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Surface Water Pollution Control by Appropriate Effluent Taxation: The Thachin River Basin Study, Thailand

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Abstract: This research aims to determine the appropriate effluent tax scheme and construct an optimized mathematical decision making model in order to maximize profits while bearing economic and environmental constraints in the Thachin River basin. The Thachin River is ranked as the most polluted river in Thailand where pig farms, urban communities, aquaculture and industries significantly contribute to deteriorating water quality in the basin. Therefore, the comparison of applied mathematical models for uniform and non-uniform taxation were developed, This approach can prohibit the amount of pollution discharges from exceeding the total maximum daily loading of the river. As the results, the mathematical models indicated that applying the uniform tax policy is effectively more saving of 45.25% than the non-uniform tax policy in total expenses. By modifying the uniform taxation model to consider the amount of end-of-pipe pollution emissions, the aggregate amount of wastewater contaminant in the surface water and constraints of waste loading can be prohibited from exceeding the carrying capacity of the river ecosystem.

Key words: Uniform tax, pollution tax, Thailand, effluent pollution

INTRODUCTION

At present, Thailand's environmental protection agencies fail to enforce its existing environmental laws and regulations in an effective manner. Thailand has developed a reputation for relatively poor environmental performance and the country ranked 46th out of 56 countries according to the World Economic Forum (2002). Thailand employs an end-of-pipe approach (water quality standard) to environmental regulation. Factories and industrial parks are legally obligated to treat their wastewater in order to meet industrial effluent standards. These standards only specify the concentration of contaminants allowed in the effluents. This shortsighted approach fails to take into consideration the total amount of contaminant loading. This renders the environmental regulations ineffective in protecting the environment due to failure to curtail the total amount of waste released in effluents, which exceed the carrying capacity of the receiving river ecosystem (PCD, 2005a).

Twenty-five river basins in Thailand are continually subjected to pollution loading exceeding their respective carrying capacities according to PCD (2002).

PCD (1997) states the Thachin River faced a particularly serious problem with surface water quality due to accumulation of upstream wastewater discharges. Subsequently, PCD (2003a, b, 2005a-c) details the nature and magnitude of wastewater overloading in the Thachin River originating from an array of industrial, agricultural and urban sources.

From a technological standpoint, there are a number of approaches that may be employed to reduce wastewater discharge into river basins. Bauman *et al.* (2008) explained that innovations in pollution control have the capacity to maximize the amount of social welfare derived by optimizing the tradeoff between environmental protection and industrial production. The discourse on environmental protection approaches has been of significant interest to economists since at least the mid-1970s. A survey conducted by Jaffe *et al.* (2003)

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summarizes the consensus of findings: market based instruments for environmental protection provide better incentives than command-and-control approaches for the cost-effective diffusion of desirable, environmentally friendly technologies.

Wastewater treatment surcharge planning as Polluter Pay Principle in Thai (PCD, 2003b) reported that many researchers have suggested use of a non-technological approach that utilizes tariffs to control wastewater effluents from industrial, agricultural and domestic sources. At present, the pollution control act applies a uniform tariff to control pollution emissions nationwide. This policy has proven to be unsuccessful in inducing sustainable pollution levels, because carrying capacity of pollution loading is different in each water body.

A more comprehensive approach should be considered. The taxation model must be adjusted to account for control the Total Maximum Daily Load (TMDL) of pollution as well as the aggregate amount of wastewater contaminant in the surface water. This approach is capable of prohibiting waste loading from exceeding the carrying capacity of the river ecosystem. To solve these problems based with a non-technological method, an incentive based method coupled with a prudently applied taxation scheme could effectively control and reduce pollution discharge into rivers (Thompson, 1998; Glachant, 2002). Based on this premise, uniform and non-uniform tax policies are applied to explore their efficacy in controlling waste effluent.

The approach taken in this study is to optimize the mathematical model in order to control the surface water quality of the Thachin River. The two primary objectives of the research are as follows:

- To determine the appropriate effluent tax system suitable to control pollution loading in the Thachin River
- To develop and optimize the mathematical decision making model in order to maximize utility with sensitivity to economic and environmental constraints thus ensuring pollution discharges do not exceed the total maximum daily loading in the Thachin River

The results of study should provide useful information about the optimal taxation level for controlling pollution emissions in each sub-basin of the Thachin River.

MATERIALS AND METHODS

Study site: This study was conducted since 2006 to 2008, the focus of that covers the boundary of Thachin River as shown in Fig. 1. It is located in the central region of Thailand and is the main river traversing south along nine provinces. The report of PCD (1997) defines that Thachin River is the only major river in the Thachin River. It has been known in many different names depending on location it passes through, such as Makhamtao canal, Supanburi River, Nakornchaisri River and Thachin River. However, it is commonly known as Thachin River. It originates from stream that separate from the right bank of Chaopraya River at Ban Paakklongmakhamtao, Makamtao subdistrict, Watsing district, Chainat province. It then passes through Hanka district, Chainat province, going to Supanburi province through districts of Dermbangnangbuat, Samchuk, Sriprachan, Muang, Bangplama and Songpinong. It passes through Nakornpathom province at districts of Banglane, Nakornchaisri and Sampran and flow into the gulf of Thailand at Samutsakorn province by passing through Banprao, Kratumban and Muang districts. Total length of the river is 325 km.

The Thachin River serves the domestic, agricultural and industrial needs of approximately eight million people. The basin covers 11,763 km^2 (7.35 million Rai) across 9 provinces including Bangkok, Ayutthaya, Nonthaburi, Chainart, Uthaithani, Suphanburi, Nakornphathom and Samutsakorn. PCD (2005a) illustrates that the significant pollution-generating sources in Thachin River are divided into four main point sources. A number of pig farms are dispersed along the middle and the lower regions of the Thachin River basin in Nakornphathom and Suphanburi provinces. A number of densely populated communities are major point pollution sources dispersed along the river, especially the lower basin. Located in the centers of provinces and districts, these communities sustain many commercial and noncommercial activities that generate significant amounts of wastewater on a scale similar to city municipalities. Aquaculture, cultivating primarily prawns and fish, is practiced along the middle and lower parts of Thachin River. Industrial activities are the main pollution generators due to the discharge of massive amounts of wastewater directly into the river. The quantity and variety of waste effluent from each site differs depending upon the raw material, products, processes and machinery each factory utilizes in production. Some factories produce no waste effluent as no water is required for the production process. Of the factories that do require the use of water, most have wastewater treatment systems that process waste effluents to meet concentration standards before release into the river. A variety of factory types are scattered along the Thachin River with a higher concentration along the lower stretch of the basin.

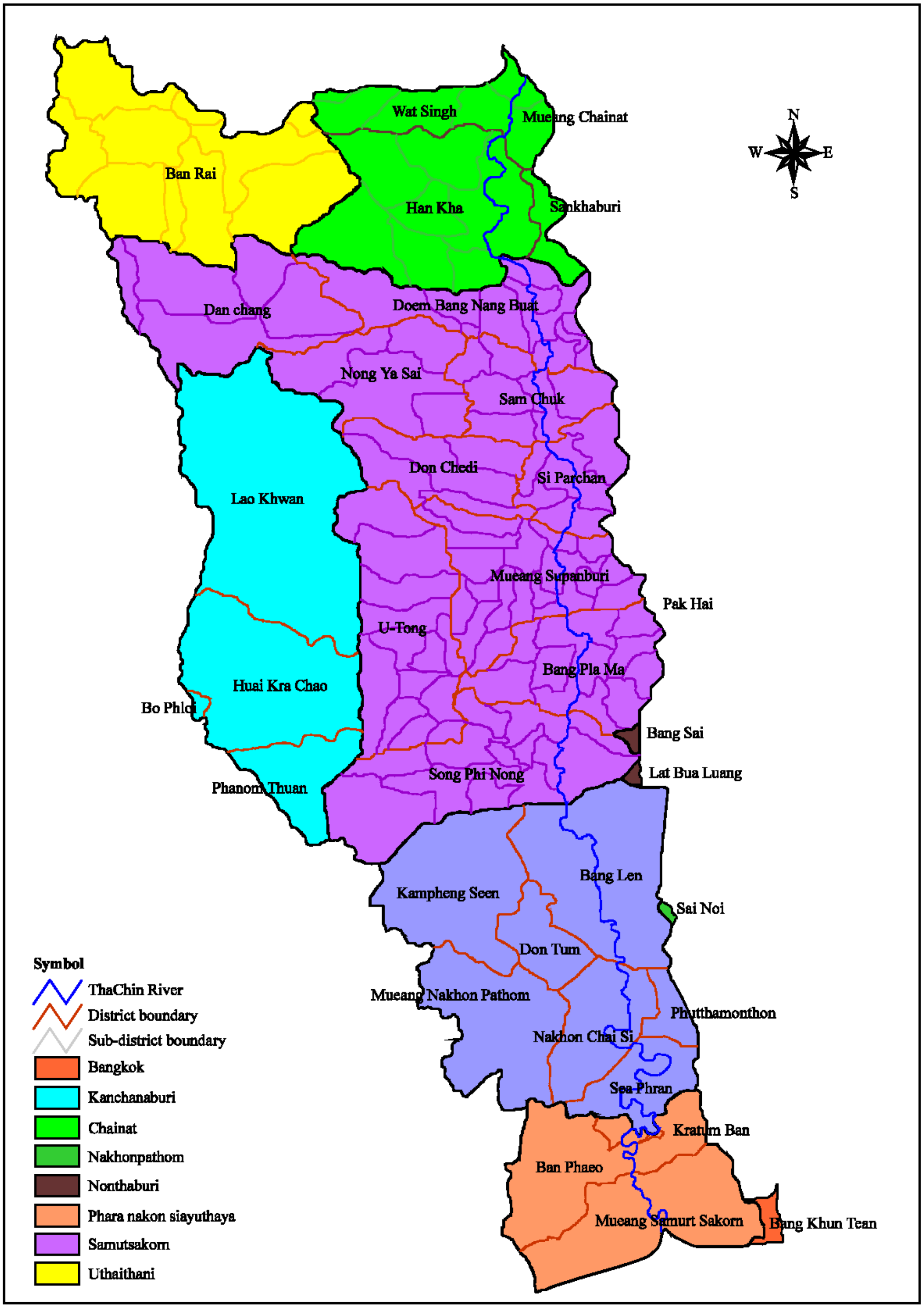

Fig. 1: The boundary of Thachin River Basin. PCD (2005a)

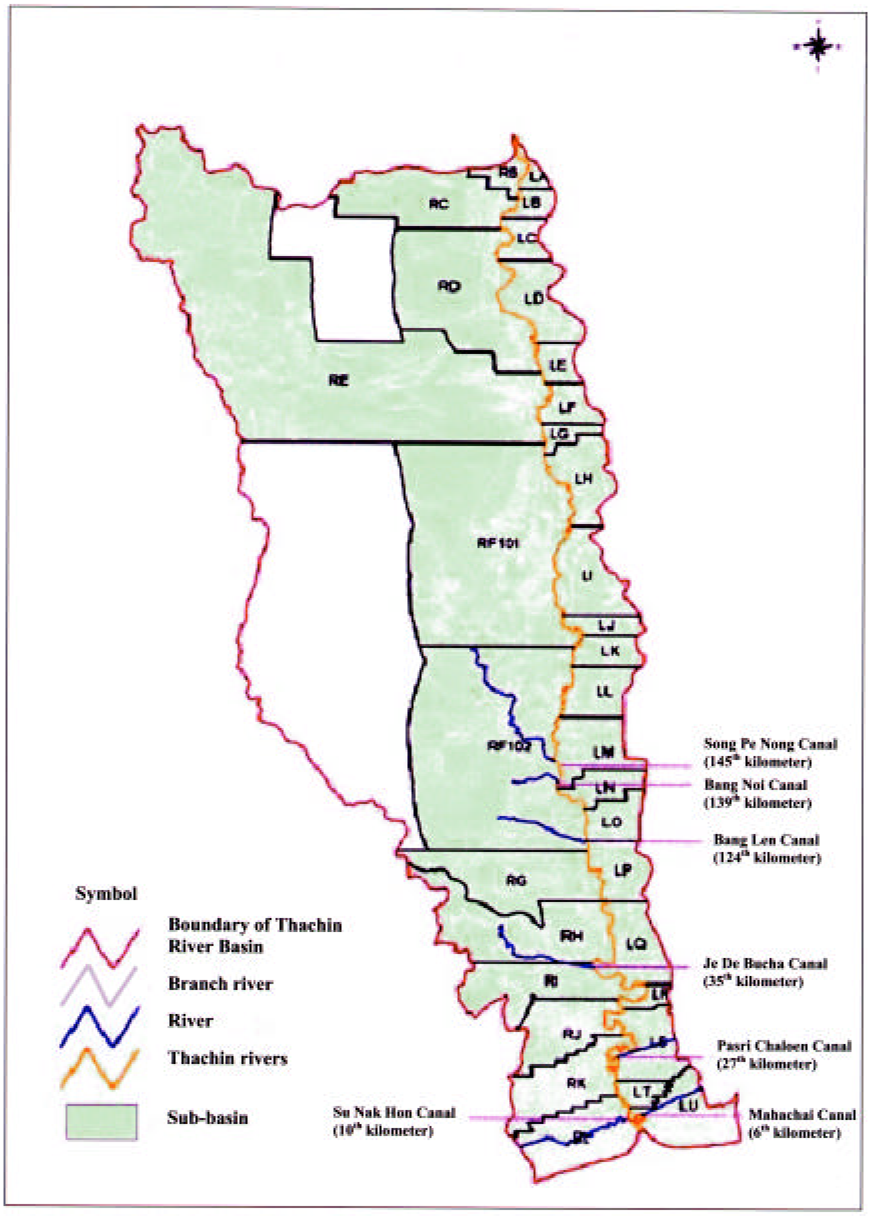

Fig. 2: Sub-basin which has potential to cause water quality deterioration. PCD (2005a)

Thailand's Pollution Control Department (PCD) is responsible for monitoring and collecting wastewater discharge data. Data and information for this study was sourced from the PCD databases.

Total Maximum Daily Loading (TMDL) and Target of emission reduction: A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and non-point sources. The calculation must include a margin of safety to ensure that the water body can be used for the purposes the State has designated. The calculation must also account seasonal variation in water quality (Enviornmental Protection Agency, 2007).

PCD has divided Thachin River into 33 sub-basins which have potential to cause water quality deterioration as shown in Fig. 2. Eighteen sub-basins are identified as generating high Biochemical Oxygen Demand (BOD), details are in Table 1. In this study, BOD is used as a proxy of waste effluent.

Table 1: Percentage of pollution from any sources in each sub basin and target of emission reduction

			Type of pollution sources			
No.	Sub basin	Reduction (%)	Pig form (%)	Aqua culture (%)	Urban community (%)	Industry (%)
1	LI	50.00	12.49	42.47	43.83	1.25
2	RF	85.00	62.27	17.73	14.38	0.62
3	LJ	55.00	0.00	97.30	2.69	1.01
4	LK	55.00	0.00	99.00	0.00	0.00
5	LL	55.00	0.00	99.49	0.51	0.00
6	LM	70.00	0.00	100.00	0.00	0.00
7	Rfm	70.00	14.11	81.08	3.21	1.60
8	LP	60.00	11.20	75.15	7.50	6.15
9	RG	60.00	37.63	58.16	0.64	3.57
10	LQ	95.00	40.19	34.72	24.82	0.27
11	RH	95.00	53.59	3.96	13.92	28.53
12	RI	30.00	13.34	67.99	5.16	13.52
13	LS	25.00	16.16	18.13	21.38	44.32
14	RJ	35.00	3.85	74.51	3.90	17.74
15	RK	25.00	0.25	96.57	2.87	0.32
16	LT	25.00	0.00	0.73	10.00	89.77
17	LU	25.00	0.00	43.81	22.67	33.52
18	RL	25.00	0.03	77.59	2.13	20.26

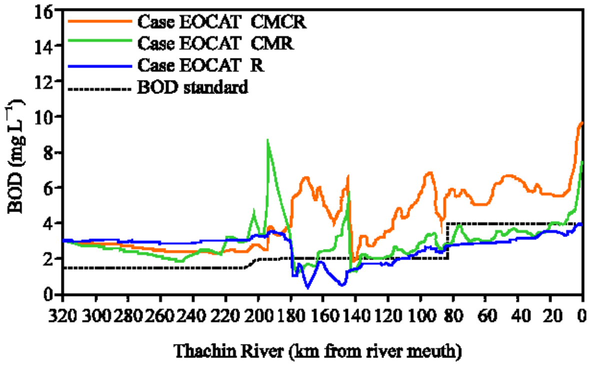

Fig. 3: Simulation of current water quality in Thachin River using BOD loading from each sub-basin. PCD (2005a)

The monitoring of water quality in the Thachin River from the Pollution Control Department (PCD, 2002) found that Thachin River has continuously deteriorating BOD values and dissolved oxygen as pollution indicators. The Thachin River catchment has a BOD higher than the surface water standard which should not exceed 4.0 mg L^{-1} for downstream, 2.0 mg L^{-1} for midstream and 1.5 mg L^{-1} for upstream sections. Correspondingly, the dissolved oxygen is lower than the standard limit 2.0 mg L^{-1} for downstream, 4.0 mg L^{-1} for midstream and 6.0 mg L^{-1} for upstream sections. Figure 3 shows current situation of BOD loading in Thachin River, the simulation start from Kilometers 325th at Chainat province to Kilometers 0th at Samutsakorn province. Three colors lines are substitute for dry season without rain, dry season with rain and rainy season by orange line, green line and blue line, respectively. As Fig. 3 indicates, the orange line shows BOD concentration higher than water qualification standard (dash line) entire the river and green line and blue line in some part of the river. How to deal with this situation, PCD (2005a) explains how the waste effluent reductions are derived for each sub-basin utilizing the Mike 11 water quality model for analysis originating from Hanley *et al.* (1998).

PCD (2005a) found that the problems of water resources have been continuously deteriorated due to the carrying capacity are incapable to receive the load of activities such as agriculture and especially industry. The activities of industry need a load of water which generates the wastewater as well. The wastewater from industry has highly contaminated with organic matter and non-organic matter; however, the control pollution act has been compelled the manufactures treat their waste in the standard compulsory. The controlling emission standard has been considered only the effluent loaded-concentration but unaware of effluent loading lead to the volume of effluent excess than the carrying capacity. The solution of this problem is to control the pollutant sources by limiting the effluent volume to match the carrying capacity. Each of basins has different capacity to receiving the pollutant. From Ministry of Science (1992) appointed to define the effluent standard for the pollutant generators in industrial park.

PCD (2005a) estimate the Total Maximum Daily Loading (TMDL) of BOD effluent allowable without causing unacceptable deterioration in the river ecosystem in each sub-basin.

As Table 1 indicates, each sub-basin has its own reduction target to meet water quality standards. Relative pollution from four major pollution release is detailed as well For example, sub-basin RF has a reduction target at 85.00%, it mean this sub-basin has allowable pollution permit at 15.00%. In this number of all pollution release in RF sub-basin, Pig farm, Aqua culture, Urban community

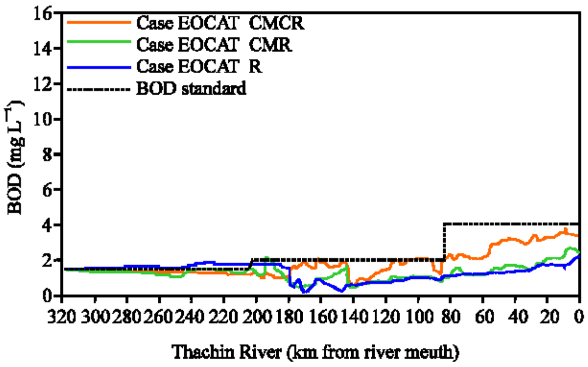

Fig. 4: Simulation of BOD values after reducing BOD loading accord to target of emission reduction. PCD (2005a)

and Industry have percentage of pollution release at 67.27, 17.73, 14.38 and 0.62%, respectively. The simulation of PCD (2005a) shows the water quality of Thachin River after reducing pollution loading accord to target of emission reduction as Fig. 4, it passes the water quality standard and meet total maximum loading of entire the river .

Marginal Abatement Cost (MAC): Klepper and Peterson (2006) and McKitrick (1999) explain the concept of a Marginal Abatement Cost Curve (MAC) is derived from company or plant level models of reducing pollution. This is a straightforward interpretation in production theory. Whereas certain activities in the production process lead to emissions of wastes, marginal abatement cost pertains to either the marginal loss in profits from avoiding the last unit of emissions or the marginal cost of implementation of abatement technologies to reduce waste for each marginal product. Costs associated with implementing abatement technologies are straightforward. Determining losses due to output avoidance or adjustment of a company's output induced by emission constraints requires further consideration. According to Klepper and Peterson (2006), marginal abatement cost curves are the standard tool used to analyze the impacts of the Kyoto Protocol and emissions trading. Other authors have used the MAC approach such as Brechet and Jouvet (2008), Collinge and Bailey (1983), Den Elzen *et al.* (2005), Gallaher *et al.* (2005), Markusen (1997), Misiolek (1980), Murty *et al.* (2006) and Soloveitchik *et al.* (2002).

Non-uniform and uniform tax: The underlying reasoning for the use of Non-uniform tax and Uniform tax policies are detailed in Economic Efficiency and Equity in Water Quality Control (Herzog, 1976).

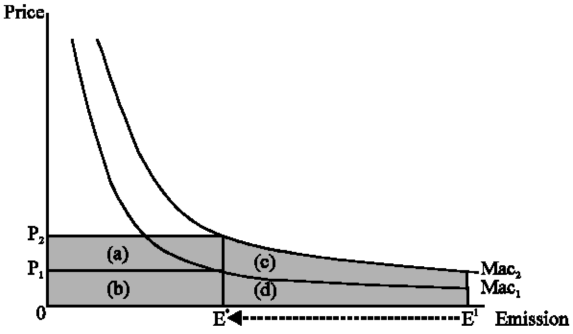

Fig. 5: Non-uniform tax equivalent to CAC

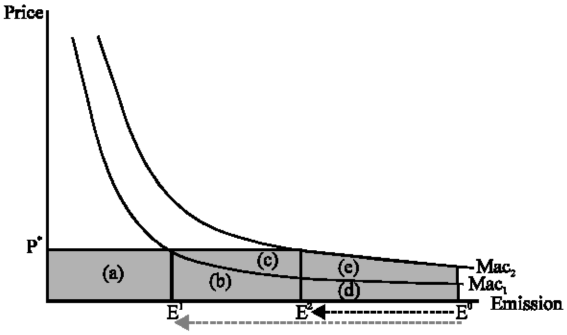

Fig. 6: Uniform tax

If the regulator employs an non-uniform tax policy (Fig. 5), differentiated taxes are applied to each point source in order to control the pollution discharge of all activities. Under this plan, the regulator requires each main point source to reduce their effluent from E^1 to E^*. Main point source 1 has marginal abatement cost function of mac1 and main point source 2 has marginal abatement cost function of mac2. The regulator applies a tax rate for main point source 1 at P1 and applies a tax rate for main point source 2 at P2. The abatement cost of main point source 1 is equal to the area of d and tax expense of main point source 1 is equal to the area of b. The abatement cost of main point source 2 is equal to the area of c + d and tax expense is equal to the area of a +b.

If the regulator adopts a uniform tax policy (Fig. 6), the regulator must determine the maximum allowable the waste effluent levels to achieve acceptable ambient water quality. Under this policy, tax rate is equal to $MAC_1 = MAC_2$. This results in that main point source1 having an abatement cost equal to the area of b + d and a tax expense equal to a while main point source2 having an abatement cost equal to the area e + d and a tax expense is equal to a + b + c.

Within each sub-basin, the uniform tax policy achieves the same degree of improvement of ambient water quality as the non-uniform tax policy. While the non-uniform tax policy uses differentiated pricing to induce the same level of reductions for each emitter, the uniform tax policy uses a single tariff to induce differentiated emission reductions for each emitter dictated by their unique marginal abatement curves. Generally, sub-basins with higher levels of waste effluents due to higher amount of economic activity are forced to make greater abatements on aggregate.

Callan and Thomas (1996) and Moffatt *et al.* (1991) concludes the point where $MAC_1 = MAC_2 =$ Emission Charge represents the least-cost allocation of abatement responsibilities across the two polluters and satisfies the equi-marginal principle of optimality.

THE MODEL

Mathematical Decision-Making model: This model is created for simulate the effect of tax enforcing to the four main point sources activities by the objective function representing the maximization of system profits is:

$$\text{Maximize} \prod_{j=1}^{N} = \prod_{pj} + \prod_{uj} + \prod_{aj} + \prod_{ij} \qquad (1)$$

where, $\prod_{j=1}^{N}$ is the system profit in sub-basin. Π_{pj} is the system profit of aggregate pig farm activities in sub-basin j with internalized social costs including any associated abatement costs as shown in Eq. 6. In the same manner, Π_{uj} is the system profit of the aggregate urban community's activities within sub-basin j. Π_{aj} is the system profit from aggregate aquaculture activities within sub-basin j. Π_{ij} is the system profit from aggregate industrial activities within sub-basin j.

Sub-basin pollution function: The objective function is subject to sub-basin pollution function:

$$E_j = \sum_{k=1}^{N} E_{pjk} + \sum_{k=1}^{N} E_{ujk} + \sum_{k=1}^{N} E_{ajk} + \sum_{k=1}^{N} E_{ijk} \qquad (2)$$

where, $\sum_{k=1}^{N} E_{pjk}$ E_j is the pollution loading of the aggregate effluent in sub-basin j. is the sum of pollution loading of aggregate pig farm effluent in sub-basin j. $\sum_{k=1}^{N} E_{ujk}$ is the sum of pollution loading of aggregate urban communities effluent in sub-basin j. $\sum_{k=1}^{N} E_{ajk}$ is the sum of pollution loading of aggregate aquaculture based effluent in sub-basin j. $\sum_{k=1}^{N} E_{ijk}$ is the sum of pollution loading of aggregate industrial effluent in sub-basin j.

Sub-basin pollution constraint: A fundamental requirement for effective pollution control is assurance that pollution loading throughout the river system conforms to environmental regulations and is prohibited from exceeding specified standards. Control points and discharge locations are constraints in the mathematical model. The typical framework for the water quality constraint is as follows (Hanley *et al.*, 1997):

$$A_j = E_j + \gamma A_{j-1} \qquad (3)$$

and

$$A_j^* \geq A_j \qquad (4)$$

The general form for Eq. 3 and 4 are derived from Hanley *et al.* (1997) and the transfer coefficients are explained in further detail in Hass (1970) and Streeter and Phelps (1958). Other relevant research includes the Brown and Mar (1968) study on the effect of water quality management on dynamic economic efficiency, the Upton (1970) study on uncertainty and the Herzog (1976) study on effluent taxes and information requirements.

A_j is the total pollution loading in sub-basin j. E_j is the pollution loading from aggregated effluents in sub-basin j, γ (transfer coefficient) is the residual pollution loading of sub-basin j-1 affected by pollution loading of sub-basin j, A_{j-1} is the total pollution loading of aggregated effluents in sub-basin j-1. A_j* is the regulated ambient water standard which classifies the maximum allowable daily pollution loading in sub-basin j.

Production benefit constraint: These constraints determine the profit potential for each production type. The production process is subject to capital, variable and abatement costs. Introduction of an appropriately administered tax scheme is an additional cost burden that should not trigger wide scale business failures. When production exceeds the break-even point of production, obtaining a profit is achievable. Thus, the profit constraint of each industry is specified as:

$$\pi > 0 \qquad (5)$$

π is a benefit in this model.

Production function: In general, the net benefit from the production function is defined by the profit derived from production sales minus the cost of abatement and tax expense:

$$\Pi_j = \sum_{k=1}^{N} PQ_{jk} - \sum_{k=1}^{N} ABC_{jk} - T_{jk}\sum_{k=1}^{N} E_{jk} \tag{6}$$

where, Π_j is the system profit of each type of production in sub-basin j. $\sum_{k=1}^{N} PQ_{jk}$ is the sum of each main point source per unit profit multiplied by the quantity of production at source k in sub-basin j. (note: The calculated value of P it is variety on the characteristics of Q_{jk} in each type of main point source as shown in appendix A). is the sum of abatement cost of each main point source in sub-basin j. $\sum_{k=1}^{N} ABC_{jk}$ the tax levy of each main point source in sub-basin j multiplied by the aggregate amount of pollution loading from effluent at each main point source in sub-basin j.

Abatement cost function (Mehta *et al*., 1997):

$$ABC_{jk} = e^{a} F_{jk}^{b} I_{jk}^{c} E_{jk}^{d} \tag{7}$$

where, ABC_{jk} is the abatement cost function of each type of main point source in sub-basin j. e = natural logarithm. F_{jk} is total volume of wastewater at each type of main point source in sub-basin j. I_{jk} is the pollution loading of the influent at each type of main point source in sub-basin j. E_{jk} is the pollution loading of the effluent at each type of main point source in sub-basin j. a, b, c and d are coefficient parameters at that main point source.

Volume of wastewater per production unit:

$$F_{jk} = \alpha Q_{jk} \tag{8}$$

where, F_{jk} is the volume of wastewater at each main point source in sub-basin j. α is the volume of wastewater generated per unit production at each main point source.(note: magnitude of α it is variety on the characteristics of Q_{kj} at each type of main point source as shown in appendix A) Q_{jk} is the quantity of production at each main point source in sub-basin j.

Influent pollution loading:

$$I_{jk} = \beta Q_{jk} \tag{9}$$

where, I_{jk} is the pollution loading in the effluent at each main point source in sub-basin j. β is the amount of pollution released in each production type. (note: magnitude of β it is variety on the characteristics of Q_{jk} as shown in Appendix A). Q_{jk} is the quantity of production at each main point source in sub-basin j.

Pollution constraint:

$$\text{Case 1: } \sum_{k=1}^{N} E_{jk} \le \bar{E}_{jk} \tag{10}$$

where, E_{jk} represents the pollution loading of the effluent at each type of main point source in sub-basin j. $\bar{E}_j$ (note: it is target of emission reduction by PCD as shown in Table 1) is the required water classification standard at each type main point source in sub-basin 'j' or permitted pollution loading at each type main point source in sub-basin j.

In order to find tax which equivalence to CAC, Eq. 10 have to put in the model for simulate that tax.

In summary, after applying the above stated functions to all main point sources, then the model of each sub-basin can be expressed as shown in Appendix B

METHOD

Calculated tax rate equivalent to command and control approach (non-uniform tax): In order to reduce the ambient water quality in each sub-basin meets the target of emission reduction in Table 1. Tax system is one of method to simulate this situation. This step is action to find out the tax rate which equivalence to that target.

E-view is used to perform a regression on Eq. 7 for each main point source along the entire Thachin River. The regression reveals the coefficient set for the abatement cost equation for each type of main point source. The set of coefficients relevant to abatement costs are derived as demonstrated in Eq. 7. These figures are used to estimate the marginal abatement cost function by substituting the coefficients. With an estimate of the marginal abatement cost function, applying a partial derivative reveals the cost of abatement E.

A spreadsheet is constructed in Microsoft Excel that combines the estimated marginal abatement cost function, substituted coefficients and separate F, I and E parameters in Eq. 7 per individual sub-basin for each type of main point sources. A calculation sheet is created in order to find the tax variation of each main activity within each sub-basin by incorporating the data of each parameter into the Eq. 13.

Take log to Eq. 7:

$$LnC = a + bLnF + cLnI + dLnE \tag{11}$$

$$\frac{d}{dE}C = e^{a}F^{b}I^{c}(-d)E^{d-1} \tag{12}$$

$$\text{Tax} = \text{MC} = e^{a}F^{b}I^{c}(-d)E^{d-1} \tag{13}$$

The derivative of abatement cost is equal to the marginal abatement costs as well as equal to the tax rates as shown in the figure above.

Applying Mathematical Decision-making model to two Scenarios: The analysis explores 2 scenarios: (1) first scenario use non-uniform tax for each type of main point source in each sub-basin and (2) second scenario applies a uniform tax to main point sources in across each sub-basin in aggregate.

The scope of the problem for each scenario is as follows. Case 1 Non-Uniform Tax: The government forces the polluter to reduce their effluent by imposing Non-Uniform tax rates at each type of main point source within each sub-basin (Profit maximization). Excel Solver is used to investigate a) Ambient water pollution of each sub-basin b) Profit of each type of production in each sub-basin and c) Abatement costs and tax expenses. Case 2: Uniform Tax: The government set the minimum effluent tax which brings sub-basin emissions inline with total maximum loading and water quality standard of each sub-basin (Profit maximization). Excel Solver is used to investigate (1) Uniform Tax (2) Ambient water pollution in each sub-basin (3) Profit of each type of production in each sub-basin (4) Abatement costs and tax expenses.

Excel solver: Microsoft's Excel Solver tool can be applied to solve optimization problems. Walsh and Diamond (1995) demonstrates the suitability of using excel solver for the purpose of non-linear curve fitting: An analysis tool has been evaluated for solving non-linear equations. Test and experimental data sets have been processed and the results suggest that solver can be successfully used for modeling data obtained in many analytical situations. In addition, complete control of the modeling process lies with the user, who must present the raw data and enter the equation of the model, in contrast to many commercial packages bundled with instruments which perform these operations with a black-box approach. The practice of using Excel solver has gained more acceptability with its use in other studies such as Abdel-Malek and Areeratchakul (2007), Benli and Kodal (2003), Berman and Cutler (2004), Brown (2001, 2006), Cetin and Esen (2006), Hariga and Al-Fawzan (2005), Kuo *et al.* (2003), Paredes *et al.* (2001), Ravikumar *et al.* (2007) and De Reyck and Degraeve (2006).

In this study, excel solver is used to derive the values of certain cells in the spreadsheet while optimizing specific parameters. Target is set to maximize the value of system profit in each sub-basin. Next, the emission release cells are subject to manipulation by Excel Solver to reveal the effect of tax charges on the volume of pollution emitted by each main point source. The results of the target and change-cells are limited by the constraints that are set in the model.

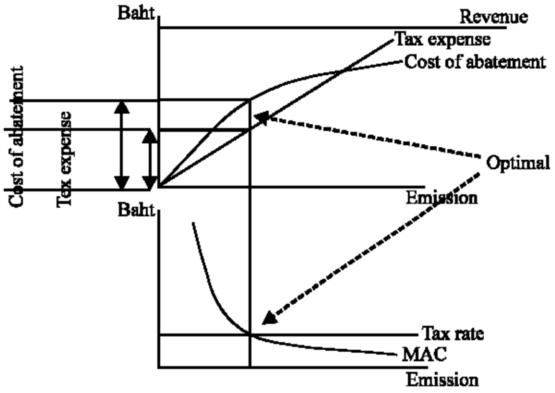

Fig. 7: Evaluation of tax expense between Non-uniform and Uniform tax in each sub-basin

How the optimization mathematical decision-making model works with excel solver: Case 1, Non-Uniform Tax: The objective is to maximize net benefits involving 'E' for abatement costs (Eq. 7) and Tax Expense (TE). Follow Fig. 7, after reducing 'E' for one unit, Tax expenses decreases T Baht and abatement cost increases marginally MAC Baht. Therefore, whenever reducing E and T Baht is greater than MAC Baht, the model will continue decreasing E until the marginal unit of 'E' makes value of MAC>T. According to the model, Main Point Sources will stop reducing E when point T = MAC then profit is maximized.

Case 2, Uniform Tax: The objective is to apply a single tax rate where MAC values in every activity are equal and profits maximized. The same manner with Fig. 7, where, T = MAC. Thus, the Uniform Tax is equal to $MAC_1 = MAC_2 = MAC_3 = MAC_4$ and aggregate waste loading limited to a predetermined level. With these specifications in mind, the analysis will reveal the minimum tax rate to achieve this objective.

RESULTS AND DISCUSSION

The effect of the effluent charge: Figure 8 indicates that, in the RI, LS, RJ, LU and RL sub-basins, abatement costs associated with the non-uniform and uniform tax schemes vary greatly. Some firms possess characteristics such as significantly higher marginal abatement costs at all levels of production that prohibits engagement in abatements as well as exposes the firm's full production to tax expenses.

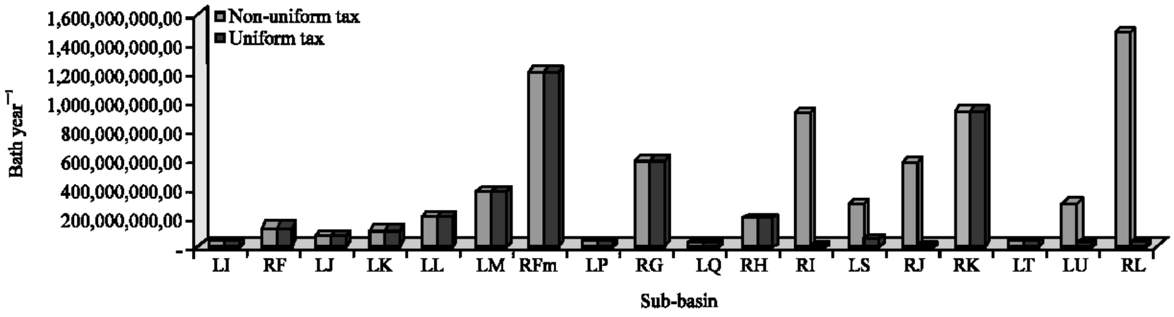

Fig. 8: Evaluation of cost of abatement between non-uniform and uniform tax in each sub-basin

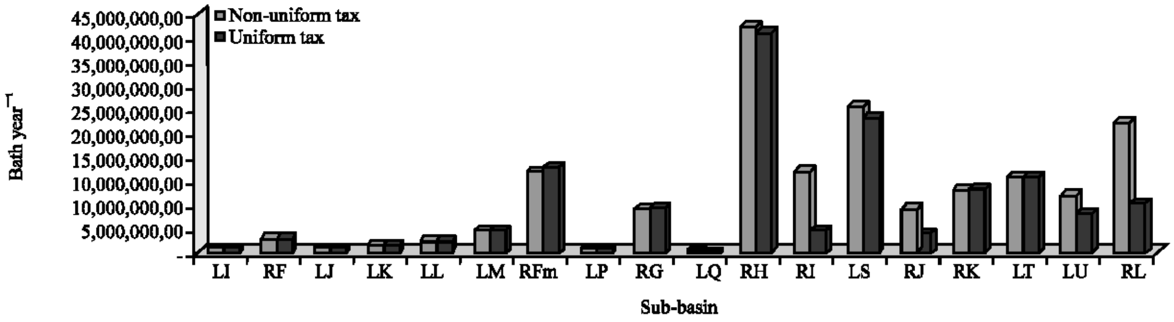

Fig. 9: Evaluation of tax expense between non-uniform and uniform tax in each sub-basin

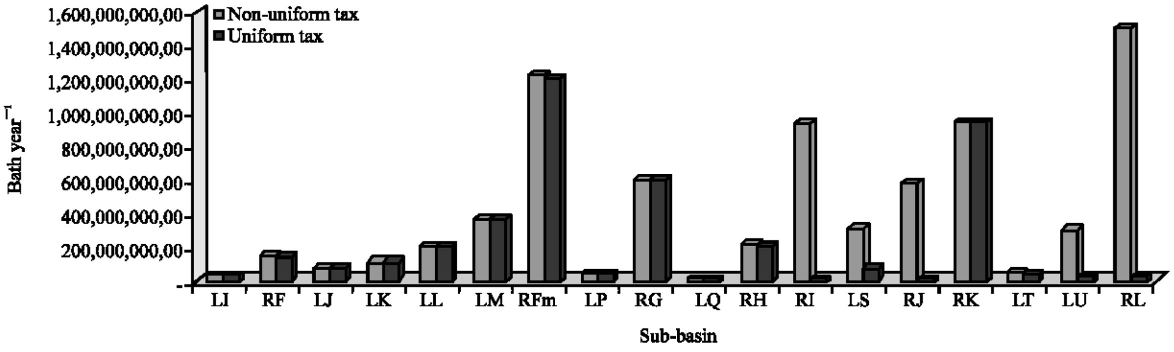

Fig. 10: Evaluation of total expense between non-uniform and uniform tax in each sub-basin

Figure 9 shows that, compliance expenditures in sub-basins RI, LS, RJ, LU and RL are entirely allocated towards tax levies under the uniform tax scheme. In sub-basin RI and RJ, aggregate tax expense is significantly lower under the uniform tax

Total expenses are lower with the uniform tax scheme than with the non-uniform tax scheme in every sub-basin as shown in Fig. 10. The greatest disparities occur in the RI, LS, RJ, LU and RL sub-basins due to the inherent efficiency of uniform tax schemes. Based on the analysis of tax expense and cost of abatement, some sub-basins have highly differentiated net profits under the two schemes.

Total pollution control cost is negligible when compared to revenue figures (Fig. 11). For practical purposes, conforming to environmental regulations under either scheme should not present an undue burden to the present activities in the region.

There is an abundance of literature on the effects of effluent charges which have been introduced in many countries. Indab *et al*. (2003), support our research, studied effluent charges in Sarangani Bay, Philippines concluding the existing effluent charge scheme is under CAC fails to adequately reduce water pollution. Their recommendation is to apply a new effluent charge scheme achieving a 92% greater reduction in pollution

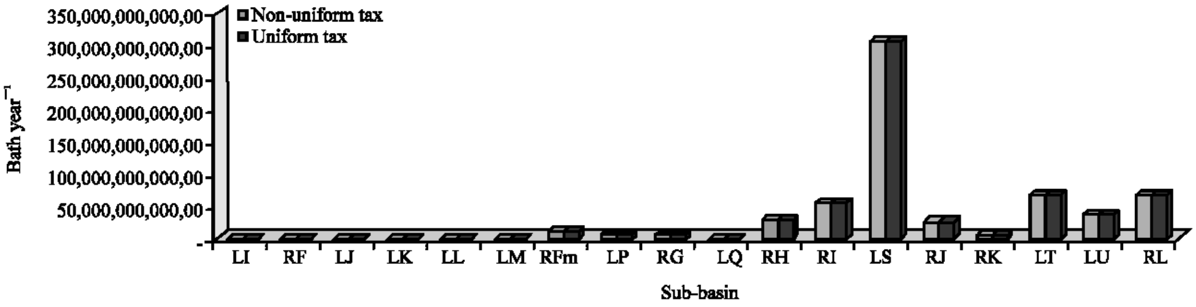

Fig. 11: Evaluation of net profit between non-uniform and uniform tax in each sub-basin

accompanied with a 23% increase in total abatement costs. Present study employs a uniform tax scheme as a management tool for protecting and maintaining water quality while possessing a total abatement cost to non-uniform tax schemes. Dasgupta *et al.* (1996) conducted a study in China that concluded its current policy provides an economic incentive to abate by charging a levy on pollution in excess of regulatory standards. However, the results of the study suggest that changing to a full emissions charge system would significantly reduce overall abatement costs. Uniform pollution charges would likely improve environmental quality. If China adopts an emissions charge policy, it would be appropriate to give local regulators the authority to adapt levies according to local circumstances. Our study assesses the suitability of uniform tax policies as a viable charge system. At the same way, their study concluded that a uniform tax policy is the most suitable effluent charge scheme. Corrigan (2009) has studied about the Relative Effectiveness of Emissions Taxes and Tradable Permits. A system of uniform command-and-control regulation, a tradable emissions permit framework and an emissions tax was set. The results of its also follows our research as well, it concludes that tax would yield the highest rate in net benefit and the lowest rate in dead weight loss among these systems.

However, some researchers have the contradiction of our research. A good example can be found in Peretto (2008) that illustrates the effects of effluent taxes on firms' allocations of resources to cost and emissions reductions. In terms of environmental benefits, taxes are able to induce a positive rate of pollution abatement capable of offsetting the dirty side of economic growth. A tax set at an endogenous rate and held at a constant tax burden per unit of output results in an increased cost per unit of output which decreases firms' marginal revenues and/or increases prices the of their products. . In the study of Stavins (2002) mentioned about reasons of water effluent charges ineffective: (1) legislated charges have been significantly eroded by the high inflation that has accompanied economic transition; (2) charges typically have been set below marginal abatement costs (Morris *et al.*, 1997; Stepanek, 1997; Ylicz, 1996); (3) pollution limits-the point above which emissions are charged at a penalty rate-are typically set too high to influence firm behavior (Brunenieks *et al.*, 1997); (4) tax rates are often the result of implicit or explicit negotiation between industries and state or regional governments (Gornaja *et al.*, 1997; Kozeltsev and Markandya, 1997); (5) many countries set upper bounds on pollution charge liabilities; (6) unprofitable enterprises are often exempted (Kozeltsev and Markandya, 1997; Owen *et al.*, 1997) and (7) regulatory systems are insufficient to support adequate monitoring and enforcement (Bluffstone and Larson, 1997; Gornaja *et al.*, 1997; Kozeltsev and Markandya, 1997; Morris *et al.*, 1997)

Evaluation of non-uniform tax and uniform tax: In this model, E consists of two parts: Tax and Cost of abatement. When effluents (E) decrease 1 unit, tax expense decreases by t baht and cost of abatement increases MAC baht. Polluters are induced to reduce effluents for the proportion tax expense t baht exceeds marginal abatement costs MAC. Emission reductions cease when MAC is equal to or exceeds t. Non-uniform tax policies use differentiated pricing, where $Tax_i = MC_i$, to reduce emissions resulting in no intra-sub-basin competition. Uniform tax policies set a per sub-basin, optimized $Tax_t = MC_i$. Under these conditions, polluters are simultaneously induced to adjust emissions with the initial activities occurring with polluters with the lowest MAC.

CONCLUSION

According to Table 2, utilizing a uniform rather than a non-uniform policy results in an estimated 1,344,399.32 Kg-BOD/year of additional effluent with compliance to environmental regulations. Utilizing a uniform rather than non-uniform tax policy results in an estimated savings of

Table 2: Differentiation of non-uniform tax and uniform tax to thachin river

	Type of regulation		
Measurement	Command and control non-uniform tax	Market based tax incentive uniform	Difference
Effluent (kg body year^{-1})	171,933,645.26	173,274,193.21	-1,340,547.95
Reduction (Active)(%)	38.10%	37.62%	0.48%
Cost of abatement (Baht year^{-1})	7,579,208,523.25	4,098,278,631.53	3,480,929,891.71
Tax expense (Baht year^{-1})	192,982,306.15	156,413,160.39	36,569,145.76
Total expense (Baht year^{-1})	7,772,190,829.39	4,254,691,791.92	3,517,499,037.47
Net profit (Baht year^{-1})	629,922,818,608.04	633,440,317,645.51	3,517,499,037.47
Cost saving of	100%	54.74%	45.26%

3,480,944,681.53 baht per year in aggregate cost of abatement, an estimated savings of 3,517,515,764.60 baht per year in total expenses and an estimated 3,518,058,488.41 baht per year in additional aggregate net profits.

In conclusion, non-uniform and uniform tax policies are capable of efficiently reducing wastewater emissions in the Thachin River while complying with environmental regulations. From an economic perspective, applying a uniform tax policy is found to be more efficient with an estimated 45.25% savings in total expense and results in differentiated marginal damage cost for main point sources.

ACKNOWLEDGMENT

Author is thankful to Asst. Prof. Dr. Charit Tingsabadh and Assoc. Prof. Dr. Nantana Gajaseni for their supervision to this research work.

APPENDIX A

Characteristics of each type of four point sources: There are four significant point sources in this study. This section explains how to gather the data relating to costs and estimating economics.

First, obtain the current BOD results, and compare the total maximum daily loading with the water classification standard. Then the BOD has to be reduced to meet Total maximum daily loading, this reduction of volume is called the emission reduction target.

The emission reduction target will be used with the marginal abatement cost curve in order to find the tax variation in each type of four point sources in each sub-basin.

Pig farm: Data from the PCD report Development and Technology of Wastewater Management where parameters comprise the cost of abatement in any type of pig farm, i.e., price of 100 kg of pig unit and variable cost (Table A1, A-2).

Urban communities: The Ministry of Natural Resources and Environmental declaration issued in 2/2546 has stipulates that every household in each community have to pay a wastewater treatment charge. Thus, treatment charge rates from the Ministry of Natural Resources and Environment are used in the Table A-3 to A-5.

The urban community revenue comes from budget per capita. Parameter (P) is derived from public service budget. Social development is supported by the provincial government and can be divided by the provincial population. The quantity (Q) is derived from the population in each sub-district. The revenue of urban community in each sub-basin is derived from (P) multiply by (Q). (P)and (Q) of each province are shown in the Table A-6 below.

Aqua culture: Most of the economic data are from the Development of Effluent Treatment Management for Aquaculture projects, PCD (2005a). The abatement cost for aquaculture can be divided into 2 groups. All fish farms treatment methods refer to the use Aerated Lagoons with Constructed wetlands. All prawn farms treatment methods refer constructed wetlands. The details of expenses are shown in the Table A-7 to A-9.

Industry: There are 44 types of factory along the Thachin river giving a total of 8,160 factories. In arriving at the abatement cost, we investigated the wastewater treatment processing systems of each factory from the Department of Industry. The expense for each processing referred to the average expense was obtained from the research of The Standard of Wastewater Treatment Charge.

Revenue section, the net profit per ton of whole industrial type, referred to table 202 of I/O model (Office of the National Economic and Social Development Board), divided by the Quantity of National Production (tons) (information comes from the Ministry of Industry). The profits per production (ton) of each manufacturing type multiplied by Q (number of manufacturers of each type in each sub-basin). Finally, the revenue per unit of each type in each sub-basin are shown in the Table A-10 to A-11.

Table A-1: Transaction cost of pig farm waste water treatment in each size

Detail	Small biogas (Digester+FP[b]+MP[c])	Medium biogas (Carmatec digester+FP[b]+MP[c])	Large biogas (UASB[a]+FP[a]+MP[c])
Volume of wastewater (cubic-meter/day)	10.00	30.00	50.00
Area of wastewater treatment system (square meter)	100.00	1,750.00	2,000.00
Land price (Baht)	-	-	-
Construction cost (Baht)			
Civil structure (a)	54,000.00	367,000.00	760,000.00
Machinery equipment (b)	-	-	-
Electricity system and piping (c)	2,000.00	10,000.00	60,000.00
Preliminary cost	56,000.00	377,000.00	820,000.00
Safety factor 20%	11,200.00	75,400.00	164,000.00
Transaction cost 10%	6,720.00	45,240.00	98,400.00
Total construction cost	73,920.00	497,640.00	1,082,400.00
Construction cost (Baht/cubic-meter)	2.03	4.54	5.93
Construction cost (Baht/unit)	5.23	8.79	7.65
Operating and Maintenance cost (Baht year^{-1})			
Maintenance	2,500.00	5,705.00	12,600.00
Electricity system and piping (c)	-	-	-
Chemical (lime)	-	-	-
Officer	1,200.00	2,500.00	40,000.00
Total operating and maintenance	3,700.00	8,205.00	52,600.00
Operating and Maintenance cost(Baht/cubic-meter)	1.01	0.75	2.88
Operating and Maintenance cost(Baht/unit)	2.62	1.45	3.72
Total cost (Baht unit^{-1})	7.84	10.24	11.37

[a]Upflow Anaerobic Sludge Blanket, [b]Facultative Pond, [c]Maturation Pond. Source: PCD (2003a)

Table A-2: Cost and revenue of pig farm production

			Total cost			
BE	Variable cost	Fixed cost	Baht/unit	Baht kg^{-1}	Price Baht kg^{-1}	Revenue Baht kg^{-1}
2527	2,242.63	52.81	2,295.44	22.95	21.74	(1.21)
2528	1,707.58	81.86	1,789.44	17.89	17.00	(0.89)
2529	1,575.63	56.51	1,632.14	16.32	19.15	2.83
2530	1,927.56	57.28	1,984.84	19.85	22.11	2.26
2531	2,246.60	70.67	2,317.27	23.17	25.96	2.79
2532	2,367.41	79.08	2,446.49	24.46	28.17	3.71
2533	2,261.67	83.84	2,345.51	23.46	24.92	1.46
2534	2,238.12	74.34	2,312.46	23.12	30.00	6.88
2535	2,658.15	73.34	2,731.49	27.31	31.31	4.00
2536	2,301.19	62.69	2,363.88	23.64	23.75	0.11
2537	2,202.44	64.68	2,267.12	22.67	26.70	4.03
2538	2,849.18	67.12	2,916.30	29.16	35.21	6.05
2539	3,237.73	70.17	3,307.90	33.08	40.57	7.49
2540	3,529.66	78.28	3,607.94	36.08	39.07	2.99
2541	3,497.55	80.74	3,577.62	35.78	41.65	5.87

Source: PCD (2003a)

Table A-3: Evaluated operating cost of stabilization pond in each local government

		Current volume of wastewater treatment				
No.	Municipality	(m^3 day^{-1})	(m^3 year^{-1})	Operating and Maintenance cost (Million Baht year^{-1})	Current operating cost (Baht m^{-3})	Evaluated operating cost (Baht m^{-3})
1	District U-thong, Suphanburi province	3,500	1.28	0.39	0.31	0.40
2	Mueng Rajburi	17,000	6.21	2.19	0.35	0.46
3	Varin-chumrab, ubomratchathani province	2,896	1.06	0.40	0.38	0.49
4	Mueng Chanthaburi	5,000	1.83	0.86	0.47	0.61
5	City municipal of Nakorn prathom province	15,000	5.48	2.80	0.51	0.66
6	City municipal of Nakornratchasrima province	50,884	18.57	9.79	0.53	0.69
7	Mueng Kumpaeng-phet	2,500	0.91	0.60	0.66	0.85
8	Mueng Baan-mee	600	0.22	0.15	0.68	0.89
9	Mueng Chainat	2,500	0.91	0.70	0.77	1.00
10	Mueng Tak	2,903	1.06	0.83	0.78	1.02
11	Mueng Panus-nikom	2,000	0.73	0.65	0.89	1.16
12	Mueng Hat yai	50,000	18.25	17.52	0.96	1.25
13	District Tha-Raae, Sakolnakorn province	958	0.35	0.34	0.97	1.26
14	Mueng Suphanburi	2,000	0.73	0.80	1.10	1.42
15	Mueng Payao	3,598	1.31	1.86	1.42	1.84
16	Mueng Sakolnakorn	7,295	2.66	3.84	1.44	1.87

Table A-3: Continued

		Current volume of wastewater treatment				
No.	Municipality	(m^3 day^{-1})	(m^3 year^{-1})	Operating and Maintenance cost (Million Baht year^{-1})	Current operating cost (Baht m^{-3})	Evaluated operating cost (Baht m^{-3})
17	Mueng Nan	1,400	0.51	0.81	1.59	2.06
18	District Pakchong	2,000	0.73	1.25	1.71	2.23
19	District Huakwang, Mahasarakham province	600	0.22	0.51	2.33	3.03
20	Mueng Phetburi	3,500	1.28	3.55	2.78	3.61

Source: PCD (2003b). Remark: Other municipals in each province referred to the regulation of Municipality of Amphoe Mueng

Table A-4: Evaluated operating cost of aerated lagoon in each local government

		Current volume of wastewater treatment				
No.	Municipality	(m^3 day^{-1})	(m^3 year^{-1})	Operating and Maintenance cost (Million Baht year^{-1})	Current operating cost (Baht m^{-3})	Evaluated operating cost (Baht m^{-3})
1	Mueng Nondhaburi	20,000	7.30	7.93	1.09	1.41
2	Mueng Pattaya(wat bun)	5,500	2.01	2.57	1.28	1.66
3	Mueng Pa-tong	6,500	2.37	3.15	1.33	1.73
4	District pra-in racha, Ayuthaya province	1,900	0.69	0.96	1.38	1.80
5	Mueng Laem chabang	1,450	0.53	0.78	1.47	1.92
6	Mueng Pattaya(Na kluea)	50,000	18.25	28.44	1.56	2.03
7	Mueng Phuket	20,443	7.46	12.00	1.61	2.09
8	Meung Kanchanaburi	12000	4.38	8.20	1.87	2.43
9	Mueng Chacheungsao	3,000	1.10	2.11	1.93	2.51
10	Provincial local government, Chonburi	10,315	3.76	7.69	2.04	2.66
11	District Baan paae	941	0.34	0.72	2.10	2.73
12	Mueng Saensuk north-west	17,131	6.25	16.00	2.56	3.33
13	Mueng Potharam	2500	0.91	2.60	5.85	3.70
14	City Pranakorn Sriayuthaya	1,500	0.55	2.00	3.65	4.75

Source: PCD (2003b). Remark: Other municipals in each province referred to the regulation of Municipality of Amphoe Mueng

Table A-5: Evaluated operating cost of activated sludge in each local government

		Current volume of wastewater treatment				
No.	Municipality	(m^3 day^{-1})	(m^3 year^{-1})	Operating and Maintenance cost (Million Baht year^{-1})	Current operating cost (Baht m^{-3})	Evaluated operating cost (Baht m^{-3})
1	City Trang	6,500	2.37	1.63	0.69	89.00
2	Mueng Burirum	6,500	2.37	2.02	0.85	1.11
3	City Ubon Ratchathani	5,500	2.01	2.92	1.45	1.89
4	District Cha-am, Phetburi province	2,306	0.84	1.54	1.83	2.38
5	City Songkha	5,000	1.83	3.60	1.97	2.56
6	Mueng Prachuabkhirikhun	2,480	0.91	1.91	2.11	2.74
7	City Chieng mai	15,000	5.48	14.37	2.62	3.41

Source: PCD (2003b). Remark: Other municipals in each province referred to the regulation of Municipality of Amphoe Mueng

Table A-6: Total provincial budget of public service, social development and budget per capita, and Current operating abatement cost of each province

	Provincial budget for					
Province	Public service (Baht)	Social development (Baht)	Total (Baht)	No. of people	Budget per capita (Baht)	Current operating cost (Baht m^{-3})
Samuth sakorn	73,453,068.00	18,029,153.00	91,482,221.00	449,090.00	203.71	1.09
Suphunburi	190,698,415.00	8,683,323.00	199,381,738.00	868,681.00	229.52	1.10
Chai nat	75,415,999.00	3,596,661.00	79,012,660.00	339,032.00	233.05	0.77
Kanchanaburi	194,293,494.00	1,337,492.00	195,630,986.00	826,169.00	236.79	1.87
Uthaithani	92,063,538.00	270,831.00	92,334,369.00	326,882.00	282.47	0.77
Nakornprathom	169,141,324.00	11,062,003.00	180,203,327.00	798,016.00	225.81	0.51

Source: Bureau of the Budget (2006) and PCD (2003b)

Table A-7: Abatement cost of each type of aqua culture

Details	Fish	Prawn
Volume of wastewater (cubic meter/rai-year)	16,432.00	3,307.20
Aerated Lagoon + constructed wetland		
Abatement cost (Baht/rai-year)	72,210.00	-
Abatement cost (Baht/cubic meter)	4.39	-
Constructed wetland		
Abatement cost (Baht/rai- year)	-	16,000.00
Abatement cost (Baht/cubic meter)	-	4.84

Source: PCD (2005b)

Table A-8: Operation cost of each type of aquaculture

Detail	Cost (Baht/rai/year)
Operation cost	
Snake-head fish feeding cost	989,250
Nile tilapia feeding cost	5,500
Cat fish feeding cost	116,792
Giant freshwater prawn	38,500

Source: PCD (2005b)

Table A-9: Revenue of each type of aqua culture

Detail	Price (Baht kg^{-1})	Quantity (kg rai^{-1})	Revenue (Baht rai^{-1} year)
Benefit			
Sales of snake-head fish	60.00	21,150.00	1,269,000.00
Sales of nile tilapia fish	20.00	800.00	16,000.00
Sales of cat fish	25.00	6,742.00	168,550.00
Sales of giant freshwater prawn	250.00	-	51,708.00

Source: PCD (2005b)

Table A-10: Revenue and cost of abatement for each industrial activity

No.	Types of industry	Industrial activity	Revenue per ton thousand Baht	Wastewater technology	Cost of abatement Baht m^3 day
1	4(1)	Slaughtering	44.86	Sump area	0.29
	4(2)	The preservation of meat by toast, smoke-dried, pickled, sun-dried and sharply freezing method	44.86	Activated sludge	3.10
	4(3)	Processed food products from animal meat, fat, hide and grease or born extract	44.86	Septic tank	0.00
2	5(5)	Processed cheese and butter	23.33	RBC[a]	1.62
	5(6)	Processed yogurt	23.33	Activated aludge	3.10
3	6(1)	Processed aquatic animal food and canning	62.56	Aerated lagoon	1.49
	6(2)	The preservation of aquatic animal by toast, smoke-dried, pickled, sun-dried and sharply freezing method	62.56	Aerated lagoon	1.49
	6(3)	Processed food product from aquatic animal and hide or fat of aquatic animal	62.56	Activated sludge	3.10
	6(5)	Sliced, boiled, steamed, fired, and grinded (fish) aquatic animal	62.56	Activated sludge	3.10
4	7(1)	The extraction of vegetable and animal oils and fats	7.70	Sump area	0.29
	7(4)	Processed pure vegetable and animals oils and fats	7.70	Activated sludge	3.10
5	8(1)	Canning of fruit and vegetables	21.45	Sump area	0.29
	8(2)	Preserving of fruit and vegetables	21.45	Sump area	0.29
6	9(2)	Processed starch	3.74	Stabilization pond	0.00
	9(4)	Grain mill products manufacturing	3.74	Sump area	0.29
7	10(1)	Processed bakeries	48.94	Septic tank	0.00
	10(2)	Processed biscuits	48.94	Septic tank	0.00
	10(3)	Baked and steamed products manufacturing	48.94	Sump area	0.29
8	11(2)	Processed sugar refineries	5.21	Sump area	0.29
	11(6)	Processed glucose, dextrose, fructose and similarly other products	5.21	Activated sludge	3.10
9	12(9)	Processed chewing gum	23.33	Activated sludge	3.10
	12(11)	Processed ice-cream	23.33	Septic tank	0.00
10	13(2)	Processed additive	-	Sump area	0.29
	13(3)	Processed powder-yeast	-	Sump area	0.29
11	15(1)	Prepared animal feeds	1.58	Sump area	0.29
	15(2)	Grinded vegetable, grain, meat, bone and shellfish for animal feeds	1.58	Stabilization pond	0.00
12	16	Manufacture of distilling rectifying and blending spirits	1.20	UASB[b]	32.95
13	20(1)	Processed drinking water	8.40	Septic tank	0.00
	20(2)	Processed non-alcoholic drinks	8.40	Activated sludge	3.10
14	22(1)	Carbonize incubation, bleaching and dyeing fibers	135.00	Activated sludge	3.10
	22(2)	Spinning of cotton	135.00	Activated sludge	3.10
	22(3)	Textile finishing	135.00	Activated sludge	3.10
	22(4)	Textile printing	135.00	Sump area	0.29
15	24	Knitting mills	135.00	Activated sludge	3.10
16	30	Manufacture of fur dressing and dyeing	12.07	Activated sludge	3.10
17	38(2)	Processed paper or fiberboard	9.71	Activated sludge	3.10
18	42(1)	Processed chemicals	17.16	Sump area	0.29
19	43(1)	Processed fertilizer and pesticides	-	Septic tank	0.00
20	44	Synthetic resin rubber, plastic or synthetic fiber manufacturing	5.99	Activated sludge	3.10
21	45(1)	Processed paints	-	Activated sludge	3.10
22	46(1)	Objects which are accepted in medicine text book manufacturing	398.43	Septic tank	0.00
	46(2)	Objects which cure, relieve and protect disease for human or animal manufacturing	398.43	Septic tank	0.00
23	47(1)	Processed soap and cleaning preparations	14.39	Septic tank	0.00
	47(3)	Processed cosmetics	14.39	Septic tank	0.00
24	48(6)	Ink or carbon black manufacturing	-	Sump area	0.29

Table A-10: Continued

No.	Types of industry	Industrial activity	Revenue per ton thousand Baht	Wastewater technology	Cost of abatement Baht m^3 day
25	50(4)	Processed miscellaneous petroleum	0.13	Sump area	0.29
26	52(3)	Smoked rubber, crepe rubber, sticky rubber and liquid rubber manufacturing	5.99	Stabilization pond	0.00
	52(4)	Processed natural rubber product or synthetic rubber	5.99	Sump area	0.29
27	54	Grass and fiberglass manufacturing	1.69	Sump area	0.29
28	55	Manufacture of tile, pottery or ceramic	27.90	Sump area	0.29
29	59	Smelt, melt, mold, press out, haul or produce iron or primary steel (Iron and steel basic)	7.57	Sump area	0.29
30	60	Smelt, mix, purify, melt and mold (non-ferrous metal basic)	50.23	Sump area	0.29
31	92	Manufacture of frozen	-	Activated sludge	3.10
32	98	Laundries, laundry services and cleaning and dyeing plant	-	Activated Sludge	3.10
33	101	Central waste treatment plant	-	Activated Sludge	3.10

^{a}Rotating Biological Contactor, ^{b}Upflow Anaerobic Sludge Blanket. OIE (2006)

Table A-11: The necessary parameters of the model

Details	Unit
Current situation of BOD loading in Thachin river	
• Volume of wastewater treatment at each type of point source (F)	m^3
• Pollution loading in influent stream at each type of point source (I)	kg-BOD
• An ability of pollution release in each type of point source (alpha)	
Total Maximum Daily Loading, target of emission reduction	
• Total maximum daily loading	kg-BOD day^{-1}
• % Reduction in each sub-basin	Percentage
Pig farm	
• Cost of abatement of each wastewater treatment technology	Baht m^{-3}
• Profit per pig unit (100 kg)	Baht
• Amount of pig unit in each sub-basin	Unit
• Pollution loading in effluent stream (E) (depend on treatment technology)	kg-BOD
• Cost of abatement of each local government	Baht m^{-3}
• Received budget per capita	Baht
• Number of people in each sub-basin	Unit
• Pollution loading in effluent stream (E) (depend on expected treatment technology)	kg-BOD
Aqua culture	
• Cost of abatement of any wastewater treatment technology	Baht m^{-3}
• Profit per unit of aqua culture area	Baht
• Quantity of aqua culture area in each sub-basin	Unit
• Pollution loading in effluent stream (E) (depend on expected treatment technology)	kg-BOD
Industry	
• Cost of abatement of any wastewater treatment technology	Bant m^{-3}
• Profit per unit of industrial type	Baht
• Quantity of any industrial type in each sub-basin	Unit
• Total revenue from industrial production in each sub-basin	Baht
• Pollution loading in effluent stream (E) (depend on expected treatment technology	kg-BOD

APPENDIX B

Mathematical Decision-Making model:

$$\text{Maximize} \prod_{j=1}^{N} = \prod_{pj} + \prod_{uj} + \prod_{aj} + \prod_{ij}$$

Subject to:

$$E_j = \sum_{k=1}^{N} E_{pjk} + \sum_{k=1}^{N} E_{ujk} + \sum_{k=1}^{N} E_{ajk} + \sum_{k=1}^{N} E_{ijk}$$

$$A_j = E_j + \gamma A_{j-1}$$

and

$$A_j^* \geq A_j \pi \ > 0$$

Pig farm production:

$$\prod_{pj} = \sum_{k=1}^{N} P_p Q_{pjk} - \sum_{k=1}^{N} ABC_{pjk} - T_{pjk} \sum_{k=1}^{N} E_{pjk}$$

$$ABC_{pjk} = e^a F_{pjk}^{bp} I_{pjk}^{cp} E_{pjk}^{dp}$$

$$F_{pjk} = \alpha_p Q_{pjk}$$

$$I_{pjk} = \beta_p Q_{pjk}$$

$$\sum_{k=1}^{N} E_{pjk} \leq \bar{E}_{pj}$$

Urban community production:

$$\prod_{uj} = \sum_{k=1}^{N} P_u Q_{ujk} - \sum_{k=1}^{N} ABC_{ujk} - T_{ujk} \sum_{k=1}^{N} E_{ujk}$$

$$ABC_{ujk} = e^a F_{ujk}^{bu} I_{ujk}^{cu} E_{ujk}^{du}$$

$$F_{ujk} = \alpha_u Q_{ujk}$$

$$I_{ujk} = \beta_u Q_{ujk}$$

$$\sum_{k=1}^{N} E_{ujk} \le \bar{E}_{uj}$$

Aquaculture production:

$$\prod_{aj} = \sum_{k=1}^{N} P_a Q_{ajk} - \sum_{k=1}^{N} ABC_{ajk} - T_{ajk} \sum_{k=1}^{N} E_{ajk}$$

$$ABC_{ajk} = e^{a} F_{ajk}^{ba} I_{ajk}^{ca} E_{ajk}^{da}$$

$$F_{ajk} = \alpha_a Q_{ajk}$$

$$I_{ajk} = \beta_a Q_{ajk}$$

$$\sum_{k=1}^{N} E_{ajk} \le \bar{E}_{aj}$$

Industry production:

$$\prod_{ij} = \sum_{k=1}^{N} P_i Q_{ijk} - \sum_{k=1}^{N} ABC_{ijk} - T_{ijk} \sum_{k=1}^{N} E_{ijk}$$

$$ABC_{ijk} = e^{a} F_{ijk}^{bi} I_{ijk}^{ci} E_{ijk}^{di}$$

$$F_{ijk} = \alpha_i Q_{ijk}$$

$$I_{ijk} = \beta_i Q_{ijk}$$

$$\sum_{k=1}^{N} E_{ijk} \le \bar{E}_{ij}$$

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