount of BOD loading produced in deciding what technology to use. It was less effective for businesses with a lower influent load or a smaller size to invest in individual treatment plants; it was more cost-effective for small-scale polluters to share a common treatment plant.

For domestic treatment facilities at the municipal level, the CEA showed that the cost of treating the BOD per kilogram was very high even at full capacity. Large-scale domestic treatment facilities tended to be ineffective due to under-utilization and such operations required effective administrative management. Smaller-scale domestic treatment facilities are recommended because these are easier to operate effectively and also offer more flexibility for later development.

6.4 Policy Recommendations

The major objective of this study was to develop appropriate policy alternatives for a sustainable fishery in Southern Lake, and the impact of water pollution was the first consideration. In order to draft appropriate policy alternatives, policy problems and primary solutions were first identified:

- With inappropriate water quality control standards, the major pollution problem was found to be pollution loading, in terms of concentration and volume of major pollutants such as BOD.
- With ineffective incentives for pollution reduction, it was necessary to introduce incentive mechanisms such as ECS or TDPs.
- As there were no clear measures to control small-scale firms and farms, polluters which release less than or equal to 100 kg BOD/day should be required to pay for their discharge and set up domestic treatment facilities or common wastewater treatment plants.
- To counter the lack of domestic discharge control measures, small-scale common sewage treatment facilities for each community should be set up to deal with the combined waste from households, small firms, and farms.
- As the monitoring system was ineffective, it needed to be restructured to incorporate incentive mechanisms and public participation.

Based on our literature review and survey, it became evident that firms and farms had the potential to improve their wastewater treatment technologies but there was no incentive for them to do so. The concept of market-based instruments in pollution control systems is quite new to Thailand, although the ECS has already been proposed. Further studies are required to implement appropriate new systems, particularly in special areas such as the Songkhla Lake basin.

Market-based instruments have many advantages over CAC regulations, and each instrument has different advantages and disadvantages. For example, it is difficult to define an optimal fee level for the ECS; if the fee is too low, there will be insufficient incentive for pollution control, whereas a TDP system provides greater flexibility to firms to meet their discharge targets under market mechanisms. With the situation of a variety of industries with different abatement costs around Southern Lake, the potential gains from trading effluent permits are likely to be proportionately large, therefore, the TDP is an interesting alternative.

In the end, three policy alternatives were carefully compared in the study: the CAC, ECS, and TDP. The comparisons were considered based on four basic assumptions: (a) the BOD loading was used as the basis for water quality control standards for all three policies; (b) for the ECS option, firms which discharged more than 100 kg BOD/day would be forced to participate in the ECS program using a variable rate, while firms which discharged less than or equal to 100 kg BOD /day would be charged a flat rate; (c) for the TDP, firms which discharged more than 100 kg BOD/day would be forced to participate in the TDP program, while firms which discharged less than or equal to 100 kg BOD/day would be allowed to discharge their wastewater through municipality sewage treatment plants; and (d) all three policy designs included domestic discharge.

There were ten criteria selected to compare the different policies, namely, public acceptability, legal feasibility, implementation complexity, effectiveness, capital costs, operating costs, transaction costs, impacts, equity, and decentralization. The summary of the advantages, disadvantages, and implications of each policy are discussed below.

(a) The CAC policy

There were several advantages of the CAC, namely, high public acceptability and legal feasibility, low implementation complexity, no initial investment requirements, and lower operating costs than the other two options.

However, the CAC had several disadvantages compared to the TDP and ECS: low effectiveness, low equity, and low decentralization. Under the CAC, it would be quite difficult to solve water pollution control problems because of serious disadvantages to some stakeholders.

(b) The ECS policy

Although similar to the TDP in theoretical concept, the practical effectiveness of the ECS was found to be lower than the TDP because of various limitations. Firstly, it is difficult to define an optimal fee level to provide sufficient incentives for pollution control. Even if an optimal fee level could be identified, it could still be distorted by factors like corruption. Secondly, the implementation complexity is high due to additional resources being required to collect the charges. There is also a higher administrative burden with the ECS system in having to deal with polluters who do not want to or are unable to pay the required fees, thus leading to conflict, deceit, and corruption. Therefore, if the ECS was applied to the U-Tapao catchment area, there was no guarantee that it would achieve its goals.

However, ECS has the advantage of high legal feasibility because the legislative framework was already in place to enable its implementation. Moreover, it had high public acceptability.

(c) The TDP policy

For the TDP, the main advantage was high effectiveness because it is a self-incentive mechanism which provides great flexibility to firms to meet their discharge targets using market mechanisms. Because of the large variety of firms with different abatement costs in the U-Tapao catchment area, the potential gains from trading effluent permits are potentially significant. This is an important situation because the system can stimulate firms to seek and develop the most effective sewage treatment technologies for their businesses. Also, with market operations, a permit trading system will take some of the administrative burden out of the hands of the government officers, which is another advantage. Moreover, with the highest outcome effectiveness, the TDP is expected to provide the most positive social impacts.

However, there are also some disadvantages with the TDP. First, there are problems with legalities, as implementing the TDP would require additional legislative mechanisms. Secondly, in terms of implementation complexity, the TDP requires a well-organized system from the earliest stages, primarily the identification of BOD-carrying capacities in the areas where the TDP will be applied, a well-defined initial permit distributional system, and a trading system. Thirdly, with this complexity, the TDP requires a greater initial investment and also has higher transaction costs; and fourthly, the TDP was found to have the lowest rating for public acceptability due to lack of understanding of it. Therefore, in order to apply the TDP, further education of the communities involved will be required.

In order to select the best option, policy-makers could apply different weights to the different criteria depending on their specific desired goals. Moreover, some congruence among the advantages of each policy option can also be considered. For example, due to the high outcome effectiveness of the TDP and high capital costs, it could best be applied to large-sized firms and farms, while the ECS would better suit small and medium-scale firms and farms because it involves lower capital costs. Whichever combination of policy options is ultimately selected, further studies will be needed to determine the effectiveness of such combinations.

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